Delta Risk Management Strategy (DRMS) Phase 1

Risk Analysis Report

Draft 4

Prepared by:
URS Corporation/Jack R. Benjamin & Associates, Inc.

Prepared for:
California Department of Water Resources (DWR)

July 2008

July 10, 2008

Mr. Ralph R. Svetich, P.E.
Delta Risk Management Strategy Project Manager
Department of Water Resources
Division of Flood Management
Delta-Suisun Marsh Office
1416 Ninth Street, 16th Floor
Sacramento, CA 94236

**Subject: Delta Risk Management Strategy
Phase 1 Draft 4 Risk Analysis Report**

Dear Mr. Svetich:

We are enclosing a revised version of the Risk Analysis Report. Members of the Steering Committee and agency staff reviewed the June 2007 draft of the Risk Analysis Report. After their comments were incorporated, the CALFED Science Program Independent Review Panel (IRP) reviewed the report and provided comments in August 2007. The IRP comments were also incorporated and then the revised draft was provided to the California Department of Water Resources for further review and comment. This draft of the Risk Analysis Report responds to and incorporates these comments from DWR staff.

This draft report was prepared by the undersigned and the DRMS team members listed in Section 1.4. Internal peer review was provided in accordance with URS' quality assurance program, as outlined in the DRMS project management plan.

Sincerely,

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Preamble

In response to Assembly Bill (AB) 1200 (Laird, chaptered, September 2005), the California Department of Water Resources (DWR) authorized the Delta Risk Management Strategy (DRMS) project to perform a Risk Analysis of the Sacramento–San Joaquin Delta (Delta) and Suisun Marsh (Phase 1) and to develop a set of improvement strategies to manage those risks (Phase 2).

AB 1200 amends Section 139.2 of the Water Code to read: “The department shall evaluate the potential impacts on water supplies derived from the Sacramento–San Joaquin Delta based on 50-, 100-, and 200-year projections for each of the following possible impacts on the Delta:

1. Subsidence
2. Earthquakes
3. Floods
4. Changes in precipitation, temperature, and ocean levels
5. A combination of the impacts specified in paragraphs (1) to (4) inclusive.”

AB 1200 also amended Section 139.4 to read: “(a) The Department and the Department of Fish and Game shall determine the principal options for the Delta. (b) The Department shall evaluate and comparatively rate each option determined in subdivision (a) for its ability to do the following:

1. Prevent the disruption of water supplies derived from the Sacramento–San Joaquin Delta.
2. Improve the quality of drinking water supplies derived from the Delta.
3. Reduce the amount of salts contained in Delta water and delivered to, and often retained in, our agricultural areas.
4. Maintain Delta water quality for Delta users.
5. Assist in preserving Delta lands.
6. Protect water rights of the ‘area of origin’ and protect the environments of the Sacramento–San Joaquin river systems.
7. Protect highways, utility facilities, and other infrastructure located within the Delta.
8. Preserve, protect, and improve Delta levees.…”

To meet the requirements of AB 1200, the DRMS project has been divided into two parts. Phase 1 involves the development and implementation of a Risk Analysis to evaluate the impacts of various stressing events on the Delta. Phase 2 evaluates the risk reduction potential of alternative options and develops risk management strategies for the long-term management of the Delta.

As part of the Phase 1 work, 12 technical memoranda (TMs), which address individual topical areas, and one risk report have been prepared. The TMs and the topical areas covered in the Phase 1 Risk Analysis are as follows:

1. Geomorphology of the Delta and Suisun Marsh
2. Subsidence of the Delta and Suisun Marsh
3. Seismology of the Delta and Suisun Marsh

4. Climate Change in the Delta and Suisun Marsh
5. Flood Hazard of the Delta and Suisun Marsh
6. Wind-Wave Hazard of the Delta and Suisun Marsh
7. Levee Vulnerability of the Delta and Suisun Marsh
8. Emergency Response and Repair of the Delta and Suisun Marsh Levees
9. Hydrodynamics, Water Quality, and Management and Operation of the Delta and Suisun Marsh (Water Analysis Module)*
10. Ecosystem Impacts to the Delta and Suisun Marsh
11. Impact to Infrastructure of the Delta and Suisun Marsh
12. Economic Consequences to the Delta and Suisun Marsh

*Two separate topical areas—the Hydrodynamics topical area and the Water Management topical area—were combined into one TM because of the strong interaction between them. The resulting TM is referred to as the Water Analysis Module (WAM).

The work products described in all of the TMs are integrated in the DRMS Risk Analysis. The results of the Risk Analysis are presented in the attached technical report, which is referred to as:

13. Risk Analysis Report

Taken together, the Phase 1 TMs and the Risk Analysis Report constitute the full documentation of the DRMS Risk Analysis.

The Business-as-Usual Delta and Suisun Marsh: Assumptions and Definitions

To carry out the DRMS Phase 1 analysis, it was important to establish some assumptions about the future “look” of the Delta. To address the challenge of predicting the impacts of stressing events on the Delta and Suisun Marsh under changing future conditions, DRMS adopted the approach of evaluating impacts absent major future project implementation in the Delta as a baseline. Thus, the Phase 1 work did not incorporate or examine proposals for Delta improvements. Rather, Phase 1 identified the characteristics and problems of the current Delta (as of 2005), with its practices and uses. This approach, which allows for consideration of pre-existing agreements, policies, funded projects, and practices, is referred to as the “business-as-usual” (BAU) scenario. Defining a BAU Delta is necessary because one of the objectives of this project is to estimate whether the current practices of managing the Delta (i.e., BAU) are sustainable for the foreseeable future. The results of the Phase 1 Risk Analysis based on the BAU assumption not only maintained continuity with the existing Delta, but also served as the baseline for evaluating the risk reduction measures considered in Phase 2.

The existing procedures and policies developed to address “standard” emergencies in the Delta, as covered in the BAU scenario, do not cover some of the major (unprecedented) events in the Delta that are evaluated in the Risk Analysis. In these instances, prioritization of actions is based on (1) existing and expected future response resources and (2) the highest value of recovery/restoration given available resources.

This study relied solely on available data. In other words, the effects of stressing events (changing future earthquake frequencies, future rates of subsidence given continued farming practices, the change in the magnitude and frequency of storm events, and the potential effects of global warming) on the Delta and Suisun Marsh levees were estimated using readily available engineering and scientific tools or based on a broad and current consensus among practitioners. Using the current state of knowledge, the DRMS project team made estimates of the future magnitude and frequency of occurrence of the stressing events 50, 100, and 200 years from now to evaluate the change in Delta risks into the future.

Because of the limited time available to complete this work, no investigation or research was conducted to supplement the current state of knowledge.

Perspective

The analysis results presented in the individual TMs do not represent the full estimate of risk for the Delta and Suisun Marsh. The full estimate of risk is the probable outcome of the hazards (earthquake, floods, climate change, subsidence, wind waves, and sunny day failures) combined with the conditional probability of the subject outcomes (levee failures, emergency response, water management, hydrodynamic response of the Delta and Suisun Marsh, ecosystem response, and economic consequences) given the stressing events. The attached Risk Analysis Report presents a full characterization of risk for the Delta and Suisun Marsh. The Risk Analysis Report integrates the initiating (stressing) events, the conditional probable response of the Delta levee system, and the expected probable consequences to develop a complete assessment of risk to the Delta and Suisun Marsh.

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List of Acronyms and Abbreviations

AB	Assembly Bill
BAU	business as usual
BDCP	Bay-Delta Conservation Plan
BNSF	Burlington Northern Santa Fe Railroad
BPA	Brownian Passage Time
cfs	cubic feet per second
CDEC	California Data Exchange Center
CDFG	California Department of Fish and Game
CEM	Coastal Engineering Manual
CIMIS	California Irrigation Management Information System
cm	centimeter(s)
CPT	cone penetrometer test
CVP	Central Valley Project
CVPM	Central Valley Production Model
Delta	San Joaquin–Sacramento River Delta
DRMS	Delta Risk Management Strategy
DSM2	Delta Simulation Model 2
DWR	Department of Water Resources
EBMUD	East Bay Municipal Utility District
ER&R	Emergency Response and Repair
FEMA	Federal Emergency Management Agency
GIS	geographic information system
HD	Hydrodynamics submodel
I-O	input-output
kV	kilovolt(s)
KMEP	Kinder Morgan Energy Partners
LPIII	Log Pearson Type III
M	magnitude
MHHW	mean high higher water
MSL	mean sea level
NGA	Next Generation of Attenuation

NDAL	Net Delta Area Losses
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
OD	outside diameter
PGA	peak horizontal acceleration
PMF	probability mass function
POD	pelagic organism decline
PSHA	probabilistic seismic hazard analysis
ROD	Record of Decision
RPC	regional purchase coefficient
SA	spectral acceleration
SRRQ	San Rafael Rock Quarry
SWP	State Water Project
TDI	Total Delta Inflow
TM	technical memorandum
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
UWMP	Urban Water Management Plan
V_S	shear-wave velocity
WAM	Water Analysis Module
WGCEP	Working Group on California Earthquake Possibilities
WY	Water Year
WGNCEP	Working Group on Northern California Earthquake Potential
WOCSS	Winds on Critical Streamline Surfaces (model)

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Figures

The Sacramento–San Joaquin Delta (Delta) and Suisun Marsh are critically important to the state and the nation for a wide variety of environmental and economic services (benefits derived from the area). Approximately 1,115 miles of levees in the Delta and 230 miles of levees in Suisun Marsh define the configuration of the waterways and landforms of the area. Most of these levees hold back water (i.e., prevent water from flowing onto the adjacent land) for 365 days per year, not just during floods. Over the years, many state and federal agencies and stakeholders have voiced concern over the condition of the Delta and Suisun Marsh levees and the consequences when they fail.

> DRMS progress can be followed on the Delta Risk Management Strategy web portal:
>
> http://www.drms.water.ca.gov/

1.1 PURPOSE

The overall purpose of the Delta Risk Management Strategy (DRMS) is to assess expected performance of Delta and Suisun Marsh levees (under various stressors and hazards) and the potential economic, environmental, and public health and safety consequences of levee failures to the Delta region and to California as a whole (Phase 1). After the completion of Phase 1, the purpose of DRMS is to address the consequences of levee failures by developing and evaluating risk reduction strategies (Phase 2). This report presents the methodology and results for Phase 1 of the work, the risk assessment. A separate report presents the methodology and results for Phase 2 of the work, the risk reduction strategies.

The Record of Decision for the CALFED Bay-Delta Program (CALFED 2000) called for a DRMS to be completed by 2001. The California Department of Water Resources (DWR), California Department of Fish and Game (CDFG), and U.S. Army Corps of Engineers (USACE) initiated DRMS in response to Assembly Bill (AB) 1200.

1.1.1 Assembly Bill 1200

AB 1200 (Laird, Chaptered October 2005) required the DWR to evaluate the potential impacts on water supplies derived from the Delta resulting from a variety of risks.

The bill amends Section 139.2 of the Water Code, to read, “The department shall evaluate the potential impacts on water supplies derived from the Delta based on 50-, 100-, and 200-year projections for each of the following possible impacts on the Delta:

Delta Facts

- About 1,115 miles of levees protect 700,000 acres of lowland in the Sacramento–San Joaquin Delta. In Suisun Marsh, approximately 230 miles of levees protect over 50,000 acres of marshland.
- Only about a third of the Delta levees (385 miles) are “Project Levees,” which were part of an authorized federal flood control project for the Sacramento and San Joaquin River systems. However, the vast majority of Delta levees, over 730 miles, and about 210 miles of Suisun Marsh levees are non-project (local) levees.
- Local levees were constructed, enlarged, and maintained over the last 130 years by local reclamation districts. In general, the levee work by these districts was financed by the owners of the lands protected by the levees. Over about the last 30 years, the State of California has provided supplemental financial support for levee maintenance and emergency response.
- Flooding from levee failures can influence the following services:
  - Land use (agriculture, urban, and conservation areas)
  - Flood management
  - Ecosystem
  - Water supply
  - Water quality management
  - Transportation
  - Utilities
  - Recreation and tourism
  - Local and state economics

1. Subsidence
2. Earthquakes
3. Floods
4. Changes in precipitation, temperature, and ocean levels
5. A combination of the impacts specified in paragraphs (1) to (4) inclusive"

In addition, Section 139.4 was amended to read: "(a) The department and the Department of Fish and Game shall determine the principal options for the Delta. (b) The department shall evaluate and comparatively rate each option determined in subdivision (a) for its ability to do the following:

1. Prevent the disruption of water supplies derived from the Delta.
2. Improve the quality of drinking water supplies derived from the Delta.
3. Reduce the amount of salts contained in Delta water and delivered to, and often retained in, our agricultural areas.
4. Maintain Delta water quality for Delta users.
5. Assist in preserving Delta lands.
6. Protect water rights of the 'area of origin' and protect the environments of the Sacramento-San Joaquin river systems.
7. Protect highways, utility facilities, and other infrastructure located within the Delta.
8. Preserve, protect, and improve Delta levees."

DRMS was developed to address the provisions of Sections 139.2 and 139.4 of AB 1200.

1.1.2 Goals and Objectives

The project sponsors and the project Steering Committee (see Sections 1.3.1 and 1.3.2 for more details), developed the following objectives for the DRMS work in accordance with the provisions of AB 1200:

1. Evaluate the risk and consequences to the state (e.g., water export disruption and economic impact) and the Delta (e.g., levees, infrastructure, and ecosystem) associated with the failure of Delta levees and other assets considering their exposure to all hazards (seismic, flood, subsidence, seepage, sea-level rise, etc.) under present as well as foreseeable future conditions. The evaluation shall assess the total risk as well as a disaggregation of the risk for individual islands.
2. Propose risk criteria for consideration for alternative risk management strategies and for use in management of the Delta and the implementation of risk-informed policies.
3. Develop a DRMS, including a prioritized list of actions to reduce and manage the risks or consequences associated with Delta levee failures.

1.2 RISK ANALYSIS OVERVIEW

In meeting the requirements of AB 1200, the DRMS project is divided into two parts. Phase 1, the work covered by this report, involves the development and implementation of a risk analysis to evaluate the risks from various stressing events to Delta and Suisun Marsh levees. The DRMS Phase 1 risk analysis provides a framework for evaluating major threats, or hazards, to the Delta levee system and the consequences of levee failures. Phase 2 of the project covers risk reduction and risk management strategies for long-term management of the Delta.

The risk analysis report draws information from 12 technical memoranda (TMs). The topics of the TMs are listed below. The TMs can be found at the DWR DRMS web site: http://www.drms.water.ca.gov.

1. Climate Change	7. Levee Vulnerability
2. Flood Hazard	8. Emergency Response and Repair
3. Seismology	9. Water Analysis Module (WAM) (Hydrodynamics and Water Management)
4. Wind-Wave Hazard	10. Impact to Ecosystem
5. Subsidence	11. Impact to Infrastructure
6. Geomorphology	12. Economic Consequences

Each TM presents the scientific and engineering data and assumptions, the methodology applied to each topic area, and the analysis results, which become input to the risk analysis. The Risk Analysis Report summarizes selected relevant information from the TMs to provide a context and background for the risk analysis. Readers should review relevant TMs to access more information on their topics of interest.

This Risk Analysis Report provides an abbreviated compilation of this information and summarizes risk results for 2005 and future conditions. Risk is first evaluated under 2005 base year conditions. Then risks are assessed for future years, assuming that existing management practices (policies, funding, maintenance, etc.) continue (“business as usual”).

1.2.1 Hazards

The hazards evaluated in this report for 2005 include:

- Seismic events (earthquakes) that cause levees or their foundations to fail
- Floods (high storm runoff) that can rise above the tops of the levees or increase pressure for seepage through and under the levees and cause them to fail
- Normal sunny-day events caused by undetected problems, such as rodent activity, that cause levees to fail during normal, nonflood flow periods (“sunny-day events”)
- High wind waves and erosion that can weaken levees, but are especially damaging to the interior of islands when they are flooded
- The effects of climate change and continuing subsidence, which increase the vulnerability of the levee system over time

The hazard analyses were carried out probabilistically when a probabilistic model existed or when a model could easily be developed. Other hazards, such as climate change and wind-wave models are represented using more of a range of possible outcome as opposed to a formal probabilistic treatment of the subject matter.

1.2.2 Consequences of Levee Failure

DRMS includes analysis of the consequences of levee failures for 2005, including the costs and other impacts due to the failures and resultant flooding. Damage to buildings, infrastructure, flooding of farmland, impacts to the ecosystem, and disruption of water supply are a few examples of consequences. Many of the economic consequences extend well beyond the Delta and Suisun Marsh, especially for the water supply that is exported from the Delta.

1.2.3 Risk Analysis

The DRMS risk analysis combines the various types of hazards, the frequency of different magnitudes of these hazards, and the consequences of failures under each condition in a probabilistic approach. The overall risks of levee failures are calculated for the 2005 base year conditions. All the various components of the risk "equation" are described in more detail in later chapters and in their respective technical memoranda. The risk analysis considers the range of possible outcomes and their associated probability of occurrence, from the more frequent events that affect a smaller number of islands/tracts to the less frequent (major) events that affect multiple islands/tracts.

1.2.4 Risk in Future Years

In the future, the magnitude of the hazards, the frequency at which they occur, and the consequences are expected to change. For example, sea-level rise is expected to put more pressure on Delta levees in the future. Climate change is expected to increase high winter flood flows into the Delta. Increases in the population within the Delta will increase the consequences of levee failures and flooding. Therefore, the DRMS risk analysis estimates how conditions are expected to change for 50, 100, and 200 years from now. These estimates of future conditions allow computation of risks in future years.

1.2.5 Limitations

For the past few decades, the Delta has been the subject of intense data collection, analysis, and scientific investigation. Despite this new knowledge, a great deal about the Delta and Suisun Marsh is still unknown. These circumstances are not unique to the Delta and DRMS. Rather, they are common to risk analyses of complex natural and man-made systems (SSHAC 1997; USDOE 1998).

> A great deal about the Delta and Suisun Marsh is still unknown. The DRMS work includes an analysis of uncertainty.

The DRMS work relied on existing data and information. For example, no opportunity existed to conduct new topographic or bathymetric surveys, obtain subsurface borings to better define levee and foundation material, or conduct other new research. Some areas with data gaps required extrapolation of available data tempered by engineering judgment and experience.

A particular challenge for DRMS is the analysis of risks as they change from the present (2005 base year) over the next 200 years. As one might expect, the scientific and information uncertainties and data gaps increase when estimating conditions 50, 100, and 200 years from now, particularly with estimates for the ecosystem, population growth, and future changes in the state's economy.

Unlike other risk analyses involving the potential for flooding, the approach developed for DRMS is unique because it addresses multiple hazards and their combination, their individual and aggregated impacts on the levee system, and the consequences resulting from individual events to multiple events. Further, the consequences are estimated for individual islands/tracts or for the Delta and the region as whole. For example, a similar evaluation for New Orleans would consider the risk associated with a single hurricane on 350 miles of levees (e.g., Katrina)—a relatively straightforward exercise. In the case of DRMS, all potential floods, earthquakes, and other hazards that might cause levee failures now or in the future are to be considered. To our knowledge, no other risk evaluation has been attempted for the Delta and Suisun Marsh on the scale and at the level of complexity of DRMS. The DRMS evaluation was conducted for:

- About 1,345 miles of levees (over three times the length of the levees for New Orleans)
- An area of 1,315 square miles (almost four times the area of New Orleans)
- Highly variable foundation conditions, including compressible peat soils
- Levees that were constructed without the benefit of modern engineering and construction techniques
- Multiple hazard conditions, including seismic, flood, wind-wave, and even sunny-day breaches from unforeseen conditions
- Changing future conditions, including land subsidence, sea-level rise, more winter flooding, and an increasing risk of a moderate to severe earthquake occurring in the near future
- Consequences of levee failure that extend well beyond the boundaries of the Delta and Suisun Marsh to the entire state of California

The intended result of this risk analysis is a better understanding of the risks that the Delta and Suisun Marsh face today and in the future. The risk results should be considered for the levee system as a whole rather than for any specific levee reach. Some readers may attempt to focus on an individual island or land tract for information—but this tendency should be discouraged. The information in the report should not be used as a basis for design for any individual island or land tract. In essence, the risk results from this analysis can be considered as a more accurate indication of levee risk for the collective area than for a specific spot in the Delta or Suisun Marsh.

Use of Risk Analysis

The results of the risk analysis are intended to provide a broad indication of the risks associated with the Delta and Suisun Marsh levee system. The information in the report should not be used as a basis of design for any individual island or land tract.

As a result of the DRMS project, parties interested in the future of the Delta and Suisun Marsh will be in a position to begin to assess the relative importance of different hazards, and the nature (both type and severity) of the risks that they face. The analysis will quantify and put into context how significant of a threat the ongoing, relatively frequent events and levee failures are to the future of managing the Delta. The analysis will also quantify what the state may face from a major catastrophe—our version of the flooding of New Orleans as a result of the effects of Hurricane Katrina.

1.3 PROJECT TEAM

1.3.1 Project Funding/Sponsors

The DRMS project was funded entirely by the California Department of Waster Resources. DWR, CDFG, and USACE serve as the project sponsors for DRMS. The sponsors are assisted by a Steering Committee, which consists of Technical Advisors and Delta stakeholders.

1.3.2 Steering Committee

Steering Committee members are policy advisors that represent the interests of those within the Delta and the interests of those outside the Delta who rely on the Delta infrastructure. The role of the Steering Committee members is to ensure the maintenance of proper coordination among agencies, the public, and the DRMS Consultant. The members are expected to speak with authority on the positions of their constituencies and have access to policymakers within their organization, when needed. The Steering Committee provides policy advice to the project sponsors and the DRMS Consultant. The Steering Committee reviews the interim and final work products of the DRMS consulting team and provides written comments. Appendix A provides the written comments on the reports and technical memoranda from the Steering Committee and member agencies and the responses of the DRMS consulting team. The Steering Committee consists of the following members:

Norman Abrahamson, Ph.D., University of California, Davis

Gary Bobker, The Bay Institute

Marina Brand, California Department of Fish and Game

Jon Burau, U.S. Geological Survey

Marci Coglianese, Bay Delta Public Advisory Board

Gilbert Cosio, MBK Engineers

Roger Fuji, U.S. Geological Survey

Jim Goodwin, U.S. Bureau of Reclamation

Sergio Guillen, California Bay Delta Authority

Leslie F. Harder, Jr., Ph.D., former DWR Deputy Director, Public Safety and Business Operations

Wim Kimmerer, Ph.D., Romberg Tiburon Center for Environmental Studies

Dennis Majors, State Water Contractors

Frances Mizuno, San Luis and Delta-Mendota Water Authority

Peter Moyle, Ph.D., University of California, Davis

Michael Ramsbotham, U.S. Army Corps of Engineers

Curt Schmutte, Division of Flood Management

Raymond Seed, Ph.D., University of California, Berkeley

Judy Soutiere, U.S. Army Corps of Engineers

Robert Twiss, Ph.D., University of California, Berkeley

Tom Zuckerman, Bay Delta Public Advisory Board

1.3.3 Technical Advisory Committee

Members of the Technical Advisory Committee (TAC) are the non-stakeholder constituents of the Steering Committee. The TAC members are technical subject matter experts, and serve at the direction of the project sponsors, as technical advisors to the DRMS project team. The TAC provides technical guidance or, in some instances, participates in expert elicitation, depending on the topic (e.g., the ecosystem impact analysis topic uses the TAC experts for elicitation). The TAC members who participated in expert elicitation or technical guidance in specific topical areas included:

The TAC for Levee Vulnerability was composed of the following members:

Leslie F. Harder, Jr., Ph.D., former DWR Deputy Director, Public Safety and Business Operations

Raymond Seed, Ph.D., TAC Chair, University of California, Berkeley

Ralph Svetich, Project Manager, DWR

David Mraz, Contract Manager, DWR

Michael Driller, DWR

Michael Ramsbotham, U.S. Army Corps of Engineers

Lynn O'Leary, U.S. Army Corps of Engineers

Gilbert Cosio, MBK Engineers

The TAC for Ecosystem Impacts (for expert elicitation) was composed of the following members.

Wim Kimmerer, Ph.D., Romberg Tiburon Center for Environmental Studies

Peter Moyle, Ph.D., University of California, Davis

William (Bill) Bennett, Ph.D., University of California, Davis

1.3.4 CALFED Science Program Independent Review Panel

The Independent Review Panel (IRP) conducted the formal independent review of the Risk Analysis Report dated June 26, 2007. The written comments from the IRP and the responses of the DRMS consulting team are included in Appendix B. The IRP was composed of the following members:

Rich Adams, Ph.D., Oregon State University, Corvallis, OR

Bob Gilbert, Ph.D., University of Texas, Austin, TX

Katharine Hayhoe, Ph.D., Texas Tech University and ATMOS Research & Consulting, Lubbock, TX

Bill Marcuson, Ph.D., P.E., American Society of Civil Engineers

Johnnie Moore, Ph.D., University of Montana, Missoula

Arthur Mynett, Sc.D., Delft Hydraulics, UNESCO-IHE Delft, The Netherlands

Deb Neimeier, Ph.D., P.E., University of California, Davis

Kenny Rose, Ph.D., Louisiana State University, Baton Rouge

Roy Shlemon, Ph.D., Roy J. Shlemon, and Associates, Inc., Newport Beach, CA

1.3.5 Special Topics Independent Review Panels

The Levee Seismic Vulnerability Review Panel (SRP) members provided thorough technical review of the characterization, modeling, and results of the development of the seismic fragility functions and the seismic probability of levee failure. Members of the SRP included:

Ross W. Boulanger, Ph.D., University of California, Davis
Jeffrey A. Schaeffer, Ph.D., USACE, Louisville District, KT
Richard (Dick) Volpe, Santa Clara Valley Water District, CA

The written comments from the SRP and the responses from the DRMS consulting team are included in Appendix C.

The Probabilistic Seismic Hazard Review Panel (PSHRP) provided independent review of the Probabilistic Seismic Hazard Analysis Technical Memorandum. The PSHRP was composed of the following members:

U.S. Geological Survey representatives

California Geological Survey representatives

The written comments from the PSHRP and the responses from the DRMS consulting team are included in Appendix C.

The Economic Analysis Independent Review Panel: Professor David Sunding from University of California, Berkeley, provided independent review of the Economic Impact Technical Memorandum. His review letter and the DRMS responses are included in Appendix C.

1.3.6 DRMS Consulting Team

The project sponsors selected the consulting team of URS Corporation and Jack R. Benjamin & Associates, Inc., to perform the DRMS work. The team was given authorization to proceed with work in March 2006. The work schedule called for a draft of the Phase 1 work to be completed in Spring 2007 and a draft of the Phase 2 work to be completed in Fall 2007.

The consulting team includes 30 firms and independent consultants located in the Sacramento/Bay Area/Stockton region. These local firms and independent consultants bring extensive local experience with the Delta in their respective fields of specialization. The firms and the services they provided are described below. Figure 1-1 shows the program functional organization. (Tables and figures are typically located at the end of each section.) Figure 1-2 shows the project team organization.

URS Corporation: Risk Analysis, Geotechnical Engineering, Seismic Hazard and Earthquake Engineering, Hydraulic/Hydrology, Flood Hazard, Water Quality, Vegetation and Habitat Analysis, Infrastructure, GIS

Jack R. Benjamin & Associates, Inc. (JBA): Risk Analysis and Modeling, Water Management

Resource Management Associates (RMA): Delta Hydrodynamic Modeling

MBK Engineers: Reservoir Operation and Water Management

Bay Modeling-Hydrodynamics (Bay Modeling): 3-D Hydrodynamic Modeling, Sea-Level Rise Simulation

Watercourse Engineering, Inc. (WE): Hydrodynamics and Water Management

Geomatrix Consultants, Inc.: Seismic Hazard, Earthquake Engineering, Geotechnical Engineering

Kleinfelder, Inc.: Geotechnical Engineering

Hultgren & Tillis Engineers (HTE): Geotechnical Engineering

HydroFocus, Inc.: Subsidence

WLA Consulting, Inc.: Seismic Geology, Fault Characterization

Pacific Engineering & Analysis (PE&A): Ground Motions and Site Response

Phillip Williams Associates (PWA): Geomorphology, Wind-Wave Modeling

Moffatt & Nichol Engineers (MNE): Emergency Response, Erosion

Economic Insight (EI): Economic Analysis

RM Econ: Economic Analysis

Western Resource Economics (WR Economics): Economic Analysis

M-Cubed: Economic Analysis

Redars Group (RG): Traffic Impact Analysis

Hanson Environmental, Inc. (HEI): Environmental and Ecosystem Impact Analysis

Stevens Consulting: Environmental and Ecosystem Impact Analysis

Science Applications International Corporation (SAIC): Terrestrial Habitat

Jones & Stokes: Water Quality, Environmental Impacts

Coppersmith Consulting, Inc.: Seismic Hazard

JRP Historical Consulting: Delta Historical Resources

Philip B. Duffy, Ph.D., Lawrence Livermore National Laboratory: Climate Change

C. Allin Cornell, Ph.D., Stanford University: Risk Analysis

Gregory Baecher, Ph.D., University of Maryland: Risk Analysis

Aquatic Restoration Consulting: Environmental Impacts

Loren Bottorff, Independent Consultant: Technical Writing and Editing

1.3.7 Topical Work Groups

The DRMS consulting team is organized into 15 topical work groups. The topical groups, the lead for each group, and other contributors are listed below.

1) **Seismic Hazard:**
Lead: Ivan Wong (URS)
Patricia Thomas (URS)
Walt Silva, PhD (PE&A)
Robert (Bob) Young (Geomatrix)
Jeffrey Unruh (WLA)
Kathryn Hanson (Geomatrix)
Kevin Coppersmith, PhD (I)
2) **Flood Hazard:**
Lead: Thomas MacDonald, PhD (URS)
Phillip Mineart (URS)
Joe Countryman (MBK)
3) **Subsidence:**
Lead: Steven Deverel (HydroFocus)
4) **Climate Change:**
Lead: Philip Duffy, PhD (LLNL)
Louis Armstrong (URS)
5) **Levee Vulnerability:**
Lead: Said Salah-Mars, PhD (URS)
Rajendram Arulnathan, PhD (URS)
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Edward Hultgren (HTE)
Kevin Tillis (HTE)
Segaran Logeswaran (URS)
Thang Kanagalingam, PhD (URS)
Scott Shewbridge, PhD (Kleinfelder)
Ron Heinzen (Kleinfelder)
Lelio Mejia, PhD (URS)
Michael Forrest (URS)
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6) **Geomorphology:**
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7) **Emergency Response:**
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Curtis Loeb (MNE)
H. Frank Du (MNE)
8) **Wind-Wave Modeling:**
Lead: Nick Garitty (PWA)

(I) = Independent Consultant

9) **Hydrodynamic Modeling:**
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Michael MacWilliams, PhD (Bay Modeling)
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10) **Water Management:**
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Michael Deas (WE)
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11) **Infrastructure:**
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12) **Economic Impacts:**
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Liz Elliott (URS)
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13) **Ecological Impacts:**
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Kristie Karkanen (HEI)
Alexandra Fraser, PhD (URS)
Jeannie Stamberger, PhD (URS)
John Rosenfield, PhD (I)
Peter Rawlings. PhD (SAIC)
Craig Stevens (Stevens Consulting)
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Elizabeth Nielsen (URS)
14) **Risk Modeling and Analysis:**
Lead: Martin McCann, Jr., PhD (JBA)
Said Salah-Mars, PhD (URS)
Ram Kulkarni, PhD (URS)
Chi-Wah Wong (URS)
15) **GIS Support:**
Lead: Amy Keeley (URS)
Douglas Wright (URS)
Sarah Lewis (URS)

1.3.8 Risk Resources Group

The team also includes a Risk Resources Group, which was formed to advise the DRMS project team on specialized risk modeling issues in the various topical groups. These individuals served primarily as individual consultants on an as-needed basis. The Risk Resources Group consists of the following experts:

C. Allin Cornell, PhD (Stanford University): Risk Analysis, Uncertainty, Seismic Hazard
Gregory Baecher, PhD (University of Maryland): Probability, Reliability, Geotechnical
Des Hartford, PhD: Policy and Risk Analysis, Geotech, Flood
Ralph Keeny, PhD (Purdue University): Decision Analysis, Public Policy
James H. Cowan, Jr., PhD (LSU): Aquatic Fishery
Mark T. Stacey, PhD (UCB): Fluid Mechanics/Hydrology
Michael W. Hanemann, PhD (UCB): Economics
Stuart W. Siegle, PhD: Wetland, Estuarine and Riparian Ecosystem
Mark A. Snyder, PhD (UCSC): Climate Change
Jeff Hart, PhD: Delta Botanicals and Restoration
Chris Kjeldsen, PhD: Delta Botanicals and Restoration

1.4 RELATIONSHIP TO OTHER INITIATIVES

1.4.1 Delta Vision

The role of the Delta Vision initiative (Governor Schwarzenegger's Executive Order S-17-06) is to identify a strategy for managing the Delta as a sustainable system for all environmental and economic services that the Delta provides. The Delta Vision initiative is a significant public process designed to find substantial agreement on recommendations among elected officials, government agencies, stakeholders, subject matter experts, and affected California communities on:

1. The multiple uses, resources, and ecosystem in the Delta that can be sustained over the next 100 years or more
2. The array of public policies and resource management strategies needed to move toward this strategic vision for the Delta
3. A near-term (next 25–50 years) contingency and emergency response plan for a catastrophic event in the Delta.

Although the DRMS risk analysis focuses on the Delta levees and the effects of flooding, the Delta Vision initiative directly considers the needs of a wide variety of resources and activities within the Delta and Suisun Marsh and beyond.

A key principle is to build the Delta Vision initiative around existing Delta planning, technical, and scientific efforts and avoid creating redundant organizational structures. In this way, DRMS will become a major source of scientific and technical information on the Delta and Suisun Marsh levees. Before the Delta Vision initiative, DRMS has already considered and taken on many of the same goals, activities, and functions as the Delta Vision initiative relating to levees. The Delta Vision initiative will build on the information developed from the DRMS effort. The Delta Vision initiative will use many work groups that will work closely with, and preferably include, subject matter experts from ongoing Delta evaluations, such as the DRMS.

A key component of Delta Vision is a Governor-appointed independent Blue Ribbon Task Force that is responsible for recommending future actions to achieve a sustainable Delta. The process includes a diverse Stakeholder Coordination Group and broad public outreach to evaluate different Delta visions and management scenarios. The Task Force will submit a Delta Vision

Report by the end of 2008 as well as a Delta Strategic Plan. A recommendation for conveyance should be included in the plan. A Cabinet-level Delta Vision Committee will submit the Delta Strategic Plan to the Governor and Legislature by December 31, 2008. More detail on the Delta Vision initiative can be found on its web site: http://www.deltavision.ca.gov/.

1.4.2 Bay-Delta Conservation Plan

The Bay-Delta Conservation Plan (BDCP) is a Natural Community Conservation Planning effort to address water operations and facilities in the legal Delta. The BDCP focuses primarily on aquatic ecosystems and natural communities, but may also cover adjacent riparian and floodplain natural communities. Among other things, the plan will:

- Provide for conservation and management of covered species
- Preserve, restore, and enhance aquatic, riparian, and associated terrestrial habitats
- Provide clear expectations and regulatory assurances for the water operations and facilities

The results from DRMS will provide levee risk information to inform the BDCP process. BDCP will work on a conservation strategy through late 2008. The Final BDCP is expected to be completed in October 2009. More information on BDCP can be found on its web site: http://www.resources.ca.gov/bdcp/.

1.4.3 CALFED End of Stage 1

CALFED is preparing an assessment of performance toward objectives during Stage 1 (first 7 years of implementation) and the likelihood that the program will meet its objectives in the future (CALFED 2007). Levees play a major role in the landscape of the Delta and how the CALFED program is implemented in the future. CALFED will use the results of DRMS to inform its planning process. More information on CALFED program planning can be found on the CALFED Bay-Delta Program web site: http://calwater.ca.gov/index.aspx.

1.4.4 Other Initiatives

The results of DRMS could prove useful to other initiatives in the region, including:

- The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP), which is under the direction of California Department of Fish and Game
- The Habitat Management, Preservation, and Restoration Plan for Suisun Marsh (Suisun Marsh Plan), which is currently being prepared by the Suisun Marsh Charter agencies
- Planning activities by state and federal agencies and local entities (for example, the Delta Islands and Levees Feasibility Study, which is being undertaken by the U.S. Army Corps of Engineers)
- Other new initiatives

1.5 REPORT ORGANIZATION

Following this introduction, the following sections and appendices collectively present the risk analysis of the Delta and Suisun Marsh levees:

- **Section 2** provides an overview to the Delta and Suisun Marsh for those unfamiliar with the region. It is based largely on the recent report *Status and Trends of Delta-Suisun Services* (URS 2007).
- **Section 3** is an overview of the scope of work for the risk analysis.
- **Section 4** summarizes the risk analysis methodology.
- **Section 5** provides the technical basis for the 2005 Base Case, the current conditions used for the risk analysis.
- **Section 6** summarizes the seismic risk analysis.
- **Section 7** summarizes the flood risk analysis.
- **Section 8** summarizes the wind and wave risk analysis.
- **Section 9** summarizes the sunny-day, high-tide risk analysis.
- **Section 10** summarizes the planned response to levee breaches.
- **Section 11** summarizes salinity impacts and use of the Water Analysis Module (WAM).
- **Section 12** summarizes the consequences modeling.
- **Section 13** summarizes the risk analysis for the 2005 Base Case, under existing regulatory and management practices.
- **Section 14** summarizes the risk analysis for future conditions in the Delta and Suisun Marsh, assuming continuation of present regulatory and management practices.
- **Section 15** describes assumptions and limitations of the analyses.
- **Section 16** provides the references consulted to prepare the report.
- **Appendix A** contains the August 23, 2007, comments of the IRP on the June 26, 2007, draft of the Risk Analysis Report and the responses of the consulting team (dated November 2, 2007).

The report is supported by 12 TMs that provide background and other technical information used in the risk analysis. Each TM should be considered to be a technical appendix to this report. The following TMs can be found on the DWR DRMS web site (http://www.drms.water.ca.gov).

Technical memoranda	Technical memoranda
1. Climate Change 2. Flood Hazard 3. Seismology 4. Wind-Wave Hazard 5. Subsidence 6. Geomorphology 7. Levee Vulnerability	8. Emergency Response and Repair 9. Water Analysis Module (WAM) (Hydrodynamics and Water Management) 10. Impact to Ecosystem 11. Impact to Infrastructure 12. Economic Consequences

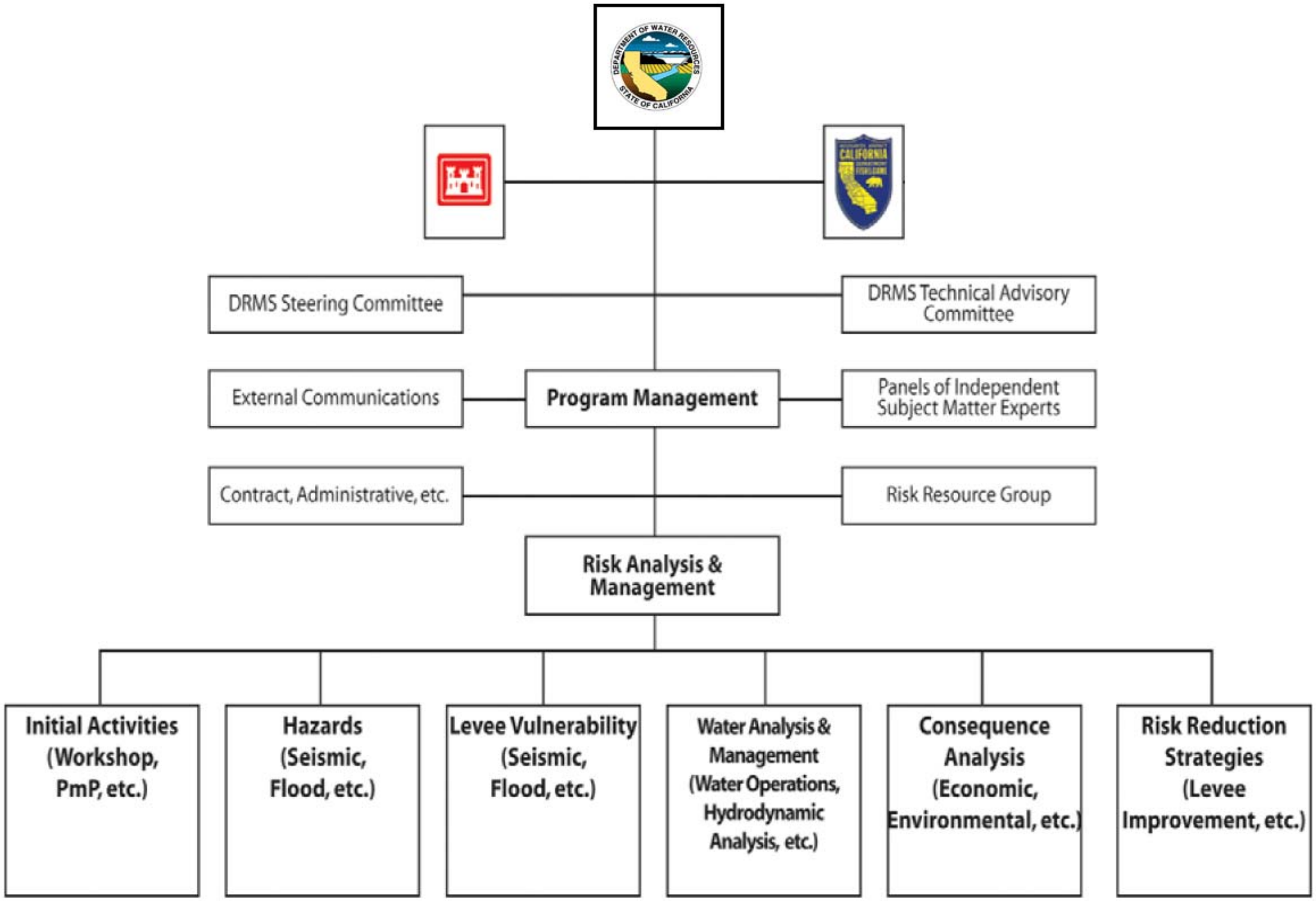

Figure 1-1 Program Functional Organization

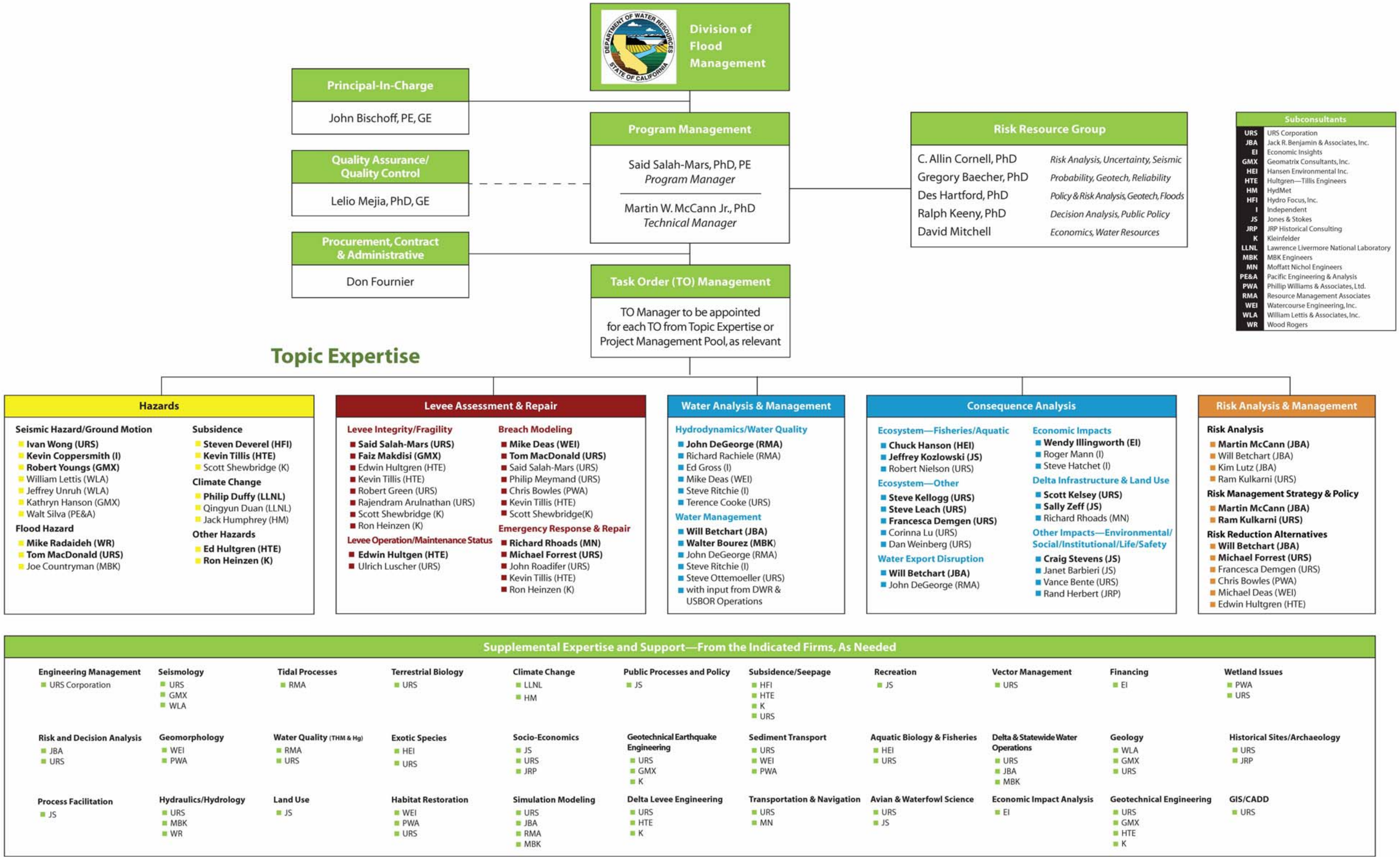

Figure 1-2 Consulting Team Organization

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Figures

This section provides background information on the Sacramento/San Joaquin Delta and Suisun Marsh. The early subsections below draw heavily on the document *"Status and Trends of Delta-Suisun Services,"* developed as a foundation for DRMS and the Delta Vision initiative (URS 2007).

2.1 LOCATION

The Sacramento-San Joaquin Delta and Suisun Marsh are at the confluence of the Sacramento River and San Joaquin River basins, which provide drainage to about 40 percent of California (Figures 2-1, 2-2, and 2-3). Unlike the Mississippi River Delta and other river deltas that form where rivers drop their sediments as they enter the ocean, the Sacramento-San Joaquin Delta is an interior delta whose western side lies about 50 miles upstream from the Golden Gate. The major rivers entering the Delta are the Sacramento River flowing from the north, the San Joaquin River from the south, and the Cosumnes, Mokelumne, and Calaveras Rivers from the east.

The Delta and Suisun Marsh, together with the greater San Francisco Bay, make up the largest estuary on the west coast of North America. The Delta and Suisun Marsh together cover about 1,315 square miles in portions of six California counties. Although the Delta and Suisun Marsh cover only about 1 percent of California's area, the region is at the heart of critical California water supply issues. Many users compete for freshwater from the Delta. These users include the many water agencies/contractors and their customers in Northern and Southern California, the San Joaquin Valley agricultural industry, local in-Delta agriculture, and the Delta ecosystem. The competition for freshwater from the Delta becomes exacerbated during summer, when the inflows of freshwater into the Delta are low.

2.2 HISTORICAL PERSPECTIVE

About 20,000 years ago, sea levels were about 400 feet lower than they are today and the coastline was near the Farallon Islands, about 30 miles west of the Golden Gate and about 80 miles west of the present Delta. About 130,000 years ago, sea levels were as much as 10 feet higher than they are today. During these dramatic swings in sea level, the Delta would have existed in its current location only at times when sea level was near the present level.

The rich organic peat soils in the Delta and Suisun Marsh built up over about the last 5,000 years as the sea level rose and as marsh plants grew and died in the swampy environment. Because the land was waterlogged and anaerobic (devoid of oxygen), organic soils accumulated faster than they could decompose, forming large expanses of organic soil.

The Delta and Suisun Marsh consisted of hundreds of miles of tidally influenced sloughs and channels, and hundreds of thousands of acres of marsh and overflow land. The braided channels surrounded many natural islands. The river systems accommodated large populations of anadromous fish that passed through and spent parts of their lives in the Delta. The region once supported large mammal species such as the grizzly bear, tule elk, and gray wolf. Native Americans hunted, fished, and foraged for food.

During the gold rush beginning in 1849, the Delta waterways were used to transport supplies and prospectors to the gold fields. Figure 2-2 is an historical illustrative map showing the Delta area in the mid-1800s, before agricultural development and levee construction began. In the 1850s, farmers began to recognize the great potential of the rich Delta soils. Natural levees existed along some river channels where sediments had been deposited when high water overflowed the channel banks. Farmers began to reclaim the land areas to grow crops by building small levees, 3 to 5 feet high, on the tops of the natural levees. High water periodically caused these levees to fail, and some were rebuilt only to fail again.

Large-scale reclamation of the Delta for agriculture began in 1868. Levee building became more aggressive, accomplished with both hand labor and mechanical equipment. Large-scale land development companies were formed, with one firm accumulating 250,000 acres. This period of development ended around 1900. By this time, most of the lands with mineral-organic soils had been reclaimed. With the exception of Bouldin Island, lands with organic soils in the central Delta were generally not reclaimed.

The final period of Delta reclamation occurred between 1900 and 1920 on lands in the Delta's interior. These lands contain mostly organic soils, which make levee construction difficult because of their high organic matter. Figure 2-4 shows which islands and tracts were reclaimed in decade-long periods from 1868 through 1921. The result of these reclamation efforts is largely what is seen as the Delta today – approximately 700 miles of meandering waterways with levees protecting over 538,000 acres of farmland, homes, and other structures. Many of the levees are considered relatively fragile with respect to today's design and construction standards.

With the construction of levees and draining for agriculture, the organic soils were exposed to the atmosphere since most agricultural practices require an aerated root zone. Some soil has blown away with the wind, some has burned as part of an agricultural process, but the major portion has simply decomposed, producing land subsidence. The aerobic (oxygen-rich) condition favors microbial oxidation, which consumes the organic soils. Most of the carbon loss is emitted as carbon-dioxide gas to the atmosphere. In addition, large volumes of organic soil were used for levee construction. Over the past 150 years, as much as half of the original soil volume that accumulated over 5,000 years has disappeared, placing much of the Delta land surface 15 feet or more below sea level. Many of the Delta islands and tracts have flooded multiple times. Since 1900, levee failures have flooded Delta islands and tracts 166 times (see Figure 2-5 for historical island flooding since 1900). Some, like Franks Tract, were never recovered.

Significant diversion and modification of stream flows in Delta watersheds began during the gold

History of Delta Conflict Up to the 1994 Delta Accord

Throughout the 1970s, 1980s, and 1990s, as both in-Delta and export water users attempted to increase their use of water from the Delta in response to growing demands, conflicts between urban users, agricultural and the environmental water users continued to escalate. This led to a crisis that resulted in creation of the CALFED Bay-Delta Program.

By 1994, Governor Pete Wilson became increasingly concerned about the declining state of the Delta ecosystem, the increasing uncertainty associated with Delta water supplies for urban and agricultural uses, and the increasing amount of rancor and litigation surrounding SWRCB's unsuccessful 16-year effort to establish Delta water quality standards. He led an effort to bring together the numerous federal and state agencies with responsibilities in the Delta, and stakeholder representatives to work toward a resolution of the conflicts over the Delta. In December 1994, the Delta Accord was signed. It set interim water quality standards and established the CALFED Bay-Delta Program to develop long-term Delta water quality standards, coordinate operations of the state and federal water projects, and develop a long-term solution for the Delta.

Because of the importance of the Delta levee system, the CALFED Record of Decision in 2000 called for preparation of a Delta Risk Management Strategy. This report summarizes Phase 1 of DRMS.

rush to facilitate placer and, later, hydraulic mining. The upstream mining sent large volumes of sediment into the rivers that flow to the Delta. Sediment that migrated to the Delta reduced channel capacity and contributed to flooding. The federal government passed the Caminetti Act of 1893 that led to the creation of the Yolo bypass and prescribed Delta levee heights. In 1960, the Sacramento River Flood Control Project was completed by the USACE, improving flood protection for much of the Sacramento Valley and a portion of the Delta. About a third of the Delta levees are part of the Sacramento River Flood Control Project and eligible for USACE's support for rehabilitation. The remaining levees are not part of a state/federal flood control project. Local landowners, reclamation companies, and reclamation districts constructed the majority of these non-project (local) levees.

In the 1970s, the California Legislature recognized that the Delta levee system benefits many segments and interests of the public, and approved a preservation plan. The Delta Levee Maintenance Subventions Program (Subventions Program) was established in 1973 and amended by the Delta Flood Protection Act of 1988. The Delta Flood Protection Fund was created to provide for local assistance under the subventions Program and for Special Delta Flood Protection Projects (Special Projects) to protect services such as roads and utilities, urbanized areas, water quality, and recreation.

Water development has significantly shaped the inflows to the Delta and changed its hydrodynamics. Construction of upstream dams has lowered peak flows and raised dry weather flows to the Delta, significantly changing the inflow pattern to the Delta. In 1921 the California legislature authorized development of a comprehensive water plan for the state. This plan was largely complete in 1932 and identified Delta salinity control as an issue for northern water users and Delta facilities as a major component of the plan.

By 1939 the federal government had initiated construction on the Central Valley Project's (CVP) Friant, Shasta, and Contra Costa (Delta) Divisions. A portion of the water for the Delta Division was to be exported to San Joaquin River users in exchange for their existing San Joaquin River rights. This arrangement was necessary for two reasons: (1) to allow San Joaquin River water to be exported south and (2) because it was acknowledged that sufficient flow was needed at Antioch and Pittsburg to repel seawater.

Work continued on the CVP for many years, with Trinity Dam completed in 1962. San Luis reservoir was completed in 1967, while New Melones reservoir was not completed until 1978.

In 1957, the State of California released Bulletin 3, The California Water Plan. Bulletin 3 called for the construction of dams, canals, pipelines, and significant alteration of northern streams to meet expected water demands south of the Delta. The 1957 State Plan proposed immediate construction of the Oroville Dam and reservoir project on the Feather River. This reservoir was completed in 1967 and is the major storage reservoir for the State Water Project (SWP). Figure 2-6 shows the major features of the federal, state, and local projects in California.

Construction of the state's Delta facilities began in 1963 and included Clifton Court Forebay, the Harvey O. Banks pumping plant, and San Luis Reservoir (jointly with the federal project). The initial capacity of the Banks pumping plant was 6,400 cubic feet per second (cfs), later expanded to 10,300 cfs in 1991, although diversion into Clifton Court Forebay is still limited to 6,400 cfs.

Today, the Delta is managed as a freshwater system to support in-Delta agriculture and export water supplies. The changes in hydrodynamics (flow and salinity) have contributed to a significantly altered ecosystem, as compared with 150 years ago. Today, about one fourth of the urban water used in California is diverted from the Delta; about two thirds of Californians get some portion of their drinking water from the Delta. Also, about 3 million acres of agricultural lands receive some irrigation water from the Delta.

2.3 STATUS OF THE DELTA AND SUISUN MARSH

Most of the Delta is agricultural land and most of Suisun Marsh is managed wetlands and other lands managed for waterfowl hunting and conservation. Out of almost 840,000 acres, the 2004 land use consisted of about 9 percent urban, 67 percent agricultural, 14 percent conservation and other open lands, and 10 percent water. In 1992, the Delta Protection Act defined the Primary Zone of the Delta, with stringent protection against further urban development. The Secondary Zone contains the rest of the legal Delta with less stringent protection. The zones are illustrated on Figure 2-2. Small, unincorporated communities and historic towns (Clarksburg, Courtland, Hood, Locke, Ryde, and Walnut Grove), within the Delta's Primary Zone (see Figure 2-3), serve as social and service centers for surrounding farms. A small portion of Rio Vista lies within the Primary Zone. The incorporated city of Isleton and portions of Stockton, Pittsburg, Antioch, Oakley, Elk Grove, Tracy, Lathrop, Sacramento, and West Sacramento are within or just outside the Delta's Secondary Zone (see Figure 2-3). The expanding cities of Fairfield and Suisun City are encroaching on the edges of Suisun Marsh secondary management area, creating population pressures on all services.

About 65 major islands and tracts in the Delta rely on the levee system. The levee system generally provides low levels of protection for adjoining lands. Most levees have been locally built and maintained. All of the existing services provided by the Delta and Suisun Marsh rely on the existing levee system. The *Status and Trends of Delta-Suisun Services* (URS 2007) provides information on nine key services (bullet list below). The following provides some observations on the status of the key services:

- Land use (agricultural, urban, and conservation)
  - The Delta includes about one-half million acres of highly productive farmland.
  - Since 1990, about 40,000 acres of farmland have been converted to urban and conservation uses.
  - About 165,000 dwellings and a population of about 470,000 are within the area protected by Delta and Suisun Marsh levees (2000 census); Delta islands and tracts house only about 26,000 people. These islands and tracts include nearly all of the Primary Zone and a portion of the Secondary Zone.
  - The region is surrounded by some of the areas where population is growing at the fastest rates in California
- Flood management
  - Land subsidence on the interior of islands and tracts has created large areas below sea level; some areas are as much as 25 feet below sea level.
  - Levee failures and flooding are possible at any time since the levees hold back water 365 days per year.

  - Levee failures during times of moderate to low Delta inflow can result in saltwater from Suisun Bay flowing upstream into the Delta as islands flood.
  - Land subsidence in some areas continues at the rate of 0.5 to 1.5 inches of soil loss per year.
- Ecosystem
  - The region provides unique habitat for hundreds of species of resident and migratory fish, birds, plants, mammals, and insects, some listed as federally threatened or endangered species.
  - The region is very different from the historical ecosystem in which the native organisms evolved.
  - The ecosystem is subject to rapid change.
  - More than 10 percent of California's remaining wetlands are in Suisun Marsh.
  - Biomass in benthic samples typically is 95 percent or more from nonnative species.
  - The decline of pelagic (open water) organisms, such as Delta smelt and longfin smelt, has increased concern over the sustainability of the Delta ecosystem.
- Water supply
  - The Delta channels serve as water conveyance for millions of acre-feet of export water per year.
  - The Delta is one of few estuaries in the world used as a major drinking water source.
- Water quality management and discharges
  - About 42,500 square miles drain to Delta.
  - Water quality can be negatively affected by upstream discharges, in-Delta discharges, and seawater intrusion.
  - Both the Delta and Suisun Marsh are managed to control salinity.
- Transportation
  - Most corridors serve other areas of the state or nation (highways, shipping channels, and rail).
  - Pipelines crossing the Delta deliver gasoline, diesel and aviation fuel to Northern California, northern Nevada and the Central Valley.
  - Transportation within the Delta and Suisun Marsh follows more of a maze pattern than a straight corridor.
  - Bridges and auto ferries connect Delta islands.
- Utilities
  - A wide variety of utilities (electrical transmission, natural gas pipelines and wells, and water pipelines) cross the area.
  - Most utilities serve large areas of the state.

- Recreation/tourism
  - Recreation is focused on water-based activities.
  - Private land ownership limits land-based recreation.
  - The Delta and Suisun Marsh support a wide range of activities including boating, fishing, waterfowl and upland game bird hunting, wildlife viewing, bird watching, sightseeing, and photography.
- Local and state economics
  - The asset value protected by Delta levees is about $56 billion.
  - Areas protected by Delta levees provide more than 205,000 jobs.
  - The Delta contributes to the statewide economy, especially through water exports.

2.4 TRENDS FOR THE DELTA AND SUISUN MARSH

The Delta and Suisun Marsh levees and waterways are a complex network. Water volumes, velocities, salinity, and pollutants all affect the ecosystem, agriculture, and drinking water supply. Changes in one area can create changes in other areas. A number of influences or "drivers," most beyond direct human control, may change the Delta-Suisun Marsh and its vulnerability to levee failures in the future (see textbox).

Drivers of Change

- Subsidence
- Global Climate Change – Sea-Level Rise
- Regional Climate Change – More Winter Floods and Less Snowpack
- Seismic Activity
- Introduced Species
- Population Growth and Urbanization

Key observations about future trends from *Status and Trends of Delta-Suisun Services* (URS 2007) include:

- Land subsidence will continue where organic soils are conventionally farmed.
- Rates of land subsidence can far outpace rates of sea-level rise.
- Changes in agricultural management and crop types may help stabilize or increase Delta elevations.
- More pressure will be exerted on levees from continued sea-level rise by at least another 0.6 foot to 1.9 feet by 2100, with a possible additional 0.5-foot rise if the rate of Greenland ice melt increases.
- Sea-level rise will increase salinities in the Delta, unless additional freshwater inflows to the Delta are provided to prevent this.
- More winter precipitation will fall in the mountains as rain rather than snow (decreasing mountain snow pack by as much as 25 percent by 2050).
- Average winter flood flows to the Delta will likely become larger.
- Natural summer flows will likely be lower, adding to dry season water supply and quality problems.

- About a two out of three chance exists of at least one magnitude 6.7 or greater earthquake in the Bay Area before 2032. Such an event has the potential to cause multiple Delta islands to flood from levee failures.
- Some islands may remain permanently flooded after a levee failure.
- Species known to be problems in other regions, such as northern pike, zebra mussel, and various aquatic plants, are likely to invade the Delta and Suisun Marsh.
- Over the next decade, projections indicate that 130,000 new homes will be built within the Delta and Suisun Marsh protected area.
- Under the present approach to land use planning, urbanization of available land within the Secondary Zone could add 600,000 to 900,000 people.
- Population growth and urbanization are expected to place more demand on the Delta and Suisun Marsh's services (recreation, transportation, utilities, water supply, and urban runoff).
- Urbanization is expected to place more pressure on agriculture and other open space uses.
- Expected urbanization will cover more land and reduce options for future management choices for other resources.

2.5 RECENT GROWTH OF CONCERN

Recognition of the importance of the Delta and Suisun Marsh as a changing, dynamic system is growing. Within the past several years, the Delta and Suisun Marsh areas have gained an unprecedented level of political, public, and funding support.

The California Bay-Delta Authority Program (referred to as CALFED) environmental documentation culminated in the Record of Decision (ROD) in 2000 (CALFED 2000a). The ROD laid out a program to simultaneously meet objectives for water supply reliability, ecosystem, water quality, and levee system integrity. The ROD specifically recognized the need to prepare DRMS. The preferred alternative called for a through-Delta conveyance alternative based on the existing Delta configuration with some modifications and seven other program elements: a long-term levee protection plan, a water quality program, an ecosystem restoration program, a water use efficiency program, a water transfers program, a watershed program, and new groundwater and surface water storage.

Since the CALFED ROD was issued, billions of dollars have been spent towards achieving the four objectives, although only about 20 percent of the funds identified for maintaining and improving Delta levees during the 2000–2007 period were actually made available.

Several events in recent years have heightened concern over the sustainability of the Delta in its current form:

- Many people associate potential levee failures with high winter flood flows in the rivers. That is the most common type of failure but, by contrast, seven Delta levees have failed during low flow periods. Thus, the June 2004 failure of a Jones Tract levee provided a reminder that the Delta levees have water against them 365 days per year and failures at any time are possible. This one island failure resulted in nearly $100 million in repair, recovery, and damage costs. The levee failure did not significantly affect the Delta water exports, but highlighted the risks of such impacts if islands flood in other locations or if multiple islands flood at the same time.

- News of Hurricane Katrina and the resulting damage to the Gulf Coast, and especially flooding in New Orleans, was on the front pages of newspapers and on television news programs for weeks during August and September 2005. The public, politicians, and scientists and engineers became concerned about parallels between levee failures and flooding in New Orleans and the potential for similar occurrences in the Delta. While this lesson wasn't necessarily new, it was a vivid reminder about the vulnerability of Delta levees and the possible statewide and national impacts of catastrophic levee failures.
- Although climate change is not a new concept, it has received wide attention since the turn of the century. California's climate is expected to become warmer during this century. Climatologists have already documented changes in California's climate during the latter half of the 20th century. By the end of the current century, depending on future heat-trapping gas emissions, statewide average temperatures are expected to rise between 3 and 10.5 °F. Estimates indicate that more winter flooding will occur and that sea levels will continue to rise. Both of these pose significant threats to the Delta levees.
- On the basis of research conducted since the 1989 Loma Prieta earthquake, the U.S. Geological Survey (USGS) and other scientists conclude that a 62 percent probability exists of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking the San Francisco Bay region before 2032 (USGS Open-File Report 03-214). It can be noted that no Delta levee has ever failed from an earthquake. However, the current network of levees has not experienced a large earthquake. While the 1906 magnitude 7.8 San Francisco earthquake was a significant event, levees were not as tall as they are now. The last 100 years of land subsidence has made the Delta islands deeper and resulted in building the levees higher. These levees now are more susceptible to failure during an earthquake than they were in 1906 as has been confirmed by the analyses described in subsequent sections.
- Preliminary estimates by DWR (JBA 2006a, 2006b) indicate the potential for $30 to $40 billion statewide loss from a large earthquake causing significant levee failures and island flooding. Such an event could lead to multiyear disruptions in water supply, water quality degradation, and permanent flooding of multiple islands. Much of this cost comes from the realization that a significant portion of the state's water supply would be vulnerable to massive levee failures.
- Since the CALFED ROD was issued for the 2000 Programmatic Environmental Impact Statement/Report, a continued pelagic organism decline has occurred in the Delta. These are open-water organisms such as Delta smelt and longfin smelt.
- The varied successes of implementation of the CALFED Bay-Delta Program have caused some to question whether it is possible to achieve all four CALFED objectives at the same time. The four interrelated CALFED objectives are:
  - **Levee System Integrity –** Reduce the risk to land use and associated economic activities, water supply, infrastructure, and the ecosystem from catastrophic breaching of Delta levees.

- **Ecosystem –** Improve and increase aquatic and terrestrial habitats, and improve ecological functions in the Bay-Delta to support sustainable populations of diverse and valuable plant and animal species.
- **Water Supply Reliability** – Reduce the mismatch between Bay-Delta water supplies and current and projected beneficial uses dependent on the Bay-Delta system.
- **Water Quality –** Provide good water quality for all beneficial uses.

- CALFED is currently reevaluating its program after the first 7 years of implementation and considering whether the preferred alternative identified during 2000 in its programmatic EIR/EIS and ROD is capable of meeting all four objectives (CALFED 2007).
- Recognition is also growing that prior Delta planning efforts have been too narrowly focused on a few resources and haven't adequately included the full range of Delta uses and resources.
- In AB 1200, the Legislature found and declared the following:

  (a) Substantial water supplies are derived from the Sacramento-San Joaquin Delta for the greater Silicon Valley area, Alameda County, eastern Contra Costa County, Napa County, Solano County, the San Joaquin Valley, and southern California.

  (b) In a document entitled "Seismic Stability of Delta Levees," the DWR estimated that a single 100-year earthquake would result in 3 to 10 Delta levee breaks and that a single 1,000-year earthquake would result in 18 to 82 Delta levee breaks. A 100-year earthquake is defined as having a mean annual frequency of occurring or being exceeded equal to 0.01 (or 1 percent). Similarly, a 1,000-year earthquake would have a mean annual frequency of occurring or being exceeded of 0.001 (or 0.1 percent).

  (c) A report to the California Bay-Delta Authority Independent Science Board estimated that sea-level rise caused by climate change, continuing subsidence of Delta lands, floods, and earthquakes, have a 64 percent probability of resulting in catastrophic flooding of Delta islands over the next 50 years. The state's economy, and the governmental programs that are dependent on a healthy economy and a healthy environment, cannot afford a catastrophic disruption of the water supplies derived from the Delta (Mount et al. 2006).

All of these concerns have combined to prompt new action on making the Delta more sustainable into the future. Although knowledge about the area is growing, the area's complexity continues to present data gaps and uncertainties. New studies and initiatives aimed at making the area and its services sustainable are under way. Some of the actions that have been taken to address these concerns within the past few years include:

- In November 2006, California voters entrusted DWR with about $5 billion in new bond funds for flood management, a portion of which will be available for the Delta.
- DRMS work was initiated to evaluate the risks associated with levees in the Delta and Suisun Marsh and evaluate ways to mitigate that risk.
- The Delta Vision initiative was initiated to devise a strategy for the Delta and Suisun Marsh sustainability that considers all services.

- The Public Policy Institute of California (2007) evaluated nine alternatives and concluded that several promising alternatives deserve more study; all are different than the current system.

2.6 ASSESSING THE RISK OF DELTA LEVEE FAILURES

A comprehensive and thorough probabilistic risk analysis of Delta levees has not been performed previously. The following previous work addressed portions of the risk question and advanced some ideas on risk management. This provides important background and a starting point for the present DRMS effort to prepare the first comprehensive, quantitative assessment of Delta levee risks.

Although the risks of Delta levee failures are obvious and have been recognized for quite some time, efforts to quantitatively assess the likelihood and consequences of levee failures have occurred only infrequently. Most early efforts simply recognized the risks and concentrated on how to best respond to such an adverse event when it occurred (e.g., DWR 1986). Recently, however, it has been recognized that there is an advantage to a quantitative understanding of levee failure likelihood and consequences. With such information, more rational consideration can be given to actions that can be taken to reduce failure likelihoods and consequences.

2.6.1 CALFED Levee Seismic Vulnerability

In response to the CALFED objective of levee system integrity, a first assessment of Delta levee seismic vulnerability was performed (CALFED 2000b). This effort looked only at the possibility of failures due to earthquakes and it characterized the scale of a failure event by the number of simultaneous breaches that might occur. This restricted the interpretation of consequences because it was not stated how many islands were flooded or what impacts would be expected to result from a given number of simultaneous levee breaches. Still, this effort provided an initial estimate of seismic failure likelihood, as illustrated by Figure 2-7.

Note that, in 50 years of exposure, the common benchmark of a 1 percent annual frequency of exceedance event would have about a 39.5 percent probability of exceedance. The common example of this magnitude event is the 1 percent flood, frequently called the “100-year flood.” Thus, the figure indicates that the 1 percent annual earthquake would result in four or five levee breaches and can be expected to occur or be exceeded with 39.5 percent probability in a 50-year exposure period under current conditions. More severe events might cause 70 to 90 breaches.

2.6.2 JBA Preliminary Seismic Risk Analysis

As an extension of the CALFED work already described, Jack R. Benjamin & Associates (JBA 2005) analyzed the potential extent of flooding, the water quality impacts, and the economic consequences of seismically induced levee failures. The JBA analysis used the CALFED (2000b) results as input, selected an example earthquake that would lead to levee breaches and used those levee breaches to define flooded islands, repair time and costs, salinity intrusion and persistence, duration of water export pumping disruption, and widespread economic impacts due to water export disruption. The results were then interpolated and extrapolated to estimate similar results for other earthquakes.

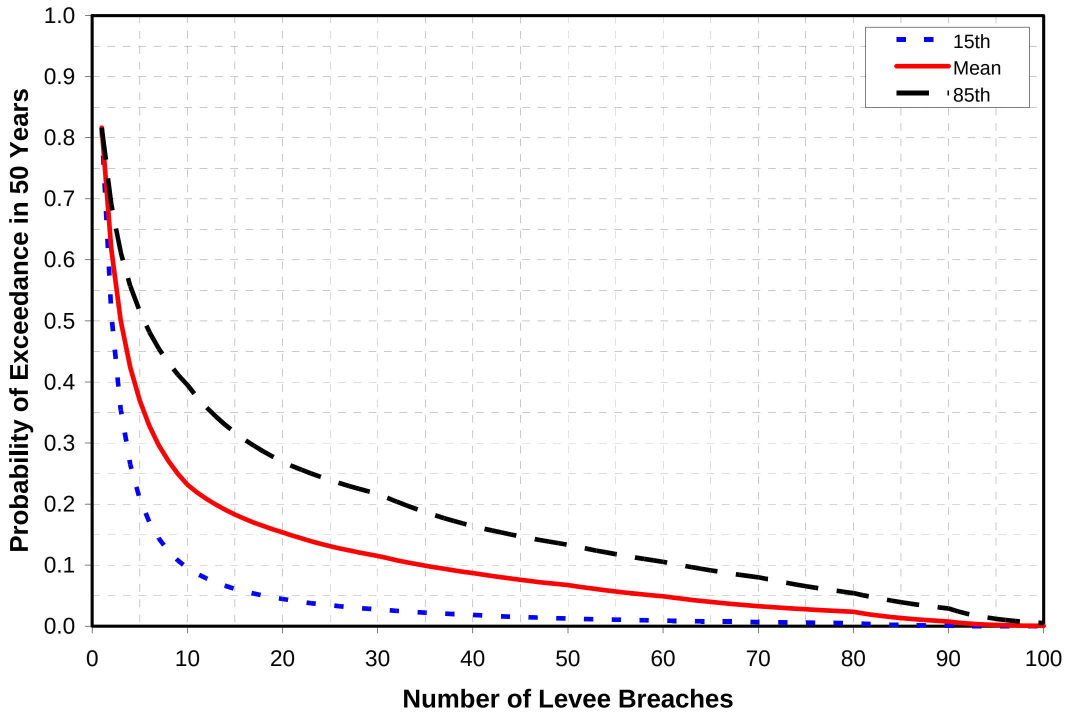


Figure 2-7 Probability distribution on the number of seismically initiated simultaneous levee breaches in the Delta for an exposure period of 50 years under current conditions (scaled from Fig. 5-3 [CALFED 2000a]).

The results were recognized as preliminary, with a need to extend to other hazards (e.g., floods), update the seismic input information, develop a broader set of earthquakes for analysis of impacts, and generally improve the robustness of the analytical approach used. However, the analysis did provide an initial quantification of risk in terms of the likelihood of an important consequence – the economic impact to the state – as illustrated in Figure 2-8.

Note that, in 50 years of exposure, the common benchmark of a 1 percent annual frequency of exceedance event would still have about a 39.5 percent probability of exceedance. Thus, the figure indicates that the 1 percent annual earthquake would result in $1 to $2 billion of economic impact and can be expected to occur or be exceeded with 39.5 percent probability in a 50-year exposure period under current conditions. More severe events might cause $20 to $30 billion worth of impacts to the state's economy.

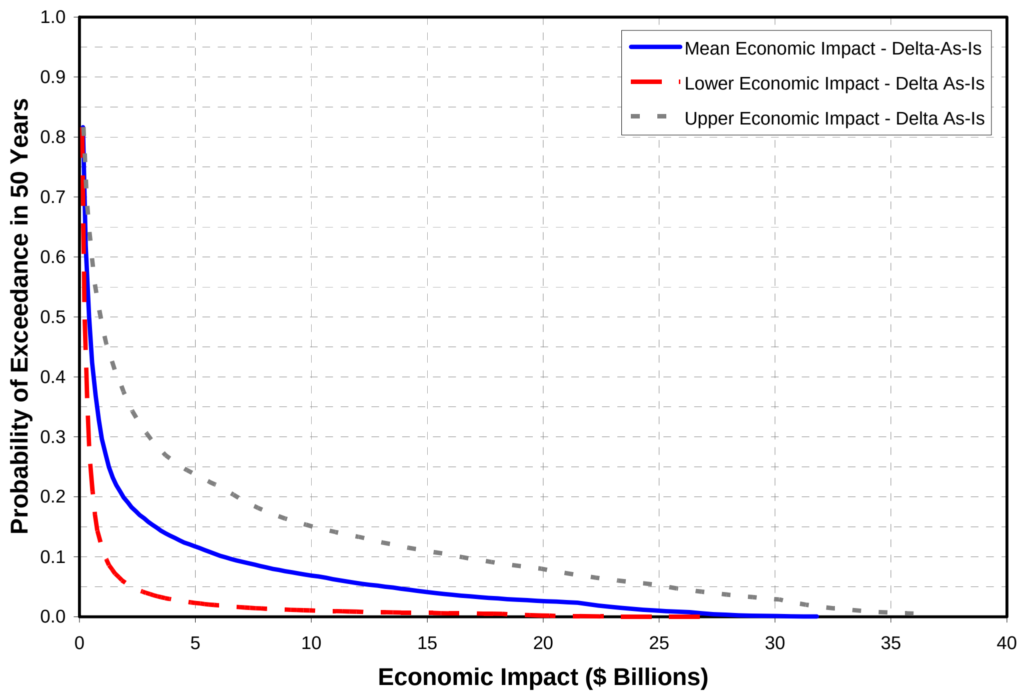


Figure 2-8 Probability distribution on the economic impact to the state as a result of seismically initiated levee failures in the Delta as it currently exists, assuming an exposure period of 50 years (JBA 2005).

2.6.3 Mount and Twiss

As part of their work for the California Bay-Delta Authority (CALFED) Independent Science Board assessment of significant scientific issues relative to Delta management, Mount and Twiss (2005) focused on "Accommodation Space" and a "Levee Force Index" to call attention to the risks associated with potential Delta levee failures. "Accommodation Space" is the volume of Delta space between land surface and sea level. It is physically situated to accommodate flood water in event of levee failures. Accommodation space is substantial and increasing due to both continuing subsidence and sea-level rise. The "Levee Force Index" is proportional to the square of the hydraulic head (the difference between the water surface elevation and the behind the levee land surface elevation), which is the nature of the formula for calculating the water force on levees. The force index is also substantial and increasing due to subsidence and sea-level rise.

Mount and Twiss point out the hazard posed by earthquakes and floods that may cause multiple levee failures. They use the CALFED (2000b) seismic results and FEMA National Flood Insurance Maps to observe that substantial flooding of islands in the Delta should be expected due to either the 100-year flood or major earthquake, and that at least one or the other has about a 64 percent probability of occurrence in a 50-year time frame. Although this provides a reasonable, first-order estimate of risk, the magnitudes of potential consequences are not addressed.

2.6.4 Summary

The DRMS project team developed initial characterizations of risk for portions of the hazards faced by Delta levees. Prior to the DRMS effort, there was not a comprehensive, quantitative characterization of risk associated with Delta levees. To reduce the likelihood of failures and their consequences, such an effort would need to address all hazards, levee failure consequences, and both present and future conditions. That is the scope established for DRMS and detailed in Section 3.

Figures

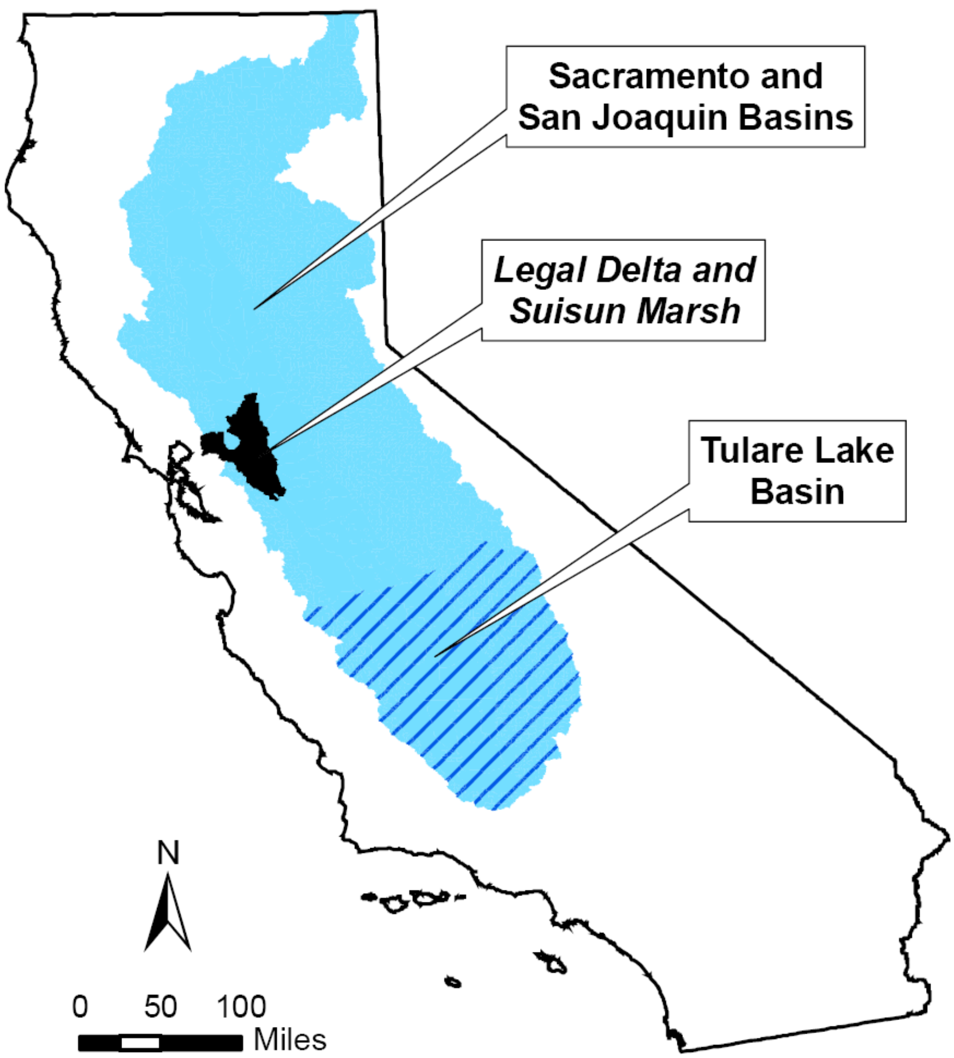
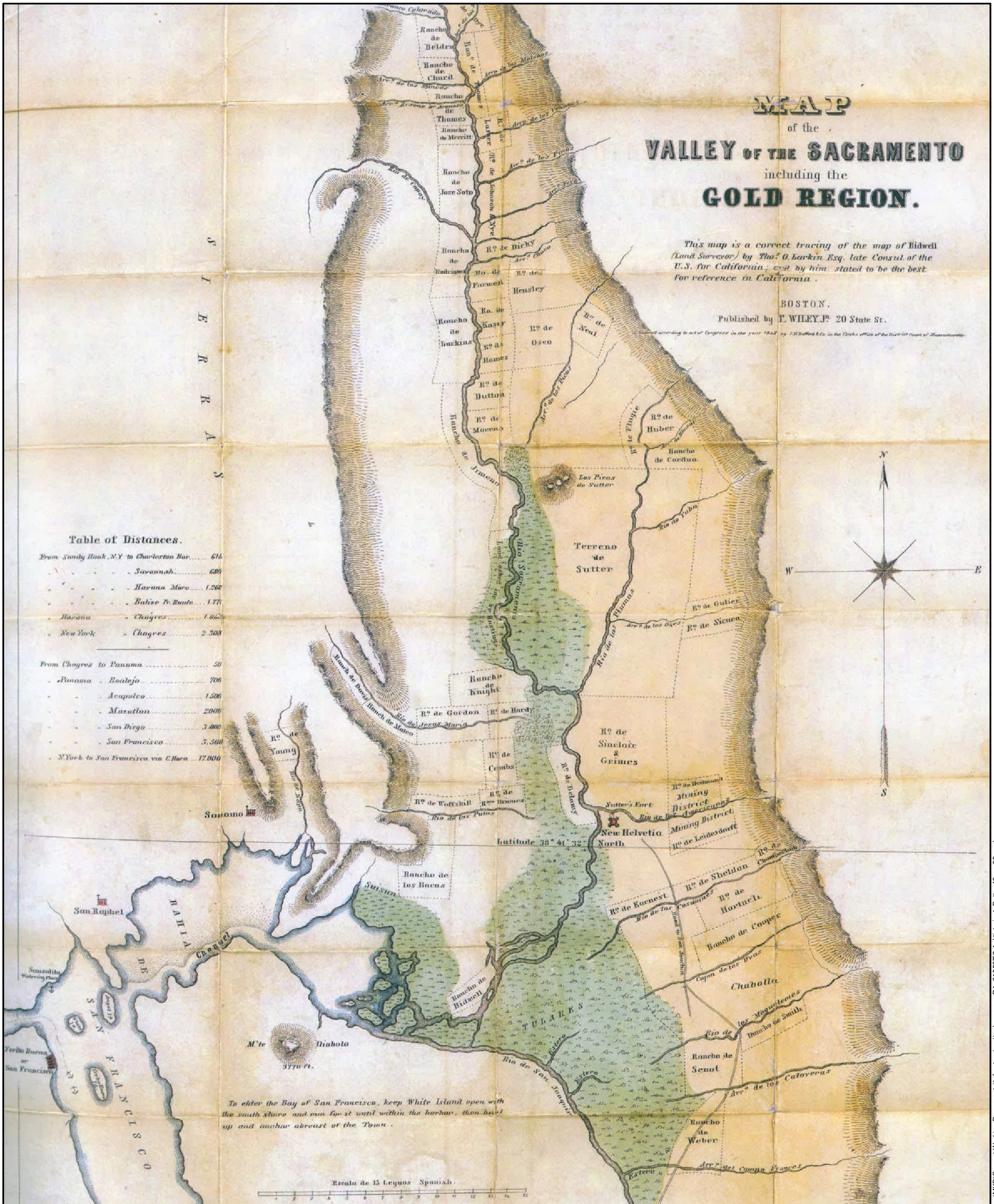


Figure 2-1 Watershed for Delta and Suisun Marsh



Source: Hayes, 2007

URS	DRMS	Sacramento Delta Region Map from mid-1800s	Figure 2-2
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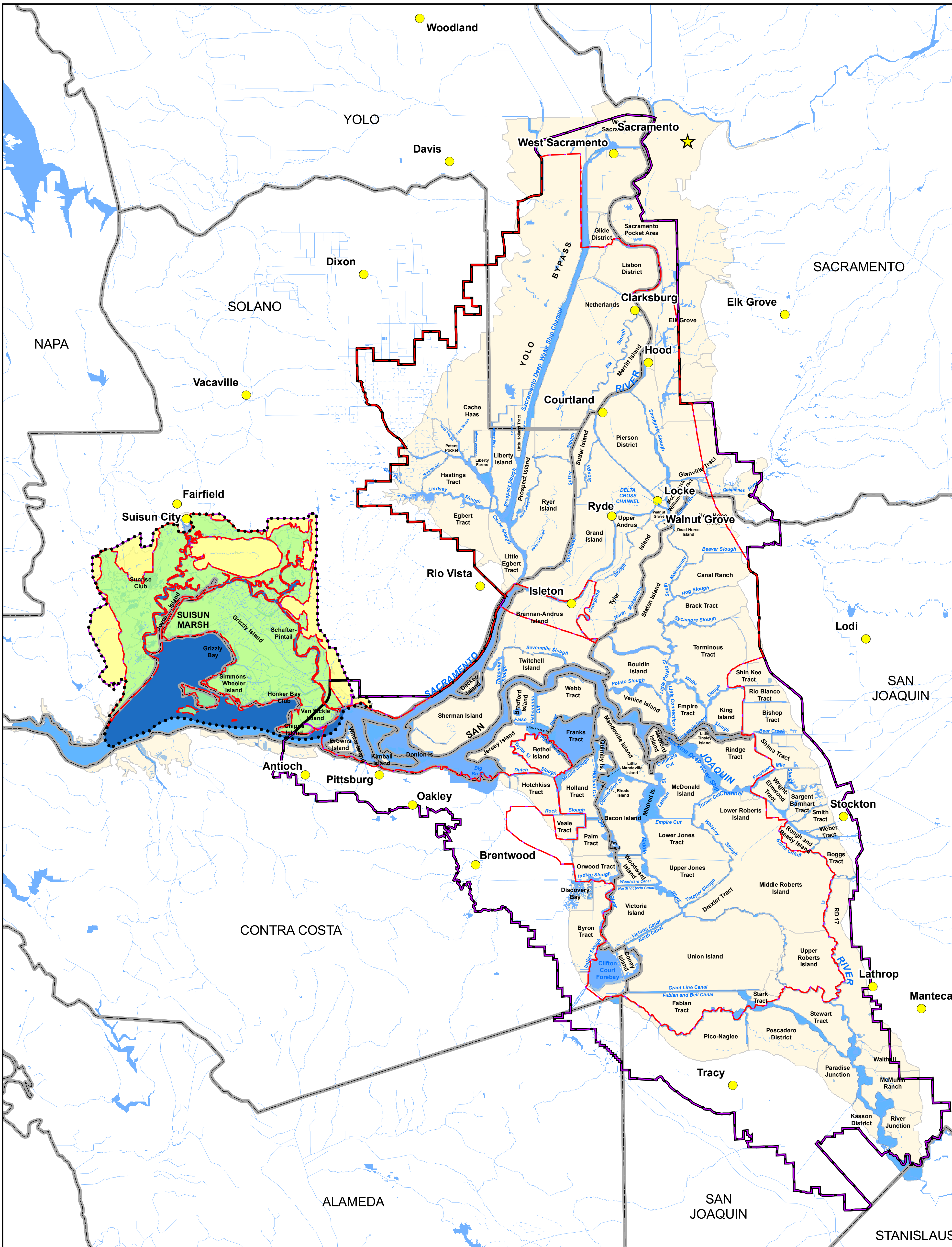

County boundary

Legal Delta

Suisun Marsh

Intermittent waterway

Perennial waterway

Water

Primary Zone boundary

Secondary Zone boundary

Suisun Marsh

Primary Management Area

Primary Management Area - Water

Secondary Management Area

0 5 10

Miles

N

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Delta Islands and Sloughs

Figure 2-3

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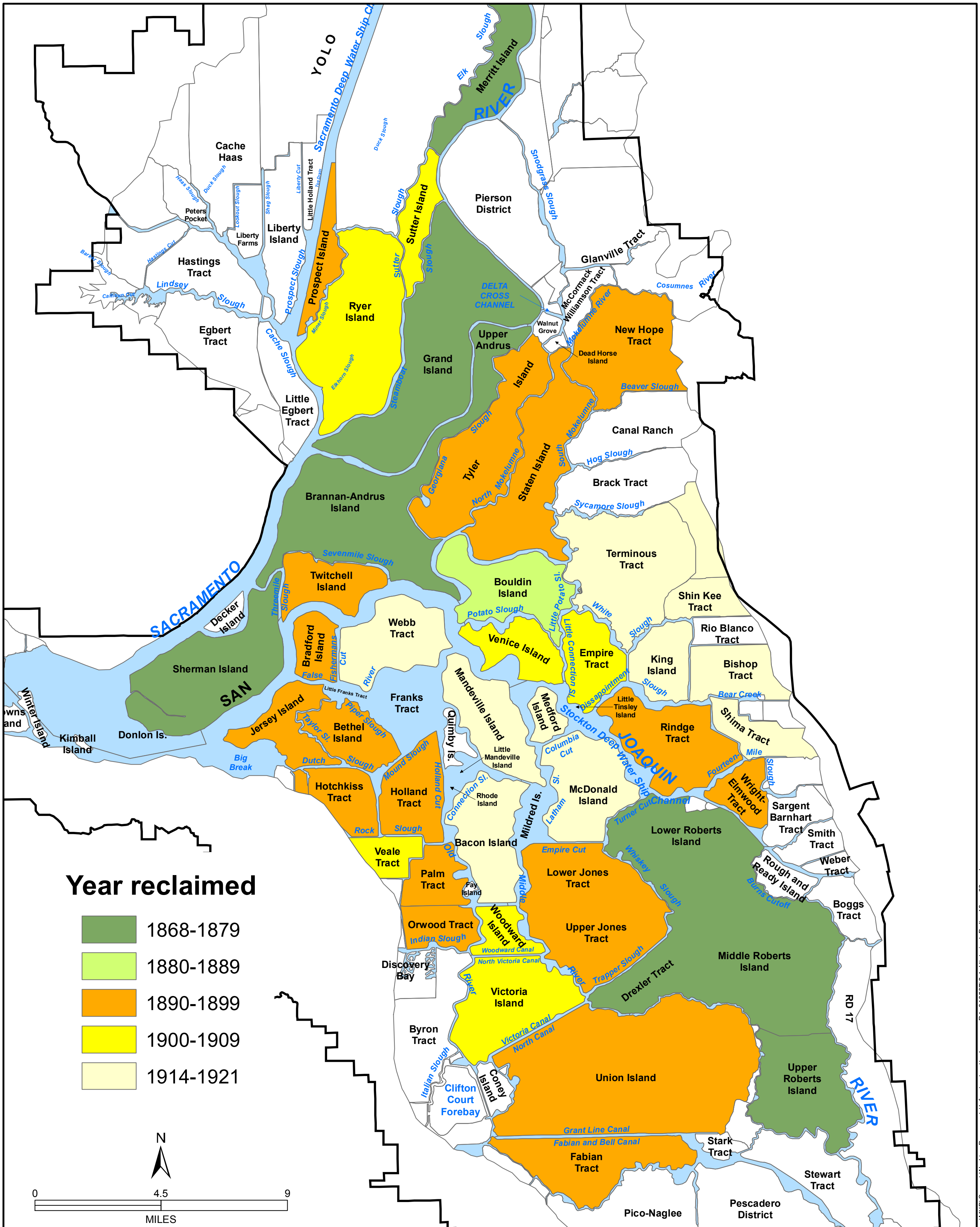

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Year of Initial Drainage

Figure 2-4

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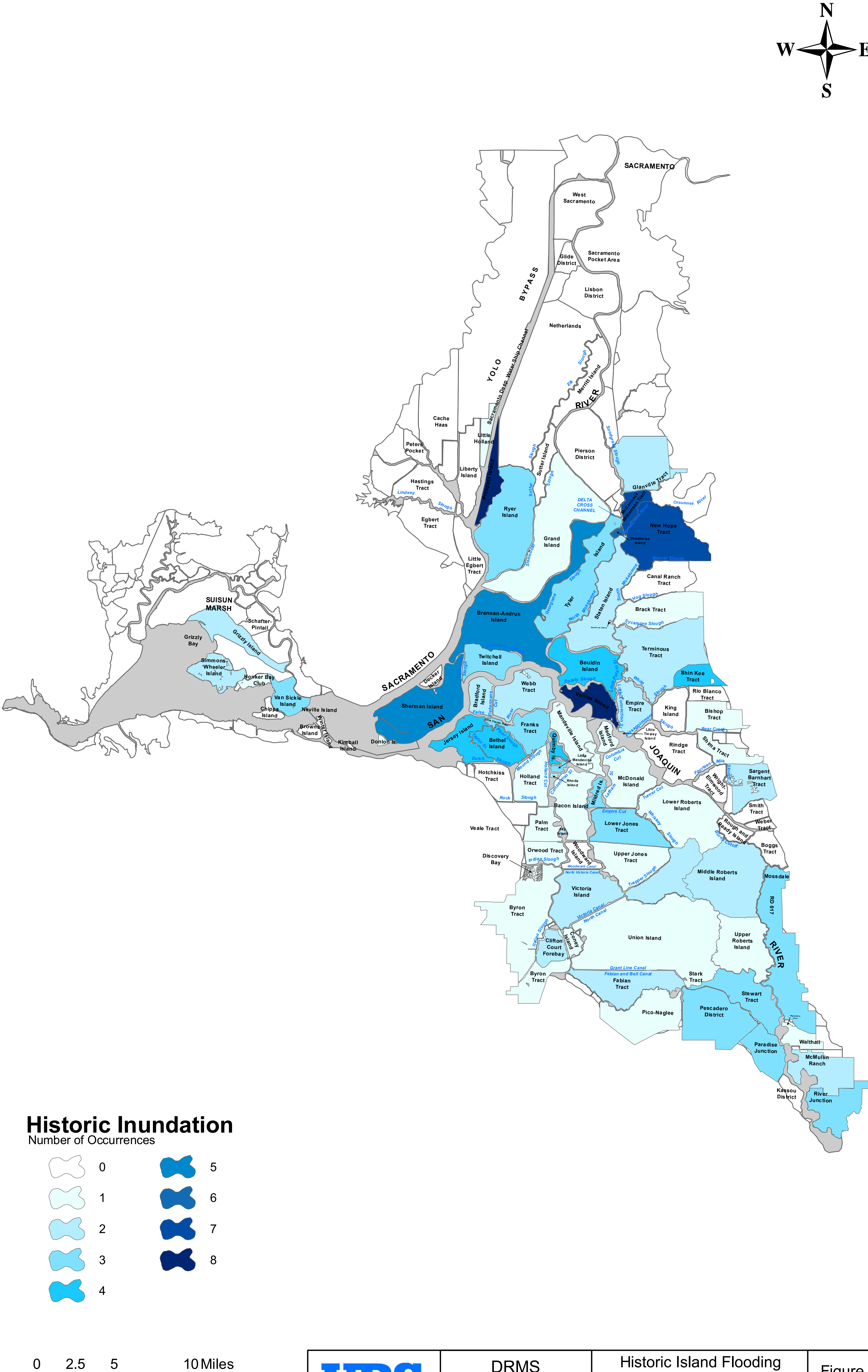

URS

DRMS	Historic Island Flooding in the Delta and Suisun Marsh Since 1900	Figure 2-5
26815431		

URS	DRMS 26815431	Federal, State, and Local Projects in California	Figure 2-6

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In the DRMS analysis, risk is defined as the likelihood (frequency) of adverse consequences that could occur as a result of levee failures in the Delta. Quantitatively, risk is defined in terms of three components; loss or consequence, frequency of occurrence, and probability as a measure of uncertainty (Kaplan and Garrick 1981). While the focus of DRMS is on analysis of risk as defined above, it is worth noting that the events that are modeled may involve benefits (rather than only losses), such as potential changes for the ecosystem (e.g., from stopping the water export pumps and their associated damage to fish).

This section defines the scope and the limits of the DRMS risk analysis, especially what is included in the analysis and what is not included. The DRMS project is not a planning study; rather it is a quantitative analysis of risk and alternative risk-informed strategies for managing the Delta. This work, when incorporated with other studies and information, will provide planning-type information to guide design activities. The risk analysis results and the identification of risk-informed management strategies will be available to (and hopefully helpful to) other initiatives including the Delta Vision initiative, BDCP, the assessment of CALFED End of Stage 1, CALFED planning for Stage 2, and to others performing planning studies.

The most important contributions the DRMS makes are the methodology and submodels developed and integrated for the purpose of quantifying Delta levee risks. Those comprehensive tools can be used again in future planning studies to explicitly quantify the risks associated with alternatives that are of special interest in the planning process. Thus, if the tools are carefully used, planners and decision makers can obtain specific information for comparing risks of competing alternatives. Such information has not been available previously. In the past, such comparisons have usually been made only on a qualitative or intuitive basis, if risks were considered at all.

3.1 OVERVIEW

The focus of the DRMS study is the assessment of risk to the Delta area and California associated with Delta levee failures. The risk analysis addresses events (e.g., earthquakes, floods, climate change) that impact the performance of Delta levees and the consequences that may ensue due to levee damage or failures.

Earthquakes (or floods) that cause levee damage may, of course, also cause other infrastructural damage not involving Delta levees. The other damage could be in or out of the Delta area. For example, water aqueducts may breach, bridges may fail, or water distribution systems may be affected. Such damage that is not caused by Delta levee failure is not addressed within the present DRMS analysis. Aspects of such damage may warrant consideration in future risk analysis updates. Non-levee or out-of-Delta damage could make overall event consequences worse by delaying Delta repairs or by their own causative effects on infrastructure and economic activity. Similarly, other damage (by itself) could cause some of the same consequences that would stem from levee damage. The synergistic/antagonistic effects and the double mechanisms for impact are not addressed here. Consequences are attributed to levee damage as if that were the only mechanism of causation.

3.2 GEOGRAPHIC AND EVALUATION SCOPE

With respect to the evaluation of levee systems, the geographic scope of the DRMS risk analysis includes the area of the Delta and Suisun Marsh:

- Suisun Marsh east of the Benicia-Martinez Bridge on Interstate 680
- Legally defined Sacramento–San Joaquin Delta, as defined in Section 12220 of the Water Code

This area, which is identified on Figure 2-3, is the area within which the damage to and failure of levees and island or tract flooding, including levee/flooding impacts on infrastructure, is evaluated.

However, the consequences of levee failure within this area may be more widespread; they can extend well beyond the defined boundary to other regions and the entire state. For example, although outside the Legal Delta, parts of Sacramento could be flooded as a result of levee failure in the Delta. These consequences are within the DRMS scope. Therefore, the economic impacts of levee failures within the Delta and Suisun Marsh are evaluated for the entire area that could be flooded or otherwise affected. However, only the direct impacts to the in-Delta ecosystem resulting from levee failure are addressed in this work. The potential indirect impacts to ecosystems outside the Delta caused by levee failures within the Delta and Suisun Marsh are complex and difficult to model and are therefore outside the scope of this project.

An assessment of risks and the evaluation of risk management strategies must be made on the basis of the current state-of-knowledge. To the extent the present knowledge is incomplete, an assessment of risk is uncertain (and may specifically recognize uncertainty). That uncertainty will be assessed and characterized as part of the overall DRMS analysis results.

This analysis of risks associated with Delta levee failures is a complex and challenging undertaking, especially in light of the incomplete information available and other constraints imposed. The following precepts guide the Delta risk analysis:

- The DRMS project must be carried out, for the most part, using existing information (data and analyses). The project schedule does not afford the opportunity to conduct field studies, laboratory tests, research investigations, or complex new modeling efforts.
- The analysis must include an assessment of the epistemic (lack of knowledge) uncertainty – i.e., reflecting the uncertainty associated with the current state of knowledge (data, information, cause-effect relationships, and engineering and scientific understanding) regarding the events and consequences that are modeled.
- Measures of risk (e.g., risk metrics) and risk reduction strategies must address the impacts (e.g., economic, environmental, etc.) outlined in AB 1200. Life safety was subsequently added to consequences that must be addressed.
- A “business-as-usual” (BAU) approach is taken to guide the analysis with respect to modeling the current risks as well as in making estimates of risks for future years. This approach assumes that existing regulatory and management practices are carried forward into the future and serves as a base case. More discussion about BAU and its influence on the risk analysis can be found in Section 3.4.

3.3 DELTA DYNAMIC AND FUTURE

Several factors, or drivers of change, will affect future levee risks in the Delta and Suisun Marsh. These factors include forces of nature over which little human control exists (e.g., earthquakes), and factors like urbanization for which no single oversight is in place, given existing regulatory and management practices. The Delta and Suisun Marsh are facing changes that may be gradual or sudden, as summarized in the Delta Vision “Status and Trends” document (URS 2007). The respective DRMS Technical Memorandums (TMs) provide additional detail (URS/JBA 2007a–2007f, 2008a–2008f).

- **Subsidence –** Land subsidence has placed most of the Delta land surface below sea level. Subsidence varies with location, but rates of 0.5 to 1.5 inches of soil loss per year are common in the Delta. This historical subsidence has left multiple islands with average land surface elevations as much as 15 feet or more below mean sea level. Several islands have areas as much as 25 feet below sea level. The dramatic reduction of land surface elevation on Delta islands has increased the differential head between the landside and water surface elevations in the channels. Although the areal extent and rate of subsidence of Delta islands and tracts have reduced in recent years, subsidence is still continuing in many areas. Continued subsidence will increase levee vulnerability and add to both the chances and consequences of levee failure.
- **Global Climate Change and Sea-Level Rise –** Sea levels have been rising for approximately the past 20,000 years. They rose rapidly after the last ice age and then at a modest rate for about the last 5,000 years (Gornitz 2007). But the rate appears to have increased during the past century. Current estimates by the Intergovernmental Panel on Climate Change (IPCC) indicate that sea level will rise by about 0.6 foot to 1.9 feet over the next 100 years, with a possible added 0.5 foot if the rate of Greenland ice melt increases. Other estimates predict more rise (Climate Change TM [URS/JBA 2008b]). If levees are to be maintained, a continuing effort to repair, raise, strengthen, and expand the levee system is required. Even if the effort keeps up with the rate of seal-level rise, both the chances and consequences of levee failure are likely to increase.
- **Regional Climate Change and More Winter Flooding –** By the end of the century, depending on future heat-trapping emissions, statewide average temperatures are expected to rise between 3 and 10.5 °F. The estimates show more winter precipitation occurring as rain and less as snow, leading to more winter flooding. Higher flood stages in the Delta would increase the chances and consequences of levee failure.
- **Seismic Activity –** From research conducted since the 1989 Loma Prieta earthquake, the USGS and other scientists presently assign a 62 percent probability to the likelihood of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking the San Francisco Bay region before 2032 (USGS Open-File Report 03-214). This shaking has the potential to cause multiple levees in the Delta to fail. Furthermore, the probability of such an earthquake (within a given number of years) is increasing as time passes, assuming no major earthquake occurs in the interim (Seismology TM [URS/JBA 2007a]).
- **Delta-Suisun Land Use –** Although agricultural and conservation uses are encouraged for the Delta and Suisun Primary Zones, further urbanization is expected in the Secondary

Zones. There is uncertainty on when full development of the Secondary Zones will have occurred, but consensus seems to point toward mid-century rather than later (URS 2007).

- **Delta-Suisun Population** – Projections of study area population increases indicate the present (year 2000) population of 470,000 will increase by 600,000 to 900,000 people by 2050 for a total population of between 1,070,000 and 1,370,000 (URS 2007).
- **State Population** – Similarly, but less dramatically, the state population is expected to increase from 33.8 million in 2000 (DOF 2007a) to 59.5 million in 2050 (DOF 2007b).

In assessing risks for the future as contrasted with the present, these progressive changes and the evolving probabilities of sudden changes must be explicitly recognized and factored into the analysis. Quantification of the various changes can be complex and challenging and will be accompanied by increasing uncertainty as projections extend further into the future.

3.4 BUSINESS AS USUAL

During the Phase 1 analysis, various models of stressing events and their consequences are used to characterize Delta levee damage events now and in the future. The events resulting from uncontrollable natural and physical processes are estimated using engineering and scientific tools that are readily available or on the basis of a broad consensus among the practicing community. Such events include the likely occurrence of future earthquakes of varying magnitude in the region, future rates of subsidence given continued farming practices, the likely magnitude and frequency of storm events, the potential effects of global warming (sea-level rise, climate change, temperature change) and their effects on the environment.

The estimate of risk to the Delta and the state will be made for the present and for 50-, 100-, and 200-years in the future. It becomes apparent that projections and/or assumptions defining the future “look” of the Delta need to be established. The Delta will change in the next 50, 100, and 200 years. The question facing the DRMS project is: what type of Delta should one assume in these future year projections?

Again recognizing that risk-informed decisions will be made to shape the Delta of the future, one must establish the BAU scenario for the Phase 1 risk analysis as a base case. Defining a BAU Delta is required, because one of the objectives of this work is to estimate whether continuation of existing management practices provides for a sustainable Delta for the foreseeable future. Furthermore, setting a BAU scenario helps to establish an unbiased measure of risk for the Delta and remove potential speculations.

The BAU scenario can only be defined as far as the limited duration of existing agreements, policies, and practices. Hence, longer time spans may not be covered by such policies or be well represented by current practices. The study assumes that current policies and practices are maintained to the extent possible for the longer periods of time (50, 100, and 200 years). Exceptions to this assumption may potentially arise in conditions where the changes in the Delta overwhelm the financial and human resources normally devoted to maintaining the Delta. The bullet points listed below present examples to illustrate these potential conditions.

Also, certain water transfers would likely occur during a catastrophic event, so it was assumed that the state would not allow the pumps to south-of-Delta areas to be out of service for more than 2 years. However, it would be speculative to identify the specific water transfers and exchanges that might occur in this situation, so the BAU analysis does not attempt to do so.

Furthermore, instances will occur where procedures and policies may not exist to define standard emergency response procedures during a major (unprecedented) stressing event in the Delta or the restoration guidelines after such a major event. In such conditions, prioritization of action will be based on: (1) existing and expected future response resources, and (2) the highest value recovery/restoration given available resources.

Below are some examples illustrating the development of the BAU scenario:

- **Flood Protection –** Flood protection levees will be maintained in urban areas to provide the same level of protection (e.g., 100-year flood) for the period of study considered (e.g., 50, 100, 200 years from now).
- **Delta Levees –** Levees in the Delta will be maintained in accordance with current maintenance practices as defined by the recent record of available resources. That is, it will be assumed that appropriations of subvention and special projects funding will continue at the 2005 rate. Note that this does not include recent bond funding, which is not viewed as a BAU mechanism.

  Present state appropriations are not adequate to keep up with current maintenance and repair needs, even without sea-level rise. Thus, should sea level rise by several feet in the next 100 years, raising the levees to keep up with sea-level rise cannot be considered BAU. The resources and funding required to build and maintain levees several feet higher than they are now would clearly exceed BAU resources. This has been viewed as a severe restriction. To facilitate understanding, a modified version of the base case is to be developed – one in which levee improvement funding is assumed to increase to keep up with sea-level rise by raising, but not structurally strengthening (or weakening) Delta levees.
- **Emergency Response (Levee Repair) –**-Human and financial resources available at the time of a major disruption to the Delta (earthquake, flood, etc.), will limit the emergency response as it relates to the repair of levees (breaches and nonbreach damage). As an example, if tens of levees breach during a major event in the near future, the state, federal, and local entities may not have enough resources to reclaim them all quickly. The islands will be stabilized to prevent future deterioration, if possible.

  Prioritization of certain islands for early recovery efforts will be based on the highest benefit for the available resources (public health and safety, infrastructure, water supply and water quality, habitat, etc.). Furthermore, during a flood fight, prioritization will have to be considered, depending on available resources, to protect those islands with highest opportunities first, considering both the value of the threatened resources and the prospect for success in preventing flooding of the island.
- **Delta Improvements –** Delta improvements in the planning stage will be considered if those projects are funded and approved in the 2006 calendar year. Planning studies under consideration for future years will not be considered in the Phase 1 risk analysis. Such examples include: the planned upgrades of the levees to bring them to a PL84-99 status, or other south Delta improvement planning studies. Although, these potential projects will not

be considered in the BAU scenario for Phase 1, they will be included in the risk reduction evaluations in Phase 2. They may turn out to be prime candidates for improvements.

- **Land Use –** Urbanization and land use for the Phase 1 BAU scenario will be based on the assumption that the Delta's Primary Zone will continue to be free from new urban development as is now required by the Delta Protection Act. However, development in the Secondary Zone will continue at the current trend, based on current and projected urban development plans. These Delta zones are defined in Figure 2-3.
- **Habitat Restoration –** Habitat restoration has been underway for at least 5 years. The Phase 1 analysis assumed an ecosystem with no additional restored areas.
- **Water Operations –** Operations following an event in the Delta will be based on current project operating procedures (including reservoir operation guidelines, any formalized standing orders and emergency procedures, pre-action consultation procedures with fisheries agencies or others) and stated priorities as expressed to the DRMS project team by the State Water Board staff. These water allocation priorities are first for human health, and second for endangered species to the extent mechanisms exist to implement them, and then other uses according to water rights.

Major levee failures are difficult and expensive to repair. The 2004 failure of the Upper Jones Tract levee caused damages that cost about $100 million to repair. Multiple levee failures caused by a single earthquake or flood could have a devastating effect on the Delta and the entire state economy. All Delta and Suisun Marsh services would be impacted.

3.5 HAZARDS AND ENVIRONMENTAL FACTORS

The risk analysis focuses on natural hazards that have the potential to cause the failure of levees and subsequent flooding of islands. The specific hazards considered in the analysis include:

- Floods
- Earthquakes
- Sunny-day failures (nonflood flows)
- Winds/waves

The analysis is to consider appropriate combinations of these hazards. Time-dependent processes (such as subsidence and climate change) that impact the frequency or severity of hazards in future years, or change the vulnerability of Delta levees, are analyzed as characteristics of the Delta environment in each analysis for a given future year.

For floods and winds/waves, the analysis considers both normal (i.e., usual) conditions that occur each year and transient events; that is, events having a low estimated frequency of occurrence in any given year. The impacts of these hazards are combined with subsidence and climate conditions as projected for each specified future analysis year.

The risk analysis does not consider hazards that could cause failure of a Delta asset, but poses no threat or relationship to the Delta levees. Thus, for example, the failure of a gas pipeline within the Delta due to corrosion is not considered, unless such an event would put a Delta levee at risk. If such a pipeline failure occurred at a levee and resulted in a levee breach, it would be considered an example of a sunny-day failure. Furthermore, man-made hazard events (such as vandalism or a terrorist act) also are not considered in this analysis.

3.6 CONSEQUENCES OF LEVEE FAILURES

The potential consequences of levee failures are many:

- Death or injury of people
- Damage to residences
- Damage to businesses
- Damage to public buildings and disruption of public services
- Damage to contents of structures
- Damage to utilities
- Damage to transportation corridors
- Change in Delta salinity
- Changes in ecosystem conditions that can have a wide variety of impacts
- Disruption or cessation of in-Delta and export water supplies
- Loss of crops and future agricultural production
- Loss of use for residences, businesses, utility infrastructure, recreation, etc.
- Repair and recovery costs including debris removal
- Additional loss to the economy through economic linkages
- Potential permanent flooding of some island and tracts or portions of islands and tracts.

These are discussed in more detail in Chapter 12.

3.7 ESTIMATING RISK FOR FUTURE YEARS

AB 1200 called for DWR to estimate potential impacts on water supplies derived from the Sacramento-San Joaquin Delta based on 50-, 100-, and 200-year projections. Estimating conditions even 10 years into the future is difficult for some aspects of risk, especially since these evaluations are based only on readily available information. For some key variables (e.g., Delta Smelt species viability), the uncertainties are simply too great.

However, after evaluating risk under the 2005 Base Case (Chapter 13), the report estimates risks for future years (Chapter 14) based on best available information. Like any projections of this type, they should be relied upon only until better information becomes available to make improved estimates.

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The purpose of the Delta Risk Management Strategy (DRMS) risk analysis is to estimate the risks to the Delta and the state that are a result of Delta levees failures. Delta and statewide risks are evaluated in terms of the economic, environmental, and public health and safety impacts that levee failures may have.

To start, this section describes the risk problem being evaluated. This is followed by a presentation of a conceptual model of events in the Delta that are modeled in the DRMS risk analysis, the risk analysis methodology, the DRMS risk model, and finally the steps in the quantification process. As part of the discussion, Delta risks not addressed are also identified.

4.1 THE RISK PROBLEM

As discussed in Section 2, the DRMS study is intended to evaluate the risks of levee failures in the Delta and Suisun Marsh. The hazards or stressing events that are considered are defined in the DRMS project work scope (JBA 2006a, 2006b) and parallel those identified in AB 1200.

The DRMS study must also assess how risks may change into the future (over the next 200 years), taking into account environmental factors such as subsidence and climate change that alter the landscape of the Delta, changes in the potential for future hazards (i.e., earthquake occurrences, flood events), population growth and development in the Delta, the state's reliance on the Delta as a water source, etc. An analysis of future risks is limited by the availability of projections in each topical area (e.g., future population growth). Nonetheless, information on short-term projections to 2050 and in some cases to 2100 are available, making it possible to project how current risks may change in the future. The approach for considering future risks is generally described in Section 4.9 and presented in detail in Section 14.

The following sub-sections describe the elements of the DRMS risk problem and the analysis conceptual model. In addition, hazards and risks that are not addressed in the DRMS analysis are identified.

4.1.1 Threats and Hazards that Affect the Delta

As in any other region or community, the Delta and Suisun Marsh face a number of hazards or threats that can initiate a sequence of events that result in damage or loss. The Delta is unique in terms of the natural and man-made hazards that threaten it (earthquakes, floods, winds, industrial accidents, etc.) and the exposure to loss (discussed further in Section 5), which includes the local population, a valued and varied ecosystem, local and regional infrastructure (pipelines, state highways, rail lines etc.), a water export system that relies on levee integrity for conveyance, and local, regional, statewide, and national business interests.

Events that pose a threat to or could initiate events resulting in adverse consequences to the Delta (i.e., the environment and those who live and work there, etc.), include, but are not limited to:

- Natural hazards:
  - Earthquakes
  - High winds
  - Wind waves
  - Hydrologic events
  - Wildfires

  - Surges due to low-pressure meteorological systems
  - Meteor strikes

- Man-made hazards:
  - Oil, gas or chemical spills
  - Terrorist acts
  - Highway accidents
  - Vandalism
  - Rail accidents
  - Commercial shipping accidents
  - Recreational boating accidents
  - Commercial or private aircraft accidents
  - Military aircraft accidents
  - Explosions associated with any of the above man-made events
  - Man-caused fires
  - Accidents or events outside the Delta or Suisun Marsh that may affect the Delta, such as upstream toxic spills, dam failures, etc
- Environmental/Ecological:
  - Invasive (non-native) species
  - Processes (currently not well understood) associated with the observed pelagic organism decline in the Delta and Suisun Marsh
- Intrinsic Factors/Forces that effect levees:
  - Hydrostatic Forces
  - Tidal variations
  - Channel flow variations due to State Water Project (SWP) and Central Valley Project (CVP) pumping (a man-made hazard which is intrinsic to the current operation of the Delta)
  - Ambient waves
  - Animal burrowing in levees
  - Internal erosive or deteriorating effects of through- or under-seepage in levees
- Public Health-Related Events:
  - Disease
  - Contaminated foods
- Public Safety:
  - Crime
  - Public unrest

The foregoing list of threats or initiating events is not exhaustive, but is indicative of the range of events that could adversely affect the Delta, Delta levees, the ecosystem, the public, and Delta infrastructure.

Looking to the future, there are a number of drivers of change that affect the Delta landscape and the chance and magnitude of future hazards. These drivers of change (identified in Section 2 and repeated here) include[1]:

- Subsidence
- Global Climate Change – Sea-level Rise
- Regional Climate Change – more winter floods and less snow pack
- Seismic Activity
- Introduced Species

As these changes evolve, they will change the Delta landscape, affect the severity and likelihood of occurrence of future hazards, , the performance of Delta levees, and the future of the Delta ecosystem.

4.1.2 Scope of the DRMS Risk Analysis

While the hazards and risks that may impact the Delta are varied, the DRMS risk analysis is focused on specific events and a limited number of hazards that may initiate them. The focus of DRMS is to analyze the risks to the Delta and the state that are the result of levee failures only. Further, the threats to Delta levees that are considered are limited to (DRMS 2006a, 2006b):

- Earthquakes
- Hydrologic events (floods)
- Wind waves
- Combinations of the above
- Intrinsic forces or factors (as identified in Section 4.1.1)

Hereafter in this report, the intrinsic forces/factors that affect levees are referred to as “normal” or “sunny-day” events. In evaluating the potential for levee failure in the future, the DRMS risk analysis also addresses environmental factors that could change the Delta landscape. These include (DRMS 2006a, 2006b):

- Subsidence
- Climate change (as it may effect sea level, changes in hydrologic patterns, winds, and air temperature)

In evaluating these hazards and environmental factors, consequences that could occur in the Delta, but are not the result of a levee failure, are not addressed in the DRMS analysis. For instance, the impact of hydrologic events in the Delta that are not associated with levee failures (damages that occur as a result of flooding not associated with levee failure), are not evaluated in the DRMS risk analysis. DRMS is levee-centric; the risk analysis evaluates the performance of Delta levees and the impact their failure has on the Delta itself and the state as a whole. Other

[1] This subsection addresses only the threats or hazards the Delta is exposed to. Therefore, only drivers of change related to threats or hazards are listed.

hazards or threats, not identified above as specifically considered in this analysis, even if they could adversely impact Delta levees, are not addressed.

4.1.3 Conceptual Model of Hazards, Levee Failures, and the Response of the Delta

An analysis of any system, natural or man-made, begins with an initial characterization of the events/processes to be evaluated; a conceptual model. This characterization is followed by the development of a model that is an analytic representation of the events of interest that serves as the basis for quantification. The model is a representation of a "real" system and how it performs or reacts to the hazards or conditions it may be exposed to. Such a representation is limited by the state-of-knowledge (scientific understanding, data, etc.). As a result, a model is an approximation. In this sense, the DRMS risk analysis is a model of the events that can lead to levee failure and the events that ensue, including levee damage, the hydrodynamic response of the Delta to levee breaching and island flooding, and the consequences of these events. This subsection presents a conceptual model of events considered in the DRMS risk analysis.

The conceptual model of levee failure events is shown in Figure 4-1. The following describes the elements of the model.

Initiating Events. A levee failure can be initiated by external hazards or intrinsic forces that can cause a failure (breach) or damage to a levee. The DRMS analysis considers external events such as earthquakes, hydrologic events, and wind waves. Intrinsic forces/factors are persistent day-to-day, year-to-year for Delta levees, and periodically result in a local instability and a levee failure. These intrinsic factors include hydrostatic forces, tidal cycles, burrowing animals, ambient wave action, and the cumulative effects of deterioration.

Levee Performance and Failure. When an external hazard occurs in the Delta, levees are exposed to transient forces that affect part of and even the entire Delta. These forces may lead to single or multiple levee failures during a single event (e.g., earthquake or flood). If all the levees on an island survive (do not fail and are not damaged), island flooding does not occur, and post-event repair is not required. Alternatively, if one or more reaches were to fail, island flooding occurs. When an external event does occur, the performance of Delta levees can be characterized into the following three general states:

- **OK (no failure or significant damage).** A levee is modeled as "OK" if neither damage nor failure has occurred anywhere along the levee system that protects an island tract. External events, particularly earthquakes, can cause damage to levees that require repair after the event and may be susceptible to post-event damage or failure.
- **Non-breach damage.** This term applies if a levee experiences damage, but not a failure (i.e., no breaching). In the DRMS risk analysis, non-breach damage to levees is only considered in the case of earthquakes.
- **Failure (breach).** Levee failure (a breach) occurs when it has been damaged to the point that it does not remain stable. As a result, it loses its hydraulic integrity (its ability to prevent uncontrolled inflow to an island) and island flooding occurs.

In the Delta, an island or tract is protected by a system of levee reaches. For example, there is over 126,000 feet of levee that protects Sherman Island. This system of levees, which varies in its characteristics around the island, is modeled by a series of reaches based on levee characteristics (referred to as vulnerability classes in Section 6). If one or more of the levee reaches on Sherman Island fails, flooding results.

Island Flooding. When one or more sections of levee on an island fail – waters in adjacent sloughs enter the island, until levels on the island and the sloughs have reached equilibrium. The inflow to a flooding island results in the opening of an initial breach which may grow to a final width of 200 feet or more. In addition there is scour that occurs in the slough adjacent to the breach, in the levee foundation and on the island (DWR 2004). This scour can be a cause of damage to structures located on the island and contributes to the volume of material required to close a breach. Depending on the island's volume below sea level, the time to flood an island may take about 1 to 3 days. For example, it took about 3 days to flood Upper and Lower Jones Tract in June 2004, an area of over 12,000 acres.

Hydrodynamic Response of the Delta. As islands breach and flood, the normal flow patterns in the Delta are disrupted. Water that floods islands is replaced by river inflows and/or saltwater from San Pablo and San Francisco Bays[2]. Beyond the initial disruption of the Delta caused by island flooding, the response of the Delta will depend on upstream water operations (see below), and the rate of breach closures and island dewatering. The interaction of these factors produces a dynamic system that affects the level of salinity intrusion into the Delta, which in turn has implications for water quality and the impacts on the ecosystem.

Water Operations. The intrusion of saltwater into the Delta can be managed to a degree by controlled releases from upstream reservoirs and curtailing/halting exports from the Delta. The decision to release water depends on a number of factors, including the magnitude of the levee failure event (how many islands are flooded), available upstream reservoir storage, type of water year, etc.

Emergency Response and Repair. After a levee failure and island flooding, repairs are initiated to stabilize and close the breach and dewater the island. In addition, as evidenced by the Jones Track event in 2004, once an island floods winds can generate waves that lead to erosion of levee interior slopes. For cases involving multiple levee breaches and/or non-breach damage on multiple islands, the order and timing of breach closures and levee repairs impacts the timing of repairs to damaged structures (residences, businesses, and infrastructure), the return of residents and workers, and the hydrodynamic response of the Delta. The order of island closures alone affects the salinity intrusion into the Delta and the duration of SWP and CVP export disruptions (JBA 2005).

An island whose levees are damaged following an earthquake (non-breach damage) is vulnerable to seepage, further slumping, overtopping, and wind-wave damage. Not only has the internal integrity of the levee been compromised (possibly with extensive cracking), the riprap protection on the levee exterior slope is likely to have been disrupted, and substantial crest loss (in the case of liquefaction failures) will mean that failure can occur from only a moderate high tide, wind waves, or a flood. Whether or not failure occurs will depend on how quickly this damage is addressed to stabilize the levee. During this period, the chance of a moderate challenge to the levee from tides, surge, wind waves or flood is high. If several islands are damaged but not

[2] The degree to which saltwater intrudes into the Delta depends on whether the levee failures occur during a flood or another type of event.

breached during an earthquake, the wait for repair attention may leave an island vulnerable to subsequent breaching.

Consequences of Levee Failure and Island Flooding. When a levee failure event occurs, there are a number of varied impacts that could occur in the Delta and the state. These can include:

- Public health and safety impacts of island flooding
- The direct flood related damages to structures, infrastructure (pipelines, roads, rail lines, etc.) crops, etc. on flooded islands
- The local and regional economic consequences to residents and businesses
- The environmental impact to Delta and Suisun Marsh habitat and species
- Water quality effects and the disruption of water exports
- The economic impact of export disruptions, etc.

The impacts that are realized from a levee failure event depend on the number of and which islands are flooded, the water operations following the levee failures and levee repair operations. At one extreme, experiences in the Delta and modeling studies suggest that individual island failures have little impact on Delta exports. Historically, disruptions that have occurred have been short-lived and thus would have little effect outside the Delta (see Section 4.4.5). At the other extreme, studies of more extensive levee failure events indicate salinity intrusion and export disruptions can be extensive. For example, analysis of a levee failure event involving 21 islands resulted in export disruptions of approximately 23 months and considerable statewide economic impact (JBA 2005).

4.2 FRAMEWORK OF THE RISK ANALYSIS

This section describes the general framework of the risk analysis. The elements of the analysis that correspond to quantitative modules are illustrated schematically in Figure 4-2. The figure and subsequent descriptions are oriented principally with respect to the evaluation of external hazards such as earthquakes and floods. For levee failures that occur during normal conditions (sunny-day levee breaches), the elements of the risk analysis are essentially the same. The exception is the fact that varying levels of loading and fragility (conditional probability of failure) do not apply.

The following paragraphs summarize the elements of the risk analysis.

Hazard Analysis. The hazard analysis estimates the frequency of occurrence and the magnitude of hazards (loads) that may impact Delta levees. In the case of seismic events, the hazard is characterized in terms of peak ground acceleration for a reference site condition. For floods, the hazard is defined in terms of the peak water-surface elevation at a levee. The characterization of hazards must take into account their correlated spatial distribution to model the simultaneous loading that occurs at many (possibly all) levees throughout the Delta. For example, the seismic hazard analysis estimates the ground motions throughout the area that will occur as a result of an earthquake event (e.g., an earthquake of a given magnitude, which occurs on a specific fault). In sum, the purpose of the hazard analysis is to estimate the frequency of occurrence of events that can compromise the integrity of Delta levees.

In the Delta, normal or intrinsic events are ongoing forces that persistently load and challenge the structural and ultimately the hydraulic integrity of levees day-to-day. Per se there is no frequency of occurrence that is evaluated for these forces.

Levee Vulnerability Analysis. Given the occurrence of a hazard (loads on levees), the levee vulnerability analysis estimates the conditional probability of levee breach or damage as a function of the hazard characterization parameter (e.g., peak ground acceleration for seismic events or peak water-surface elevation for floods). Since the hazard level that causes failure is not exactly known, the conditional probability of failure or damage will vary. It will be low (zero) at low hazard (load) levels and ultimately rise to a conditional probability of failure of one (certain failure) at some much higher level. This result is called a fragility curve.

For normal or intrinsic events, the levee vulnerability analysis estimates the frequency of occurrence of levee failures as opposed to a conditional probability as in the case for the external hazards.

System Model. Given the occurrence of a hazard that challenges the water detention capability of Delta and Suisun Marsh levees, a model is required to evaluate the potential combination of events and levee failures/damage that can occur. The system model defines the relationship between hazards and their possible combination to assess the state of the Delta immediately after an event (e.g., an earthquake of magnitude [**M**] 6 on the Hayward Fault). The term "state-of-the-Delta" refers to the condition of all levees and islands immediately after the event. Given an earthquake and the probabilistic nature of levee performance (see levee vulnerability above), numerous combinations exist in which various levees will breach and different islands flood. The system model describes the potential combination of events and the framework for calculating their frequency of occurrence. Each combination of flooded islands is referred to as a levee failure sequence.

The system model also models islands that have not flooded, but whose levees may be damaged and could deteriorate (as a result of wave action) and result in further island flooding. Other factors or random events such as the time of year an event occurs, the type of hydrologic water year, etc. are also included in the system model because of their importance in assessing the hydrodynamic response to and consequences of levee failures.

Risk Quantification and Uncertainty Analysis. This element in the risk analysis combines all of the elements of the analysis and calculates the frequency of occurrences and their consequences that are considered. As part of the quantification, the uncertainties (epistemic, discussed in the next subsection) are also evaluated.

4.3 METHODOLOGY

This section describes the methodology used in the DRMS risk analysis. As summarized in the previous section, the occurrence of levee failures and their effects (consequences) depends on the occurrence and combination of many factors and events. The relationship of these events and their combination (joint, simultaneous occurrence) can be independent (random), such as the time of year an earthquake occurs, to events that are causally related, such as the liquefaction of a levee foundation due to earthquake ground motion.

From historic experience in the Delta and risk modeling experience in general for spatially distributed systems (e.g., earthquake engineering lifeline risk analysis), the performance of Delta and Suisun Marsh levees and the state of the "levee system" (which levees failed and which did not) determines the extent of damage on Delta islands, the impact on businesses, the adverse (or beneficial) affect on the ecosystem, and the impact on the state water system. The effect of levee failures depends on the details of the events that occur; time of year, how many and which islands are flooded, how much flushing of the Delta is attempted (water operations), the order and timing of levee repairs, etc. The frequency of occurrence of a given sequence (the coincident combination) of events depends on the frequency and magnitude of the initiating event and the probability of events in the sequence. To model the risks of levee failures and the consequences that result, an event-based approach is used. This approach is represented by an event tree that models the random events that relate initiating events to levee failures and their consequences (Baecher and Christian 2003; Hartford and Baecher 2004).

4.3.1 Uncertainty

One of the reasons for conducting a risk analysis is to quantitatively consider the uncertainties that affect events of interest (i.e., the performance of levees subjected to earthquake ground motion, the consequences of flooding, the impact of events on the environment, etc.). Fundamentally different sources of uncertainty affect an analysis of events. The first source is attributed to the inherent randomness of events in nature (e.g., a roll of the dice, the occurrence of an earthquake or flood). This uncertainty corresponds to unique (often small-scale) details that are not explained by a 'model'. This source of uncertainty is known as aleatory uncertainty and is, in principle, irreducible. Given a model, one cannot reduce the aleatory uncertainty by collection of additional information. One may be able, however, to better quantify the aleatory uncertainty by using additional data. These events can only be predicted in terms of their probability, or frequency of occurrence.

The second source of uncertainty is attributed to lack of knowledge (information, scientific understanding, and data). For example, the ability to estimate the frequency of occurrence of an event requires that certain data or a model be available. If the amount of data is adequate, the estimate of frequency may be quite accurate. On the other hand, if only limited data are available, the estimate will be uncertain (i.e., statistical confidence intervals on parameter estimates will be large).

This second type of knowledge uncertainty is attributed to our lack of understanding (e.g., knowledge) about a physical process or system that must be modeled. This source of uncertainty is referred to as epistemic (knowledge-based) uncertainty. In principle, epistemic uncertainty can be reduced with improved knowledge and/or the collection of additional information.

Figure 4-3 illustrates the effect of epistemic uncertainty on the estimate of the frequency of occurrence per year that a Delta island may be flooded as a result of levee failure (due to any cause; earthquakes, floods, etc.). The figure shows a probability distribution on the estimated frequency of flooding. If no epistemic uncertainty existed (for example, in the estimated frequency of occurrence of future earthquake ground motions or floods in the Delta, or in the failure frequency of levees due to normal events), there would be no probability distribution in Figure 4-3, but rather a single point estimate. The uncertainties that contribute to this distribution are the amount of data that are available, the accuracy of engineering methods to model the performance of levees, the uncertainty in the estimate of hazards (e.g., uncertainty in the frequency of earthquake occurrences, ground motion attenuation models, etc.).

The distinction between what is aleatory and what is epistemic uncertainty can be unclear. For example, the distinction depends on the models that are used in a particular analysis. As part of a given probabilistic analysis (e.g., seismic hazard, levee vulnerability), it is useful to develop a taxonomy of uncertainty, identifying the sources of different types and how they can be estimated.

The identification and evaluation of epistemic uncertainties can vary, depending on the subject, the development of scientific or engineering understanding, observational and modeling experience, etc. For example, in a field or topical area where considerable observational experience exists and models are used to develop predictive tools, the analysis of epistemic uncertainties may be an integral and in-depth part of the state-of-practice. In other fields, direct observational evidence may be limited and predictive models are based on theoretical models, estimates of the model parameters, the analysts' experience, comparisons of model predictions with observations, etc. In areas where direct observation of events/parameters of interest is limited, competing models and/or scientific interpretations exist, it is often necessary to elicit input from experts to evaluate and quantify epistemic uncertainties (Morgan and Henrion 1990; USNRC 1996; SSHAC 1997).

4.3.2 Definition of Risk

In this analysis, risk is defined as the likelihood (expressed as a frequency) of adverse consequences that could occur as a result of levee failures in the Delta. Quantitatively, risk is defined in terms of three entities; frequency of occurrence, loss or consequence, and probability as a measure of uncertainty (Kaplan and Garrick 1981).[3] This is denoted,

$$\{v, C, p\} \qquad (4\text{-}1)$$

where

$v =$ frequency of occurrence

$C =$ a consequence metric (e.g., economic cost)

$p =$ probability

Here probability is a measure of the relative degree to which an estimate of v is the true value. Figure 4-3 is an example of this characterization of risk. In this example, the figure denotes that the adverse event or consequence is levee failure and island flooding. A frequency of occurrence of this event is determined and the uncertainty in the estimate of the frequency of this event is quantified by the probability density function shown. For consequences such as economic impacts or fatalities that may vary over a range of possible values, equation 4-1 is represented in terms of a frequency of exceedance distribution. This representation is denoted as follows:

$$\{\lambda(C_i > c), p\} \qquad (4\text{-}2)$$

where $\lambda(\;)$ is the frequency of exceedance.

In this analysis, risk is evaluated for a number of metrics. The measures of risk that will be evaluated are:

[3] While the focus of the DRMS risk analysis is the analysis of risk as defined above, it is worth noting that modeled events may involve benefits (for example, the possible benefit of levee failures on the ecosystem).

- Frequency of levee failure and flooding of individual Delta islands.
- Frequency of exceedance distribution on the number of islands that flood during a single event (e.g., hydrologic event)
- Frequency of exceedance distribution for fatalities that occur as a result of a single event (e.g., a hydrologic event) that causes levee failures.
- Frequency of exceedance distribution for a number of different economic consequence metrics (see Section 4.8)
- Frequency of exceedance distribution for a number of ecosystem metrics (see Section 4.8).
- Frequency of exceedance distribution on the time to extinction of aquatic species.

The evaluation of these risk metrics is described later in this section.

4.3.3 Analysis of Uncertainty in Risk Estimates

As described previously, risk for this study is expressed in terms of the exceedance frequency curve that shows the annual frequency of exceeding different consequences (e.g., the annual frequency of exceeding economic losses of 1, 10, and 100 billions of dollars). As described above, the probabilistic framework for the risk analysis incorporates both *aleatory* and *epistemic uncertainty*.

The main components of the risk analysis are the hazard, levee vulnerability, hydrodynamic response of the Delta, emergency levee repair, and the consequences of levee failures. For the first two components – hazard and levee fragility, the risk analysis methodology explicitly models both types of uncertainty; aleatory and epistemic. However, other parts of the analysis are performed using deterministic methods in which the best estimates are developed, but neither type of uncertainty is formally assessed.

In principle, all aleatory and epistemic uncertainties (at least those important to the analysis results) would be identified, evaluated, and incorporated in the analysis. However, a number of factors contributed to the approach used, including the level of probabilistic development with respect to the modeling of aleatory and epistemic uncertainties, and time and resources available to perform the necessary evaluations.

The second of these issues is closely tied to the first. In some topical areas in the risk analysis, the explicit modeling and evaluation of aleatory and epistemic uncertainties is an integral part of standard practice. This is true in probabilistic seismic hazard analysis for example (SSHAC 1997), in geotechnical engineering (CALFED 2000, Baecher and Christian 2003), to a degree in flood hazard analysis (USACE 1996), etc. In other topical areas that are a part of the DRMS, the practice of evaluating uncertainties (in particular epistemic uncertainties) is not considered at all. For instance, in the evaluation of climate change, the pace of scientific development is considerable. While the range of estimates for sea-level rise is wide, evaluations of epistemic uncertainty in the estimates that have been made do not exist (Climate Change Technical Memorandum [TM] [URS/JBA 2008b]).

The effort to quantify uncertainties in topical areas where little has been done would be large in terms of both the cost and schedule. The constraints of the DRMS study precluded such an effort. With respect to the economic consequences analysis, this subject was discussed with two advisors to the project. These advisors, two economics professors at U.C. Berkeley, confirmed the difficulty (level of effort and scope) that would be required to undertake such an evaluation.

The development and implementation of probabilistic models are even less common in the evaluation of ecological impacts, because numerical measures may not be readily available for such impacts and qualitative indices of impact are often used. Further, it is often difficult and time consuming to make best estimates of ecological impacts. Analyzing probabilities of different ecological impacts is not a common practice.

In the DRMS risk analysis, the following approach was followed with respect to the consideration of uncertainties. For the analysis of levee failures, mean estimates of the frequency of island flooding (for individual and multiple islands) was evaluated. The estimate of the mean frequency of island flooding takes into account the aleatory and epistemic uncertainty in the hazard and the levee vulnerability. The epistemic uncertainty in the frequency of island flooding was estimated taking into account the uncertainty in both the frequency of occurrence of the hazard (i.e., earthquake ground motions, peak flood elevations) and levee vulnerability (see Figure 4-3). The epistemic uncertainty in the frequency of island flooding was combined with estimates of the consequences of levee failures (e.g., economic costs and impacts) to estimate the uncertainty in the frequency of distribution of consequences.

4.3.4 Event-Based Approach to Risk Analysis

The risk analysis for this study requires evaluating a large network of levees that protect islands under a number of hazards. Two broad approaches to risk analysis could be used. One is the traditional "single site" approach and the other is an "event-based" approach. A brief discussion of the two approaches and the reason for selecting the latter approach follows.

In the "single-site" analysis approach, the levee protecting each island is analyzed separately under each hazard event, the risk of island flooding is assessed in terms of the expected consequences under each event, the total risk for each island is calculated by summing the risk from individual hazard events, and the total risk for the study area is calculated as the sum of the risks of individual islands. Although such an approach would be valid for a single island, it would substantially under-estimate the risk for a network of islands. This is because the consequences of *simultaneous* failures of given islands could be much higher than the sum of consequences of *isolated* failures of the same islands at different times.

One main difference in consequences of simultaneous versus isolated failures is in the disruption of water exports. The failure of a single island would have a minimal impact on the amount of the Delta water that would be drawn into the island. The salinity and water quality in the Delta, in turn, would not be significantly affected and there may be little disruption in water export (see Section 4.4.3). On the other hand, if many islands fail simultaneously during the same event, a large amount of Delta water could be drawn into the islands, the salinity intrusion would increase substantially, and water pumping may have to be halted for many months.

In an "event-based" approach, the performance of the entire network of levees in the study area is evaluated when subjected to each possible specific hazard event (e.g., an earthquake of magnitude 7.5 on the San Andreas fault). The probability and consequences of simultaneous failures of multiple islands are, therefore, properly analyzed. Simply stated, the "single-site" approach would not account for the possibility of a sequence involving the simultaneous failure of many islands, while the "event-based" approach does properly analyze such a sequence.

Within the general framework of an event-based approach, alternative methods of risk analysis are feasible. One method is to assess risk in terms of the expected consequences, which are calculated as the product of probability of undesirable outcome and consequences of such an outcome. In this method, no distinction is made between aleatory and epistemic uncertainties. Both types of uncertainties are combined in calculating the probabilities of undesirable outcomes. An advantage of this method is that it is computationally efficient. However, it does not provide a measure of the confidence in the risk analysis results. An alternative method, which was used in this study, is to treat the two types of uncertainties separately. Risk is assessed in terms of the frequency of exceeding different consequence thresholds, and the uncertainty in this frequency is estimated. This method is computationally more involved. However, it provides a good understanding of how data gaps for certain factors impact the confidence in the risk analysis results. It is also the recommended method for analyzing different risks (National Research Council 2000 for flood risks; EPA 2004 for health risks).

4.3.5 Analysis of Future Risks

The DRMS risk analysis must estimate risks for current conditions, the current or base-case analysis, as well as in the future (50, 100, and 200 years from now). The analysis for 2005 (i.e., current conditions), 2050, 2100 are assessed under "business as usual" conditions. Specifically, it is assumed that no systematic program to improve levees or to change the current configuration of the levee network would be undertaken during the intervening years. Furthermore, it was also assumed that no major hazard event (such as a large earthquake) would occur in the future that would cause a simultaneous failure of many levees and flooding of many islands. If such an event were to occur, there would be two basic effects on the risk analysis. First, in the case of earthquakes the occurrence of a major seismic event on a Bay Area fault would alter the estimated frequency of occurrence of future events. Second, a major event could dramatically change the current integrity or configuration of the Delta levees. For example, some of the islands may be abandoned or the most vulnerable Delta levees may be reconstructed. Under those circumstances, an assessment of the failure risks in the future that is based on the current integrity and configuration of Delta levees would not be meaningful.

For each analysis year, the risk was estimated by combining the estimated annual frequency of hazard events, the probabilities of different levee failures sequences given each event, and the consequences of levee failures for the conditions that are estimated to exist in that the time. The estimated risk in the analysis years is a snapshot, an "instantaneous" measure, of the risk in each year.

In the DRMS analysis, snapshot or instantaneous, estimates of the frequency of events (risk metrics; see Section 4.4.1) are made for current (2005) conditions, 2050, and 2100.[4] These estimates are made for conditions that are estimated to exist at that time (in the evaluation year) assuming business-as-usual with respect to the operations and management of the Delta and assuming natural or other man-caused events do not change processes that are understood to be

[4] Note, risk estimates for 2200 are not explicitly evaluated. As described in Section 14, little or no information is available to support a quantification of risks 200 years from the present.

occurring presently (e.g., increasing strain on major Bay Area faults, climate change). The analysis provides point estimates of risk, for the conditions that are estimated to exist at that time (e.g., the drivers of change as described above), in the future evaluation years considered. The result, for a given risk metric, is illustrated schematically in Figure 4-4.

The analysis for estimating risks in the future uses the 2005 results as a benchmark. Estimates are then made of the percentage change that is estimated to occur between the evaluation year (e.g., 2050) and the base year (2005) with respect to the major elements in the risk analysis; frequency of hazards, levee vulnerability, and consequences. The changes in these elements of the analysis are combined to estimate change in risk with respect to the basis year. The approach is discussed further in Section 14.

4.4 RISK MODEL

The purpose of the DRMS risk analysis is to estimate the frequency of consequences of interest (i.e., public health and safety, economic, environmental) that may occur as a result of levee failures in the Delta.

The analysis is performed first for 2005 conditions. (The approach for addressing risks in future years is described in Section 4.9.) As described in Section 4.3.1, the measure of risk for a consequence, C, is denoted:

$$v_i = \text{frequency of flooding for island i}$$

and

$\lambda(C_k > c)$ = frequency per year that a consequence metric C_k, will exceed a value c (4-3)

As described in Section 4.3.5, the analysis will be conducted for a number of risk metrics.

The potential for levee failures will be evaluated for a number of different hazards (e.g., earthquakes, floods, etc.). The total risk for a given metric, considering the hazards to which Delta and Suisun Marsh levees may be exposed, can be determined according to:

$$v_{T,\,i} = \sum_j v_{ij} \qquad (4\text{-}4)$$

and

$$\lambda_T(C_k \geq c) = \sum \lambda_j(C_k \geq c) \qquad (4\text{-}5)$$

where the sum is carried out for the initiating events considered.

Note, as discussed earlier, subsidence and climate change are not considered hazards in the sense of random events that impose transient loads/forces on a levee system. Rather, they are addressed as ongoing processes that change the state of the Delta landscape and are considered in the assessment of future years (see Section 14). The task in the risk analysis is to estimate the consequences associated with each hazard, $\lambda_j(C_k > c)$, in Equation 4-4. In the following sections, the risk analysis for external hazards and normal events is described.

4.4.1 Initiating Events

Initiating events that are explicitly evaluated in the analysis are:

- Normal events
- Earthquakes – ground motion
- Hydrologic events – peak water-surface elevation

Wind waves – Not evaluated as an initiating event. Wind waves are considered in combination with failures initiated by other events. As described in Section 7.10, wind-wave action on the exterior slopes of levees was not explicitly considered in the analysis as an event that could initiate levee failures. Excluding floods and earthquakes, and considering the existing waterside slope riprap projection and human intervention, this particular hazard was considered relatively insignificant and, hence was not considered explicitly as an initiating event.

4.4.2 Event Tree

To model the sequence of events that may result in levee failure and which affect the consequences of failure an event tree approach is used. An event tree is a graphical construct that can be used to model the logical combination of events that lead to outcomes of interest (Baecher and Christian 2003; Hartford and Baecher 2004). In this analysis, the following events contribute to the sequence of events related to levee failures in the Delta and the consequences that may result:

- Hydrologic conditions at the time of the event
- Month of the year the initiating event and levee failures occur
- Time of day
- Initiating event (earthquake or flood)
- Levee performance on each island in the Delta
- Secondary levee failures on non-flooded islands
- Levee repair sequences following an event
- Delta hydrodynamic response to levee failure events
- Consequences (life safety, economic, environmental)

Figure 4-5 illustrates a generalized event tree with these events. Each event is summarized in the following paragraphs. For each event in the event tree that is modeled probabilistically (has random outcomes that could be realized), branches are defined in the tree for each outcome/value that is modeled.

Moving from left-to-right in the tree along a branch for each event to its termination defines a combination of events, a sequence, that defines the state of levees in the Delta and the conditions under which failures occurred.

Hydrologic Conditions. The consequences of levee failures in the Delta, particularly with respect to water quality depend on the hydrologic conditions that exist at the time (prior to and after the event) of the occurrence of the initiating event and levee failures. The importance of hydrologic conditions to the hydrodynamic response of the Delta and the water quality and conveyance is described in Section 11 and the Water Analysis Module (WAM) TM (URS/JBA

2007e). In this analysis the historical record is used to model the randomness of hydrologic conditions that may exist at the time of a levee failure.

Month. The month when an initiating event and levee failure occurs has implications with respect to upstream water storage, agricultural consequences, SWP, CVP pumping, etc. In combination, the hydrologic conditions and the month of the year when an event occurs are important factors in assessing the consequences of levee failures.

Time of Day. For most events in the analysis the time of day is not an important variable. However, to estimate the life safety consequences of levee failures, the time of day (daytime versus nighttime) is an important factor.

Initiating Events. As identified above, three initiating events are considered in this analysis. For hydrologic events and earthquakes, the initiating event is defined in terms of the size of the event and the spatial distribution of the hazard. In the case of a flood the initiating event is a water-surface elevation (WSE) event that has a frequency of occurrence and defines a spatial field of water-surface elevations throughout the Delta. Section 7 and the Flood Hazard TM (URS/JBA 2008a) describe the hazard analysis methodology to estimate the frequency and magnitude of flood events. For earthquakes, the initiating event is an earthquake of a given magnitude that occurs on a fault and generates a spatial field of ground motions throughout the Delta.

For normal events, the initiating event is the group of intrinsic factors/forces that persist and challenge the levee day-to-day.

Levee Performance. Given the occurrence of an initiating event, the state (condition) of each levee reach on each island is evaluated to determine which islands have flooded and which levee reaches have been damaged or breached and thus require repair after the event.

Secondary Levee Failures. When a seismic event occurs, extensive non-breach damage to levees can occur, leaving them vulnerable to wind waves, high water levels due to floods, etc. (see Section 6 and the Levee Vulnerability TM [URS/JBA 2008c]).

Levee Repair. As discussed above, the repair of levees following an event is not considered a random variable, however it is an important event in the chain to assessing the hydrodynamic response of the Delta and the economic consequences of an event.

Delta Hydrodynamic Response. Similar to levee repair, the hydrodynamic response of the Delta and associated water management actions are not a random part of the analysis.

Consequences. Best-estimates of the consequences of levee failures are evaluated in all cases with the exception of life safety. In the analysis of life safety, the potential for fatalities from levee failures is estimated probabilistically.

An event tree can also be used to quantify the sequence events by simple enumeration of all the combination of event branches to define the collectively exhaustive set of sequences that could occur. For this analysis, such an enumeration is not possible due to the large number of combinations that would result.

Alternatively, for events that involve a large number of possible outcomes, simulation methods are used. For instance, simulations methods are used to estimate sequences of levee failures for different initiating events (water-surface elevation events and earthquakes). Similarly, simulation methods are used to simulate the large number of possible hydrologic conditions and months of occurrence when the initiating event and failures might occur.

For purposes of estimating risk, event sequences that consider the combination of multiple island breaches and/or damage are modeled. In addition, other factors that impact the assessment of consequences are also considered. Table 4-1 lists the primary events to be considered in the assessment of Delta sequences.

4.4.3 Evaluation of Island Flooding Frequencies

The initial step in the risk analysis is the assessment of island flooding frequencies:

$$v_{ij} \text{ and } \lambda_j(N \geq n),$$

where i denotes the island and j is the index on the initiating event. N corresponds to the number of flooded islands that could occur during a single event. The approach to evaluating the frequency of island flooding for each initiating event is described.

Normal, sunny-day events. As described in Section 9, historically, levee failures have occurred during normal or "sunny-day" conditions. The cause of these failures is not always known (e.g., piping through the embankment during normal high tides, the deteriorating effects that rodents have). Estimating the potential for these failures cannot be assessed using mechanistic models similar to what is done in the case of seismic stability or embankment overtopping. Alternatively, the rate of occurrence of levee breaches during normal conditions can be estimated on the basis of historic rates and expert evaluations of the condition, effectiveness of maintenance practices, and vulnerability of levee reaches to failure.

The mean frequency of failure of individual Delta islands is estimated by the following expression:

$$\bar{v}_{i,N} = \bar{\varphi} \times L_i \qquad (4\text{-}6)$$

where

$\bar{\phi}$ = mean rate of Delta levee failures per year per mile

L_i = Length of island i (miles)

N = the subscripted N denotes normal events

As described in Section 9, an estimate of the mean rate of levee failures has been made for Delta levees and Suisun Marsh levees.

The epistemic uncertainty in the estimate of the frequency of island failures is attributed to the length of the historic record. An analysis of this uncertainty estimates the coefficient of variation in the mean rate is 0.44 (or a logarithmic standard deviation of 0.18). The uncertainty in the frequency of normal event failures is assumed to be lognormally distributed. The estimate of the uncertainty in the rate of levee failures is described in Section 9.

The significant difference between external hazards (discussed later) and normal events is the potential for multiple, simultaneous levee breaches during the same event.. Historically, these events have occurred as single isolated events involving individual islands. They do represent some potential for impacting adjacent islands due to increased seepage or as a result of erosion of levee interiors on the flooded islands due to wave action or overtopping of low spots (e.g., Jones Tract). If additional breaches do occur (due to wave action for example), adjacent islands may be exposed to wind-wave effects associated with the additional fetch that may exist and thus possible erosion. In this analysis, the potential for additional levee failures following an initial sunny-day breach is not modeled. Historic experience indicates the annual frequency of occurrence of sunny-day failures for an individual island is low compared to other initiators of failure under present (2005) conditions. As a result, the possibility of further (secondary) failures that follow these events is also low and thus not considered. As a result,

$$\lambda_N(N \geq n) = \nu_{i,N} \qquad n = 1 \qquad (4\text{-}7)$$

$$\lambda_N(N \geq n) = 0.0 \qquad n > 1 \qquad (4\text{-}8)$$

As a result, the Delta states that result from normal hazards will be reduced in number and complexity given that multiple breaches at the same time are not likely to occur (e.g., Jones Tract breach in 2004).

Hydrologic Events. When a flood event occurs in the Delta, high water-surface elevations may be experienced over a large area. The analysis of hydrologic events and the probabilistic estimate of their frequency of occurrence are described in Section 7 and in the Flood Hazard TM (URS/JBA 2008a).

The modeling of the performance of Delta levees to the hazards posed by hydrologic events (floods) is similar to that for earthquakes, with a few exceptions. As has been the case historically, floods can result in multiple levee failures on different islands (for example 1986, 1997, etc.).

In the analysis of hydrologic events and the performance of levees, it is assumed that only one breach occurs on an island and that non-breach damage that might occur due to wind waves, overtopping is relatively minor. Thus, it is assumed that non-breach damage does not occur to the extent that it requires emergency levee repair. However, erosion of levee interiors as a result of wave action is considered and does require emergency repair.

Given the occurrence of elevated water elevations at an island, the frequency of island flooding is determined by:

$$\nu_{iH} = \sum \nu(wse_j) P(F_i / wse_j) \qquad (4\text{-}9)$$

where

$\nu(wse_j)$ = frequency of occurrence of water-surface elevation event j

$P(F_i/wse_j)$ = mean conditional probability of island i flooding given water-surface elevation event j; this is the island fragility curve.

The summation is carried out for all water-surface elevation events.

The flooding of an island occurs if one of more levee reaches on the island fails. Section 7 describes how the reaches on an island are defined for the hydrologic risk analysis and how levee fragility is estimated. The Levee Vulnerability TM (URS/JBA 2008c) describes the estimation of the levee fragility for flooding in detail.

To estimate the frequency of multiple flooded islands during a hydrologic event, a Monte Carlo simulation approach is used. This approach is equivalent to sampling from the event tree (see

Figure 4-5) that would enumerate all the possible combinations of levee performance (failure or non-failure) and thus island flooding events for a given flood. The simulation is carried out as follows. For a given water-surface elevation event wse_j, which defines the water level at each levee in the Delta, the state of each island in the Delta is randomly sampled from the levee fragility curves (see Figure 4-6). For a flood event, wse_j, the state of each levee (and thus each island) is determined – a random sample from the fragility curve determines whether a levee has failed or not and thus whether an island is flooded.. The process is carried out for each levee in the Delta. At the conclusion of the simulation for the flood (wse_j), the state of each island is known. A simulation defines a (random) sequence of island flooding events.

For each water-surface elevation this process is repeated, generating a series of flooded island sequences for each hydrologic event (each wse_j). The frequency of occurrence of each sequence is:

$$\nu\left(S_{Hjk}(n)\right) = \nu\left(wse_j\right) \times p \qquad (4\text{-}10)$$

where

$S_{Hjk}(n)$ = hydrologic sequence k associated with water-surface elevation event j and n is the number of flooded islands

p= probability associated with each simulation

= 1/(number of Monte Carlo simulations)

The frequency of occurrence of numbers of islands flooding, $\nu_H(n)$, is determined by summing over all water-surface elevation events and all sequences that generate the same number of flooded islands.

Based on the number of islands that flood in each sequence, the frequency distribution on the number of flooded islands, $\lambda_H(N \geq n)$, is determined.

Seismic Events. In the event an earthquake occurs in the vicinity of the Delta, ground motions will be experienced over a potentially large area, depending on the magnitude of the earthquake and its location in proximity to Delta levees. The ground motions generated by the earthquake will challenge the stability of levee embankments and their foundation. Section 6 and the Seismology TM (URS/JBA 2007a) describe the probabilistic analysis of earthquake ground motions in the Delta. For a moderate to large magnitude earthquake, particularly one that occurs in or near the Delta (say, on the Southern Midland Fault), all island levees are likely to experience ground motions that could result in damage or failure.

The frequency of failure of a single levee (due to earthquakes on a single fault) is determined by:

$$\nu_{Levee\,Reach} = \sum_m \nu(m_i) \sum_r P(R = r_j \mid m_i) \sum_a P(A = a_k \mid m_i, r_j) P(f \mid a_k) \qquad (4\text{-}11)$$

where

$\nu(m_i)$ = frequency of occurrence of an earthquake of magnitude m_i

$P(R = r_j \mid m_i)$ = probability that an earthquake occurs a distance r_j from the levee given an earthquake of magnitude m_i.

$P(A = a_k \mid m_i, r_j) =$ probability of ground motions equal to a_k, given an earthquake of magnitude m_i and distance r_j.

$P(f \mid a_k) =$ conditional probability of failure of the levee reach (levee fragility) due to a ground motion of level a_k[5].

The elements in equation 4-11, with the exception of the levee fragility, are the same as in the seismic hazard analysis and are described in the Seismology TM (URS/JBA 2007a). The development of the levee fragility is described in Section 6 and in the Levee Vulnerability TM (URS/JBA 2008c).

In the seismic risk calculation, the ground motion predicted in the seismic hazard model and the characterization of the levee fragility is defined at a common reference site condition (see Section 6 and the Levee Vulnerability TM [URS/JBA 2008c]). The effects of site response are incorporated in the estimate of the levee fragility.

Each island in the Delta is modeled by a series of levee reaches, where each reach is defined according to the characteristics of the embankment and levee foundation (see Section 6 and the Levee Vulnerability TM [URS/JBA 2008c]). Island flooding occurs if one or more levee reaches fails and breaches during an earthquake. Equation 4-11 can be re-written to take into account the multiple reaches that protect an island.

$$\nu_{IslandFlooding} = \sum_{m} \nu(m_i) \sum_{z} P(Z = z \mid m_i) \sum_{a} P(a(\underline{x}) \mid m_i, z) P(F \mid a(\underline{x})) \qquad (4\text{-}12)$$

where

F = denotes the event that one or more levee reaches fail given an event of magnitude m and a ground motion field, $a(\underline{x})$

$a(\underline{x})$ = spatial field of earthquake ground motions given an earthquake of magnitude m that occurs at a location Z=z on a fault.

$P(a(\underline{x})|m_i, z)$= probability of the ground motion field, given an earthquake of magnitude m_i and that occurs on a fault at a location z.

The probability of the event F (island flooding) is the probability of one or more reaches on an island failing during an earthquake. This depends on the ground motion that is experienced at each levee reach during the same seismic event. For the simple case of an island comprised of two levee reaches, R_1 and R_2, $P(F|a(\underline{x}))$ is determined by,

$$P(F|a(\underline{x})) = P(R_1 \text{ fails or } R_2 \text{ fails or both } R_1 \text{ and } R_2 \text{ fail}|a(\underline{R_1},\underline{R_2})) \qquad (4\text{-}13)$$

$$= P(R_1 \text{ fails}|a(R_1,R_2)) + P(R_2 \text{ fails}|a(R_1,R_2)) - P(R_1 \text{ fails and } R_2 \text{ fails}|a(R_1,R_2))$$

where $a(\underline{R_1},\underline{R_2})$ denotes the ground motion at the location of levees R_1 and R_2.

The ground motion generated by an earthquake, $a(\underline{x})$, is random. A typical logarithmic standard deviation for the aleatory variability in ground motion is 0.6. This variability has two

[5] As described in Section 6 and in the Levee Vulnerability Technical Memorandum, the seismic fragility of levees depends on earthquake magnitude as well as ground motion. This dependence is considered in the risk quantification, but is not shown here for simplicity.

components; the inter-event and the intra-event variability. The randomness in ground motions is denoted by,

$$\sigma_T^2 = \tau^2 + \sigma_I^2 \tag{4-14}$$

where

σ_T^2 = total aleatory variability (variance) of ground motions

τ^2 = inter-event variability

σ_I^2 = intra-event variability

Estimates of the aleatory variability in ground motion are made as a part of ground motion attenuation model development (Boore and Atkinson 2007).

The inter-event variability, τ, models the systematic (though random) variation that is observed in ground motions for earthquakes of the same magnitude. Due to differences in the details of earthquakes of the same size (earthquake magnitude), ground motions from one event may be systematically higher or lower than the median motion for all events of that magnitude at all sites.

The intra-event variability of ground motions captures the randomness of motions within events of a given size. Ground motion studies have shown this variability is spatially correlated (Boore et al. 2003; Park et al. 2007), meaning the motion at nearby sites (levee reach locations) is correlated due to the commonality of wave travel path, earthquake source characteristics, etc. This correlation varies as a function of the separation distance between sites, as illustrated in Figure 4-7. The figure shows the correlation model developed by Boore et al. (2003) that is used in this analysis in conjunction with the intra-event variability in equation 4-14.

Each of these components of ground motion variability has implications with respect to risk analysis for spatially distributed systems such as the network of levees in the Delta (Park et al. 2007). Park et al. (2007) show the importance of the inter-event variability and the spatial correlation in estimating the magnitude and frequency of occurrence of consequences of interest for spatially distributed assets (levee failures or economic consequences in the example of Park et al. [2007]).They show that the magnitude of the consequences (damage to structures and thus economic consequences) can be significantly underestimated if the inter-event variability and the spatial correlation of ground motions is not considered.

For this analysis, ground motion correlations for the Delta were modeled using the Boore et al. (2003) model. A dataset of random, spatially correlated (in the Delta and Suisun Marsh) variables was generated using the methods described by Park et al. (2007) (AIR Corporation 2007).

The quantification of equation 4-13 to estimate the frequency of island flooding due to seismic events was carried out through a combination of numerical integration and Monte Carlo simulation. The numerical integration is carried out over earthquake magnitude and distance as it is performed in the seismic hazard analysis. The integration with respect to earthquake ground motion and levee performance is carried out by simulation.

For an earthquake of a given magnitude and distance, three random variables are simulated; the inter-event variability, the intra-event variability and the levee performance. The inter-event and intra-event variability (including the spatial correlation of ground motions) were simulated for each earthquake in the analysis and for each levee reach location on an island. For each levee reach, its performance was simulated (failed or not), given the simulated ground motion (in the same manner that levee performance was simulated in the hydrologic analysis [see Figure 4-6]). This process was used to estimate the frequency of flooding of individual islands and to estimate the frequency of exceedance distribution of multiple flooded islands.

The total frequency of failure for an individual island is obtained by summing over all seismic sources considered in the analysis as follows:

$$\nu_{i,S} = \sum_{AllFaults} \nu_{ij,S} \tag{4-15}$$

where the subscript S denotes seismic events and i is the island index. Similarly, the frequency distribution on multiple flooded islands considering all seismic sources, $\lambda_S(N \geq n)$, in the analysis is estimated in the same manner.

To model the occurrence of multiple flooded islands from the same earthquake, sequences of levee failure and island flooding events, the same simulation approach described for hydrologic events was used. For purposes of estimating levee repairs and evaluating the hydrodynamic response of the Delta, non-breach damage as well as levee failure were also considered in the simulation.

4.4.4 Emergency Response and Repair of Damaged Levees

For each levee failure sequence that is modeled, the timing and cost of repairs is estimated using the emergency response and repair model described in Section 10 and in the Emergency Response and Repair (ERR) TM (URS/JBA 2008d). As described in Section 10, the repairs to levees are made according to a priority system. As part of the analysis, which is a time simulation of repairs, the expected erosion that could occur on flooded islands due to wind waves is modeled. Based on an analysis described in the Emergency Response and Repair TM (URS/JBA 2008d), island and direction specific erosion curves are used to estimate the amount of erosion on the interior face of a levee occurs as a function of time. The erosion model, which was calibrated to the 2004 Jones Track experience and the observed erosion that occurred on Franks Tract in the years immediately following the flooding of that island, estimates the expected amount of erosion that would occur in time as an island remains flooded.

For flooded islands there are three levels of repair that are carried out – closure of the levee breach(es), interior levee slope protection and repair, and in the case of seismic events, repair of non-breach damage. As described in the Levee Vulnerability TM (URS/JBA 2008c), the extent of non-breach levee damage from an earthquake can be considerable. Thousands to tens of thousands of feet of levee may be damaged as a result of earthquake ground motions.

As described in Section 4.8, the ERR analysis is deterministic and represents a best estimate of the timing and cost of levee repairs. The results of the ERR analysis serve as input to the WAM (hydrodynamic) analysis and the economic consequence analysis. The inputs to the WAM analysis include the timing of breach closures on each flooded island and the timing and volume of island dewatering. The inputs to the economic consequence analysis include the cost of levee repairs and the timing of island dewatering.

In the event of an earthquake, islands may be damaged but not breached. Damaged levees will typically be slumped and have reduced freeboard; there will be damage to the exterior face of the levee and riprap, and cracking of the embankment. As a result, the integrity of damaged levees will be compromised in terms of protection against overtopping, wave action, and internal erosion (see the Levee Vulnerability TM [URS/JBA 2008c]). For levee failure sequences that involve multiple islands, the time to stabilize and repair damaged, non-flooded islands can be considerable. To approximate the random sequences of secondary failures that could occur following a seismic event, two cases are considered. One case considers that all damaged islands are stabilized after the event and no longer vulnerable (any more than they were prior to the earthquake). As described in Section 10, stabilizing these non-flooded islands is given the highest priority. The second case considers that all of the non-flooded islands breach and flood during the repair period. For the case involving many islands, flooded or not, the period of repair may be considerable (many months). Depending on the time of year when the earthquake occurred, the probability that high water-surface elevations (relative to the post-event crest elevations of slumped and damaged levees) are experienced due to one or more causes, including a hydrologic event, or a surge, high tides, and/or wind waves is relatively high. Further, the vulnerability of an island that has thousands to tens of thousands of feet of damaged levees to overtopping or failure due to seepage and piping, is also high. These two cases are not models of actual events that could occur, but rather are bookends of the range of random, secondary failures that could occur.

4.4.5 Estimating the Hydrodynamic Response of the Delta

When levee failures occur in the Delta, they disrupt the normal hydrodynamic patterns. The WAM model, developed as part of the DRMS project (see Section 11 and the Water Analysis Module TM [URS/JBA 2007e]), is used to evaluate the hydrodynamic response of the Delta to levee failure events. The inputs to the WAM model, for each levee failure sequence, are generated by the ERR model (described above).

For each levee sequence that is evaluated, a range of hydrologic years and start dates (defined by the month the failure occurs) are considered. Historic experience and detailed hydrodynamic modeling show the hydrologic conditions prior to, during and after a levee failure event impact the water quality consequences. To account for the hydrologic conditions that may exist at the time of a seismically initiated levee failure sequence, the distribution of historic hydrologies is used. There are 910 month-year pairs in the historic record that are randomly sampled (using a stratified sampling approach) for each levee failure sequence.

Outputs from the WAM analysis for a levee failure sequence include:

- Duration of water export disruption – months until water exports return to normal
- Reservoir storage (end of month, for each modeled reservoir)
- Water deliveries to SWP and CVP contractors
- Ambient Delta water salinity (monthly average, for a reference point for selected islands, µmhos/cm).

As described in Section 4.8 the hydrodynamic calculations are deterministic, with the exception that random hydrologic conditions are used to generate a distribution of hydrodynamic results for each levee failure sequence.

Historic experience and detailed hydrodynamic studies indicate the salinity impacts to the Delta water quality are not significant when levees fail and islands flood as a result of flood events, nor when they occur as individual failures as a result of intrinsic or normal (sunny-day) events. As a result, the WAM model is not used to evaluate the water quality impact of levee failures during these events. This limits the economic consequences of levee failures during hydrologic (flood) events and normal events to those that occur in the Delta (e.g., direct damages due to flooding, damage to infrastructure, impact to businesses). The following provides the historic and analytic basis for this.

Hydrodynamic Response During Hydrologic Events. Salinity impacts due to multiple breaches on multiple islands that are caused by inflow floods are not expected to have significant impacts on Delta salinity or export pumping. High Delta inflows that occur during major floods force the fresh/saline water interface downstream from its typical dry-season location. If the flows (or coincident high tides or storm surges) are so high that they cause several breaches and island floodings, the continuing high inflow provides a substantial volume of island flooding water, and any additional water needed that moves upstream from Suisun Bay is generally low in salinity – much lower than the drinking standard. Since 1978, there have been four large inflows flooding two or more Delta islands, as indicated in Table 4-2.

In each of these cases, electrical conductivity (EC) at Antioch stayed in the neighborhood of 200 µmhos/cm (800 µmhos/cm is the approximate drinking water standard). Although the upstream EC (at Holland Cut) closer to export locations was higher (up to about 400 µmhos/cm), however this reflects salinity in the Delta already, not salinity drawn in by the levee breaches. The largest inflow flood (1997) flushed this upstream salinity out of the system even though it had a larger number of breaches and flooded islands.

In January 1980, flooding occurred on Webb and Holland almost simultaneously. These islands are near enough to the flow path to the pumps that one might see a salinity impact if it were going to occur. EC at several stations in the vicinity was between 160 and 300 µmhos/cm (seemingly unaffected by the breaches), and thus not a concern for export water supply.

These observations indicate there has been no experience involving immediate salinity problems from floods. In contrast, there could be some effect in the long term if many islands were flooded by a very large flood event. Hypothetically, if the repairs occur over many months, tidal mixing may occur in subsequent low flow seasons that may allow some intrusion of salinity. At the same time, this tidal mixing would occur not as a result of the initial, large intrusion of salt water at the time of the failures (which does not occur, as described) above, but rather as a result of the fact that islands that remain open provide greater volumes for tidal exchange and mixing than is normally the case (when islands are not open and flooded). The effect of this tidal mixing if it were to have an impact on water quality could be mitigate during the levee repair process by simply closing breaches to a point so that tidal mixing involving flooded islands does not occur. Further modeling would be required to address these longer term effects.

Normal Events. The most dramatic example of historical salinity intrusion due to a levee breach and island flooding is the Brannon-Andrus event on June 21, 1972, which occurred during the dry season of a "Below Normal[6]" water year. There was significant salinity intrusion, but the extent of disruption of water exports amounted to reduced CVP and SWP pumping for about two weeks and moderately increased salinity for about two months. Drinking water quality standards for salinity were violated at Contra Costa Water District's (CCWD's) Rock Slough intake and, although some fresher water was available for blending, total compliance with the standard was not achieved by CCWD. Overall, however, the magnitude of the disruption was not major. Details are summarized below, based primarily on the testimony provided on behalf of the California Department of Water Resources (DWR) and the United States Bureau of Reclamation at legislative hearings the following September (California Senate, 1972).

- The Bureau of Reclamation began to reduce CVP Tracy Pumping Plant exports on the day of the breach (normally 4,300 cfs) and reached one-pump operation (900+/- cfs) on June 23, the third day of the event. Salinity, measured as chlorides, increased dramatically at Antioch within 1 day of the breach. The salt influx upstream at water intake locations was anticipated and motivated the pumping decreases. On June 29, the Bureau began increasing its pumping, reaching the normal, maximum rate on July 3 with the explicit strategy of removing the salt from the Delta channels by exporting it. The period of decreased pumping was effective in keeping salinity from intruding further toward the export pumps until flushing water from Sacramento River reservoirs arrived and repulsed as much of the salinity as could be accessed by those flows. Salinity at the Bureau's Tracy Pumping Plant peaked at 165 mg/l chloride – i.e., less than the 250 mg/l drinking water standard (for salinity expressed as chloride), but substantially above the pre-breach level of approximately 70 mg/l. Elevated salinity at the Bureau intake persisted for approximately 1 month.
- CCWD had little storage and was dependent on continued pumping from the Delta. Their intake location at Rock Slough peaked at 440 mg/l chloride on July 4, substantially above the drinking water salinity standard of 250 mg/l as chloride. They continued pumping after the breach and were able to lessen the impact on most of their customers by blending with the limited storage available from Contra Loma Reservoir and an intertie with the East Bay Municipal Utility District's Mokelumne Aqueduct (implemented by July 4 through cooperation with East Bay Municipal Utility District and expedited construction). Even with blending from storage and the aqueduct, customers upstream of the dilution sites on the Contra Costa Canal had to use the salty Delta water. Chloride concentrations of CCWD Delta withdrawals exceeded 250 mg/l chloride for about 15 days.
- SWP stopped diversions from the Delta into Clifton Court Forebay within several hours of the breach. After a few days, the SWP commenced partial Delta diversions in order to serve the South Bay Aqueduct. Only the South Bay Aqueduct was served with Delta water until July 23 and that Delta water was blended with lower salinity water stored in Del Valle Reservoir (near Livermore).

Both the CVP and the SWP used San Luis Reservoir storage to serve their south of Los Banos demands on their respective canals. Delta pumping was disrupted for two weeks. Additional salt exported by the CVP and the SWP was estimated at 53,000 tons. But only CCWD and some in-

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[6] As defined by the Sacramento Index

Delta water users in the Central/Western portion of the Delta experienced salinity levels in excess of the drinking water standard.

Since Brannon-Andrus is one of the larger islands and is located in a crucial position relative to salinity intrusion and water exports, the above experience indicates that flooding of one-island can generally be managed to make the economic consequences minimal – although they are important to the water users that have to absorb saltier water. There was no time during the event when all export pumping was halted.

Economic Consequences to Exports from 3 to 4 Months of No Pumping. Economic consequences to water export due to a levee breach event rise as the length of export disruption increases. Consequences are estimated to be particularly severe when the salinity intrusion into the Delta dictates a total shut down of export pumping. Even then, no pumping durations of up to 3 to 4 months are estimated to have low economic consequences.

Based on analyses performed for this report, the export water supply consequence estimates indicate that disruptions of less than 4 months are not significant to the risk analysis results. For disruptions of less than 2 months, the costs are largely insignificant –i.e., potentially just millions of dollars. From 3 to 4 months, cost estimates may be approximately $200 million, depending on the time of year and other factors. So, depending on the distribution of those months, it seems reasonable in the context of the risk analysis to: (a) use a threshold of 3 months, and (b) assume economic consequences are limited to about $200 million for disruptions of 3 or 4 months. Note that this only addresses export costs; all other costs need to be addressed separately.

Seismic Events. Table 4-3 summarizes the results from a series of hydrodynamic calculations carried out using the WAM model using all of the first-of-month event start times (910 start times) for the years 1923 to 1998 for seismic failure sequences involving from 1 to 30 flooded islands (These cases correspond to Cases 2 through 6 in this series. The analysis is described in the Water Analysis Module TM [URS/JBA 2007e, Appendix D]).

As shown in Table 4-3, Cases 2 and 3 both involved three flooded islands. Case 3 also assumed some non-breach damage to other islands that did not flood, but required repairs before the flooded islands could be addressed. For Cases 2 and 3 the following detailed information about periods of no pumping was obtained:

- Case 2 – Start times with no pumping > 90 days = 66 (of 910); 29% of these were wet season breach events (December thru April)
- Case 2 – Start times with no pumping > 120 days = 21 (of 910); 62% of these were wet season breach events (December thru April) concentrated in drought years when it just didn't rain (e.g., 1931 and 1977)
- Case 3 – Start times > 90 days = 86 (of 910); 27% were wet season events
- Case 3 – Start times > 120 days = 23 (of 910); 65% were wet season events with the same concentration as Case 2.

In general, events that flood as many as three islands do not result in more than 4 months of no exports. If the event occurs even during the wet season of a year that has few or no storms, a longer period of no pumping could result.

4.4.6 Consequences of Levee Failures

For each initiating event, the consequences of levee failure sequences are evaluated. The risk metrics for which risks are estimated is given in Section 4.4.7.

Normal Events. For Normal events that involve individual island failures, the consequences are generally limited to those that occur in the Delta or to Delta businesses. In cases where state highways or other regional infrastructure is impacted, the assessment of consequences is described in Section 12. For each risk metric, the frequency distribution, $\lambda_N(C_k \geq c)$, is determined.

Hydrologic and Seismic Events. For hydrologic events, the consequences are determined for each hydrologic sequence that is evaluated. For each sequence, S_H, the consequences C_k are estimated as described in Section 12. Similarly, for each seismic sequence, S_S, consequences are estimated.

4.4.7 Risk Metrics

The risk metrics evaluated in the analysis are listed in Tables 4-4 and 4-5. These metrics include measures of Delta island vulnerability (flooding), economic impacts and costs, and environmental consequences. Section 12 describes the elements of each consequence measure.

4.5 CO-LOCATED EFFECTS

The risk analysis will address events (e.g., earthquakes, floods, climate change) that impact the performance of Delta levees and the consequences that may ensue. These same events present a hazard to other parts of California and thus there is the potential for additional consequences that may further impact the state. For instance, the consequences associated with a major seismic event east of San Francisco Bay could be substantial outside the Delta (e.g., damage to the Contra Costa County water distribution system). The impact to other water system assets in and beyond the Delta are assessed to the extent that levee breaches and island flooding cause damage to these assets. For example, damage to the Mokelumne Aqueduct as a result of a breach and scour that results in pipeline failure is addressed. The simultaneous occurrence of island flooding and the failure of co-located water system assets could significantly increase the interruption of local water supply and/or statewide water export. With the exception noted above, co-located effects are not addressed in the DRMS risk analysis.

4.6 IMPLEMENTING BUSINESS AS USUAL

The objective of the DRMS study is to identify and evaluate alternative risk management strategies for managing the Delta in the future. To do this, the risk analysis is performed, assuming a “business-as-usual” approach to the management, operations, and use of the Delta. The estimate of risks will be referred to as the “business-as-usual (BAU) scenario.”

Implementing a BAU approach will apply to many aspects of the risk analysis. These include:

- Environmental factors (e.g., continuation of estimated rates of subsidence)
- Hazards (e.g., non-occurrence of a major earthquake that changes the rate of future earthquake occurrences)

- Levee maintenance and repair practices (e.g., level of expenditures for levee maintenance and raising as might be effected by sea-level rise)
- Water management following an event in the Delta (potentially involving significant salinity intrusion)
- Water management practices as it might be effected by climate change
- Levee repair operations
- Land-use and development in the Delta
- Growth of the state economy
- Water demand and supply
- State of the ecosystem over time

The BAU approach is carried out assuming current trends, policies, and practices are continued over the duration of the study period. Implementing such an approach requires some interpretation. For instance, the risk analysis will consider events that have not occurred in the past and may not have been explicitly contemplated in the development of current policies or procedures (e.g., emergency response to multiple levee failures, operations for upstream reservoirs after a significant island flooding and salinity intrusion into the Delta occurs). As a result, some interpretation and/or discussion with DWR and others was required to fill these policy gaps to establish the BAU approach as implemented in the risk analysis.

In addition, it also requires that lessons or insights learned as a part of this effort not be used to make more informed choices or decisions. A BAU approach must be uninformed by the Phase 1 DRMS analysis. Lessons or insights will be considered as part of the Phase 2 evaluation and the consideration of risk reduction options.

4.7 RISK ANALYSIS IMPLEMENTATION

To perform the DRMS risk analysis required a multidisciplinary team of professionals to address the broad range of subject areas. From the perspective of actually conducting the analysis it was important for the team members to develop a common foundation of understanding. This understanding was required at a number of levels, including:

- Project scope and objectives
- Elements of the risk analysis
- Perspective and approach with regard to modeling uncertainty
- Risk model development approach
- Technical interface requirements
- Project schedule

For purposes of developing the DRMS risk model, topical area teams were formed corresponding to the different topical areas in the analysis. In general, the teams consisted of professionals from different organizations.

Table 4-6 identifies elements of the risk analysis (see Figure 4-2) and the topical areas within each element that were identified at the start of the project, and areas around which teams were formed.

As part of the startup for the project, a 2-day workshop was convened. The purpose of the workshop was to acquaint and train the team with respect to the topics listed above. In addition, the workshop also served as a starting point for teams to define a detailed work scope in each topical area.

After the workshop, each team submitted an initial technical framework (ITF) paper that outlined the technical problem being addressed, the approach to be taken, the interface requirements with other technical areas, and the project tasks.

One of the objectives of the risk analysis was to estimate the uncertainty (aleatory and epistemic) for each part of the analysis. For the hazard and levee vulnerability evaluations, it was possible to carry this estimation out. For other parts of the analysis this proved difficult due to the development effort to gather information and build the foundational model, coupled with the time available for the project in general. These factors, coupled with the varying levels of probabilistic modeling ‘experience’ in different topical areas (a great deal exists in the seismic hazard area and relatively little in the economic and ecosystem areas), resulted in assessments that are best estimates of the outcomes of interest (i.e., economic consequences).

4.8 RISK QUANTIFICATION

This section describes the steps in the risk quantification and the interface between the different parts of the risk model. The steps as described are performed for each initiating event. These results are then combined to estimate the total risk.

The steps in the quantification are:

1. Estimate the Frequency of Island(s) Flooding
2. Generate Levee Failure Sequences for use in the levee repair and hydrodynamic analysis
3. Perform Levee Emergency Response and Repair Analysis
4. Evaluate Delta Hydrodynamic Response
5. Estimate the Consequences for Each Sequence
6. Combine the Results of Steps 1, 2, and 5 to Estimate Risk
7. Estimate the Uncertainty in the Frequency of Levee Failure
8. Combine the Results for the Individual Initiating Events (Steps 1–7) to Estimate the Total Risk

The steps in the quantification process are listed in Table 4-7. The following describes each step in the quantification.

1. Estimate the Frequency of Island(s) Flooding

In this first step of the quantification, two calculations are performed:

- Estimate the frequency of levee failure and island flooding, ν_{ij}, for each island (i) in the Delta and selected islands in Suisun Marsh, and each initiating event (j),
- Estimate the frequency that multiple islands (N) could be flooded during a single event (e.g., a single earthquake or hydrologic event), $\lambda_j(N \geq n)$, for each initiating event (j).

In this analysis, the assessment of the frequency of levee failure for external and intrinsic (normal) events is different as described in the text.

2. Generate Levee Failure Sequences
For hydrologic and seismic events, levee failure and island flooding sequences are generated by Monte Carlo simulation. For the range of events (floods and earthquakes of different magnitude) considered in the estimation of the frequency of island failure, sequences that define the state of each island (flooded or not) in the Delta are generated. For hydrologic events, sequences are denoted, $S_{Hi}(n_f)$ where i is the index on the number of sequences and n_f is the number of flooded islands.

For seismic events, sequences are denoted $S_{Si}(n_f, n_d)$, where n_f is the number of flooded islands and n_d is the number of damaged (but non-breached/flooded) islands[7]. The subscript i denotes the sequence number.

3. Perform Levee Emergency Response and Repair Analysis
For each levee failure sequence, the ERR analysis is carried out to estimate the time to close (all breaches) and dewater flooded islands and the costs of island repair and dewatering. The results of the ERR analysis are input to the hydrodynamic analysis (WAM model) and the economic consequence analysis. Figure 4-8 shows the inputs and outputs of the ERR analysis.

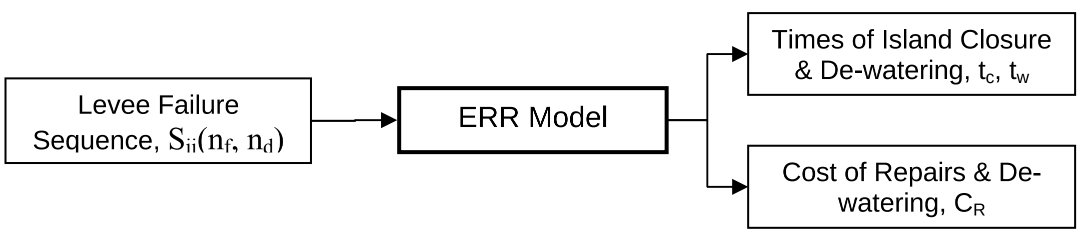

Figure 4-8 Inputs and outputs for the ERR analysis

The ERR analysis is described in Section 10.

4. Evaluate Delta Hydrodynamic Response
For each levee failure sequence, $S_{ij}(n_f, n_d)$, the hydrodynamic response of the Delta to island flooding is evaluated by the WAM model. The WAM analysis is carried out for a series of event start times that are simulated from the historic hydrologic record. The results of the WAM analysis serve as input to the ecosystem analysis, the In-Delta Infrastructure analysis, and the economic consequence analysis. The inputs and outputs to the WAM model are shown in Figure 4-9.

[7] Damaged, non-breached islands are only considered in the seismic analysis.

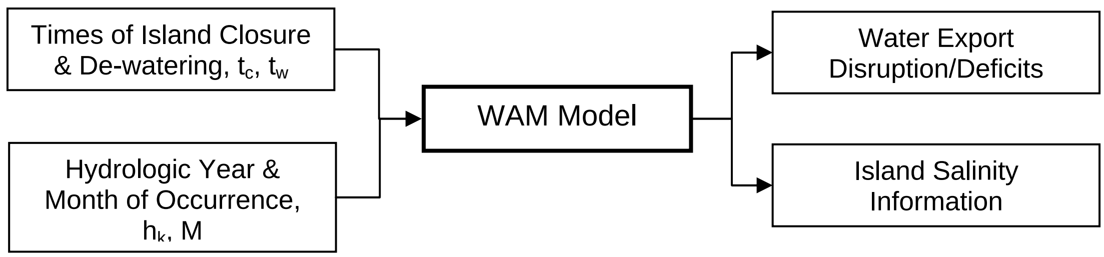

Figure 4-9 Inputs and outputs for the WAM analysis

The WAM model is described in Section 11.

5. Estimate the Consequences for Each Sequence

For a sample of the sequences that are evaluated in the hydrodynamic analysis, the In-Delta and statewide consequences are evaluated. As described in Section 12, best-estimates of the consequences of levee damage and island flooding are evaluated. Figure 4-10 shows the inputs and outputs to the economic consequence analysis, which includes the evaluation of damage costs associated with island flooding (In-Delta Infrastructure Model) and the costs of levee repair. Figure 4-11 shows the inputs and outputs to ecosystem consequence analysis.

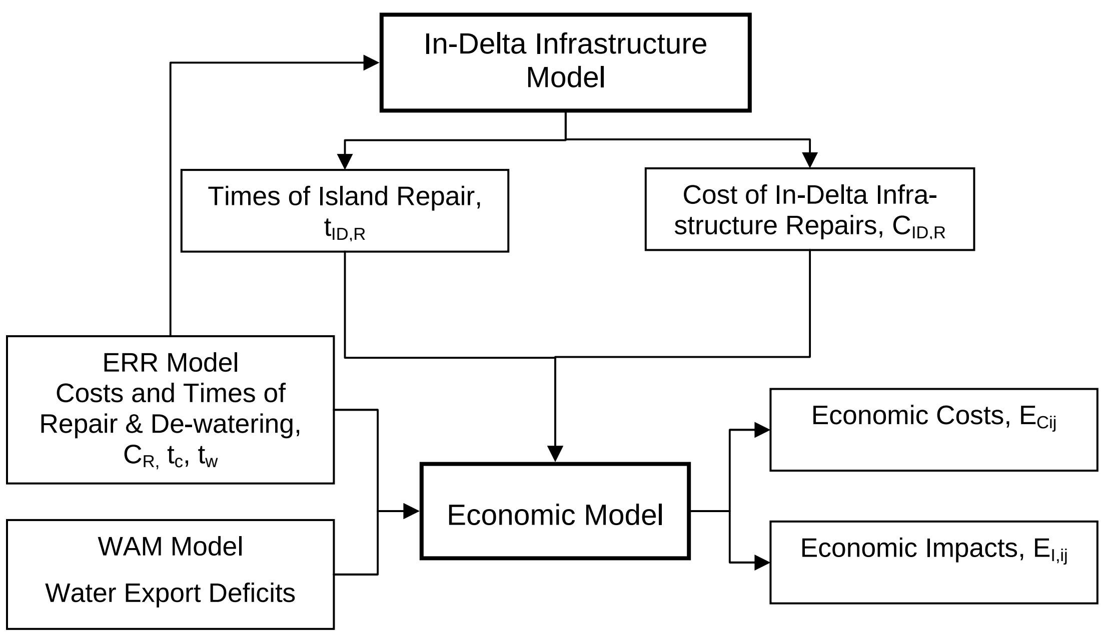

Figure 4-10 Inputs and outputs of the economic impact model

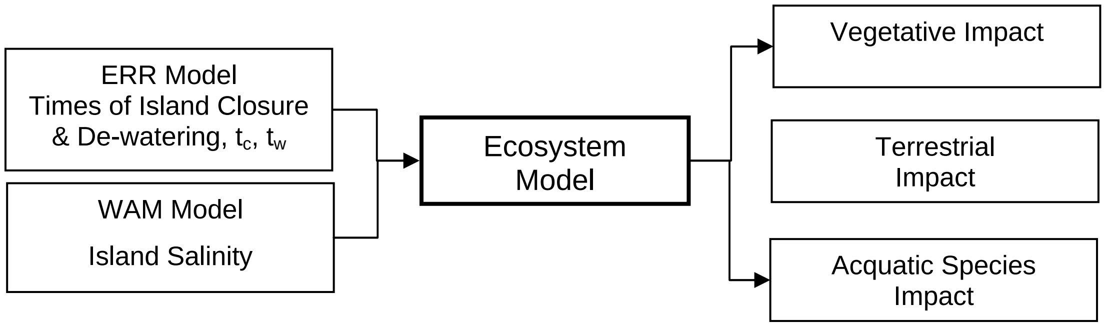

Figure 4-11 Inputs and outputs of the ecosystem impact analysis

6. Combine the Results of Steps 1 and 5 to Estimate Risk

The results of the frequency of island flood evaluation (Steps 1 and 2) and the consequences for each sequence are combined to determine the frequency distribution of each consequence (risk metric).

7. Estimate the Uncertainty in the Frequency of Levee Failure

As described in Section 4.3, the uncertainty in the hazards and levee performance are evaluated and combined with the best estimates of the economic and life safety consequences to estimate the uncertainty in each risk metric.

8. Combine the Results for the Individual Initiating Events (Steps 1-7) to Estimate the Total Risk

For each risk measure (e.g., island flooding, economic consequences) the total risk is determined by combining the results of all initiating events. With respect to levee failure, these results are determined by the following expressions. The total frequency of flooding island i is:

$$\nu_i = \sum_j \nu_{ij} \qquad (4\text{-}16)$$

where the sum is carried out over all initiating events.

The total frequency distribution on the number of flooded islands is:

$$\lambda(N > n) = \sum_j \lambda_j (N > n) \qquad (4\text{-}17)$$

The summations in equations 4-17 and 4-18 are carried out over all initiating events.

With respect to consequences of levee failures, the total risk is:

$$\lambda(C_k \geq c) = \sum_j \lambda_j (C_k \geq c) \qquad (4\text{-}18)$$

where k denotes the risk metric (e.g., economic impact, economic cost, life safety).

4.9 RISKS IN THE FUTURE

To meet the requirements of AB 1200, an analysis of risks 50, 100, and 200 years from the present must be made. This assessment must be based on existing information (models and data). Table 4-8 shows a timeline that indicates the availability of projections for hazards and environmental factors that threaten the Delta. Table 4-9 provides a similar summary of information available to assess future risks with respect to Delta assets and infrastructure.

It is common in risk studies to estimate the frequency of occurrence of events, based on available information and, assuming events are Poissonian (time-independent), to calculate lifetime risks. This approach is reasonable and appropriate if events (hazards) are Poissonian and if conditions (i.e., integrity of the systems being analyzed), and the assets that are exposed in the event of system failure do not vary over the project lifetime. For the Delta, the current state-of-knowledge makes it apparent these conditions do not exist. In fact, it is anticipated that significant changes are taking place in and around the Delta and Suisun Marsh that do not permit a simple projection of lifetime risks.

To assess risks in the future, an approach is taken to estimate the change in individual factors (i.e., changes in earthquake occurrence rates, changes in the Delta population, etc.) relative to the base case 2005 analysis. These factors are then combined and used to estimate the degree of change in future risks, relative to the estimate of the current, 2005 risks. Ideally, a reassessment of the ‘instantaneous’ frequency of occurrence of events of interest in future years would be made. However, the availability of information limits the opportunity to make a detailed quantitative assessment.

To evaluate the degree of change of risk, relative to 2005, the following will be considered:

- Update the state of the environmental factors (e.g., subsidence and climate change) that may influence the performance of levees or the size or occurrence of hazards for an evaluation year (e.g., 2050, 2100, 2200).
- Estimate the effect changes in these environmental factors have on levee performance, Delta hydrodynamics, and future consequences.
- Modify the rate of occurrence of events based on available information and changes to the environment; the frequency of occurrence per year of events at the time (e.g., earthquakes or floods in future years).
- Estimate the change in the in-Delta and statewide exposure (i.e., increasing population and property development, ecosystem changes, etc.) to the effects of levee failures.
- Assume (based on BAU) that no major event (hazard or a proactive policy) occurs in the intervening years that would result in a significant change in the integrity or configuration of the Delta system.

Consideration of natural processes, such as subsidence and climate change, that produce an ongoing change in the Delta and Suisun Marsh are assessed based on BAU responses to these evolving processes. For instance, assuming current trends of levels of funding for levee maintenance and repair, it is likely that Delta islands and Suisun Marsh may be under water when considering future sea-level rise. Increasing funding to upgrade all levees to keep pace with sea-level rise would not be BAU. Similarly, as subsidence continues in the Delta, an effect may occur to levee stability, agriculture, and island conditions due to increased seepage, etc.

For each evaluation year (present, 2050, 2100, and 2200) the relative effect (increase, decrease, or neutral) with respect to the 2005 analysis is assessed. The assessment considers:

- Changing frequency and severity of hazard events (earthquakes, floods, normal forces)
- Update of the state of the Delta levees (updated levee vulnerability taking into account subsidence, maintenance practices, increased sea level, etc.)
- Changing Delta assets such as increased population on Delta islands, decline/improvement or changes in the ecosystem

Conducted over the study period, the results provide an estimate of the evolution of risk as measured by the change in the frequency of occurrence. The results of this evaluation of risk changes in future years are presented in Section 14.

Table 4-1 List of Events/Variables

Type	Event	Description	States/Values
State of Nature	Condition Variables in the Delta & Suisun Marsh	These events/factors relate to the characterization of the Delta and Suisun Marsh for the time the risk estimates are made. In the DRMS risk analysis, the variables/ factors that characterize the state of nature include climate change and subsidence. Climate change will impact the loads (static hydraulic head) and hazards (e.g., flood size, timing) that occur.	Sea-level Rise Hydrologic (annual runoff amounts and patterns and frequencies of floods) Amount of Subsidence
Event Timing	Type of Year	The availability of water varies substantially from year to year and plays a role in the severity of consequences.	CALSIM 82-year trace based on historic data is used to model the randomness of the availability of water
	Month of the Year	The time of the year when an event occurs, plays an important role in the consequences (economic, environmental) in the Delta.	
	Time of Day	The of day that levee failures occurs plays a role in the potential for loss-of-life	Day/Night
Initiating Events (Hazards)	Seismic Events Hydrologic Intrinsic Events (Normal Events)	Each hazard type is defined in terms of individual events. This definition preserves the correlations within an event that are important for assessing consequences. For example, for seismic events, an event is an earthquake of a given magnitude, on a specific fault, and at a particular location on the fault.	The full range of events is considered and a hazard appropriate characterization as defined by the hazard analysts and the levee vulnerability team. For seismic events, the full range of earthquake sizes (e.g., **M** 7. 5 – maximum magnitude) and their possible locations on a fault are considered and the hazard is characterized in terms of the spatial, random distribution of peak ground acceleration.
Levee Performance – Primary Response	Levee breaches	Given the occurrence of a stressing event, the number of levee breaches, the islands where the breaches occur, and the breach locations on an island are considered.	For each island, the number and location of possible levee breaches is defined.

Table 4-1 List of Events/Variables

Type	Event	Description	States/Values
	Non-breached Levee Damage	Given the occurrence of a seismic event, the levee reaches that have been damaged are identified.	Damaged levee reaches for each island.
Hazard (secondary)	Wind waves	In the period following an event that has resulted in levee breaches and/or damage, ambient waves or those generated during a wind event can result in deterioration of levees (see below).	Levels of wind waves and duration
Levee Performance - Secondary Response	Levee breaches	Given ongoing wave action or waves caused by wind events, the number of levee breaches that develop as a result of erosion of levee interiors (on flooded islands) and on islands where levees have been damaged, the islands where the breaches occur, and the breach locations on an island are considered.	For each island, the number and location of secondary levee breaches that develop (including breaches on flooded island interiors, as well as breaches on initially nonflooded islands).
	Non-breached Levee Damage	Ongoing wave action and wind events can result in erosion of levees and deterioration of initially damaged levee reaches. These events require additional emergency response resources and increase the time required to stabilize vulnerable levee reaches.	Damaged levee reaches for each island.
Response and Repair	Response and Repair	Given the primary response of levees to the hazard event, and then the subsequent secondary damage that could occur, repairs are undertaken to stabilize breached and vulnerable islands, and to undertake levee repairs (e.g., closure of breaches).	Timing and cost of individual island repairs.

Table 4-1 List of Events/Variables

Type	Event	Description	States/Values
Water Management	Reservoir Management Hydrodynamic Response	This event includes two coupled elements of the analysis; management of water resources (upstream reservoirs) following the breach event and the hydrodynamic response of the Delta and Suisun Marsh to the breaches that have occurred (primary and secondary), water management actions, and the timing of island breach closures.	Delta salinity levels; export disruption durations

Table 4-2 Salinity During Inflow Flood Levee Breaches

Year	Dates	Islands[a]	Inflow (annual peak day, cfs)[b]	Number of Delta Breaches	Peak EC (umhos/cm)[c]	
					Antioch	Holland Cut
1980	January 18	Holland, Webb	339,000 (2/22)	2	129 (1/24)	301 (1/18)
1983	January 27-30	Grizzly, Van Sickle, Mildred, Fay, Shima, Prospect (1/30)	422,000 (3/4)	6	240 (1/30) Blind Pt.	393 (1/29)
1986	February 19-25	Dead Horse, McCormack-Williamson, Tyler, New Hope (2/20), Shin Kee (2/25)	661,000 (2/20)	5	210 (2/23)	342 (2/27)
1997	January 3-10	Dead Horse, McCormack-Williamson, McMullin Ranch, Paradise Jct., River Jct., Stewart, Walthall, Wetherbee Lake, Prospect, Pescadero (1/10)	562,000 (1/7)	10	212 (1/07)	137 (1/05)

[a] URS 2006. Delta Levee Failures_Water Level Levee Breaches 121106.xls

[b] Flood Hazard TM (URS/JBA 2008a), Table 2-4.

[c] Interagency Ecological Program, 2008. http://iep.water.ca.gov/cgi-bin/dss/dss1.pl

Table 4-3 Duration of No Exports

(Percentage of Start Times Exceeding Indicated Number of Days or Months)

Case*	3 Months	4 Months	6 Months	9 Months	12 Months	18 Months	36 Months	42 Months
2	7.9%	2.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
3	9.8%	2.8%	0.4%	0.0%	0.0%	0.0%	0.0%	0.0%
4	51.4%	44.7%	22.3%	3.7%	0.4%	0.0%	0.0%	0.0%
5	88.0%	86.0%	81.7%	68.1%	46.7%	11.2%	0.0%	0.0%
6	95.2%	93.7%	90.2%	84.8%	71.6%	46.0%	5.2%	0.0%

***** These cases are described in the Water Analysis Module (WAM) TM (URS/JBA 2007e).

Table 4-4 List of Economic Risk Metrics

Category	Metrics
Delta Island Vulnerability	Individual Island Flooding Multiple Islands Flooding
Economic Impacts	Value of Lost Output
	Lost Employment (Jobs)
	Lost Labor Income
	Lost Value Added
Economic Costs	In-Delta Cost
	Statewide Cost
	Total Cost

Table 4-5 List of Environmental Risk Metrics

Fish Species Quantified Fish impacts are estimated by considering specific scenario occurrences for factors that affect fish populations or habitat conditions and totaling to a "score" for that scenario and species.	Delta Smelt
	Chinook Salmon
	Green Sturgeon
	Inland Silverside
	Longfin Smelt
	Steelhead
	Striped Bass
	Threadfin Shad
Wildlife Wildlife impacts are estimated by totaling the portion (of the acres) of that species' habitat that is flooded.	California Black Rail
	California Clapper Rail
	Greater Sandhill Crane
	Saltmarsh Common Yellowthroat
	Saltmarsh Harvest Mouse
	Suisun Ornate Shrew
	Waterfowl (ducks, geese, and swans)
Vegetation Vegetation impacts are estimated by totaling the portion (of the acres) of that habitat category that is flooded.	Alkali Marsh High
	Alkali Marsh Low
	Alkali Marsh Mid
	Aquatic Vegetation
	Herbaceous Upland
	Herbaceous Upland, Ruderal
	Herbaceous Wetland, Perennial
	Herbaceous Wetland, Seasonal
	Herbaceous Wetland, Seasonal, Ruderal
	Shrub Upland
	Shrub Wetland (Riparian)
	Tree Upland
	Tree Upland, Nonnative
	Tree Wetland (Riparian)

Table 4-6 List of Topical Areas

Category	Topical Area
Hazards	Probabilistic Seismic Hazard Analysis
	Flood Hazard Analysis
	Wind-Wave Action
	Normal Hazards
	Climate Change
	Subsidence
Levee Vulnerability	Levee Vulnerability
Emergency Response	Emergency Response and Repair of Delta Levees
Water Analysis Management	Water Operations
	Hydrodynamics
Geomorphology	Geomorphology of the Delta
Consequences	Economic Consequences
	In-Delta Infrastructure
	Ecosystem Consequences

Table 4-7 Summary of the Risk Quantification Steps

No.	Quantification	Products
1	Evaluation Levee System Performance (see Sections 6 – 9)	a. Frequency of failure of individual islands. b. Frequency of sequences of multiple island breaches and damage
2	Emergency Response and Repair (ERR) Evaluation (see Section 10)	a. Prioritize levee repairs for each sequence for damaged and flooded islands. b. Evaluate the repairs for each island, estimating the volume of materials, costs, and time to complete each repair type and dewater flooded islands.
3	WAM Evaluation (see Section 11)	For each sequence WAM calculations are performed to evaluate the water quality impact (salinity intrusion). These calculations are performed for the CALSIM historic trace to account for the randomness in hydrologic conditions and event months. The results of this calculation are: a. Estimate of the time for storage recovery b. Estimate of export deliveries during the period of disruption c. Estimate of the water quality impact required to evaluate environmental consequences
4	In-Delta Consequence Assessment (see Section 12)	For each sequence estimate: a. Direct economic consequences of island flooding b. Time to repair/recover island infrastructure after dewatering c. Damage to an island infrastructure such as pipelines, bridges, etc., due to levee breaches and scour
5	Economic Consequence Assessment (see Section 12)	For each sequence estimate: a. Statewide economic impact, including impact to in-Delta businesses, and costs associated with water export disruptions, job losses, etc. b. Total economic costs and impacts associated with levee repair, in Delta costs, statewide impacts, etc.
6	Environmental Consequences	For each sequence estimate for various environmental metrics (aquatic species, terrestrial species, vegetation, etc.) the impact of levee failures, and water quality.

Table 4-8 Summary of the Information Available to Evaluate Future Hazards and Environmental Factors

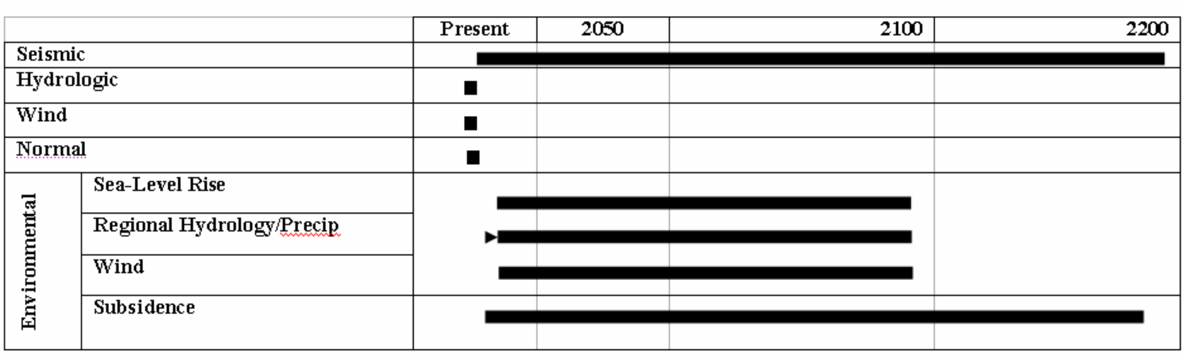

Table 4-9 Summary of the Information Available to Evaluate Future Delta Risks

	Present	2050	2100	2200
Levee Vulnerability	Direct data to support levee conditions in the future are not available. Projections and conditions can be based on past experience and practices. Factors such as subsidence can be projected and taken into account.			
Water Supply/ Demand/ Operations	Models and data are available to 2030. Hydrologic projections to 2100 are available to take into account			
Hydrodynamic	No data are available to account for bathymetry changes in the Delta. Sea-level rise effects are being considered as part of DRMS. Factors such as subsidence can be projected and taken into account.			
Environmental	Projections of species populations are not available. Observation of pelagic organism decline is not understood. Habitat restoration goals are identified; however data to support model projections accounting for all factors (land use, restoration, etc.) are not available.			
Economic	Models and data are available to 2030.			
Delta Infrastructure	Projections of land use and population changes are available to 2030. For commercial infrastructure, specific projections for change/growth are not available.			

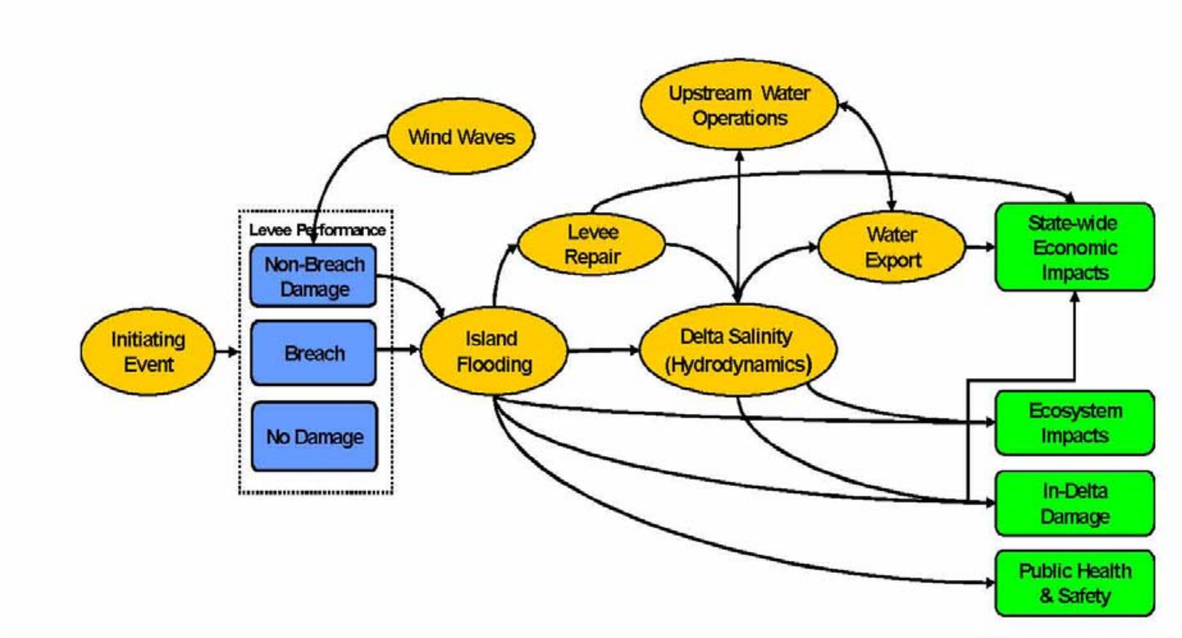

Figure 4-1 Influence diagram illustrating the basic elements of levee performance, repair, and Delta hydrodynamic response after a seismic event

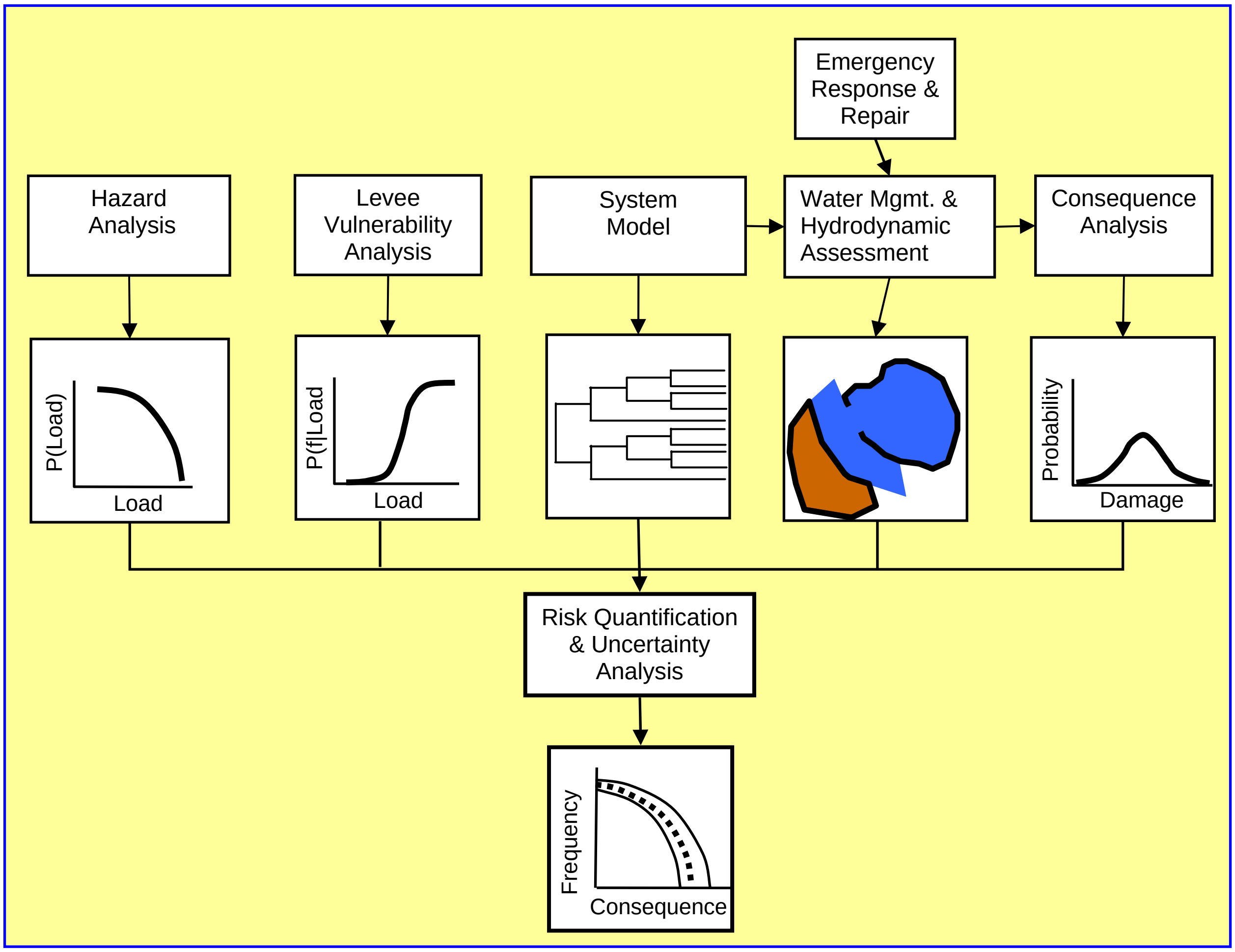

Figure 4-2 Schematic illustration of the elements of the risk analysis

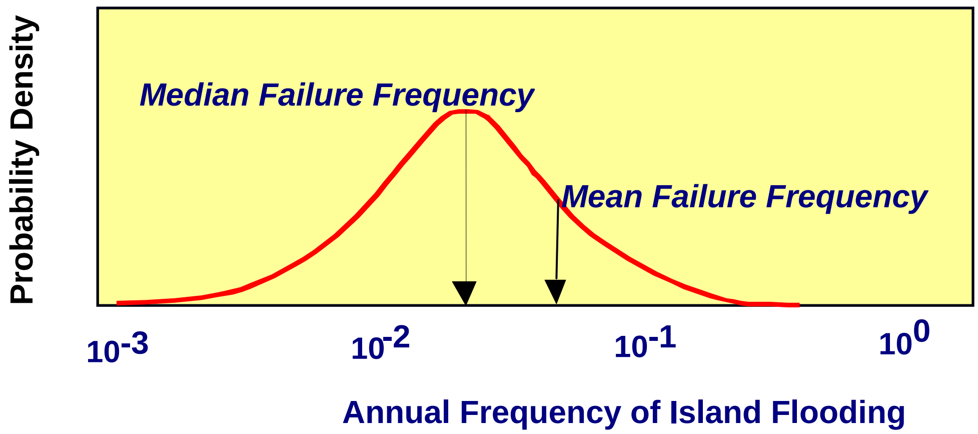

Figure 4-3 Illustration of the epistemic uncertainty in the estimate of the annual frequency of island flooding due to levee failure

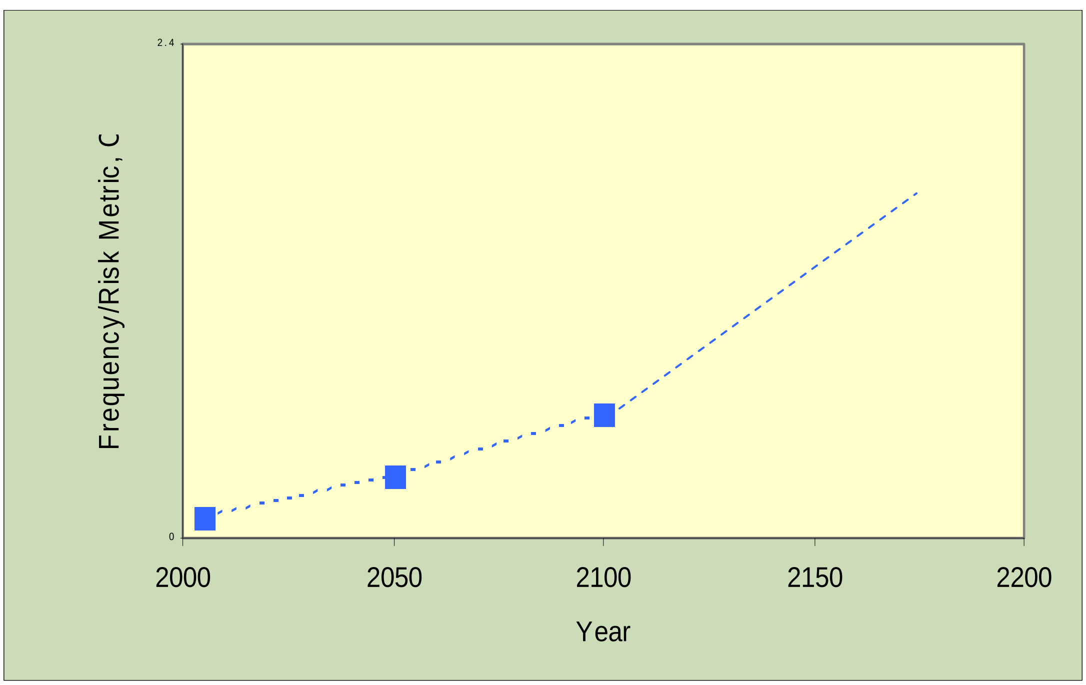

Figure 4-4 Illustration of time-varying estimates of risks in the Delta

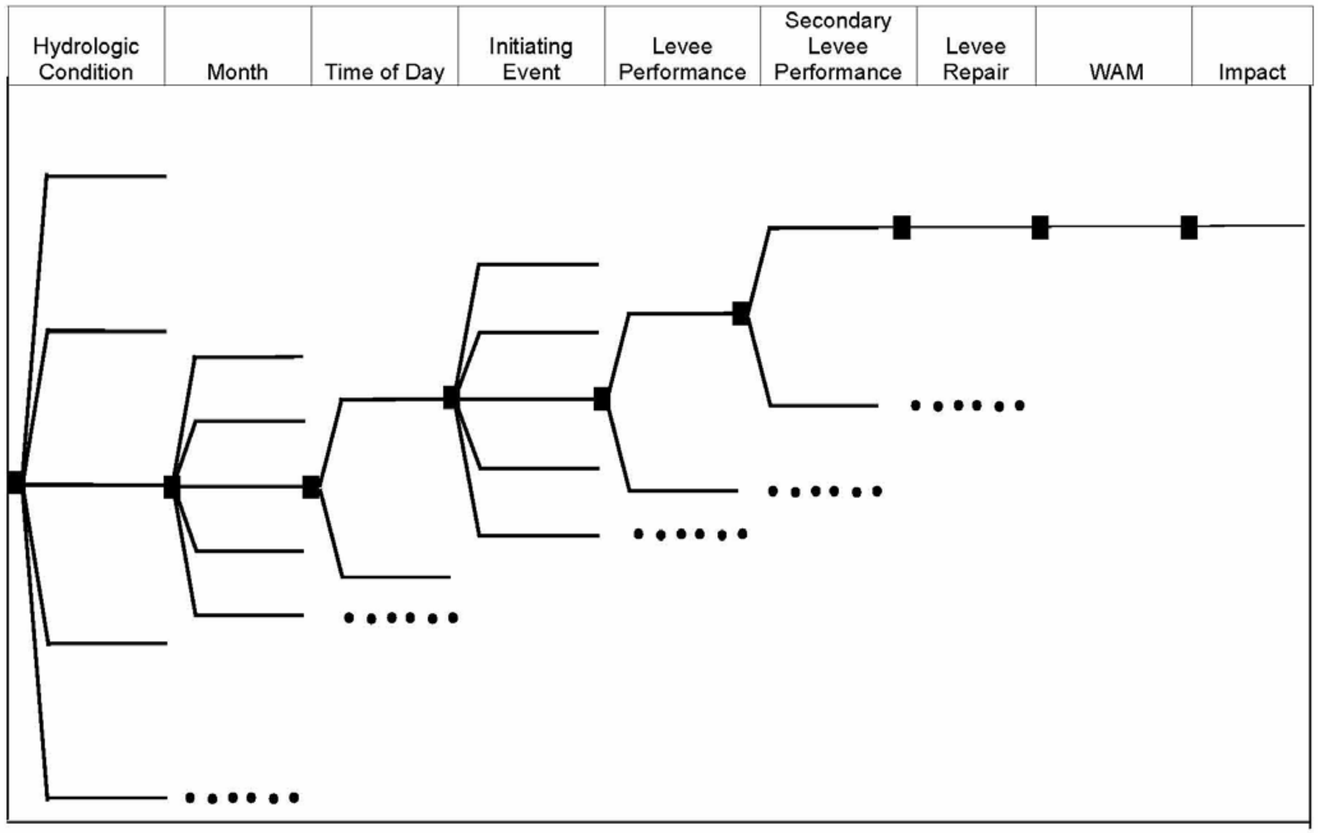

Figure 4-5 Illustration of an event tree used in the system model to organize and assess sequences

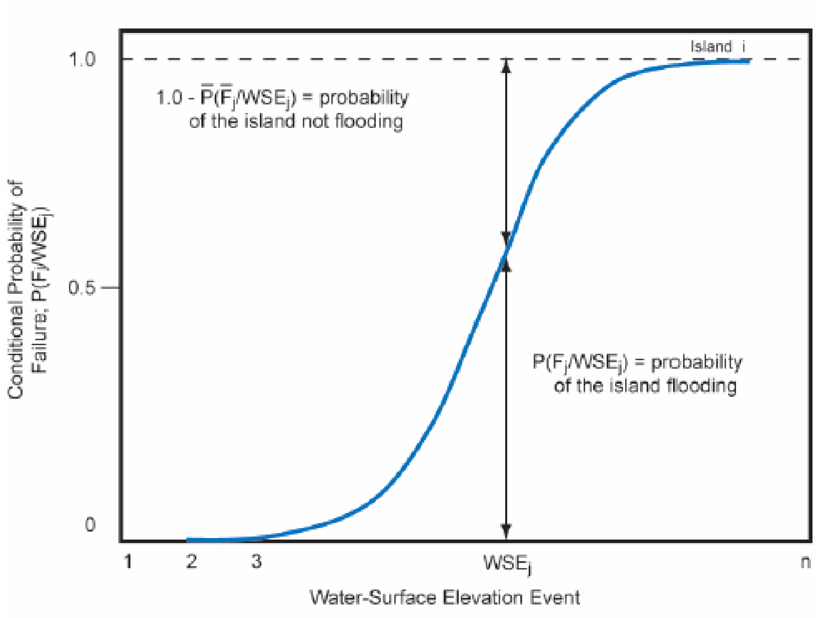

Figure 4-6 Illustration of an island hydrologic fragility curve and the simulation of island flooding

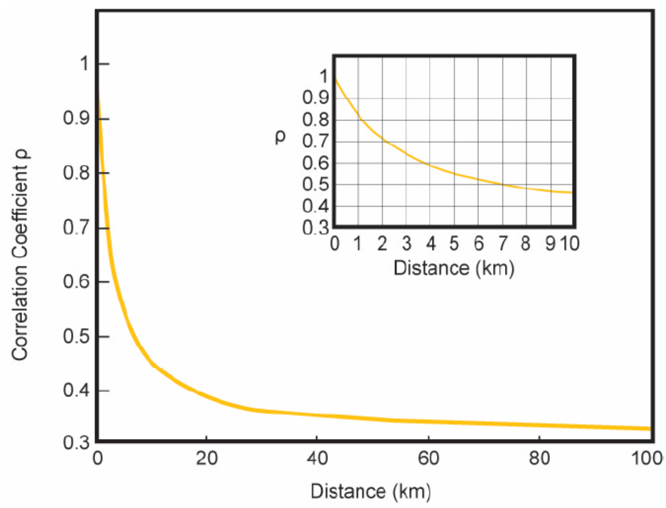

Figure 4-7 Ground motion correlation model developed by Boore at al. (2003)

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California is now the sixth largest economy in the world, with a gross state product in 2005 of $1.6 trillion. Water exported from the Delta plays a major role in sustaining the California economy. Utilities and transportation that pass through the Delta and Suisun Marsh also contribute to the statewide economy and especially to the greater San Francisco Bay Area. The Delta itself is a distinct region with its special lifestyle, economic activities, and recreational opportunities. The towns and cities on the fringes of the Delta are growing rapidly as bedroom communities for nearby cities and for the Bay Area. The Delta and Suisun Marsh also support a wide variety of aquatic and terrestrial species.

The purpose of this section is to describe what is at risk due to levee breaches and island flooding in the Delta. We do not intend to provide a complete Delta overview, nor a detailed inventory in this section, but we do want to provide summary information about the assets in the Delta and also activities outside the Delta that may be affected by levee breaches. Delta Vision has prepared a report on the "Status and Trends of Delta – Suisun Services" (URS 2007). Many other Delta inventories, overviews, summaries, and assessments are referenced in the Status and Trends Report and thus have influenced this section. Readers who want more extensive detail can access it by referring to the Status and Trends Report and its references.

5.1 POPULATION

One can view the populations influenced by the Delta and Suisun Marsh in many different ways. The 2000 census shows that the Delta islands and tracts had a population of about 26,000 people. These are the people who would have the most difficulty with evacuation in the event of levee failures because road access to most areas requires passing over bridges, riding on auto ferries, driving through low-lying areas that may be flooded, and traversing roads on the tops of levees.

The 2000 census also shows that the area protected by levees that are within the legal boundary of the Delta and the Suisun Marsh contains a population of about 470,000 people. The protected area includes portions of urban areas such as West Sacramento, the Pocket Area in Sacramento, and parts of Stockton and Tracy. Some portions, especially in West Sacramento and the Pocket Area are outside the legal Delta but are protected by Delta levees. Most of the residents of these areas would not be subject to flooding from a levee failure at the Mean Higher High Water (MHHW) level (e.g., in the context of most earthquakes), but could be affected by levee failures during a flood with a recurrence interval of 1 in 100 years or higher (see Economic Consequences TM [URS/JBA 2008f]).

Six California counties have land within the legal Delta. Sacramento, San Joaquin, Solano, Contra Costa, and Yolo counties have portions of both the Delta Primary Zone and the Secondary Zone. Alameda County has a portion of only the Secondary Zone. The combined population of the six counties is about 3.3 million based on the 2000 census and 5.1 million in 2005 (DOF 2007a; U.S. Dept. of Commerce, BEA 2008).

The Delta's importance extends beyond the Delta counties and is directly relevant to the well being of many people in the Greater San Francisco Bay Area, with its population of 7.2 million. Together with the Delta counties not included in the Bay Area, this amounts to a total population of 9.4 million. These people's standards of living and conveniences are directly influenced by Delta-Suisun services including highways, railroads, recreational opportunities, and a host of less obvious utilities.

East Bay Municipal Utility District's (EBMUD's) Mokelumne Aqueduct crosses the Delta, bringing water from the Sierra to serve 1.3 million people in the Bay Area. About 500,000 more people in the Contra Costa Water District use water diverted from the Delta. Finally, the Federal Central Valley Project and the State Water Project, which draw water from the Delta channels, are key water suppliers to several other parts of the Bay Area, including the Santa Clara Valley ("Silicon Valley"), Tracy, the Livermore/Pleasanton area, San Benito County, and communities in the northern Bay Area served by the North Bay Aqueduct. Electrical transmission lines and natural gas pipelines also cross the Delta, delivering these commodities to Bay Area homes and businesses.

Many California residents further to the south of the Delta and Suisun Marsh have never heard of the region, although they also are highly dependent on water withdrawn from the Delta and delivered by the state and federal projects to their communities. About 18 million people served by the Metropolitan Water District of Southern California count on the Delta as part of their drinking water supply. Many other water agencies and districts could have a portion of their supplies interrupted by Delta levee failures. In all, about 27 million people in California currently have water supplies that could be affected by Delta levee failures. Millions of additional people in Northern California and Nevada could have natural gas or petroleum supplies affected by levee failures in the Delta because pipelines carry these products across the Delta.

Considering that a Delta levee failure could affect the economy of California, practically all of the state population has an interest in the Delta. The 2005 population of the state was about 37 million people and it is growing rapidly.

5.2 DELTA LAND USE

Most of the Delta is agricultural land and most of the Suisun Marsh is managed wetlands and other lands managed for conservation. The Status and Trends (URS 2007) provides the following key points on Delta land use:

- Out of almost 840,000 acres, the 2004 land use consisted of about 9 percent urban, 67 percent agricultural, 14 percent conservation and other open lands, and 10 percent water. A land use map is shown on Figure 5-1.
- Highly productive agriculture occurs on more than 500,000 acres in the Delta, taking advantage of the rich organic (peat) soils to produce high value crops such as fruits and vegetables.
- The organic soils are vulnerable to decomposition and other losses, resulting in subsidence of the ground surface. Elevation losses of 0.5 to 1.5 inches per year have been common, particularly with traditional agricultural practices. As a result, in most Delta land surface elevation lies below sea level, some by as much as 15 to 20 feet.
- About 40,000 acres of land-use conversions from agriculture to urban and conservation uses (approximately half to each) have occurred between 1990 and 2004.
- The Delta Protection Act limits urban growth in the Delta Primary Zone (see Figure 2-3, which shows the area within the Primary Zone).
- The Suisun Marsh Preservation Act also limits urban growth in its Primary Management Area.

- The Secondary Zone of the Delta and the areas immediately adjacent to the Delta and Suisun Marsh are subject to urban development pressures. They are some of the fastest-growing areas of California, particularly near Sacramento, Stockton, Manteca, Tracy, Brentwood/Antioch, and Fairfield/Suisun City.

5.3 ECOSYSTEM

The Delta and Suisun Marsh provide habitat for a diverse estuarine community including fish, wildlife, and aquatic and terrestrial plants. Several unique habitats supporting diverse ecologies exist in the Delta and Suisun Marsh including vernal pool habitat and the marsh/upland transition zone, which is an area of high biodiversity of plants and wildlife. Many endemic species occur in the Delta, including many species of vascular plants in vernal pool habitat, and species of fish including delta smelt. The estuarine ecosystem supports extensive recreational fishing, bird watching, aesthetic enjoyment, and commercial fisheries.

Over the past 150 years, the fish and wildlife communities inhabiting the Delta and Suisun Marsh have lost access to upstream habitat because of a number of factors including construction of dams and impoundments, land use changes, reclamation and channelization/levee construction, exotic species introductions, water diversions with changes in seasonal hydrologic patterns, and other changes. As a result of these and other factors, many of the species in this area have experienced substantial declines in abundance and geographic distribution, leading to the listing of several species under the California and/or federal Endangered Species Acts and the identification of others as species of special concern. Table 5-1 provides a listing.

Levees in the Delta and Suisun Marsh have distinct differences in stature and function. Those differences are relevant to predicting the response of vegetation and animals to levee failure. In the Delta, levees are more robust in stature (e.g., heights up to 20 feet) and support an extensive infrastructure (e.g., paved roads, pipelines, electrical transmission, rail lines). Although Suisun Marsh was originally diked to allow draining for agriculture, the dikes were later altered to facilitate managed flooding to support wildlife habitat consisting of marsh and aquatic vegetation (Chappell 2006). Levees in Suisun Marsh include exterior levees (>9 feet high), and a network of shorter interior levees (>4 feet high) that allow for spatially complex controlled flooding regimes to cultivate different marsh habitats.

Over the past several years many of the pelagic fish species inhabiting the Delta and Suisun Marsh, such as delta smelt and longfin smelt, have experienced a significant decline in abundance, referred to locally by regulatory agencies, scientists, and stakeholders as the pelagic organism decline (POD). The forces contributing to the POD are hypothesized to include changes in seasonal hydrology (due to long-term climatic changes and water export project operational changes), competition from or predation by introduced species, exposure to toxic substances (especially pesticides), and other factors (Armor et al. 2006).

California and federal resource agencies are actively investigating the significance of these and other factors affecting pelagic fish species, their population dynamics, habitat suitability, and the overall condition of the Delta and Suisun Marsh. To date, the relative importance of each of these factors on populations of pelagic species has not been determined. Discriminating direct impacts and interactions among the multiple potential drivers of the POD is difficult, and contributes to the uncertainty surrounding predictions of future states of the estuary’s aquatic ecosystems.

The Delta and Suisun Marsh ecosystem supports a high diversity of resident and migratory wildlife, including birds, mammals, reptiles, and amphibians. Until European settlement, the Bay-Delta was dominated by tidal marsh, with extensive riparian forests distributed along the floodplains of its tributaries. Today, the species composition, distribution, and abundance of wildlife in the Bay-Delta are determined primarily by the distribution and extent of the communities that support their habitats.

The major changes in Delta and Suisun Marsh habitats from historical conditions have been the loss of tidal influence with construction of levees and dikes and the conversion of marsh and riparian communities to agricultural uses. Consequently, the distribution and abundance of resident marsh- and riparian-associated species has declined (e.g., California black rail, salt marsh harvest mouse, western yellow-billed cuckoo). The distribution and abundance of species for which agricultural lands provide habitat have been less severely affected or benefited (e.g., wintering waterfowl, raptors).

In addition to resident wildlife, the Bay-Delta serves as a wintering and migration stopover habitat for a large number of waterfowl, sandhill cranes, and shorebirds of the Pacific Flyway. Bay-Delta habitats (e.g., marshes, tideflats, and agricultural lands) provide these species with the food resources needed to sustain their populations during winter, and the energy reserves necessary to sustain migration and initiate breeding on their nesting grounds.

The primary ongoing threats to wildlife habitats in the Delta are those related to loss and degradation of habitat. Such threats include the following:

- Changes in salinity or other water quality parameters that could effect a change in vegetation communities that support existing habitats
- The potential for conversion of agricultural and managed wetland habitats that support large numbers of wintering waterfowl and other birds that winter or migrate through the Delta to habitats that provide lower forage production or to other uses (e.g., development)
- The permanent loss of these habitats due to catastrophic levee failures

5.4 ECONOMY

As with population, several regional economies (and the economy of the whole state) are influenced by the Delta-Suisun area and the integrity of its levees.

Delta Area. The area protected by Delta levees includes about 15,900 businesses that are counted by the ESRI database (PBS&J 2007). These businesses have sales of about $35 billion annually and employ 205,000 people. Table 5-2 summarizes the study area economy in terms of value of sales and employment by sector. Note that much of this economic activity is situated in Sacramento and West Sacramento on land that is outside the legal Delta but could be flooded by the failure of levees located in the Delta. Of course, each of these businesses is vulnerable to direct economic impacts if a levee failure were to result in flooding of their particular island or tract.

Greater San Francisco Bay Area and Delta Counties. Economic activity in a much wider area could be impacted by a major levee failure event in the Delta, including impacts through disruption of water supplies, electrical and natural gas transmission, petroleum product deliveries, recreational opportunities, and multiple modes of transportation. Table 5-3 provides key economic information for the state and the Greater Bay Area, including the three Delta counties not included in the Bay Area (Sacramento, San Joaquin, and Yolo) and for the Delta counties and the Greater Bay Area separately.

Table 5-3
2005 Economic Data for California, the Greater Bay Area, and Delta Counties

	California	Greater Bay Area (GBA)	Three Delta Counties not in GBA	GBA and Delta Counties	Six Delta Counties
Population (M)	37	7.2	2.2	9.4	5.1
Personal Income (B$)	1,350	363	68	431	237
Per Capita Personal Inc. ($)	37,462	50,836	31,119	46,187	55,284
Employment (M)	20.0	4.5	1.2	5.6	2.9

Source: U.S. Dept. of Commerce, BEA 2008.

The Greater Bay Area and the Delta counties contain more than one fourth of the populations and employment in the state and generate nearly one third of the state's personal income. Intensive service disruptions for this region as the result of a major Delta levee breach event would be bound to affect economic productivity. This would add to the direct impacts of flood damage.

State. The state economy might see major disruptions of water deliveries, affecting most south-of-the-Delta agriculture and all urban areas that receive water supplies from the Delta, including essentially all of southern California. This would be in addition to whatever state economic participation occurred for restoration expenditures and the obvious economic impacts to the state of the disruptions that are more specific to the local area and nearby region.

These prospective economic consequences are discussed in more detail in Section 12 together with the method used to estimate actual numbers for a given levee breach event. More detail on the infrastructure that resides in the Delta is presented below to provide the basis for understanding these regional and statewide economic consequences.

5.5 INFRASTRUCTURE

A large amount of infrastructure is located within the Delta and Suisun Marsh. Some of the infrastructure that crosses the Delta to other parts of California provides vital resources such as water, gas, power, communications, shipping, and railroad freight transportation. By infrastructure, we mean the physical assets that have been constructed or shaped in the Delta to enhance the human environment and provide services. This generally excludes ecosystem features although they are important assets of another type. Also, two aspects of Delta infrastructure are so all-encompassing and pervasive as to be easily overlooked in the summary that follows. These are:

- The Delta levee system – This is a system of man-made embankments that defines the Delta's land/water character. This is clearly infrastructure. It is addressed more specifically in following sections and in the Levee Vulnerability TM (URS/JBA 2008c).

- The Delta channel system that serves as a conveyance route for state, federal, and other water supply – This is also infrastructure, since it is defined by and functions due to the levees, even though it functions in a somewhat passive manner. It is invaluable in transporting water from Delta inflow sources (primarily the Sacramento River) to the state and federal pumping plants (identified as point infrastructure assets) and to the widely dispersed in-Delta water users. The Delta conveyance system is addressed comprehensively in the Water Analysis Module (WAM) TM (URS/JBA 2007e).

The more commonly known elements of Delta infrastructure can be divided into linear and point assets. Linear infrastructure includes railroads, highways, shipping channels, transmission lines, aqueducts, and gas and petroleum pipelines. Point infrastructure includes bridges, marinas, natural gas fields/storage areas, natural gas wells, commercial and industrial buildings, residences, and pump stations. Although the Delta levees themselves are infrastructure assets, they are not itemized here.

The descriptions of the Delta assets that follow are summarized from information collected in 2004–2005 for the In-Delta Storage Project (URS 2005), from information collected from asset owners (from meetings, telephone conversations, and reports), HAZUS-MH MR2 (FEMA 2006), and from information provided by the California Department of Water Resources (DWR). It has been documented in detail in the Impact to Infrastructure TM (URS/JBA 2007f). The information was then used as described in Section 12 to estimate direct and loss-of-use damages in the context of any specific levee breach event.

5.5.1 Linear Assets

PG&E Natural Gas Pipelines
(Figure 5-2 [Proprietary information. Publication not Permitted.])

The main PG&E natural gas pipelines that were considered for infrastructure damage estimates are:

- Backbone Line (L400/401): west side of Delta running north-south, 26- to 42-inch outside diameter (OD).
- Line 196: traverses east to west through the middle of the Delta, 12- to 16-inch OD; mostly 16-inch OD.
- Line 108: east side of Delta running north-south, 16- to 24-inch; mostly 24-inch OD.
- StanPac (Standard Oil, now Chevron, and PG&E) Line: west side of Delta, 10- to 16-inch OD.
- Line 57A (18-inch OD) and Line 57B (22-inch OD) from the McDonald Island Gas Storage Field. Line 57C (24-inch OD), which will be 4.7 miles long, is under construction in 2007 (PG&E 2005). This new line will provide redundancy for gas delivery from the gas storage field.

PG&E has used several methods for installing gas pipelines at water crossings, and these include the following:

- Exposed “overhead crossings”: generally used at shorter ditch crossings.

- Hung-on-bridge crossings: very limited use due to required permissions involved and limited availability.
- Trenching: widely used for short to river-wide lengths in which a pipe was originally installed approximately 5 feet deep following the contours of the levee and streambed with a concrete water-break-wall on the top of the levee.
- Horizontal Directional Drilling: Initiated in the mid-1970s and widely adopted in the mid-1980s for water crossings.

PG&E Electrical Transmission Lines (Figure 5-3)

The transmission lines for 500-, 230-, and 115-kilovolt (kV) voltage levels within the Delta and Suisun Marsh areas are constructed on tower structures (some 115-kV lines are on wood poles). Most of the towers have augered footings with a minimum diameter of 2 feet and are installed at various depths. Only about 10 percent of the towers are on pile foundations.

- The 500-kV transmission lines are constructed on single-circuit tower structures. The depths of the footings range from 9 to 15 feet.
- The majority of the 230-kV transmission lines are constructed on double-circuit tower structures. The depths of the footings range from 9 to 20 feet.
- The majority of the 115-kV transmission lines are constructed on double-circuit tower structures. The depths of the footings range from 7.5 to 12.5 feet. Some of the 115-kV lines are constructed on wood poles. The wood pole standards show that the typical depths of the pole settings range from 5 to 10 feet.
- Almost all the 60-kV transmission lines are constructed on wooden poles. The classes and settings of wood poles are designed to meet or exceed the minimum requirements of General Order 95. The pole-setting depths of wood poles vary from 5 to 10 feet depending on the height of the wood poles. Some of the 60-kV transmission lines are constructed on tubular steel poles. The typical foundation size for tubular steel poles at this voltage level is about 4.5 feet in diameter and 17 feet deep.

Information in the Levee Fragility Technical Memorandum indicates that major transmission lines are outside the areas of significant peat and organic marsh deposits, except for the transmission lines across Sherman Island.

Highways and Roads (Figure 5-4)

The following main roads/highways traverse the Delta:

- Interstate 5 – runs north-south on the eastern side of the Delta
- Interstate 205 – runs east-west on the southern side of the Delta
- State Highway 160 – runs north-south along the Sacramento River from Freeport to Oakley
- State Highway 12 - traverses east-west through the middle of the Delta from Fairfield through Rio Vista to Lodi
- State Highway 4 – runs east-west from Interstate 5 to Oakley

- County Roads J4 and J11 – are in the central and southern parts of the Delta, respectively

Kinder Morgan Petroleum Products Pipeline (Figure 5-5)

The Kinder Morgan pipeline traverses the Delta from east to west, from Stockton to west of Veale Tract, a distance of about 27 miles. Information provided by DWR indicates that the Kinder Morgan pipeline is a buried steel 10-inch diameter pipeline.

Mokelumne Aqueduct – Raw Water from the Sierra (Figure 5-6)

The Mokelumne Aqueduct consists of three pipelines (aqueducts) along the route where it crosses the Delta. The three aqueducts are described as follows (EBMUD 1995, 1996):

- Aqueduct #1: built in 1929; 65-inch diameter
- Aqueduct #2: built in 1949; 67-inch diameter
- Aqueduct #3: built in 1963; 87-inch diameter

Within the Delta, the aqueduct has both buried and elevated sections as follows (EBMUD 1995; 1996):

- Stockton to Whiskey Slough (Holt) – buried section (about 8½ miles). The depth of burial in trenches is about 5 feet; at the sloughs the burial depth is 15 to 20 feet.
- Whiskey Slough (Holt) to Indian Slough (Bixler) (just west of Palm-Orwood Tract) – elevated section, except at the crossings at Middle River and Old River (about 9½ miles). The elevated section is supported on steel bents at 60-foot intervals. Each bent is supported by at least four concrete batter piles.
- West of Bixler – buried section (about 18 miles). About 12 miles of the aqueduct, west of Veale Tract, is close to the legal Delta boundary.
- River crossings – River crossings are at San Joaquin, Middle River, and Old River. At the river crossings, the aqueducts are buried in trenches and backfilled with rockfill. Aqueducts #1 and #2 are on piles that are founded in dense sand at Middle and Old Rivers. Aqueduct #3 is buried 30 feet below slough bottoms.

Aqueduct #3 was seismically upgraded so that it could be returned to service within 6 months after the "Maximum Earthquake" on the Coast Range Central Valley fault (EBMUD 1995, 1996). EBMUD has very limited local storage or supplemental local supply sources. Thus an aqueduct outage would be of major concern.

Railroads (Figure 5-7)

The Burlington Northern Santa Fe railroad traverses the Delta and Suisun Marsh from east to west, from Stockton to Interstate 780. The other railroads are generally around the periphery of the Delta.

The railroad tracks are mainly supported on embankments in the Delta. On the north side of Woodward Island, the railroad is on a trestle bridge that is supported on piles. No direct information about the depth of piles was available. However, based on experience with similar trestle bridges, the depth of piles is expected to be 70 to 80 feet.

The railroad traverses between Upper and Lower Jones tracts on an embankment fill, except for a bridge over a passage between the two islands. The west abutment of the bridge was scoured during the June 2004 Jones Tract levee failure (URS 2005).

5.5.2 Point Assets

The locations of point assets are shown on Figure 5-8 (solid waste facilities and sewage treatment plants), Figure 5-9 (businesses), and Figure 5-10 (miscellaneous data, e.g., ports, airports, and health care facilities).

Residences

Residences are scattered throughout the Delta; however, not all islands are populated or have residential structures. Urban areas (with concentrations of residences) within or near the Delta include Rio Vista, West Sacramento (and the "Pocket Area"), Elk Grove, Clarksburg, Hood, Courtland, Walnut Grove, Isleton, Oakley, Brentwood, Stockton, Lathrop, Manteca, and Tracy.

The data pertaining to residential structures were generated by HAZUS (FEMA 2006). Several different types of residential structures include single-family housing (one to three stories), mobile homes, duplexes, triplets/quads (one to five stories), apartment buildings, motels/hotels, institutional dormitories, and residences.

Commercial Buildings

Commercial buildings are scattered throughout many Delta islands (Figure 5-9) and include low, mid-size, and high-rise structures. HAZUS (FEMA 2006) has defined the following types of commercial structures in the Delta: agricultural structures, retail and wholesale trade, repair services, professional/technical, services, banks, hospitals, medical offices/clinics, and entertainment and recreation.

Industrial Facilities

Industrial buildings are also scattered throughout the Delta. HAZUS data shows that industrial structures in the Delta include heavy and light industry, high technology industry, construction industry, metals and mineral processing, and food and drug chemicals.

Bridges

Three types of bridges lie within the Delta: highway bridges, railroad bridges, and nonhighway bridges.

Oil/Gas and Water Wells

Oil, gas, and water wells scattered throughout the Delta are shown on Figure 5-5.

Natural Gas/Field Storage

PG&E has a natural gas field on McDonald Island. The gas field equipment is on platforms 30 feet above ground level.

Ports

These assets include the ports of Sacramento and Stockton and ports along the west side of the Delta.

Water System Assets

Water system assets within, or close to, the Delta include pumping plants, gates, and intakes owned by DWR, Contra Costa Water District, and Bureau of Reclamation. The pumping plants are shown on Figure 5-6 and include the following:

- DWR pumping plants: Harvey O. Banks (California Aqueduct), South Bay (South Bay Aqueduct), and Barker Slough (North Bay Aqueduct)
- Contra Costa Water District pumping plants: Old River, Mallard Slough, Rock Slough Intake, and Pumping Plants 1 through 4
- Bureau of Reclamation's Central Valley Project: C.W. "Bill" Jones Pumping (formerly Tracy Pumping Plant) (Delta-Mendota Canal).

Power Plants

Power plants in the Pittsburg–Antioch area are within the Delta study area; however, these assets are not protected by levees.

5.5.3 Asset Value of Infrastructure

The asset value (defined herein as replacement cost) of infrastructure was considered for two levee failure scenarios. For the DRMS project, the term "infrastructure" is used to designate all structures and buildings, and their contents. The first looked at the assets that could be flooded if all levees were to fail with sea level at MHHW; the average elevation of the highest of the two tides each day over a 19-year period). The second looked at the assets that could be flooded if all the levees were to fail at the 100-year flood level. (The estimate of the boundary of the 100-year floodplain was developed from Federal Emergency Management Agency Flood Insurance Rate Maps, which are currently being updated.) The current (2005) estimated value of assets (including building contents) for these two scenarios follows:

- MHHW: $6.7 billion
- 100-year flood: $56.3 billion

The total value of assets for the 100-year flood significantly exceeds the value of the assets that are below the MHHW level. The 100-year flood event has the potential to inundate major urban areas, such as in West Sacramento, the Pocket Area of Sacramento, and Stockton, that have large inventories of infrastructure assets. However, the MHHW limits do not extend to these large urban areas. Small towns and rural/agricultural areas mainly fall within the MHHW limits. Figure 5-11 shows the areas included in the MHHW and the 100-year limit designations.

Besides inundation damage, infrastructure assets are subject to damage due to scour at levee breach locations. Assets that are within the scour zones adjacent to a levee breach are assumed to be destroyed (i.e., scour holes could occur anywhere within the island perimeter and a location is to be specified for each breach in any given levee breach scenario so that scour damage can be assessed). Based on historical data, the scour zones were defined to be 2,000 feet long (perpendicular to the island perimeter/levee) (see Section 12). Scour limits are shown on Figure 5-12. The location of the scour can be a significant part of loss-of-use and repair cost estimates, depending on the location of a specific breach. In such a case the scour limit is the edge of the scour zone; i.e., 2000 feet landward of the levee (perpendicular to the island perimeter/levee), 500 feet wide (parallel to the island perimeter/levee), and 50 feet deep. These dimensions are based on historical scour events.

Because some asset types lack attribute information, it was not always possible to estimate asset costs from the GIS data (geographic information system files) developed as part of DRMS drawing on several sources. This information was used to estimate the Delta infrastructure losses in each specific levee breach scenario in the risk analysis. The GIS data usually include attributes or characteristics of the infrastructure assets. Attributes include pipeline diameters, number of stories of buildings, number of tanks in a tank farm, etc. These attributes are needed to develop replacement cost estimates for the various assets that may be damaged by flooding or scour. The initial GIS database and its augmentation with data from other sources is described in more detail in the Impact to Infrastructure TM (URS/JBA 2007f).

In cases where some of this attribute data are missing, available information may be insufficient to evaluate reliable replacement and repair costs. Assumptions had to be made so that damage losses could be estimated. As a result of this limitation, the replacement and repair costs may be under-represented. Further characterization of the Delta infrastructure assets would reduce the uncertainty in the damage estimates. In addition, because of the lack of information on repair times (due to the absence of historical experience), especially for multi-island failures, URS' staff used its best engineering judgment to estimate repair times.

Note that this compilation of infrastructure subject to levee breach damage does not address the issue of public safety and potential injuries or death. That is a different topic.

5.6 GEOMORPHOLOGY, SUBSIDENCE, AND TOPOGRAPHY

The freshwater tidal marshes of the historic Delta were created after the last ice age as wetland vegetation growth kept pace with gradually rising sea level by capturing sediment and forming peat soils. Over the last 5,000 years this phenomenon allowed the marsh to expand vertically and laterally into the Central Valley, eventually creating about 380,000 acres of tidally influenced marsh and channels, the largest freshwater tidal marsh on the west coast of North America (Figure 5-13). Because this marsh was a freshwater system, marsh vegetation could colonize below low tide level, vegetating emergent mudflats and precluding the formation of large wind-wave-generated expanses of open water that occur in the saltwater-influenced portion of the estuary.

This scenario meant that in the historic Delta, the morphology of the marshes and channels maintained a dynamic equilibrium with the main physical processes; the tides, floods, the transport of sediment, and sea-level rise that shaped it. It also meant that the tidal prism, the volume of the tides that flowed in and out of the Delta on a tidal cycle, was quite limited for such an extensive estuarine system, and was determined almost entirely by the volume of water in the sinuous tidal channels that drained the marshes. Sediments discharged into the Delta during large floods on the Sacramento or San Joaquin Rivers would either be conveyed through the Delta to Suisun Bay or captured within the tidal marsh.

Over the last 150 years, the natural landscape elements of the Delta have been transformed by human activities. The large tule marsh of the Delta has been converted by levee building into a highly dissected region of channels and leveed islands used for agriculture (Simenstad et al. 2000). Only a few examples of relatively pristine tidal marsh still exist, such as Browns Island

and on narrow bands of emergent vegetation located between the channels and levees. Even though marshes grow on the exterior of levees in the Delta, and Suisun Marsh has managed marshes, creation of the levees removed the marsh/upland transition zone, an area of unique biodiversity. These marshes amount to less than 2 percent of the historic marsh. Much of the natural riparian vegetation bordering distributary channels has also been lost. In general, levees were constructed either along firmer ground on the natural levees of distributary channels or along the edge of the larger natural tidal channels.

As the tidal marsh was reclaimed, the natural tidal and distributary channel system was extensively modified to provide for navigable access to farms and by excavation to build up levees. The main Delta channels have been widened, dredged, and straightened to allow for passage of ships. Dredging of the Sacramento River Deep Water Ship Channel makes it navigable for ocean-going ships as far inland as Sacramento. Cache Slough is also dredged as it forms part of this Ship Channel. Along the San Joaquin River, the dredged Stockton Deep Water Ship Channel makes the lower reach of the river navigable for ocean shipping as far inland as Stockton. At Stockton, an abrupt change occurs in channel geometry from a deep channel downstream to a shallow river channel upstream.

Land subsidence has placed most of the Delta land below sea level. Subsidence varies with location, but rates of 0.5 to 1.5 inches of soil loss per year are common in the Delta. This historical subsidence has left multiple islands with average land elevations as much as 15 feet or more below MSL. Several islands have areas as much as 25 feet below sea level. Subsidence of the peat soils behind the levees has created a large artificial empty space below high tide level, or potential accommodation space. This accommodation space of over 2 billion cubic meters below sea level can be filled by flood waters in the event of levee failures (Mount and Twiss 2005).

Over the last 80 years several islands, including Franks Tract and Big Break, have been abandoned after the levees failed. Because the abandoned island floors were subsided below the limit of colonization of marsh vegetation, large expanses of open water were formed. These large flooded islands allowed for long wind fetches and high levels of wind-wave action that resuspend sediments deposited during flood events. These human-created large expanses of open water have been a major contributor to an approximate doubling of the tidal prism of the Delta even though approximately 98 percent of the historic tidal marsh has been converted to agricultural land. Alluvial sediment deposition in the Delta is currently estimated to be 1.8 million tons per year.

In the Suisun Marsh, subsidence is also occurring, but less information is available about rates and processes affecting rates. The land use for much of the Suisun Marsh is managed wetlands, which has reduced the subsidence rate compared with the Delta. Permanently flooded areas may have reversed subsidence by accumulating vegetation and sediment.

The topography of the area is relatively flat. Much of the area lies below the MHHW elevation. Figure 5-14 shows the land surface elevations in the Delta and Suisun Marsh.

Tables

Table 5-1 Listed Species in the Delta and Suisun Marsh

Species name	Common Name	No. in Delta & Suisun Marsh	Status			
			Federal	CA	CDFG	CNPS
Acipenser medirostris	Green Sturgeon southern Distinct Population Segment	NA	T	SC	--	--
Agelaius tricolor	Tricolored blackbird	7	--	--	SC	--
Ambystoma californiense	California tiger salamander	13	T	--	SC	--
Anniella pulchra pulchra	Silvery legless lizard	3	--	--	SC	--
Archoplites interruptus	Sacramento perch	2	--	--	SC	--
Arctostaphylos auriculata	Mt. Diablo manzanita	1	--	--	--	1B.3
Asio flammeus	short-eared owl	1	--	--	SC	--
Aster lentus	Suisun Marsh aster	129	--	--	--	1B.2
Astragalus tener var. *ferrisiae*	Ferris' milk-vetch	3	--	--	--	1B.1
Astragalus tener var. *tener*	alkali milk-vetch	12	--	--	--	1B.2
Athene cunicularia	burrowing owl	104	--	--	SC	--
Atriplex cordulata	heartscale	1	--	--	--	1B.2
Atriplex depressa	brittlescale	2	--	--	--	1B.2
Atriplex joaquiniana	San Joaquin spearscale	9	--	--	--	1B.2
Atriplex persistens	vernal pool smallscale	1	--	--	--	1B.2
Blepharizonia plumosa	big tarplant	4	--	--	--	1B.1
Branchinecta conservatio	Conservancy fairy shrimp	4	E	--	--	--
Branchinecta lynchi	vernal pool fairy shrimp	10	T	--	--	--
Buteo regalis	ferruginous hawk	1	--	--	SC	--
Buteo swainsoni	Swainson's hawk	294	--	T	--	--
California macrophyllum	round-leaved filaree	2	--	--	--	1B.1
Carex comosa	bristly sedge	3	--	--	--	2.1
Carex vulpinoidea	fox sedge	1	--	--	--	2.2
Centromadia parryi ssp. *congdonii*	Congdon's tarplant	1	--	--	--	1B.2
Centromadia parryi ssp. *parryi*	pappose tarplant	3	--	--	--	1B.2
Circus cyaneus	northern harrier	3	--	--	SC	--
Cirsium crassicaule	slough thistle	2	--	--	--	1B.1
Cirsium hydrophilum var. *hydrophilum*	Suisun thistle	3	E	--	--	1B.1
Coccyzus americanus occidentalis	western yellow-billed cuckoo	2	C	E	--	--
Cordylanthus mollis ssp. *mollis*	soft bird's-beak	17	E	R	--	1B.2
Cryptantha hooveri	Hoover's cryptantha	1	--	--	--	1A

Table 5-1 Listed Species in the Delta and Suisun Marsh

Species name	Common Name	No. in Delta & Suisun Marsh	Status			
			Federal	CA	CDFG	CNPS
Delphinium recurvatum	recurved larkspur	4	--	--	--	1B.2
Desmocerus californicus dimorphus	valley elderberry longhorn beetle	3	T	--	--	--
Downingia pusilla	dwarf downingia	7	--	--	--	2.2
Emys (=Clemmys) marmorata	western pond turtle	45	--	--	SC	--
Emys (=Clemmys) marmorata marmorata	northwestern pond turtle	10	--	--	SC	--
Eremophila alpestris actia	California horned lark	1	--	--	SC	--
Eriogonum truncatum	Mt. Diablo buckwheat	2	--	--	--	1B.1
Eryngium racemosum	Delta button-celery	2	--	E	--	1B.1
Erysimum capitatum ssp. *angustatum*	Contra Costa wallflower	3	E	E	--	1B.1
Eschscholzia rhombipetala	diamond-petaled California poppy	1	--	--	--	1B.1
Fritillaria liliacea	fragrant fritillary	3	--	--	--	1B.2
Geothlypis trichas sinuosa	saltmarsh common yellowthroat	22	--	--	SC	--
Gratiola heterosepala	Boggs Lake hedge-hyssop	1	--	E	--	1B.2
Hesperolinon breweri	Brewer's western flax	1	--	--	--	1B.2
Hibiscus lasiocarpus	rose-mallow	80	--	--	--	2.2
Hypomesus transpacificus	delta smelt	3	T	T	--	--
Isocoma arguta	Carquinez goldenbush	2	--	--	--	1B.1
Juglans hindsii	Northern California black walnut	1	--	--	--	1B.1
Lanius ludovicianus	loggerhead shrike	2	--	--	SC	--
Lasthenia conjugens	Contra Costa goldfields	1	E	--	--	1B.1
Laterallus jamaicensis coturniculus	California black rail	30	--	T	--	--
Lathyrus jepsonii var. *jepsonii*	Delta tule pea	116	--	--	--	1B.2
Legenere limosa	legenere	5	--	--	--	1B.1
Lepidium latipes var. *heckardii*	Heckard's pepper-grass	3	--	--	--	1B.2
Lepidurus packardi	vernal pool tadpole shrimp	8	E	--	--	--
Lilaeopsis masonii	Mason's lilaeopsis	139	--	R	--	1B.1
Limosella subulata	Delta mudwort	42	--	--	--	2.1
Madia radiata	showy madia	1	--	--	--	1B.1
Melospiza melodia maxillaris	Suisun song sparrow	33	--	--	SC	--
Navarretia leucocephala ssp. *bakeri*	Baker's navarretia	3	--	--	--	1B.1

Table 5-1 Listed Species in the Delta and Suisun Marsh

Species name	Common Name	No. in Delta & Suisun Marsh	Status			
			Federal	CA	CDFG	CNPS
Oenothera deltoides ssp. *howellii*	Antioch Dunes evening-primrose	9	E	E	--	1B.1
Oncorhynchus mykiss	Central Valley steelhead	NA	T	--	--	--
Oncorhynchus tshawytscha	Sacramento River winter-run Chinook salmon	NA	E	E	--	--
Oncorhynchus tshawytscha	Central Valley spring-run Chinook salmon	NA	T	T	--	--
Phalacrocorax auritus	double-crested cormorant	3	--	--	SC	--
Plagiobothrys hystriculus	bearded popcorn-flower	2	--	--	--	1B.1
Pogonichthys macrolepidotus	Sacramento splittail	5	--	--	SC	--
Potamogeton zosteriformis	eel-grass pondweed	1	--	--	--	2.2
Rallus longirostris obsoletus	California clapper rail	20	E	E	--	--
Rana aurora draytonii	California red-legged frog	8	T	--	SC	--
Reithrodontomys raviventris	salt-marsh harvest mouse	48	E	E	--	--
Riparia riparia	bank swallow	1	--	T	--	--
Sagittaria sanfordii	Sanford's arrowhead	3	--	--	--	1B.2
Scutellaria galericulata	marsh skullcap	3	--	--	--	2.2
Scutellaria lateriflora	blue skullcap	2	--	--	--	2.2
Sorex ornatus sinuosus	Suisun shrew	7	--	--	SC	--
Spirinchus thaleichtys	Longfin smelt	NA	--	SC	--	--
Sterna antillarum browni	California least tern	3	E	E	--	--
Sylvilagus bachmani riparius	riparian brush rabbit	2	E	E	--	--
Taxidea taxus	American badger	3	--	--	SC	--
Thamnophis gigas	giant garter snake	15	T	T	--	--
Trichocoronis wrightii var. *wrightii*	Wright's trichocoronis	1	--	--	--	2.1
Tropidocarpum capparideum	caper-fruited tropidocarpum	6	--	--	--	1B.1
Tuctoria mucronata	Crampton's tuctoria or Solano grass	1	E	E	--	1B.1
Vulpes macrotis mutica	San Joaquin kit fox	8	E	T	--	--

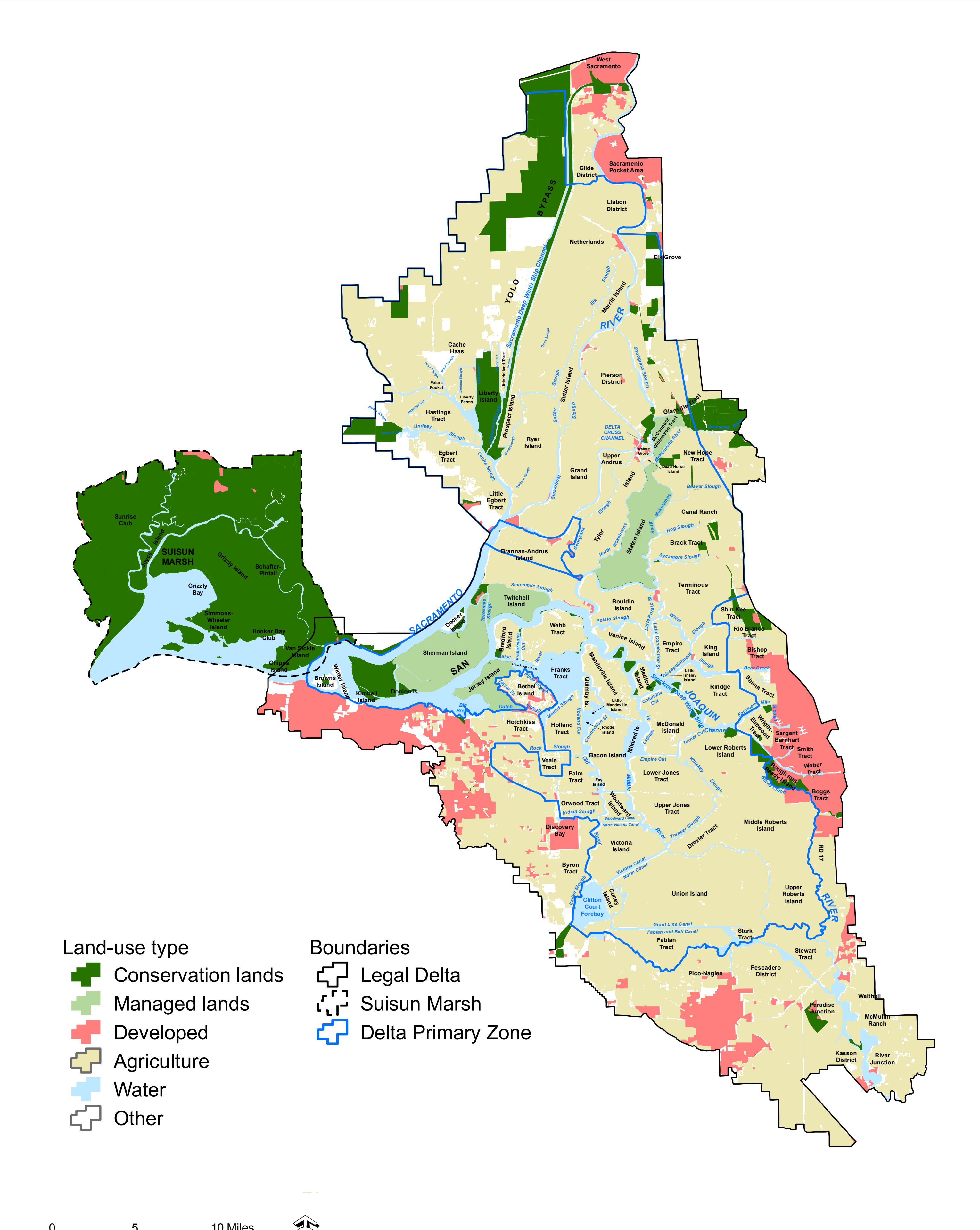
Legend: E = Endangered; SC= Species of Concern; R = Rare; T = Threatened; 1B = listed by the California Native Plant Society as rare, threatened or endangered in California and elsewhere, based on statewide review by CNPS botanical experts and network of field observers; 2 listed by CMPS as rare/threatened /endangered in California, but more abundant elsewhere; .1 - Seriously endangered in California (over 80% of occurrences threatened / high degree and immediacy of threat); .2 – Fairly endangered in California (20 - 80% occurrences threatened); .3 – Not very endangered in California (<20% of occurrences threatened or no current threats known)

Table 5-2
Delta Protected Area Business Profile: 2005 Output and Employment by Sector

Sector	NAICS[1]	Annual Billion $ Sales	Number of Employees
Agriculture	11299013	$0.21	1,132
Fishing	11421004	$0.01	25
Agricultural support	11531005	$0.08	827
Oil & gas	21111102	$0.01	2
Drilling	21311209	$0.03	135
Power generation	22112202	$0.11	39
Natural gas distribution	22121001	$0.00	4
Water, sewer	22131003	$0.02	65
Construction	23899096	$1.70	7,129
Manufacturing	33999940	$3.37	9,567
Wholesale & distribution	42512086	$9.14	12,021
Motor vehicles & parts	44132001	$0.93	2,034
Retail	45439017	$2.91	15,427
Transportation warehousing and storage	48899102	$0.62	4,918
Publishing, telecommunications, IS	51919020	$0.70	6,225
Financial, insurance, real estate, rental	53249013	$2.13	8,200
Services	56299806	$3.81	24,238
School & education	61171010	$0.09	9,611
Medical, day care, social assistance	62441006	$6.55	32,363
Entertainment	71399050	$0.27	5,629
Accommodations	72131006	$0.16	2,556
Restaurants etc	72241006	$0.53	11,173
Auto services, repair and maintenance, personal services	81299041	$0.47	5,240
Religious, civic	81399005	$0.13	6,350
Other	99999000	$0.03	39,202
TOTAL		$34.01	204,112

[1] NAICS number of the last business in that named group

Figures



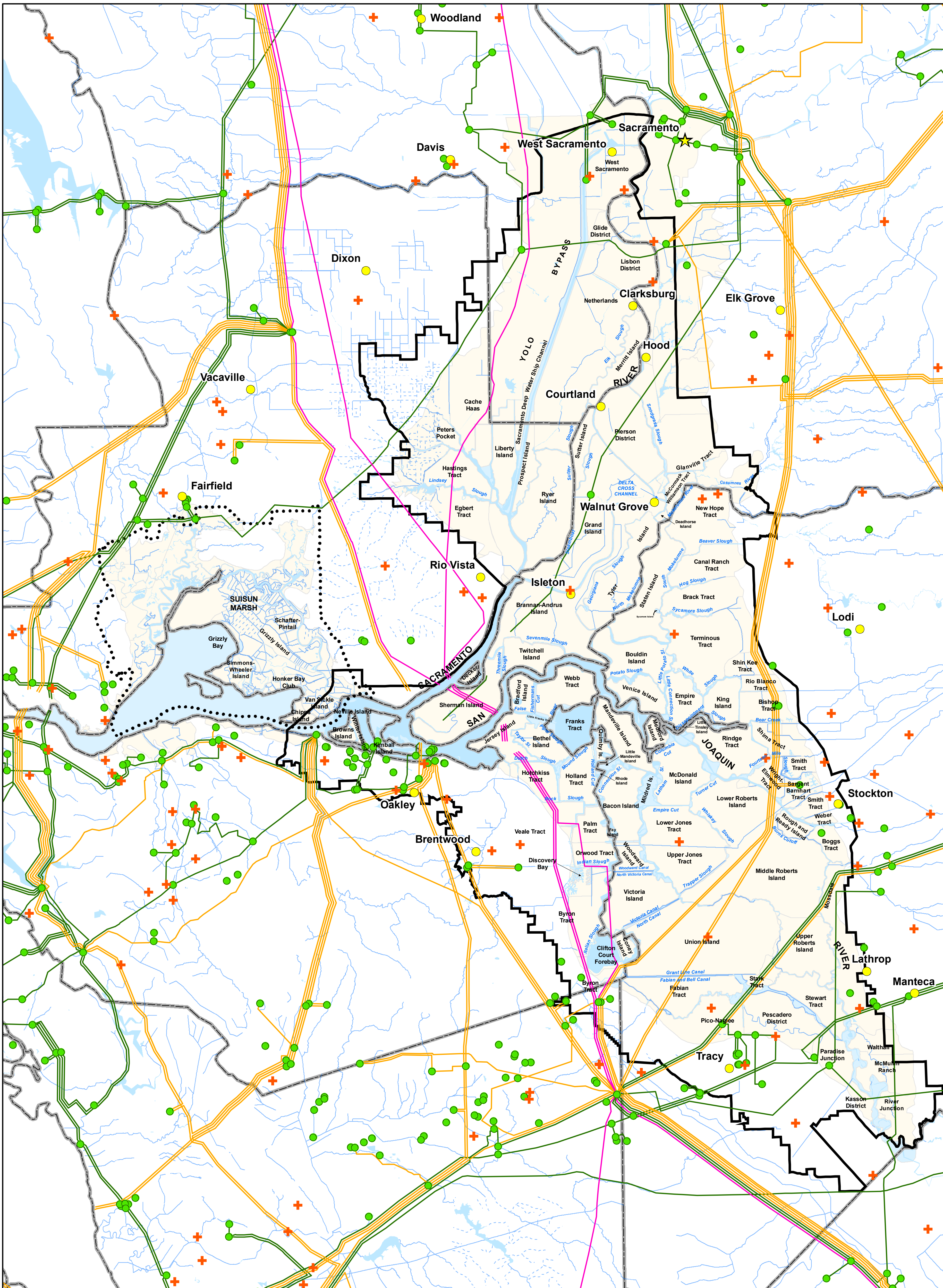
URS	DRMS	Delta-Suisun Land Uses	Figure 5-1
	26815431		

URS Corporation P:\GIS\GIS_Project_Files\MXD\Analysis\Landuse\landuse_041807.mxd Date: 4/18/2007 4:09:02 PM Name: smlewis0

Figure 5-2

PG&E Natural Gas Pipelines

[Proprietary information. Publication not Permitted.]



Legend

- Substations
- US Cell Towers

Transmission Lines

- 230kV - 344kV
- 500kV - 734kV
- Below 230kV

- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; reservoir
- CA Water

- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

N

URS

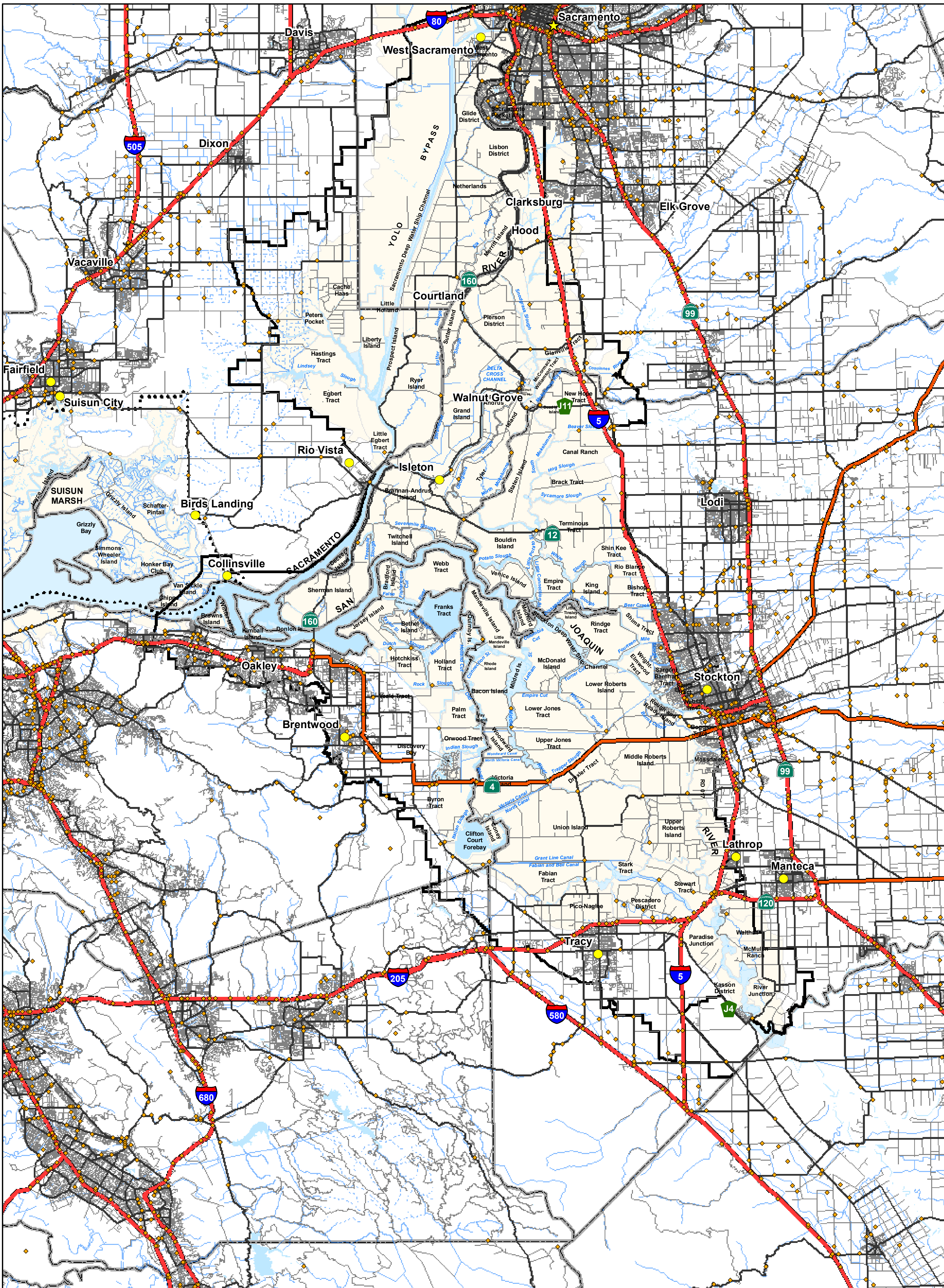
DRMS

26815431

Transmission Lines, Substations & Cell Towers

Figure 5-3

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\tech_memo_R1_0105072-3 Transmission Lines, Substations & Cell Towers.mxd Date: 1/5/2007 9:10:23 AM Name: smlewis0



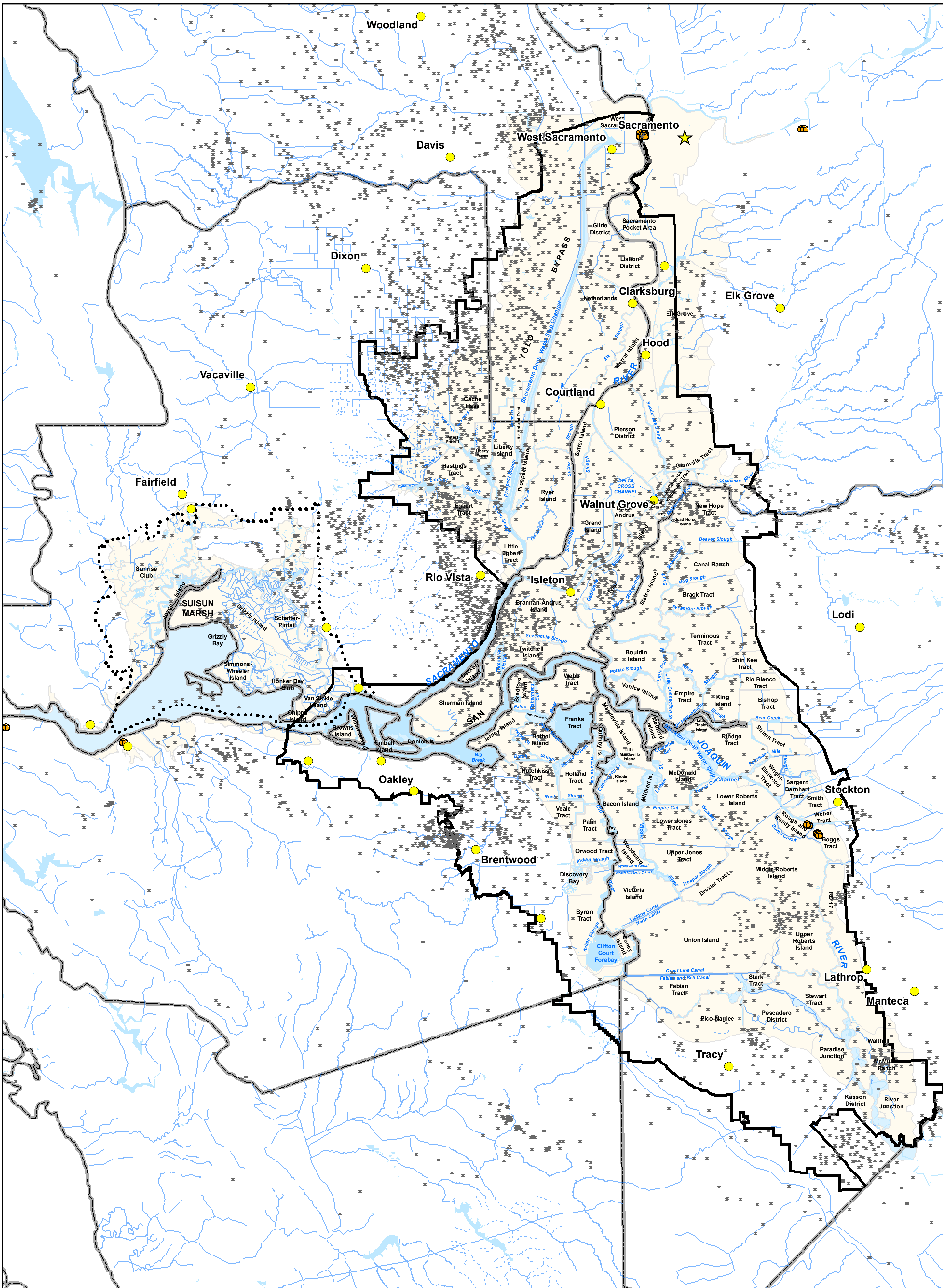
Legend

- Highway
- Major Road
- Local Road
- Bridges
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; reservoir
- CA Water
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS	DRMS / 26815431	Highways and Roads	Figure 5-4

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\tech_memo\2-7 Highways and Roads.mxd Date: 1/2/2007 11:02:54 AM Name: smlewis0

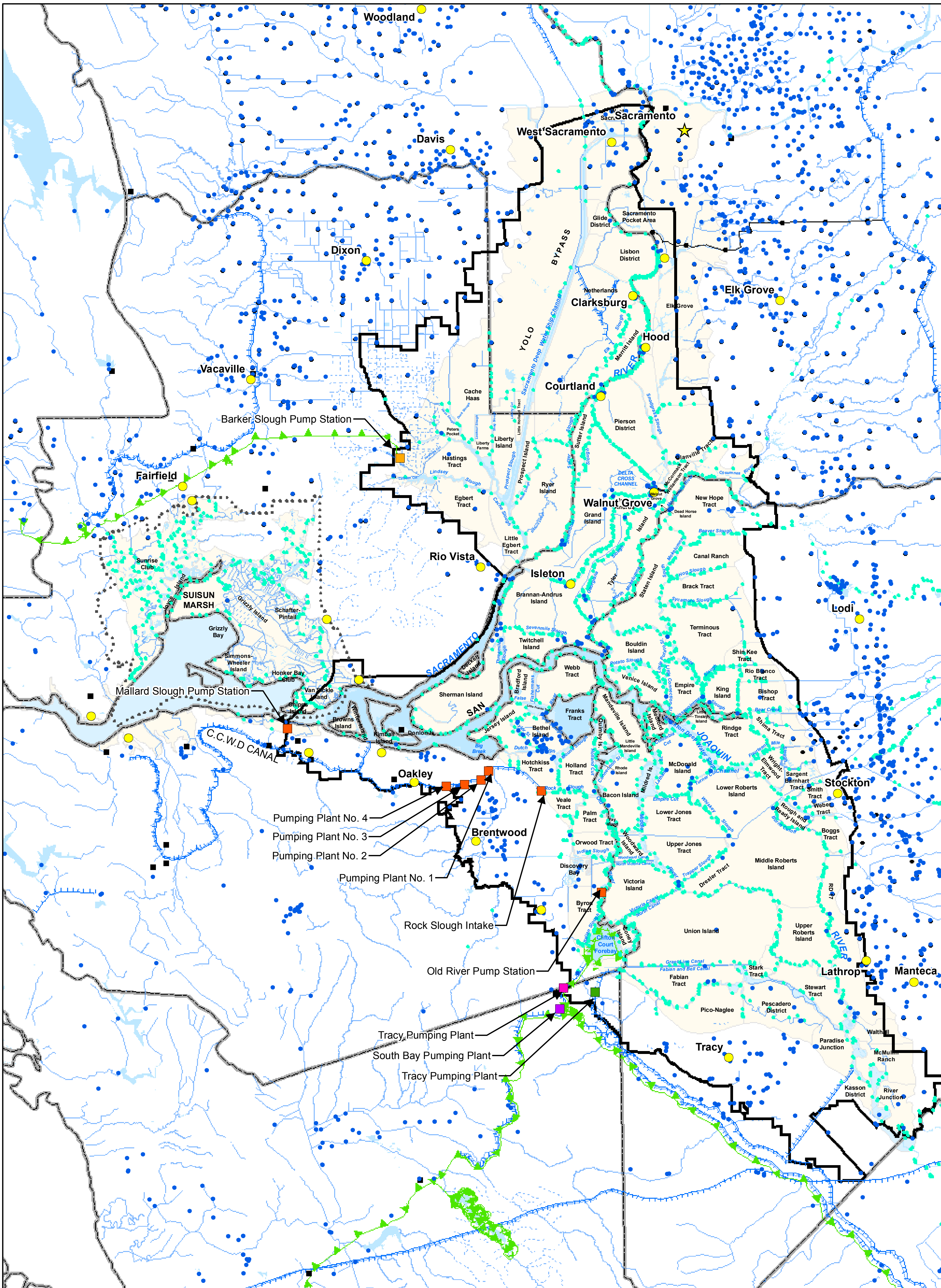


Tank Farm
Gas and Oil Well
Gas and Oil Production Field
Intermittent canal, ditch, aqueduct, stream, river, or wash
Perennial canal, ditch, or aqueduct; stream, river; reservoir
CA Water
CA Counties
Legal Delta
Suisun Marsh

0 5 10 Miles

URS

DRMS	Oil & Gas	Figure 5-5
26815431		



Points of Diversion
Water Use Wells
Public Water Supply
Delta Cross Channel Gate
Barker Slough Pumping Plant
CCWD Pumping Plants
Harvey O. Banks DWR Pumping Plant
Tracy Pumping Plant
South Bay Pumping Plant

Mokelumne Aqueduct
Under Ground
Above Ground
Canals
Folsom South Canal Preferred Alignment

State Water Project Waterways
Freeport Pipe Route Preferred
Intermittent canal, ditch, aqueduct, stream, river, or wash
Perennial canal, ditch, or aqueduct; stream, river; reservoir

Delta Cross Channel
CA Water
CA Counties
Legal Delta
Suisun Marsh

0 5 10 Miles

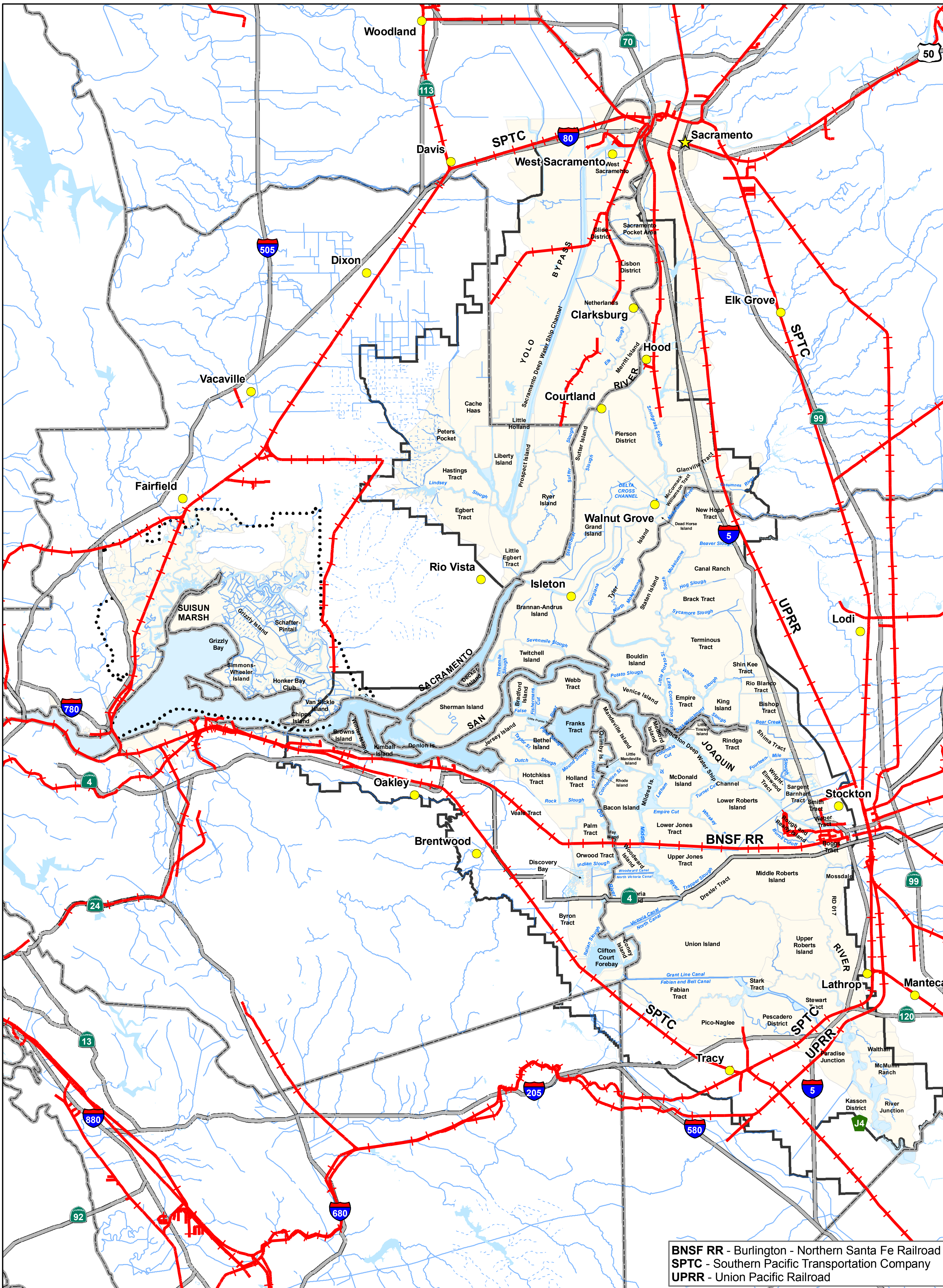
URS

DRMS

26815431

Water Wells, Canals & Mokelumne Aqueduct

Figure 5-6



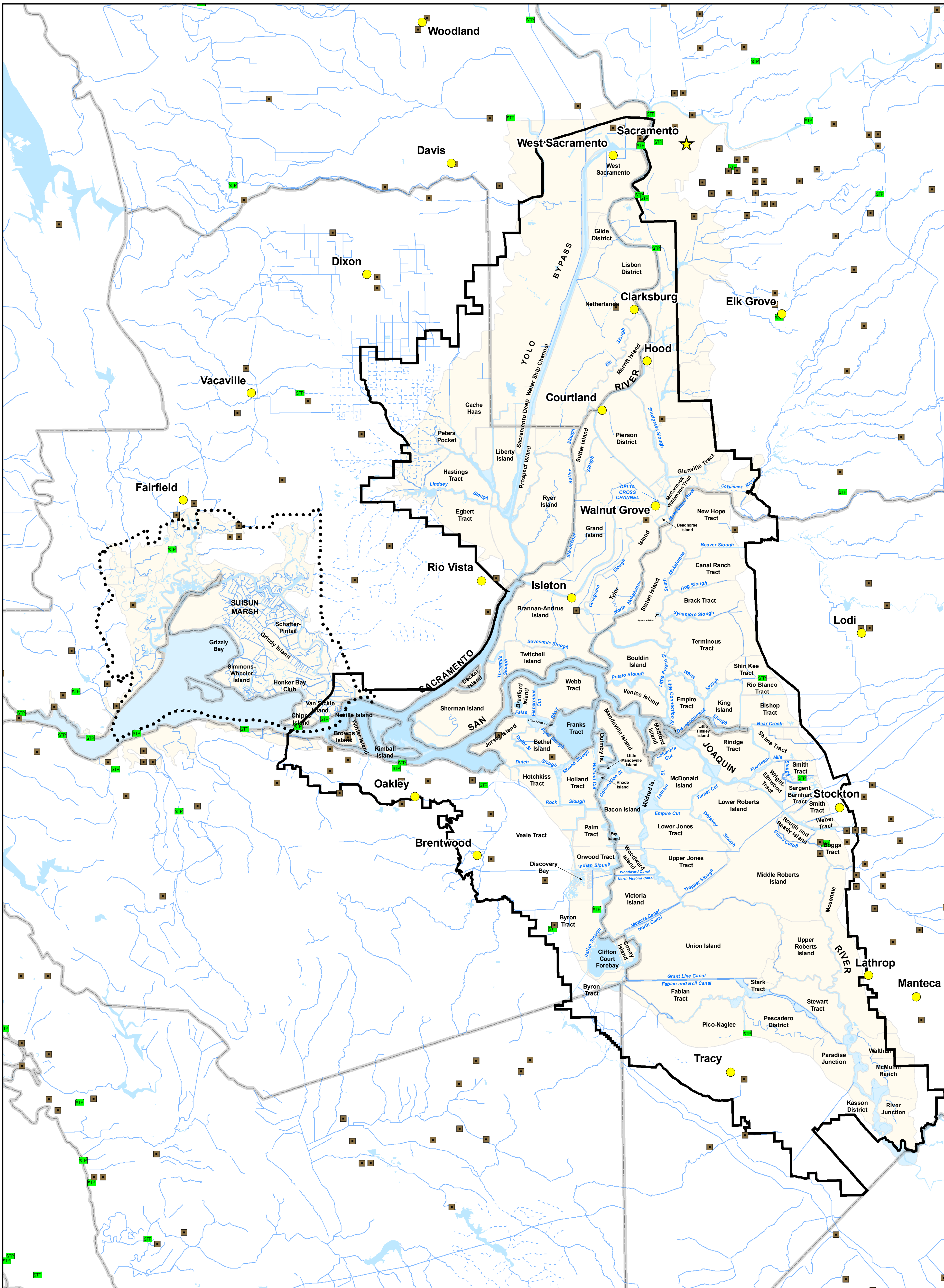
Legend

- Railroads
- Highway
- Railroad Nodes
- Intermodal Terminal Facilities
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; reservoir
- CA Water
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS	DRMS 26815431	Railroads	Figure 5-7

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\tech_memo_R1_010507\2-7 Railroads.mxd Date: 1/5/2007 11:12:14 AM Name: smlewis0



Legend

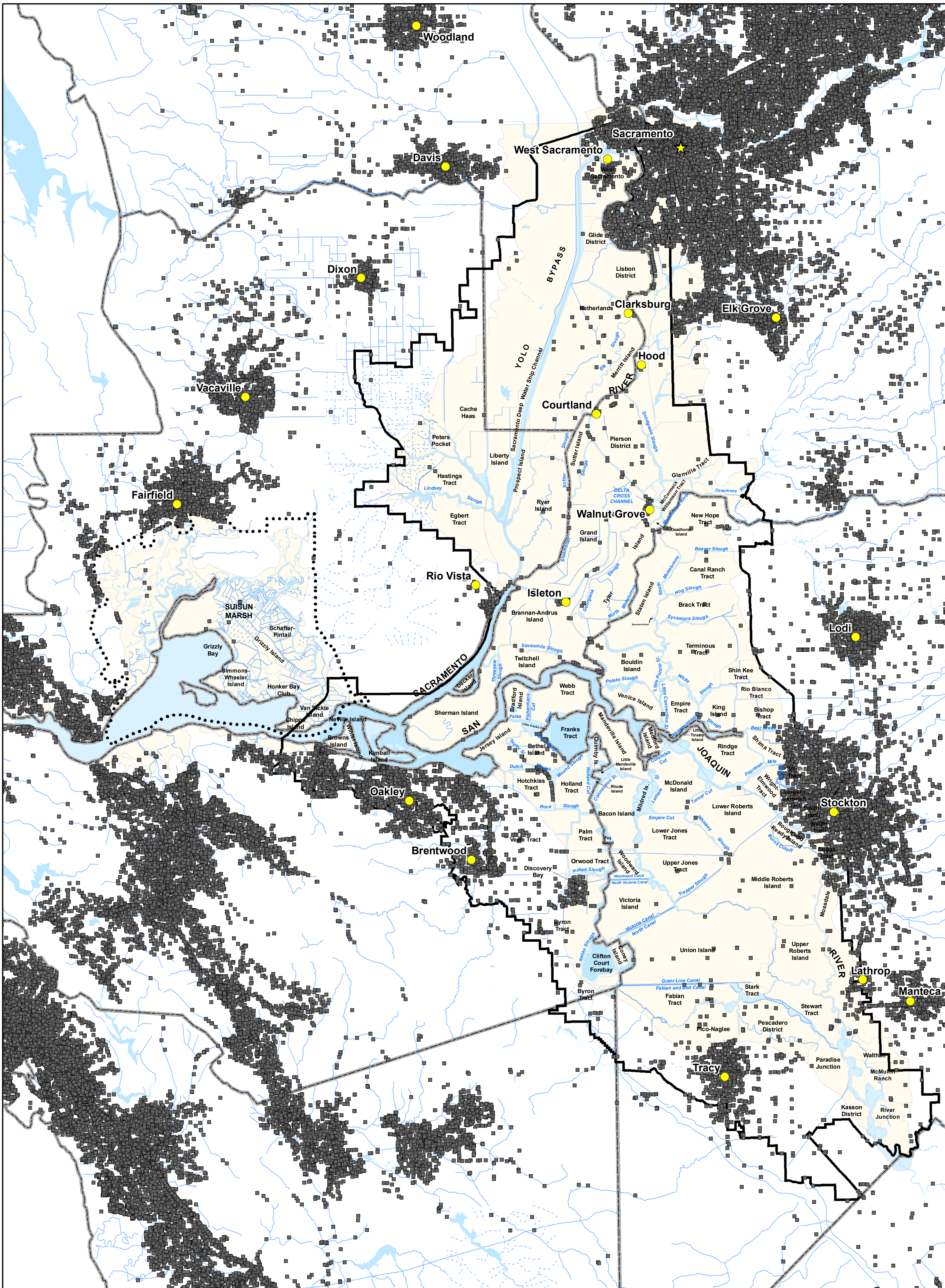
- Solid Waste Facilities
- Sewage Treatment Plant
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; reservoir
- CA Water
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

N

URS	DRMS 26815431	Solid Waste Facilities & Sewage Treatment Plants	Figure 5-8

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\tech_memo_R1_010507\2-8 Solid Waste Facilities & Sewage Treatment Plants.mxd Date: 1/5/2007 9:54:38 AM Name: smlewis0



Legend

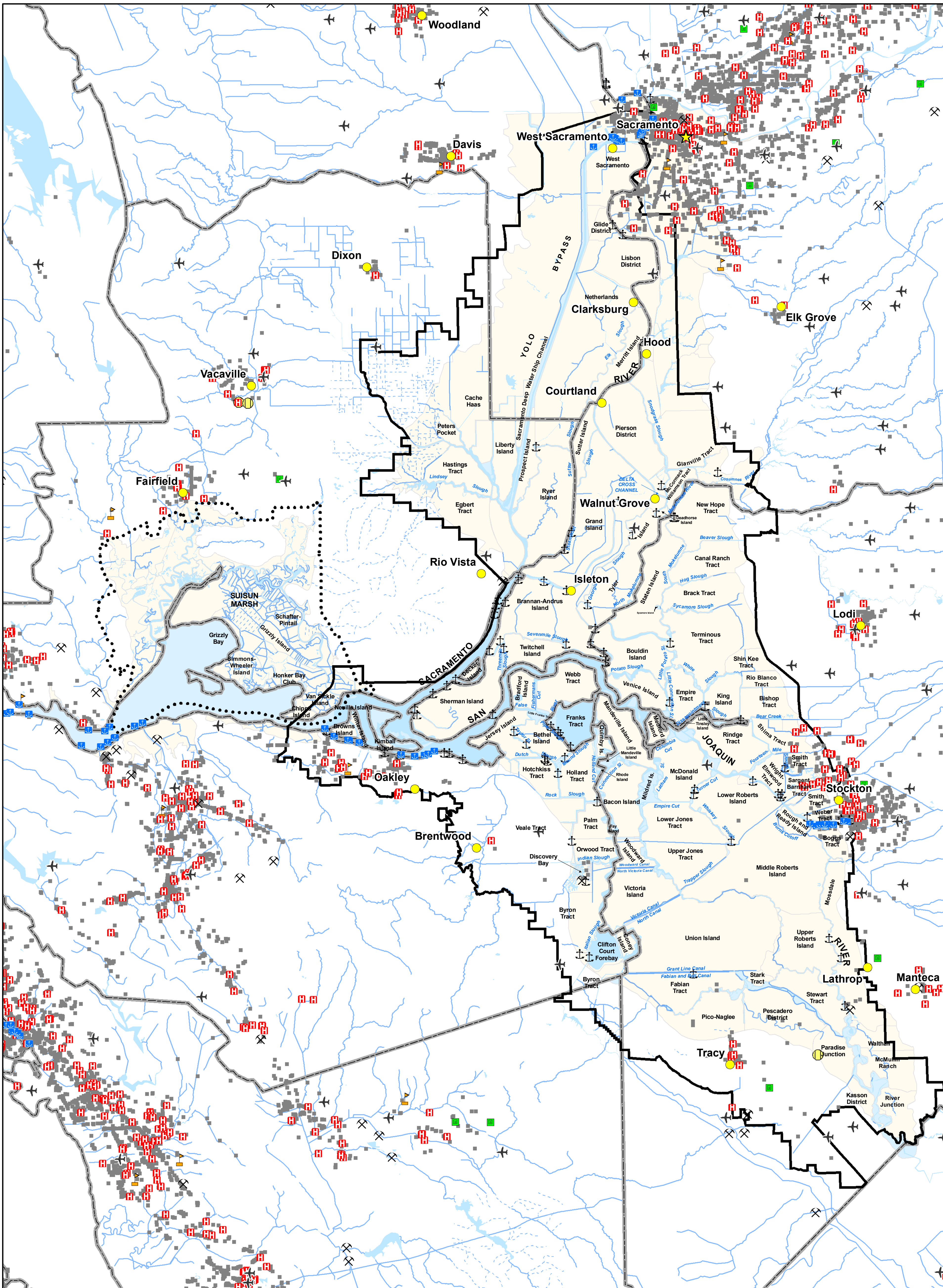
- Business
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; reservoir
- CA Water
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS

DRMS	Businesses	Figure 5-9
26815431		

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\tech_memo_R1_010507\2-9 Buisnesses.mxd Date: 1/5/2007 11:03:40 AM Name: smlewis0

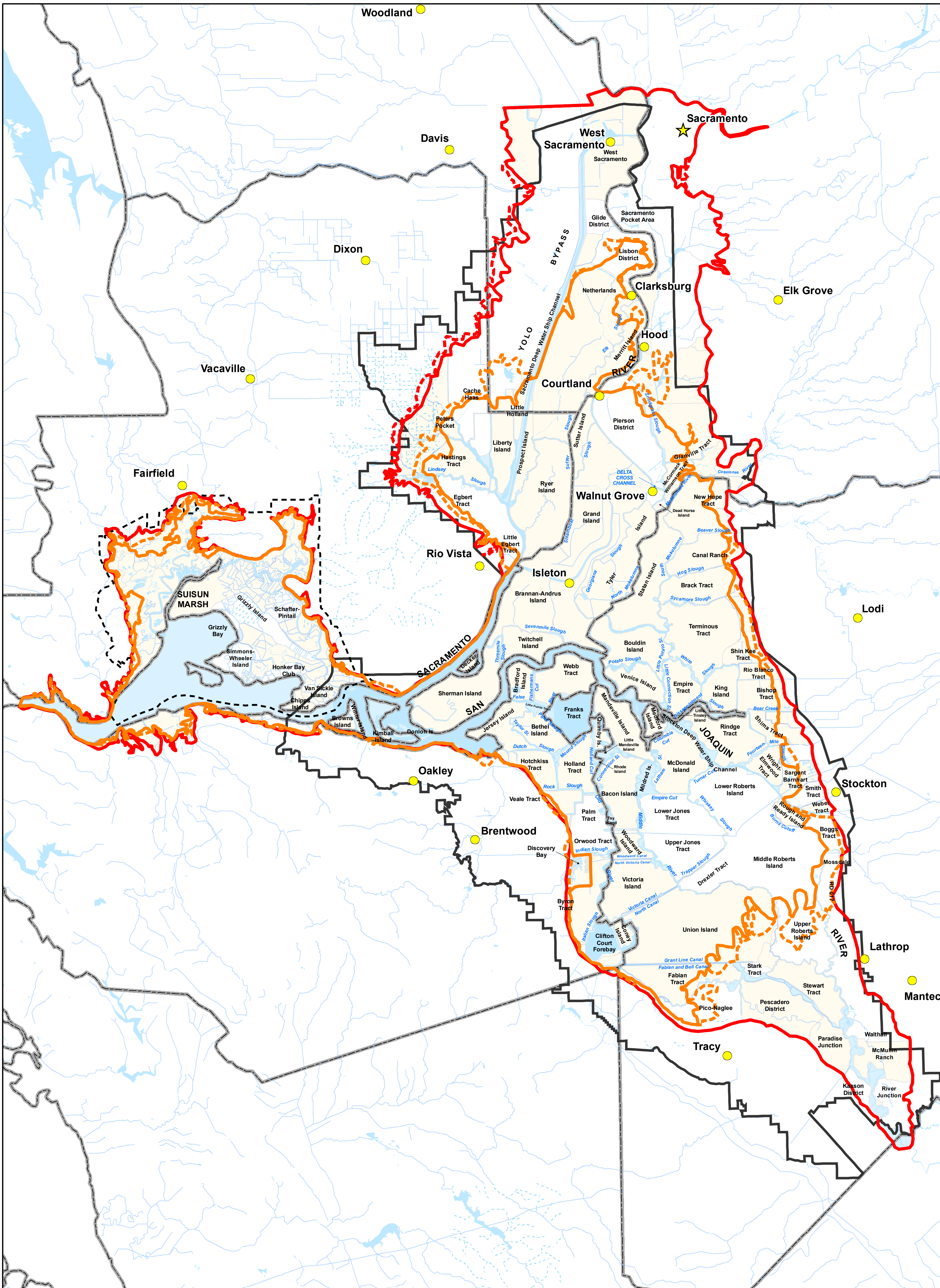


Legend

- Higher Education
- Boatlaunch
- Prison
- Superfund Sites
- Licensed Healthcare Facilities
- BLM Quarry and Mining Operations
- Airports
- buildings
- port
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; reservoir
- CA Water
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS	DRMS 26815431	Miscellaneous Data	Figure 5-10



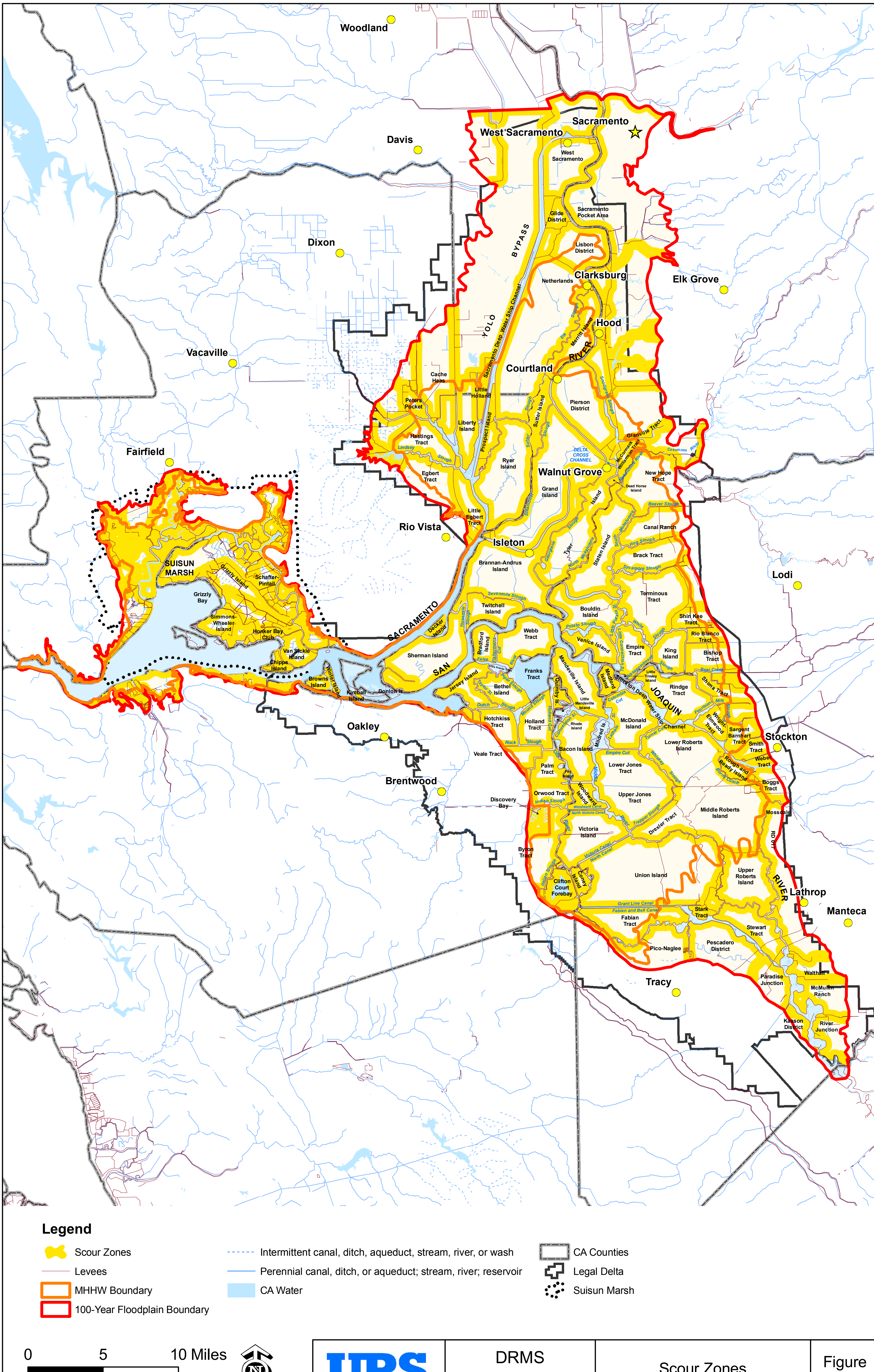
Legend

- MHHW Boundary (Current)
- MHHW (2050)
- 100-Year Floodplain (Current)
- 100-Year Floodplain (2050)
- CA Water
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; Reservoir
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS	DRMS 26815431	MHHW and 100-Year Flood Boundaries	Figure 5-11

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\Floodplains+1 ft and subsided surfaces\4-1 MHHW and 100-year flood boundaries.mxd Date: 2/28/2007 12:49:32 PM Name: dhwright0



URS

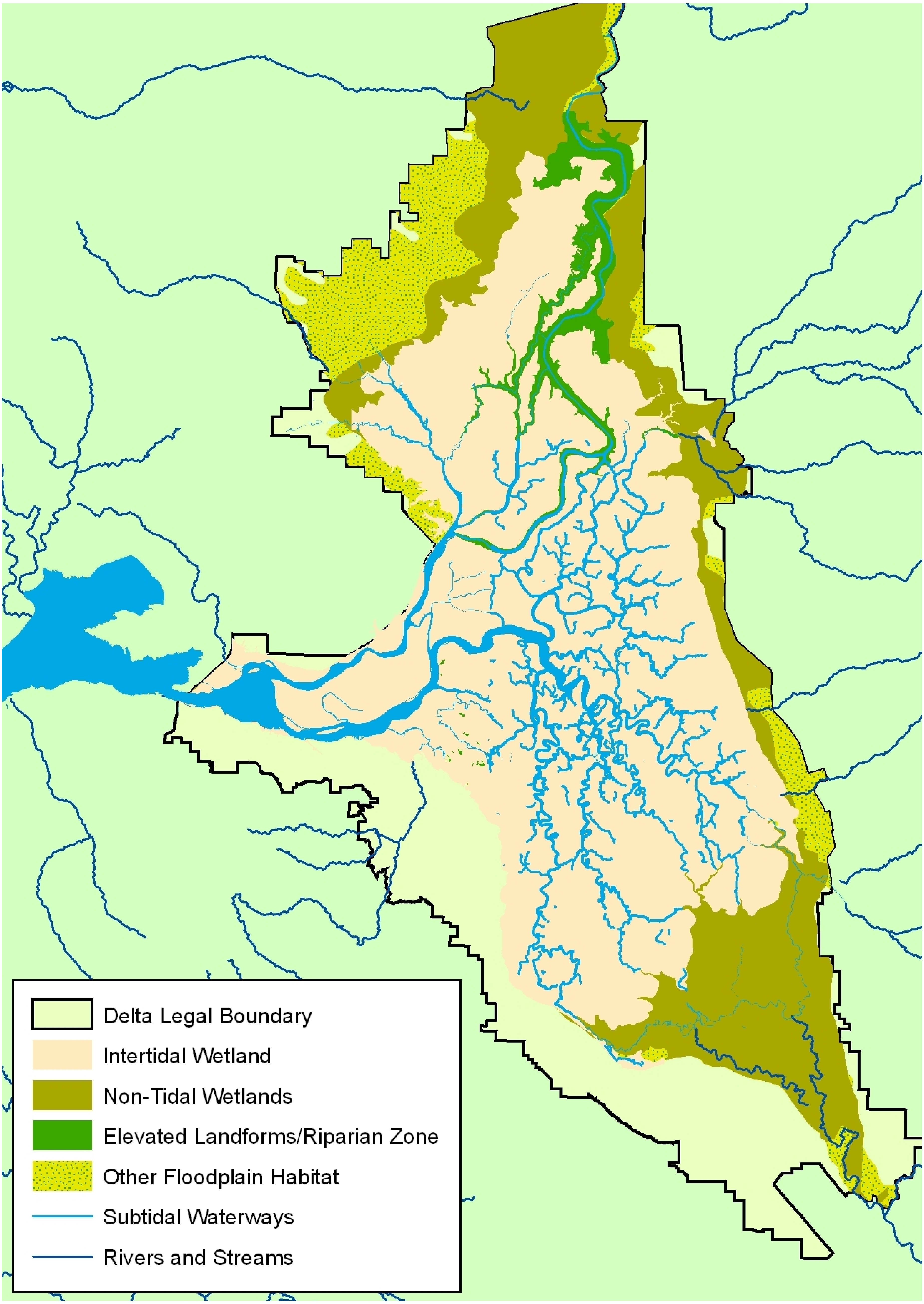
DRMS

26815431

Scour Zones

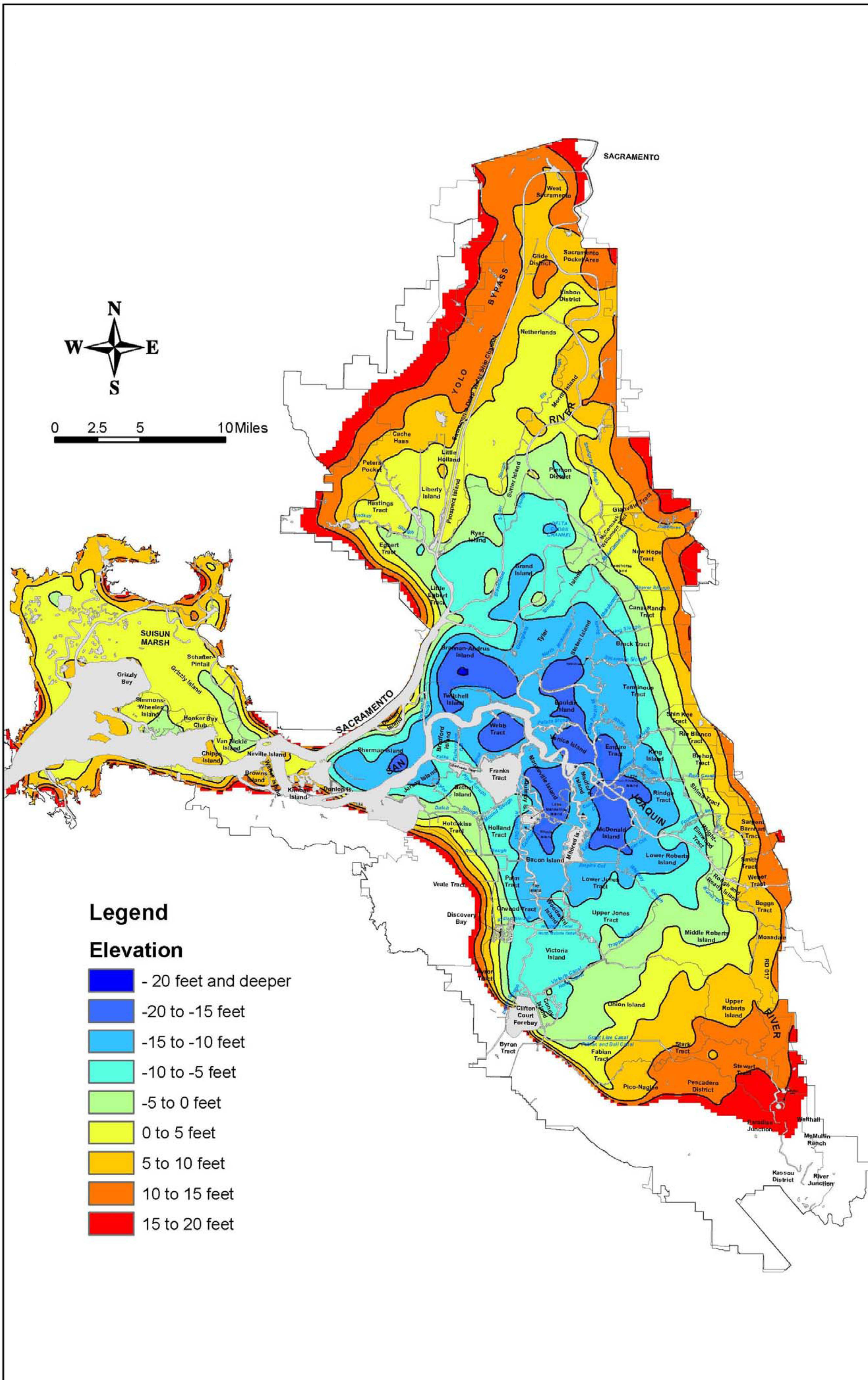
Figure 5-12

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\tech_memo_R1_01050714-2 Scour Zones.mxd Date: 1/5/2007 11:44:43 AM Name: smlewis0



From: PWA, Draft Technical Memorandum - Geomorphology
Source: Bay Institute, 1998

URS	DRMS 26815431	Map of Historic Delta Habitats	Figure 5-13



URS	DRMS	Surface Elevation Map	Figure 5-14
	26815431		

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This section presents the framework for the seismic risk analysis of levee failures and discusses the results of this analysis. The first step in evaluating the seismic risk of the Delta and Suisun Marsh levees is to assess the seismic hazard of the site. The input from seismic hazard analysis is then used for evaluating the seismic vulnerability of levees. The effects of earthquakes may be the most significant natural hazard that can impact the Delta and the Suisun Marsh levees. These levees face an increasing risk of damage and failure from a moderate to severe earthquake in the San Francisco Bay region, as shown later in this section.

The Working Group on California Earthquake Probabilities (WGCEP 2003) estimated that the probability of large earthquakes ($\mathbf{M} \geq 6.7$) in the region is increasing with time. In 2002, the Working Group estimated that the probability of such an earthquake in the succeeding 30-year period was 62%, and this value will increase with time. The Seismology Technical Memorandum (TM) (URS/JBA 2007a) presents a detailed analysis of the expected ground motions and their probabilities for the various seismic sources affecting the project area. The Levee Vulnerability TM (URS/JBA 2008c) presents the detailed calculations and the analysis results of the expected levee system performance under these seismic events.

6.1 EVALUATION OF SEISMIC HAZARD

6.1.1 Introduction

The seismic hazard of the project site was evaluated using a probabilistic seismic hazard analysis (PSHA), which is a standard practice in the engineering seismology/earthquake engineering community (McGuire 2004). The PSHA methodology allows for the explicit consideration of epistemic uncertainties and inclusion of the range of possible conditions in the seismic hazard model, including seismic source characterization and ground motion estimation. Uncertainties in models and parameters are incorporated into the hazard analysis through the use of logic trees.

A key assumption of the standard PSHA model is that earthquake occurrences can be modeled as a Poisson process. The occurrence of ground motions at the site in excess of a specified level is also a Poisson process, if (1) the occurrence of earthquakes is a Poisson process, and (2) the probability that any one event will result in ground motions at the site in excess of a specified level is independent of the occurrence of other events.

In a departure from standard PSHAs, which assume a time-independent Poissonian process, time-dependent hazard was calculated from the major Bay Area faults using the range of models that were considered by the WGCEP. (Note, the models considered by WGCEP [2003] do not result in a 100% time-dependent hazard) The seismic hazard is calculated at selected times over the next 200 years. In this study, the seismic analysis team calculated the time-independent hazard in the Delta for the purposes of comparison.

The seismic hazard analysis generates probabilities of occurrence of all plausible earthquake events (defined by their locations, magnitudes, and ground motions). These are used to develop estimates of risk (defined as the annual probability of seismically induced levee failure) at selected times over the next 200 years. The products of the PSHA include hazard-consistent site-specific acceleration response spectra at selected levee sites distributed throughout the Delta area.

The products developed in this study included the following elements of seismic risk analysis:

- The annual probabilities of occurrence at selected times over the next 200 years (e.g., 2005, 2050, etc.) of plausible earthquake events, defined by their location, magnitude, and ground motion amplitude, for all seismic sources that could impact the Delta.
- The likelihood of multiple/simultaneous levee failures during individual scenario earthquakes (includes the correlation in ground motions that occurs during an event).
- Time-dependent seismic hazard results for six sites in the Delta in the years of 2005, 2050, 2100, and 2200 (Figures 6-1 and 6-2). The results include the following elements:
  - fractile hazard curves for all ground motion measures the 5th, 15th, 50th (median), 85th, and 95th percentiles, and the mean;
  - M-D (magnitude-distance) deaggregated hazard results for all ground motion measures for 0.01, 0.001, 0.002 and 0.0004 annual probabilities of exceedance
  - mean hazard curves for each seismic source for each ground motion measure.

  The seismic hazard results are defined for a stiff soil condition.
- Probabilistic ground shaking hazard maps for 2% and 10% probabilities of exceedance in 50 years (2475 and 475 year return periods, respectively) for peak horizontal acceleration and 0.2 and 1.0 sec spectral accelerations (SAs), and an outcropping stiff soil site condition.

6.1.2 Seismic Hazard

In their analyses to estimate earthquake probabilities along the major faults in the San Francisco Bay Area, the WGCEP (2003) used several models including non-Poissonian models that are time-dependent, i.e., they account for the size and time of the last earthquake. In this study, the probabilities of occurrence for all significant and plausible earthquake scenarios for each seismic source at specified times over the next 200 years are required for the risk analysis, which mandates heavy reliance on the results of WGCEP (2003). For many seismic sources, insufficient information exists to estimate time-dependent probabilities of occurrence and they were treated in a Poissonian manner.

Seismic source characterization is concerned with three fundamental elements: (1) the identification, location and geometry of significant sources of earthquakes; (2) the maximum size of the earthquakes associated with these sources; and (3) the rate at which they occur. In this study, the dates of past earthquakes on specific faults are also required in addition to the frequency of occurrence. The source parameters for the significant faults in the site region (Figure 6-1) are characterized for input into the hazard analyses. Both areal source zones and Gaussian smoothing of the historical seismicity are used in the PSHA to account for the hazard from background earthquakes.

The fundamental seismic source characterization came from the work done by the USGS Working Group on Northern California Earthquake Potential (WGNCEP 1996), the USGS Working Group on California Earthquake Probabilities (WGCEP 2003) and the CGS's seismic source model used in the USGS National Hazard Maps (Cao et al. 2003). This characterization was updated and revised based on recent research. Table 6-1 describes the final seismic source model used in the time-independent PSHA calculations.

The basic inputs required for the PSHA and the risk analysis are the seismic source model and the ground motion attenuation relations or more accurately ground motion predictive equations.

The Seismology Technical Memorandum (URS/JBA 2007a) includes detailed descriptions of the faults in the area.

The seismic hazard calculations were made using the computer program HAZ38 developed by Norm Abrahamson. An earlier version of this program HAZ36 was validated as part of PG&E's submittal to the Nuclear Regulatory Committee and the new features resulting in HAZ38 were validated as part of ongoing URS work for the U.S. Department of Energy.

6.1.3 Seismic Source Characterization

The time-dependent hazard calculations are based on WGCEP (2003). The source characterization and the time-dependent earthquake probability models were used directly with computer codes obtained from the USGS to obtain rates of characteristic events for the seven major faults in the San Francisco Bay Area considered by WGCEP (2003): San Andreas, Hayward/Rodger's Creek, Calaveras, Concord/Green Valley, San Gregorio, Greenville, and Mt. Diablo referred to as the San Francisco Bay Region (SFBR) model faults. All other faults considered in the hazard analysis were modeled only with a time-independent probability model due to the lack of data to characterize time dependence for these faults.

The SFBR model consists of many rupture sources (i.e., a single fault segment or combination of two or more adjacent segments that produce an earthquake). For instance, the Greenville source has three rupture sources: southern segment (GS), northern segment (GN), and unsegmented (GS+GN). A rupture scenario is a combination of rupture sources that describe complete failure of the entire fault, i.e., the Greenville fault has three scenarios: GN and GS rupture independently, GN+GS, and a floating rupture along GN+GS. Fault rupture models are the weighted combinations of the fault-rupture scenarios. These weights were determined by each expert considering what would be the frequency (percentage) of each rupture scenario if the entire length of the fault failed completely 100 times. These weights are adjusted slightly to account for moment balancing. The rupture scenarios and adjusted model weights provide the long-term mean rate of occurrence of each rupture source for each of the characterized faults. The WGCEP (2003) approach described above differs from the logic tree characterization used in typical time-independent hazard analyses. Rupture scenarios in the WGCEP (2003) model are treated as an aleatory variable. The experts were asked to consider the distribution of the rupture scenarios for each fault. Logic trees characterize rupture scenarios as epistemic uncertainty, with each rupture scenario given a weight representing the expert's estimation of how likely it is the actual rupture scenario. The rupture sources and their characteristics are shown in Table 6-2. The experts referred to in this section are the members of the Working Group on California Earthquake Probabilities. Their names and affiliations are listed in the report in the section titled 'working Group Participants" (WGCEP 2003) and is too long to list in this report.

The time-dependent hazard is calculated using the range of earthquake probability models that were considered by WGCEP (2003), which considered five probability models that take into account date of last rupture, recent seismicity rates, and slip in the 1906 earthquake. One of the models in the suite is the Poisson model, which yields time-independent probabilities. Therefore, the results using the WGCEP (2003) model are not 100% time-dependent. The five probability models (Poisson, Empirical, Brownian Passage Time [BPT], BPT-step, and Time-Predictable) as described by the WGCEP (2003) are alternative methods for calculating earthquake probabilities. WGCEP (2003) applied weights to these five models for each of the seven major faults it considered (Table 6-3). The five probability models and their weights along with the source characterization were used to compute the rates of characteristic events on each rupture source, which would then be used in the hazard analysis. Rupture probabilities were calculated for 1-year exposure windows using starting dates of 2005, 2055, 2105, and 2205. The following modifications to the WGCEP (2003) inputs were made.

The program for computing the time-predictable probabilities for the San Andreas rupture scenarios was obtained from Dr. William Ellsworth, USGS. The inputs to this program were modified to change the exposure time to 1 year and to compute results for the four starting times. Figures 6-3 through 6-6 show the program output plots for each case.

The Empirical Model of Reasenberg et al. (2003) was used to obtain the scale factors to modify the long-term rate. WGCEP (2003) used Reasenberg et al. (2003) models A through F as shown in WGCEP (2003, Table 5-1) and assigned weights of 0.1, 0.5, and 0.4 to the minimum, average, and maximum scale factor, respectively. The values listed in Table 6-4 were obtained by using the values for models A through D listed in the WGCEP (2003, Table 5.1) and scaling the linear models E and F from WGCEP (2003, Figure 5.6),

The only modifications made for the Poisson, BPT and BPT-step model inputs were to change the exposure time to 1 year and to compute results for the four starting times (2005, 2050, 2100, and 2200).

6.1.4 Ground Motion Attenuation

To characterize the attenuation of ground motions in the PSHA, empirical attenuation relationships appropriate for the western U.S., particularly coastal California were used. All relationships provide the attenuation of peak ground acceleration (PGA) and SAs at 5 percent damping.

New attenuation relations developed as part of the Next Generation of Attenuation (NGA) Project sponsored by the Pacific Earthquake Engineering Research Center Lifelines Program have been released to the public in 2007. These new attenuation relationships have a substantially better scientific basis than current relationships because they are developed through the efforts of five selected attenuation relationship development teams working in a highly interactive process with other researchers who have: (1) developed an expanded and improved database of strong ground motion recordings and supporting information on the causative earthquakes, the source-to-site travel path characteristics, and the site and structure conditions at ground motion recording stations; (2) conducted research to provide improved understanding of the effects of various parameters and effects on ground motions that are used to constrain attenuation models; and (3) developed improved statistical methods to develop attenuation relationships including uncertainty quantification. Review of the NGA relationships indicate that, in general, ground motions particularly at short-periods (e.g., peak acceleration) are significantly reduced particularly for very large magnitudes ($\mathbf{M} \geq 7.5$) compared to current relationships.

At this time, only the relationships by Chiou and Youngs, Campbell and Bozorgnia, and Boore and Atkinson are available (see Pacific Earthquake Engineering Research's NGA web site) and these were used in the PSHA. The relationships were reviewed and weighted equally in the

PSHA. Intra-event and inter-event aleatory uncertainties for each attenuation relationship are required for the risk analysis. The basin depth beneath the Delta ($Z_{2.5}$) was assumed to be 5 km based on Brocher (2005).

For the Cascadia subduction zone megathrust, the relationships by Youngs et al. (1997), Atkinson and Boore (2003), and Gregor et al. (written communication, 2007) were used with equal weights.

A geologic site condition needs to be defined where the hazard will be calculated. Often this condition has been parameterized as a generic condition such as rock or soil or more recently the average shear-wave velocity (V_S) in the top 100 feet (V_S30) of the stiff reference site. In this analysis, the hazard will be defined for a stiff soil site condition characterized by an average V_S30 of 1,000 ft/sec. The fragility estimates for the levees are referenced to these ground motions. All of the NGA relationships use V_S30 as an input.

6.1.5 Individual Site Hazard Results

The results of the time-dependent PSHA of the six locations in the Delta are presented in terms of ground motion as a function of annual exceedance probability. This probability is the reciprocal of the average return period. Figures 6-7 to 6-12 show the mean, median, 5th, 15th, 85th, and 95th percentile hazard curves for PGA for 2005 at the six sites. These fractiles indicate the range of uncertainties about the mean hazard. A return period of 2,500 years has a factor of 50% difference between the 5th and 95th percentile values at the Montezuma Slough. The probabilistic PGA and 1.0 sec horizontal SA are listed in Table 6-5 for a return period of 2,500 years for the year 2005 as well as 2050, 2100, and 2200. The PGA values range from 0.30 g in Sacramento, which is the most eastern site on the edge of the Delta faults to 0.74 g at Montezuma Slough. The latter site is located adjacent to the Pittsburg-Kirby Hills fault.

The contributions of the various seismic sources to the mean PGA and 1 sec SA hazards in 2005 are shown on Figures 6-13a to 6-18a and Figures 6-13b to 6-18b, respectively. The controlling seismic source varies from site to site but the Southern Midland fault and Northern Midland zone are a major contributor to several sites within the Delta at a return period of 2,500 years. At long-period ground motions, e.g., 1.0 sec SA, the Southern Midland and the Cascadia subduction zone are contributing significantly to the hazard in 2005. The San Andreas fault becomes a major contributor, at long periods, due to it approaching a 1906-type rupture.

The PGA contour maps for 100, and 500-year return periods are shown on Figures 6-19 through 6-20. The calculated PGAs for a 200-year return period for the six sites are compared in Figure 6-21 to the 1992 “Seismic Stability of Delta Levees” by DWR and the 2000 “Seismic Vulnerability of the Sacramento-San Joaquin Delta Levees” by CALFED. The three studies show that the results are relatively similar. The slight differences can be attributed to the new attenuation relationships and the time-dependant models. The DWR 1992 and the CALFED 2000 studies used time-independent Poissonian model.

6.1.6 Source, Magnitude and Distance Deaggregation

Figures 6-22 to 6-27 illustrate the contributions by events for the deaggregated mean PGA hazard by magnitude and distance bins in 2005. At the 2,500-year return period, the PGA hazard is controlled by nearby events (< 20 km) in the **M** 6 to 7 range. For Sacramento and Stockton, the hazard is relatively low and more distant events are contributing. At long period, > 1.0 sec SA, the pattern is similar but the contribution from **M** ~8.0 San Andreas earthquakes is quite apparent.

6.2 LEVEE SEISMIC VULNERABILITY

6.2.1 Introduction

This section describes the development of the seismic vulnerability of the Delta and Suisun Marsh levees. Historically, there have been 166 Delta and Suisun Marsh flood-induced levee failures leading to island inundations since 1900. No reports could be found to indicate that seismic shaking had ever induced significant damage. However, the lack of historic damage is not a reliable indicator that Delta levees are not vulnerable to earthquake shaking. Furthermore, the present-day Delta levees, at their current size, have not been significantly tested by moderate to high seismic shaking.

The largest earthquakes experienced in recent history in the region include the 1906 Great San Francisco Earthquake and the 1989 Loma Prieta Earthquake. The 1906 earthquake occurred while the levees were in their early stages of construction. They were much smaller than they are today, and were not representative of the current configuration. The epicenter of the 1989 Loma Prieta earthquake was too distant and registered levels of shaking in the Delta too small to cause perceptible damage to the levees. Nonetheless, the DRMS seismic analysis team performed a special simulation analysis of the 1906 Great San Francisco Earthquake to evaluate the potential effects of this event on the current levees. The results of this simulation are presented later in this section.

In addition to the simulation of these largest regional earthquakes, recent smaller and closer earthquakes were also evaluated. They include: the 1980 Livermore Earthquake (**M** 5.8) and the 1984 Morgan Hill Earthquake (**M** 6.2). Except for the 1906 earthquake, which would have caused deformations of some of the weakest levees, the other earthquakes were either too small or too distant to cause any significant damage to the Delta levees. These results are consistent with the seismic vulnerability prediction model developed for this study.

The analyses and assessments presented in this technical memorandum are based on available information. No investigations, or further research to fill data gaps, were part of this study. As described in Section 2 of the Levee Vulnerability TM (URS/JBA 2008c), several thousands of borings and laboratory tests describing subsurface conditions of the Delta levees were reviewed to characterize the hundreds of miles of levees and foundations. The data from these borings were also digitized and entered into a database to support the GIS mapping needs for the various analyses.

6.2.2 Seismic Failure Modes

The earthquake-induced levee deformations can result either in liquefaction-induced flow slides, inertia-induced seismic deformation in non-liquefiable case, or a combination of the two. The potential seismically induced modes of failure include: overtopping as a result of crest slumping and settlement, internal piping and erosion caused earthquake-induced differential deformations, sliding blocks and lateral spreading resulting in transverse cracking, and exacerbation of existing seepage problems due to deformations and cracking.

Unlike the flood-induced failures (conventional breaches, see Section 7), the seismically induced levee failures tend to extend for thousands of feet if not miles. The seismic analysis team reviewed past performances of levees/dams under seismic loading to identify potential seismically induced modes of failure. The review included:

1. During the 1995 Kobe Earthquake, many levees slumped as a result of ground shaking. Figure 6-28 shows a picture of one of these slumped levees. The damage extends as far as the eye can see. Figure 6-29 shows a reconstruction and interpretation of the damage resulting from liquefaction-induced failure.

2. During the 1940 Imperial Valley Earthquake, the irrigation canal levees experienced extensive and continuous slumping as far as the eye can see as shown on Figure 6-30. The mark on the white post in the figure indicated that the levee crest slumped by about 7 feet.

3. During the 1989 Loma Prieta Earthquake, levees in Moss Landing breached as a result of liquefaction-induced slumping and lateral spreading as shown on Figure 6-31.

4. During the 1971 San Fernando Earthquake, Van Norman Dam experienced extensive damage. Figure 6-32 shows that the upstream shell and crest of the dam failed as a result of liquefaction-induced slide.

Most of these historical observations show that, the earthquake-induced deformations result in a much extended damage (thousands of feet) than the breach failures associated with flood or sunny-day failures (few hundred feet). A discussion on the flood-related levee breaches is presented in the Levee Vulnerability TM (URS/JBA 2008c). Even if some levees do not breach during the earthquake, the miles of damaged levees can fail during the succeeding wet season, if they are not repaired immediately. To estimate the cost associated with repairing levees damaged by an earthquake, a typical slumped levee cross section was developed based on review of the patterns of historical levees damages by earthquakes. Figure 6-33 shows a schematic illustration of a slumped levee. The emergency repair consists of raising the levee, removing portion of the slumped levee materials on the landside, and reconstructing the levee. Figure 6-33 shows the proposed emergency repair, which includes rock placement on the waterside slope (3:1 slope), reconstructing the levee crest, and landside slope. The berm on the landside will be constructed at much flatter slope (6:1) than the original levee (i.e., pre-earthquake levee).

6.2.3 Definition of Vulnerability Classes

Because of the large area covered by the Delta and Suisun Marsh and the extensive variability of the levee and foundations conditions, the study area was divided into a number of “similar” zones. For the purpose of this analysis, these similar zones are referred to as levee Vulnerability Classes (VC). Two vulnerability classes are defined similar if they yield the same probability of failure when subjected to same seismic shaking. The description is the vulnerability classes follows.

The factors that would differentiate the performance of these classes will include the subsurface profile, the levee fill conditions and geometry, past performance, and maintenance history. The use of GIS mapping was very instrumental in allowing spatial display of subsurface conditions and discretization into desired zones. Examples of these displays include the thickness of peat throughout the Delta as shown in Figure 6-34, and the distribution of foundation sand blow counts and levee fill description as shown in Figures 6-35 and 6-36, respectively. Specifically, the VCs were defined using the following factors:

- The equivalent clean sand blow count [$(N1)_{60\text{-cs}}$] of levee fill – The SPT blow counts and the equivalent CPT blow counts were considered only for levees designated as sandy levees (details of this levee designation are presented in Section 2 of the Levee Vulnerability TM [URS/JBA 2008c]). $(N1)_{60\text{-cs}}$ values were grouped into two intervals: less than 20 and greater than 20. Only two groups were defined for the levee sand: potentially liquefiable or not. It was assumed that because of the sloping condition of the levees and the low confining stresses, any saturated sand with blow count below 20 has potential to liquefy and may result in flow failure. The potential liquefaction of the levee fill was evaluated probabilistically with $(N1)_{60\text{-CS}}$ and the cyclic stress ratios (CSR) considered as random variables.
- The equivalent clean sand SPT blow count $(N1)_{60\text{-CS}}$ of the foundation sand – The $(N1)_{60\text{-CS}}$ were considered in the levee reaches that have loose foundation sands and silts. The $(N1)_{60\text{-CS}}$ were grouped into four intervals: 0-5, 5-10, 10-20, and greater than 20. The probability of liquefaction of the saturated sands in the levee foundation is dependent on the blow count, the effective overburden stresses. The post-liquefaction residual strength is estimated from the corrected blow counts $(N1)_{60\text{-CS}}$. Both the corrected blow count and the post-liquefaction residual strength are treated as random variables.
- The thicknesses of the peat/organic deposits – The peat and organic deposits were divided into four depth intervals representing the variation of the peat thickness (in feet) within the Delta region: no peat, 0.5-10, 10-20, and greater than 20.
- The waterside levee slope – The waterside slopes show steep cuts in places, and hence were defined by two broad groups representing the variability in the waterside slope of the levee: steep (steeper than 1.5H:1V) and non-steep (flatter than 1.5H:1V).

For the purpose of this study, we defined 64 (2 × 4 × 4 × 2) vulnerability classes. Further examination of these classes indicated that although different classes have distinctly different properties, they yielded similar deformations under seismic loading. Such cases include classes with liquefiable foundation and levee fill and classes with only liquefiable levee fill. The liquefaction of the levee fill generally controls the deformation regardless of whether the foundation or the waterside slope is liquefiable. As a result of the screening of the performance of the vulnerability classes, only 22 classes remained in the Delta and two classes in the Suisun Marsh (Table 6-6). The following paragraphs discuss the justification for the selection of the 22 classes.

- If a levee reach had liquefiable levee fill with $(N1)_{60\text{-CS}}$ less than 20, the seismic behavior of that levee reach would not be controlled by the liquefaction potential of the foundation sand and the levee geometry. Nonetheless, the liquefaction probability of the foundation sand is considered for the full range of $(N1)_{60\text{-cs}}$. This screening resulted in a total of only 4 classes [$(N1)_{60\text{-cs}}$ as opposed to a possible 32 classes (1 × 2 × 4 × 4). These four classes were numbered from VC1 to VC4, as shown in Table 6-6.

- If a levee had non-liquefiable fill (no sand or $(N1)_{60\text{-}cs}$ greater than 20) and foundation had liquefiable sand (i.e., $(N1)_{60\text{-}cs}$ less than 20), the seismic behavior of the levee would not be controlled by the levee geometry. This screening resulted in a total of 12 classes (4 × 3) as opposed to 24 classes (3 × 2 × 4). Furthermore, in the case of shallow foundation sand (no peat), the levee deformation is insensitive to the blow count in the liquefiable foundation sand. This reduces further the number of classes by 2, resulting in a total of 10 vulnerability classes. These 10 classes were numbered from VC5 to VC14, as shown in Table 6-6.
- Finally, if a class had non-liquefiable levee fill and non-liquefiable foundation sand, then only the levee geometry (steep or non steep) and the thickness of peat would influence the seismic behavior of the levee. The resulting 8 classes were numbered from VC15 to VC22, as shown in Table 6-6.

The following table summarizes the development of the 22 vulnerability classes.

Liquefiable Levee Fill	Liquefiable Foundation	Presence of Peat in Foundation	Waterside Slope	No. of VCs
1 (Yes)	1 (Yes)	4	NC	1 x 4 = 4
1 (No)	3 (Yes)	3	NC	3 x 3 =9
		1 (No peat)	NC	1
	1 (No)	4	2	4 x 2 = 8
Total VCs				22

Note: NC = not considered, or not appropriate. See Table 6-6 for definition of VC.

The levees in Suisun Marsh were divided into two VCs mainly based on presence or absence of potentially liquefiable levee and foundation sands. Table 6-6 also lists classes VC 23 and VC 24 considered for Suisun Marsh. Figure 6-37a shows the spatial distribution of the VCs for the study region, Figure 6-37b shows the percent of levee length of the weakest classes 1 through 4 for each island.

6.2.4 Uncertainty in Assigning Vulnerability Class

The spatial variation of the peat thickness and the blow counts $(N1)_{60\text{-}CS}$ of the levee fill and foundation were used to develop the vulnerability classes in the geographic space forming the study area. This distribution was considered to be deterministic. However, the variation of these factors within each class was considered to be random. For example, there was little uncertainty that the peat thickness would fall outside, say, 0 and 5 feet for a given vulnerability class, but within that interval the peat thickness was treated as a random variable. Similarly, the range of blow counts within a given class was treated as random variable. Other random variables included the material properties, the ground motions, and the post-liquefaction residual shear strength. Finally, the liquefaction occurrence was treated probabilistically. The random variables considered in this evaluation are further explained in the following sections.

6.2.5 Methodology for Developing Seismic Fragility Functions

The development of the seismic fragility functions followed the method illustrated in Figure 6-38 for each vulnerability class. The first step involved the evaluation of ***levee response functions***, which estimate the horizontal deformations as a function of the magnitude and peak ground acceleration for the reference site (see Figure 6-38, diagram a). The seismic deformations were evaluated using generalized geotechnical models as discussed in the Section titled Analysis Methods below.

The second step involved the development of the ***conditional probability of failure functions***, which relate the conditional probability of a levee breach to the loss of freeboard (see Figure 6-38, diagram b). This step relied solely on expert elicitation. The range of expert elicitation was used to quantify the epistemic uncertainty in the estimated probability of failure. The potential seismic modes of failure included the following:

- Overtopping as a result of crest slumping and settlement
- Internal piping and erosion caused by earthquake-induced differential deformations
- Sliding blocks and lateral spreading resulting in transverse cracking
- Exacerbation of existing seepage problems due to deformation and cracking

The third and last step involved the development of the ***levee fragility functions***, which relate the probability of failure to the ground motions and earthquake magnitudes for each VC (see Figure 6-38, diagram c). This step combines the levee response functions with the conditional probability of failure functions, using Monte Carlo simulations, to generate the fragility functions. Sections 6.2.5 through 6.2.7 describe in detail each of the above three steps, respectively.

6.2.6 Evaluation of Levee Response Functions

The evaluation of levee response functions requires the estimation of seismic-induced levee and foundation deformations for each vulnerability class. The seismic-induced levee deformations can result from liquefaction-induced flow slides, inertia-induced seismic deformation in a non-liquefiable case, or a combination of the two. Two-dimensional effects were considered in the seismic deformation analysis to account for the interaction between the levee and foundation soil (upper foundation soil above the reference stiff half space).

6.2.6.1 Ground Motions

The evaluation of levee response function requires the development of ground motions for the study area. The levee response was calculated in terms of the seismic deformation of the levee for a given event. The earthquake event is represented by a given magnitude and acceleration response spectrum (ARS) calculated at a reference site. The PGA associated with each ARS is often used as a proxy for the ARS in the remainder of this section.

The ARS were generated for a reference site with an average shear wave velocity profile V_{S-30} of about 1000 feet/sec. The reference site ARS are the calculated ground motions at an outcropping stiff reference site, with an average shear wave velocity of 1000 feet/sec. In most of the Delta this reference site underlies the upper loose sand and soft organic deposits. A review of the site geology indicates that the bedrock within the Delta study area is at a depth of 400 feet or greater below ground surface. Overlying the bedrock are dense and stiff sand and clay deposits, with an average shear wave velocity equal to or greater than 1,100 feet/sec (reference site). The stiff and dense deposits are in turn overlaid by the more recent deltaic loose and soft sediments and organic layers.

Three magnitudes were considered, **M** 5.5, **M** 6.5, and **M** 7.5, to represent small-to-medium local earthquakes and medium-to-large earthquakes in the region. For each magnitude, mean response spectra and ranges around the mean spectra were generated using the new generation attenuation relationships. The same relationships were used in the Seismology TM (URS/JBA 2007a). The response spectra were then scaled up and down to generate a suite of values to represent the various distances from the sources to different parts of the Delta and Suisun Marsh.

Figure 6-39 shows the 5 percent-damped mean response spectra corresponding to the selected three earthquake magnitudes. These response spectra represent free-field motions for the outcropping reference stiff soil site condition mentioned above.

6.2.6.2 Development of Time Histories for Dynamic Analyses

To perform the dynamic response analyses of the levee and foundation system, earthquake acceleration time histories were developed as input to the numerical models. Recorded motions from past earthquakes were selected to match the magnitudes and distances used for the analysis. The selected records were: the **M** 5.5 1991 Sierra Madre earthquake recorded at Station USGS 4734, the **M** 6.5 1987 Superstition Hills earthquake recorded at the Wildlife station, and the 1992 **M** 7.3 Landers earthquake, recorded at Hemet fire station. The site conditions at these stations are classified as stiff soils. The record from the 1992 Landers earthquake was selected to represent the **M** 7.5 events on the San Andreas and Hayward faults. The 1991 Sierra Madre and 1987 and the Superstition Hills earthquakes were selected to represent the **M** 5.5 and **M** 6.5 seismic events on the local seismic sources, respectively.

The selected acceleration time histories were spectrally matched to the response spectra (**M** 7.5, **M** 6.5 and **M** 5.5 events) using the method proposed by Lilhanand and Tseng (1988) and modified by Abrahamson (1993). The plots of the acceleration, velocity and displacement time histories of the spectrally matched motions are presented in Figures 6-40 through 6-45. The 5% damped response spectra for the modified motions are shown in Figures 6-46 through 6-48 along with the smooth target spectra.

The modified time histories were then scaled to PGAs of 0.05g, 0.1g, 0.2g, 0.3g, 0.4g, and 0.5g for each earthquake magnitude to cover the range of possible ground shaking levels for the entire study area.

6.2.6.3 Uncertainties in Ground Motions

The seismic fragility functions are calculated as conditional probabilities of failure given the probability of the seismic events. The probabilities of the seismic events are calculated in the Seismology TM (URS/JBA 2007a). The PSHA methodology allows for the explicit consideration of aleatory and epistemic uncertainties associated with the seismic sources and ground motions. The shapes of the response spectra generated from natural time histories are random and irregular. The aleatory and epistemic uncertainties in the estimated spectral accelerations at different periods due to multiple acceleration time histories for an event with the same magnitude and same distance are captured in the PSHA. Since the levee fragility was assessed conditional on a given event, these uncertainties are not considered in the levee fragility analysis. Otherwise, these uncertainties would be double-counted. The levee fragility analysis did incorporate the aleatory uncertainty due to the fact that the recurrence of the same earthquake event with the same time history at a given location would not produce the same levee deformation.

To simplify the numerical analysis for estimating levee deformations, the selected acceleration time histories of past earthquakes were spectrally matched to the response spectra. Smoothed response spectra were developed and used in the numerical deformation analysis. To incorporate the effects of different PGAs and spectral accelerations, the smoothed response spectra were scaled up or down to cover the range of interest. This assumes that the response spectra at different periods are perfectly correlated. That is, if the PGA (i.e., the response spectrum at zero period) increases, the response spectrum at any other period would also increase proportionately. Both the use of smoothed response spectra and its scaling with PGA are common practice.

In reality, the response spectra would show a jagged pattern and the correlation of the response spectra at different periods would be less than perfect. However, the expected uncertainty in the estimated deformation due to these two factors is much smaller than the uncertainty due to multiple time histories for recurrence of events, and the latter uncertainty is properly captured in the analysis.

6.2.6.4 Seismic Deformation Analysis Methods

The seismic deformation of the levees was evaluated using the following two approaches.

The first approach consisted of estimating the dynamic response analysis using the two-dimensional equivalent-linear finite element method using the computer program QUAD4M (Hudson et al. 1994). The seismic-induced inertial deformations were then calculated using the Newmark sliding block procedure. This procedure requires input parameters such as the average acceleration within a potential sliding mass and the associated yield acceleration for that potential sliding mass. QUAD4M calculates the average acceleration within a potential sliding mass given an input acceleration time history. The yield acceleration (K_y) value associated with each potential sliding mass, defined as the horizontal acceleration that results in a pseudo-static factor of safety of 1.0, was computed using a limit-equilibrium slope stability analysis (UTEXAS3 [Wright 1992]). This approach was mainly used for the non-liquefaction susceptible cases i.e., for VCs 15 through 22.

In the second approach, the earthquake-induced levee deformations were directly calculated using a time-domain nonlinear analyses with the computer program FLAC, Version 5.0 (Itasca 2005) coupled with an empirical pore-pressure generation scheme (Dawson et al. 2001). This second approach was mainly used for liquefaction-susceptible cases i.e., for VCs 1 through 14.

These analyses were performed for the best estimate mean values and for the full range of distribution around the mean for the random variables contributing to the levee responses as discussed in the following sections.

6.2.6.4.1 VCs 1 through 5

VCs 1 through 5 have either potentially liquefiable levee fill and/or liquefiable foundation materials. When the levee fill or when both the levee fill and foundation materials are susceptible to liquefaction, the earthquake-induced deformations tend to be very large and may cause the computer programs to not converge. Typically, large strains are not well accounted for in numerical codes, and when excessive deformations take place, the computer programs will not converge on the solution. To mitigate these conditions (when the runs do not converge), a simplified use of the FLAC model was considered to capture the "post-liquefaction static slumping." In this simplified method, the levee fill was first modeled using the pre-liquefied shear strength values, then in a quasi-static fashion, these strength values were reduced in a step-wise function to the post-liquefactions residual shear strength values. Most of the calculated "post-liquefaction static slumps" for these cases showed large deformations leading to levee breaches, and therefore the calculations of the inertial deformation were not necessary.

6.2.6.4.2 VCs 6 through 14

By definition, VCs 6 through 14 have non-liquefiable levee fill but potentially liquefiable foundation materials. For these classes, a time domain fully coupled non-linear analysis was performed using the computer program FLAC. Soil behavior was simulated by a Mohr-Coulomb, elastic/perfectly plastic model. For the liquefiable foundation layer, this model was coupled with an empirical pore pressure generation scheme. Pore pressure is generated in response to shear stress cycles, following the cyclic-stress approach of H.B. Seed (Seed 1979). However, unlike the standard cyclic-stress approach, pore pressure is generated incrementally during shaking. Thus, pore-pressure generation is fully integrated with the dynamic effective stress analysis.

In the current analyses, pore pressures are updated continuously for each element in response to shear stress cycles. As pore pressures increase, the effective stresses decrease and a state of liquefaction is approached for frictional materials. As the available shear strength of the material decreases, increments of permanent deformation are accumulated. The simultaneous coupling of pore-pressure generation with the stress analysis results in a more realistic dynamic response of the model. Specifically, the plastic strains generated as a result of increased pore pressures significantly contribute to the internal damping of the modeled earth structure.

6.2.6.4.3 VCs 15 through 22

VCs 15 through 22 have non-liquefiable materials in both the levee and foundation. The seismic deformations of these levees were estimated using the first approach, QUAD4M-K_y-Newmark. A limited number of runs were performed to compare the results of the first approach, QUAD4M-Newmark, to the second approach, using the FLAC method. The results of these comparison runs showed a reasonable agreement between the two approaches. Results from one of these comparison runs are presented in Figure 6-49. This run was performed for a **M** 7.5 event with a range of PGAs between 0.1g and 0.5g. The first approach was used for the multiple runs because it offers more ease in its use and the ability to produce multiple runs in a shorter time frame.

QUAD4M Analysis. QUAD4M uses an equivalent linear procedure (Seed and Idriss 1970) to model the nonlinear behavior of soils. The softening of the soil stiffness is represented by shear modulus reduction (G/G_{max}) and damping ratios (ξ) versus shear strain curves. QUAD4M also incorporates a compliant base (energy-transmitting base), which can be used to model the elastic half-space. This program was used to calculate shear stresses and acceleration time histories within the levee and foundation for a given seismic event. This program was also used to calculate the average acceleration time histories of potential sliding masses.

Calculation of Yield Acceleration K_y. The limit-equilibrium slope stability program UTEXAS3 was used to calculate the K_y associated with each potential slip surface. The computer program UTEXAS3 is capable of performing two stage computations to simulate seismic loading conditions. To perform two-stage computations, both effective (S-envelope) and total (R-envelope) strength envelopes need to be defined for fine-grained soils. Two-stage stability computations consist of two complete sets of stability calculations; of which the first step is performed to calculate the long-term steady-state stresses along the potential sliding mass, and the second step is performed to compute the factor of safety for the undrained loading due to earthquake event. The seismic coefficient representing the earthquake load is applied and a pseudo-static factor of safety is calculated. The seismic coefficient that results in a pseudo-static factor of safety of 1.0 is referred to as K_y.

Newmark Sliding Block. Seismic-induced permanent deformations of the embankment slopes were estimated using the Newmark Double Integration Method (Newmark 1965). The Newmark Double Integration Method is based on the concept that deformations of an embankment will result from incremental sliding during the short periods when earthquake inertia forces in the critical slide mass exceed the available resisting forces. This method involves the calculation of the displacement (deformation) increment of a critical slide mass at each time step using the average horizontal acceleration (k_{ave}) and K_y calculated for the slide mass. The displacement increment is calculated by double integrating the difference between k_{ave} and k_y values acting on the slide mass. The estimated permanent deformation of the slide mass is then taken as the sum of the displacement increments at the end of ground shaking.

6.2.6.4.4 VCs 23 and 24

The analysis method used to calculate the response of VC 23 was the same as that used for VCs 15 through 22. There is no levee reach in the Suisun Marsh area that belongs to VC 24 (see Figure 6-37a) and therefore no analysis was performed for this class.

6.2.6.5 Material Properties and Characterization

The main engineering properties required for the evaluation of levee response function include: shear wave velocities, unit weights, drained and undrained shear strength parameters (c’, ϕ’, c, ϕ), residual undrained strength (Sr), shear modulus reduction (G/Gmax vs. γ) and damping ratios (ξ vs. γ) as a function of shear strain for the levee embankment and foundation materials. In the following subsections, the raw data and the characterization of the engineering properties and their statistical distributions are presented.

Several geotechnical and environmental studies have been performed in the Delta. A list of these past studies and the compilation and interpretation of the data are presented in Section 2.0 of the Levee Vulnerability TM (URS/JBA 2008c). These studies included several field investigations and laboratory tests dating back to 1950s (early data developed for the salinity control projects). The field investigations included exploratory borings, cone penetration tests, and down-hole geophysical surveys.

The laboratory test results pertaining to seismic analysis were reviewed to develop both static and dynamic properties. The aleatory uncertainties associated with the dynamic properties of the levee and foundation soils (e.g., modulus reduction and damping as a function of shear strain, shear wave velocity, c, ϕ, Su, unit weight) were considered in the seismic analyses as described in Section 6.2.5.8.

The available shear strength test data for the peat/organic soils consisting mainly of unconsolidated undrained (UU) and consolidated undrained (CU) triaxial strengths are compiled in Appendix B. These test data showed progressive increase in deviator stress as axial strain increased, often resulting in large strain levels as high as 15 percent before failure is reached. Shear strength data suggest that large strains are needed to cause shear failure in peat and peaty soils. The levee fill materials generally behave more like mineral soils (reaching peak shear strength at about 4 to 6 percent strain) compared to foundation peat and organic marsh deposits. During large induced strain in the foundation (i.e., due to seismic loading) the levee embankments may experience cracking and differential displacement while the foundation peat is still undergoing larger deformation but not reaching its ultimate shear strength. This will result in strong strain incompatibility as shown in Figure 6-50. Because the levee embankment may reach failure earlier, while the peat foundation is still below the failure state, it was estimated that the shear strength of peat/organic soils at 5 percent strain or less would represent the "apparent" strength threshold for use in these analyses or a strain compatible with the failure strain of the mineral soils.

6.2.6.5.1 Static Strength Data for Peat/Organic Deposits

The mean principal stress versus maximum shear stress for each of the tests was plotted for both total stress and effective stress at the 5 percent strain level. This is referred to as a p-q plot. The best linear fit of the total stress p-q data has an intercept of 130 psf and a slope angle of 18 degrees (Figure 6-51). This corresponds to a Mohr-Coulomb envelope with cohesion intercept (c) of 140 psf and a slope angle (ϕ) of 19 degrees. In a similar manner for the effective stresses, the best linear fit of p'-q data has an intercept (c') of 205 psf and a slope angle (ϕ') of 30 degrees (Figure 6-52). This corresponds to a Mohr-Coulomb envelope with a cohesion intercept of 250 psf and a slope angle of 35 degrees.

6.2.6.5.2 Post-Liquefaction Residual Strength for Saturated Cohesionless Soils

The liquefaction of loose saturated sandy and silty materials in the foundation and levees will result in substantial loss of strength (post-liquefaction residual shear strength) as a result of increasing pore pressure. The residual shear strength values were estimated using the relationships by Seed and Harder (1990). For a given $(N1)_{60\text{-}cs}$, this relationship provides a range of possible residual shear strength values. The range of Sr was used as an aleatory uncertainty. A discussion of the treatment of this uncertainty is presented in Section 6.2.7.

The $(N1)_{60\text{-}cs}$ value was selected from the data distribution developed for both levee fill and foundation materials in the study area. Figures 6-53 and 6-54 show the data distribution of the $(N1)_{60\text{-}cs}$ values of the foundation and levee sand materials, respectively, within the Delta. CPT data obtained within the top 20 feet through the levee fill were also digitized and converted to equivalent SPT blow counts (Figure 6-54) using the procedure proposed by Boulanger and Idriss (2004). Review of the blow count data indicates that about 75 percent of the blow counts collected in the upper loose foundation sands are less than 20 and 95 percent of the blow counts collected in the levee sand fill are below 20.

6.2.6.5.3 Shear Wave Velocity and Maximum Shear Modulus (Vs, G_{max})

DWR conducted shear (Vs) and body (Vp) wave velocity measurements of levee and foundation materials in at least five locations, extending about 100 to 120 feet below the crest of the levees. Most of these velocity measurements were conducted during the installation of downhole array of accelerometers at Sherman Island, Clifton Court Forebay, Staten Island, and Montezuma slough. Although there is significant variability throughout the Delta, the data suggests that the shear wave velocity (Vs) is less than 100 feet/sec for the free field peat, and over 200 feet/sec for peat confined under the levees. The shear wave velocity profiles tend to increase with depth, reaching values of about 1100 to 1200 feet/sec in the lower dense sand and stiff clay stratum located 100 to 120 feet below the levee crests. Representative shear wave velocity profiles are shown in Figures 6-55a through 6-55g. The shear wave velocity profiles along with the boring data were used to identify the stiff soil layer used as the reference site for the ground motion calculations.

Depending on the location of the near-surface soft deposits (peat and organic marsh deposits), the relationships between maximum shear modulus, over-consolidation ratio and effective pressure proposed by Wehling (2001) for peat were used to evaluate the dependency of the shear modulus (or shear wave velocity) on the effective vertical stresses. This relationship is expressed in the following equation.

$$\frac{G_{max}}{Pa} = 75.7\left[\frac{\sigma'_{1c}}{Pa}\right]^{0.87} OCR^{0.65}$$

where Pa and σ'_{1c} are the atmospheric and effective vertical pressures, respectively.

6.2.6.5.4 Modulus Reduction and Damping Ratio (G/Gmax, ζ)

The variations of shear modulus and damping with shear strain for the various soil profiles were represented by modulus reduction and damping relationships. The modulus reduction relationship with shear strain corresponds to the variation of normalized secant shear modulus, G/Gmax, with strain.

G/Gmax and damping curves were obtained from UC Davis (Wehling et al. 2001) for the peat/organic soils as shown in Figures 6-56a and 6-56b. The series of curves, along with their distribution around the mean, were used in the statistical model to generate mean and standard deviations for the probabilistic seismic deformation analysis.

The shear modulus reduction curves (G/G_{max}) and damping curves of Seed and Idriss (1970) and Vucetic and Dobry (1991) were applied for the sandy soils (embankment fill and alluvium) and clay, respectively. The selected dynamic soil properties used for the response analyses are summarized in Table 6-7. Plots of the selected G/G_{max} and damping vs. shear strain relationships are presented in Figure 6-57.

The sensitivity of the seismic deformation of the levees to the range of values of the shear modulus and damping curves indicated a second order effect compared to the other soil parameters discussed in this section.

The variation of the soil parameters for the other deposits (non-peat and non-liquefiable deposits) such as the stiff clays and dense sands also produce second order effects on the levee and foundation seismic deformations and hence their best estimate properties were used deterministically.

6.2.6.6 Calibration Analysis

Very often data collected in the field and tests performed in the laboratories do not represent fully the levee and foundation conditions, particularly when dealing with hundreds of miles of levees across varying geologic and soil conditions. It was desirable to perform a calibration of the soil parameters using the best estimate values from the data sets compiled for the Delta and discussed above. The calibration was performed at sites with known geotechnical issues (i.e., failed or cracked levees due to slope instability of steep levee slopes that are still stable). The objective of the calibration was to run stability analyses with the best estimate values compiled for those known cases, and compare the results to the field observations. When applicable, the material properties were then adjusted to match the field observations. Based on discussions with the local geotechnical engineers and maintenance agencies, two sites were identified as prime candidates. The site at Bradford Island is experiencing tension crack and vertical offset at the levee crest while the site at Holland Tract is experiencing erosion resulting in over-steepened waterside slope. The calibration analysis and results are discussed below.

6.2.6.6.1 Bradford Island Station 169+00

Stability-induced cracking was reported at the Station 169+00 in Bradford Island. Figure 6-58 shows the approximate location of this site, located at the midpoint of the northern boundary of the island along with the known geometry, subsurface information, water level and piezometric line. The local District engineer reported that the cracking resulted from placement of approximately 2 feet of fill on the levee crest in the late 2002. No fill was placed on the slopes. Cracking was first observed in 2005 with some vertical and horizontal offsets in the crest. It appears that the crest movement has been gradually increasing since 2005. A vertical offset in the range of 6 to 12 inches was observed in the summer of 2006. Some horizontal offsets have also occurred. The movement of the crest may be attributed to the consolidation of soft foundation materials such as peat/organic and soft clays resulting from additional weight of the new fill and creeping of the peat/organic soils under sustained shear stresses.

An analysis cross section was developed at this location based on available topographical and subsurface data. Since cracking was observed at this location, it was assumed that this levee section is at best marginally stable. A static factor of safety of 1.1 to 1.15 was considered to represent appropriately the observed condition. The stability of the levees was analyzed using the limit equilibrium method based on Spencer's procedure as coded in the computer program UTEXAS3. UTEXAS3 was used to compute factors of safety using circular slip surfaces.

The slope stability analysis was first performed using the best estimate shear strength parameters for the peat/organic soils from previous laboratory tests. Subsequently, the shear strength was adjusted until it yielded a factor of safety of about 1.13 as shown in Figure 6-58.

6.2.6.6.2 Holland Tract Station 60+00

The waterside slope at this location is very steep and therefore this section was selected for testing the reasonableness of the calibrated shear strength parameters of peat/organic soils. The results of the slope stability analysis for this section are presented in Figure 6-59. The calibrated peat strength parameters for Bradford Island above produce a factor of safety of 1.0 for Holland Tract.

Back calculation performed by Hultgren-Tillis Engineers (2003) for Holland Island at Station 60+00 indicated that for water side factor of safety of about 1.0, the effective cohesion and friction angle were100 psf and 28 degrees, respectively. These are reasonably similar to the 120 psf and 28 degrees estimated in the calibration described above. The results of this analysis is shown in Figure 6-59. These “calibrated” strength parameters were then used for the rest of the stability analyses for this project.

6.2.6.6.3 Back Calculations from Four Island Levee Failures

M.W. Driller (1990) investigated the failures of island levees in the Delta and Suisun Marsh from 1950 to 1982, and performed back calculations for four slope failures of Delta levees to estimate the strength parameters of the peat/organic deposits. The four island were: Tyler Island, Twitchell Island, Webb Tract, and McDonald Tract. The back-calculated strength parameters were developed for a range of coupled cohesions with effective friction angles. For a cohesion of 140 psf, the results yielded friction angles ranging from 11.5 to 16 degrees compared to an effective cohesion of 140 psf and a friction angle of 18 degrees used in this analysis.

6.2.6.6.4 Further Comparisons and Verifications

The purpose of this comparison and verification section was to compare the outcome of the levee stability analyses to those levees where other previous studies have been completed recently. There were a number of studies performed by others in Sherman Island in the recent past (DWR 1993; GEI 1996; URS 2000; Hultgren-Tillis Engineers [HTE] 2003). It should be noted that the slope stability analyses for DRMS 2007 and GEI (1996) were conducted for the same station. For the remaining three other references (URS 2000; HTE 2003; DWR 1993) the slope stability analyses were performed by the DRMS seismic analysis team at the same location using the material properties developed by those studies. The comparison analysis was performed for a cross section at station 650+00 in Sherman Island (south side of the island). At that location the peat layer forming the foundation exceeds 40 feet in thickness. As shown in Figures 6-60a and 6-60b, the long-term factors of safety for the best estimate material parameters are equal to 1.29 and 1.60, and the corresponding yield accelerations are 0.05 and 0.07 for the landside and waterside slopes, respectively. The results are generally consistent with the other previous studies of Sherman Island as shown below.

Studies	Landside Factor of Safety	Comments
This Study (URS/JBA 2008h)	FS = 1.29	
GEI (1996)	FS = 1.20	
Hultgren-Tillis Engineers (2003)	FS = 1.49	Calculated for this study*
DWR (1992)	FS = 1.24	Calculated for this study*
URS (2000)	FS = 1.21	Calculated for this study*

*Indicates results calculated in this study using their material properties.

Seismic deformation analysis was also conducted for the same cross-section. The analysis was performed for three earthquake magnitudes (**M** 5.5, **M** 6.5, and **M** 7.5) and a range of reference site peak ground accelerations ranging from 0.1 to 0.5 g. The dynamic analysis was conducted using both FLAC and QUAD4M-Newmark type procedures. The finite element mesh is illustrated in Figure 6-61. The results of the dynamic analysis indicate that the two methods, QUAD4M-Newmark and FLAC, produce generally similar results as shown in Figures 6-62 and 6-63, respectively. The results further indicate that under large earthquake shaking, the south levee could undergo 5 feet or more of deformation.

6.2.6.7 Simulation of Levee Response To Past Earthquakes

On January 24, 1980, an earthquake of magnitude **M** 5.8 occurred near Livermore, about 18 km south of the Delta. A recording station maintained by the California Department of Mines and Geology (CDMG-67070) at Antioch located at a site with a $V_{S\text{-}30}$ = 338.5 m/sec recorded a PGA of 0.0355g.

On March 24,1984, an earthquake of magnitude **M** 6.19 occurred in Morgan Hill on Calaveras Faults about 80 km south of the Delta. No recording station at or near the Delta was reported. However, a recording station maintained by the California Department of Mines and Geology CDMG-56012 at Los Banos (80 km south east) located at a site with a $V_{S\text{-}30}$ =271.4 m/sec recorded a PGA of 0.0560g.

These events were the closest and strongest recorded earthquakes near the Delta in recent history (since the beginning of strong motion instrumentation). There were no observations of damage reported in the Delta following these events. Similar observations are also drawn by applying the recorded PGA values and associated magnitudes to the calculated levee deformation functions and fragility function presented in this section. Generally, we estimate no damage or insignificant damage for PGAs equal to or less than 0.05g.

A simulation of the 1906 Great San Francisco Earthquake (**M** 8.0) was conducted to estimate the mean PGA at the western portion of the Delta. The calculated mean PGA was obtained using the four new attenuation relationships for the reference site and assigning equal weight to each. The attenuation relationships used were the same ones used in the PSHA. The calculated PGA near Sherman Island (west of the Delta) was equal to 0.11g. Applying this calculated PGA and the associated magnitude to the calculated fragility functions yielded minor to moderate damage to the levees and foundations should a repeat of the 1906 earthquake occur today. The expected earthquake-induced deformations ranged from negligible to 3 feet depending on the levee vulnerability classes and its location in the Delta. The expected probabilities of failure calculated in the risk model predict on average 0.004 to 0.23 probability of failure for and **M**-8 on the San Andreas fault.

Key observations and model predictions from the above simulations are summarized in the table below.

Earthquake Event	Observations	Model Prediction
M 5.8 Livermore EQ (1980)	No damage observed	No damage calculated
M 6.19 Morgan Hill EQ (1984)	No damage observed	No damage calculated
M 8.0 San Francisco EQ (1906)	Levees were much smaller and no pots-earthquake eyewitness reports exist	Expected levee deformation, for today's levees, ranges from 0 to 3 feet and the conditional probability of levee failure ranges from 0 to 23%.

The model results were also compared to other sites where earthquake-induced liquefaction caused damage to levees. Two case histories are used in this comparison. They include the 1995 **M**-6.9 Kobe Japan earthquake and the levee failure along the Pajaro River in Watsonville, California, after the 1989 **M**-6.7 Loma Prieta Earthquake.

The Kobe earthquake generated peak ground accelerations in excess of 0.5g at the levee site shown in Figure 6-28. Figure 6-29 shows a vertical deformation (vertical slump) of about 15 feet (4.6 meters) for the flood wall and 10.5 feet (3.3 m) for the crest road. The levee was about 21 feet in height (to the top of the crest road). The calculated deformation for a levee in the Delta with liquefiable sand in the foundation (Figure 6-96) is in excess of 10 feet for a PGA equal to or greater than 0.5g. This estimated value from Figure 6-96 was interpolated between the curves for magnitudes 6.5 and 7.5. The probability of failure predicted from the fragility functions (Figure 6-137a) for class 1 (no peat) shows a probability of failure ranging approximately from 70 to 100 percent.

A similar comparison was performed for the Pajaro River levee failure in 1989. The estimated earthquake PGA at the site was about 0.33g. Sand boils were reported in many sites along the river banks (USACE 1989). The levee was about 6 feet in height. The field damage survey showed tension cracks 18 inches wide at the crest of the levee with one foot vertical offset. The calculated deformation for a levee in the Delta with liquefiable sand in the foundation (Figure 6-96) is about 4 feet for a PGA equal to 0.33g. This estimated value, from Figure 6-96, is for a 20-foot tall levee as opposed to the 6-foot tall levee along the Pajaro River. The probability of failure predicted from the fragility functions (Figure 6-137a) for class 1 (no peat) shows a probability of failure ranging approximately from 58 to 88 percent.

After the calibration analysis at Bradford Island and Holland Tract, and the comparison with other studies for Sherman Island, and the verification against past earthquakes, then the analysis of the typical/idealized cross-sections representing the range of the VCs was initiated.

6.2.6.8 Selection of Random Variables and Estimation of Their Statistical Distribution

Several parameters contribute to the seismic response of levees and their foundation. Some are primary and have first order contribution to the response functions and others are secondary and have insignificant contribution to the response of the levees response functions. Several potential material parameters were evaluated by performing sensitivity analyses. The material properties whose variations showed relatively little effects on levee deformation were treated deterministically with best point estimate values. The material properties whose variations showed significant effects on the levee deformation were treated as random variables and their probability distribution functions were calculated based on the statistical analysis of the available data. These probability distributions quantify the aleatory uncertainty in the materials properties.

A lognormal distribution was assumed for each random input variable because it is a commonly accepted probability distribution of soil properties and the shape of this distribution provides a reasonable fit to the distribution of field data. A lognormal distribution is completely defined by two statistical parameters: the median and the logarithmic standard deviation.

For VCs 1 through 14, the random variables:

$(N1)_{60\text{-}cs}$ and residual shear strength (Sr) of the liquefiable levee fill and foundation sand were treated as random variables. The $(N_1)_{60\text{-}cs}$ and Sr are based on correlation relationships proposed by Seed and Harder (1990) as shown in Figure 6-64a(1).

Liquefaction potential of levee fill and foundation sand was treated as a probability distribution. The probability of liquefaction was assessed using the procedure proposed by Seed et al. (2003) as shown in Figure 6-64a(2).

Peat thickness was treated as a random variable within each selected interval, as discussed in Section 6.2.3.

The deterministic parameters included:

Levee geometry within the ranges of “steep” or “not steep” groups as defined earlier.

Water level in the slough and rivers was considered at mean higher high water (MHHW) level. It was assumed that the probability of both flood and seismic events happening at the same time was very low and will not have significant contribution to the total hazard. The mean higher high water level typically occurs few times a month (average of the two weeks highs) and is more likely to occur during or immediately after the earthquake event. The piezometric line through the embankment for the MHHW is also considered deterministic.

For VCs 15 through 22 the random variables included:

Cohesion and friction angle of peat/organic deposits were treated as random variables. The available p-q data of peat (as discussed in section 6.4.3) were utilized to calculate the standard deviations in cohesion and friction angle of peat/organic deposits.

Peat thickness was treated as a random variable within each selected interval, as discussed in Section 6.2.3.

The deterministic parameters included:

Levee geometry - variation in the water side slope was considered to have some impact in the seismic deformation. Analyses were considered using two levee geometries: with steep and non-steep water side slopes. All other dimensions of the levee such as widths and landsides slope were found to have insignificant effects on the calculated seismic deformations, for the range of data compiled.

Water level in the slough and rivers - Water level was considered at MHHW as explained above. The piezometric line through the embankment for the NHHW is also considered deterministic.

Variation of modulus reduction and damping with shear strain - for the ranges of data shown in Figure 6-56a and 6-56b. These parameters were found to have a second order effects on the seismic deformation of the levees for the range of the statistical data.

Soil properties of other soils (i.e., other than peat and organic deposits) - Since the seismic behavior of the Delta levees are mainly controlled by the liquefaction of levee fill and/or foundation materials and the peat/organic soils, the variation of the material properties for the stiff clays and dense sands have no significant effects on the levee responses to seismic loading. Therefore, soil properties of these dense and stiff materials were treated deterministically using the best estimate values.

Unit weights of peat and loose sands - The unit weights of the loose fill, the loose foundation sand, and the peat were treated deterministically using the best estimate values.

6.2.6.9 Analyses and Results

6.2.6.9.1 Analysis and Results for VCs 1 through 14

Probability of Liquefaction Analysis

For those VCs with liquefiable fill or foundation (VC 1 through 14), seismic displacement was calculated under both liquefaction and no-liquefaction scenarios. The probability of liquefaction of either the fill or the foundation was assessed using the procedure recommended in Seed et al. (2003). The following are key steps involved in the calculation of probability of liquefaction.

Step 1: Simulate levee soil properties

For each simulation trial, the following soil properties were simulated: fill $(N1)_{60}$ foundation $(N1)_{60}$ and peat thickness. The probability distribution for each of these soil properties was characterized based on a statistical analysis of available field data over the Delta. Each distribution was assumed to be lognormal and was defined in terms of the mean and standard deviation of the natural logarithm of the variable. These parameters are shown in the following table:

Soil Property	Mean	Standard Deviation
Fill $(N1)_{60}$	6.5	1.65
Foundation $(N1)_{6o}$	14.4	2.27
Peat Thickness (ft)	Varies with Thickness Intervals	2.09

The simulated value of each soil property was constrained to lie within the applicable range for each vulnerability class. For example, for VC 2, the fill $(N1)_{60}$ was constrained to be less than or equal to 20 and peat thickness was constrained to be between 0.1 and 10 feet. Note for VC 1, peat thickness was defined to be 0 and no simulation of peat thickness was necessary for this class.

Step 2: Select a particular combination of earthquake magnitude, M, and reference peak ground acceleration, PGA

Different combinations of 3 earthquake magnitudes (**M** 5.5, **M** 6.5, and **M** 7.5) and 21 PGA values (0.05 g, and 0.1 g to 2.0 g in increments of 0.1 g) were considered in this analysis. The subsequent steps were repeated for each **M** and **PGA** combination.

Step 3: Calculate probabilities of fill and foundation liquefaction.

The following equation recommended in Seed *et al* (2003) was used to calculate the probability of liquefaction:

$$P_L\left(N_{1,60}, CSR, M, \sigma'_v, FC\right) = \Phi\left[-\frac{\begin{pmatrix}(N1)_{60}\cdot(1+0.004\cdot FC)-13.32\cdot\ln(CSR)- \\ 29.53\cdot\ln(M)-3.70\cdot\ln(\sigma'_v) \\ +0.05\cdot FC+44.97\end{pmatrix}}{2.70}\right] \qquad (1)$$

where

P_L = the probability of liquefaction in decimals (i.e., 0.3, 0.4, etc.)

$(N1)_{60}$ = fill $(N1)_{60}$ or foundation $(N1)_{60}$

CSR = cyclic stress ratio

M = earthquake magnitude

σ'_v = effective overburden stress

FC = fines content

Φ = the standard cumulative normal distribution

The use of this equation requires estimates of CSR, effective overburden stress (σ'_v), and fines content (FC). The values of these variables were obtained as follows:

Cyclic Stress Ratio

The CSR values for the probability of liquefaction were calculated using the results from a study performed by Kishida et al. (2007). As part of this study, two analysis cross sections were developed to represent general conditions at Sherman Island (peat thickness about 30 feet) and Bacon Island (peat thickness about 15 feet) and were analyzed using the computer program, QUAD4M. Two hundred and sixty four ground motions were used as input motions for the dynamic analysis. These ground motions had the following characteristics:

- PGA ranged from 0.004 g to 1.78 g
- Moment magnitude (M_w) from 4.3 to 7.9
- Seismic distance from 1.1 km to 296 km

The ratio between the crest acceleration and the acceleration within the levee fill was estimated to be about 1.0 based on analyses conducted by URS (QUAD4M and FLAC) and Kishida et al (2007). The peak crest acceleration was multiplied by the reduction factor r_d and a σ_v/σ_v' approximated to 1.0 to estimate the CSR.

Fill CSR was calculated for different earthquake time histories for each of 3 peat thickness: 0 feet, 15 feet, and 25 feet. Two separate regression equations were developed to estimate natural logarithm of fill CSR – one for peat thickness of 0 feet and the other for peat thickness greater than 0. These regression equations are as follows:

For peat thickness = 0 feet

$$\ln(CSR) = -2.35 + 0.213 \cdot M + 0.783 \cdot \ln(PGA) \quad (2)$$
$$(RMSE = 0.327)$$

where

CSR = cyclic stress ratio

M = earthquake magnitude

PGA = reference peak ground acceleration in g

For peat thickness > 0 feet

$$\ln(CSR) = -2.14 + 0.268 \cdot M + 0.743 \cdot \ln(PGA) - 0.0379 \cdot peat \quad (3)$$
$$(RMSE = 0.351)$$

where

CSR = cyclic stress ratio

M = earthquake magnitude

PGA = reference peak ground acceleration in g

$peat$ = peat thickness in feet

The root mean square error (RMSE) in each regression equation was assumed to be the logarithmic standard deviation of CSR for given values of M, PGA, and peat thickness. A lognormal distribution was assumed for fill CSR with a mean of natural logarithm of CSR calculated from Equation (2) or (3) and logarithmic standard deviation equal to the RMSE.

For the foundation loose sand, the acceleration within the foundation was estimated from Figures 6-64b(1) and 6-64b(2) given values of *M*, *PGA*, and peat thickness. The regression relationships shown in Figure 6-64b(2) were developed based on review of several analysis results by URS (Quad4M and FLAC analyses) and Kishida et al. (2007).

The equation used to calculate the CSR for foundation sand is as follow:

$$CSR = 0.65 \cdot r_d \cdot (a_{max}/g) \cdot (\sigma_v/\sigma_v') \quad (4)$$

Fines Content

Based on available gradation data, empirical probability distributions were defined for the fill and foundation FC. These distributions are shown in the table below.

Fines Content Category	Fines Content, *FC* (%)	% of Total
FC Fill C1	5	22.6
FC Fill C2	8	3.52
FC Fill C3	15	39.2
FC Fill C4	25	6.03
FC Fill C5	35	28.6
FC Foundation C1	5	4.8
FC Foundation C2	8	1.8
FC Foundation C3	15	87.5
FC Foundation C4	25	0.5
FC Foundation C5	35	5.3

Step 4: Simulate liquefaction Outcome

Using the probability of fill liquefaction estimated from Equation (1), a binary variable was simulated with an outcome of either liquefaction or no liquefaction of the fill. A similar binary variable was simulated for the foundation liquefaction. If $(N1)_{60}$ of either the fill or foundation was greater than 20, the probability of liquefaction was assumed to be negligible. The two binary variables defined four possible liquefaction outcomes, as follows:

- Outcome 1: Both fill and foundation liquefy.
- Outcome 2: Fill liquefies, but foundation does not.
- Outcome 3: Fill does not liquefy, but foundation does.
- Outcome 4: Neither fill nor foundation liquefies.
- For each simulation trial, one and only one of the four outcomes is generated.

6.2.6.10 Deformation Analysis

Liquefaction of Foundation Material

The FLAC meshes developed to model the four idealized sections are shown in Figures 6-65 through 6-68. For illustration purposes, the time history of the CSR and the pore pressure ratio in the liquefiable sand layer are shown in Figures 6-69 through 6-86 for the low (**M** 5.5), moderate (**M** 6.5) and large (**M** 7.5) earthquakes and a reference peak ground acceleration of 0.2g.

The seismic-induced post-liquefaction deformation contours are shown in Figures 6-87 through Figure 6-95. As shown in these figures, the analyses results for this case show high excess pore pressure and therefore high strength degradation in the liquefiable sand layer resulting in excessive deformations (8 to 10 feet). The mean total displacements are summarized in Table 6-8 and shown in Figures 6-96 through 6-98. It should be noted that for the section with no peat, the deformations are very large and the computer model could not converge, indicating flow failures beyond 10 feet.

Liquefaction of Levee Fill

For the case of the potentially liquefiable levee fill, the computer program FLAC was utilized. It was noted however, that in this case again, the deformation were very large (beyond 10 feet) and hence the non-linear time-domain analysis could not converge because of the excessive deformations. A simplified approach using the post-liquefaction static-slumping method (discussed earlier) was used as a substitute, recognizing that it does not represent the inertia-induced deformations. An example of the pre- and post static slump deformation is illustrated in Figure 6-99 showing 10 feet of vertical slump for a levee fill with residual strength of 230 psf. Below 230 psf residual strength, the computer program did not converge, indicating deformations in excess of 10 feet.

Non-liquefiable Levee Foundation and Fill (VCs 14 through 22)

The static stability analyses for long-term conditions were performed for five idealized cross sections with peat thickness of 0, 5-ft, 15-ft, 25-ft and a section representing Suisun Marsh. The results are summarized in Table 6-9, and the cross sections with the most critical slip surfaces and factors of safety are shown in Figures 6-100 through 6-104. The results of these analyses indicate that the yield acceleration deceases as the peat thickness increases. For Suisun Marsh, the yield accelerations range from 0.03 to 0.09g. For the Delta levees, the yield accelerations range from as low as 0.05g for peat thicker than 40 feet (Sherman Island) and as high as 0.24g in places, where peat is not present.

The seismic deformation analyses were performed using the QUAD4M-K_y-Newmark method as discussed earlier. These analyses were performed for the mean estimates of soil properties for all five idealized cross-sections. Two levee geometries were considered for these analyses depending on the VC, steep and non-steep waterside slope.

The finite element meshes for the five idealized cross sections with non-steep waterside slopes are shown in Figures 6-105 through 6-109. The acceleration time histories recorded from the base of the mesh to the crest of the levee or the free field surface are presented in Figures 6-110 through 6-124. Figure 6-125 presents a typical displacement time history from the Newmark sliding block analysis. The results of the deformation analyses for the five idealized sections are presented in Figures 6-126 through 6-130. The calculated displacements range from a fraction of an inch for the cross-section with no peat and no liquefaction, to several feet (up to 14 feet) for Suisun Marsh and the liquefiable fill cases. The results are also summarized in Tables 6-10a and 6-10b for Delta and Suisun Marsh levees, respectively. These calculated displacements correspond to horizontal translations of the center of mass of each sliding block. The corresponding vertical displacements were obtained from relationships between horizontal and vertical deformations obtained from the FLAC analysis. Generally, a ratio of 1H to 1/2 V displacement was observed in the cases evaluated. This ratio was discussed and approved by the experts elicited for the development of the ***conditional probability of failure functions*** (see Section 6.2.6)

The results of the calculated levee deformation for levees with the steep waterside slope are presented in Figures 6-131 through 6-134.

6.2.7 Conditional Probability of Failure Functions

The development of the conditional probability of levee failure given earthquake-induced deformations was solely based on expert elicitation. The group of experts selected for the levee vulnerability have either a long standing work experience with levees in the delta and/or are knows to have performed research and published technical subject matters related to the performance of the Delta levees. The following experts were convened to offer expert opinion:

- Professor Ray Seed (UC Berkeley)
- Dr. Leslie Harder (DWR)
- Mr. Michael Driller (DWR)
- Dr. Ulrich Luscher (Consultant)
- Dr. Faiz Makdisi (Geomatrix)
- Mr. Michael Ramsbotham (USACE)
- Mr. Gilbert Cosio (MBK)
- Mr. Kevin Tellis (Hultgren-Tillis)
- Mr. Edward Hultgren (Hultgren-Tillis)
- Dr. Said Salah-Mars (URS - Facilitator)

First a scope of the expert elicitation was presented to the panel of experts. The scope consisted mainly of introducing the experts to the development methodology of the entire levee fragility task, which includes the three steps forming the methodology as described in Section 6.2.3. These three steps are as follows:

1. The development of the ***levee response functions***
2. The development of the ***conditional probability of failure functions***
3. The development of the ***levee fragility functions***

The second part of the scope consisted of eliciting expert opinion and recommendations on the development of the ***conditional probability of failure functions***, given their involvement as TAC members in the levee seismic vulnerability and their understanding of the entire methodology for the development of the levee fragility functions.

For a period of few months, the experts participated and developed a full understanding of the process behind the development of the levee response and the levee fragility methodology.

Based on the understanding of the entire task, the experts were then asked to develop their own (individual) recommendations on the shapes of the ***conditional probability of failure functions***, given the knowledge and the understanding of the entire process. Specific questions were asked of the experts such as:

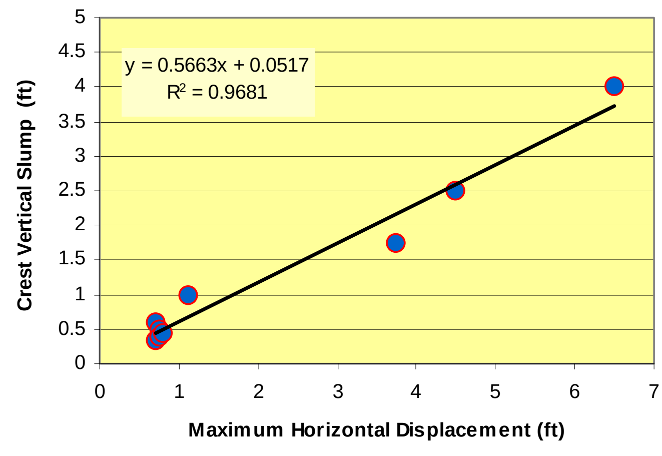
- Should the functions be developed assuming human intervention or not?
- What is a simple and reasonable relationship between vertical deformation and horizontal deformation?
- What is the proper abscissa parameter that should be used for the conditional probability of failure functions?

There questions were discussed among the experts and resolved before they developed their recommendations.

The experts submitted their recommendations on both issues: (1) developing the shapes of the conditional probability functions and (2) answering the specific questions. The experts convened in a meeting where their recommendations were shared and discussed. During this meeting the experts were able to present their thoughts on their recommendations and listened to other experts' opinions and justifications.

After the shared session the experts were given an option to revisit their recommendations in light of the discussion and knowledge exchanged during the shared session. The experts then resubmitted their recommendations, which were then processed by the seismic analysis team, giving equal weight to each of the recommendations. The mean and distribution around the mean are shown in Figure 6-135, relating the conditional probability of failure to the relative loss of freeboard (i.e., ratio of vertical deformation over initial freeboard) assuming normal flood fight efforts during emergency response. These curves represent the epistemic uncertainty associated the expected failure (levee breach) given earthquake-induced levee permanent vertical deformations. In addition to the loss of freeboard leading to overtopping, the failure mechanisms and their uncertainties consider also the likelihood of post-deformation cracking leading to internal erosion and piping.

On the issue of the vertical to horizontal deformation the consensus was to use a factor of about two to represent the horizontal to vertical deformation for a sliding mass on the side slopes of the levees. The data obtained from the finite element deformation mesh was reviewed and used in this recommendation, as shown in the figure. Although the calculated deformations using finite elements provide both vertical and horizontal deformations (they were used for the liquefaction cases), the bulk of the runs were performed using QUAD4-M and Newmark analyses, which provide horizontal deformation only.



Horizontal to Vertical Displacements from FE Model

6.2.8 Evaluation of Seismic Fragility Functions

The objectives of this analysis were to assess the (conditional) probability of levee failure due to displacement under different seismic events and to quantify the uncertainty in the estimated failure probability. The Monte Carlo simulation method was used to estimate the probability of levee failure under different combinations of earthquake magnitude and reference peak ground acceleration. The failure probability was assessed separately for the different levee VCs that were defined based on levee geometry and soil properties. Section 6.2.3 describes the definition of the different VCs and the random variables for each vulnerability class.

The Monte Carlo simulation method involved defining the probability distribution of each random variable based on a statistical analysis of available data and simulating a value of the variable by randomly sampling from its probability distribution. The commercial software Crystal Ball® was used to simulate values of random variables from their defined probability distributions. These simulated values were used to calculate levee displacement under different seismic events.

Conditional probability of failure as a function of seismic deformation was previously developed using expert opinion as discussed in the previous section. These conditional probability functions were combined with the simulated seismic displacement to assess the probability of levee failure under different combinations of earthquake magnitude and reference PGA.

6.2.8.1 Step-by-Step Procedure

Figure 6-136 shows a flowchart of the key steps of the simulation procedure. These steps are described below. The first four steps have already been discussed in the previous sections. They represented the simulation of the levee soil properties, the selection of **M** and PGA combinations, the calculation of probabilities of liquefaction for levee fill and foundation materials, and the simulation of their outcome. The following paragraphs describe the remaining steps.

Step 5: For the given liquefaction outcome, simulate levee horizontal displacement.

The procedures to estimate levee horizontal displacement for each of the four liquefaction outcomes are described below.

Displacement under Outcome 1: Both fill and foundation liquefy

For this outcome, displacement was assumed to be the sum of two components – one due to fill liquefaction alone and the other due to foundation liquefaction alone. These two components of displacement were simulated using the following procedures.

Displacement due to Fill Liquefaction Alone

Assuming liquefied fill, the residual undrained shear strength, S_r, was first simulated. A regression equation was developed to estimate the mean S_r (in psf) as a function of fill $(N1)_{60\text{-}cs}$ using the curve provided in Seed and Harder (1990) Figure 6-64a(1). This equation is as follows:

$$S_r = 11.8 + 2.82 \cdot \left((N1)_{60-cs}\right)^2 \qquad (5)$$

where

S_r = the residual undrained shear strength in psf

$(N1)_{60-cs}$ = fill $N_{1\text{-}60\text{-}cs}$

The upper-bound curve in the above reference showed an increase of about 200 psf above the mean curve over the full range of fill $(N1)_{60\text{-}cs}$. This upper bound was taken to be the 95th percentile curve (i.e., 95 percent of S_r values would be at or below this upper-bound). The spread around the mean curve, as shown in the above reference, was symmetric, suggesting that a normal distribution would be appropriate. Assuming a normal distribution for S_r at any given value of fill $(N1)_{60\text{-}cs}$, the difference between the 95th percentile and mean would be equal to 1.645 × standard deviation. Using this relationship, the standard deviation of S_r was estimated to be (200/1.645=) 121.6 psf.

A value of S_r was simulated assuming a normal distribution with the mean value from Equation (5) and a standard deviation of 121.6 psf. This value of S_r was used next to define a distribution of horizontal displacement, D_H. Using results of seismic displacement analysis under liquefied fill and the resulting S_r, a regression equation was developed to estimate the natural logarithm of D_H as a function of S_r for the case of liquefied fill. This equation is as follows:

$$\ln(D_H) = 3.26 + 0.00404 \cdot S_r - 0.0000369 \cdot S_r^{\,2} \qquad (6)$$
$$(RMSE = 0.172)$$

where

D_H = horizontal displacement in feet

S_r = the residual undrained shear strength in psf

The RMSE of this regression equation was 0.172 ft. A value of D_H was simulated assuming a lognormal distribution with the natural logarithmic mean calculated from Equation (6) and a natural logarithmic standard deviation of 0.172.

Displacement due to Liquefied Foundation Alone

Levee displacement was estimated for different combinations of **M**, PGA, peat thickness, and foundation $(N1)_{60\text{-}CS}$ under the condition of liquefied foundation. Using the results of this analysis, the following regression equation was developed:

$$\ln(D_H) = -5.89 + 0.916 \cdot M + 7.02 \cdot PGA - 0.0163 \cdot peat - 0.127 \cdot (N1)_{60-cs} \quad (7)$$
$$(RMSE = 0.650)$$

where

D_H = horizontal displacement in feet

M = earthquake magnitude

PGA = reference peak ground acceleration in g

$peat$ = peat thickness in feet

$(N1)_{60-cs}$ = foundation $(N1)_{60\text{-cs}}$

Displacement under Outcome 2: Fill Liquefies, but Foundation Does Not

For this outcome, the overall displacement was again assumed to be the sum of two components: one due to fill liquefaction alone and the other due to the movement of non-liquefied foundation alone. The first component was simulated using the same procedure as in Outcome 1. For the second component, displacements estimated for a non-liquefied foundation were used to develop a regression equation. The displacement analysis showed that the soil strength parameters c and φ influenced the estimated displacements when the levee profile included a peat layer. Therefore, two separate regression equations were derived – one for zero peat thickness and one for non-zero peat thickness. These two regression equations are as follows:

For peat thickness = 0 feet

$$\ln(D_H) = -9.69 + 0.794 \cdot M + 4.04 \cdot PGA + 1.69 \cdot waterside \quad (8)$$
$$(RMSE = 0.630)$$

where

D_H = horizontal displacement in feet

M = earthquake magnitude

PGA = reference peak ground acceleration in g

$waterside$ = waterside levee slope indicator (0 = non-steep; 1 = steep)

The variable "waterside levee slope indicator" in Equation (8) was defined to be 1 for a steep slope (defined as steeper than 1.5H:1V) and 0 for a non-steep slope. This variable was assumed to be deterministic; that is, the slope was assumed to be known for individual levee reaches. Note that the slope indicator is used only for VCs 15 through 22. For VCs 1 through 14, the fill or foundation was susceptible to liquefaction and the influence of the levee slope was assessed to be negligible. Consequently, the slope indicator was not used to define VCs 1 through 14. For these vulnerability classes, the slope indicator was set equal to its prevalent value of 0 (i.e., non-steep slope).

For peat thickness > 0 feet

$$\ln(D_H) = -7.86 + 1.19 \cdot M + 7.81 \cdot PGA + 0.0464 \cdot peat - 0.0115 \cdot c - 0.128 \cdot \phi + 0.962 \cdot waterside \quad (9)$$

$$(RMSE = 0.595)$$

where

D_H = horizontal displacement in feet
M = earthquake magnitude
PGA = reference peak ground acceleration in g
$peat$ = peat thickness in feet
c = soil strength parameter, c, in psf
ϕ = soil strength parameter in degrees
$waterside$ = waterside levee slope indicator (0 = non-steep; 1 = steep)

The parameter *c* was assumed to be lognormally distributed with the mean and standard deviation of natural logarithm of *c* of 4.79 and 0.336, respectively. The friction angle ϕ was assumed to be lognormally distributed with the mean and standard deviation of natural logarithm of ϕ of 3.33 and 0.0677, respectively. The parameters *c* and ϕ were assumed to be probabilistically independent. The same distributions were assumed to apply to all Delta levees.

<u>Displacement under Outcome 3: Fill Does Not Liquefy, but Foundation Does</u>

For this outcome, displacement was estimated using the procedure described under *Displacement due to Liquefied Foundation Alone* for Outcome 1.

<u>Displacement under Outcome 4: Neither Fill nor Foundation Liquefies</u>

For this outcome, displacement was estimated using the procedure described under Outcome 2.

Step 6: Calculate the probability of failure for given values of initial freeboard at different confidence levels.

At the end of Step 5, a simulated value of D_H was generated for each selected (M, PGA) combination. The vertical displacement was assessed to be 50 percent of the horizontal displacement. For different values of initial freeboard (IFB), the following ratio, R, was calculated:

$$R = (\text{vertical displacement} / IFB) = (0.5 \times D_H / IFB) \quad (10)$$

Levee fragility curves were previously developed using expert opinion. The development of these curves was described in Section 6.2.4. The variability of input from different experts represents epistemic uncertainty. The assessments of multiple experts were used to calculate the median (i.e., 50^{th} percentile) and 84^{th} percentile of the failure probability, p_f, for different values of R. Using these two percentiles, the mean of natural logarithm of p_f for a given R was calculated as natural logarithm of median p_f, and the standard deviation of natural logarithm of p_f was calculated as natural logarithm of (84^{th} percentile of p_f / median p_f). Regression equations were developed to estimate mean and standard deviation of natural logarithm of p_f as a function of *R*. These equations were as follows:

$$m(\ln p_f) = \ln\left(\frac{e^{(8.97\cdot R-5.67)}}{1+e^{(8.97\cdot R-5.67)}}\right) \quad (11)$$

$$s(\ln p_f) = -1.28\cdot R + 1.16 \quad (12)$$

where

$m(\ln p_f)$ = mean of logarithm of probability of failure

$s(\ln p_f)$ = stardand deviation of logarithm of probability of failure

R = ratio of vertical displacement divided by IFB

For each *R*, the mean and standard deviation of natural logarithm of p_f were calculated from Equations (11) and (12), respectively. Using these two parameters and assuming a normal distribution for natural logarithm of p_f, one hundred values of p_f were calculated for confidence levels in increments of 1% starting from 0.5% to 99.5%. The following equation was used to calculate p_f for a specified confidence level of p%:

$$p_f(p\%) = e^{(m(\ln p_f)+z_{p\%}\times s(\ln p_f))} \quad (13)$$

where

$p_f(p\%)$ = probability of failure at confidence level of $p\%$

$m(\ln p_f)$ = mean of logarithm of probability of failure

$z_{p\%}$ = standard normal variable corresponding to a cumulative probability of $p\%$

$s(\ln p_f)$ = stardand deviation of logarithm of probability of failure

This process divides the continuous distribution of p_f into a discrete distribution of one hundred values and each value has a probability of occurrence of 1 percent. This probability distribution of pf captures the epistemic uncertainty defined by the variability in the expert input.

This process was repeated for each of different values of IFB in the range of 0 feet to 20 feet.

Step 7: Repeat Steps 3 through 6 for different combinations of M and PGA.

Steps 3 through 6 were repeated for different combinations of M and PGA. Thus, for a given simulation trial, the completion of Step 7 generated values of p_f for different IFB values for each combination of M and PGA.

Step 8: Repeat Steps 1 through 7 for a specified number of simulation trials.

For this analysis, 500 simulation trials were performed. At the completion of this step, 500 simulated values of p_f were generated at each of 100 confidence levels for each IFB value for each combination of **M** and PGA.

Step 9: Calculate the overall failure probability at different confidence levels for each (M, PGA, IFB) combination.

The overall probability of failure at each specified confidence level for each combination of (**M**, PGA, IFB) was calculated by integrating over the entire probability distribution of D_H, as follows:

$$\mathrm{P}\left[\text{failure}\middle| M, PGA, IFB\right] = \sum_i \mathrm{P}\left[\text{failure}\middle| D_{H_i}, IFB\right] \times \mathrm{P}\left[D_{H_i} \middle| M, PGA\right] \quad (14)$$

The probability distribution of D_H was defined based on the 500 simulated values for each (M, PGA) combination. Because each of the 500 simulated D_H values occurs with an equal probability (of 1 in 500), the overall failure probability from Equation (14) for a given confidence level is the average of the corresponding 500 values of p_f calculated at that confidence level.

The model developed by Seed et al. (2003) was used as the primary model to estimate the probability of liquefaction. However, other published models (Liao et al. 1988; Liao and Lum 1998; Youd and Noble 1997; Toprak et al. 1999) provide somewhat different estimates of liquefaction probability for given values of $(N1)_{60}$ and CSR. The range of the liquefaction probability from the Seed model and other published models represents the epistemic uncertainty in the liquefaction probability. An analysis of the results from the different models suggested a coefficient of variation about 28 percent around the liquefaction probability estimated from the Seed model. The analysis of levee response showed that the levee failure probability varied in proportion to the change in the liquefaction probability. Therefore, an epistemic uncertainty of 28 percent in the estimated failure probability was set to reflect the range of published research on liquefaction probability.

A hand calculation on a selected vulnerability class (VC-10) for one magnitude, three PGAs, and one water level is presented in Appendix 6A. The hand calculation is provided to illustrate the steps of the development of a fragility function using the mean values to carry the calculation to the end by hand and without being too cumbersome by adding the uncertainties around the mean.

6.2.8.2 Results of Analysis of Failure Frequencies for Different Vulnerability Classes

The calculated fragility functions included a total of 22 classes, 3 magnitudes, 21 PGAs, 20 water levels, and 100 fractiles (0 to 100 confidence levels). The total number of data points amounted to 2,772,000. The digital file in the format presented in Table 6-11 was prepared as input into the risk calculation model.

A limited sample of fragility functions is shown in Figures 6-137a through 6-137f. These figures show the estimated failure probability for 16 percent, 50 percent, and 84 percent confidence levels for **M** 6-1/2 and 2 feet of freeboard.

We discuss here the interpretation of the results for the first four vulnerability classes (VC-1 throughVC-4) shown in Figure 6-137a. The difference between VC-2, VC-3 and VC-4 is explained by the difference in the relative contribution of the probability of liquefaction of the fill versus the probability of no liquefaction of the fill. The probability of failure is the weighted sum of the probability of deformation multiplied by the probability of liquefaction or no liquefaction. The CSR is the primary factor that controls the probability of liquefaction. The higher CSR results in higher probability of liquefaction of the fill, and consequently the lower probability of no liquefaction. The CSR is related to the site amplification shown in Figure 6-64b(2). The higher crest acceleration results in higher CSR. Because the probability of failure is directly related to the calculated displacement, which in turn is related to the probability of liquefaction, then the fragility curves with the higher CSR would yield higher probability of failure for a given magnitude and reference PGA. This explains why the probability of failure for VC-2 is higher than that of VC-3, which in turn is higher than VC-4.

VC-1 is somewhat different and cannot be readily compared to VC-2, VC-3, and VC-4 because it represents a different site condition. VC-1 represents sites with no peat, that have some soft clay deposits in the foundation below the loose foundation sand.

6.2.9 Sensitivity Analysis of the Geographic Extent (Length Effect) of the Vulnerability Classes

Although there is a large number of existing subsurface exploratory borings, they did not provide full coverage of all Delta levees equally, were rather irregular, and lacked a high resolution in many locations. In many places the ends of a vulnerability class were not well defined and could vary by a few hundred feet because of the widely spaced boring locations.

One of the instructions given in comments by the Seismic Review Panel (SRP) was to evaluate the sensitivity of the length effects of the various VCs around any given island or tract, and determine whether the uncertainty associated with the geographic extent of the VCs should be considered in the analysis.

At the request of the SRP, and prior to modifying the previous fragility functions, a series of test cases was performed by varying the occurrence VCs within a given island. Union Island was selected as the test case. On Union Island there are 13 reaches in the model, 11 of which are assigned to VCs 1-5. The other two are assigned to VCs 15 and 19.

The sensitivity analysis included the following variations:

1. Base Case – As modeled in the DRMS study
2. Test Case 1 – 5 reaches are in VCs 1-5, 1 reach in VC 19, and 7 reaches in VC 15
3. Test Case 2 – 5 reaches are in VCs 1-5, 7 reaches in VC 19, and 1 reach in VC 15
4. Test Case 3 – 1 reach in VC 1-5; 6 reaches in VC 15; and 6 reaches in VC 19

The results of the sensitivity analysis indicate that the probability of the island failure is generally controlled by the “weakest link” regardless of its length. There is relatively little change in the median PGA fragility value among the cases analyzed.

The results are shown in Figures 6-138a through 6-138c for earthquakes of magnitudes **M** 5, **M** 6, and **M** 7, respectively. In each figure the fragility curves for the individual VCs are shown along with the island fragility curves for each test case.

6.3 SUMMARY OF FINDINGS

The material properties controlling the behavior of the levees under static and seismic loading were developed from previous studies and laboratory tests. The stability models were further calibrated against past performance (static failures in the Delta) and compared to other studies. The calibrated properties are generally in good agreement with other geotechnical studies of the Delta levees.

- Past earthquakes were re-simulated in the seismic vulnerability of Delta levee model. These past earthquakes included the 1980 Livermore (**M** 5.8) earthquake, the 1984 Morgan Hill (**M** 6.19) earthquake, and the 1906 San Francisco (**M** 8.0) earthquake. The simulations of these earthquakes were performed to find the mean estimate of the ground motion for a stiff reference site. The results indicate that negligible to no deformations are calculated for the Livermore and the Morgan Hill earthquakes, which is consistent with the observations. For the Great 1906 San Francisco Earthquake, the calculations indicate that small to moderate damage would have occurred if the levees were at today's configuration during the 1906 event.
- The earthquake ground motions were compared to the 1992 DWR study and to the 2000 CALFED study. The results for the 200-year return period event were found to be very similar. The 200-year event is being considered as the design earthquake for the seismic upgrade of the Delta levees.
- The vulnerability classes 1 through 4 are the most vulnerable levees to seismic loading. These include islands with liquefiable levee fill, and peat/organic soil deposits and potentially liquefiable sand deposits in the foundation. Such islands include but are not limited to Sherman, Brannan-Andrus, Twitchel, Webb, Venice, Bouldin, and many others. The majority of the islands have at least one levee reach in vulnerability classes 1 to 4, as shown in Figure 6-37b.
- The sensitivity analysis showed that the weakest vulnerability class within an island levee generally controls the performance of that island, per the "weakest link" principle.
- Seismic site response in the Delta is quite complex due to the highly variable younger alluvial deposits, organic marsh deposits, and levee fill condition. Studies conducted on this topic have produced a promising generalized methodology for estimating site response in the Delta (Kishida et al. 2007). However, other studies such as the work conducted under DRMS, which looked at a limited number of sites and a limited number of earthquake time histories, showed higher site amplification when comparing the maximum crest acceleration to the reference PGA. We adopted the results from the published studies by Kishida et al. (2007) since other studies are still in progress. The use of the site response from Kishida et al. (2007) may not appear to be conservative compared to other work, but when comparing reference PGA to acceleration within the foundation loose sand or at the base of the levee, these differences become much smaller.

Assuming 2 feet of freeboard:

- The median probabilities of failure for classes 1 to 4 (liquefiable fill and peat in the foundation) range from 5 percent to 28 percent at a reference PGA of 0.10g and from 70 percent to 90 percent for a reference PGA of 0.5g.

- The median probabilities of failure for classes with no liquefiable foundation sand and no liquefiable levee fill increase with peat thickness under the levee. When peat is absent, generally the probabilities of failure are small (less than 22 percent) for the largest ground motions of 0.5g. However, the probabilities of failure at the locations of the thickest peat (more than 25 feet) range from 30 percent to 60 percent for a PGA of 0.5g.
- Where waterside slopes are steeper than 1.5H:1V, the estimated probability of failures tend to be larger for the same vulnerability classes. For example the steep waterside slope VC-18 shows a two-times-higher probability of failure when compared to the non-steep waterside slope VC-22.

General seismic performance observations:

- At Suisun Marsh, the earthquake-induced deformations under strong shaking are large as a result of deep, very soft clay deposits forming at the levee foundation.
- The areas most prone to liquefaction potential are in the northern region and the southeastern region of the Delta. The central and western regions of the Delta and Suisun Marsh show discontinuous areas of moderate to low liquefaction potential.
- Levees composed of liquefiable fill are likely to undergo extensive damage as a result of a moderate to large earthquake in the region.
- Levees founded on liquefiable foundations are expected to experience large deformations (in excess of 10 feet) under a moderate to large earthquake in the region.

Tables

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
San Andreas (Northern and Central)	1.0	Unsegmented (0.5)	1906	473	13 ± 3	90	N/A	SS	7.9	24 ± 3	Characterization based on WGCEP (2003). Unsegmented rupture scenario is a repeat of the 1906 **M** 7.9 San Francisco earthquake.
		Two Segments (0.2)	Offshore + North Coast	326	11 ± 2	90	N/A	SS	7.7	24 ± 3	
			Peninsula + Santa Cruz Mountains	147	13 ± 2	90	N/A	SS	7.4	17 ± 4	
		Three Segments (0.1)	Offshore + North Coast	326	11 ± 2	90	N/A	SS	7.7	24 ± 3	
			Peninsula	85	13 ± 2	90	N/A	SS	7.2	17 ± 4	
			Santa Cruz Mountains	62	15 ± 2	90	N/A	SS	7.0	17 ± 4	
		Floating Earthquake (0.2)	N/A	N/A	13 ± 3	90	N/A	SS	6.9	24 ± 3	
Calaveras	1.0	Unsegmented (0.05)	Northern + Central + Southern Calaveras	123	11 ± 2	90	N/A	SS	6.9	4 (0.2) 6 (0.4) 15 (0.3) 20 (0.1)	Characterization of WGCEP (2003) modified by recent paleoseismic data of Kelson (written communication, 2006).
		Two Segments (0.05)	Northern Calaveras	45	13 ± 2	90	N/A	SS	6.8	6 ± 2	
			South + Central Calaveras	78	11 ± 2	90	N/A	SS	6.4	15 ± 3	
		Three Segments (0.3)	Northern Calaveras	45	13 ± 2	90	N/A	SS	6.8	6 ± 2	
			Central Calaveras	59	11 ± 2	90	N/A	SS	6.2	15 ± 3	
			Southern Calaveras	19	11 ± 2	90	N/A	SS	5.8	15 ± 3	
		Segment + Floating Earthquake (0.5)	Northern Calaveras	45	13 ± 2	90	N/A	SS	6.8	6 ± 2	
			Floating Earthquake on Central + South Calaveras	N/A	11 ± 2	90	N/A	SS	6.2	15 ± 3	
		Floating Earthquake (0.1)	N/A	N/A	11 ± 2	90	N/A	SS	6.2	4 (0.2) 6 (0.4) 15 (0.3) 20 (0.1)	
Concord – Green Valley	1.0	Unsegmented (0.35)	N/A	56	14 ± 2	90	N/A	SS	6.7	5 ± 3	Characterization based on WGCEP (2003).
		Three Segments (0.1)	Concord	20	16 ± 2	90	N/A	SS	6.25	4 ± 2	
			Southern Green Valley	22	14 ± 2	90	N/A	SS	6.25	5 ± 3	
			Northern Green Valley	14	14 ± 2	90	N/A	SS	6.0	5 ± 3	
		Two Segments (0.15)	Concord	20	16 ± 2	90	N/A	SS	6.25	4 ± 2	
			Green Valley	36	14 ± 2	90	N/A	SS	6.5	5 ± 3	
		Two Segments (0.15)	Concord + Southern Green Valley	42	14 ± 2	90	N/A	SS	6.6	5 ± 3	
			Northern Green Valley	14	14 ± 2	90	N/A	SS	6.0	5 ± 3	
		Floating Earthquake (0.25)	N/A	N/A	14 ± 2	90	N/A	SS	6.2	5 ± 3	
Greenville	1.0	Unsegmented (0.4)	N/A	58	15 ± 3	90	N/A	SS	6.9	2 (0.2) 4 (0.6) 6 (0.2)	Characterization based on paleoseismic data from Sawyer and Unruh (2002). and T.L. Sawyer (personal communication, 2006).
		Floating (0.6)	N/A	N/A	15 ± 3	90	N/A	SS	6.5	2 (0.2) 4 (0.6) 6 (0.2)	

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
Hayward – Rodgers Creek	1.0	Unsegmented (0.05)	Hayward + Rodgers Creek	151	12 ± 2	90	N/A	SS	7.3	9 ± 2	Characterization based on WGCEP (2003) model.
		Two Segment (A) (0.1)	North Hayward + Rodgers Creek	98	12 ± 2	90	N/A	SS	7.1	9 ± 2	
			Southern Hayward	53	12 ± 2	90	N/A	SS	6.7	9 ± 2	
		Two Segment (B) (0.3)	Rodgers Creek	63	12 ± 2	90	N/A	SS	7.0	9 ± 2	
			Hayward	88	12 ± 2	90	N/A	SS	6.9	9 ± 2	
		Three Segment (0.5)	Rodgers Creek	63	12 ± 2	90	N/A	SS	7.0	9 ± 2	
			North Hayward	35	12 ± 2	90	N/A	SS	6.5	9 ± 2	
			Southern Hayward	53	12 ± 2	90	N/A	SS	6.7	9 ± 2	
		Floating Earthquake (0.05)	N/A	N/A	12 ± 2	90	N/A	SS	6.9	9 ± 2	
Mt Diablo	1.0	Unsegmented (0.5)	N/A	31	17 ± 2	30 (0.2) 45 (0.6) 50 (0.2)	NE	R	6.7	1 (0.2) 3 (0.6) 5 (0.2)	Characterization from Unruh (2006). Fault tip inferred to approach within 5 km (0.5) to 1 km (0.5) of the surface based on restorable cross section, and on map-scale relationships between surface faults and fold axis.
		Segmented (0.5)	Mt. Diablo North	12	17 ± 2	30 (0.2) 45 (0.6) 50 (0.2)	NE	R	6.3	1 (0.2) 3 (0.6) 5 (0.2)	North: Fault tip inferred to approach within 4 km (0.5) to 2 km (0.5) of the surface based on model in restorable cross section.
			Mt. Diablo South	19	17 ± 2	30 (0.2) 45 (0.6) 50 (0.2)	NE	R	6.6	1 (0.2) 3 (0.6) 5 (0.2)	South: Fault tip inferred to approach within 5 km (0.5) to 1 km (0.5) of the surface based on model in restorable cross section, and map-scale relationships between surface faults and fold axis.
San Gregorio	1.0	Unsegmented (0.35)	Northern + Southern San Gregorio	176	13 ± 2	90	N/A	SS	7.5	1 (01) 3 (0.4) 7 (0.4) 10 (0.1)	Characterization based on WGCEP (2003) model.
		Segmented (0.35)	Northern San Gregorio	110	13 ± 2	90	N/A	SS	7.2	7 ± 3	
			Southern San Gregorio	66	12 ± 2	90	N/A	SS	7.0	3 ± 2	
		Floating Earthquake (0.3)	N/A	N/A	13 ± 2	90	N/A	SS	6.9	1 (0.1) 3 (0.4) 7 (0.4) 10 (0.1)	
Briones (zone)	1.0	N/A	N/A	23	15 ± 3	90	N/A	SS	6.5	0.5 (0.2) 1.0 (0.6) 2.0 (0.2)	Characterization from Unruh (2006).
Collayomi	1.0	Unsegmented (1.0)	N/A	29	10	90	N/A	SS	6.5	0.6 ± 0.3	Cao et al. (2003)
Cordelia	1.0	Unsegmented (1.0)	N/A	19	15 ± 3	90	N/A	SS	6.6	0.05 (0.4) 0.6 (0.5) 1.0 (0.1)	Characterization based on paleoseismic data from Harlan Tait & Associates (1994).
CRSB North of Delta	1.0	Multisegment (0.1)	Mysterious Ridge	35	13 ± 2	25 ± 5	W	R	6.7	1.0 (0.7) 3.5 (0.3)	Characterization revised from WGNCEP (1996) using data from O'Connell et al. (2001). Fault tip of Mysterious Ridge, Trout Creek, and Gordon Valley at depths of 7, 9, and 8 km, respectively. Segment lengths have an uncertainty of ± 5 km.
			Trout Creek + Gordon Valley	38	13 ± 2	25 ± 10	W	R	6.8	0.5 (0.3) 1.25 (0.6) 2.0 (0.1)	
		Segmented (0.9)	Mysterious Ridge	35	13 ± 2	25 ± 5	W	R	6.7	1.0 (0.7) 3.5 (0.3)	
			Trout Creek	20	13 ± 2	20 ± 5	W	R	6.5	0.5 (0.3) 1.25 (0.6) 2.0 (0.1)	

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
CRSB North of Delta (cont'd.)			Gordon Valley	18	13 ± 2	30 ± 5	W	R	6.4	0.5 (0.3) 1.25 (0.6) 2.0 (0.1)	
Cull Canyon-Lafayette-Reliz Valley	1.0	Unsegmented (1.0)	N/A	25	12 ± 3	90°	N/A	SS	6.6	0.5 (0.2) 1.0 (0.6) 3.0 (0.2)	Characterization from Unruh and Kelson (2002) and Unruh (2006).
Foothill Thrust System	0.6	Floating Earthquake (1.0)	N/A	N/A	15 ± 3	60	SW	R	6.25 (0.3) 6.5 (0.3) 6.75 (0.3) 7.0 (0.1)	0.2 (0.2) 0.5 (0.6) 0.8 (0.2)	Simplified characterization based on WGCEP (2003) subgroup and recent studies as summarized in Kennedy et al. (2005). Incorporates Berrocal, Shannon-Monte Vista, Stanford, and Cascade faults. Although evidence of Holocene and latest Pleistocene fold deformation along this fault zone is clear (Hitchcock and Kelson 1999; Bullard et al. 2004), the fault is assigned a Probability of Activity of 0.6 to address the uncertainty as to whether the fault is an independent seismic source capable of generating moderate to large magnitude earthquakes. The seismogenic potential of the range front thrust faults is not well known. Aseismic slip (Bürgmann et al. 1994) and coseismic slip during large magnitude events on the San Andreas fault system fault, such as occurred during the 1989 Loma Prieta earthquake (Haugerud and Ellen 1990) may account for some or all of the local San Andreas fault-normal contraction, precluding the need for independent large magnitude events on the compressive structures. (Angell et al. 1997; Hitchcock and Kelson 1999).
Hunting Creek-Berryessa	1.0	Unsegmented (1.0)	N/A	60	12	90	N/A	SS	6.9	6 ± 3	Cao et al. (2003)
Las Trampas	0.5	Unsegmented	N/A	12	14 ± 3	45° 60° 75°	SW	R	6.2	0.5 (0.2) 1.0 (0.6) 3.0 (0.2)	Characterization from Unruh and Kelson (2002) and Unruh (personal communication, 2006).
Los Medanos Fold and Thrust Belt	1.0	Unsegmented (0.2)	N/A	15	17 ± 2	30 (0.2) 45 (0.2) 60 (0.6)	NE	R	6.5	0.3 (0.3) 0.5 (0.4) 0.7 (0.3)	Characterization based on Unruh and Hector (1999) and the Thrust Fault Subgroup of the 1999 Working Group. Roe thrust: fault tip inferred to lie between 0 km and 1 km depth based on analysis of gas well data.
		Segmented (0.8)	Roe Island	5	5 ± 2	30 (0.2) 45 (0.2) 60 (0.6)	NE	R	5.8	0.3 (0.3) 0.5 (0.4) 0.7 (0.3)	Roe thrust: fault tip inferred to lie between 0 km and 1 km depth based on analysis of gas well data.
			Los Medanos	10	10 ± 2	30 (0.2) 45 (0.6) 60 (0.2)	NE	R	6.0	0.3 (0.3) 0.5 (0.4) 0.7 (0.3)	Los Medanos thrust: fault tip inferred to lie between 1 km and 2 km depth based on analysis of gas well data and construction of geologic cross sections.
Maacama-Garberville	1.0	Unsegmented (1.0)	N/A	182	12	90	N/A	SS	7.4	9.0 ± 2.0	Cao et al. (2003)
Midway/ Black Butte	1.0	Floating Earthquake (1.0)	N/A	31	15 ± 3	70 ± 10	W	RO	6.25 (0.2) 6.5 (0.4) 6.75 (0.4)	0.1 (0.3) 0.5 (0.4) 1.0 (0.3)	The Black Butte fault is a documented late Quaternary-active reverse (oblique?) fault (Sowers et al. 1992) that appears to be related to the late Cenozoic dextral Midway fault by a short left-restraining bend. Limited data are available on slip rate and rupture behavior. The slip rate estimate is based on uplift of middle to early Pleistocene pediment surface across the Black Butte fault (Sowers et al. 1992) and an inferred H:V ratio for the components of slip of ≤ 3:1.
Monterey Bay-Tularcitos	1.0	Unsegmented (1.0)	N/A	84	14	90	N/A	SS	7.1	0.5 ± 0.4	Cao et al. (2003)

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
Montezuma Hills (zone)	0.5	Floating Earthquake (1.0)	N/A	N/A	15 ± 5	70	W	RO	6.0 (0.3) 6.25 (0.4) 6.5 (0.3)	0.05 (0.3) 0.25 (0.4) 0.5 (0.3)	The Montezuma Hills source zone is considered as a possible independent source of seismicity based on the following: 1) the topographic and structural gradient of the hills is to the northeast, which is contrary to what would be expected if the hills were being uplifted in the hanging wall of the Midland fault; 2) the topography dies out west of the subsurface trace of the Midland fault, rather than extending up to the fault; 3) the Montezuma hills are spatially associated with the Antioch and Sherman Island faults, as well as some anomalous topography near the town of Oakley south of the Sacramento River. Alternatively, the uplift of this region is secondary tectonic deformation related to movement in the hanging wall of the Midland fault or transfer of slip from the Vernalis/West Tracy faults to the Pittsburg/Kirby Hills fault zone. Preferred orientation of modeled fault planes within zone (N20°W).
Mt Oso	0.7	Unsegmented (1.0)	N/A	25	15 ± 2	30 (0.3) 45 (0.4) 60 (0.3)	NE	R	6.9	0.5 (0.2) 1.5 (0.6) 2.5 (0.2)	Inferred thrust fault occupying the contractional stepover between the Ortigalita and Greenville faults. NE-dipping rupture geometry inferred from the SW-vergence of the Mt. Oso anticline and analogy to Mt. Diablo thrust (Unruh, Lettis and Associates, personal communication, 2006). Activity based on slip transfer from the northern Ortigalita to the southern Greenville. Fault tip at 5 km depth.
Northern Midland (zone)	1.0	Floating Earthquake (1.0)	N/A	N/A	15 ± 5	70	W	RO	6.0 (0.3) 6.25 (0.4) 6.5 (0.3)	0.1 (0.3) 0.5 (0.4) 1.0 (0.3)	Preferred orientation of modeled fault planes within zone (N30°W). North of Rio Vista, published data from gas exploration indicate that the Midland fault breaks into a zone of right-stepping en echelon fault traces. Anomalous, apparently uplifted Quaternary topography that appears to be associated with the stepover regions may be related to recent movement on a system of underlying oblique reverse faults in this zone. Tips of faults are inferred by CDOG (1982) to extend above the base of the Tertiary Markley Formation to depths of about 1.5 km, and possibly shallower. Minimum fault depth not constrained by data in CDOG (1982).
Orestimba	1.0	Unsegmented (1.0)	N/A	60	Tip 1 (0.5) 3 (0.5) Base 15 ± 3	30° (0.2) 45° (0.6) 60° (0.2)	W	R	6.7	0.2 (0.2) 0.4 (0.6) 0.6 (0.2)	Characterization based on Anderson and Piety (2001). Segment of Coast Range/Sierran block boundary(CRSB) (also referred to as the Coast Range/Central Valley fault system.). Anderson and Piety (2001) assign steeper dips (20 to 30°) to the Orestimba fault than considered in the CGS source model (Cao et al. 2003). The Thrust Subgroup of the 1999 Working Group, that provided input to WGCEP (2003), suggested a range of dip between 25° (similar to the Coalinga thrust fault) and 60° (predicted by Coulomb failure criteria).The steepness of the range along these segments from between approximately 36.5°N to 38°N suggests that the dip of the underlying structures is probably at the higher end of this range. Anderson and Piety (2001) provide estimates for the uplift rate along several segments based on the elevation of uplifted early (?) to middle Pleistocene pediment surfaces and late Pleistocene fluvial terraces (Sowars et al. 1992). These uplift rates are converted into slip rates using the range of fault dips assigned to each segment.

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
Ortigalita	1.0	Segmented (0.3)	Northern Ortigalita	40	15 ± 3	90	N/A	SS	6.9	0.5 (0.15) (0.35) (0.35) 2.5 (0.15)	Characterization revised from Cao et al. (2003) using recent mapping and paleoseismic data from Anderson and Piety (2001) to modify the lengths and slip rates for the north and south segments of the fault. They estimate a slip rate of 1.0-2.0 mm/yr for the northern section based on abundant geomorphic evidence for probable latest Pleistocene and Holocene displacement and, paleoseismic trench investigations that indicate that Quaternary deposits estimated to be between 10 ka and 25 ka, are right laterally offset between about 13 and 25 meters by the Cottonwood Arm segment of the Ortigalita fault. They note the southern segment appears much less active and accordingly, they assign a lower slip rate of 0.2 to 1.0 mm/yr to this segment.
			Southern Ortigalita	60	15 ± 3	90	N/A	SS	7.1	0.2 (0.2) 0.6 (0.6) 1.0 (0.2)	
Ortigalita (cont'd.)		Segmented + Floating Earthquake (0.7)	Northern Ortigalita	40	15 ± 3	90	N/A	SS	6.9	0.5 (0.15) 1.0 (0.35) 2.0 (0.35) 2.5 (0.15)	
			Floating Earthquake on Southern Ortigalita	60	15 ± 3	90	N/A	SS	6.6	0.2 (0.2) 0.6 (0.6) 1.0 (0.2)	
Pittsburgh-Kirby Hills	1.0	Unsegmented (0.4)	N/A	24	20 ± 5	90	N/A	SS	6.7	0.3 (0.4) 0.5 (0.4) 0.7 (0.2)	Characterization from the Thrust Fault Subgroup of the 1999 Working Group.
		Floating Earthquake (0.6)	N/A	N/A	20 ± 5	90	N/A	SS	6.3	0.3 (0.4) 0.5 (0.4) 0.7 (0.2)	
Potrero Hills	0.7	Unsegmented (1.0)	N/A	9	9 ± 2	40 ± 10	SW	R	5.75 (0.3) 6.0 (0.6) 6.25 (0.1)	0.1 (0.2) 0.3 (0.6) 0.6 (0.2)	Characterization based on Unruh and Hector (1999). Fault tip inferred to lie between 0 km and 1 km depth based on analysis of gas well data and construction of geologic cross sections. The fault is assigned a Probability of Activity of (0.7) based on geomorphic and physiographic evidence that slip is being transferred from the active Pittsburg Kirby Hills fault to Wragg Canyon and Hunting Creek-Berryessa fault zones to the north via the Potrero Hills fault.
Pt. Reyes	0.8	Unsegmented	N/A	47	12 ± 3	40 (0.2) 50 (0.6) 60 (0.2)	NE	R	7.0	0.05 (0.2) 0.3 (0.6) 0.5 (0.2)	Cao et al. (2003)
Quien Sabe	1.0	Unsegmented (1.0)	N/A	23	10	90	N/A	SS	6.4	0.1 (0.2) 1.0 (0.6) 2.0 (0.2)	Cao et al. (2003)
San Andreas (Southern)	1.0	Unsegmented (1.0)	N/A	312	12 ± 2	90	N/A	SS	7.8	28 (0.2) 33 (0.6) 38 (0.2)	Characterization from URS.
Sargent	0.8	Unsegmented (1.0)	Sargent	52	15 ± 3	80 ± 10	SW	RO	6.9	1.5 (0.3) 3.0 (0.4) 4.5 (0.3)	Characterization based on WGNCEP (1996). Geodetic measurements indicative of right slip across the southern Sargent fault (Prescott and Burford 1976), evidence for creep of about 3-4 mm/yr, as well as associated historical microseismicity suggest that the Sargent fault is an independent seismic source. The Sargent fault experienced triggered slip during the 1989 M_W 6.9 Loma Prieta earthquake (Aydin 1982). A Probability of Activity of less than 1.0 (0.9) considers that fault slip may occur coseismically as creep or during large magnitude events on the San Andreas fault.

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
Southeast Extension of Hayward (zone)	1.0	Unsegmented (1.0)	N/A	26	10	90	N/A	SS/RO	6.4	1.0 (0.2) 3.0 (0.6) 5.0 (0.2)	Characterization based on WGNCEP (1996), Graymer et al. (2006), and Fenton and Hitchcock (2001).
Southern Midland	0.8	Unsegmented (1.0)	N/A	26	15 ± 5	70	W	RO	6.6	0.1 (0.3) 0.5 (0.4) 1.0 (0.3)	Activity and rate is inferred from displacement of late Tertiary (and possibly early Pleistocene) strata in seismic reflection profiles (Weber-Band 1994) and apparent displacement of basal peat (Holocene) inferred from analysis of Atwater (1982) data (this study). Tip of fault is inferred by CDOG (1982) to extend above the base of the Tertiary Markley Formation to depths of about 1.5 km, and possibly shallower. Minimum fault depth not constrained by data in CDOG (1982).
Thornton Arch (zone)	0.2	Floating Earthquake (1.0)	N/A	N/A	15 ± 5	70	S (E-W strike)	RO	6.0 (0.3) 6.25 (0.4) 6.5 (0.3)	0.05 (0.3) 0.10.4) 0.15 (0.3)	Possible localization of Quaternary uplift suggesting the presence of active blind fault(s) is inferred based on the deflection of the Mokelumne River north around an arch mapped in the subsurface from oil and gas exploration data (California Division of Oil and Gas 1982). EW strike - based on the orientation of the mapped arch.
Vernalis	0.8	Floating Earthquake (1.0)	N/A	46	15 ± 3	70 ± 10	W	RO	6.25 (0.2) 6.5 (0.4) 6.75 (0.4)	0.07 (0.3) 0.25 (0.4) 0.5 (0.3)	Quaternary activity of the Vernalis fault is inferred from the distribution of older Quaternary deposits (CDMG 1:25,000 San Jose quadrangle) that indicate differential uplift across the fault. Sterling (1992) describes stratigraphic and structural relationships imaged by seismic reflection data indicating "movement as recently as late Pliocene." The slip rate is estimated to be comparable to the estimated rate for the West Tracy fault.
Verona/Williams Thrust System	1.0	Unsegmented (0.6)	N/A	22	21 ± 2	30 (0.1) 45 (0.6) 60 (0.3)	NE	R	6.7	0.1 (0.2) 0.7 (0.5) 1.4 (0.3)	In this model, the Verona/Williams fault is the near surface expression of a deeper east-to northeast-dipping blind thrust fault that underlies the Livermore Valley (Unruh and Sawyer 1997; Sawyer 1998). This model explains fault and fold deformation in the Livermore Valley (including the Los Positas fault, Livermore thrust and Springtown anticline) as secondary structures that either root into the deeper structure or are secondary structures in the hanging wall of the Verona/Williams thrust. These secondary structures are nonseismogenic and are not treated as independent seismic sources. The slip rate distribution is from Savy and Foxall (2002). Fault tip is estimated to be at a depth of 3 km (0.5) or 5 km (0.5).
		Segmented (0.4)	Verona	10	10	30 (0.2) 45 (0.4) 60 (0.4)	NE	R	6.2	0.1 (0.2) 0.7 (0.5) 1.4 (0.3)	Characterization of the fault is based on information summarized in Herd and Brabb (1980), Hart (1980 1981a,b), Jahns and Harding (1982), and source parameters developed by the Thrust Fault Subgroup of Working Group 1999 (WGCEP (2003) subgroup). The total length of the fault is approximately 7-9 km. Field observations and trenching described by Herd and Brabb (1980) provide evidence for late Quaternary surface-rupturing events on the fault. A 5.65-km-long-segment of the fault is included in an Alquist-Priolo zone (Hart 1980, 1981a,b). The slip rate distribution is from Savy and Foxall (2002). Fault tip is estimated to be at a depth of 3 km (0.5) or 5 km (0.5).
			Williams	13	13	30 (0.1) 45 (0.6) 60 (0.3)	NE	R	6.3	0.1 (0.2) 0.3 (0.6) 1.0 (0.2)	Characterization of the fault is based on the following. The total length of the fault is based on mapping by Dibblee (1980, 1981). Carpenter et al. (1984) show the fault as a southwest-vergent thrust fault. The DWR (1979) suggested the fault was active based on displacements observed in Plio-Pleistocene Livermore gravels in the Hetch-Hetchy tunnel and the occurrence of moderate seismicity adjacent to its trace. In the absence of any reported slip rate estimates, a rate of slip comparable to Verona fault is used. Fault tip is estimated to be at a depth of 3 km (0.5) or 5 km (0.5).

Table 6-1 Bay Area Time-Independent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Scenario[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Slip Rate[9]	Notes
			Las Positas P(a) = 0.7	17.5	15 ± 3	90	N/A	SS	6.5	0.1 (0.2) 0.3 (0.6) 1.0 (0.2)	Characterization is based on information summarized by Carpenter et al. (1980,1984) as follows. The total length of ~17.5 km is based on geologic mapping and air photo interpretation. Movement on both southern and northern fault traces extends up into Holocene deposits: faulting may have occurred as recently as 500 to 1,000 years ago. The average slip rate for the north branch of the Las Positas fault zone is 0.4 mm/yr; the range of rates obtained from observed vertical offset and inferred horizontal-to-vertical ratios and age estimates is 0.02 to 0.9 mm/yr.
West Napa	1.0	Unsegmented (0.15)	St. Helena/Dry Creek + West Napa	52	15 ± 3	90	N/A	SS	6.9	1.0 (0.3) 2.0 (0.3) 3.0 (0.3) 4.0 (0.1)	Characterization is based on recent compilation and mapping of the West Napa fault by Hanson and Wesling (2006, 2007) and Clahan et al. (2006) conducted in support of the USGS Quaternary fault database for Northern California (Graymer et al. 2006). The slip rate for the West Napa is not well constrained, but was previously considered to be on the order of 1 mm/yr (1 ± 1 mm/yr, Cao et al. 2003). Several recent studies and observations suggest
		Floating Earthquake (0.35)	N/A	N/A	15 ± 3	90	N/A	SS	6.5	0.5 (0.1) 1.0 (0.3) 2.0 (0.3) 3.0 (0.2) 4/0 (0.1)	the slip rate is higher. These include: 1) more detailed mapping of the fault zone (Hanson and Wesling 2006, 2007) that shows that the fault is better expressed geomorphically than had been recognized previously with evidence for recent (< 600 to 700 years B. P.) displacement; 2) comparison of slip budgets between the regions north and south of Carquinez Strait suggests that a significant amount of slip is being transferred from the North Calaveras fault to the West Napa fault via the Cull Canyon/Laffette/Reliz Valley fault zone; and 3) a recent analysis of GPS data with the preferred model indicating a rate of 4 ± 3 mm/yr (d'Alessio et al. 2005).
		Segmented (0.15)	St. Helena/Dry Creek	24	15 ± 3	90	N/A	SS	6.6	1.0 (0.5) 2.0 (0.2) 3.0 (0.1)	
			West Napa	38	15 ± 3	90	N/A	SS	6.8	1.0 (0.5) 2.0 (0.2) 3.0 (0.1)	
		Segmented + Floating Earthquake (0.35)	Floating Earthquake on West Napa	N/A	15 ± 3	90	N/A	SS	6.4	1.0 (0.5) 2.0 (0.2) 3.0 (0.1)	
			St. Helena/Dry Creek	N/A	15 ± 3	90	N/A	SS	6.4	1.0 (0.5) 2.0 (0.2) 3.0 (0.1)	
		Floating Earthquake (0.9)	N/A	N/A	15 ± 5	70	W	RO	6.0 (0.3) 6.25 (0.4) 6.5 (0.3)	0.1 (0.3) 0.5 (0.4) 1.0 (0.3)	
West Tracy	0.9	Floating Earthquake (1.0)	N/A	30	15 ± 3	70 ± 10	W	RO	6.25 (0.2) 6.5 (0.4) 6.75 (0.4)	0.07 (0.3) 0.25 (0.4) 0.5 (0.3)	Quaternary activity of the West Tracy fault is inferred from the distribution of older Quaternary deposits (CDMG 1:25,000 San Jose quadrangle) that indicate differential uplift across the fault. Very limited data are available to estimate the rate of slip and recent fault behavior. The rate of reverse-oblique slip is inferred to be approximately half the rate estimated for the Midway/Black Butte fault zone. A lower bound of 0.07 mm/yr on the slip rate is estimated based on total vertical separation of about 800 feet (244 meters) of a basal Miocene unconformity across the fault as reported by Sterling (1992), and an assumed duration of deformation (active during the past ~3.5 Ma).
Wragg Canyon	0.7	Unsegmented (1.0)	N/A	17	15 ± 3	90	N/A	SS	6.5	0.1 (0.2) 0.3 (0.6) 0.5 (0.2)	Fault mapped by Sims et al. (1973) along Wragg Canyon; O'Connell et al. (2001) inferred that small earthquakes with strike-slip focal mechanisms are associated with the fault.
Zayente-Vergeles	1.0	Unsegmented (1.0)	N/A	58	12	70 ± 10	SW	R	6.9	0.1 ± 0.1	Cao et al. (2003); Dip information from USGS Quaternary Database

Table 6-2 Bay Area Time-Dependent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Source[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Year	Rate of Characteristic Event[9]			Activity Rate		
											5%	5%	Mean	95%	Mean	95%
		SAS	Santa Cruz Mountains	62	15	90	N/A	SS	6.87	2005:	0.00E+00	4.31E-04	1.79E-03	0.00E+00	1.77E-03	7.34E-03
									7.03	2050:	0.00E+00	2.19E-03	8.26E-03	0.00E+00	9.01E-03	3.39E-02
									7.19	2100:	0.00E+00	4.77E-03	1.92E-02	0.00E+00	1.96E-02	7.90E-02
										2200:	0.00E+00	7.37E-03	3.02E-02	0.00E+00	3.03E-02	1.24E-01
		SAP	Peninsula	85	13	90	N/A	SS	6.97	2005:	0.00E+00	1.31E-03	5.60E-03	0.00E+00	4.32E-03	1.85E-02
									7.15	2050:	0.00E+00	2.61E-03	9.56E-03	0.00E+00	8.63E-03	3.16E-02
									7.31	2100:	0.00E+00	3.71E-03	1.41E-02	0.00E+00	1.23E-02	4.66E-02
										2200:	0.00E+00	4.44E-03	1.64E-02	0.00E+00	1.47E-02	5.43E-02
		SAN	North Coast	191	11	90	N/A	SS	7.30	2005:	0.00E+00	2.12E-04	9.31E-04	0.00E+00	1.15E-03	5.04E-03
									7.45	2050:	0.00E+00	4.14E-04	1.67E-03	0.00E+00	2.24E-03	9.06E-03
									7.59	2100:	0.00E+00	6.07E-04	2.25E-03	0.00E+00	3.29E-03	1.22E-02
										2200:	0.00E+00	8.10E-04	2.99E-03	0.00E+00	4.38E-03	1.62E-02
		SAO	Offshore	135	11	90	N/A	SS	7.13	2005:	0.00E+00	1.80E-04	8.87E-04	0.00E+00	7.50E-04	3.70E-03
									7.29	2050:	0.00E+00	4.04E-04	1.70E-03	0.00E+00	1.69E-03	7.10E-03
									7.44	2100:	0.00E+00	7.08E-04	2.67E-03	0.00E+00	2.96E-03	1.11E-02
										2200:	0.00E+00	1.16E-03	4.33E-03	0.00E+00	4.83E-03	1.81E-02
		SAS+SAP	Peninsula + Santa Cruz Mountains	147		90	N/A	SS	7.28	2005:	3.87E-05	1.01E-03	3.22E-03	2.03E-04	5.33E-03	1.69E-02
									7.42	2050:	1.46E-04	2.06E-03	5.83E-03	7.68E-04	1.08E-02	3.06E-02
									7.55	2100:	2.08E-04	3.14E-03	9.59E-03	1.09E-03	1.65E-02	5.03E-02
										2200:	2.46E-04	4.09E-03	1.28E-02	1.29E-03	2.15E-02	6.69E-02
		SAN+SAO	Offshore + North Coast	326	11	90	N/A	SS	7.55	2005:	2.05E-05	9.43E-04	2.95E-03	1.73E-04	7.96E-03	2.49E-02
									7.70	2050:	2.82E-04	1.65E-03	4.50E-03	2.38E-03	1.40E-02	3.80E-02
									7.83	2100:	4.05E-04	2.35E-03	5.94E-03	3.42E-03	1.98E-02	5.01E-02
										2200:	4.87E-04	3.17E-03	7.99E-03	4.11E-03	2.67E-02	6.74E-02
		SAS+SAP+SAN	North Coast + Peninsula + Santa Cruz Mountains	338	13 ± 3	90	N/A	SS	7.62	2005:	0.00E+00	1.66E-05	8.98E-05	0.00E+00	1.57E-04	8.47E-04
									7.76	2050:	0.00E+00	2.71E-05	1.10E-04	0.00E+00	2.56E-04	1.04E-03
									7.89	2100:	0.00E+00	3.68E-05	1.34E-04	0.00E+00	3.47E-04	1.27E-03
										2200:	0.00E+00	4.64E-05	1.58E-04	0.00E+00	4.38E-04	1.49E-03
		SAP+SAN+SAO	Offshore + North Coast + Peninsula	411	11 ± 2	90	N/A	SS	7.67	2005:	0.00E+00	4.43E-05	2.82E-04	0.00E+00	4.84E-04	3.08E-03
									7.82	2050:	0.00E+00	7.34E-05	4.21E-04	0.00E+00	8.02E-04	4.60E-03
									7.97	2100:	0.00E+00	1.01E-04	4.99E-04	0.00E+00	1.10E-03	5.46E-03
										2200:	0.00E+00	1.31E-04	5.96E-04	0.00E+00	1.43E-03	6.52E-03
		SAS+SAP+SAN+SAO	Offshore + North Coast + Peninsula + Santa Cruz Mountains (1906)	473	13 ± 2	90	N/A	SS	7.75	2005:	7.82E-05	1.46E-03	4.25E-03	9.74E-04	1.81E-02	5.30E-02
									7.90	2050:	5.97E-04	2.30E-03	6.16E-03	7.44E-03	2.86E-02	7.66E-02
									8.06	2100:	1.03E-03	3.08E-03	7.74E-03	1.29E-02	3.83E-02	9.63E-02
										2200:	1.31E-03	3.94E-03	9.02E-03	1.64E-02	4.90E-02	1.12E-01
		Floating Earthquake	N/A	N/A	13 ± 3	90	N/A	SS	6.9	2005:	1.62E-04	1.81E-03	6.49E-03	3.87E-04	4.33E-03	1.55E-02
										2050:	1.99E-04	3.72E-03	1.32E-02	4.76E-04	8.89E-03	3.16E-02
										2100:	2.09E-04	5.80E-03	2.14E-02	5.00E-04	1.39E-02	5.12E-02
										2200:	2.12E-04	8.03E-03	3.12E-02	5.07E-04	1.92E-02	7.45E-02

Table 6-2 Bay Area Time-Dependent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Source[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Year	Rate of Characteristic Event[9]			Activity Rate		
											5%	5%	Mean	95%	Mean	95%
Hayward – Rodgers Creek	1.0	HS	Southern Hayward	53	12 ± 2	90	N/A	SS	6.42	2005:	8.66E-04	4.24E-03	1.08E-02	1.56E-03	7.63E-03	1.95E-02
									6.67	2050:	1.15E-03	5.13E-03	1.28E-02	2.06E-03	9.23E-03	2.31E-02
									6.90	2100:	1.28E-03	5.75E-03	1.48E-02	2.31E-03	1.04E-02	2.66E-02
										2200:	1.38E-03	6.41E-03	1.65E-02	2.49E-03	1.15E-02	2.96E-02
		HN	North Hayward	35	12 ± 2	90	N/A	SS	6.20	2005:	9.57E-04	5.17E-03	1.46E-02	1.44E-03	7.77E-03	2.19E-02
									6.49	2050:	1.05E-03	5.48E-03	1.54E-02	1.58E-03	8.25E-03	2.32E-02
									6.73	2100:	1.14E-03	5.75E-03	1.57E-02	1.72E-03	8.66E-03	2.37E-02
										2200:	1.20E-03	6.06E-03	1.64E-02	1.81E-03	9.13E-03	2.47E-02
		HS+HN	Hayward	88	12 ± 2	90	N/A	SS	6.71	2005:	7.36E-04	3.38E-03	8.65E-03	1.72E-03	7.91E-03	2.03E-02
									6.90	2050:	8.37E-04	3.88E-03	1.03E-02	1.96E-03	9.10E-03	2.42E-02
									7.09	2100:	9.21E-04	4.26E-03	1.14E-02	2.16E-03	9.97E-03	2.66E-02
										2200:	1.02E-03	4.67E-03	1.28E-02	2.38E-03	1.10E-02	3.01E-02
		RC	Rodgers Creek	63	12 ± 2	90	N/A	SS	6.83	2005:	1.56E-03	5.93E-03	1.44E-02	4.16E-03	1.58E-02	3.85E-02
									6.98	2050:	1.72E-03	6.49E-03	1.71E-02	4.58E-03	1.73E-02	4.56E-02
									7.14	2100:	1.89E-03	6.97E-03	1.88E-02	5.05E-03	1.86E-02	5.02E-02
										2200:	2.23E-03	7.59E-03	2.07E-02	5.93E-03	2.02E-02	5.50E-02
		HN+RC	North Hayward + Rodgers Creek	98	12 ± 2	90	N/A	SS	6.96	2005:	4.10E-05	7.60E-04	2.34E-03	1.29E-04	2.38E-03	7.35E-03
									7.11	2050:	4.49E-05	8.25E-04	2.53E-03	1.41E-04	2.59E-03	7.95E-03
									7.27	2100:	4.91E-05	8.81E-04	2.78E-03	1.54E-04	2.76E-03	8.73E-03
										2200:	4.91E-05	9.50E-04	2.97E-03	1.54E-04	2.98E-03	9.32E-03
		HS+HN+RC	Hayward + Rodgers Creek	151	12 ± 2	90	N/A	SS	7.11	2005:	6.14E-05	4.11E-04	1.11E-03	2.39E-04	1.60E-03	4.35E-03
									7.26	2050:	6.76E-05	4.59E-04	1.32E-03	2.64E-04	1.79E-03	5.14E-03
									7.40	2100:	7.33E-05	4.98E-04	1.43E-03	2.86E-04	1.94E-03	5.60E-03
										2200:	7.95E-05	5.44E-04	1.63E-03	3.10E-04	2.12E-03	6.37E-03
		Floating Earthquake	N/A	N/A	12 ± 2	90	N/A	SS	6.90	2005:	1.02E-04	2.52E-04	4.80E-04	2.44E-04	6.02E-04	1.15E-03
										2050:	1.09E-04	2.59E-04	4.85E-04	2.61E-04	6.20E-04	1.16E-03
										2100:	1.19E-04	2.70E-04	4.94E-04	2.84E-04	6.45E-04	1.18E-03
										2200:	1.35E-04	2.90E-04	5.46E-04	3.23E-04	6.94E-04	1.30E-03
Calaveras	1.0	CS	Southern Calaveras	19	11 ± 2	90	N/A	SS	0.0	2005:	0.00E+00	1.17E-02	3.77E-02	0.00E+00	1.60E-02	5.15E-02
									5.79	2050:	0.00E+00	1.21E-02	4.03E-02	0.00E+00	1.66E-02	5.52E-02
									6.12	2100:	0.00E+00	1.25E-02	4.15E-02	0.00E+00	1.70E-02	5.68E-02
										2200:	0.00E+00	1.30E-02	4.24E-02	0.00E+00	1.78E-02	5.80E-02
		CC	Central Calaveras	59	11 ± 2	90	N/A	SS	5.79	2005:	8.25E-04	6.40E-03	1.80E-02	1.00E-03	7.78E-03	2.19E-02
									6.23	2050:	1.97E-03	8.52E-03	2.49E-02	2.40E-03	1.04E-02	3.03E-02
									6.61	2100:	2.10E-03	9.12E-03	2.63E-02	2.55E-03	1.11E-02	3.20E-02
										2200:	2.38E-03	9.57E-03	2.70E-02	2.90E-03	1.16E-02	3.29E-02
		CS+CC	South + Central Calaveras	78	11 ± 2	90	N/A	SS	5.93	2005:	0.00E+00	2.16E-03	7.92E-03	0.00E+00	2.85E-03	1.04E-02
									6.36	2050:	0.00E+00	2.74E-03	1.01E-02	0.00E+00	3.61E-03	1.33E-02
									6.68	2100:	0.00E+00	2.94E-03	1.09E-02	0.00E+00	3.88E-03	1.44E-02
										2200:	0.00E+00	3.09E-03	1.14E-02	0.00E+00	4.08E-03	1.50E-02
		CN	Northern Calaveras	45	13 ± 2	90	N/A	SS	6.62	2005:	1.10E-03	5.14E-03	1.45E-02	2.28E-03	1.06E-02	3.00E-02
									6.78	2050:	1.23E-03	5.50E-03	1.57E-02	2.54E-03	1.14E-02	3.26E-02
									6.93	2100:	1.35E-03	5.82E-03	1.68E-02	2.79E-03	1.20E-02	3.48E-02
										2200:	1.56E-03	6.26E-03	1.81E-02	3.23E-03	1.30E-02	3.74E-02
		CC+CN	Central + Northern Calaveras	104	13 ± 2	90	N/A	SS	6.72	2005:	0.00E+00	1.37E-04	1.00E-03	0.00E+00	3.24E-04	2.37E-03
									6.91	2050:	0.00E+00	1.65E-04	1.14E-03	0.00E+00	3.91E-04	2.70E-03
									7.08	2100:	0.00E+00	1.81E-04	1.28E-03	0.00E+00	4.28E-04	3.02E-03
										2200:	0.00E+00	1.97E-04	1.36E-03	0.00E+00	4.67E-04	3.21E-03

Table 6-2 Bay Area Time-Dependent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Source[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Year	Rate of Characteristic Event[9]			Activity Rate		
											5%	5%	Mean	95%	Mean	95%
Calaveras (cont'd.)		CS+CC+CN	Northern + Central + Southern Calaveras	123	11 ± 2	90	N/A	SS	6.76	2005:	0.00E+00	8.05E-04	2.81E-03	0.00E+00	1.99E-03	6.96E-03
									6.94	2050:	0.00E+00	9.38E-04	3.40E-03	0.00E+00	2.32E-03	8.42E-03
									7.11	2100:	0.00E+00	1.00E-03	3.58E-03	0.00E+00	2.48E-03	8.85E-03
										2200:	0.00E+00	1.07E-03	3.71E-03	0.00E+00	2.65E-03	9.17E-03
		Floating Earthquake	N/A	N/A	11 ± 2	90	N/A	SS	6.2	2005:	6.17E-04	2.63E-03	6.66E-03	7.83E-04	3.34E-03	8.45E-03
										2050:	6.92E-04	2.73E-03	6.67E-03	8.78E-04	3.46E-03	8.47E-03
										2100:	7.43E-04	2.85E-03	6.88E-03	9.43E-04	3.62E-03	8.73E-03
										2200:	8.39E-04	3.11E-03	7.86E-03	1.06E-03	3.95E-03	9.98E-03
		Floating Earthquake on CS+CC	N/A	N/A	11 ± 2	90	N/A	SS	6.2	2005:	2.10E-03	1.04E-02	2.50E-02	2.66E-03	1.32E-02	3.17E-02
										2050:	2.22E-03	1.07E-02	2.51E-02	2.81E-03	1.36E-02	3.18E-02
										2100:	2.37E-03	1.13E-02	2.64E-02	3.00E-03	1.43E-02	3.35E-02
										2200:	2.55E-03	1.23E-02	2.88E-02	3.24E-03	1.56E-02	3.66E-02
Concord – Green Valley	1.0	CON	Concord	20	16 ± 2	90	N/A	SS	5.79	2005:	1.56E-04	1.88E-03	5.70E-03	1.91E-04	2.30E-03	6.97E-03
									6.25	2050:	2.02E-04	2.06E-03	6.03E-03	2.47E-04	2.51E-03	7.36E-03
									6.65	2100:	2.21E-04	2.21E-03	6.63E-03	2.70E-04	2.70E-03	8.10E-03
										2200:	2.66E-04	2.41E-03	7.06E-03	3.25E-04	2.94E-03	8.63E-03
		GVS	Southern Green Valley	22	14 ± 2	90	N/A	SS	5.81	2005:	6.22E-05	8.78E-04	2.85E-03	7.57E-05	1.07E-03	3.47E-03
									6.24	2050:	8.50E-05	9.57E-04	3.08E-03	1.03E-04	1.16E-03	3.75E-03
									6.60	2100:	9.77E-05	1.02E-03	3.20E-03	1.19E-04	1.25E-03	3.90E-03
										2200:	1.16E-04	1.11E-03	3.49E-03	1.41E-04	1.35E-03	4.25E-03
		CON+GVS	Concord + Southern Green Valley	42	14 ± 2	90	N/A	SS	6.20	2005:	2.78E-05	5.99E-04	2.00E-03	4.42E-05	9.54E-04	3.19E-03
									6.58	2050:	3.28E-05	6.52E-04	2.13E-03	5.23E-05	1.04E-03	3.40E-03
									6.87	2100:	4.30E-05	6.99E-04	2.29E-03	6.85E-05	1.11E-03	3.64E-03
										2200:	5.32E-05	7.60E-04	2.52E-03	8.47E-05	1.21E-03	4.01E-03
		GVN	Northern Green Valley	14	14 ± 2	90	N/A	SS	5.56	2005:	1.98E-04	2.36E-03	7.05E-03	2.17E-04	2.59E-03	7.74E-03
									6.02	2050:	2.33E-04	2.55E-03	7.56E-03	2.55E-04	2.80E-03	8.31E-03
									6.43	2100:	2.73E-04	2.71E-03	7.66E-03	3.00E-04	2.98E-03	8.41E-03
										2200:	3.14E-04	2.92E-03	8.23E-03	3.45E-04	3.21E-03	9.04E-03
		GVS+GVN	Green Valley	36	14 ± 2	90	N/A	SS	6.11	2005:	8.35E-05	1.20E-03	3.78E-03	1.22E-04	1.76E-03	5.53E-03
									6.48	2050:	1.03E-04	1.31E-03	4.23E-03	1.51E-04	1.92E-03	6.19E-03
									6.77	2100:	1.18E-04	1.40E-03	4.41E-03	1.72E-04	2.05E-03	6.44E-03
										2200:	1.39E-04	1.52E-03	4.81E-03	2.04E-04	2.22E-03	7.03E-03
		CON+GVS+GVN	Concord+Green Valley	56	14 ± 2	90	N/A	SS	6.42	2005:	2.53E-04	2.32E-03	7.37E-03	4.67E-04	4.27E-03	1.36E-02
									6.71	2050:	3.06E-04	2.57E-03	7.91E-03	5.64E-04	4.73E-03	1.46E-02
									6.95	2100:	3.70E-04	2.77E-03	8.24E-03	6.82E-04	5.11E-03	1.52E-02
										2200:	4.63E-04	3.05E-03	8.76E-03	8.54E-04	5.62E-03	1.62E-02
		Floating Earthquake	N/A	N/A	14 ± 2	90	N/A	SS	6.2	2005:	1.06E-04	2.40E-03	1.07E-02	1.36E-04	3.07E-03	1.37E-02
										2050:	1.18E-04	2.47E-03	1.08E-02	1.51E-04	3.16E-03	1.39E-02
										2100:	1.23E-04	2.56E-03	1.10E-02	1.57E-04	3.28E-03	1.41E-02
										2200:	1.32E-04	2.74E-03	1.13E-02	1.69E-04	3.51E-03	1.44E-02
San Gregorio	1.0	SGS	Southern San Gregorio	66	12 ± 2	90	N/A	SS	6.76	2005:	0.00E+00	8.17E-04	3.09E-03	0.00E+00	2.04E-03	7.71E-03
									6.96	2050:	0.00E+00	8.96E-04	3.33E-03	0.00E+00	2.24E-03	8.32E-03
									7.12	2100:	0.00E+00	9.75E-04	3.58E-03	0.00E+00	2.43E-03	8.94E-03
										2200:	0.00E+00	1.11E-03	3.83E-03	0.00E+00	2.77E-03	9.55E-03
		SGN	Northern San Gregorio	110	13 ± 2	90	N/A	SS	7.07	2005:	0.00E+00	1.41E-03	5.03E-03	0.00E+00	5.42E-03	1.93E-02
									7.23	2050:	0.00E+00	1.58E-03	5.45E-03	0.00E+00	6.06E-03	2.09E-02
									7.40	2100:	0.00E+00	1.73E-03	5.81E-03	0.00E+00	6.66E-03	2.23E-02
										2200:	0.00E+00	1.97E-03	6.23E-03	0.00E+00	7.58E-03	2.39E-02

Table 6-2 Bay Area Time-Dependent Seismic Source Parameters

Fault Name	Probability of Activity[1]	Rupture Source[2]	Segment Name	Rupture Length[3]	Width[4]	Dip[5]	Direction of Dip[6]	Sense of Slip[7]	Magnitude[8]	Year	Rate of Characteristic Event[9]			Activity Rate		
											5%	5%	Mean	95%	Mean	95%
San Gregorio (cont'd.)		SGS+SGN	Northern + Southern San Gregorio						7.30	2005:	0.00E+00	9.22E-04	2.93E-03	0.00E+00	4.94E-03	1.57E-02
									7.44	2050:	0.00E+00	1.03E-03	3.33E-03	0.00E+00	5.51E-03	1.78E-02
									7.58	2100:	0.00E+00	1.15E-03	3.52E-03	0.00E+00	6.16E-03	1.89E-02
										2200:	0.00E+00	1.33E-03	4.01E-03	0.00E+00	7.13E-03	2.15E-02
		Floating Earthquake	N/A	N/A	13 ± 2	90	N/A	SS	6.9	2005:	3.05E-04	7.23E-04	1.23E-03	7.35E-04	1.74E-03	2.96E-03
										2050:	3.21E-04	7.45E-04	1.24E-03	7.73E-04	1.79E-03	2.99E-03
										2100:	3.34E-04	7.76E-04	1.25E-03	8.04E-04	1.87E-03	3.02E-03
										2200:	3.50E-04	8.37E-04	1.45E-03	8.44E-04	2.02E-03	3.49E-03
Greenville	1.0	GS	Southern Greenville	24	15 ± 3	90	N/A	SS	6.40	2005:	3.26E-05	1.08E-03	2.80E-03	5.46E-05	1.81E-03	4.69E-03
									6.60	2050:	9.32E-05	1.19E-03	2.90E-03	1.56E-04	1.99E-03	4.85E-03
									6.78	2100:	1.91E-04	1.31E-03	3.08E-03	3.20E-04	2.19E-03	5.16E-03
										2200:	3.30E-04	1.51E-03	3.44E-03	5.52E-04	2.53E-03	5.76E-03
		GN	Northern Greenville	27	15 ± 3	90	N/A	SS	6.45	2005:	1.16E-05	1.03E-03	2.82E-03	2.06E-05	1.82E-03	4.99E-03
									6.66	2050:	6.08E-05	1.12E-03	2.80E-03	1.08E-04	1.98E-03	4.96E-03
									6.84	2100:	1.39E-04	1.23E-03	3.14E-03	2.46E-04	2.18E-03	5.57E-03
										2200:	2.32E-04	1.43E-03	3.67E-03	4.11E-04	2.53E-03	6.50E-03
		GS+GN	Southern+Northern Greenville	51	15 ± 3	90	N/A	SS	6.78	2005:	9.29E-05	5.32E-04	1.29E-03	2.34E-04	1.34E-03	3.26E-03
									6.94	2050:	1.16E-04	5.79E-04	1.36E-03	2.93E-04	1.46E-03	3.43E-03
									7.11	2100:	1.38E-04	6.38E-04	1.48E-03	3.49E-04	1.61E-03	3.73E-03
										2200:	1.75E-04	7.40E-04	1.71E-03	4.42E-04	1.87E-03	4.31E-03
		Floating Earthquake	N/A	N/A	15 ± 3	90	N/A	SS	6.2	2005:	5.82E-05	1.49E-04	2.73E-04	7.44E-05	1.91E-04	3.49E-04
										2050:	6.17E-05	1.54E-04	2.74E-04	7.89E-05	1.96E-04	3.50E-04
										2100:	6.37E-05	1.60E-04	2.85E-04	8.15E-05	2.04E-04	3.64E-04
										2200:	6.55E-05	1.72E-04	3.20E-04	8.38E-05	2.20E-04	4.10E-04
Mt Diablo	1.0	MTD	Mt. Diablo	31	17 ± 2	30 (0.2)	NE	R	6.48	2005:	3.97E-04	2.71E-03	6.72E-03	7.07E-04	4.84E-03	1.20E-02
						45 (0.6)			6.65	2050:	5.52E-04	2.97E-03	7.45E-03	9.84E-04	5.29E-03	1.33E-02
						50 (0.2)			6.83	2100:	6.16E-04	3.23E-03	7.89E-03	1.10E-03	5.75E-03	1.41E-02
										2200:	6.64E-04	3.66E-03	8.99E-03	1.18E-03	6.53E-03	1.60E-02

Table 6-3 Mean Expert Weights for Probability Models Applied to the SFBR Fault Systems (Table 5.5, WGCEP 2003)

Fault System	Poisson	Empirical	BPT	BPT-step	Time-Predictable
San Andreas	0.100	0.181	0.154	0.231	0.335
Hayward/Rodger's Creek	0.123	0.285	0.131	0.462	—
Calaveras	0.227	0.315	0.142	0.315	—
Concord/Green Valley	0.246	0.277	0.123	0.354	—
San Gregorio	0.196	0.292	0.115	0.396	—
Greenville	0.231	0.288	0.131	0.350	—
Mt. Diablo Thrust	0.308	0.396	0.092	0.204	—

Table 6-4 Empirical Model Factors

Model	Extrapolated Annual Number of Events for Year:			
	2005	2055	2105	2205
A	0.014	0.014	0.014	0.014
B	0.016	0.016	0.016	0.016
C	0.011	0.011	0.011	0.011
D	0.020	0.020	0.020	0.020
E	0.016	0.018	0.020	0.025
F	0.018	0.026	0.034	0.050
Empirical Factors Based on Long Term Rate of 0.031				
Minimum	0.355	0.355	0.355	0.355
Average	0.512	0.567	0.622	0.733
Maximum	0.645	0.850	1.107	1.623

Table 6-5 Ground Motions with a 2% Exceedance Probability in 50 Years (2,500-Year Return Period)

Peak Ground Acceleration (g)

	TI	2005	2050	2100	2200
Sherman Island	0.64	0.64	0.64	0.64	0.65
Clifton Court	0.66	0.66	0.66	0.66	0.67
Montezuma Slough	0.75	0.74	0.74	0.74	0.75
Delta Cross Channel	0.38	0.37	0.37	0.37	0.37
Stockton	0.33	0.32	0.32	0.32	0.33
Sacramento	0.30	0.30	0.30	0.30	0.30

1.0 Sec Spectral Acceleration (g)

	TI	2005	2050	2100	2200
Sherman Island	0.77	0.77	0.78	0.79	0.80
Clifton Court	0.82	0.82	0.83	0.84	0.85
Montezuma Slough	0.91	0.90	0.90	0.91	0.93
Delta Cross Channel	0.48	0.48	0.49	0.49	0.50
Stockton	0.45	0.44	0.45	0.46	0.47
Sacramento	0.43	0.42	0.43	0.43	44

TI = Time-Independent

Table 6-6 Vulnerability Class Details for Seismic Fragility

Geographic Area	Vulnerability Class Index	Waterside Levee Slope	$(N_1)_{60\text{-}cs}$ Fill	$(N_1)_{60\text{-}cs}$ Foundation	Peat Thickness (ft)	Random Input Variables
Delta	1	Any	0-20	Any	0	$(N_1)_{60\text{-}cs}$ Fill, $(N_1)_{60\text{-}cs}$ Foundation, S_u
Delta	2	Any	0-20	Any	0.1-10	$(N_1)_{60\text{-}cs}$ Fill, $(N_1)_{60\text{-}cs}$ Foundation, $S_{u,}$ Peat Thickness
Delta	3	Any	0-20	Any	10.1-20	$(N_1)_{60\text{-}cs}$ Fill, $(N_1)_{60\text{-}cs}$ Foundation, $S_{u,}$ Peat Thickness
Delta	4	Any	0-20	Any	>20	$(N_1)_{60\text{-}cs}$ Fill, $(N_1)_{60\text{-}cs}$ Foundation, $S_{u,}$ Peat Thickness
Delta	5	Any	>20	0-20	0	$(N_1)_{60\text{-}cs}$ Foundation
Delta	6	Any	>20	0-5	0.1-10	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	7	Any	>20	0-5	10.1-20	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	8	Any	>20	0-5	>20	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	9	Any	>20	5.1-10	0.1-10	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	10	Any	>20	5.1-10	10.1-20	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	11	Any	>20	5.1-10	>20	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	12	Any	>20	10.1-20	0.1-10	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	13	Any	>20	10.1-20	10.1-20	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	14	Any	>20	10.1-20	>20	$(N_1)_{60\text{-}cs}$ Foundation, Peat Thickness
Delta	15	Steep	>20	>20	0	
Delta	16	Steep	>20	>20	0.1-10	c, ϕ, Peat Thickness
Delta	17	Steep	>20	>20	10.1-20	c, ϕ, Peat Thickness
Delta	18	Steep	>20	>20	>20	c, ϕ, Peat Thickness
Delta	19	Non-Steep	>20	>20	0	
Delta	20	Non-Steep	>20	>20	0.1-10	c, ϕ, Peat Thickness
Delta	21	Non-Steep	>20	>20	10.1-20	c, ϕ, Peat Thickness
Delta	22	Non-Steep	>20	>20	>20	c, ϕ, Peat Thickness

Table 6-6 Vulnerability Class Details for Seismic Fragility

Geographic Area	Vulnerability Class Index	Waterside Levee Slope	$(N_1)_{60\text{-}cs}$ Fill	$(N_1)_{60\text{-}cs}$ Foundation	Peat Thickness (ft)	Random Input Variables
Suisun Marsh	23	Any	>20	>20	Thin layer	c
	24	Any	<=20	<=20	Thin Layer	$(N_1)_{60\text{-}cs}$ Fill, $(N_1)_{60\text{-}cs}$ Foundation, S_u

Note: $(N_1)_{60\text{-}cs}$ – corrected clean sand equivalent SPT blow count, c – cohesion, ϕ, - friction angle, S_u = Residual undrained shear strength

Table 6-7 Dynamic Soil Parameters Selected for Analysis

Description		Moist Unit Weight (pcf)	K_{2max}	Shear Wave Velocity (ft/sec)	Modulus and Damping Curves
Embankment Materials					
Sandy Fill		115	35	-	Sand[1]
Peat	- free-field	70	-	100	Peat[2]
	- under embankment			300	Peat[3]
Sand		125	65	-	Sand[1]
Bay Deposits		110		400	Clay[4]
Clay		125	-	900	Clay[4]

Note:
1. Relationships of Seed and Idriss (1970)
2: Relationships of Wehling et al (2001) for 12 kPa
3: Relationships of Wehling et al (2001) for 40 kPa
4: Relationships of Vucetic and Dobry (1991) for PI = 30

Table 6-8: Calculated FLAC Deformations – Idealized Sections Liquefiable

Earthquake Magnitude	PGA	Peat Thickness, ft	(N1-60), Foundation	Deformation, ft
5.5	0.05	5	11	0.1
			16	0.1
			6	0.1
5.5	0.1	5	11	0.2
			16	0.1
			6	0.5
5.5	0.2	5	11	0.6
			16	0.4
			6	1.5
5.5	0.3	5	11	2
			16	0.8
			6	4
5.5	0.4	5	11	3
			16	1
			6	6
5.5	0.5	5	11	3.5
			16	1.5
			6	8
6.5	0.05	5	11	0.1
			16	0.1
			6	0.1
6.5	0.1	5	11	0.2
			16	0.1
			6	1
6.5	0.2	5	11	1
			16	0.7
			6	3
6.5	0.3	5	11	2
			16	1.5
			6	6
6.5	0.4	5	11	3
			16	2
			6	8
6.5	0.5	5	11	4
			16	2.5
			6	10
7.5	0.05	5	11	0.4
			16	0.2
			6	2
7.5	0.1	5	11	3
			16	1.5
			6	7.5
7.5	0.2	5	11	6
			16	4
			6	10
7.5	0.3	5	11	10
			16	8
			6	>10

Table 6-8: Calculated FLAC Deformations – Idealized Sections Liquefiable cont.

Earthquake Magnitude	PGA	Peat Thickness, ft	(N1-60), Foundation	Deformation, ft
7.5	0.4	5	11	>10
			16	>10
			6	>10
7.5	0.5	5	11	>10
			16	>10
			6	>10
5.5	0.05	15	11	0.1
			16	0.1
			6	0.1
5.5	0.1	15	11	0.1
			16	0.1
			6	0.2
5.5	0.2	15	11	0.6
			16	0.2
			6	1.5
5.5	0.3	15	11	1.3
			16	0.5
			6	3
5.5	0.4	15	11	1.8
			16	0.6
			6	4
5.5	0.5	15	11	2
			16	0.8
			6	5
6.5	0.05	15	11	0.1
			16	0.1
			6	0.1
6.5	0.1	15	11	0.1
			16	0.1
			6	0.4
6.5	0.2	15	11	0.7
			16	0.2
			6	1.8
6.5	0.3	15	11	1.5
			16	0.6
			6	3.5
6.5	0.4	15	11	2
			16	0.8
			6	5
6.5	0.5	15	11	2.5
			16	1.3
			6	6
7.5	0.05	15	11	0.4
			16	0.2
			6	1.8
7.5	0.1	15	11	2
			16	0.6
			6	5

Table 6-8: Calculated FLAC Deformations – Idealized Sections Liquefiable cont.				
Earthquake Magnitude	**PGA**	**Peat Thickness, ft**	**(N1-60), Foundation**	**Deformation, ft**
7.5	0.2	15	11	4
			16	2
			6	8
7.5	0.3	15	11	5
			16	4
			6	10
7.5	0.4	15	11	6
			16	5
			6	>10
7.5	0.5	15	11	8
			16	6
			6	>10
5.5	0.05	>25	11	0.1
			16	0.1
			6	0.1
5.5	0.1	>25	11	0.1
			16	0.1
			6	0.3
5.5	0.2	>25	11	0.7
			16	0.3
			6	1.5
5.5	0.3	>25	11	1.3
			16	0.6
			6	2.5
5.5	0.4	>25	11	1.5
			16	0.8
			6	3
5.5	0.5	>25	11	1.8
			16	1
			6	3.5
6.5	0.05	>25	11	0.1
			16	0.1
			6	0.1
6.5	0.1	>25	11	0.1
			16	0.1
			6	0.4
6.5	0.2	>25	11	0.8
			16	0.3
			6	1.8
6.5	0.3	>25	11	1.3
			16	0.6
			6	3
6.5	0.4	>25	11	1.8
			16	1
			6	3.5
6.5	0.5	>25	11	2.3
			16	1.5
			6	4.5

Table 6-8: Calculated FLAC Deformations – Idealized Sections Liquefiable cont.				
Earthquake Magnitude	**PGA**	**Peat Thickness, ft**	**(N1-60), Foundation**	**Deformation, ft**
7.5	0.05	>25	11	0.4
			16	0.2
			6	1.5
7.5	0.1	>25	11	1.8
			16	0.6
			6	3.5
7.5	0.2	>25	11	3.5
			16	2.5
			6	7
7.5	0.3	>25	11	4
			16	3
			6	10
7.5	0.4	>25	11	7.5
			16	6
			6	>10
7.5	0.5	>25	11	10
			16	8
			6	>10

Table 6-9 Stability Analysis Results – Non-Liquefiable Sand Layer

Section	Factor of Safety		Yield Acceleration, K_y	
	Landside	Waterside	Landside	Waterside
No Peat	1.79	1.85	0.24	0.19
5 feet Peat	1.57	2.02	0.16	0.16
15 feet Peat	1.39	1.79	0.11	0.11
>25 feet Peat	1.38	1.79	0.09	0.11
Suisun Marsh	1.77	1.15	0.09	0.03

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Non-Steep	5.5	0.05	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.1	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.2	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.3	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.4	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.5	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.05	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.1	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	6.5	0.2	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.3	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.4	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.5	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.05	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.1	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.2	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.3	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Non-Steep	7.5	0.4	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.5	0	120	28	0.11
				120	29.96	0.11
				120	26.17	0.11
				168	28	0.11
				85.71	28	0.11
Steep	5.5	0.05	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.1	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.2	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.3	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.4	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.5	0	120	28	0.123
				120	29.96	0.123
				120	26.17	0.123
				168	28	0.123
				85.71	28	0.123

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Steep	6.5	0.05	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.1	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.2	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.3	0	120	28	0.141
				120	29.96	0.141
				120	26.17	0.141
				168	28	0.141
				85.71	28	0.141
Steep	6.5	0.4	0	120	28	0.32
				120	29.96	0.32
				120	26.17	0.32
				168	28	0.32
				85.71	28	0.32
Steep	6.5	0.5	0	120	28	0.678
				120	29.96	0.678
				120	26.17	0.678
				168	28	0.678
				85.71	28	0.678
Steep	7.5	0.05	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.1	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Steep	7.5	0.2	0	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.3	0	120	28	0.543
				120	29.96	0.543
				120	26.17	0.543
				168	28	0.543
				85.71	28	0.543
Steep	7.5	0.4	0	120	28	1.324
				120	29.96	1.324
				120	26.17	1.324
				168	28	1.324
				85.71	28	1.324
Steep	7.5	0.5	0	120	28	2.673
				120	29.96	2.673
				120	26.17	2.673
				168	28	2.673
				85.71	28	2.673
Non-Steep	5.5	0.05	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.1	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.2	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.3	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	5.5	0.4	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.5	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.05	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.1	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.2	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.3	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.4	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	0.11
				168	28	<0.1
				85.71	28	0.12
Non-Steep	6.5	0.5	5	120	28	0.16
				120	29.96	0.15
				120	26.17	0.21
				168	28	0.13
				85.71	28	0.22

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	7.5	0.05	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.1	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.2	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.3	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	0.13
				168	28	<0.1
				85.71	28	0.14
Non-Steep	7.5	0.4	5	120	28	0.25
				120	29.96	0.22
				120	26.17	0.36
				168	28	0.16
				85.71	28	0.38
Non-Steep	7.5	0.5	5	120	28	0.61
				120	29.96	0.56
				120	26.17	0.86
				168	28	0.44
				85.71	28	0.91
Non-Steep	5.5	0.05	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.1	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	5.5	0.2	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.3	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.4	15	120	28	0.11
				120	29.96	<0.1
				120	26.17	0.16
				168	28	<0.1
				85.71	28	0.21
Non-Steep	5.5	0.5	15	120	28	0.19
				120	29.96	0.17
				120	26.17	0.27
				168	28	0.14
				85.71	28	0.34
Non-Steep	6.5	0.05	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.1	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.2	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	0.14
Non-Steep	6.5	0.3	15	120	28	0.21
				120	29.96	0.18
				120	26.17	0.34
				168	28	0.14
				85.71	28	0.49

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	6.5	0.4	15	120	28	0.5
				120	29.96	0.42
				120	26.17	0.78
				168	28	0.3
				85.71	28	1.06
Non-Steep	6.5	0.5	15	120	28	0.98
				120	29.96	0.84
				120	26.17	1.39
				168	28	0.59
				85.71	28	1.77
Non-Steep	7.5	0.05	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.1	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.2	15	120	28	0.26
				120	29.96	0.19
				120	26.17	0.42
				168	28	0.13
				85.71	28	0.59
Non-Steep	7.5	0.3	15	120	28	1.03
				120	29.96	0.87
				120	26.17	1.47
				168	28	0.63
				85.71	28	1.9
Non-Steep	7.5	0.4	15	120	28	2.35
				120	29.96	2.07
				120	26.17	3.35
				168	28	1.54
				85.71	28	4.23
Non-Steep	7.5	0.5	15	120	28	5.17
				120	29.96	4.51
				120	26.17	6.81
				168	28	3.39
				85.71	28	8.2

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Non-Steep	5.5	0.05	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.1	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.2	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	5.5	0.3	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	0.11
Non-Steep	5.5	0.4	>25	120	28	0.13
				120	29.96	<0.1
				120	26.17	0.18
				168	28	<0.1
				85.71	28	0.22
Non-Steep	5.5	0.5	>25	120	28	0.2
				120	29.96	0.14
				120	26.17	0.26
				168	28	0.11
				85.71	28	0.31
Non-Steep	6.5	0.05	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	6.5	0.1	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	6.5	0.2	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	0.14
Non-Steep	6.5	0.3	>25	120	28	0.24
				120	29.96	0.13
				120	26.17	0.37
				168	28	0.1
				85.71	28	0.5
Non-Steep	6.5	0.4	>25	120	28	0.49
				120	29.96	0.27
				120	26.17	0.76
				168	28	0.2
				85.71	28	1.01
Non-Steep	6.5	0.5	>25	120	28	0.98
				120	29.96	0.58
				120	26.17	1.38
				168	28	0.42
				85.71	28	1.68
Non-Steep	7.5	0.05	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.1	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Non-Steep	7.5	0.2	>25	120	28	0.25
				120	29.96	0.1
				120	26.17	0.43
				168	28	<0.1
				85.71	28	0.59
Non-Steep	7.5	0.3	>25	120	28	0.98
				120	29.96	0.47
				120	26.17	1.47
				168	28	0.33
				85.71	28	1.92

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Non-Steep	7.5	0.4	>25	120	28	2.27
				120	29.96	1.14
				120	26.17	3.39
				168	28	0.82
				85.71	28	4.3
Non-Steep	7.5	0.5	>25	120	28	5.43
				120	29.96	3.07
				120	26.17	6.61
				168	28	2.32
				85.71	28	7.86
Steep	5.5	0.05	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.1	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.2	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.3	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	0.111
Steep	5.5	0.4	5	120	28	0.121
				120	29.96	0.1
				120	26.17	0.148
				168	28	0.103
				85.71	28	0.205
Steep	5.5	0.5	5	120	28	0.216
				120	29.96	0.162
				120	26.17	0.278
				168	28	<0.1
				85.71	28	0.357

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Steep	6.5	0.05	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.1	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.2	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	0.116
Steep	6.5	0.3	5	120	28	0.252
				120	29.96	0.188
				120	26.17	0.33
				168	28	<0.1
				85.71	28	0.42
Steep	6.5	0.4	5	120	28	0.458
				120	29.96	0.368
				120	26.17	0.614
				168	28	0.246
				85.71	28	0.834
Steep	6.5	0.5	5	120	28	1.013
				120	29.96	0.797
				120	26.17	1.31
				168	28	0.5425
				85.71	28	1.676
Steep	7.5	0.05	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.1	5	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Steep	7.5	0.2	5	120	28	0.157
				120	29.96	<0.1
				120	26.17	0.257
				168	28	<0.1
				85.71	28	0.391
Steep	7.5	0.3	5	120	28	0.856
				120	29.96	0.662
				120	26.17	1.109
				168	28	0.3795
				85.71	28	1.425
Steep	7.5	0.4	5	120	28	1.915
				120	29.96	1.571
				120	26.17	2.358
				168	28	1.0365
				85.71	28	2.886
Steep	7.5	0.5	5	120	28	3.809
				120	29.96	3.193
				120	26.17	4.538
				168	28	2.318
				85.71	28	5.405
Steep	5.5	0.05	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.1	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.2	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.3	15	120	28	0.119
				120	29.96	<0.1
				120	26.17	0.134
				168	28	<0.1
				85.71	28	0.184

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Steep	5.5	0.4	15	120	28	0.28
				120	29.96	0.203
				120	26.17	0.326
				168	28	0.137
				85.71	28	0.408
Steep	5.5	0.5	15	120	28	0.491
				120	29.96	0.39
				120	26.17	0.568
				168	28	0.289
				85.71	28	0.679
Steep	6.5	0.05	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.1	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.2	15	120	28	0.111
				120	29.96	<0.1
				120	26.17	0.155
				168	28	<0.1
				85.71	28	0.214
Steep	6.5	0.3	15	120	28	0.453
				120	29.96	0.293
				120	26.17	0.554
				168	28	0.198
				85.71	28	0.756
Steep	6.5	0.4	15	120	28	1.25
				120	29.96	0.939
				120	26.17	1.492
				168	28	0.655
				85.71	28	1.855
Steep	6.5	0.5	15	120	28	2.33
				120	29.96	1.75
				120	26.17	2.532
				168	28	0.655
				85.71	28	3.021

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable
Cont.

Waterside Levee Slope	Earthquake Magnitude	PGA	Peat Thickness, ft	C	phi	Deformation, ft
Steep	7.5	0.05	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.1	15	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.2	15	120	28	0.463
				120	29.96	0.314
				120	26.17	0.593
				168	28	0.18
				85.71	28	0.799
Steep	7.5	0.3	15	120	28	1.806
				120	29.96	1.375
				120	26.17	2.1
				168	28	1.008
				85.71	28	2.586
Steep	7.5	0.4	15	120	28	4.554
				120	29.96	3.611
				120	26.17	5.148
				168	28	2.736
				85.71	28	6.111
Steep	7.5	0.5	15	120	28	8.294
				120	29.96	6.571
				120	26.17	8.976
				168	28	5.276
				85.71	28	10.492
Steep	5.5	0.05	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.1	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Steep	5.5	0.2	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	5.5	0.3	>25	120	28	0.265
				120	29.96	0.135
				120	26.17	0.322
				168	28	0.105
				85.71	28	0.297
Steep	5.5	0.4	>25	120	28	0.4
				120	29.96	0.317
				120	26.17	0.495
				168	28	0.219
				85.71	28	0.611
Steep	5.5	0.5	>25	120	28	0.649
				120	29.96	0.536
				120	26.17	0.754
				168	28	0.412
				85.71	28	0.889
Steep	6.5	0.05	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.1	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	6.5	0.2	>25	120	28	0.162
				120	29.96	0.111
				120	26.17	0.222
				168	28	<0.1
				85.71	28	0.327
Steep	6.5	0.3	>25	120	28	0.96
				120	29.96	0.698
				120	26.17	1.154
				168	28	0.463
				85.71	28	1.458

Table 6-10a: Calculated Newmark Deformations – Idealized Sections Non Liquefiable Cont.						
Waterside Levee Slope	**Earthquake Magnitude**	**PGA**	**Peat Thickness, ft**	**C**	**phi**	**Deformation, ft**
Steep	6.5	0.4	>25	120	28	2.363
				120	29.96	1.804
				120	26.17	2.56
				168	28	1.363
				85.71	28	3.022
Steep	6.5	0.5	>25	120	28	3.568
				120	29.96	2.979
				120	26.17	4.06
				168	28	2.385
				85.71	28	4.744
Steep	7.5	0.05	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.1	>25	120	28	<0.1
				120	29.96	<0.1
				120	26.17	<0.1
				168	28	<0.1
				85.71	28	<0.1
Steep	7.5	0.2	>25	120	28	0.721
				120	29.96	0.549
				120	26.17	0.881
				168	28	0.38
				85.71	28	1.134
Steep	7.5	0.3	>25	120	28	3.375
				120	29.96	2.52
				120	26.17	3.642
				168	28	1.91
				85.71	28	4.41
Steep	7.5	0.4	>25	120	28	7.161
				120	29.96	5.876
				120	26.17	7.905
				168	28	4.696
				85.71	28	9.151
Steep	7.5	0.5	>25	120	28	15.102
				120	29.96	8.886
				120	26.17	16.608
				168	28	9.368
				85.71	28	16.593

Table 6-10b: Calculated Newmark Deformations – Suisun Marsh Non Liquefiable

Earthquake Magnitude	PGA	Bay Deposit Thickness, ft	C	Deformation, ft
5.5	0.05	40	120	0.003
			168	0
			85.71	>10
5.5	0.1	40	120	0.026
			168	0
			85.71	>10
5.5	0.2	40	120	0.208
			168	0
			85.71	>10
5.5	0.3	40	120	0.408
			168	0.015
			85.71	>10
5.5	0.4	40	120	0.746
			168	0.049
			85.71	>10
5.5	0.5	40	120	1.185
			168	0.096
			85.71	>10
6.5	0.05	40	120	0.008
			168	0
			85.71	>10
6.5	0.1	40	120	0.104
			168	0
			85.71	>10
6.5	0.2	40	120	0.593
			168	0.007
			85.71	>10
6.5	0.3	40	120	1.764
			168	0.049
			85.71	>10
6.5	0.4	40	120	3.28
			168	0.121
			85.71	>10
6.5	0.5	40	120	4.841
			168	0.276
			85.71	>10
7.5	0.05	40	120	0.016
			168	0
			85.71	>10
7.5	0.1	40	120	0.328
			168	0
			85.71	>10
7.5	0.2	40	120	2.19
			168	0.02
			85.71	>10
7.5	0.3	40	120	4.927
			168	0.135
			85.71	>10

Table 6-10b: Calculated Newmark Deformations – Suisun Marsh Non Liquefiable cont.				
Earthquake Magnitude	**PGA**	**Bay Deposit Thickness, ft**	**C**	**Deformation, ft**
7.5	0.4	40	120	9.083
			168	0.483
			85.71	>10
7.5	0.5	40	120	13.989
			168	1.207
			85.71	>10

Table 6-11 Distribution of Probability of Failure – Sample Results

Vulnerability Class Index	Initial Freeboard (ft)	Earthquake Magnitude	Epistemic Cumulative % Prob.	Probability of Failure for Given Ground Motion Level										
				0.05	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
1	4	5.5	50%	0.0034	0.0074	0.0663	0.2063	0.3368	0.5133	0.6075	0.6952	0.7166	0.7769	0.7975
1	4	6.5	50%	0.0094	0.0660	0.3513	0.5945	0.7332	0.8022	0.8522	0.8710	0.8898	0.9045	0.9145
1	4	7.5	50%	0.0775	0.3527	0.6696	0.8153	0.8641	0.8970	0.9171	0.9328	0.9457	0.9495	0.9564
2	4	5.5	50%	0.0094	0.0333	0.2046	0.3828	0.5047	0.6439	0.7307	0.8027	0.8470	0.8979	0.9514
2	4	6.5	50%	0.0532	0.2580	0.5790	0.7252	0.7915	0.8471	0.8928	0.9278	0.9602	0.9821	0.9907
2	4	7.5	50%	0.3029	0.6069	0.7602	0.8322	0.8857	0.9320	0.9590	0.9770	0.9862	0.9939	0.9976
3	4	5.5	50%	0.0034	0.0095	0.0768	0.2081	0.3415	0.4620	0.5498	0.6593	0.7679	0.8670	0.9416
3	4	6.5	50%	0.0134	0.1246	0.3861	0.6163	0.7043	0.8132	0.8778	0.9140	0.9606	0.9871	0.9963
3	4	7.5	50%	0.1322	0.4762	0.7133	0.8208	0.8709	0.9329	0.9578	0.9823	0.9945	0.9978	0.9987
4	4	5.5	50%	0.0035	0.0035	0.0110	0.0477	0.0953	0.1766	0.2809	0.4717	0.6876	0.8457	0.9577
4	4	6.5	50%	0.0065	0.0290	0.1305	0.2799	0.4022	0.5735	0.7483	0.8925	0.9586	0.9867	0.9974
4	4	7.5	50%	0.0310	0.1476	0.4563	0.6297	0.8091	0.9037	0.9694	0.9920	0.9971	0.9987	0.9987
5	4	5.5	50%	0.0034	0.0034	0.0038	0.0116	0.0582	0.1773	0.2975	0.4374	0.5324	0.5930	0.6649
5	4	6.5	50%	0.0034	0.0049	0.0280	0.1392	0.3508	0.5561	0.7399	0.8270	0.8593	0.8935	0.9334
5	4	7.5	50%	0.0061	0.0465	0.2408	0.4845	0.7317	0.8981	0.9358	0.9828	0.9868	0.9809	0.9951
6	4	5.5	50%	0.0034	0.0036	0.0109	0.0683	0.3267	0.6635	0.8970	0.9609	0.9855	0.9811	0.9987
6	4	6.5	50%	0.0067	0.0222	0.1760	0.4930	0.8316	0.9731	0.9904	0.9987	0.9987	0.9987	0.9987
6	4	7.5	50%	0.0679	0.2855	0.6006	0.8975	0.9801	0.9985	0.9987	0.9987	0.9987	0.9987	0.9987
7	4	5.5	50%	0.0034	0.0034	0.0077	0.0323	0.2092	0.4899	0.7545	0.8629	0.9229	0.9516	0.9918
7	4	6.5	50%	0.0044	0.0089	0.1086	0.3854	0.7510	0.9302	0.9913	0.9972	0.9931	0.9987	0.9987
7	4	7.5	50%	0.0321	0.1770	0.5491	0.8829	0.9788	0.9986	0.9987	0.9987	0.9987	0.9987	0.9987
8	4	5.5	50%	0.0035	0.0036	0.0047	0.0123	0.0598	0.1858	0.3627	0.5245	0.7481	0.9012	0.9825
8	4	6.5	50%	0.0044	0.0085	0.0346	0.1715	0.4540	0.6974	0.8714	0.9617	0.9854	0.9976	0.9968
8	4	7.5	50%	0.0129	0.0506	0.3101	0.6677	0.8899	0.9774	0.9920	0.9975	0.9973	0.9987	0.9987
9	4	5.5	50%	0.0034	0.0034	0.0045	0.0212	0.1121	0.3555	0.6524	0.8336	0.8889	0.9602	0.9750
9	4	6.5	50%	0.0035	0.0059	0.0521	0.2383	0.5644	0.8914	0.9718	0.9900	0.9974	0.9987	0.9987
9	4	7.5	50%	0.0129	0.0739	0.3396	0.7241	0.9347	0.9920	0.9968	0.9987	0.9987	0.9987	0.9987
10	4	5.5	50%	0.0034	0.0034	0.0037	0.0081	0.0450	0.2189	0.4375	0.6194	0.7410	0.8701	0.9610
10	4	6.5	50%	0.0035	0.0038	0.0269	0.1570	0.4135	0.7803	0.9312	0.9740	0.9922	0.9971	0.9987
10	4	7.5	50%	0.0103	0.0429	0.2629	0.6295	0.9012	0.9809	0.9975	0.9974	0.9987	0.9987	0.9987
11	4	5.5	50%	0.0035	0.0036	0.0040	0.0086	0.0222	0.0774	0.1827	0.3470	0.6350	0.8305	0.9423

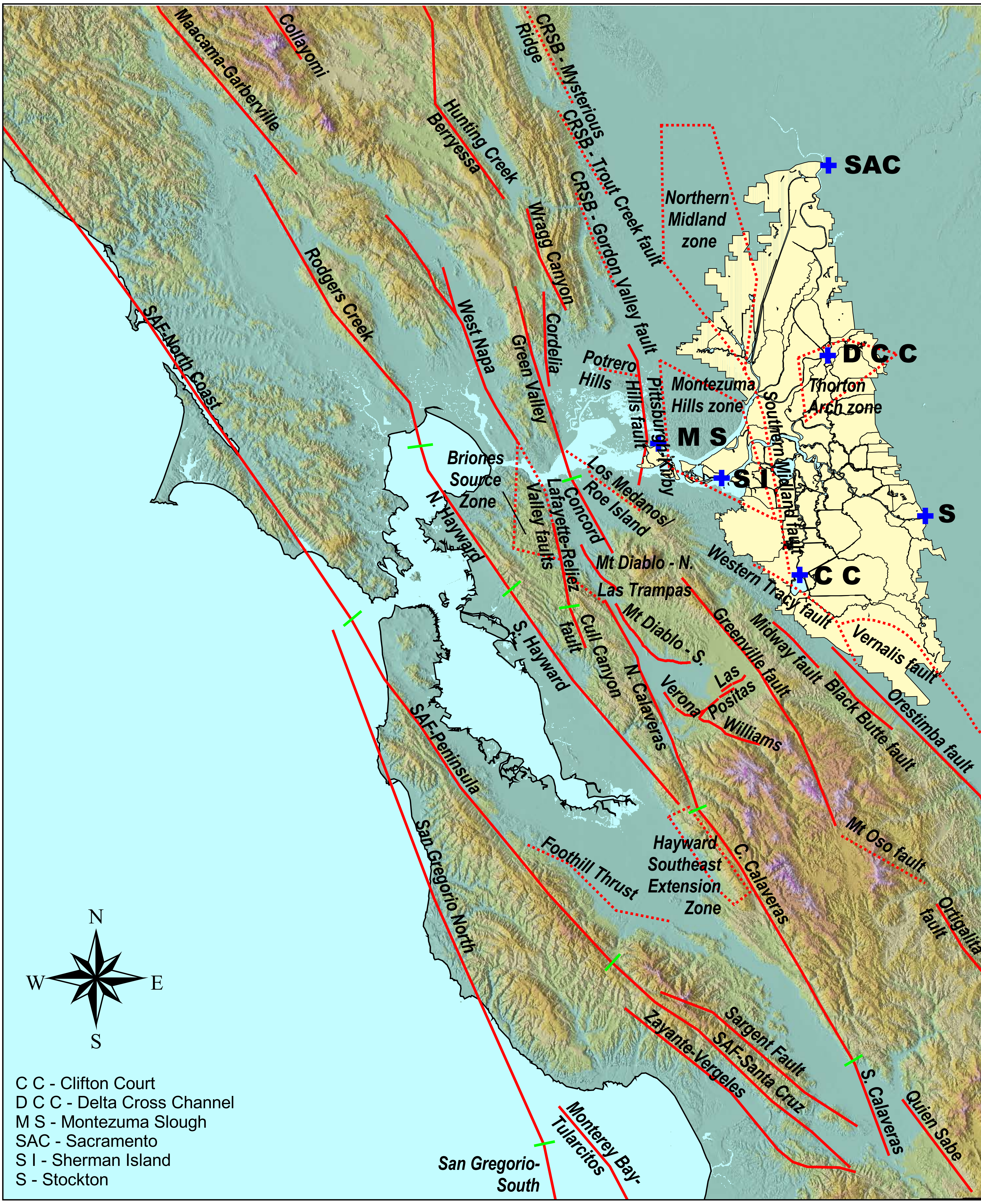
Table 6-11 Distribution of Probability of Failure – Sample Results

Vulnerability Class Index	Initial Freeboard (ft)	Earthquake Magnitude	Epistemic Cumulative % Prob.	Probability of Failure for Given Ground Motion Level										
				0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
11	4	6.5	50%	0.0046	0.0042	0.0162	0.0485	0.2272	0.4659	0.7381	0.8995	0.9683	0.9971	0.9982
11	4	7.5	50%	0.0132	0.0233	0.1316	0.4035	0.7382	0.9333	0.9864	0.9966	0.9987	0.9987	0.9987
12	4	5.5	50%	0.0034	0.0034	0.0035	0.0039	0.0152	0.0590	0.1584	0.3580	0.5319	0.7007	0.8558
12	4	6.5	50%	0.0034	0.0037	0.0071	0.0342	0.1452	0.4302	0.6832	0.8736	0.9529	0.9859	0.9967
12	4	7.5	50%	0.0050	0.0087	0.0680	0.2786	0.5777	0.8731	0.9787	0.9918	0.9986	0.9987	0.9987
13	4	5.5	50%	0.0034	0.0034	0.0035	0.0037	0.0057	0.0238	0.0740	0.2007	0.3504	0.6346	0.8413
13	4	6.5	50%	0.0035	0.0035	0.0040	0.0147	0.1049	0.2759	0.5082	0.7974	0.8981	0.9704	0.9922
13	4	7.5	50%	0.0038	0.0069	0.0369	0.2080	0.5033	0.7599	0.9433	0.9831	0.9971	0.9987	0.9987
14	4	5.5	50%	0.0035	0.0036	0.0060	0.0095	0.0161	0.0362	0.0788	0.2524	0.4606	0.7441	0.9324
14	4	6.5	50%	0.0046	0.0080	0.0093	0.0253	0.0782	0.1898	0.4481	0.7049	0.9008	0.9819	0.9939
14	4	7.5	50%	0.0125	0.0151	0.0504	0.1371	0.3734	0.6918	0.8984	0.9731	0.9961	0.9987	0.9987
15	4	5.5	50%	0.0035	0.0036	0.0037	0.0038	0.0041	0.0045	0.0055	0.0071	0.0114	0.0259	0.0623
15	4	6.5	50%	0.0037	0.0038	0.0041	0.0045	0.0056	0.0071	0.0115	0.0211	0.0571	0.1489	0.3041
15	4	7.5	50%	0.0042	0.0045	0.0052	0.0073	0.0112	0.0263	0.0583	0.1584	0.2975	0.5151	0.7376
16	4	5.5	50%	0.0034	0.0035	0.0035	0.0038	0.0042	0.0066	0.0212	0.1113	0.3167	0.6613	0.9024
16	4	6.5	50%	0.0036	0.0036	0.0040	0.0049	0.0103	0.0522	0.1930	0.5283	0.8148	0.9541	0.9890
16	4	7.5	50%	0.0040	0.0044	0.0061	0.0210	0.0951	0.3525	0.6984	0.8966	0.9757	0.9965	1.0000
17	4	5.5	50%	0.0035	0.0035	0.0036	0.0040	0.0050	0.0086	0.0486	0.1712	0.5070	0.7933	0.9401
17	4	6.5	50%	0.0036	0.0038	0.0043	0.0061	0.0172	0.0902	0.3419	0.6777	0.9031	0.9853	0.9947
17	4	7.5	50%	0.0044	0.0053	0.0093	0.0468	0.2233	0.5279	0.7990	0.9513	0.9898	0.9991	0.9987
18	4	5.5	50%	0.0038	0.0043	0.0070	0.0141	0.0433	0.0993	0.2524	0.4851	0.7651	0.9330	0.9876
18	4	6.5	50%	0.0084	0.0150	0.0285	0.0696	0.1644	0.3348	0.6697	0.8724	0.9724	0.9900	0.9981
18	4	7.5	50%	0.0303	0.0408	0.1030	0.2580	0.5049	0.7787	0.9319	0.9908	0.9982	1.0000	1.0000
19	4	5.5	50%	0.0034	0.0034	0.0034	0.0035	0.0035	0.0036	0.0037	0.0038	0.0041	0.0044	0.0051
19	4	6.5	50%	0.0034	0.0035	0.0035	0.0036	0.0036	0.0038	0.0040	0.0043	0.0051	0.0069	0.0116
19	4	7.5	50%	0.0035	0.0036	0.0037	0.0038	0.0040	0.0044	0.0052	0.0067	0.0107	0.0242	0.0535
20	4	5.5	50%	0.0034	0.0034	0.0034	0.0035	0.0037	0.0041	0.0058	0.0141	0.0535	0.2519	0.5906
20	4	6.5	50%	0.0034	0.0035	0.0036	0.0039	0.0049	0.0070	0.0295	0.1385	0.4527	0.7409	0.9315
20	4	7.5	50%	0.0036	0.0037	0.0042	0.0060	0.0153	0.0785	0.2666	0.5909	0.8593	0.9701	0.9911
21	4	5.5	50%	0.0034	0.0034	0.0035	0.0036	0.0039	0.0045	0.0089	0.0276	0.1301	0.4268	0.7293
21	4	6.5	50%	0.0035	0.0035	0.0037	0.0041	0.0059	0.0136	0.0719	0.2430	0.5918	0.8632	0.9660

Table 6-11 Distribution of Probability of Failure – Sample Results

Vulnerability Class Index	Initial Freeboard (ft)	Earthquake Magnitude	Epistemic Cumulative % Prob.	Probability of Failure for Given Ground Motion Level										
				0.05	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
21	4	7.5	50%	0.0037	0.0039	0.0051	0.0081	0.0246	0.1493	0.4250	0.7480	0.9063	0.9878	0.9979
22	4	5.5	50%	0.0036	0.0040	0.0043	0.0092	0.0153	0.0311	0.0877	0.1975	0.4387	0.7207	0.9042
22	4	6.5	50%	0.0046	0.0075	0.0102	0.0270	0.0616	0.1336	0.3099	0.6109	0.8402	0.9541	0.9915
22	4	7.5	50%	0.0129	0.0188	0.0348	0.0894	0.2018	0.4418	0.7389	0.9137	0.9789	0.9970	1.0000
23	4	5.5	50%	0.0959	0.1221	0.1764	0.2526	0.3675	0.4375	0.5460	0.6306	0.7315	0.7899	0.8265
23	4	6.5	50%	0.1222	0.1588	0.2412	0.3299	0.4108	0.5116	0.6200	0.6994	0.7702	0.8038	0.8742
23	4	7.5	50%	0.1695	0.2013	0.3032	0.3873	0.5005	0.5891	0.6913	0.7363	0.8232	0.8588	0.8900

Figures



Legal Delta Boundary V. 2002-4

Surficial faults used in the hazard analysis

Blind faults used in the hazard analysis

Bounds of delta islands

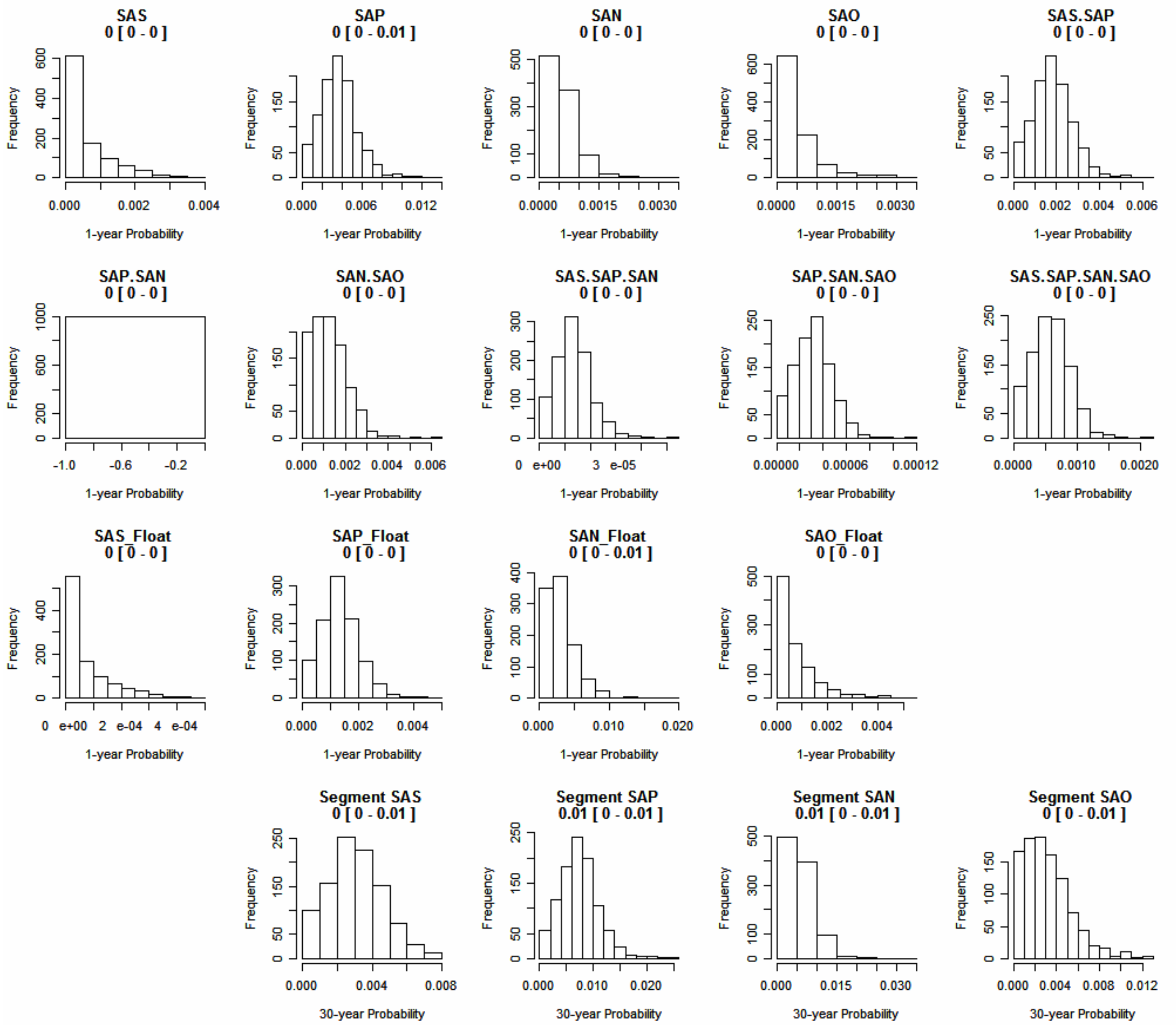
CRSB - Coast Range Sierran Block
SAF - San Andreas Fault

0 30 60 90 Kilometers

0 20 40 60 Miles

URS	Delta Risk Management Strategy, California Project No. 26815431	FAULTS IN THE SAN FRANCISCO BAY REGION	Figure 6-1

URS	Delta Risk Management Strategy, California Project No. 26815431	ACTIVE FAULTS IN THE SITE REGION	Figure 6-2



URS	DELTA RISK MANAGEMENT STRATEGY California	Time-Dependent Probabilities for the San Andreas Rupture Scenarios for 2005	Figure 6-3
Project No. 26815621			

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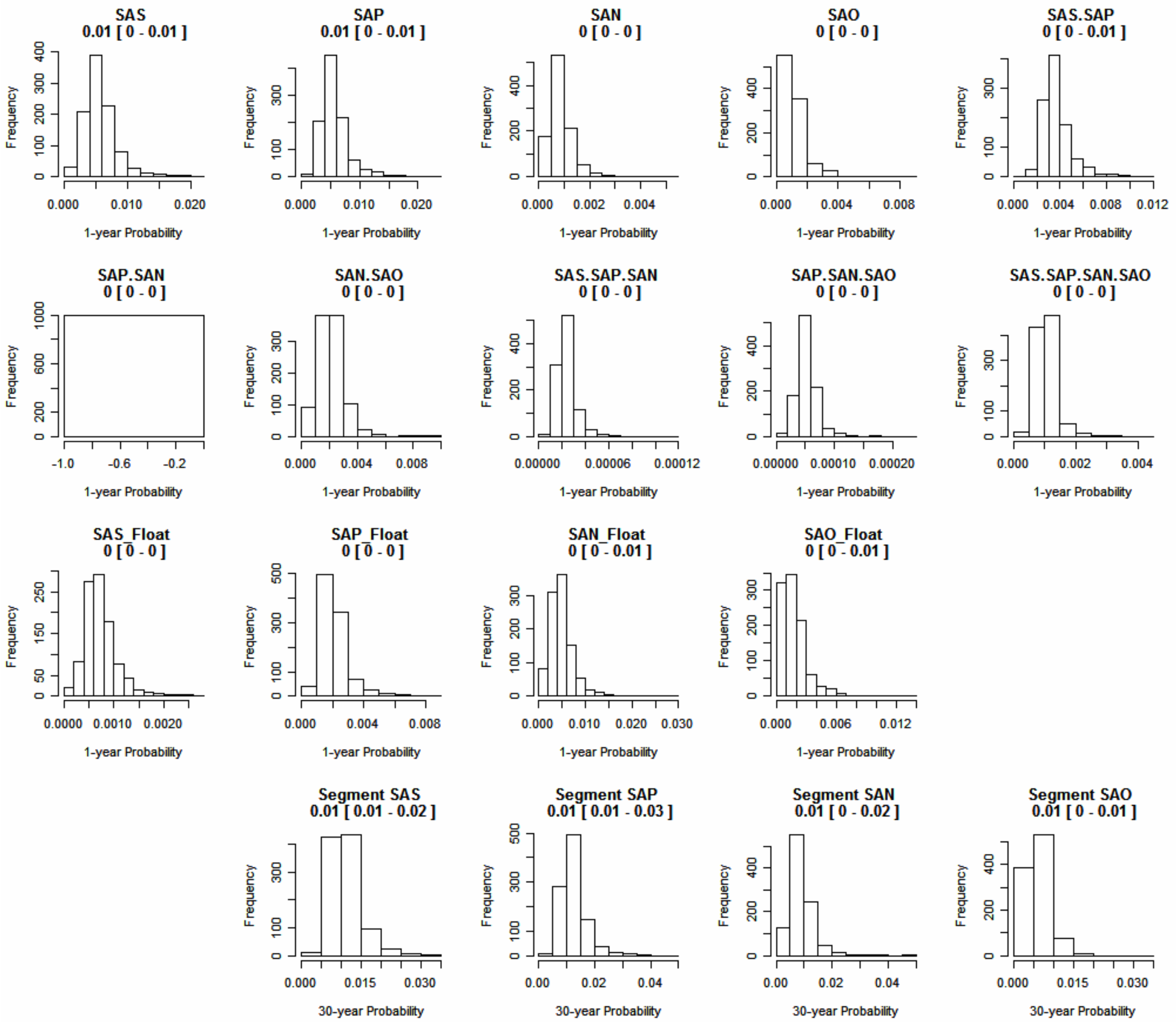
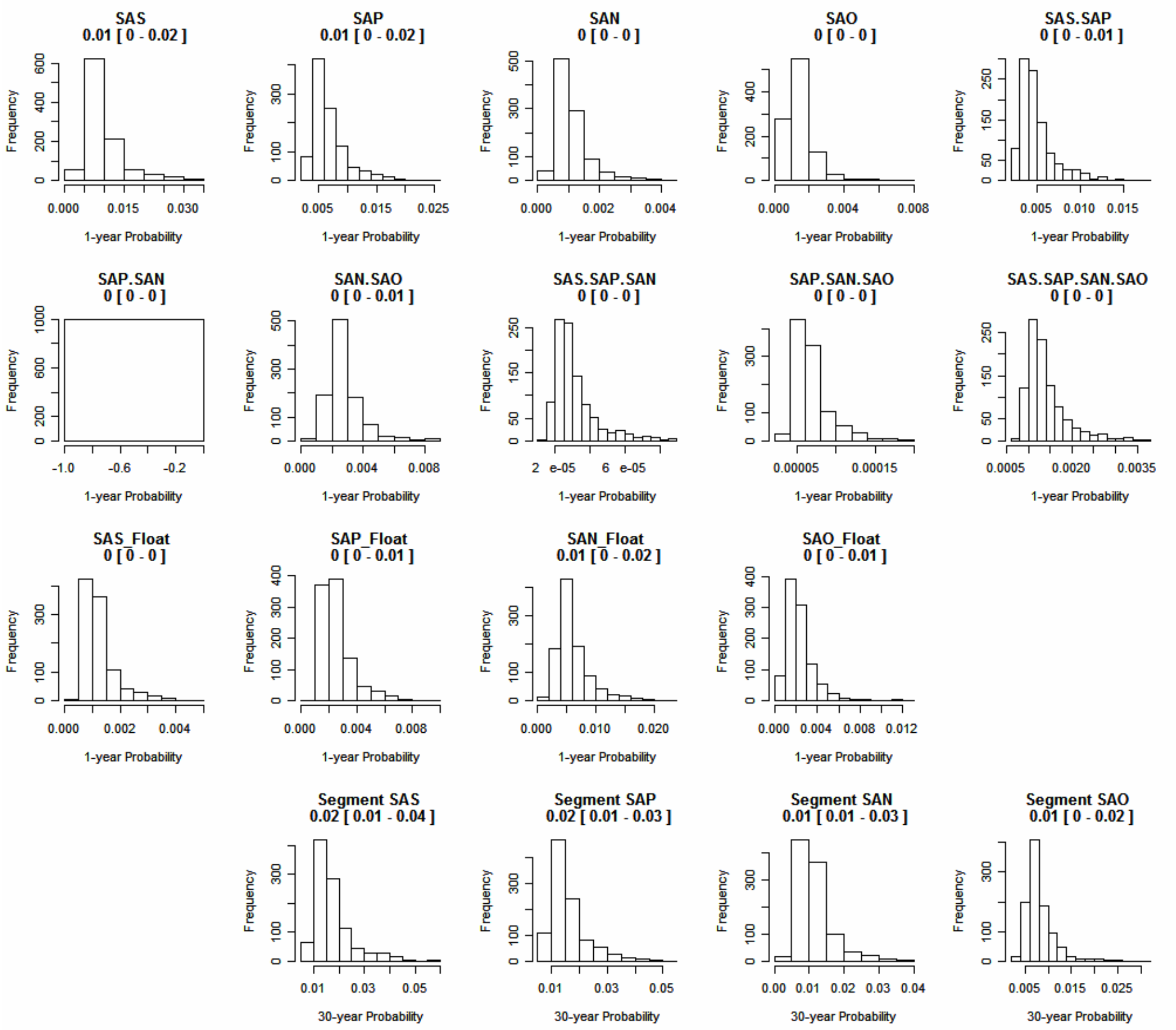
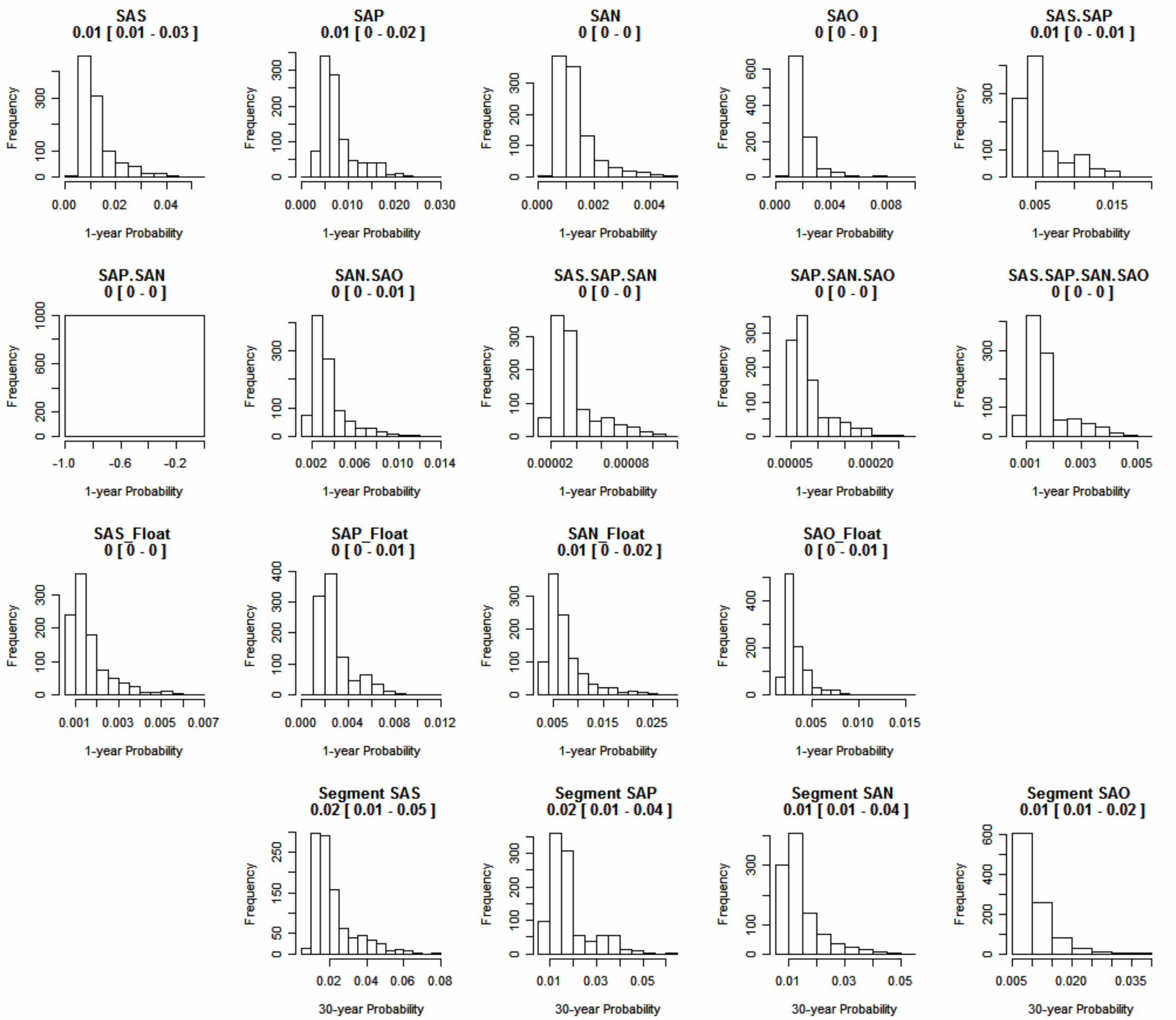


Delta Risk\Figures\TimePred2050.grf 1/31/07 3:45 PM

URS	DELTA RISK MANAGEMENT STRATEGY California	Time-Dependent Probabilites for the San Andreas Rupture Scenarios for 2050	Figure 6-4
Project No. 26815621			



URS	DELTA RISK MANAGEMENT STRATEGY California	Time-Dependent Probabilities for the San Andreas Rupture Scenarios for 2100	Figure 6-5
Project No. 26815621			



URS	DELTA RISK MANAGEMENT STRATEGY California	Time-Dependent Probabilities for the San Andreas Rupture Scenarios for 2200	Figure 6-6
Project No. 26815621			

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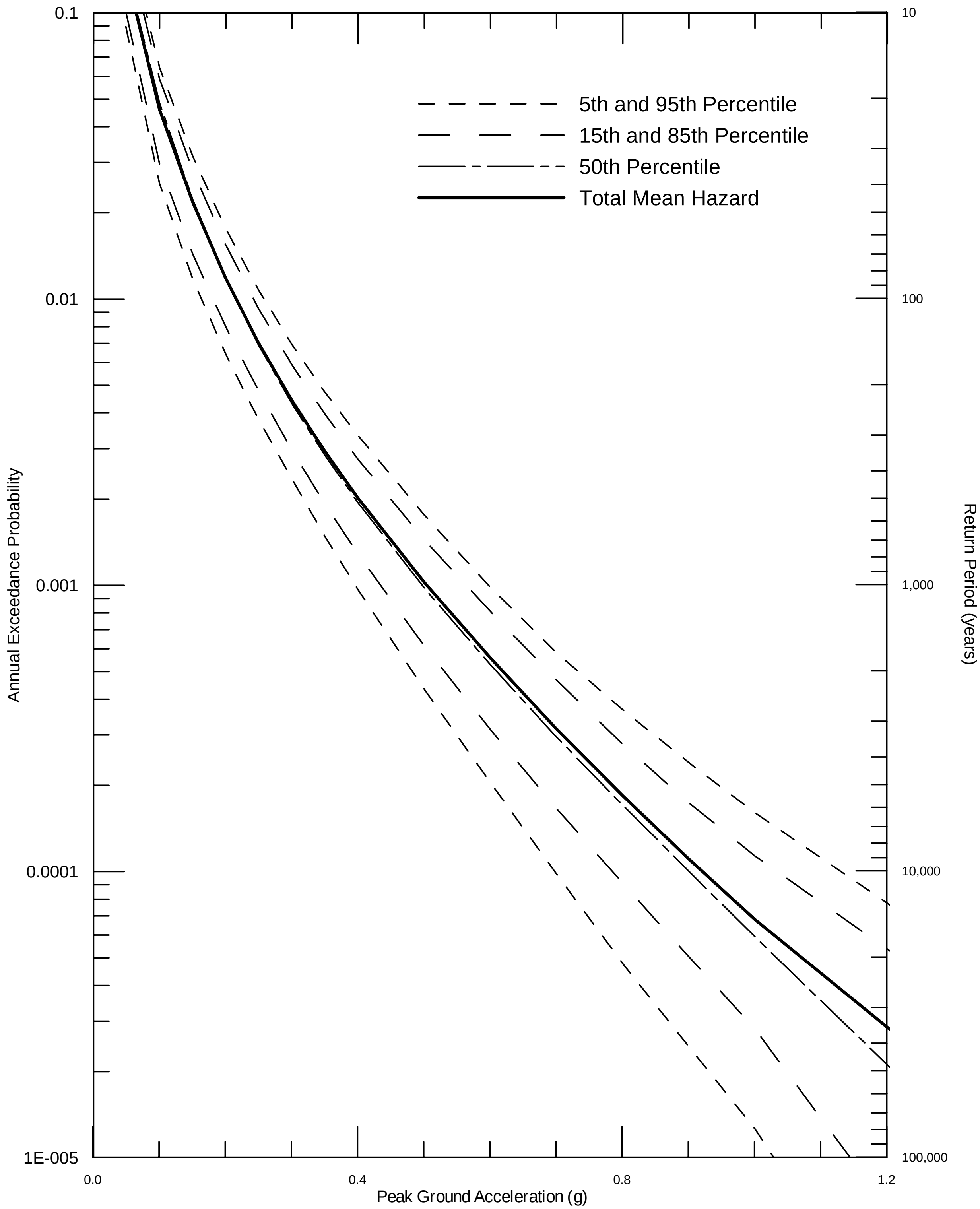
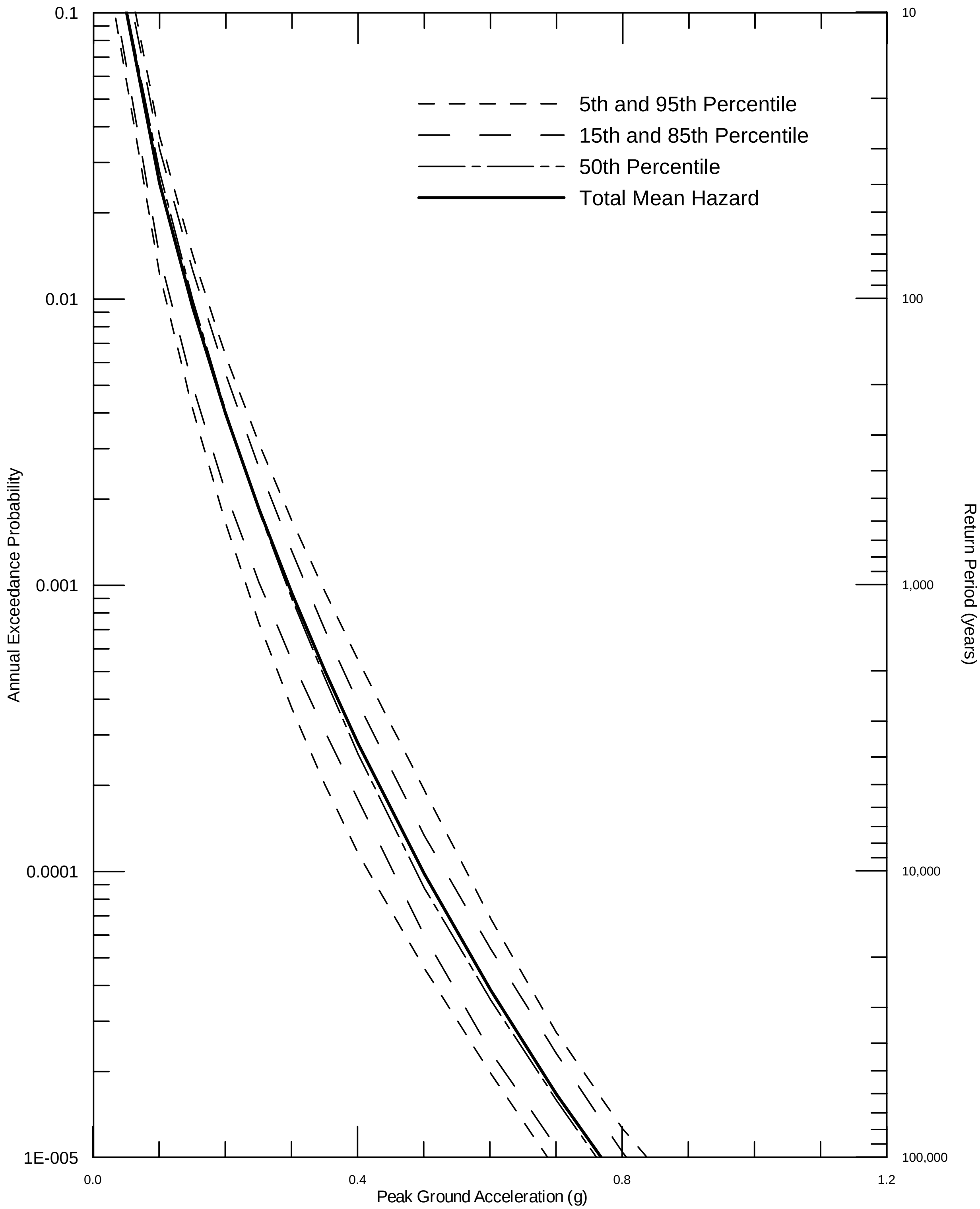
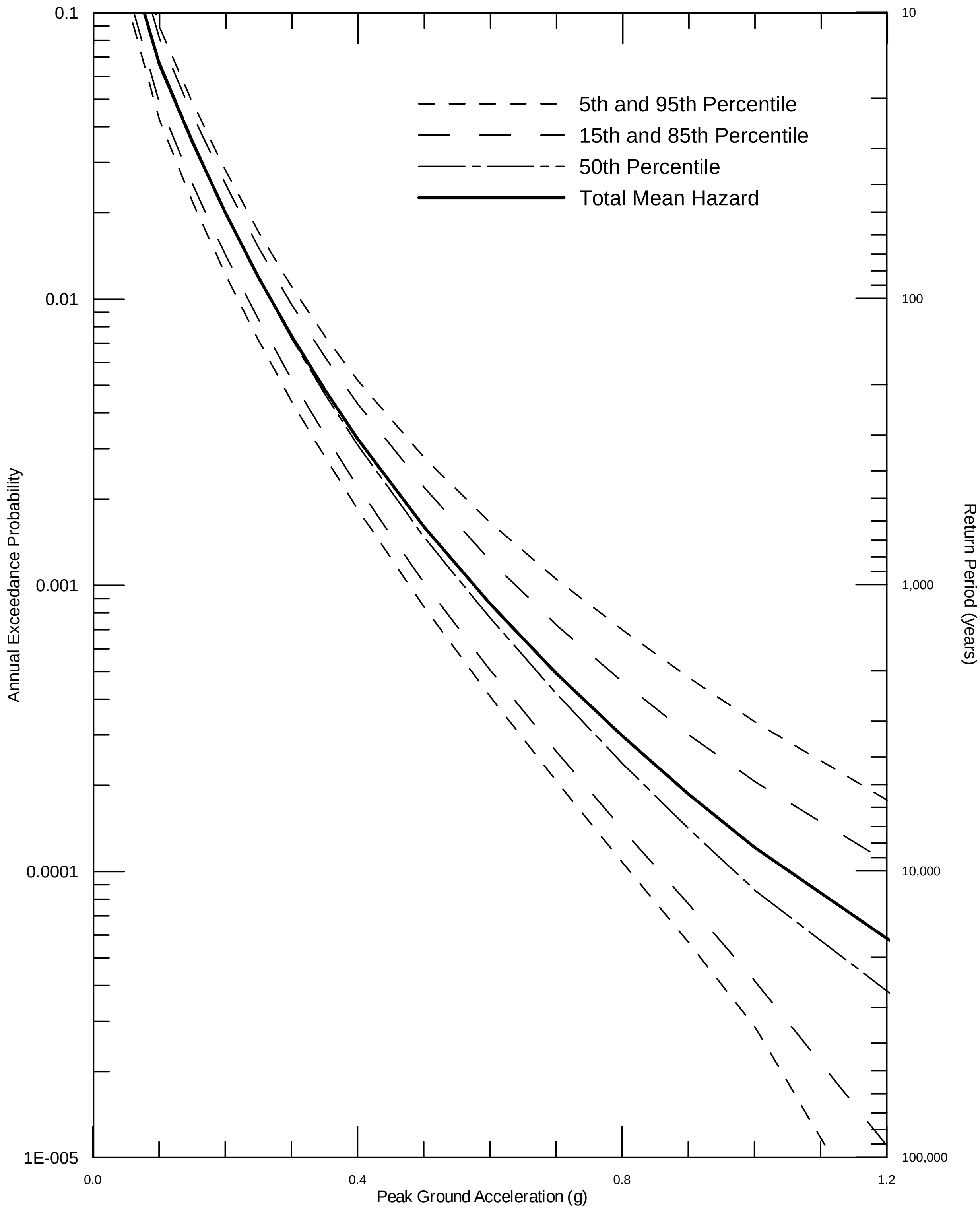


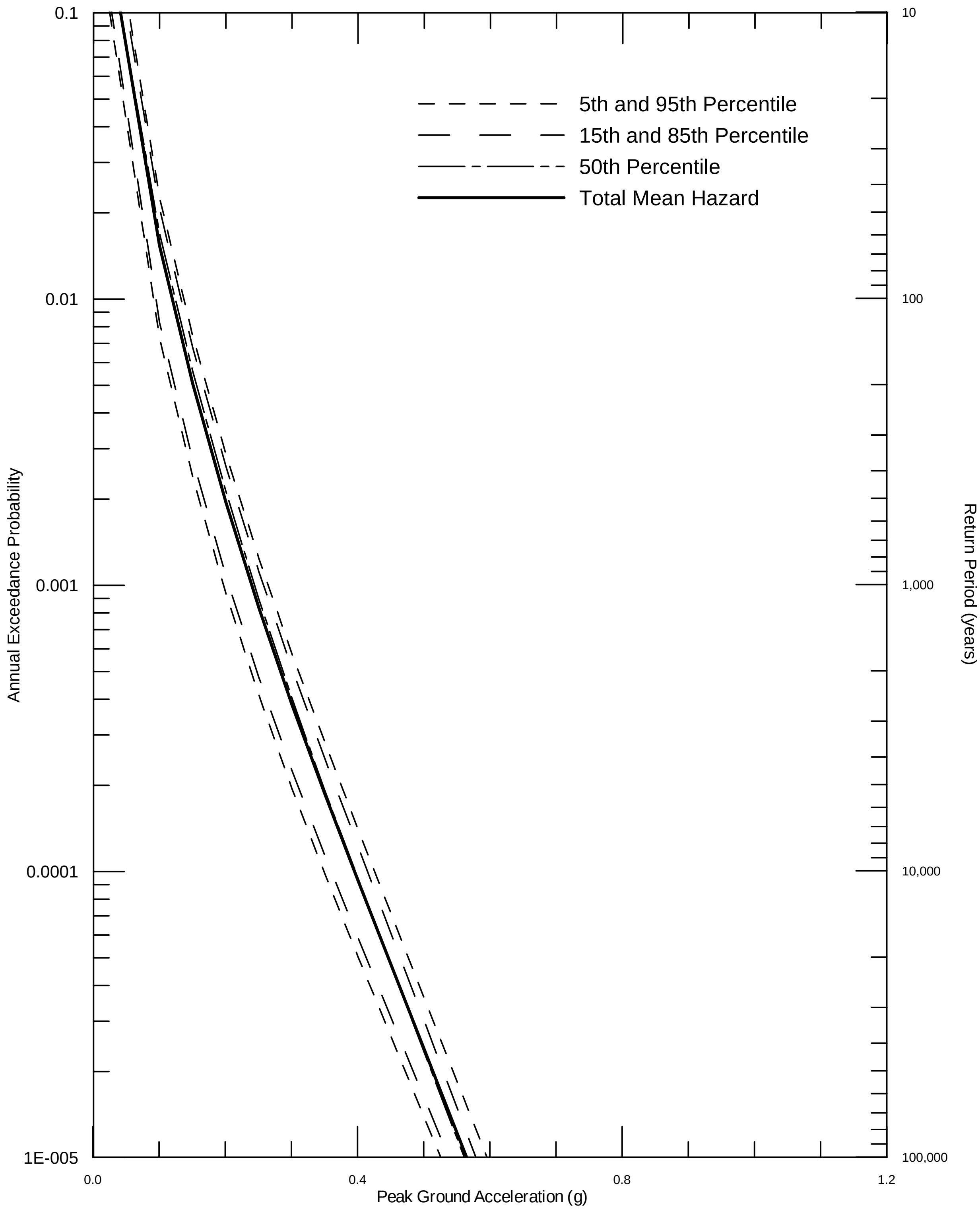
URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	TIME DEPENDENT SEISMIC HAZARD CURVES FOR MEAN PEAK HORIZONTAL ACCELERATION FOR CLIFTON COURT FOR 2005	Figure 6-7
Project No. 26815900			



URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	TIME DEPENDENT SEISMIC HAZARD CURVES FOR MEAN PEAK HORIZONTAL ACCELERATION FOR DELTA CROSS CHANNEL FOR 2005	Figure 6-8
Project No. 26815900			



URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	TIME DEPENDENT SEISMIC HAZARD CURVES FOR MEAN PEAK HORIZONTAL ACCELERATION FOR MONTEZUMA SLOUGH FOR 2005	Figure 6-9
Project No. 26815900			



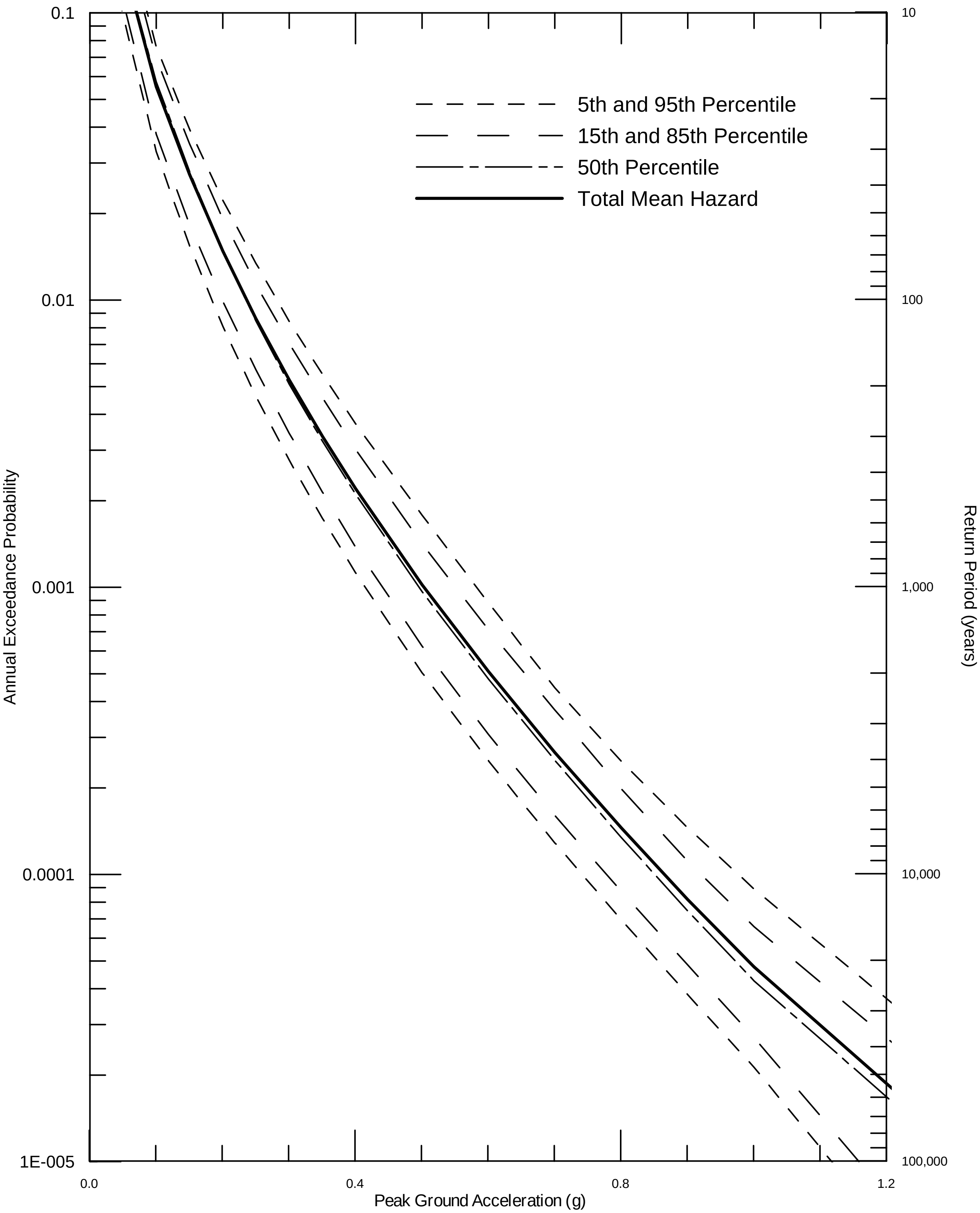
URS

DELTA RISK
MANAGEMENT STRATEGY
CALIFORNIA

Project No. 26815900

TIME DEPENDENT SEISMIC HAZARD CURVES
FOR MEAN PEAK HORIZONTAL ACCELERATION
FOR SACRAMENTO FOR 2005

Figure
6-10



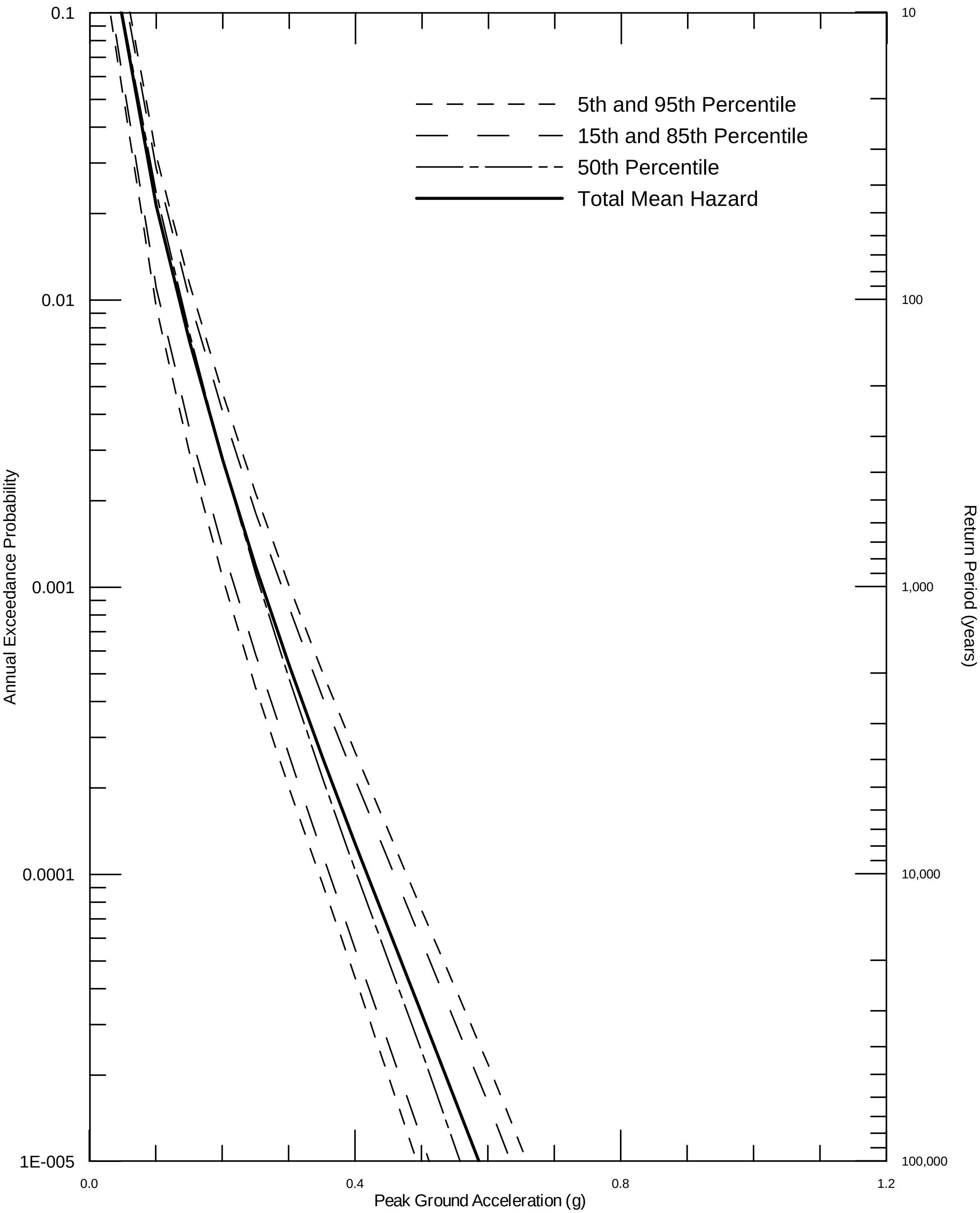
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

TIME DEPENDENT SEISMIC HAZARD CURVES FOR MEAN PEAK HORIZONTAL ACCELERATION FOR SHERMAN ISLAND FOR 2005

Figure 6-11



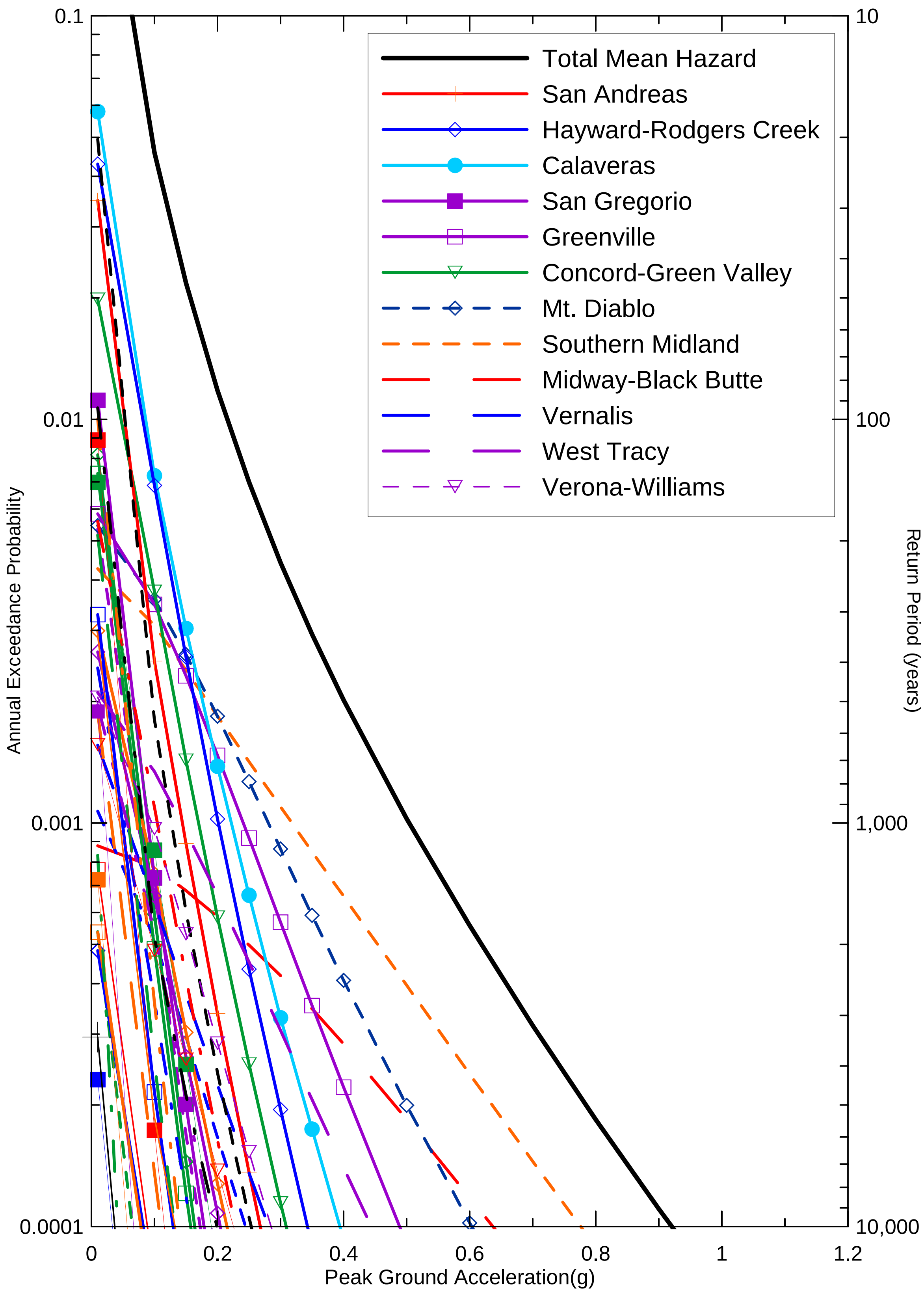
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

TIME DEPENDENT SEISMIC HAZARD CURVES FOR MEAN PEAK HORIZONTAL ACCELERATION FOR STOCKTON FOR 2005

Figure 6-12



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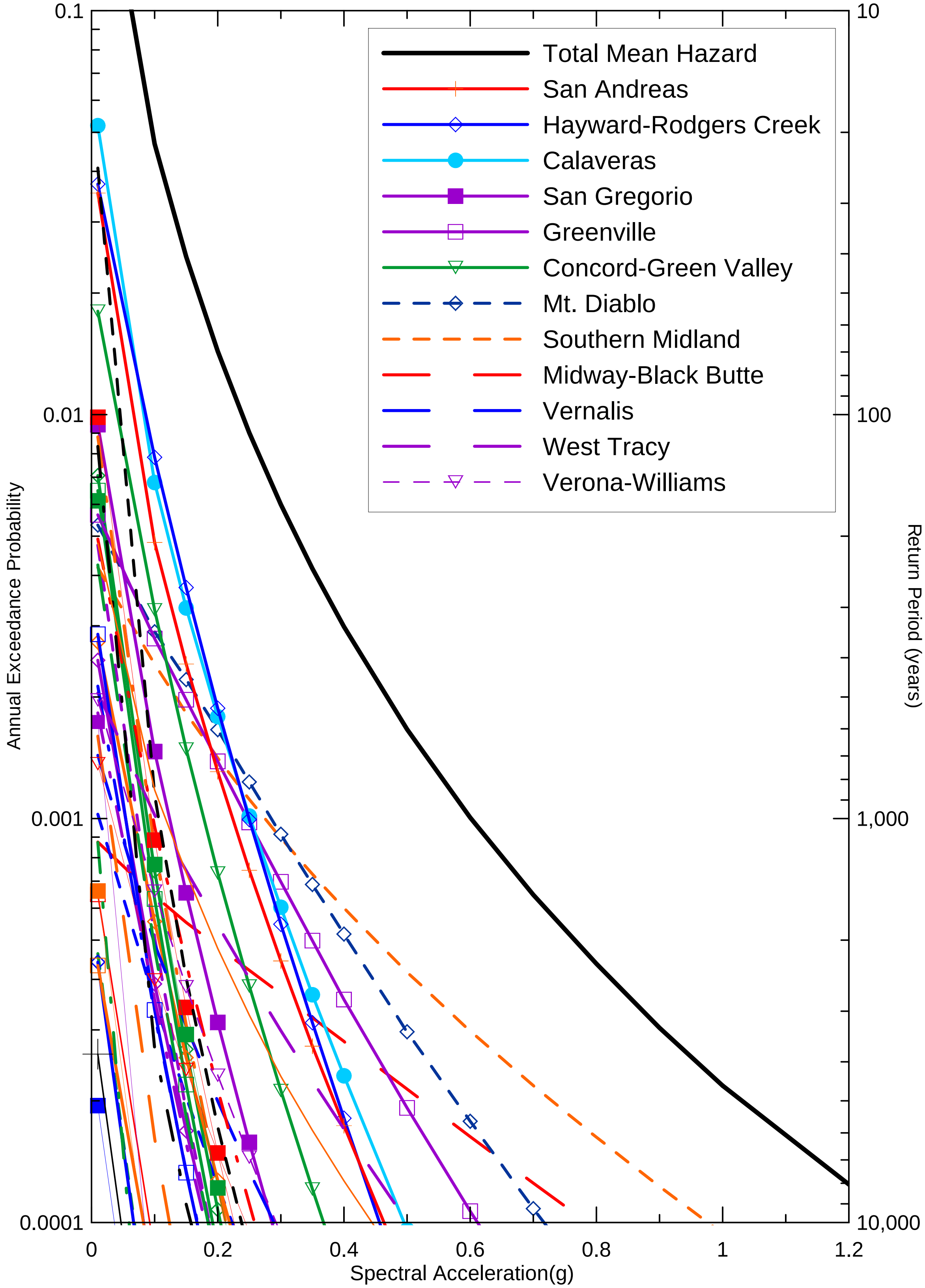
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO MEAN PEAK HORIZONTAL ACCELERATION TIME-DEPENDENT HAZARD FOR CLIFTON COURT FOR 2005

Figure 6-13a



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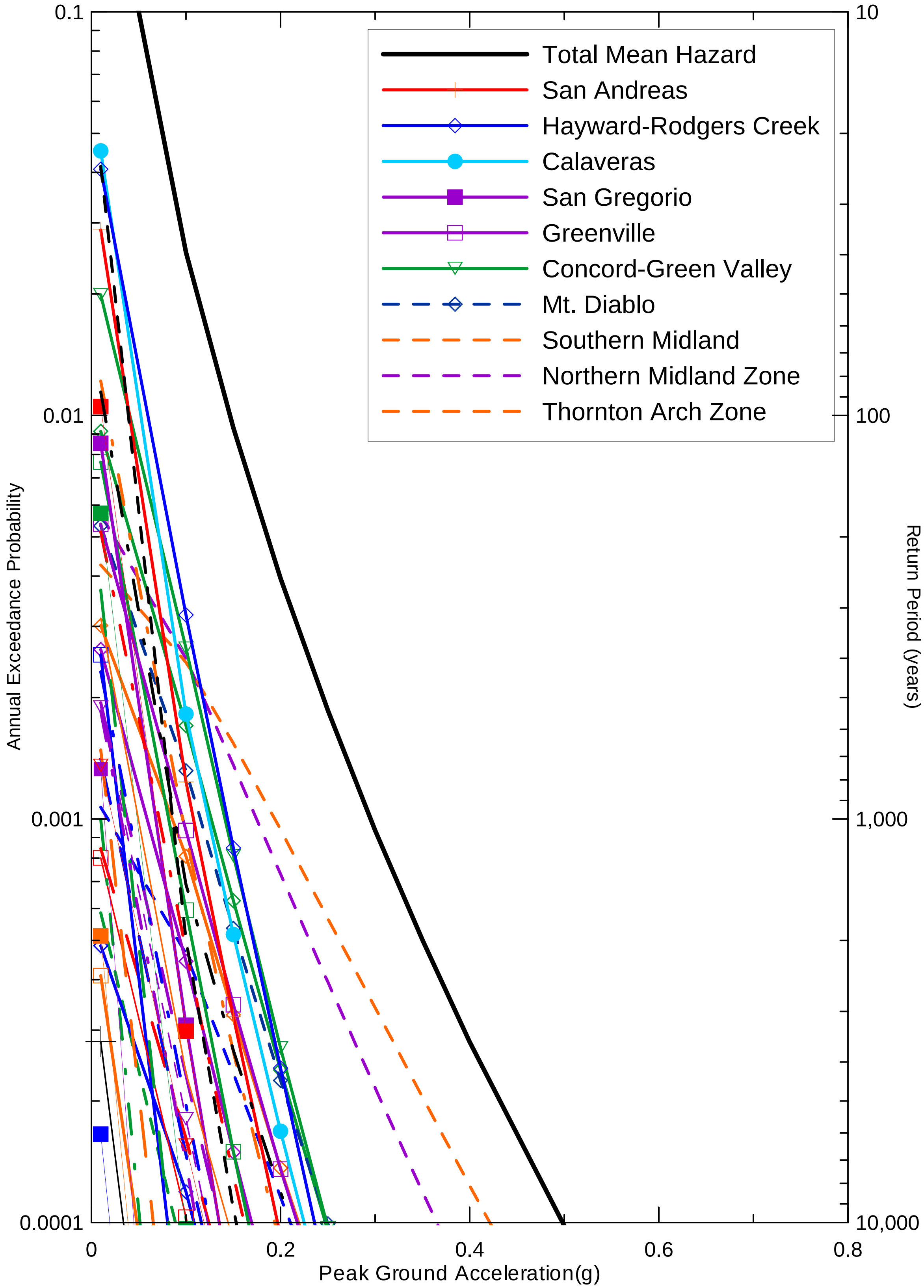
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO 1.0 SEC HORIZONTAL SPECTRAL ACCELERATION TIME-DEPENDENT HAZARD FOR CLIFTON COURT FOR 2005

Figure 6-13b



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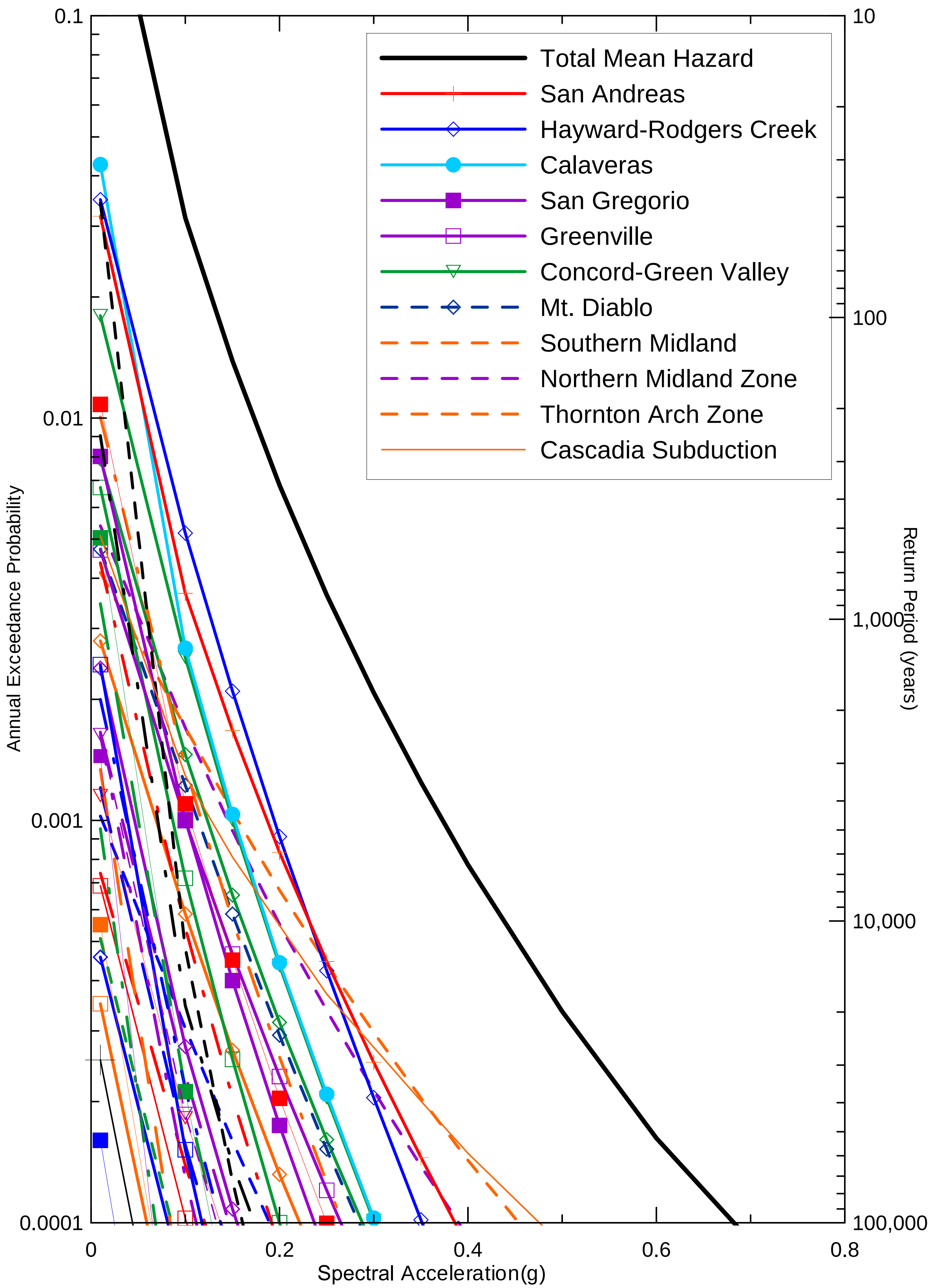
URS

DELTA RISK MANAGEMENT STRATEGY
CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO MEAN PEAK HORIZONTAL ACCELERATION TIME-DEPENDENT HAZARD FOR DELTA CROSS CHANNEL FOR 2005

Figure 6-14a



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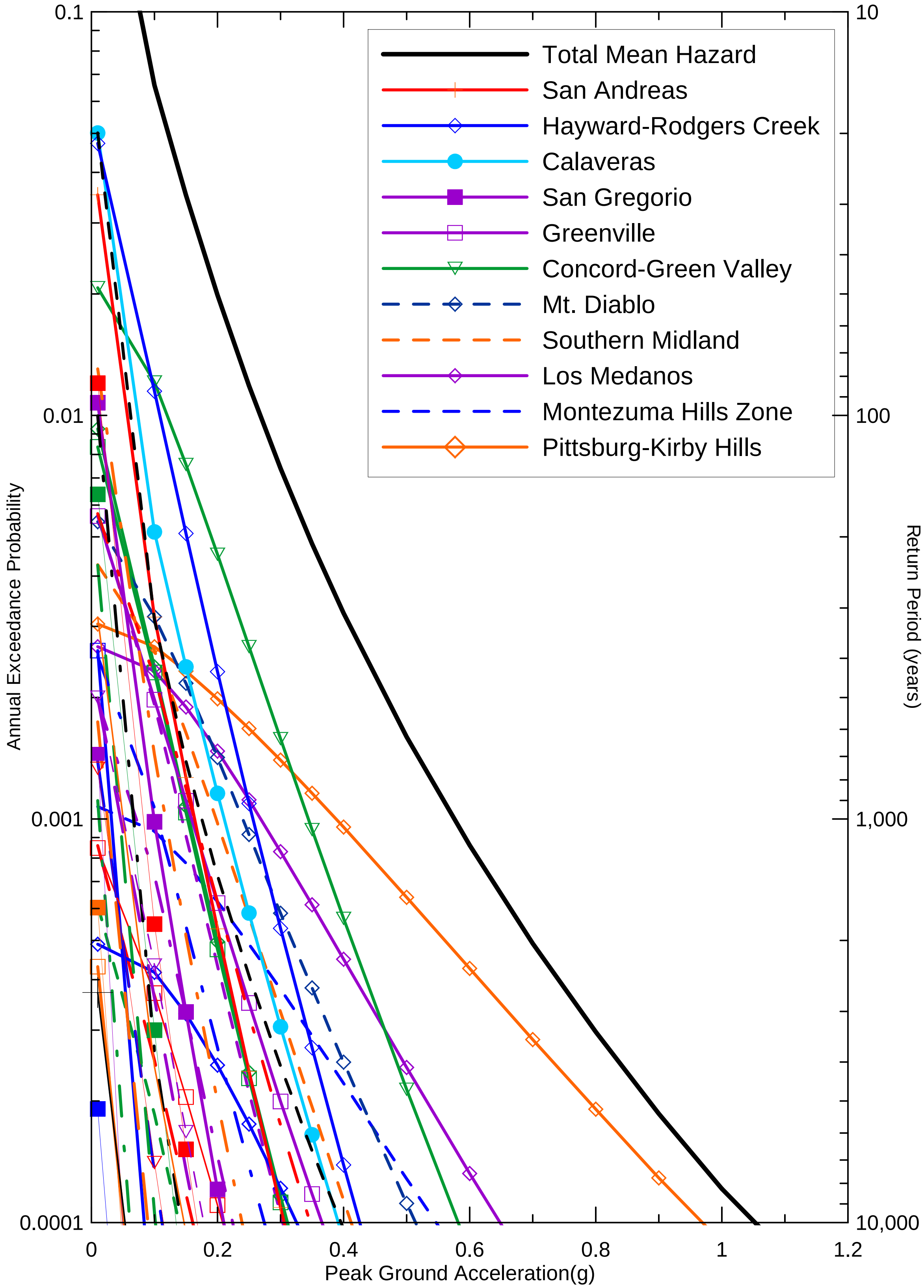
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO 1.0 SEC HORIZONTAL SPECTRAL ACCELERATION TIME-DEPENDENT HAZARD FOR DELTA CROSS CHANNEL FOR 2005

Figure 6-14b



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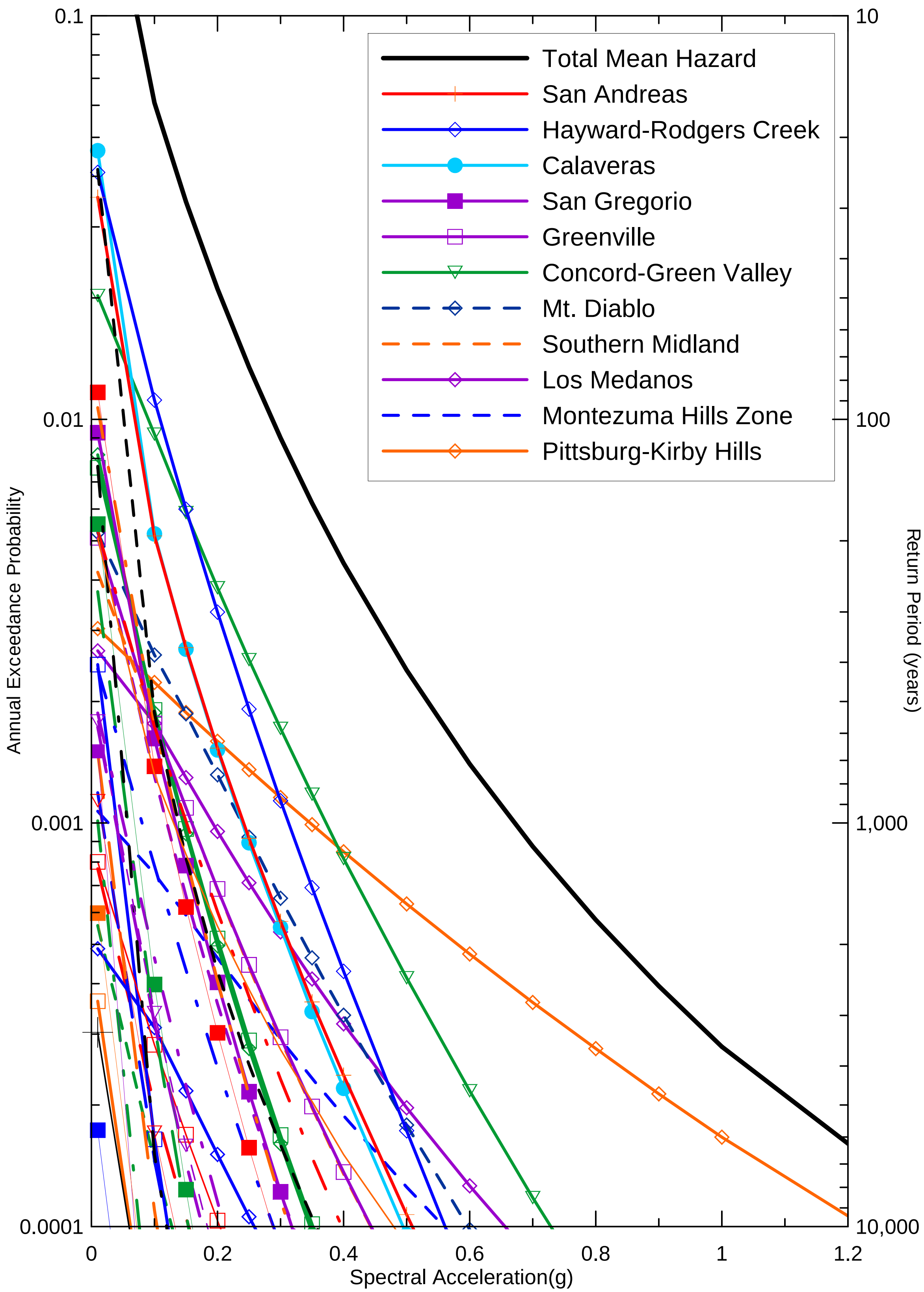
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO MEAN PEAK HORIZONTAL ACCELERATION TIME-DEPENDENT HAZARD FOR MONTEZUMA SLOUGH FOR 2005

Figure 6-15a



URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO 1.0 SEC HORIZONTAL SPECTRAL ACCELERATION TIME-DEPENDENT HAZARD FOR MONTEZUMA SLOUGH FOR 2005

Figure 6-15b

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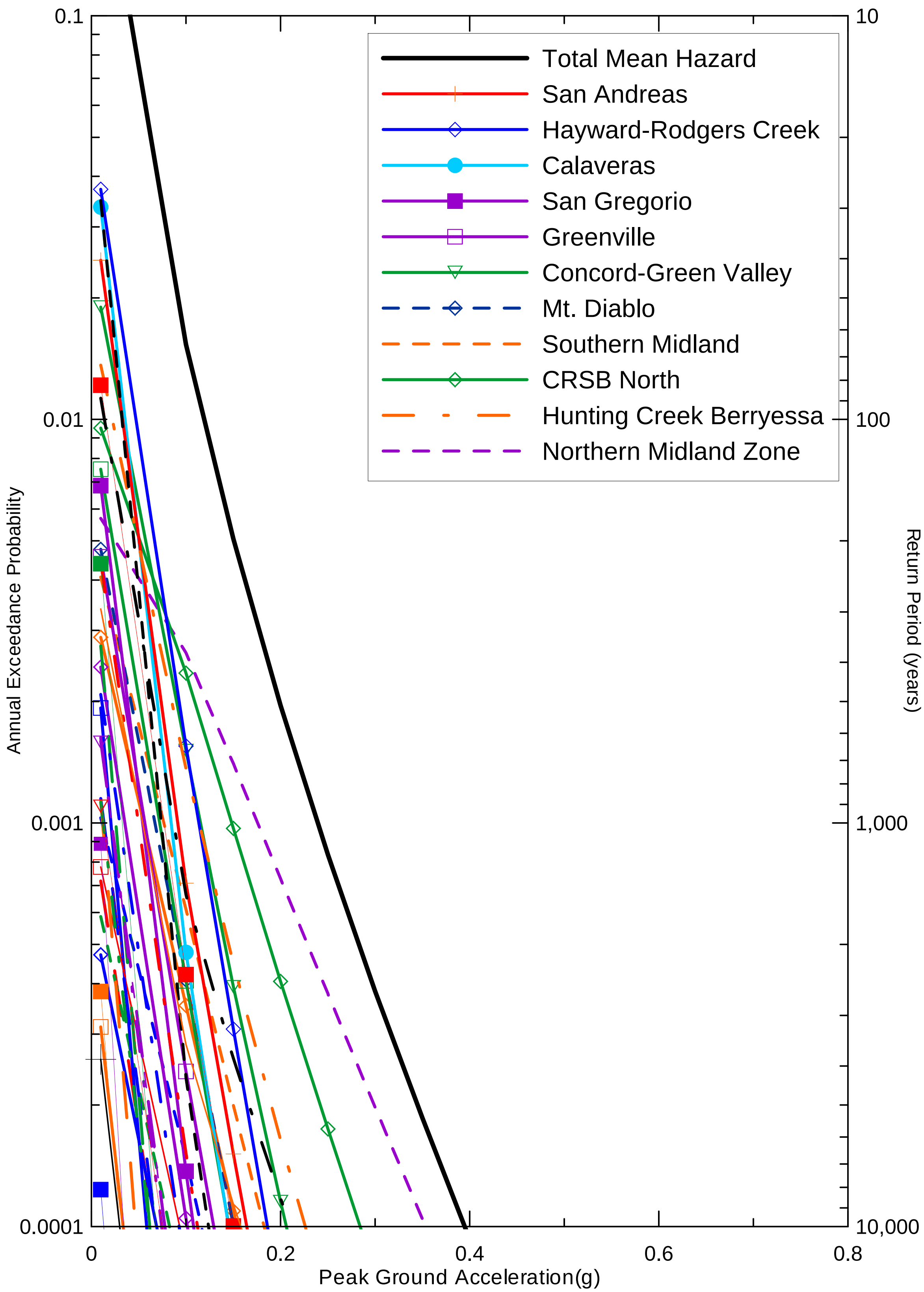

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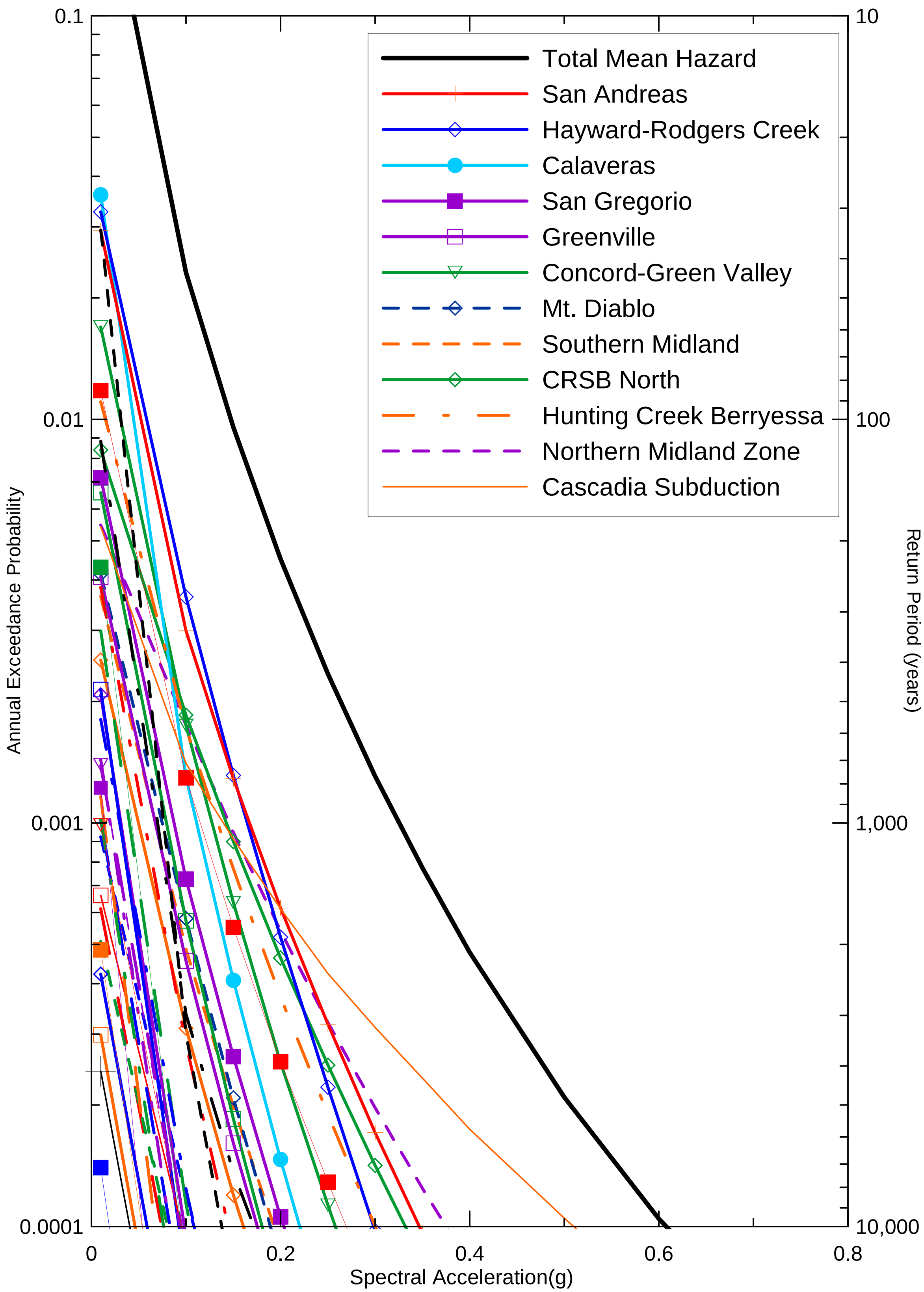
URS

DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO MEAN PEAK HORIZONTAL ACCELERATION TIME-DEPENDENT HAZARD FOR SACRAMENTO FOR 2005

Figure 6-16a



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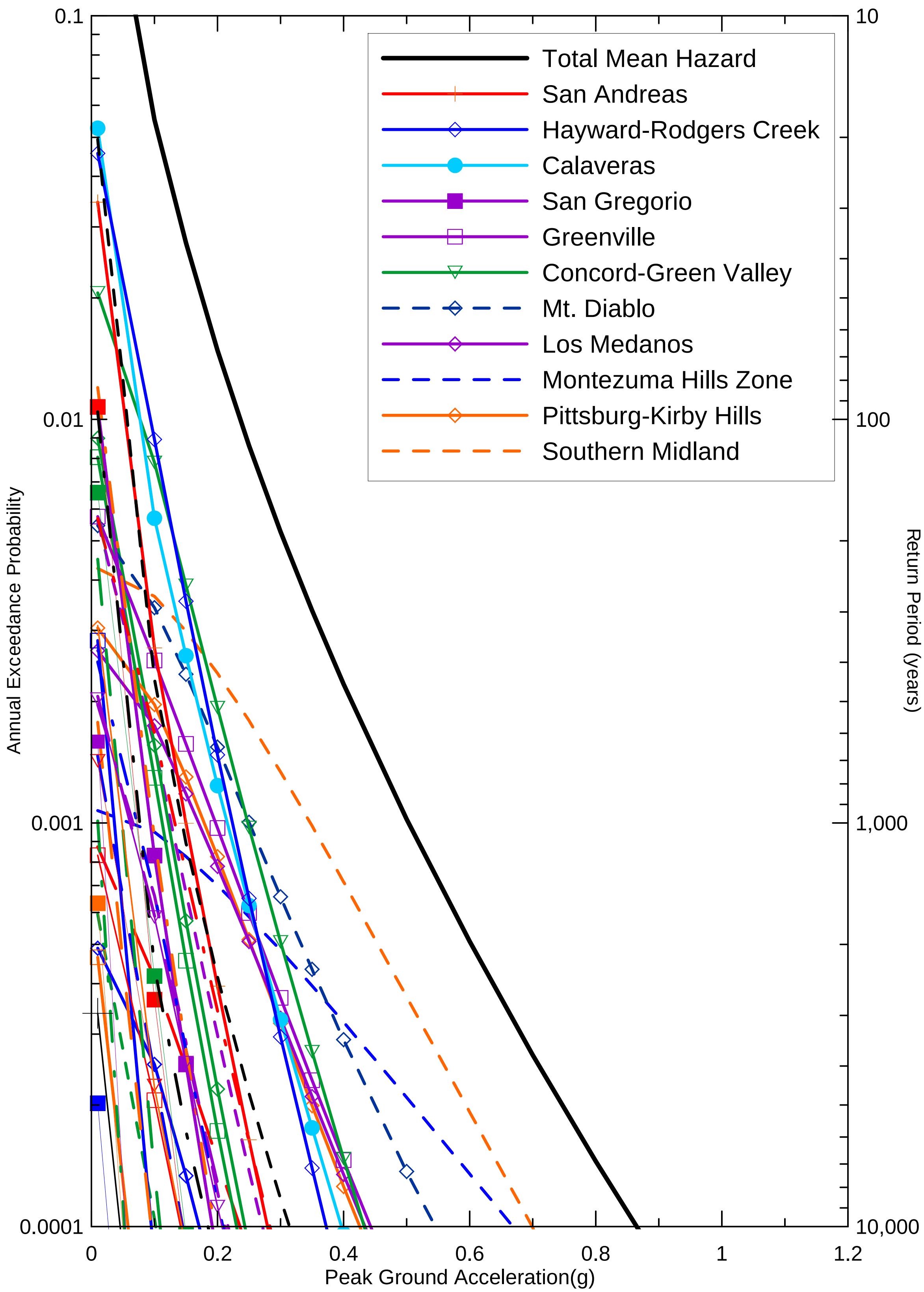
URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	SEISMIC SOURCE CONTRIBUTIONS TO 1.0 SEC HORIZONTAL SPECTRAL ACCELERATION TIME-DEPENDENT HAZARD FOR SACRAMENTO FOR 2005	Figure 6-16b
Project No. 26815900			



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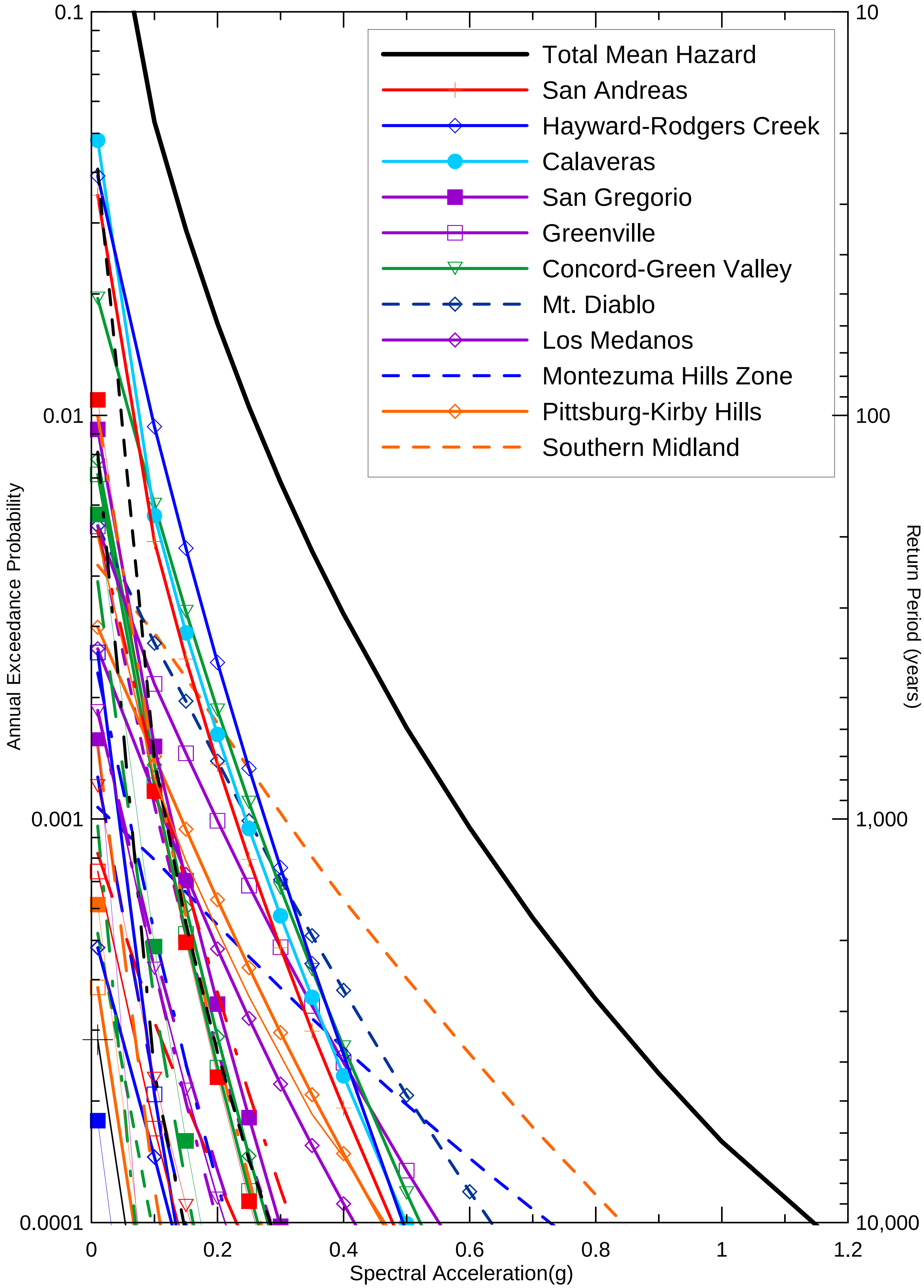
URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	SEISMIC SOURCE CONTRIBUTIONS TO MEAN PEAK HORIZONTAL ACCELERATION TIME-DEPENDENT HAZARD FOR SHERMAN ISLAND FOR 2005	Figure 6-17a
Project No. 26815900			



URS

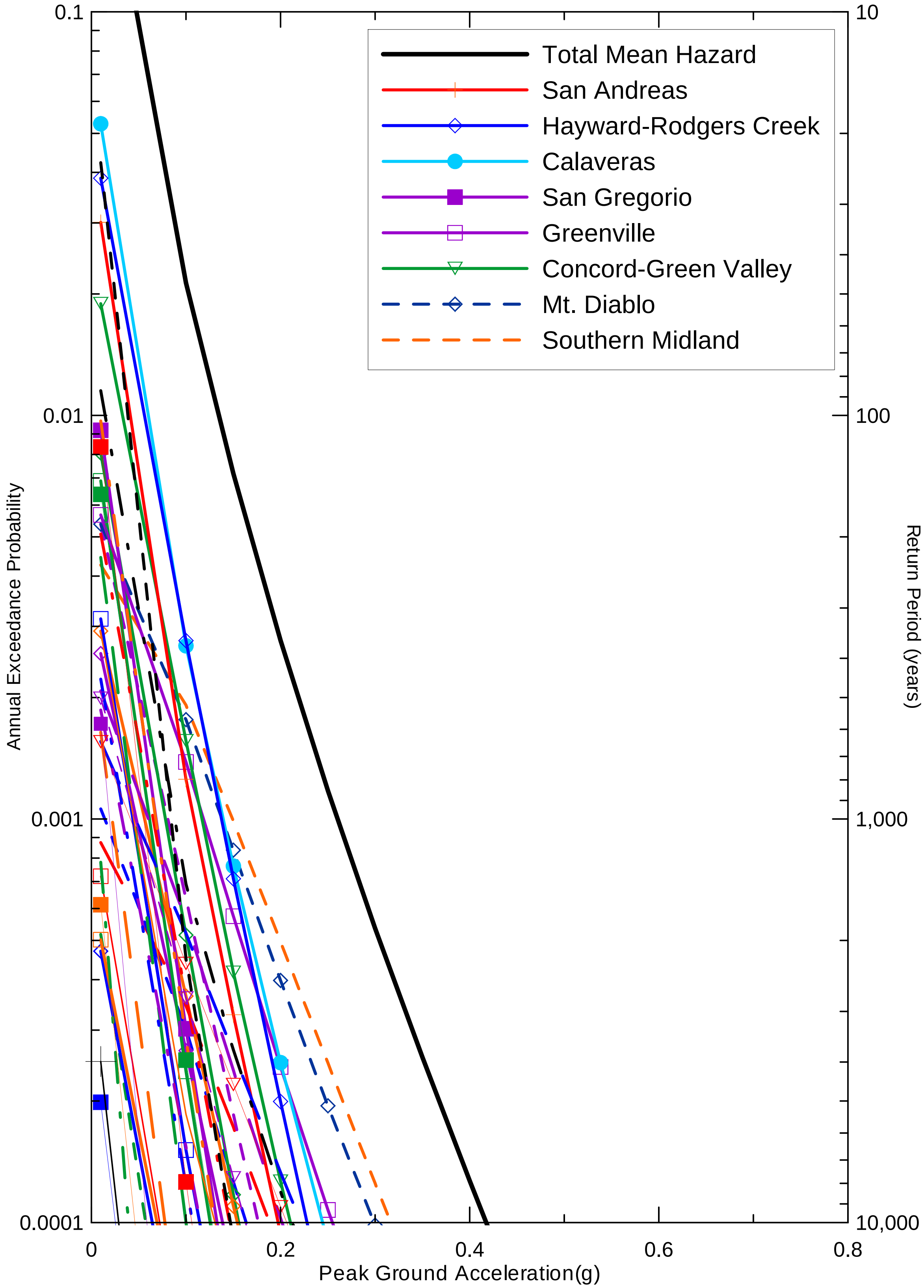
DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

Project No. 26815900

SEISMIC SOURCE CONTRIBUTIONS TO 1.0 SEC HORIZONTAL SPECTRAL ACCELERATION TIME-DEPENDENT HAZARD FOR SHERMAN ISLAND FOR 2005

Figure 6-17b

Delta Risk\figures\DR1-t1-2005.grf



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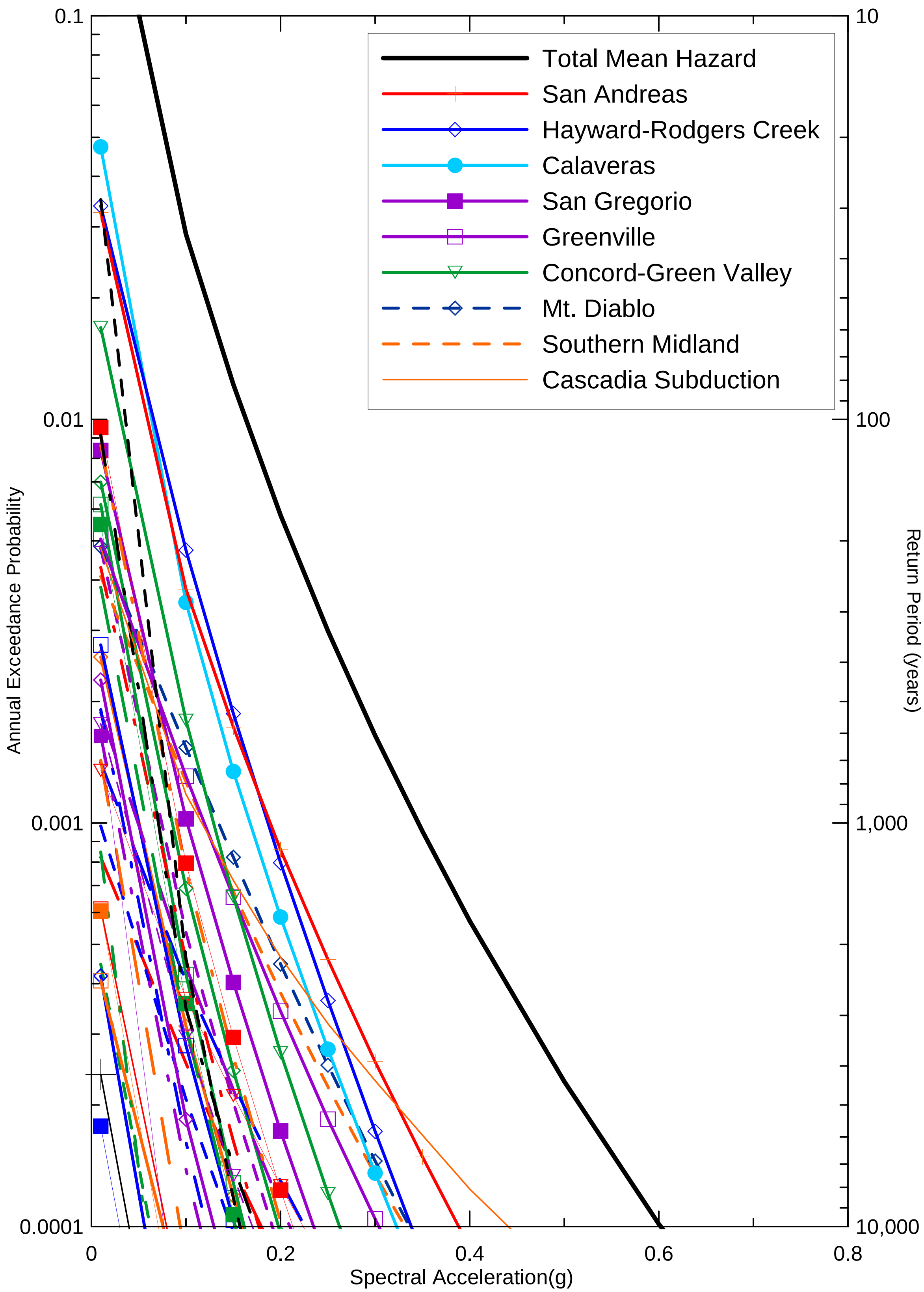
URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	SEISMIC SOURCE CONTRIBUTIONS TO MEAN PEAK HORIZONTAL ACCELERATION TIME-DEPENDENT HAZARD FOR STOCKTON FOR 2005	Figure 6-18a
Project No. 26815900			



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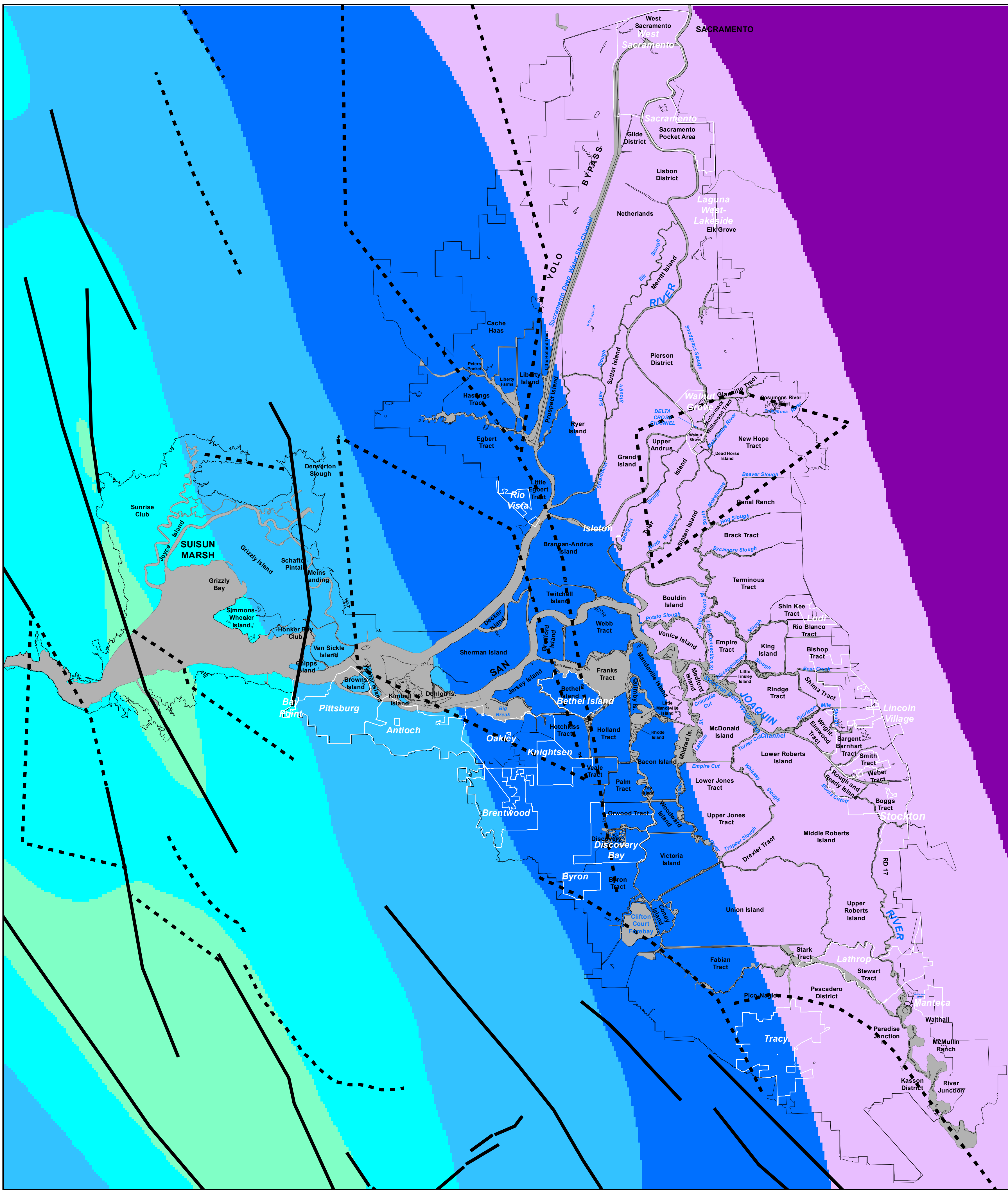
URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	SEISMIC SOURCE CONTRIBUTIONS TO 1.0 SEC HORIZONTAL SPECTRAL ACCELERATION TIME-DEPENDENT HAZARD FOR STOCKTON FOR 2005	Figure 6-18b
Project No. 26815900			



Legend

Mapped Faults

Surficial faults used in the hazard analysis

Blind Faults

Blind faults used in the hazard analysis

Legal Delta and Suisun Marsh Boundary

PGA, 100 Year Return Period

- 0.00 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20
- 0.21 - 0.25
- 0.26 - 0.30
- 0.31 - 0.35
- 0.36 - 0.40
- 0.41 - 0.45
- 0.46 - 0.50
- 0.51 - 0.55
- 0.56 - 0.60
- 0.61 - 0.65
- 0.66 - 0.70

0 5 10 Miles

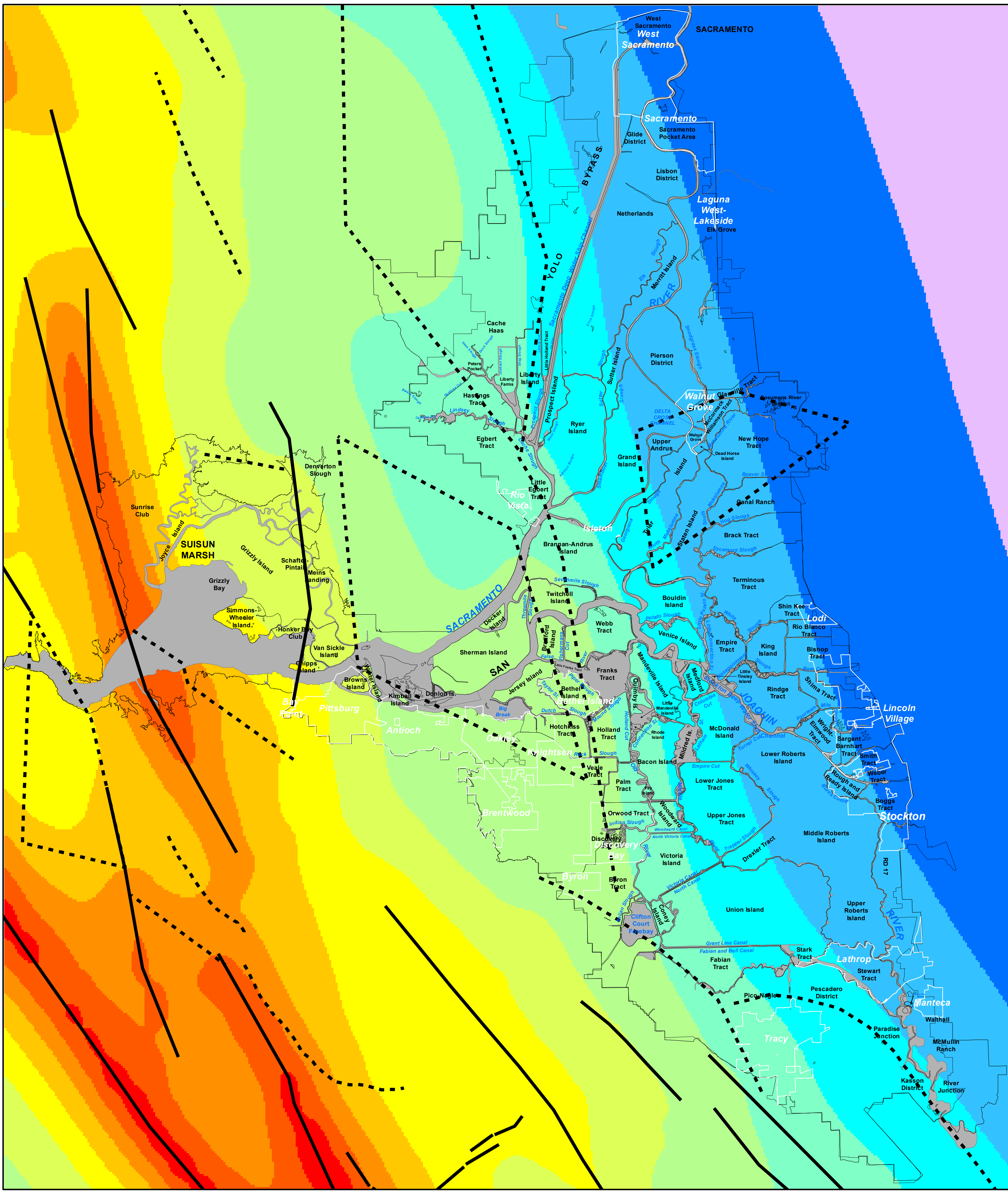
URS

DRMS

26815431

PGA Hazard for a 100-Year Return Period

FIGURE 6-19



Legend

Mapped Faults

Surficial faults used in the hazard analysis

Blind Faults

Blind faults used in the hazard analysis

Legal Delta and Suisun Marsh Boundary

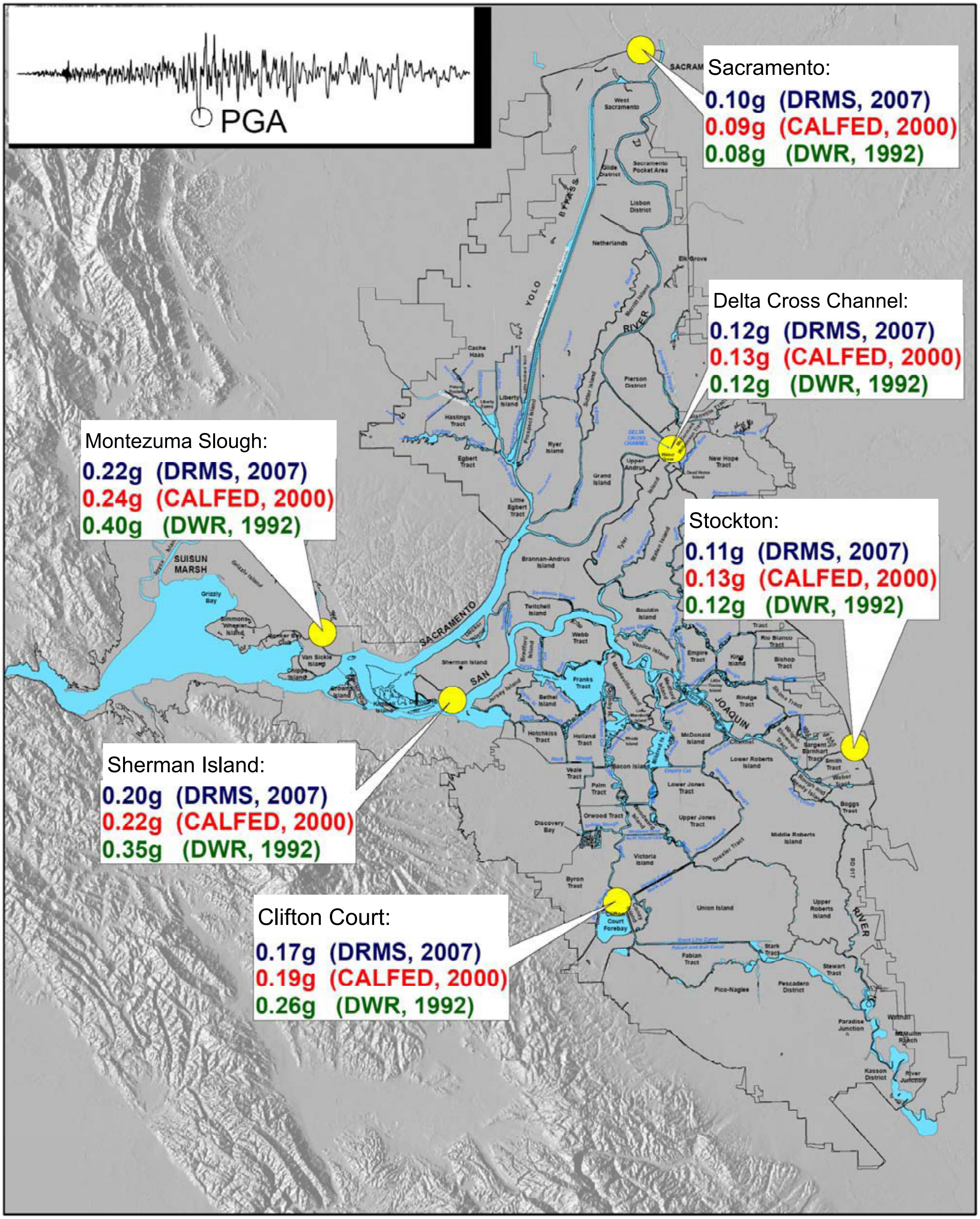
PGA, 500 Year Return Period

- 0.00 - 0.10
- 0.11 - 0.15
- 0.16 - 0.20
- 0.21 - 0.25
- 0.26 - 0.30
- 0.31 - 0.35
- 0.36 - 0.40
- 0.41 - 0.45
- 0.46 - 0.50
- 0.51 - 0.55
- 0.56 - 0.60
- 0.61 - 0.65
- 0.66 - 0.70

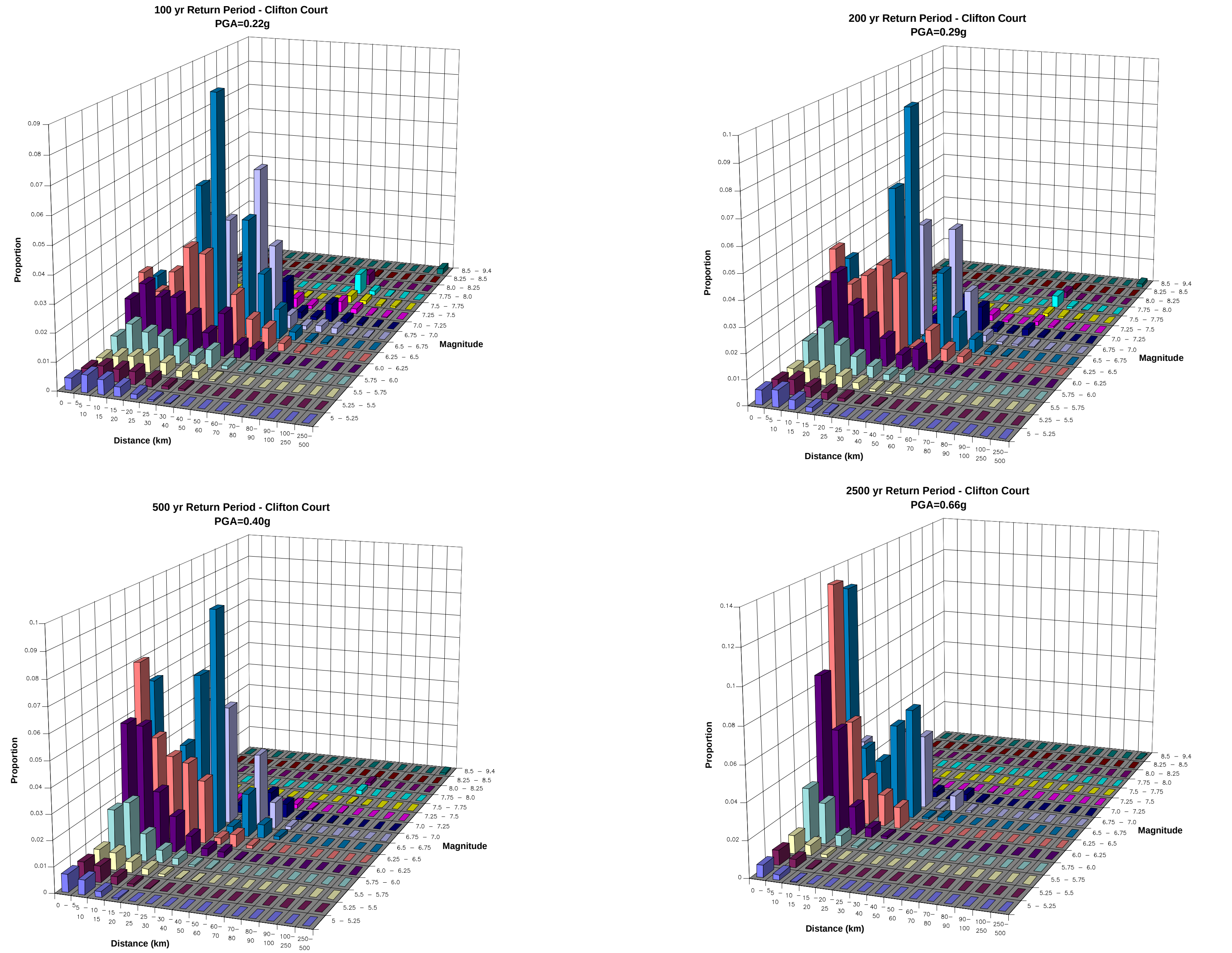
0 5 10 Miles

URS	DRMS 26815431	PGA Hazard for a 500-Year Return Period	FIGURE 6-20

URS Corporation, Oakland, CA, dhwrigh0 P:\GIS\GIS_Phase_II_Project_Files\MXD\Current Working Documents\Seismic_Motions\Seismic Motion Template.mxd - 5/28/2008 @ 1:49:14 PM



Delta Risk Management Strategy (DRMS) Levee Fragility		Comparison of Ground Motions from Other Studies Potential Stiff Soil/Rock Earthquake Motions for a 100-year Earthquake	Figure 6-21
URS	Project No. 26815621		

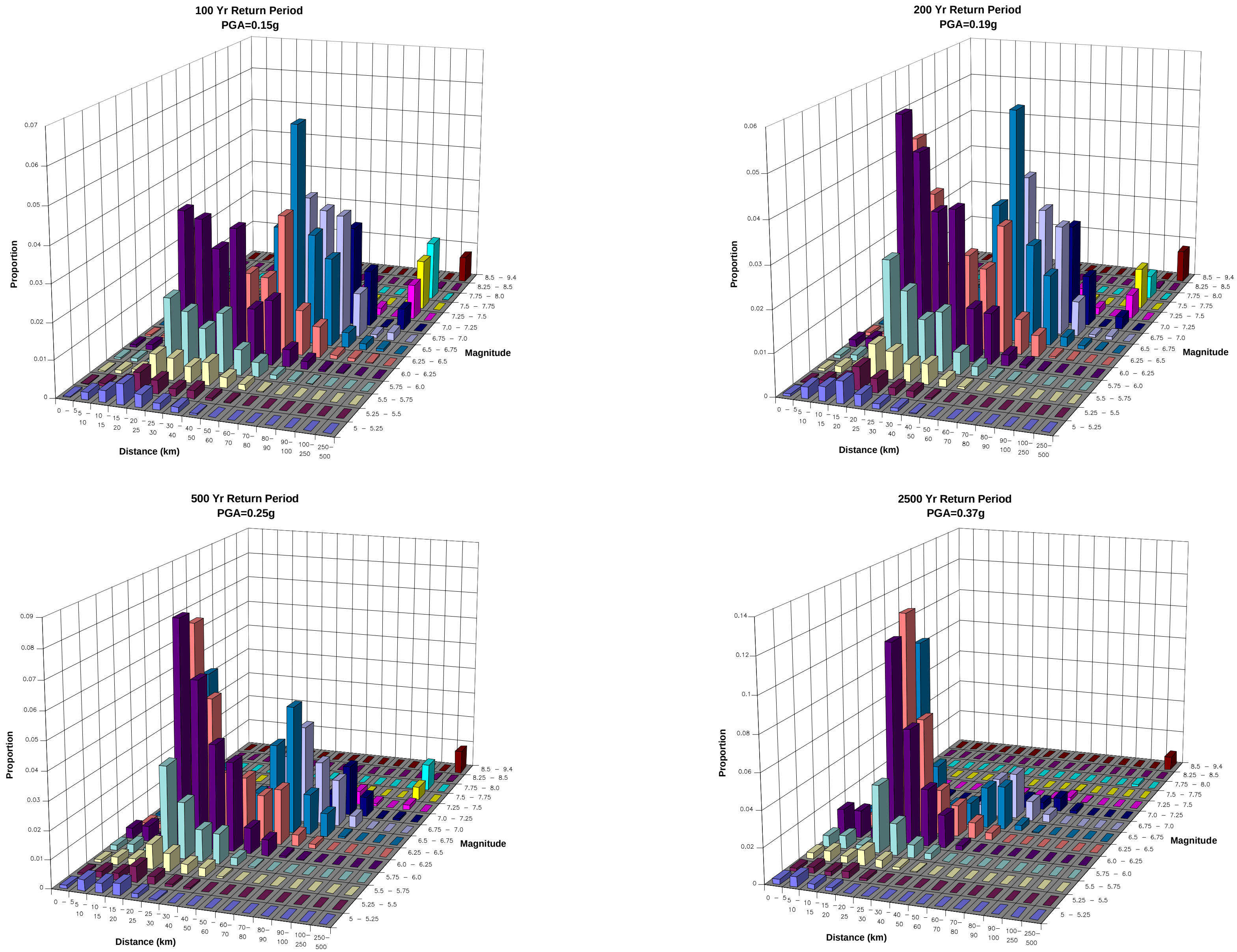


DELTA RISK MANAGEMENT STRATEGY
CALIFORNIA

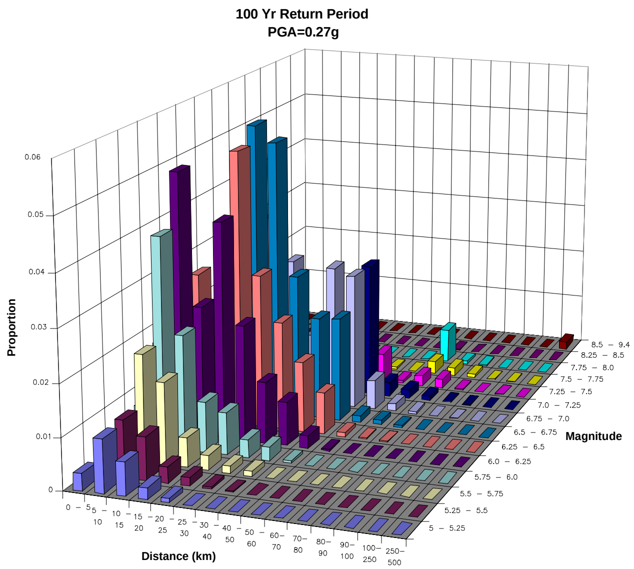
PROJECT No. 26815621

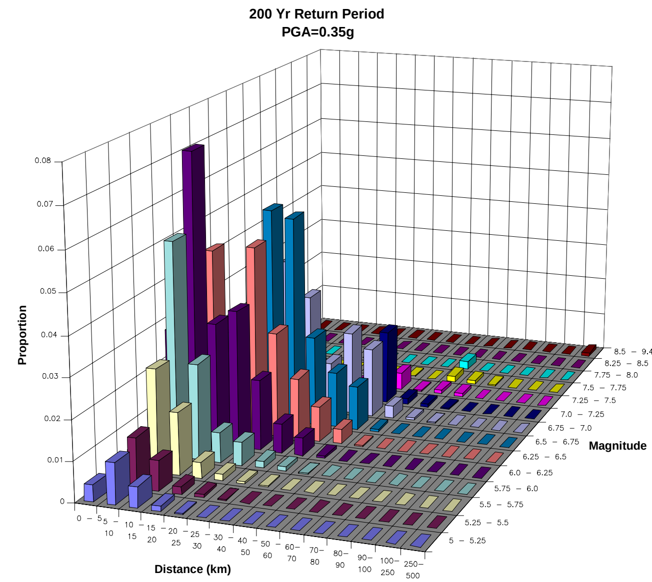
MAGNITUDE AND DISTANCE CONTRIBUTIONS TO THE MEAN PEAK HORIZONTAL ACCELERATION HAZARD FOR CLIFTON COURT FOR 2005

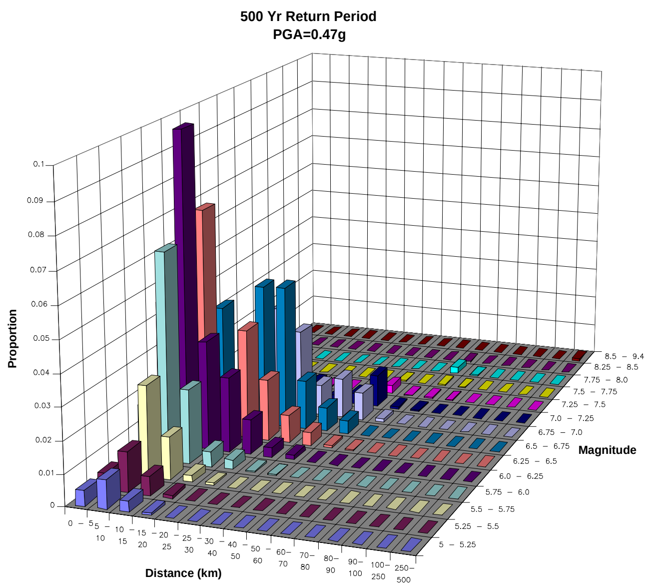
Figure 6-22

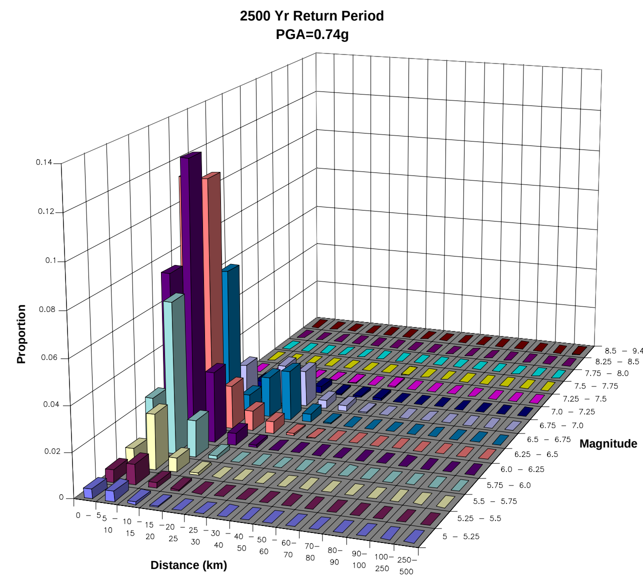


URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	MAGNITUDE AND DISTANCE CONTRIBUTIONS TO THE MEAN PEAK HORIZONTAL ACCELERATION HAZARD FOR DELTA CROSS CHANNEL FOR 2005	**Figure 6-23**
	PROJECT No. 26815621		

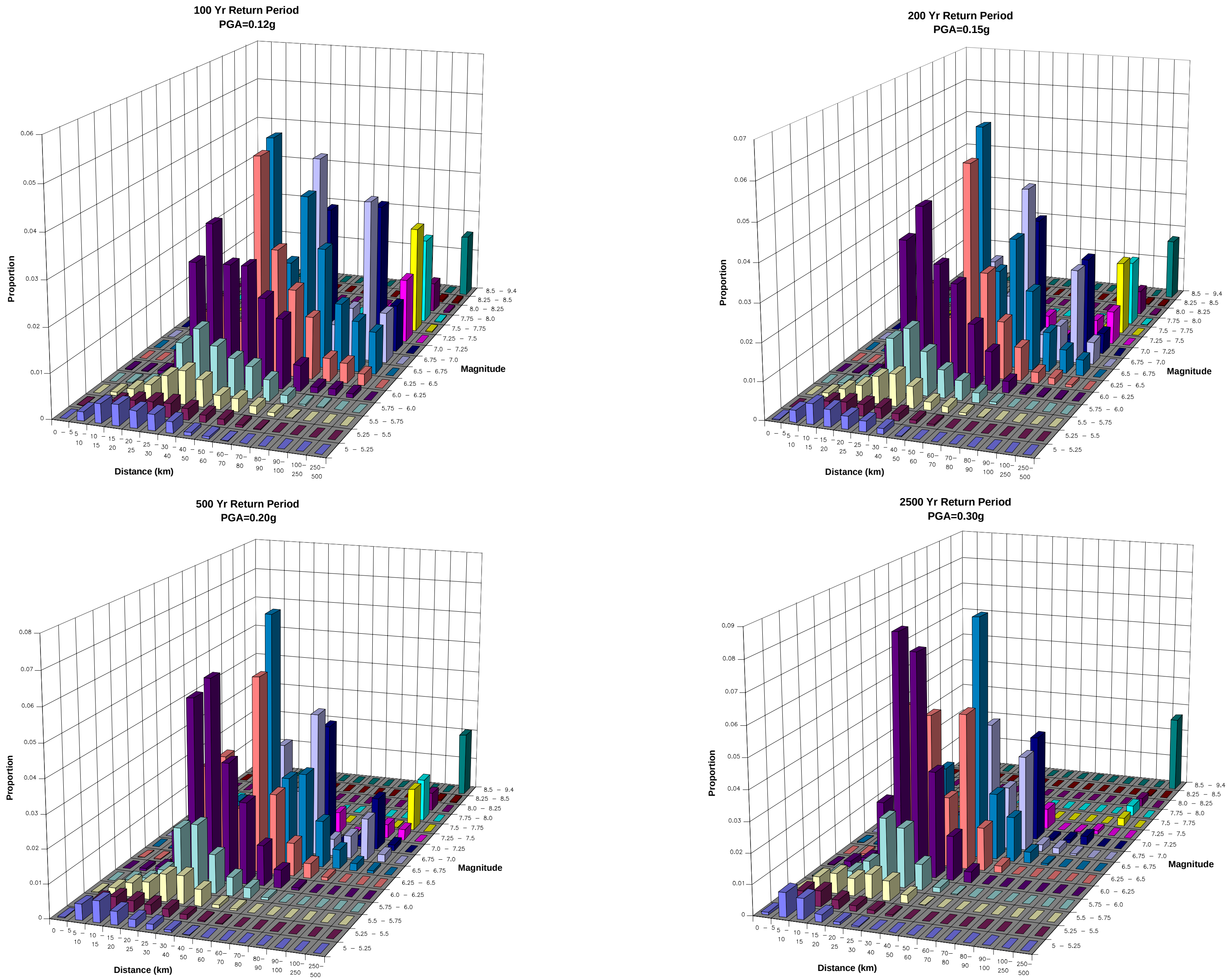




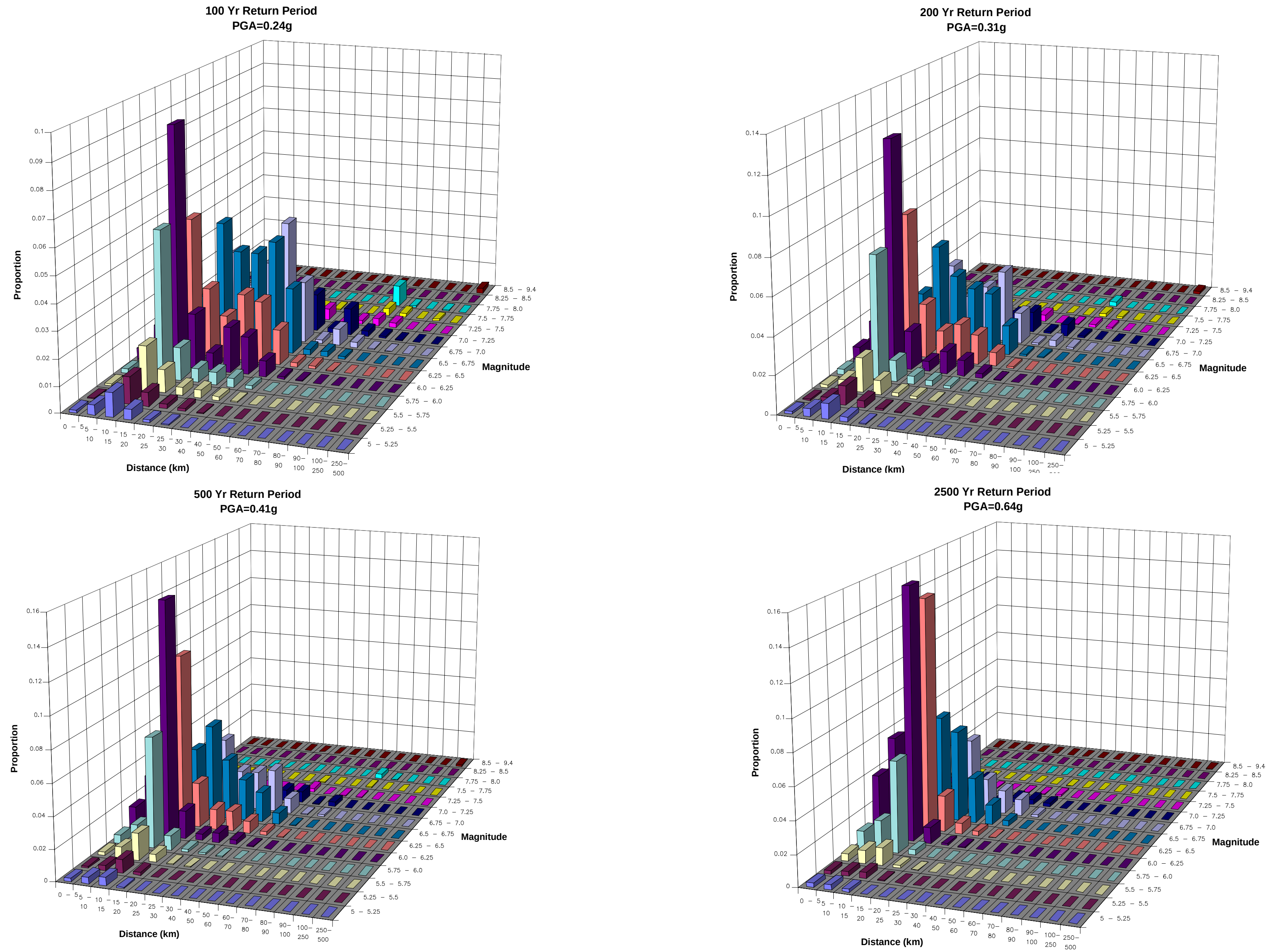




URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	MAGNITUDE AND DISTANCE CONTRIBUTIONS TO THE MEAN PEAK HORIZONTAL ACCELERATION HAZARD FOR MONTEZUMA SLOUGH FOR 2005	Figure 6-24
PROJECT No. 26815621			



URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	MAGNITUDE AND DISTANCE CONTRIBUTIONS TO THE MEAN PEAK HORIZONTAL ACCELERATION HAZARD FOR SACRAMENTO FOR 2005	Figure 6-25
	PROJECT No. 26815621		



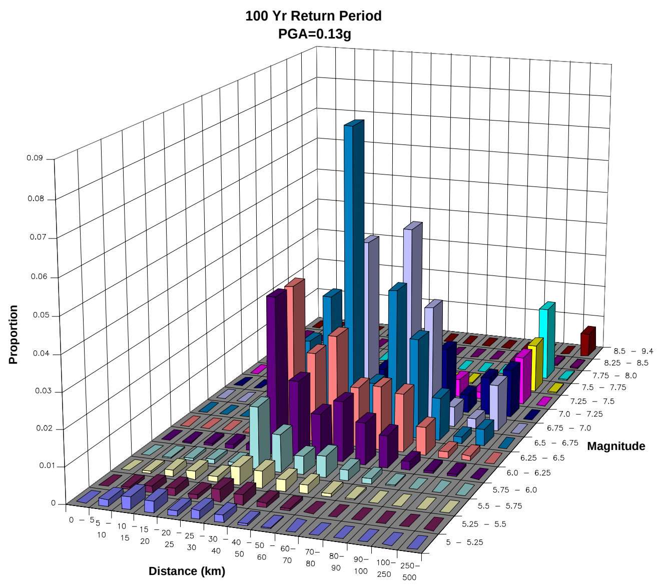
URS

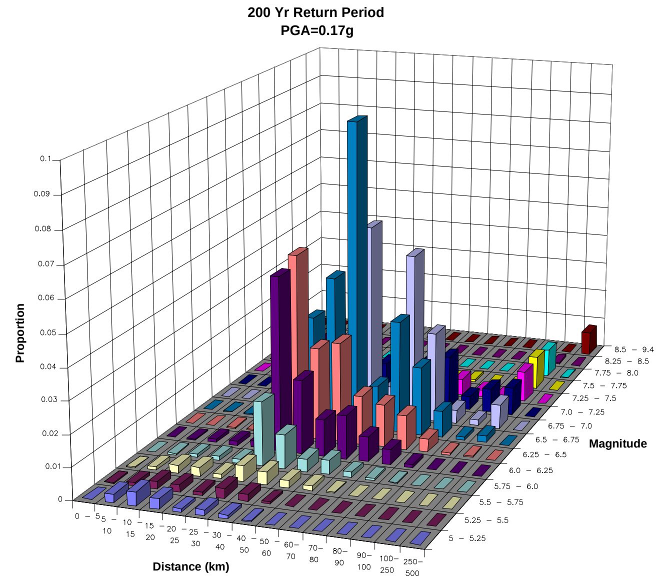
DELTA RISK MANAGEMENT STRATEGY CALIFORNIA

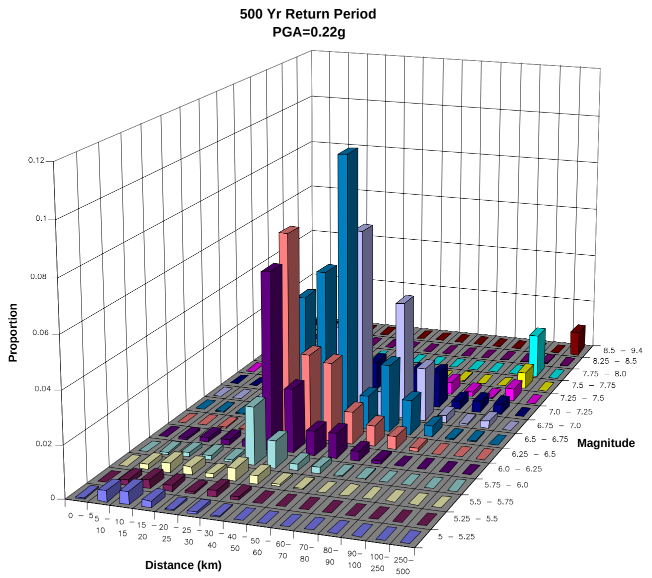
PROJECT No. 26815621

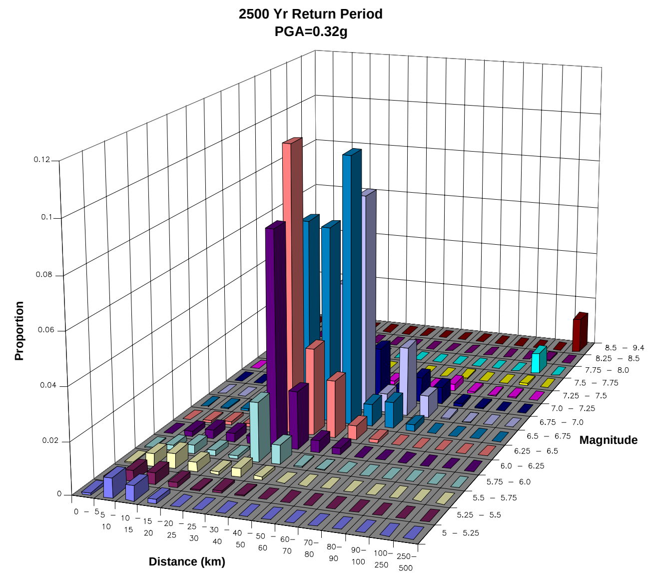
MAGNITUDE AND DISTANCE CONTRIBUTIONS TO THE MEAN PEAK HORIZONTAL ACCELERATION HAZARD FOR SHERMAN ISLAND FOR 2005

Figure 6-26



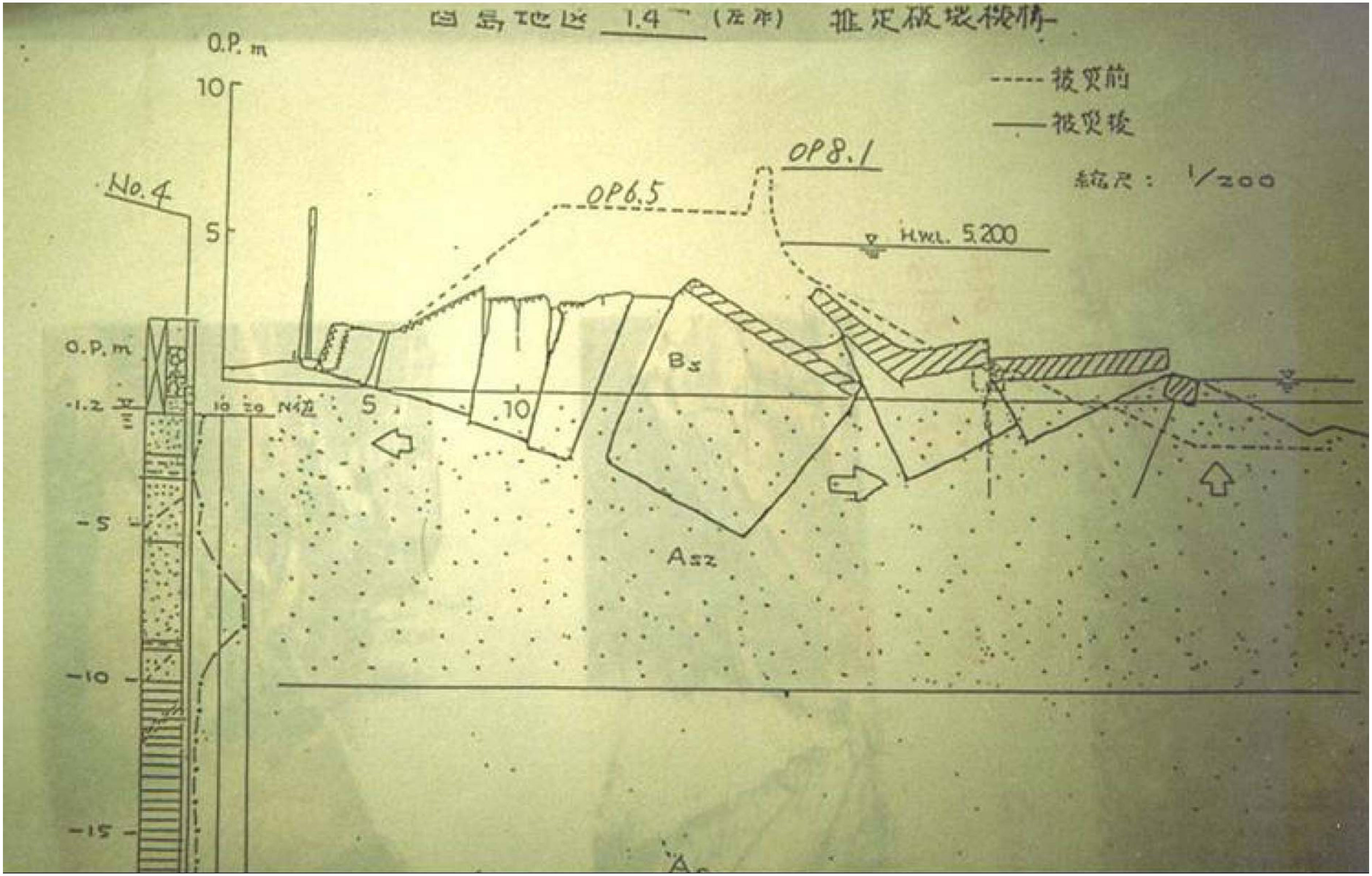






URS	DELTA RISK MANAGEMENT STRATEGY CALIFORNIA	MAGNITUDE AND DISTANCE CONTRIBUTIONS TO THE MEAN PEAK HORIZONTAL ACCELERATION HAZARD FOR STOCKTON FOR 2005	Figure 6-27
PROJECT No. 26815621			

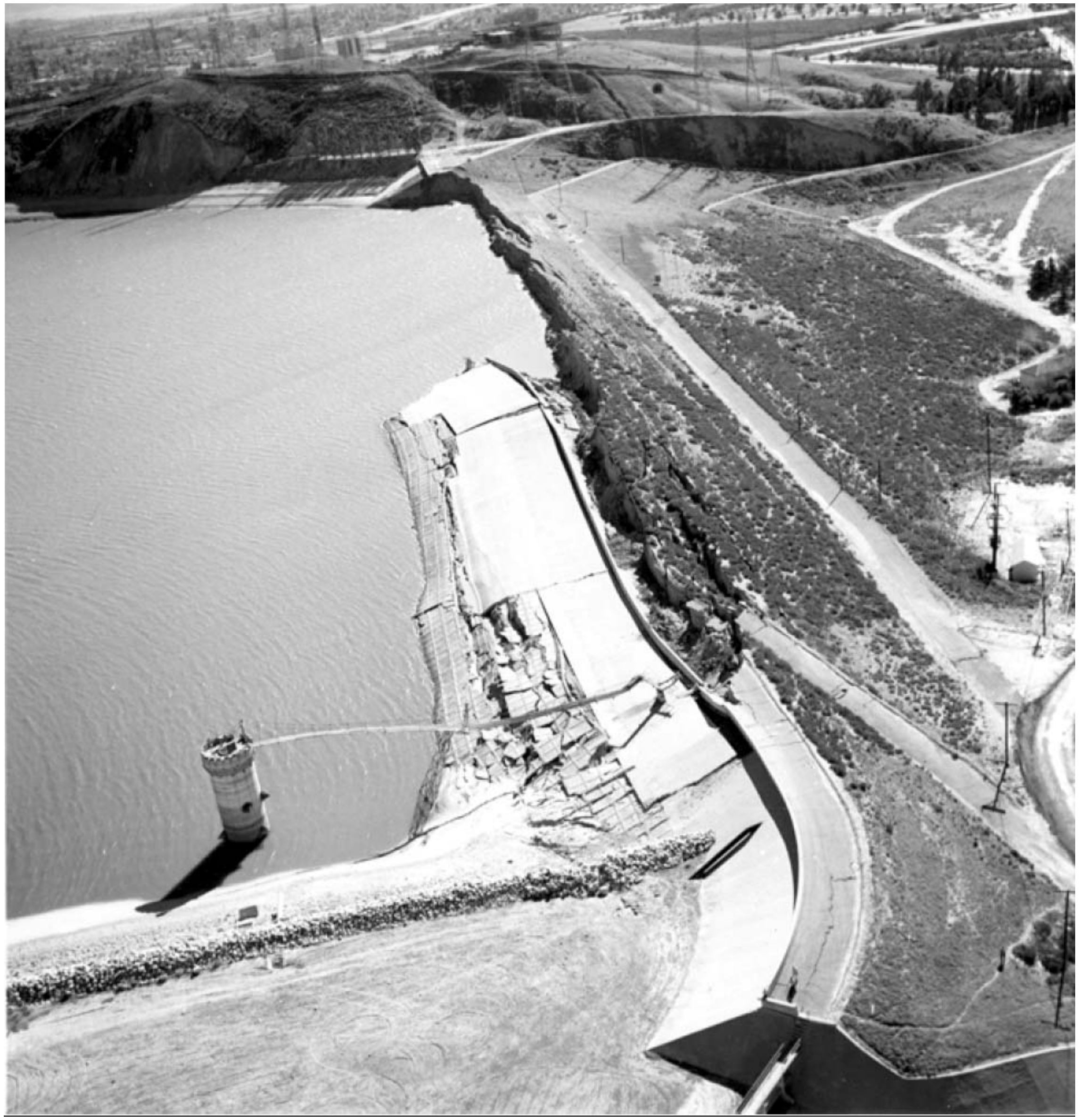
Delta Risk Management Strategy (DRMS) Levee Fragility		Levee Slumping Histories Earthquake Damage During Jan 17, 1995 Kobe Earthquake at Kobe, Japan	Figure 6-28
URS	Project No. 26815621		



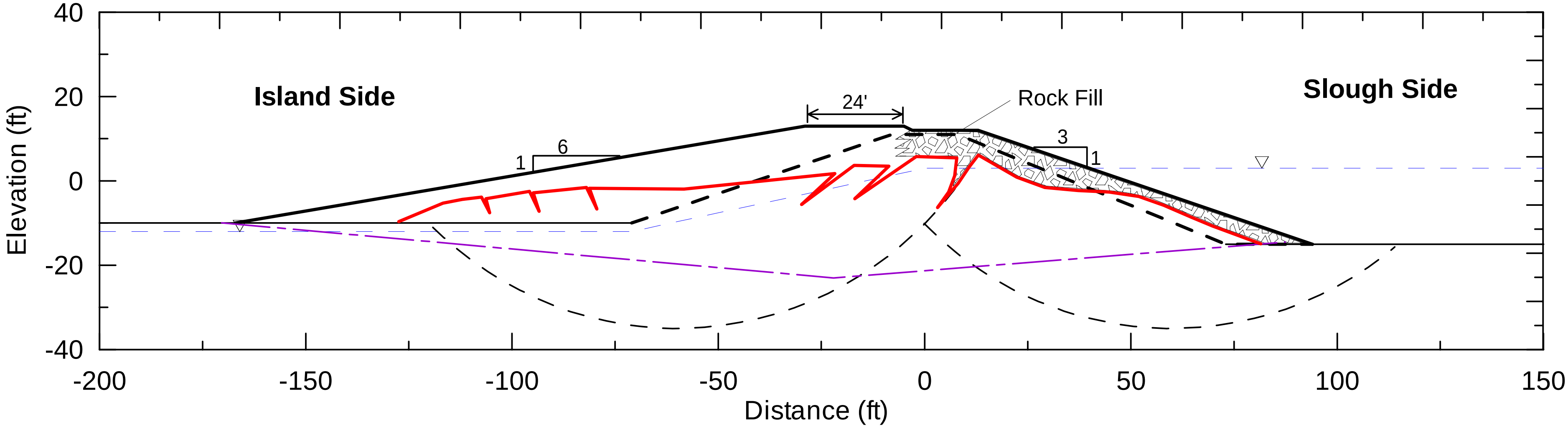
Delta Risk Management Strategy (DRMS) Levee Fragility		Levee Slumping Histories Schematic Diagram of Levee Failure During Jan 17, 1995 Kobe Earthquake at Kobe, Japan	Figure 6-29
URS	Project No. 26815621		

Delta Risk Management Strategy (DRMS) Levee Fragility	Levee Slumping Histories Earthquake Damage During May 18, 1940 Imperial Valley Earthquake	Figure 6-30
URS — Project No. 26815621		

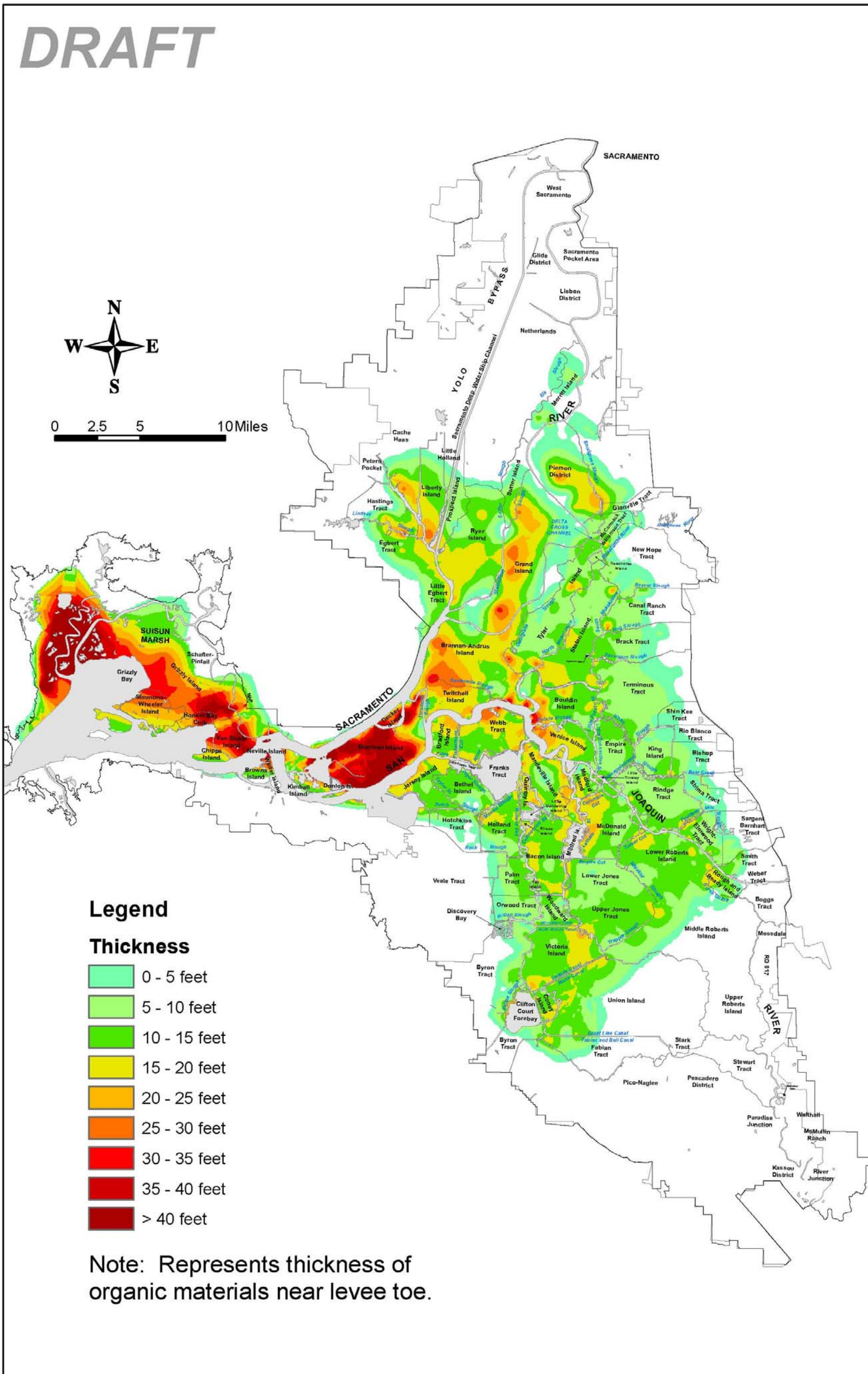
Delta Risk Management Strategy (DRMS) Levee Fragility		Levee Slumping Histories Earthquake Damage During October 18, 1989 Loma Prieta Earthquake (Moss Landing)	Figure 6-31
URS	Project No. 26815621		



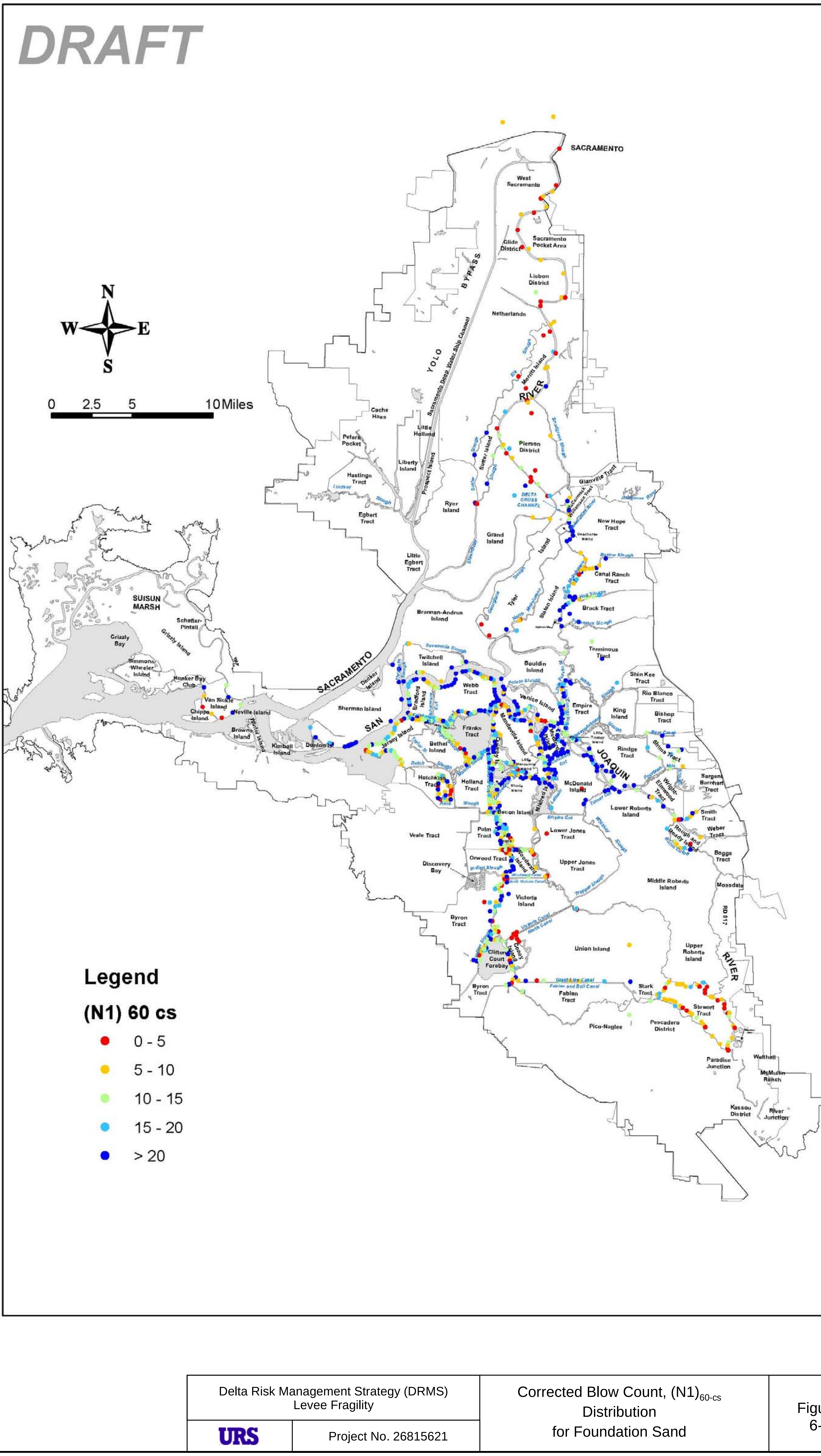
Delta Risk Management Strategy (DRMS) Levee Fragility		Dam Slumping Histories Earthquake Damage During February 11, 1971 San Fernando Earthquake (Van Norman Dam)	Figure 6-32
URS	Project No. 26815621		



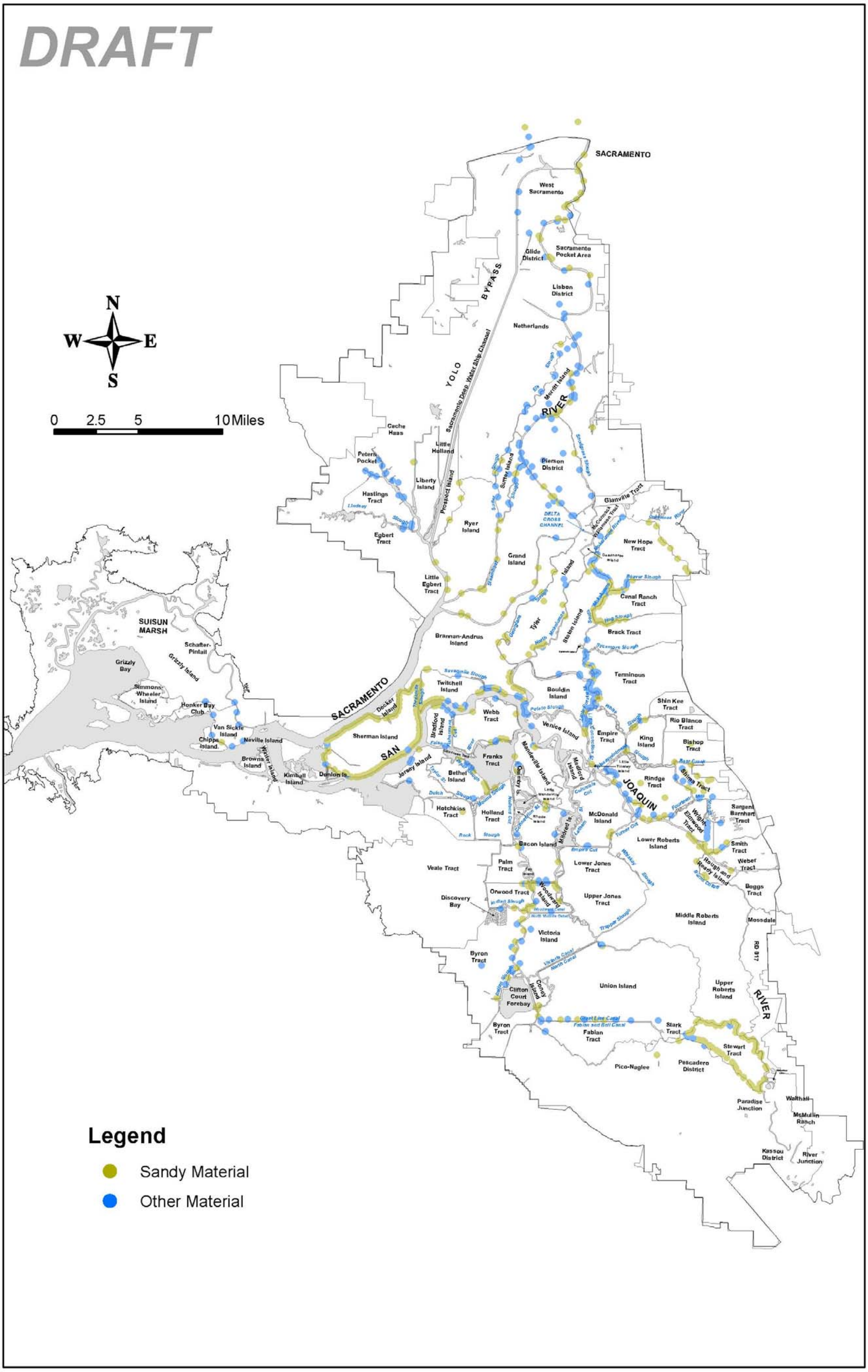
Delta Risk Management Strategy (DRMS) Levee Fragility	Schematic Diagram of Levee Slumping and Proposed Emergency Repair Method	Figure 6-33
URS — Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility	Thickness of Organic Materials	Figure 6-34
URS — Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Corrected Blow Count, $(N1)_{60\text{-}cs}$ Distribution for Foundation Sand	Figure 6-35
URS	Project No. 26815621		



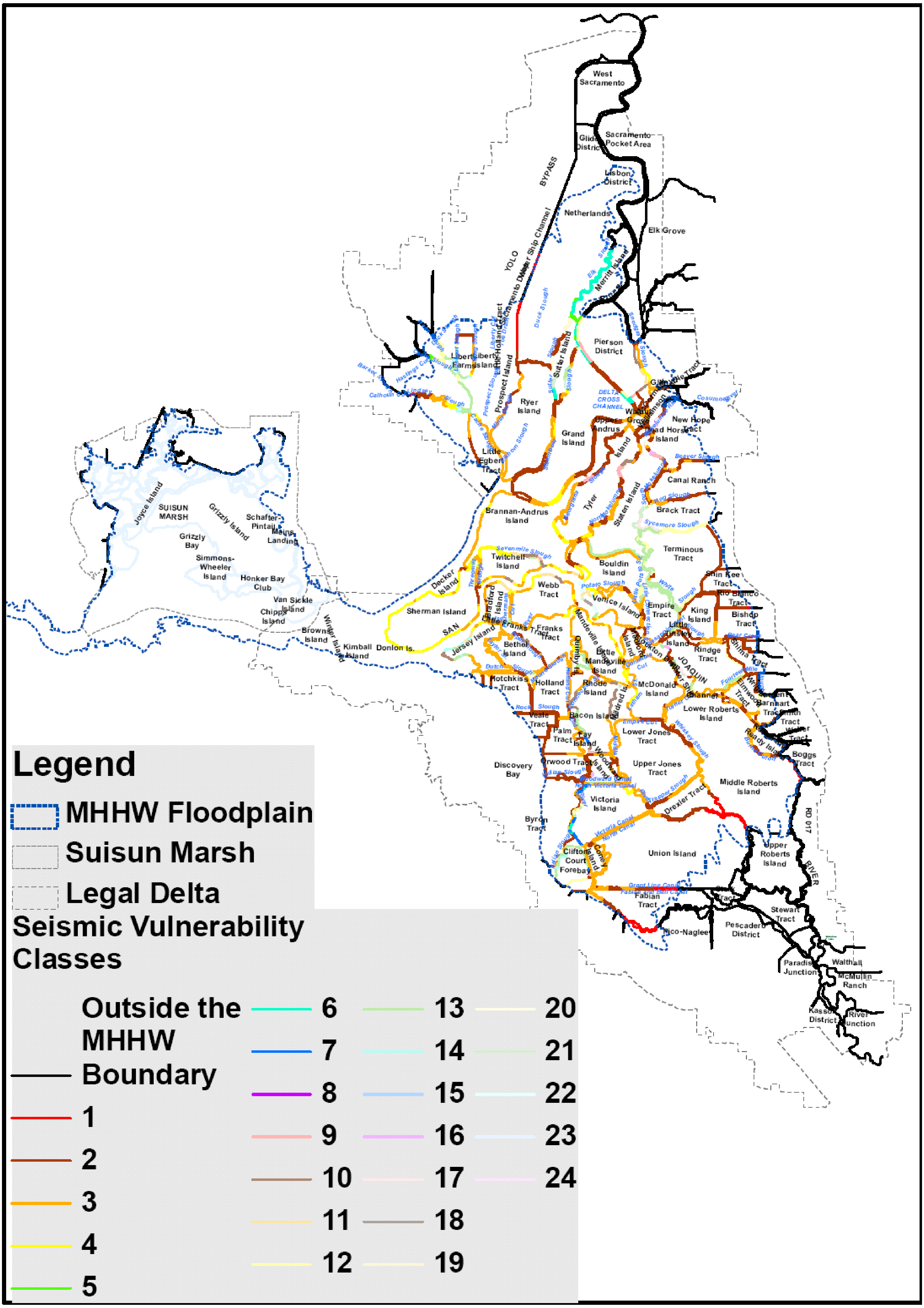
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Type of Levee Materials

Figure 6-36



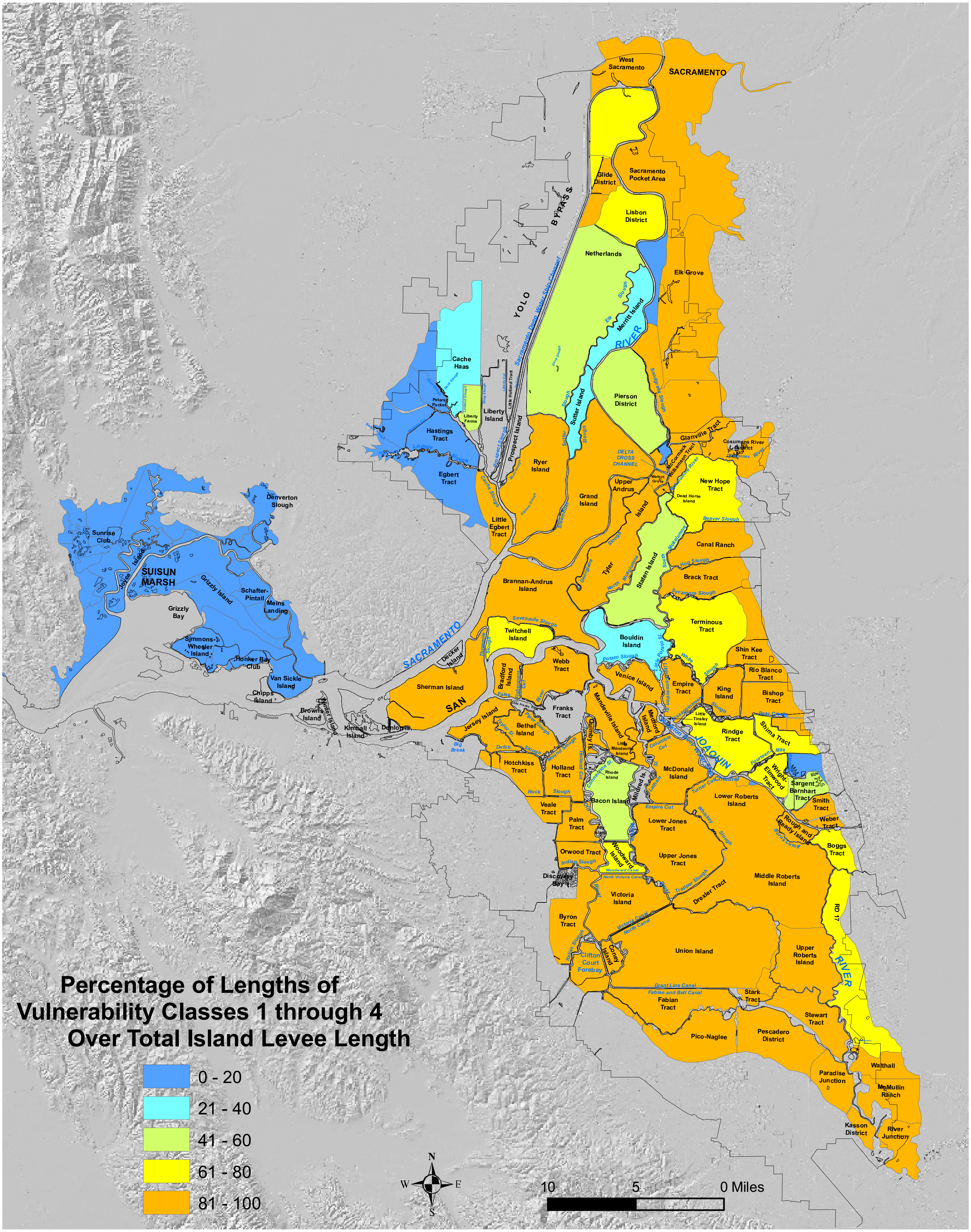
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Spatial Distribution of Vulnerability Classes

Figure 6-37a



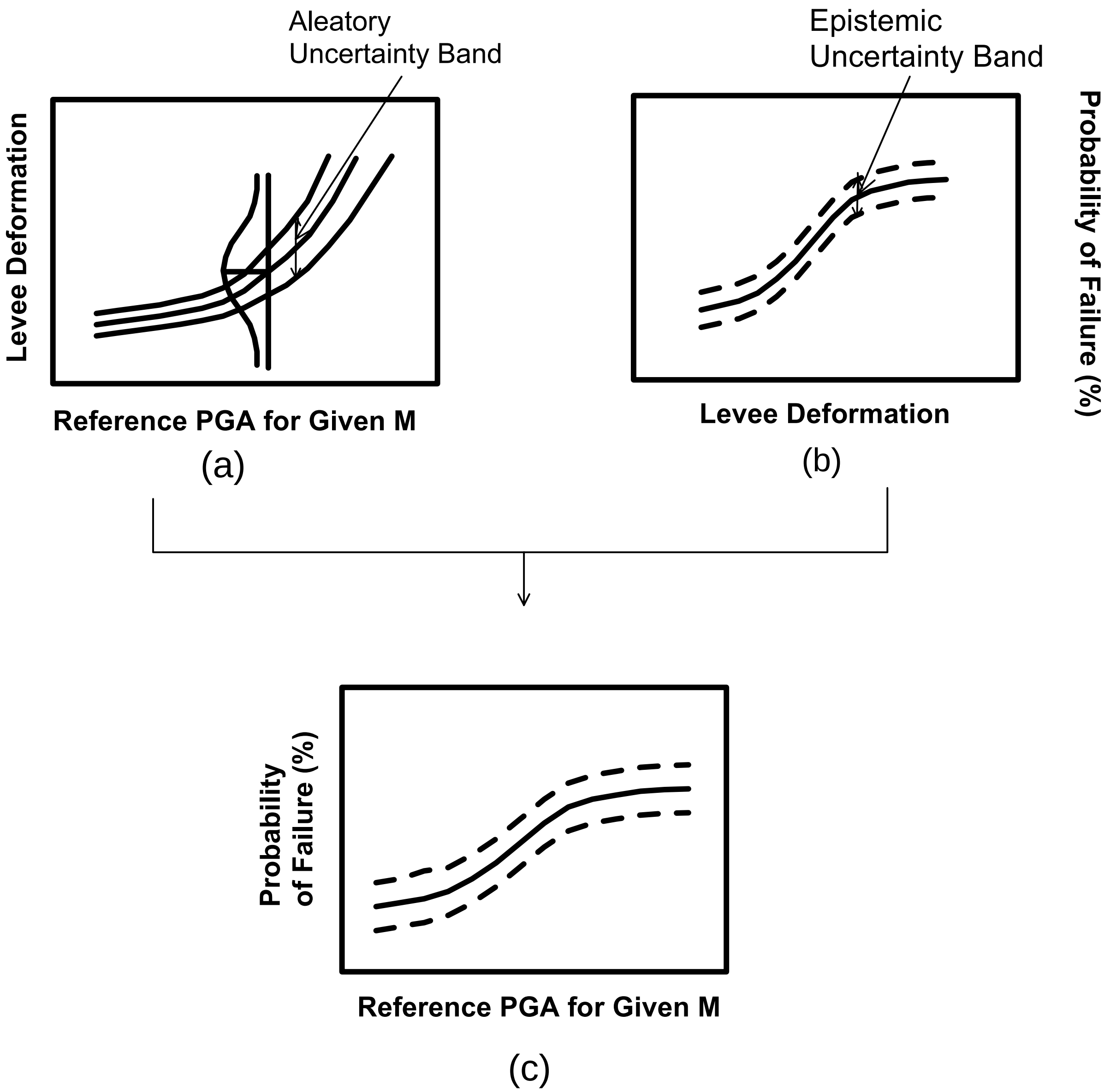
Percentage of Lengths of Vulnerability Classes 1 through 4 Over Total Island Levee Length

0 - 20
21 - 40
41 - 60
61 - 80
81 - 100

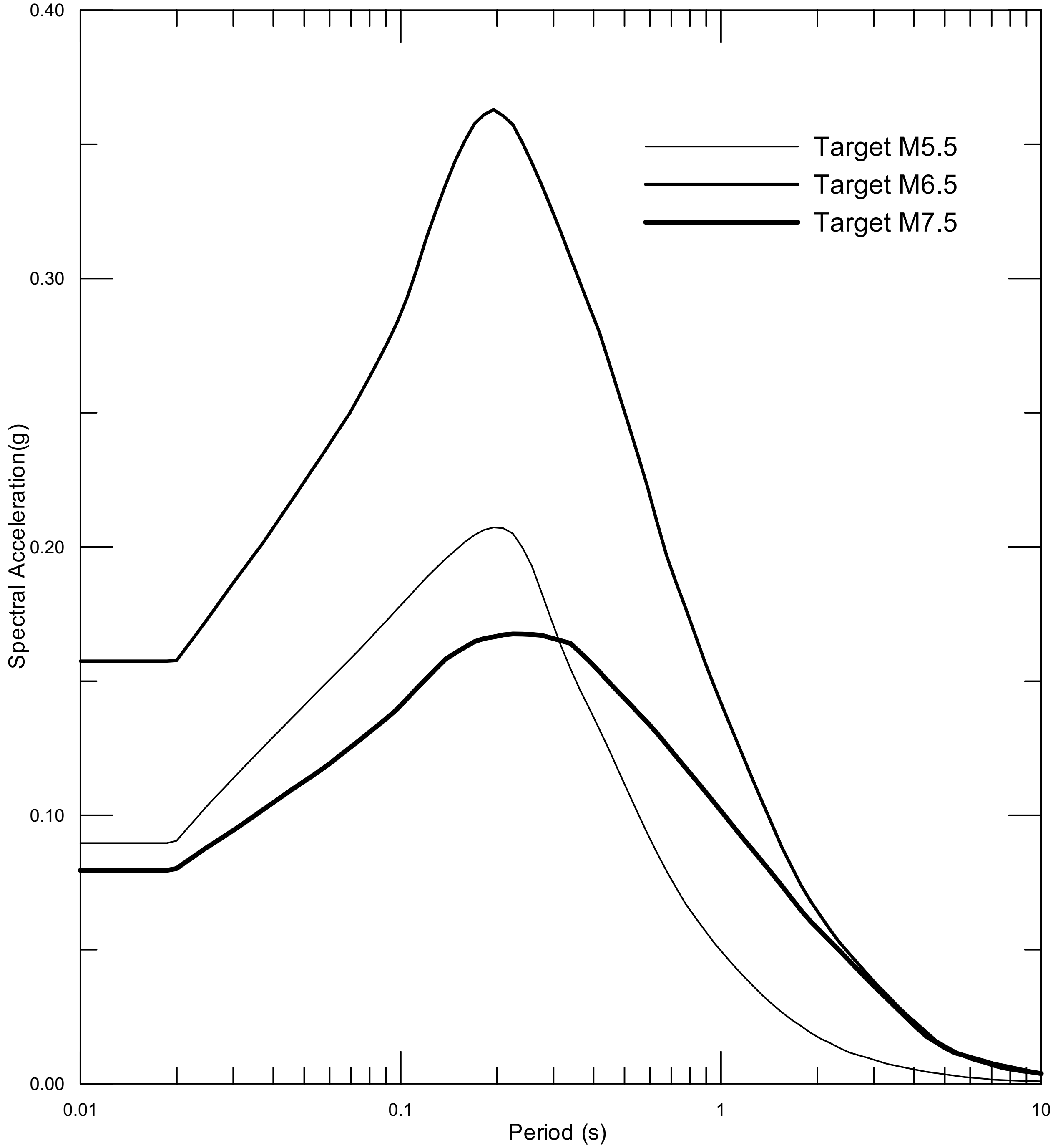
P:\GIS\GIS_Phase_II_Project_Files\MXD\Analysis\Levee Geometry\Pct_Length_Seismic_Vclasses_1_to_4_050108.mxd - 5/1/2008 @ 1:40:37 PM

URS Corporation, Oakland, CA, douglas_wright

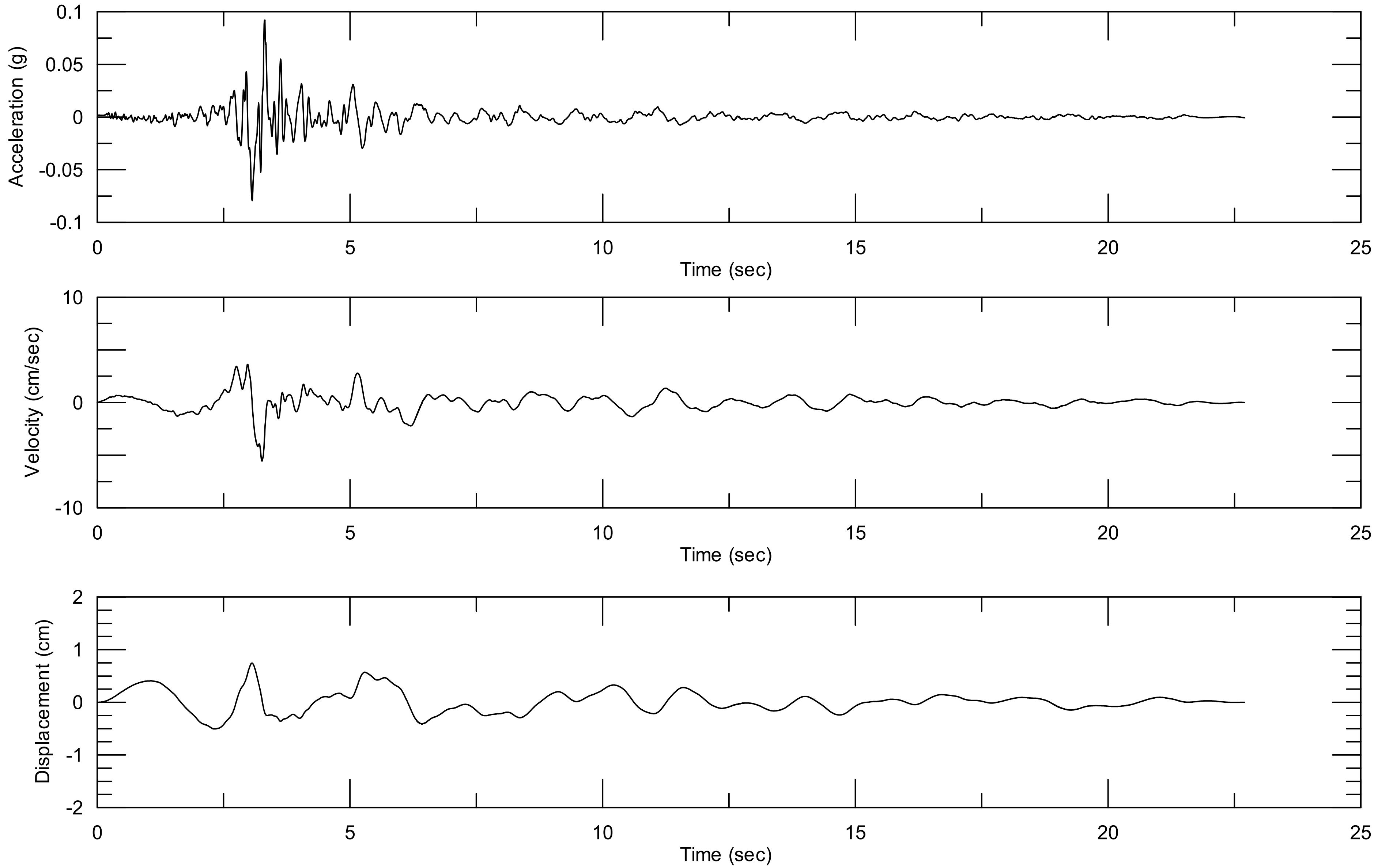
URS	Delta Risk Management Strategy (DRMS) Phase 2	PERCENTAGE OF LEVEE LENGTH WITH SEISMIC VULNERABILITY CLASSES 1 THROUGH 4	Figure 6-37b
	26815621.00019		



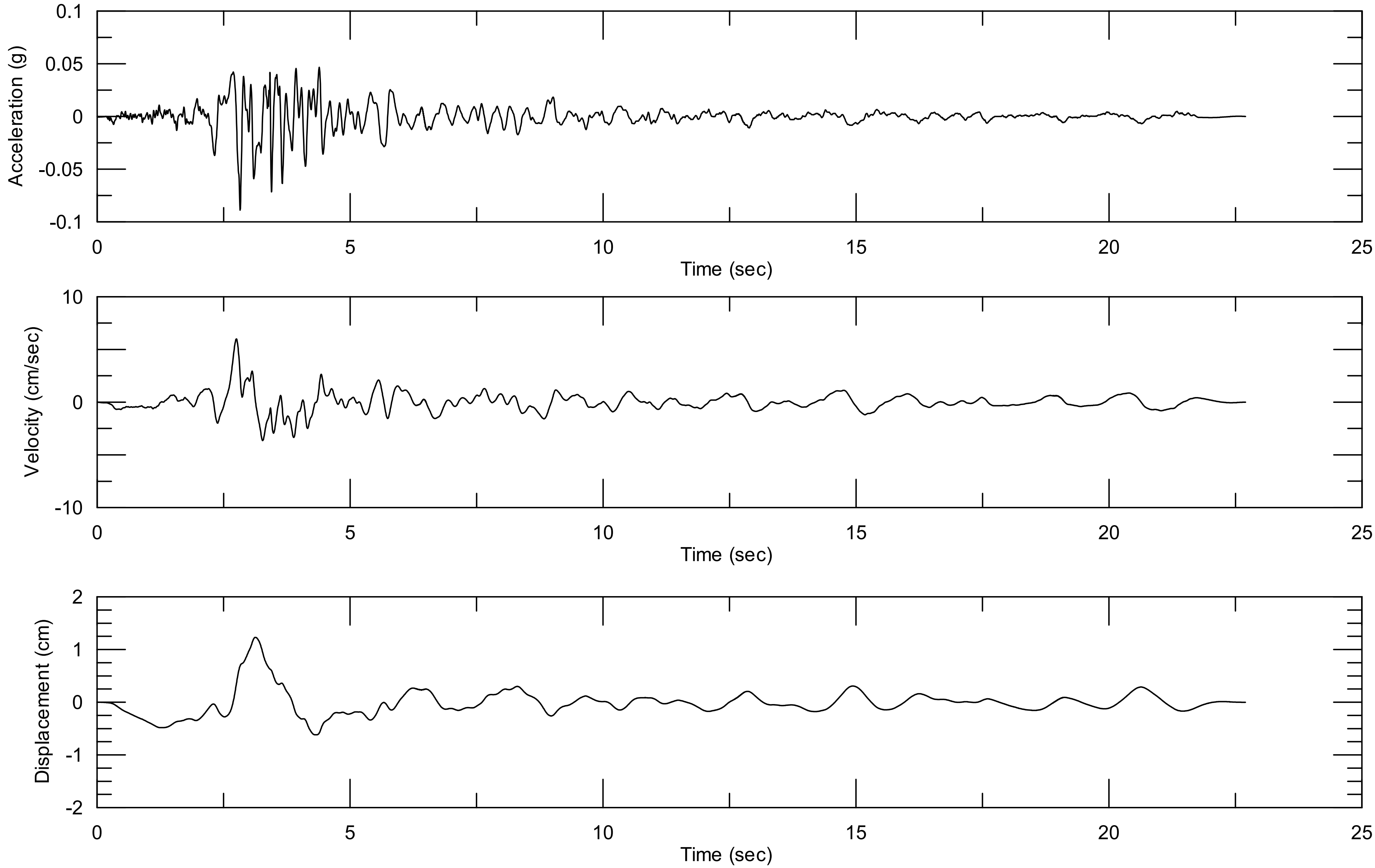
Aleatory
Uncertainty Band
Levee Deformation
Reference PGA for Given M
(a)
Epistemic
Uncertainty Band
Probability of Failure (%)
Levee Deformation
(b)
Probability
of Failure (%)
Reference PGA for Given M
(c)



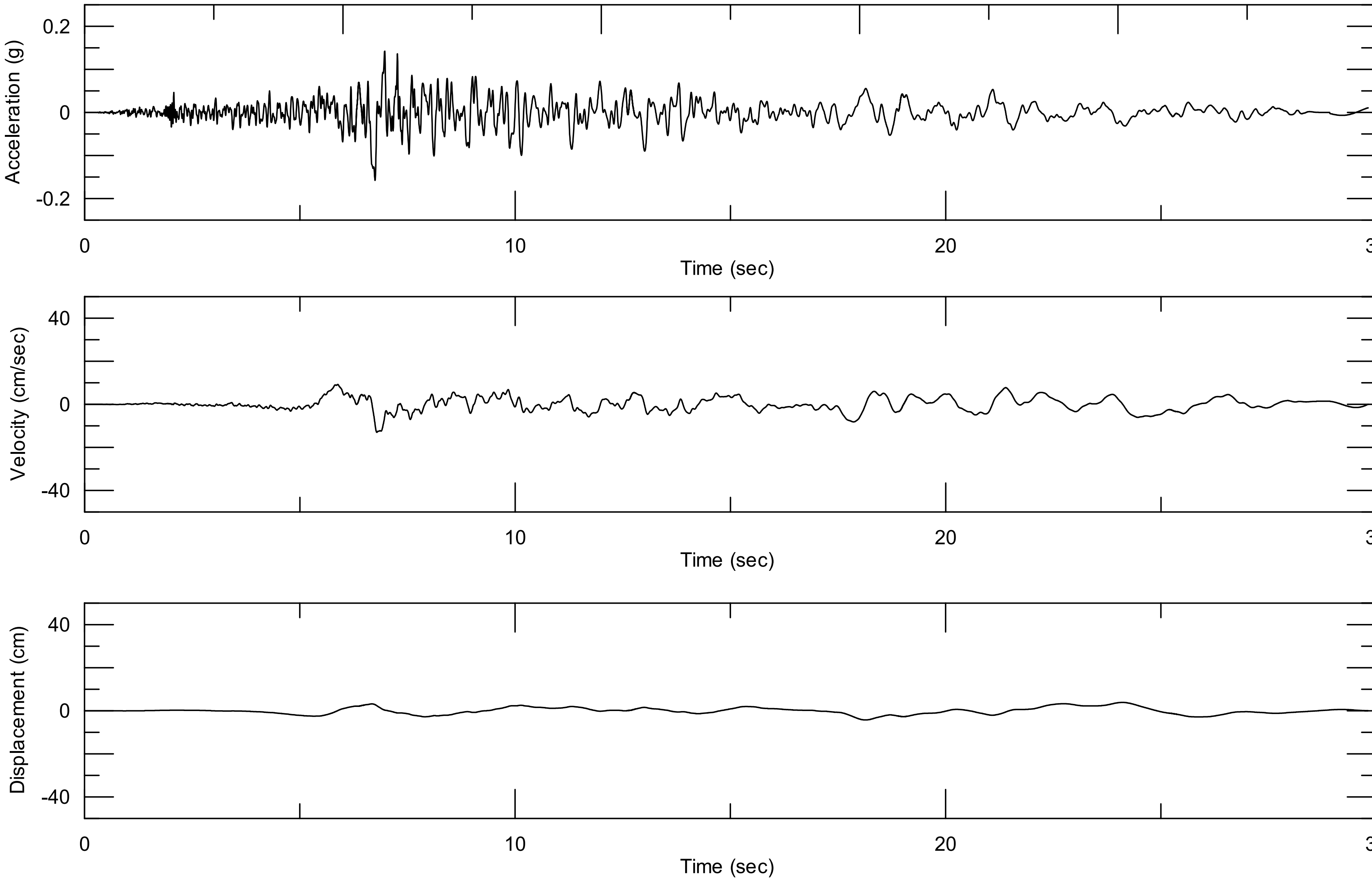
Delta Risk Management Strategy (DRMS) Levee Fragility	Target Response Spectra for M5.5 @ 20km, M6.5 @ 20km, and M7.5 @ 75km	Figure 6-39
URS — Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Spectrally-Matched Time history for M 5.5 Event for 1991 Sierra Madre Earthquake at Station USGS 4734, 360 deg Component	Figure 6-40



Delta Risk Management Strategy (DRMS) Levee Fragility		Spectrally-Matched Time History for M 5.5 Event for 1991 Sierra Madre Earthquake at Station USGS 4734, 270 deg Component	Figure 6-41
URS	Project No. 26815621		



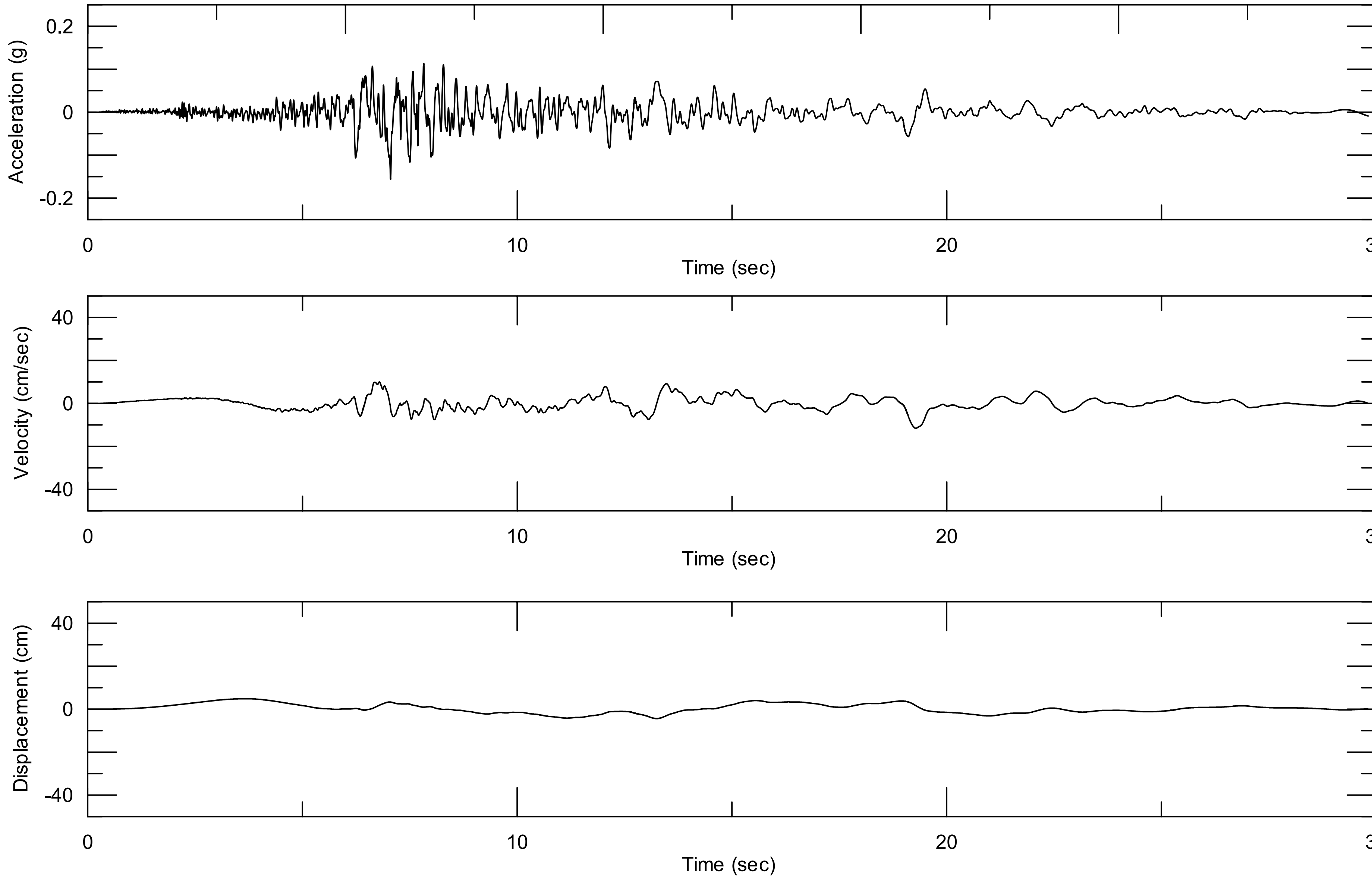
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

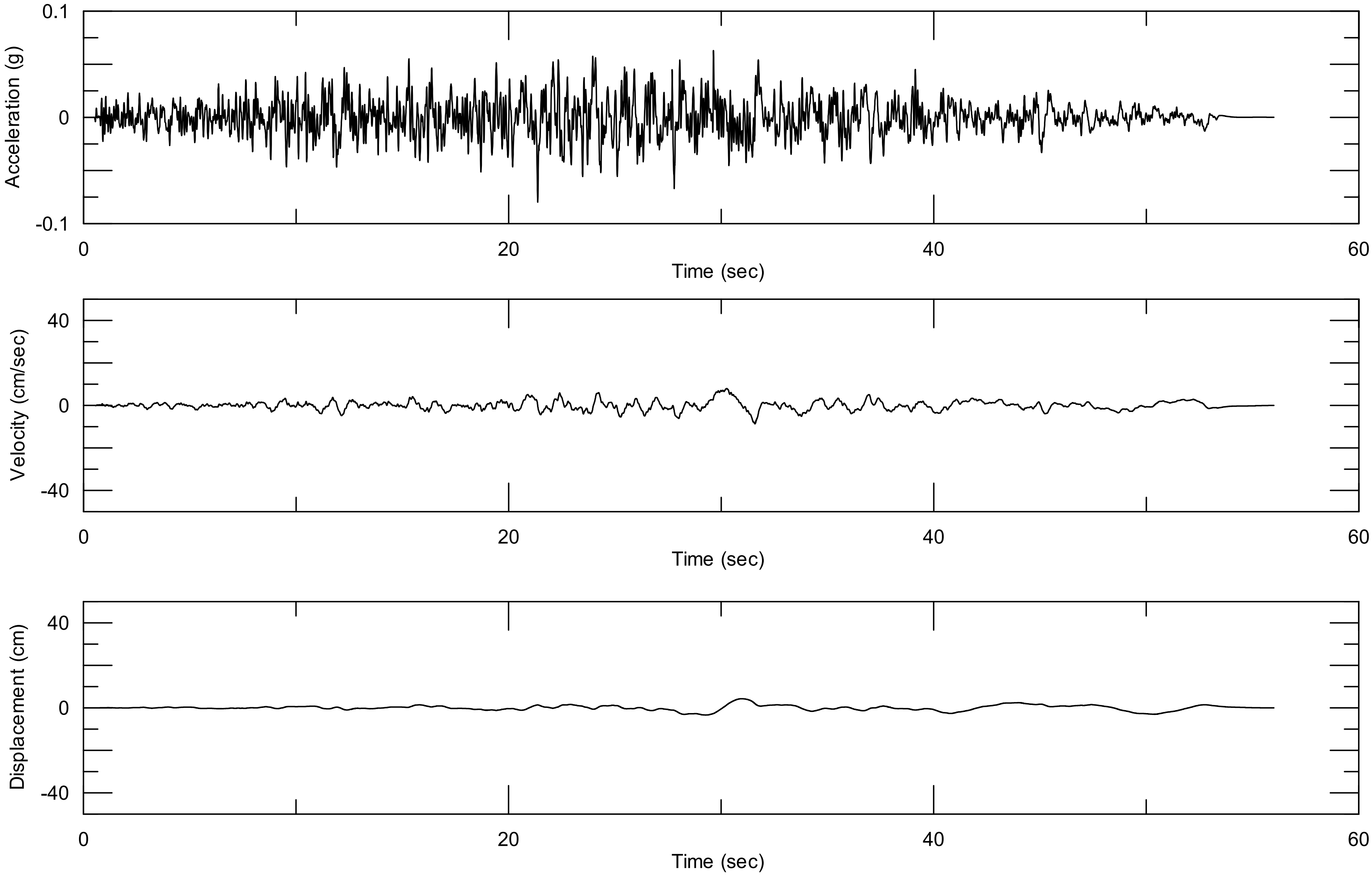
Project No. 26815621

Spectrally-Matched Time History for M 6.5 Event for 1987 Superstition Hills Earthquake at Station Wildlife Liquefaction Array, 090 deg Component

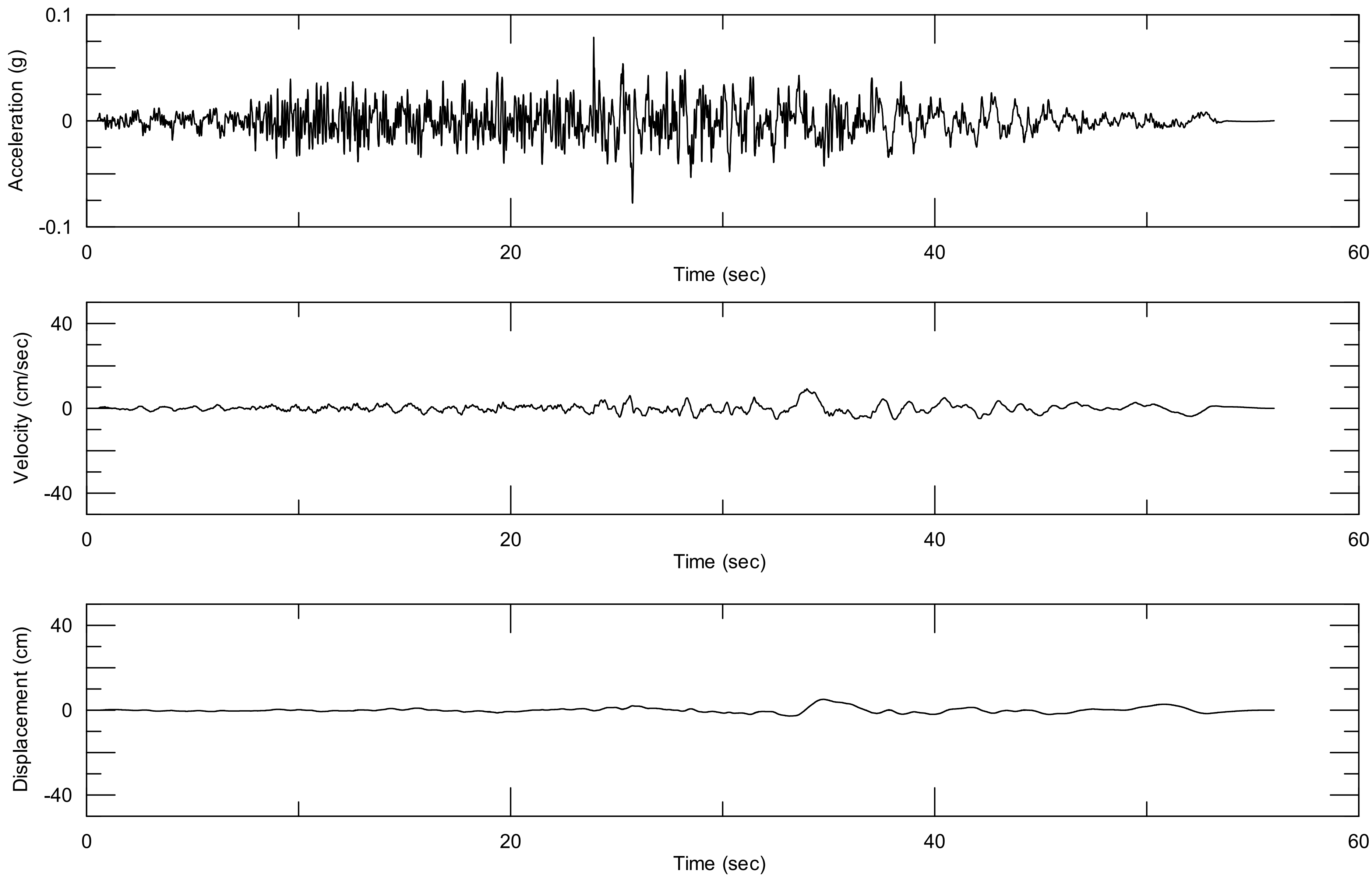
Figure 6-42



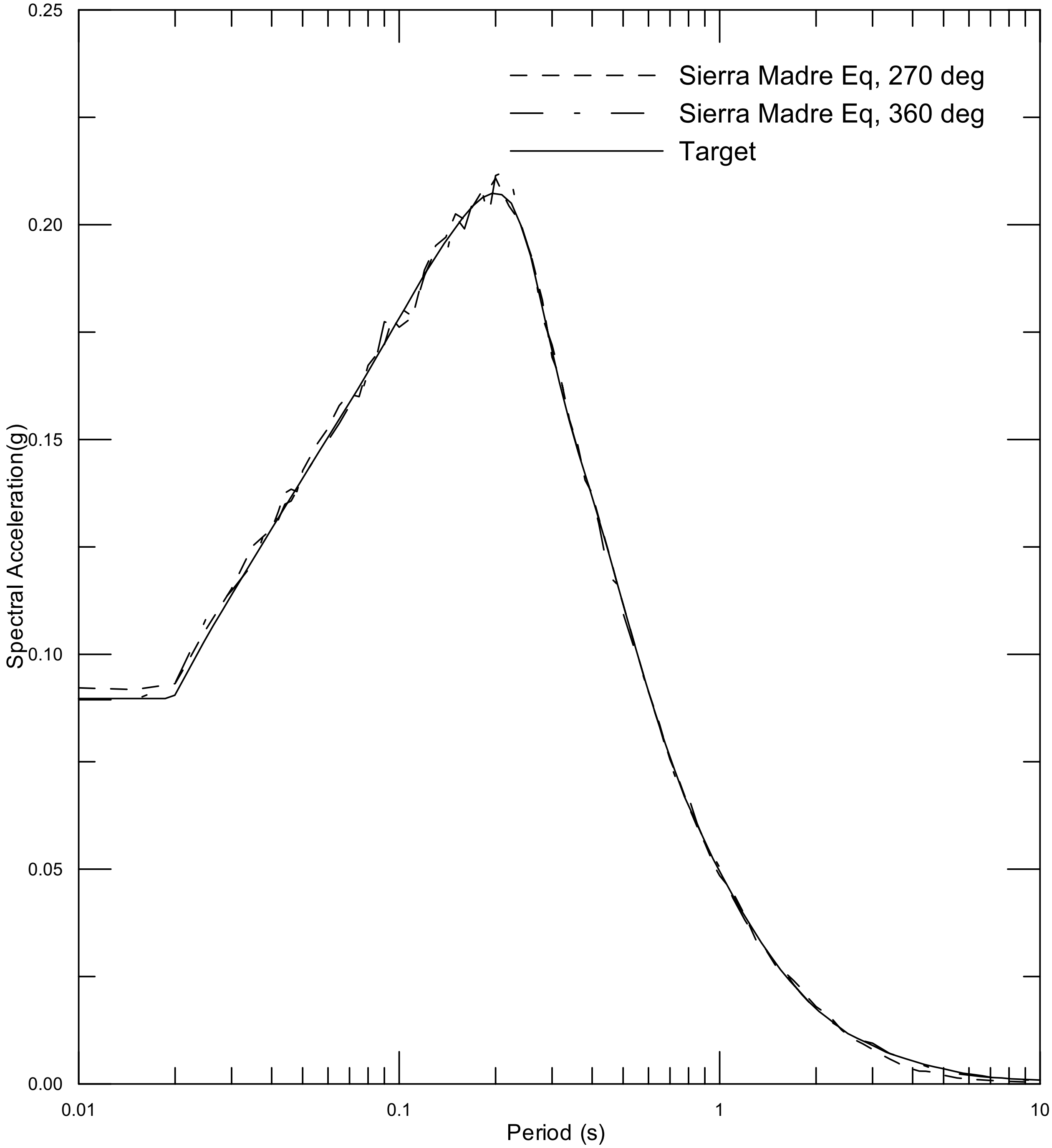
Delta Risk Management Strategy (DRMS) Levee Fragility		Spectrally-Matched Time History for M 6.5 Event for 1987 Superstition Hills Earthquake at Station Wildlife Liquefaction Array, 360 deg Component	Figure 6-43
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Spectrally-Matched Time History for M 7.5 Event for 1992 Landers Earthquake at Station Hemet Fire Station, 000 deg Component	Figure 6-44
URS	Project No. 26815621		

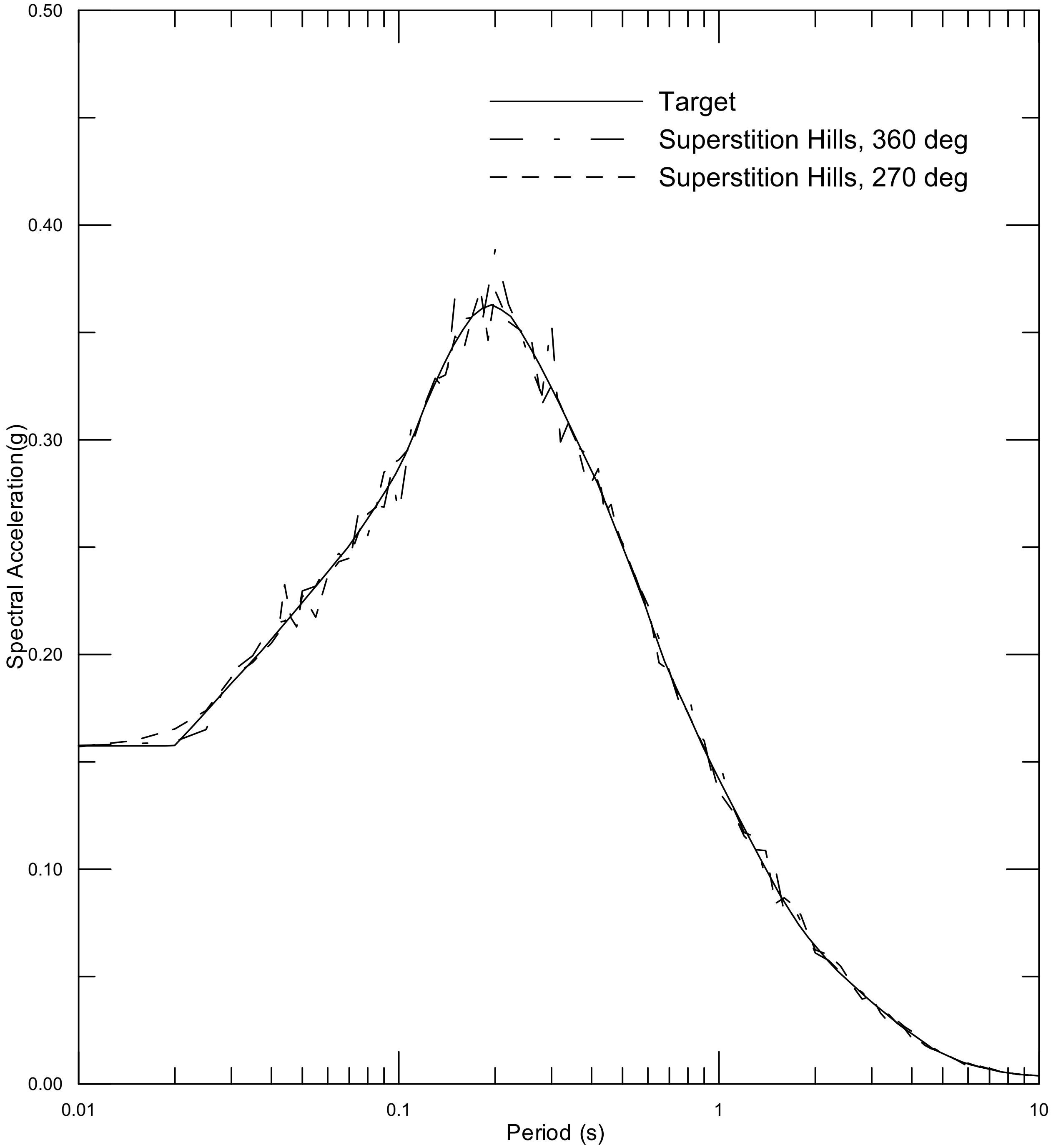


Delta Risk Management Strategy (DRMS) Levee Fragility	Spectrally-Matched Time History for M 7.5 Event for 1992 Landers Earthquake at Station Hemet Fire Station, 090 deg Component	Figure 6-45
URS — Project No. 26815621		



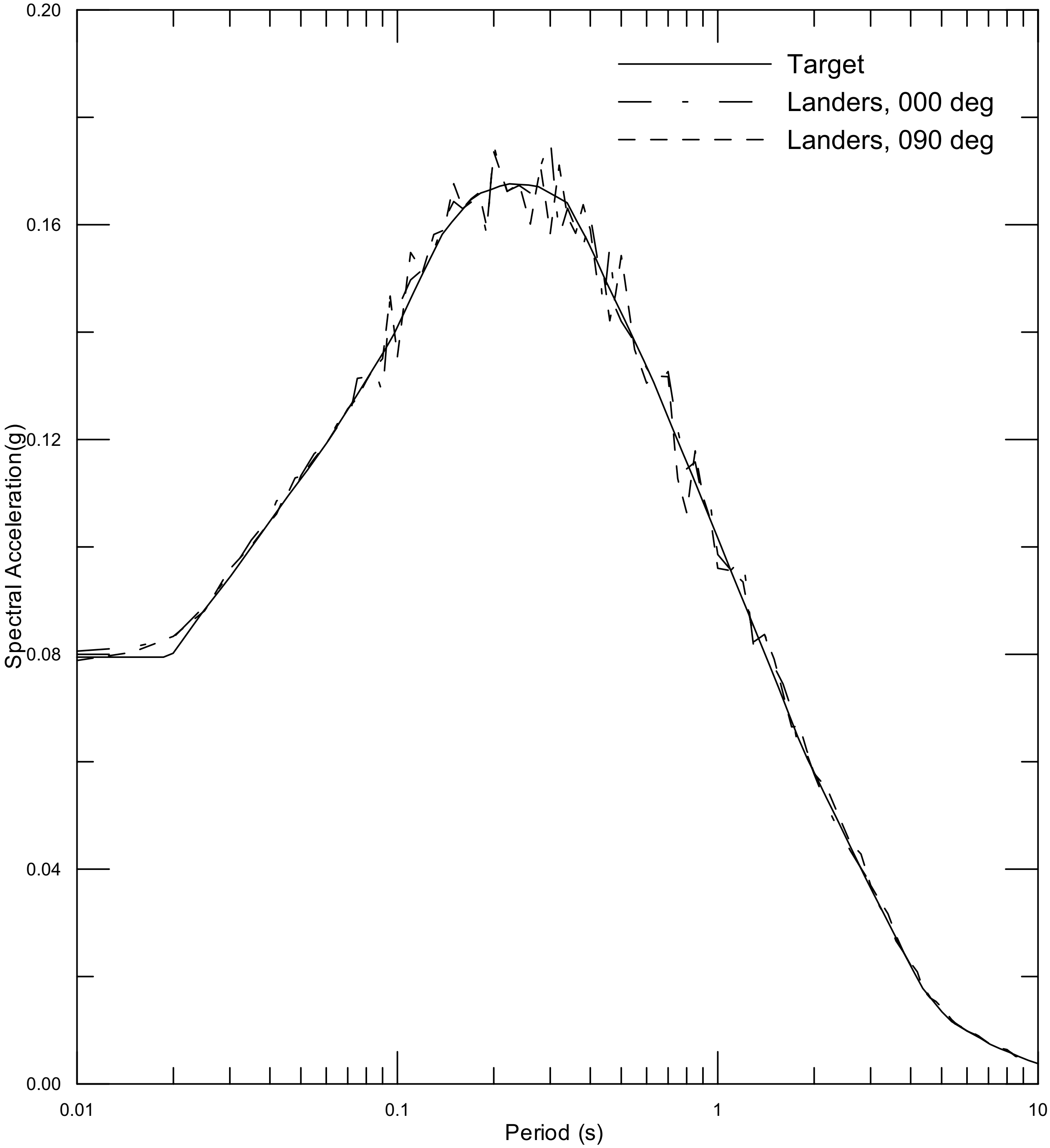
Notes:
- 5% critical damping
- Stiff soil outcrop target spectrum
- Sierra Madre Earthquake (1991): M5.5; USGS 4734 station; Site D (stiff soil)

Delta Risk Management Strategy (DRMS) Levee Fragility	Comparison of Response Spectra for M 5.5 Event	Figure 6-46
URS — Project No. 26815621		



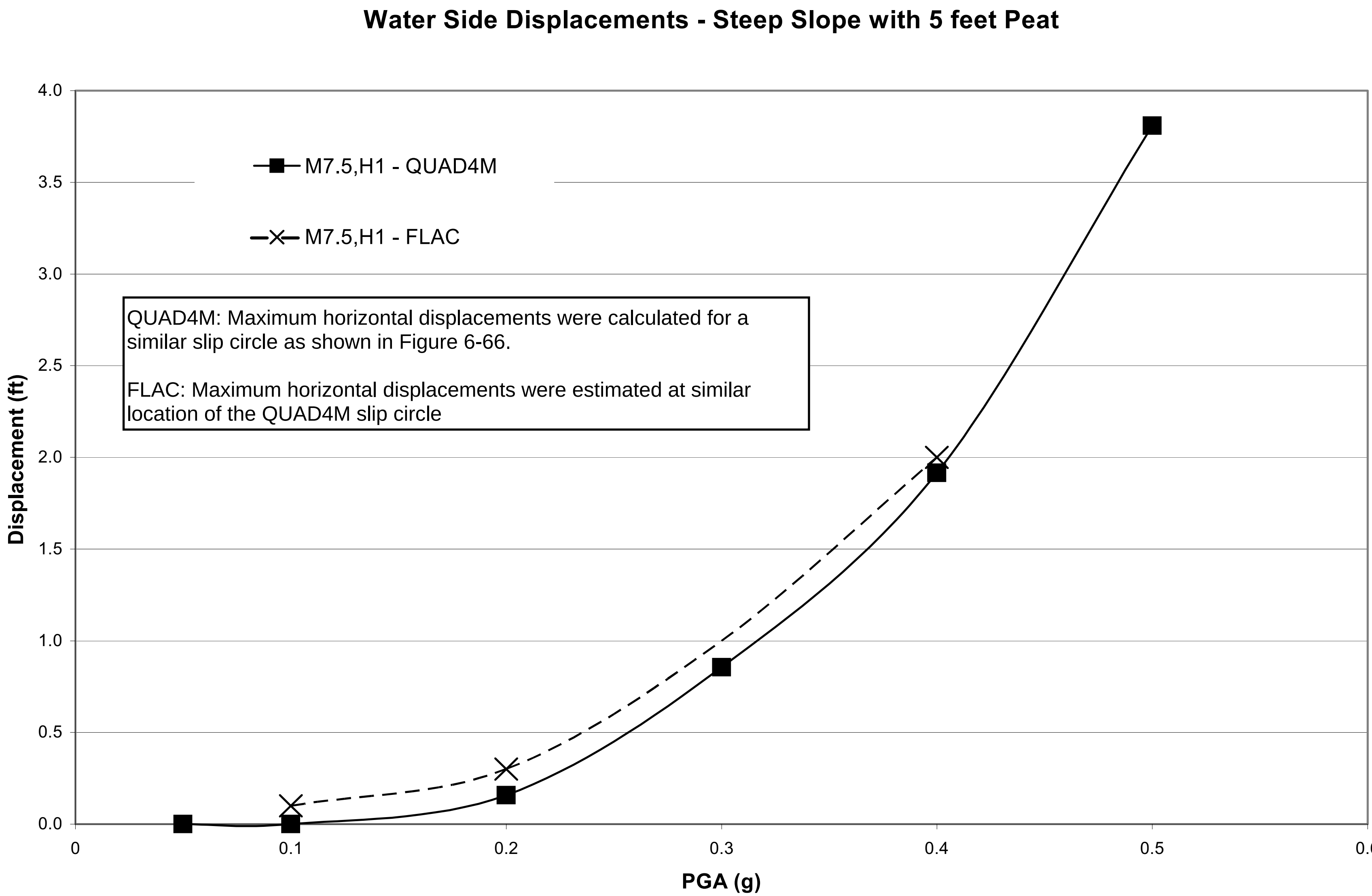
Notes:
- 5% critical damping
- Stiff soil outcrop target spectrum
- Superstition Hills Earthquake (1987): M6.5; Wildlife station; Site D (stiff soil)

Delta Risk Management Strategy (DRMS) Levee Fragility	Comparison of Response Spectra for M 6.5 Event	Figure 6-47
URS — Project No. 26815621		



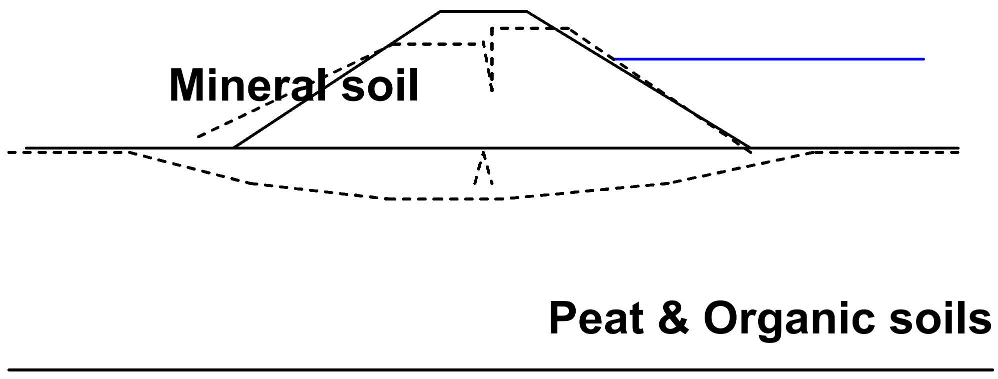
Notes:
- 5% critical damping
- Stiff soil outcrop target spectrum
- Landers Earthquake (1992): M7.3; Hemet fire station; Site D (stiff soil)

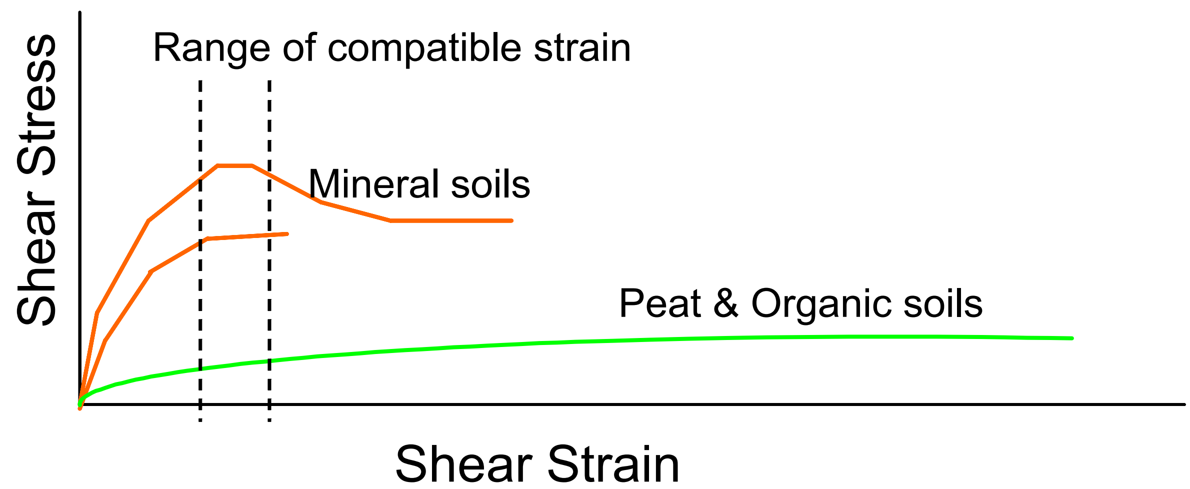
Delta Risk Management Strategy (DRMS) Levee Fragility	Comparison of Response Spectra for M 7.5 Event	Figure 6-48
URS — Project No. 26815621		



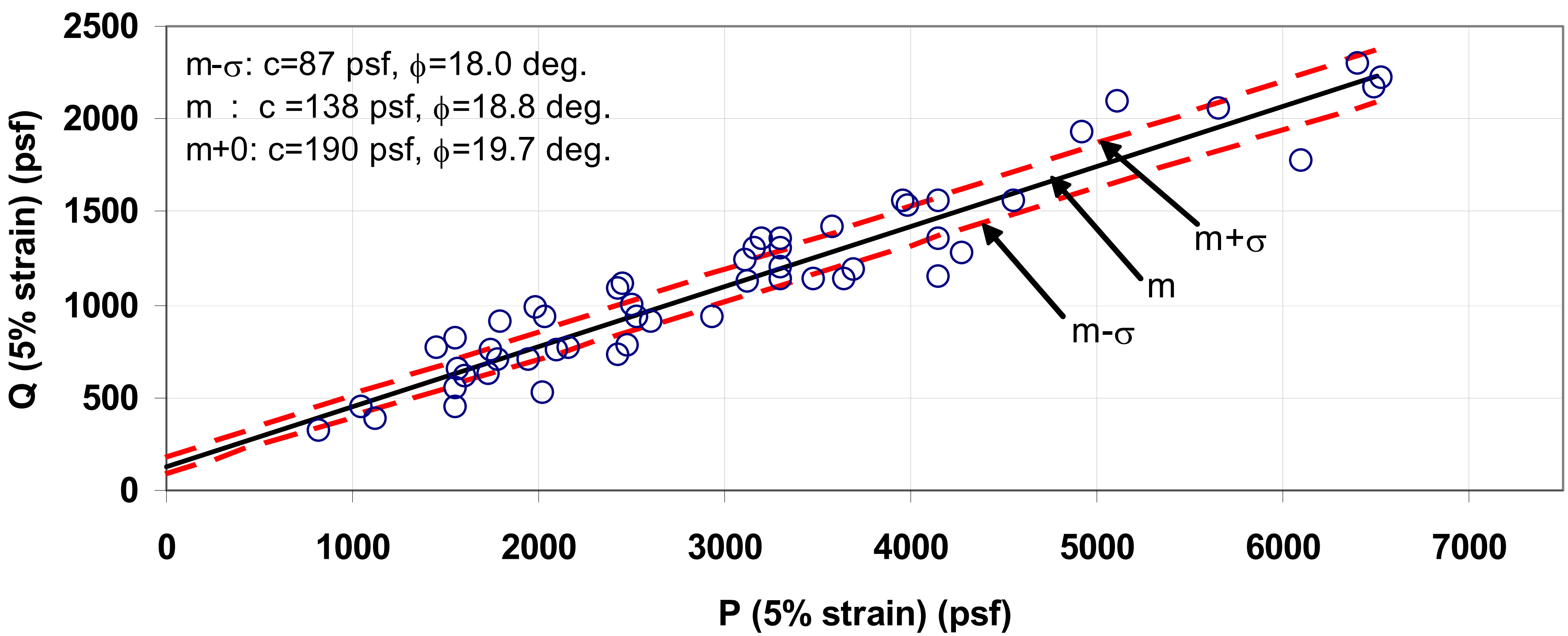
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Displacements for Validation QUAD4M vs FLAC Steep Slope Water Side Slope 5 Feet of Peat	Figure 6-49
URS	Project No. 26815621		

Deformed Levee Shape:



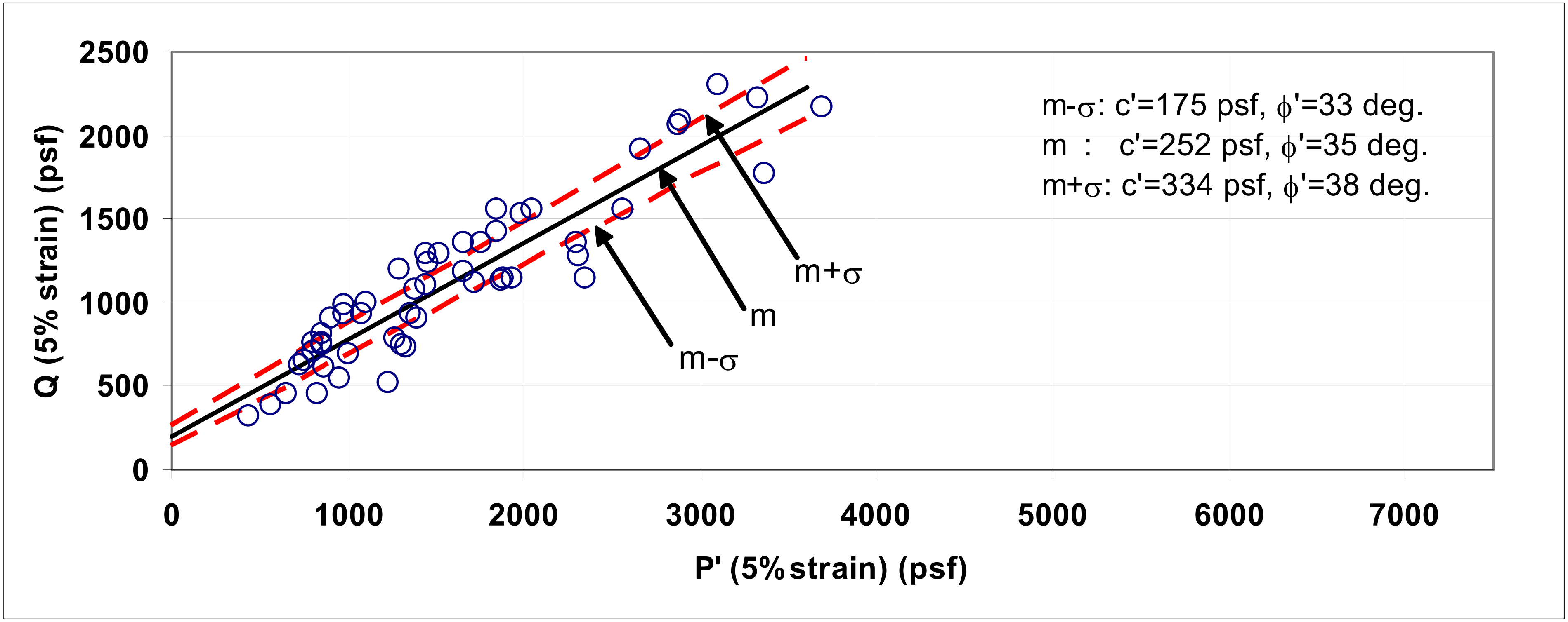


Delta Risk Management Strategy (DRMS) Levee Fragility	Strain Compatible Strength Peat vs Mineral Soil	Figure 6-50
URS — Project No. 26815621		



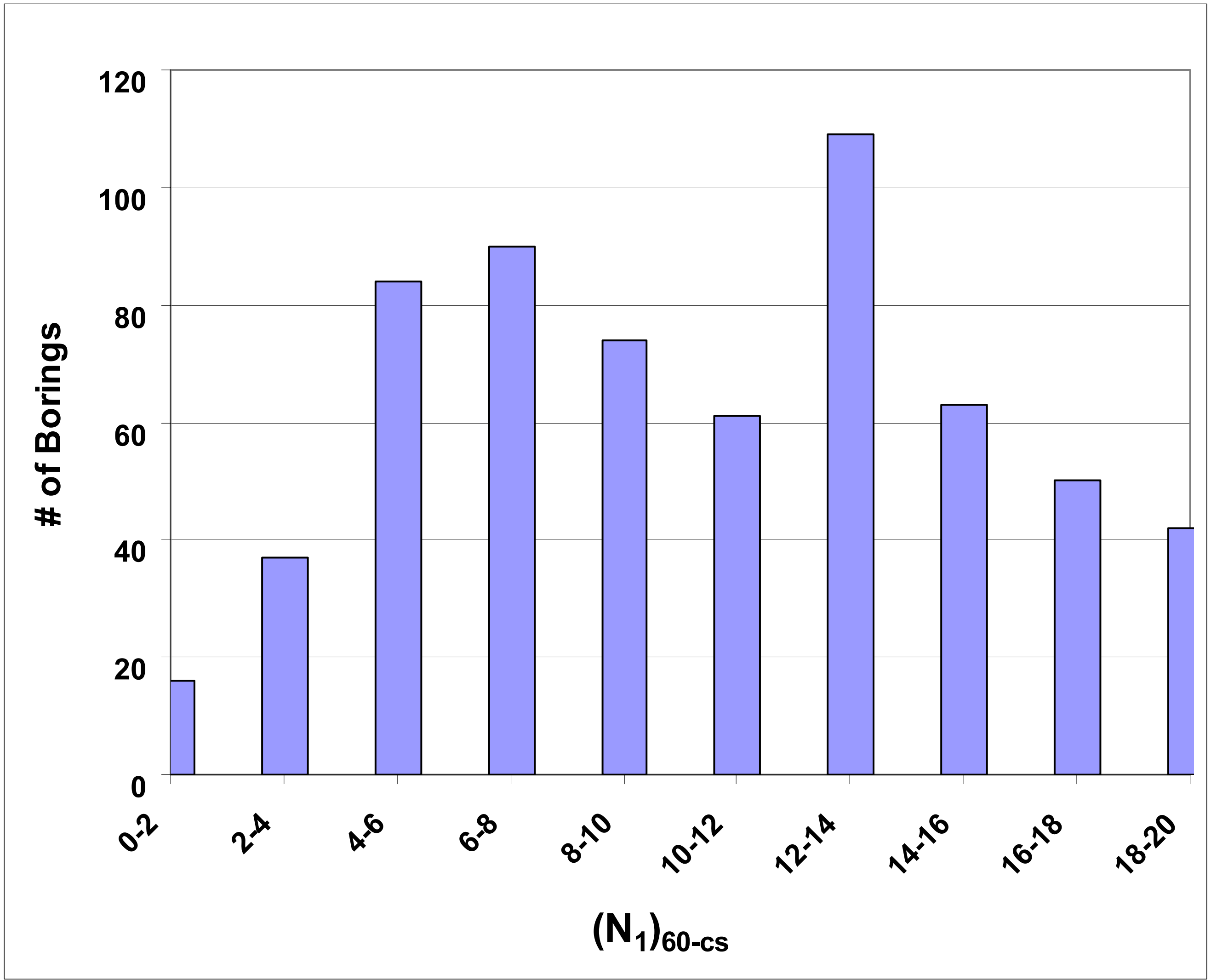
Data Source: Hultgren-Tellis Engineers, 2003

Delta Risk Management Strategy (DRMS) Levee Fragility		P-Q Plot at 5% Shear Strain for Peat Total Stress	Figure 6-51
URS	Project No. 26815621		



Data Source: Hultgren-Tellis Engineers, 2003

Delta Risk Management Strategy (DRMS) Levee Fragility		P'-Q Plot at 5% Shear Strain for Peat Effective Stress	Figure 6-52
URS	Project No. 26815621		

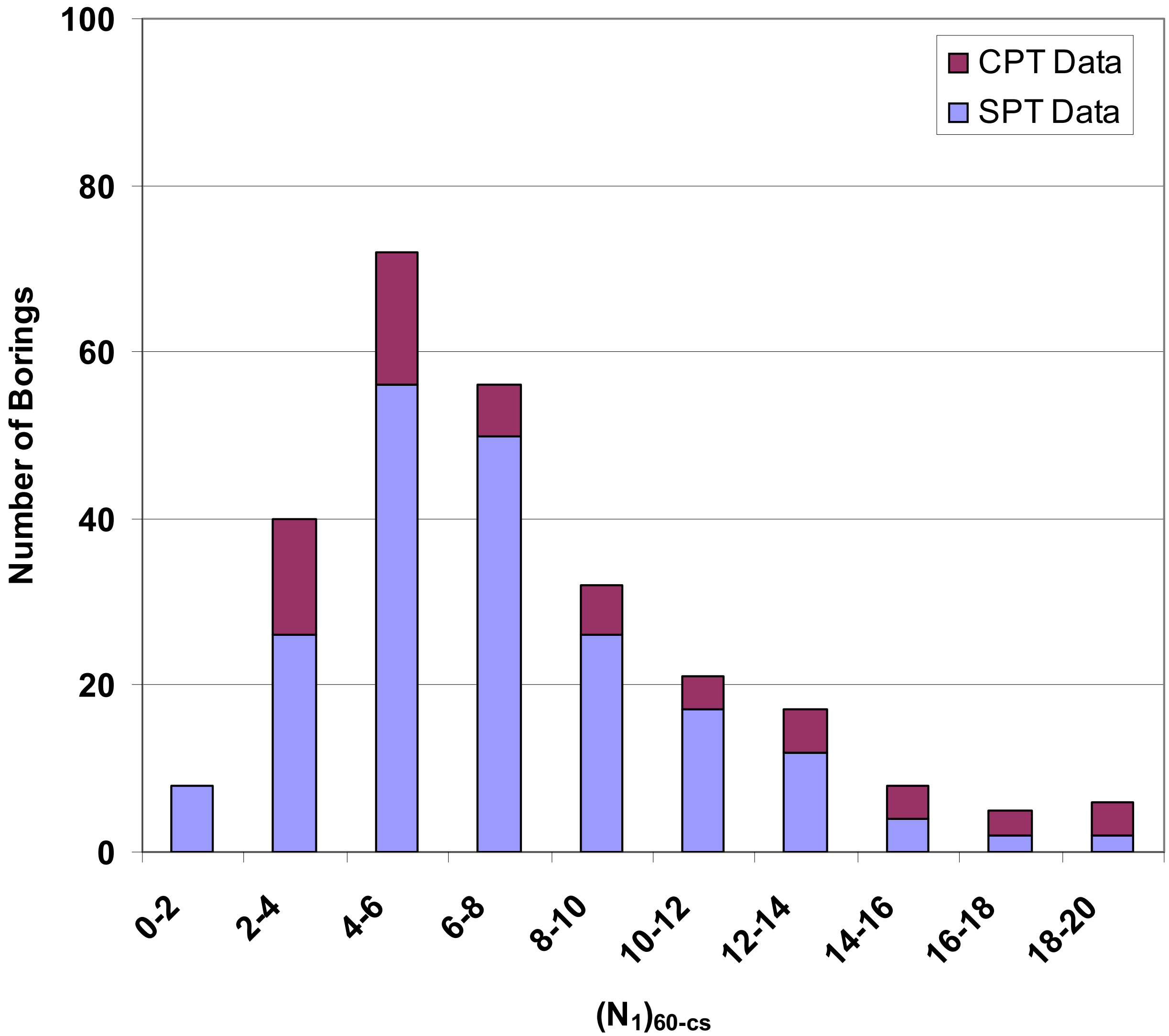


Mean = 11
Mean + σ = 16
Mean - σ = 6

Notes:
Total number of SPT borings that showed,
$(N_1)_{60\text{-}cs}$ of foundation sand <20 = 626
$(N_1)_{60\text{-}cs}$ of foundation sandl >20 = 310

Data source: Various boring logs from past studies (see Table 2-1)

Delta Risk Management Strategy (DRMS) Levee Fragility	$(N1)_{60\text{-}CS}$ Distribution for Foundation Sand with $(N1)_{60\text{-}CS}$ < 20	Figure 6-53
URS — Project No. 26815621		



Mean = 8

Mean + σ = 12

Mean - σ = 4

Notes:

Total number of SPT borings that showed

$(N_1)_{60\text{-}cs}$ of sandy levee fill <20 = 203

$(N_1)_{60\text{-}cs}$ of sandy levee fill >20 = 4

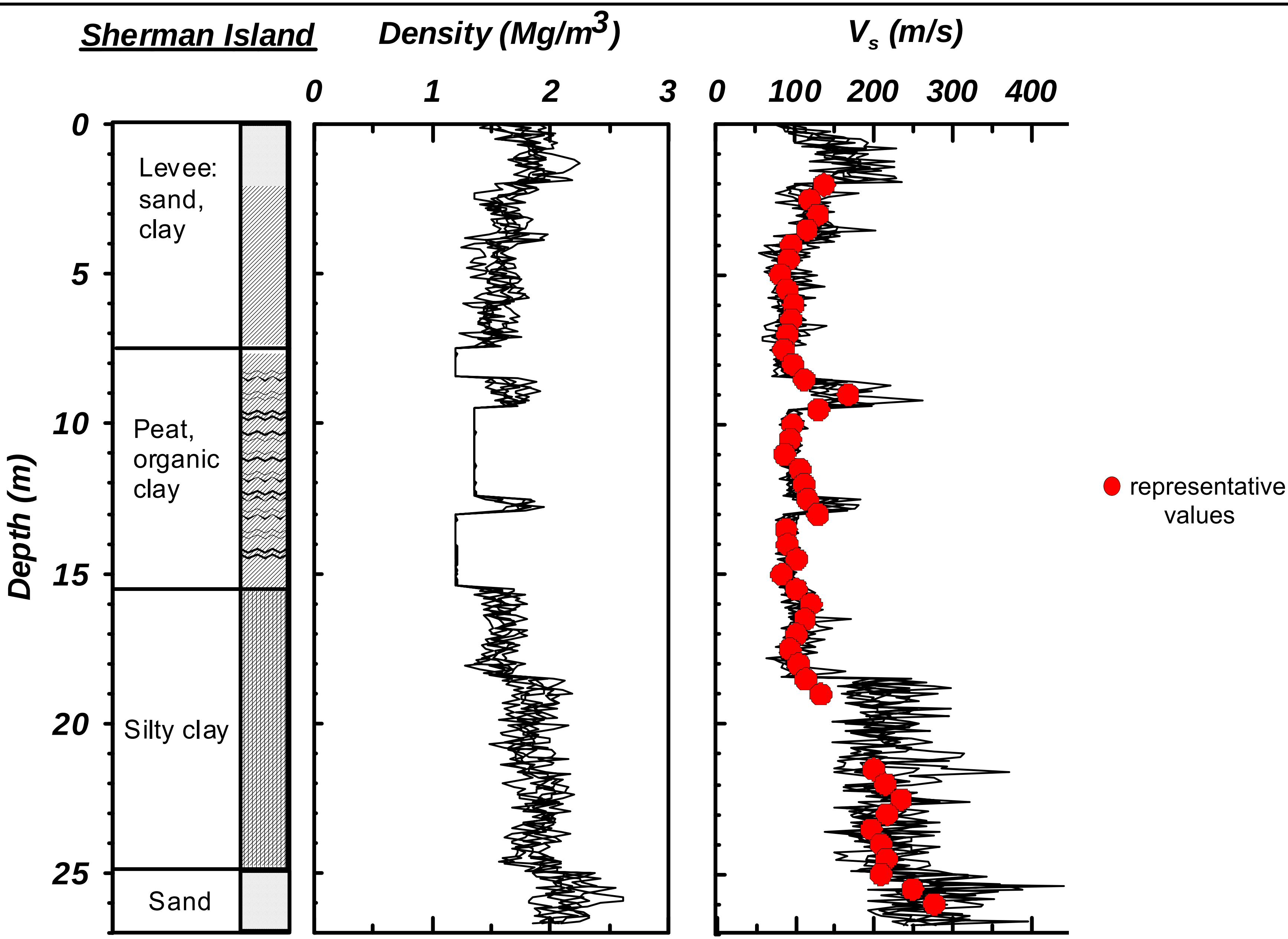
Total number of CPT borings that showed

$(N_1)_{60\text{-}cs}$ of sandy levee fill <20 = 62

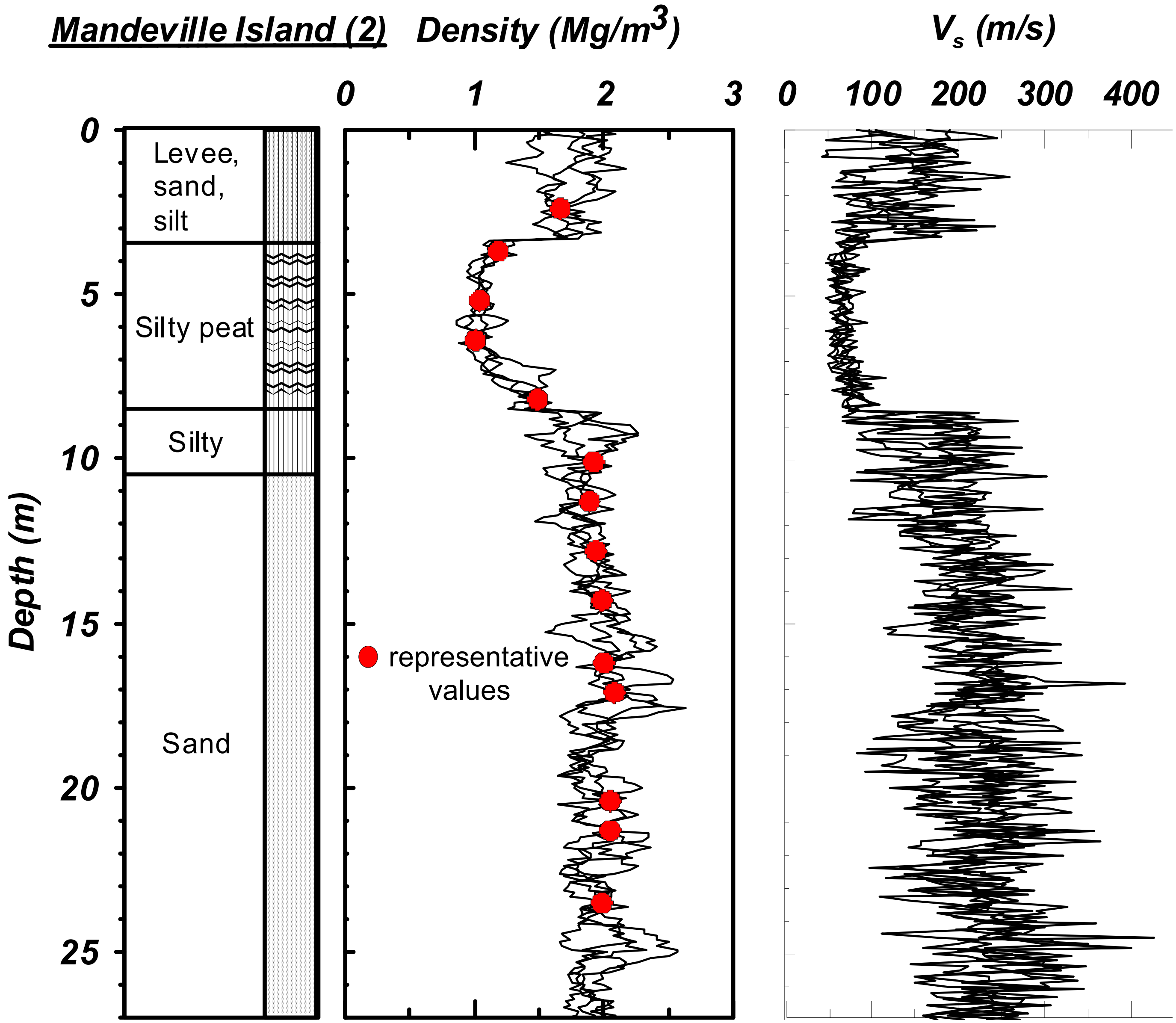
$(N_1)_{60\text{-}cs}$ of sandy levee fill >20 = 7

Data source: Various boring logs from past studies (see Table 2-1)

Delta Risk Management Strategy (DRMS) Levee Fragility		$(N1)_{60\text{-}CS}$ Distribution for Levee Sand with $(N1)_{60\text{-}CS}$ < 20	Figure 6-54
URS	Project No. 26815621		

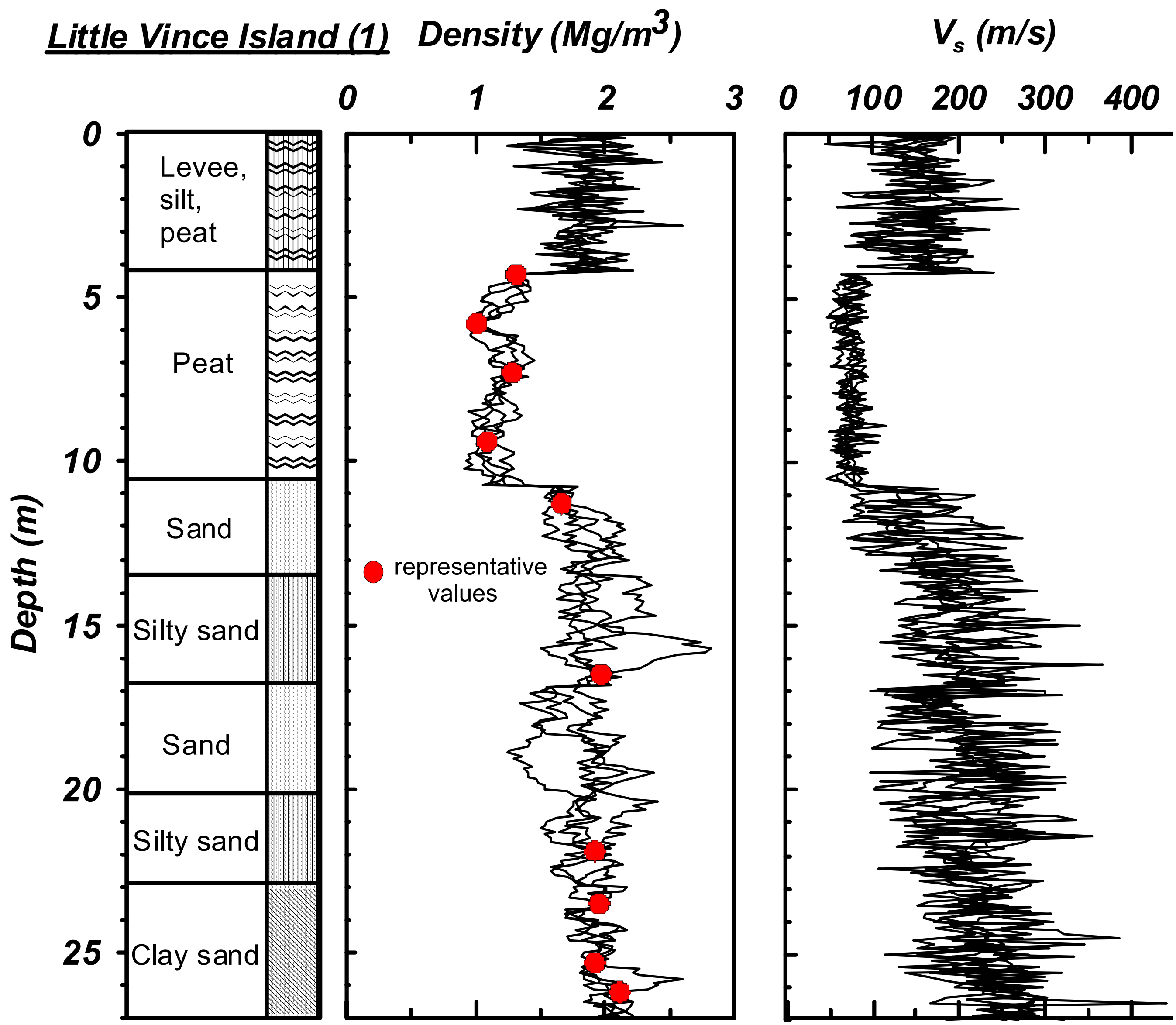


Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Sherman Island	Figure 6-55a
URS	Project No. 26815621		



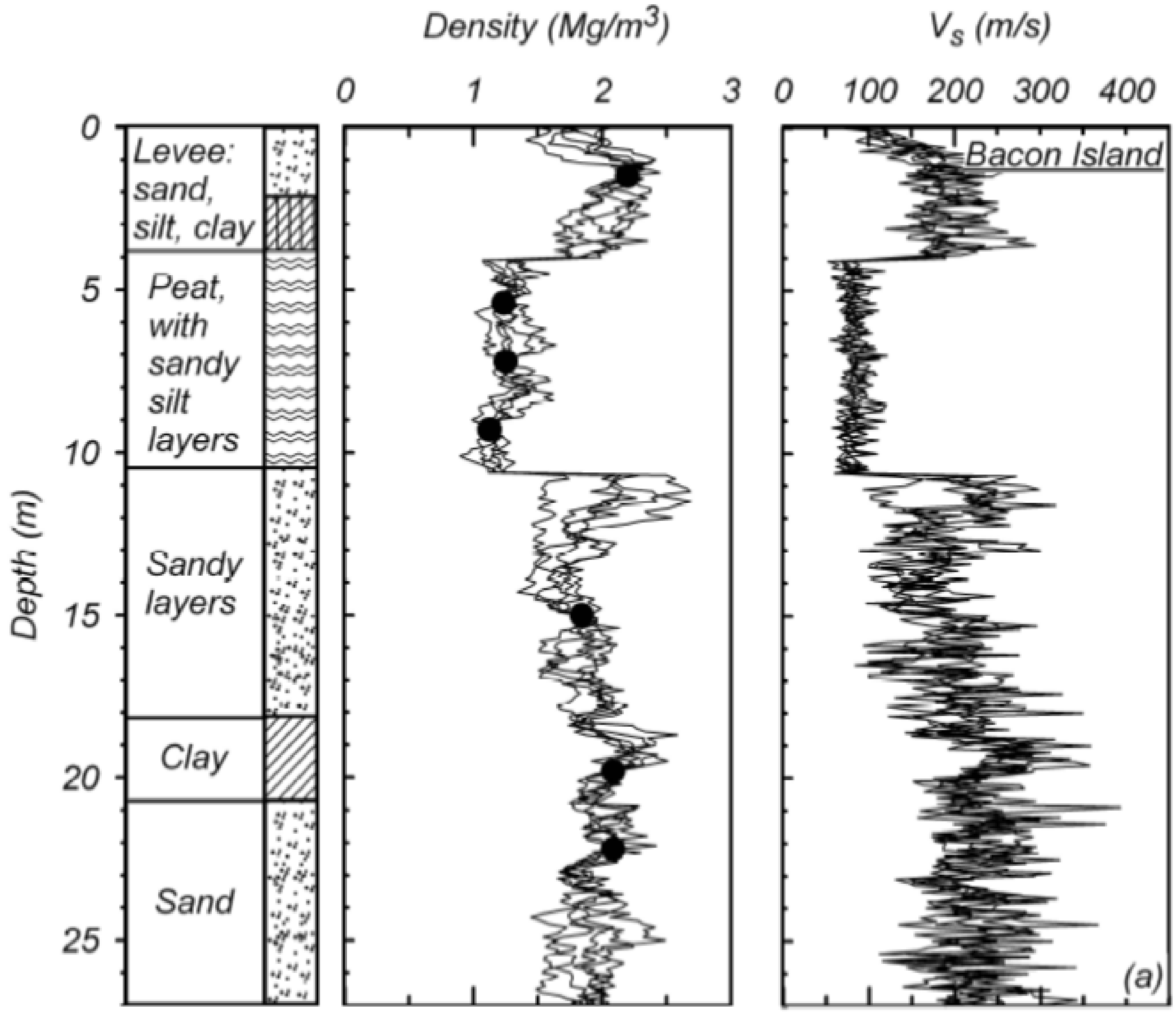
Source: Original data from DWR;
Processed by Tadahiro et al. 2007

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Mandeville Island	Figure 6-55b
URS	Project No. 26815621		



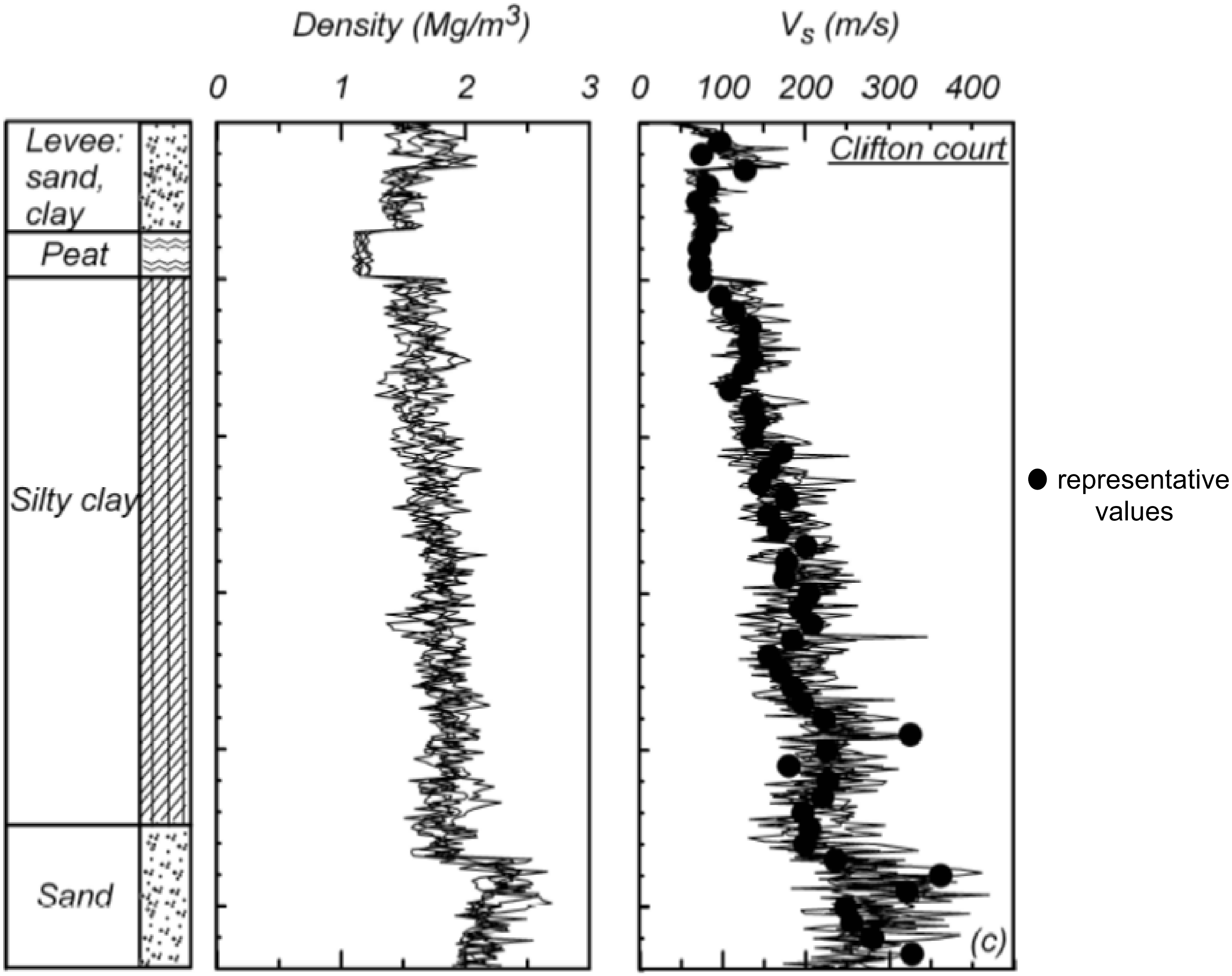
Source: Original data from DWR;
Processed by Tadahiro et al. 2007

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Little Vince Island	Figure 6-55c
URS	Project No. 26815621		



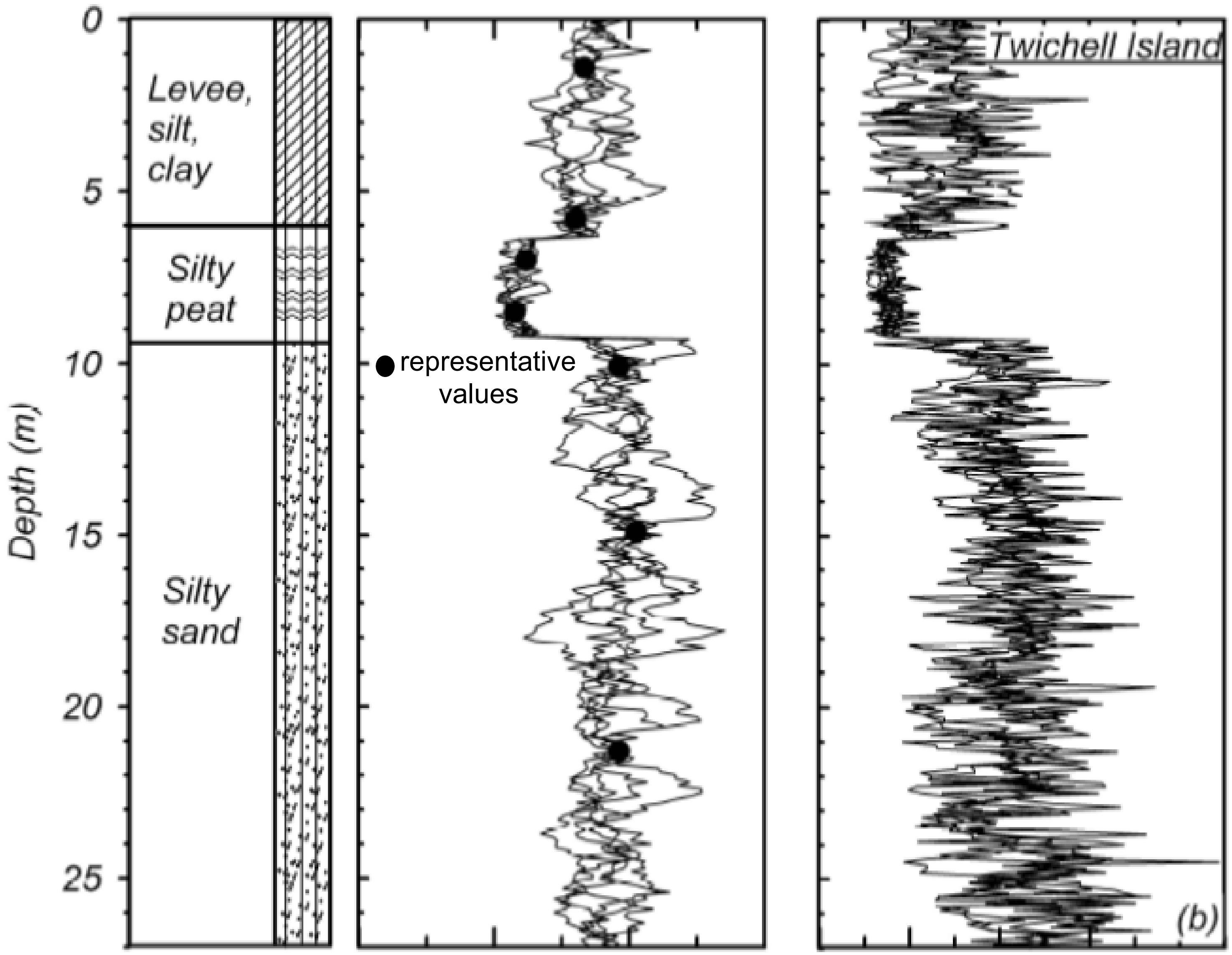
Source: Original data from DWR;
Processed by Tadahiro et al. 2007

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Bacon Island	Figure 6-55d
URS	Project No. 26815621		



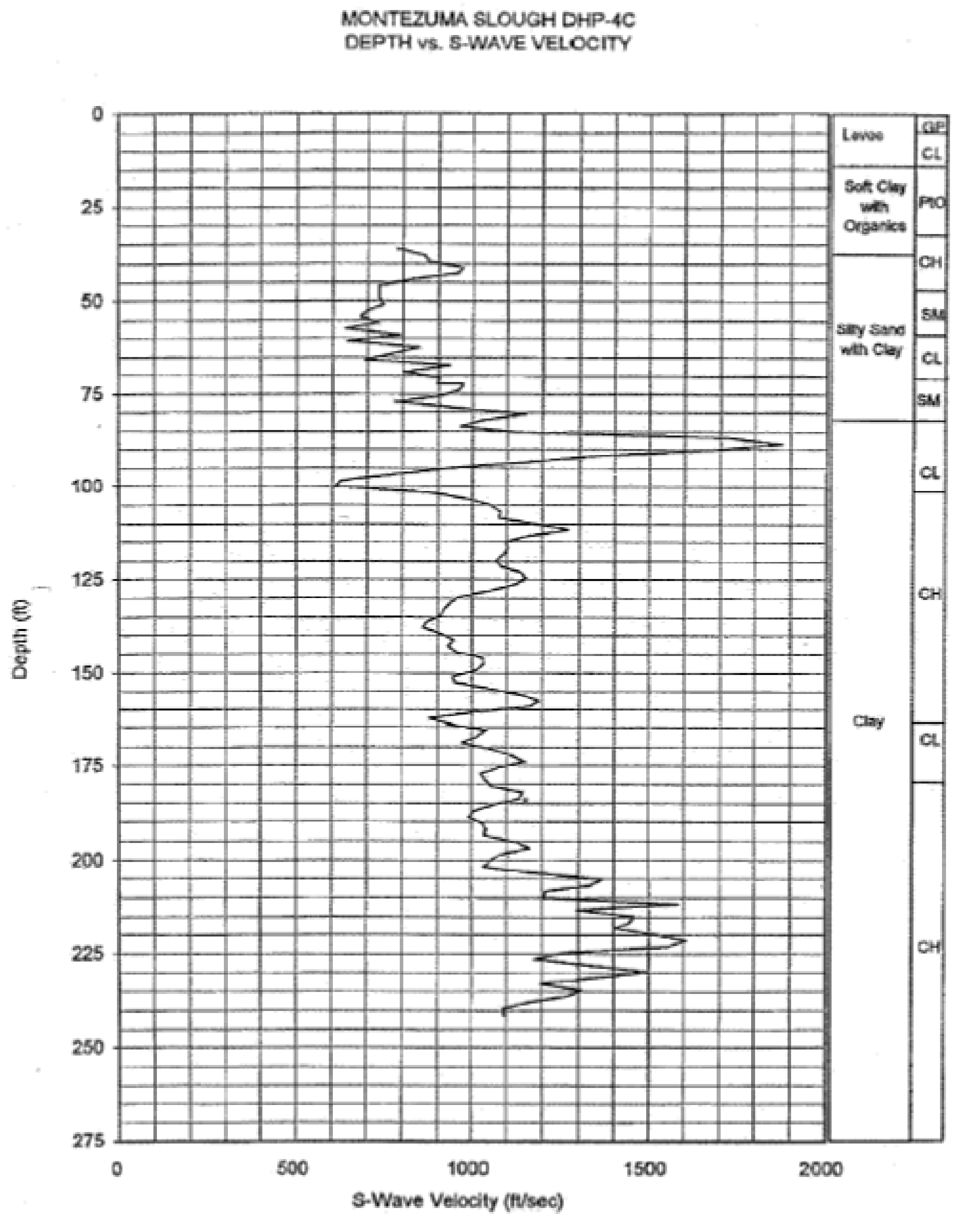
Source: Original data from DWR; Processed by Tadahiro et al. 2007

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Clifton Court	Figure 6-55e
URS	Project No. 26815621		



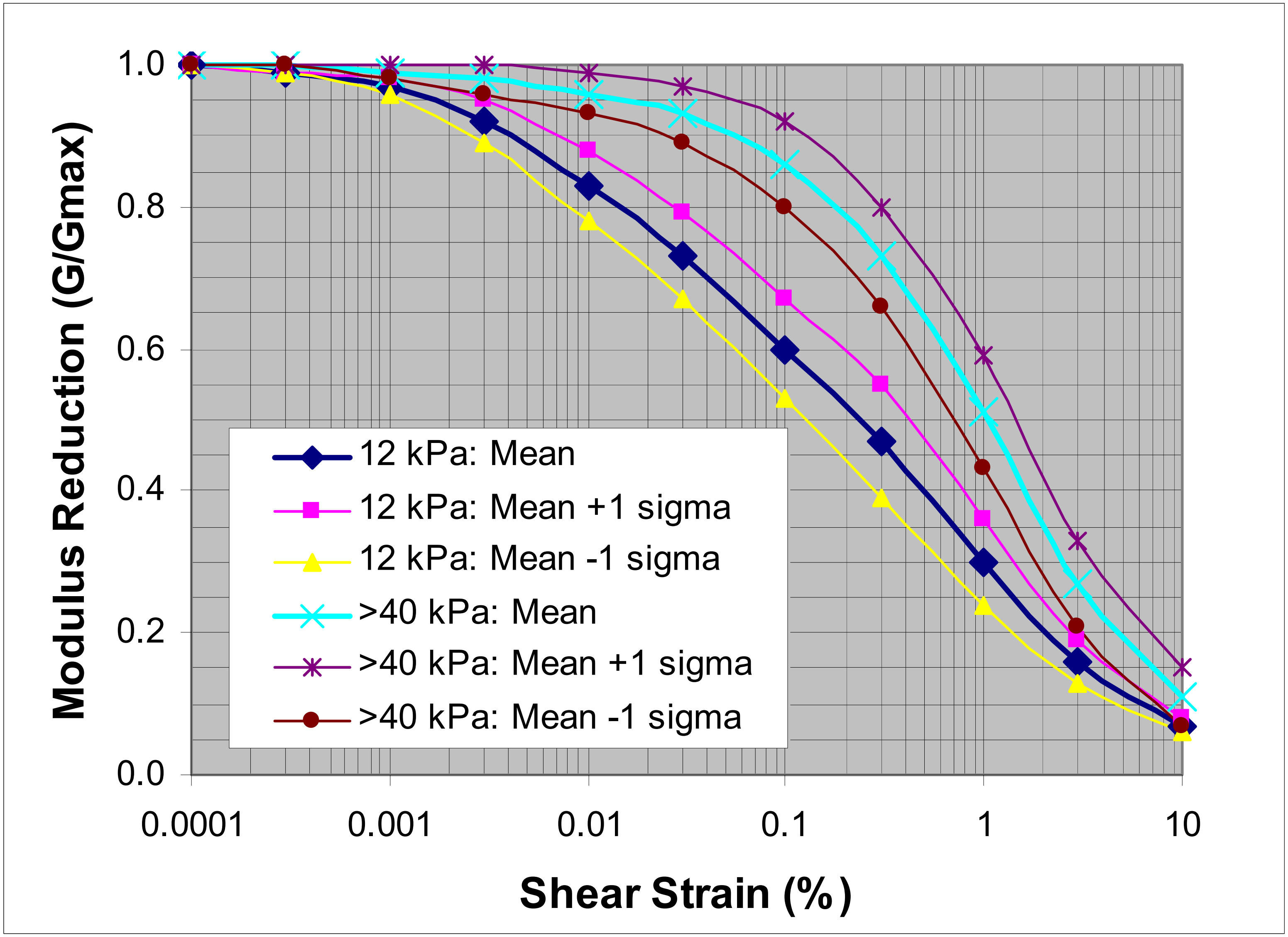
Source: Original data from DWR; Processed by Tadahiro et al. 2007

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Twitchell Island	Figure 6-55f
URS	Project No. 26815621		

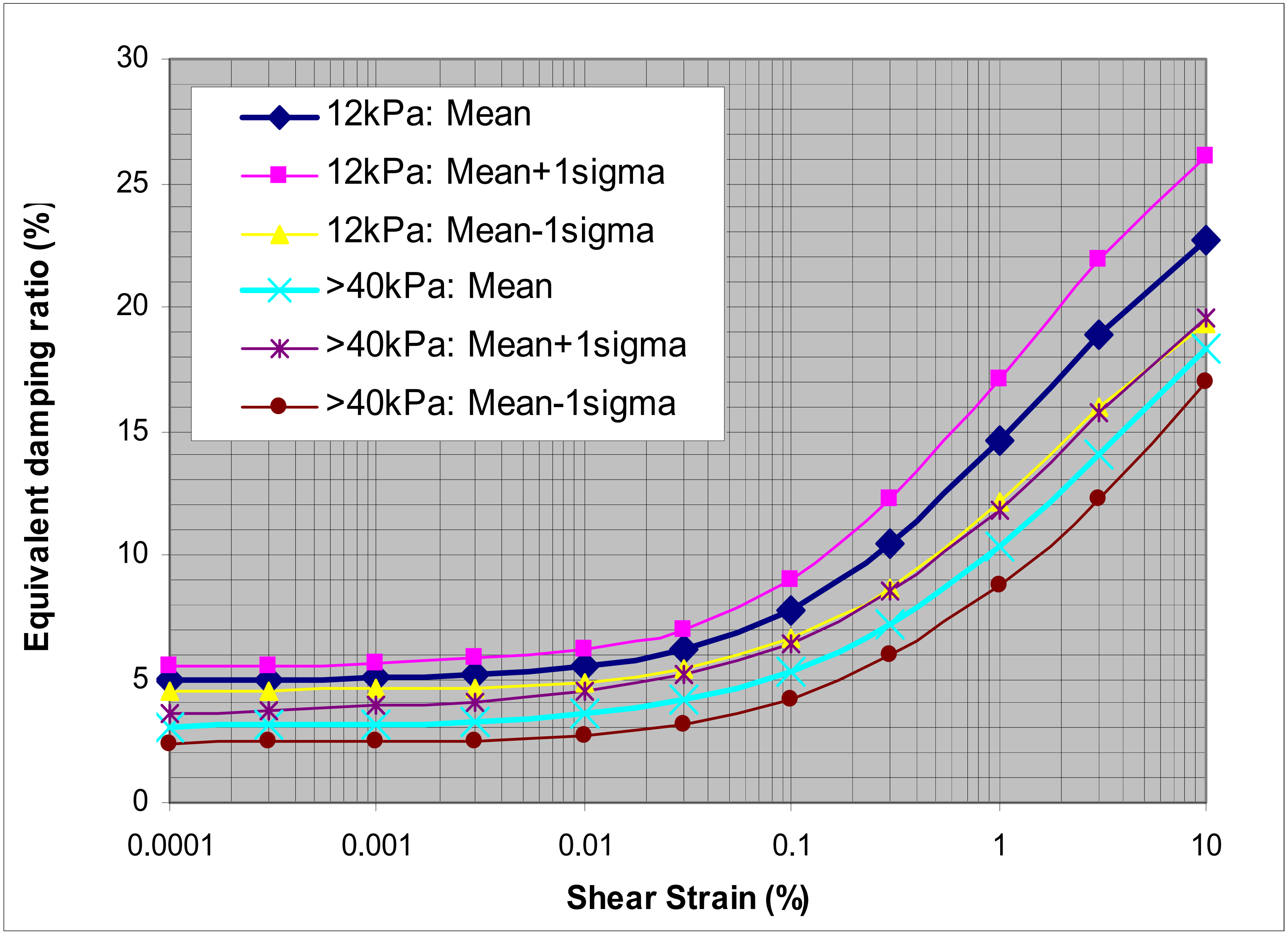


Source: Data from DWR

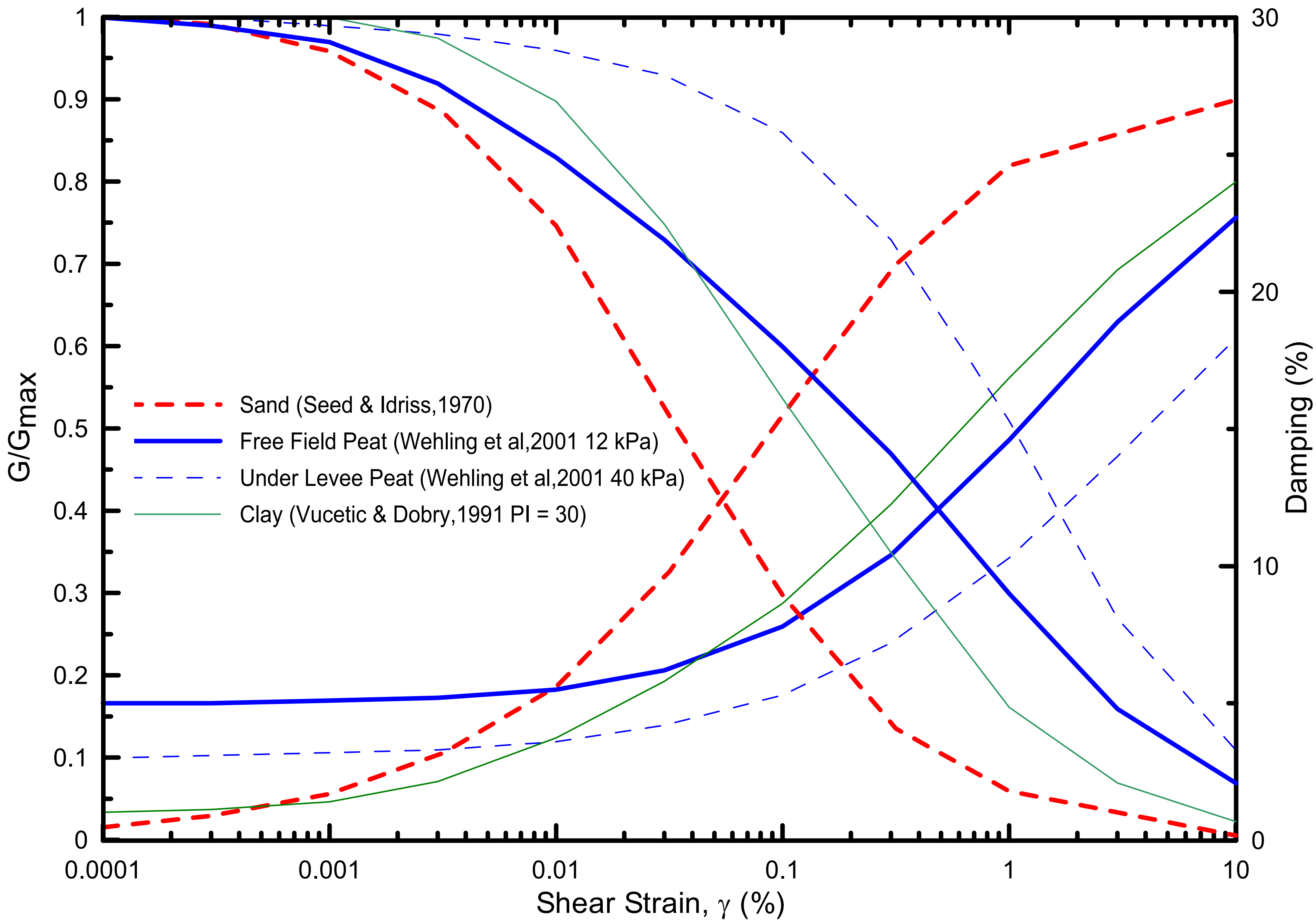
Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Vs Profile Montezuma Slough	Figure 6-55g
URS	Project No. 26815621		



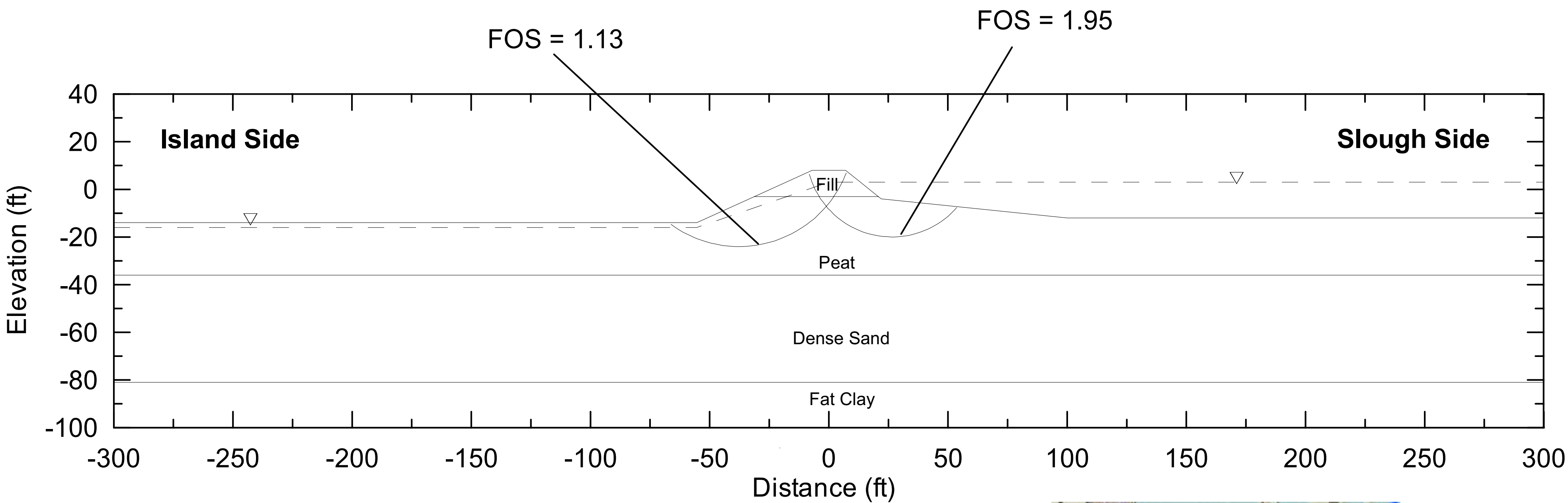
Delta Risk Management Strategy (DRMS) Levee Fragility		G/G_{max} Curves for Peat (Wehling et al., 2001)	Figure 6-56a
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Damping Curves for Peat (Wehling et al., 2001)	Figure 6-56b
URS	Project No. 26815621		

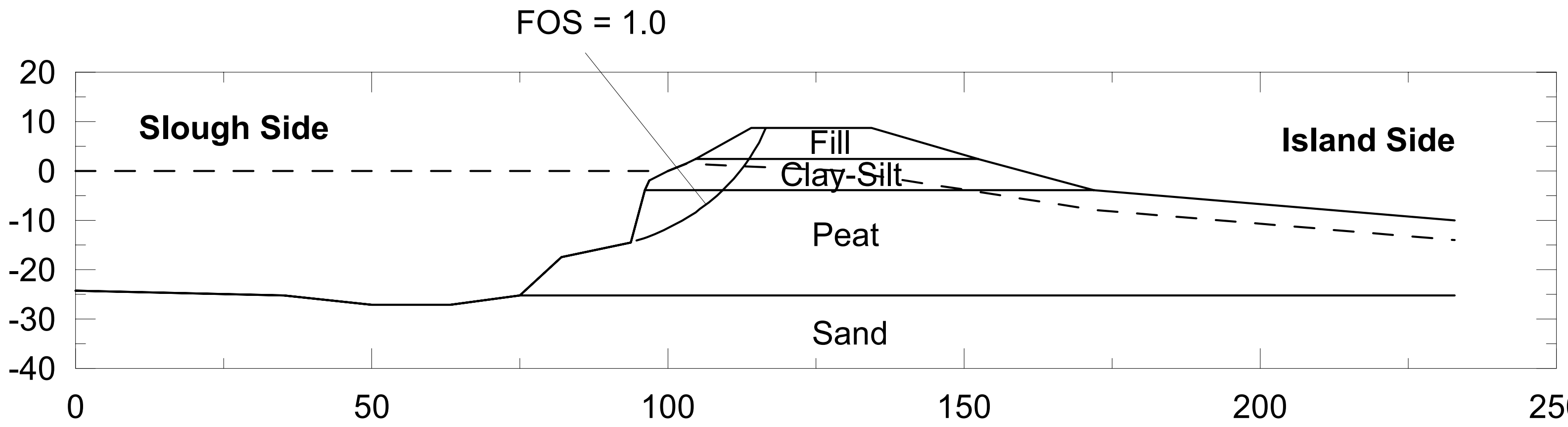


Delta Risk Management Strategy (DRMS) Levee Fragility		Modulus and Damping Curves used in Dynamic Analysis	Figure 6-57
URS	Project No. 26815621		



Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Fill	115	32	50	-	-
Peat	70	28	120	18	140
Dense Sand	125	38	0	-	-

Delta Risk Management Strategy (DRMS) Levee Fragility		Bradford Island - Station 169+00 Stability Analysis - Long Term	Figure 6-58
URS	Project No. 26815621		



Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Fill	115	35	50	-	-
Clay-Silt	90	32	100	-	-
Peat	70	28	120	18	140
Dense Sand	125	38	0	-	-

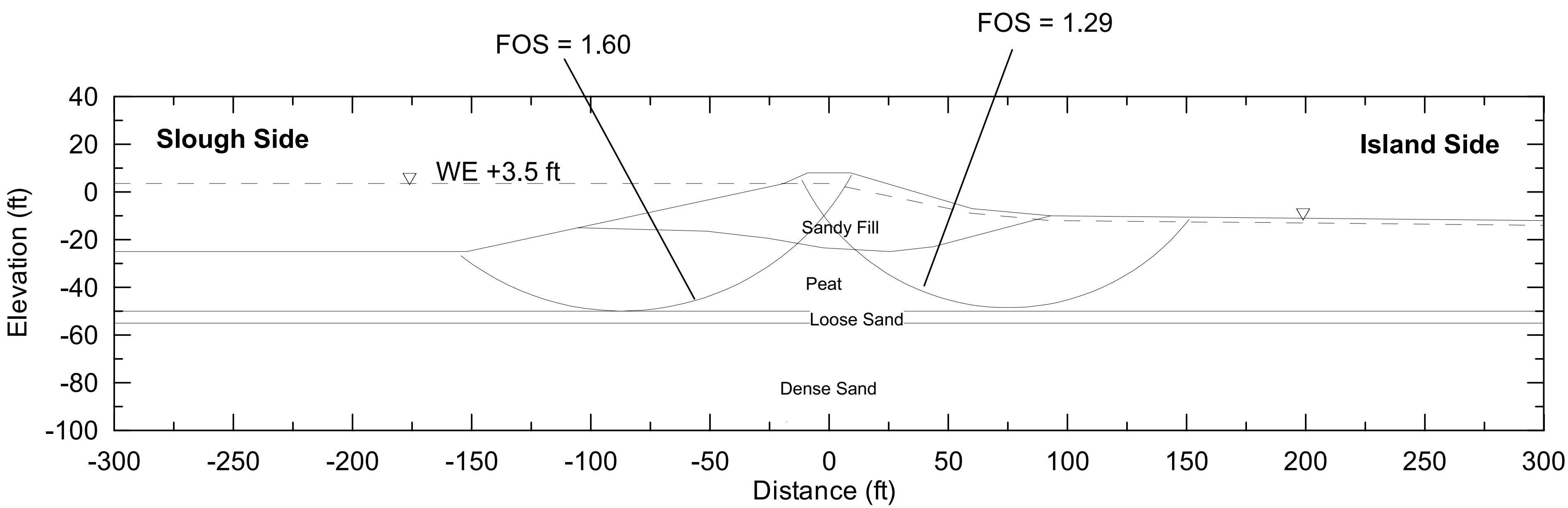
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Holland Tract - Station156+00
Stability Analysis - Long Term

Figure
6-59



Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Sandy Fill	115	30	0	-	-
Peat	70	28	120	18	140
Loose sand	125	32	0	-	-
Dense Sand	125	38	0	-	-

Note: See in-text table in Section 6.4.4.

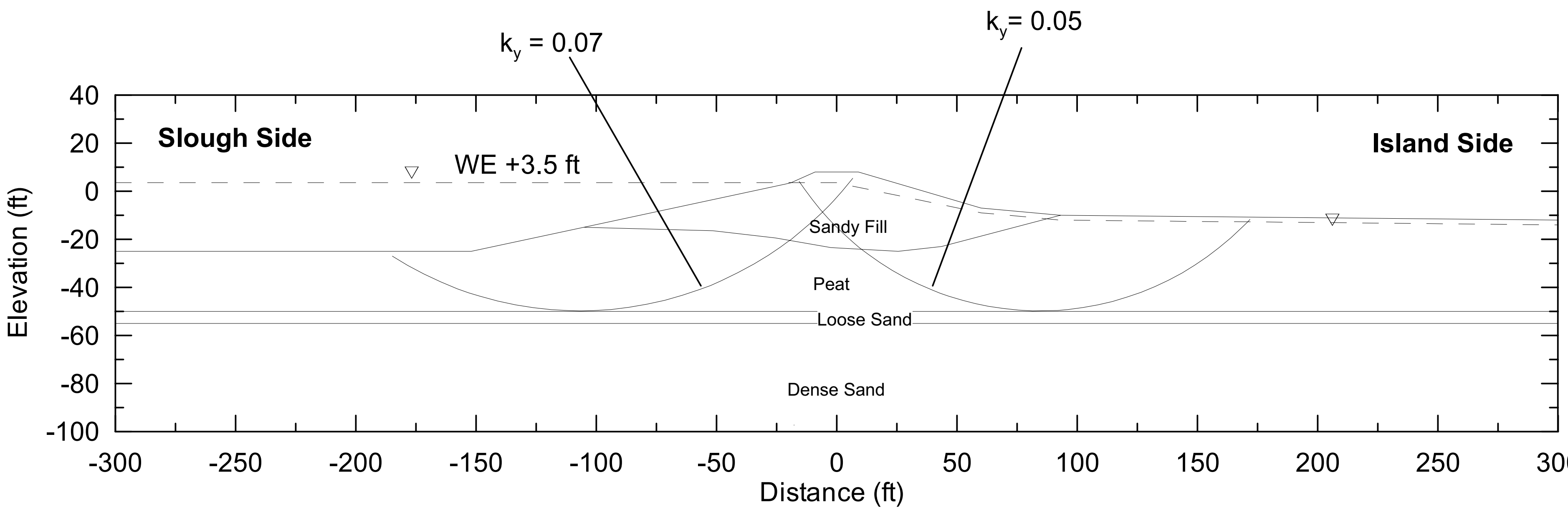
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Sherman Island - Station 650+00
Stability Analysis - Long Term

Figure 6-60a



Type	Unit Weight (pcf)	φ'	c' (psf)	φ	c (psf)
Sandy Fill	115	30	0	-	-
Peat	70	28	120	18	140
Loose sand	125	32	0	-	-
Dense Sand	125	38	0	-	-

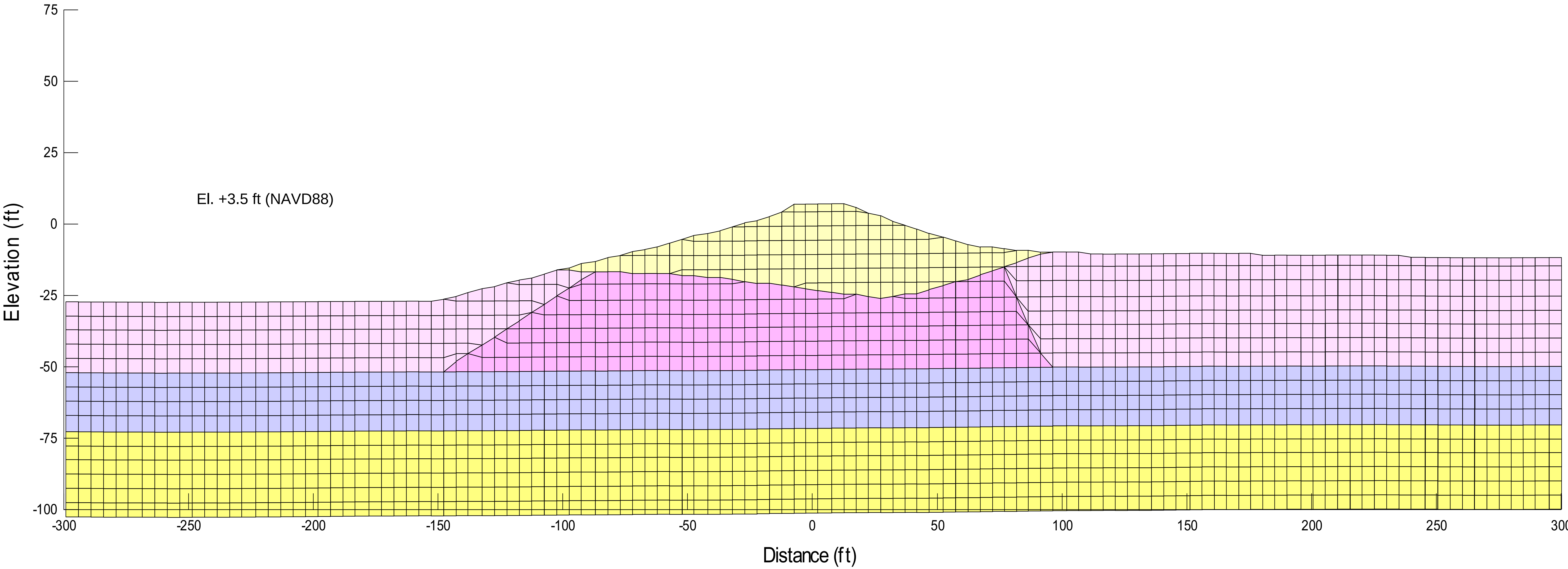
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Sherman Island - Station 650+00
Stability Analysis - Seismic

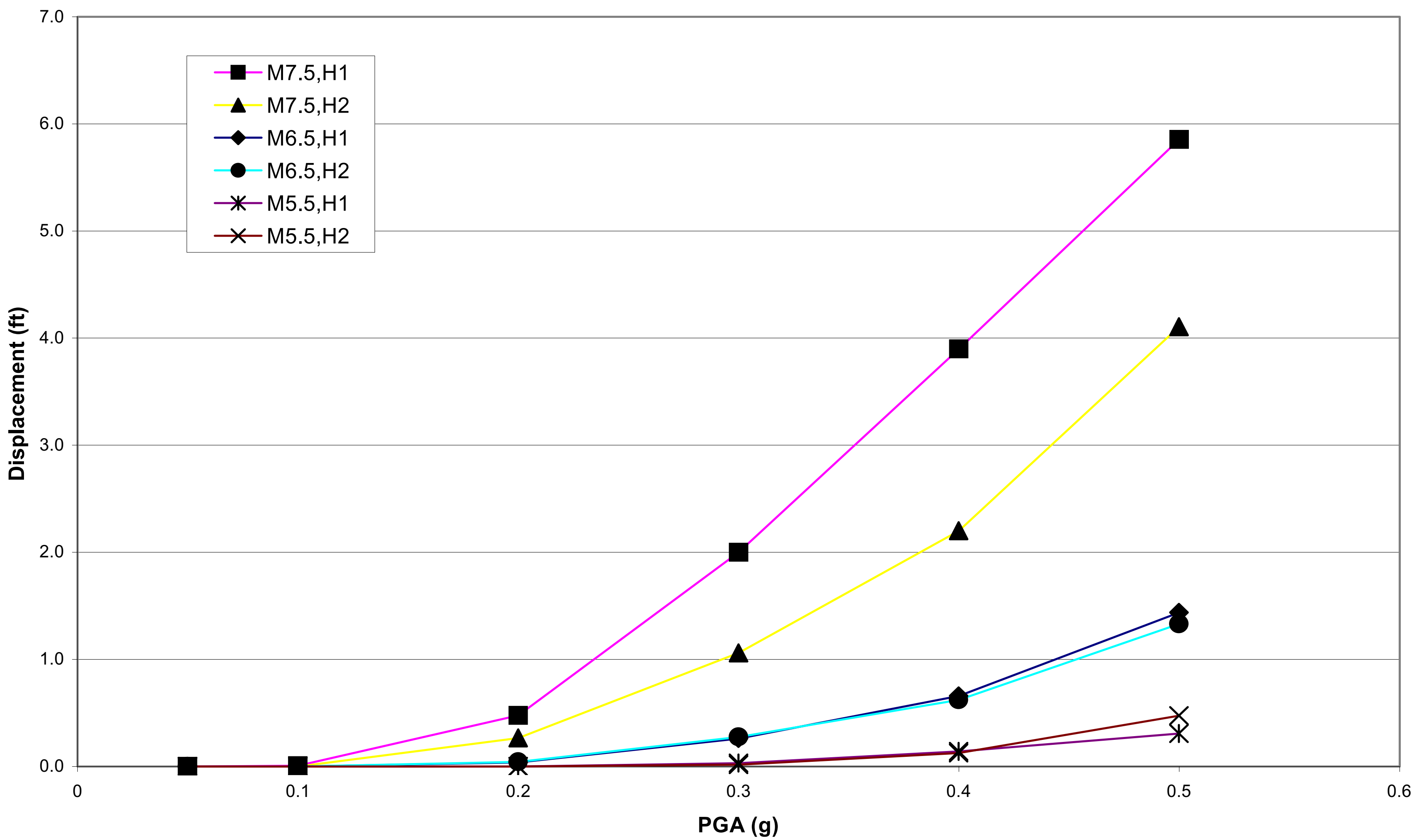
Figure 6-60b



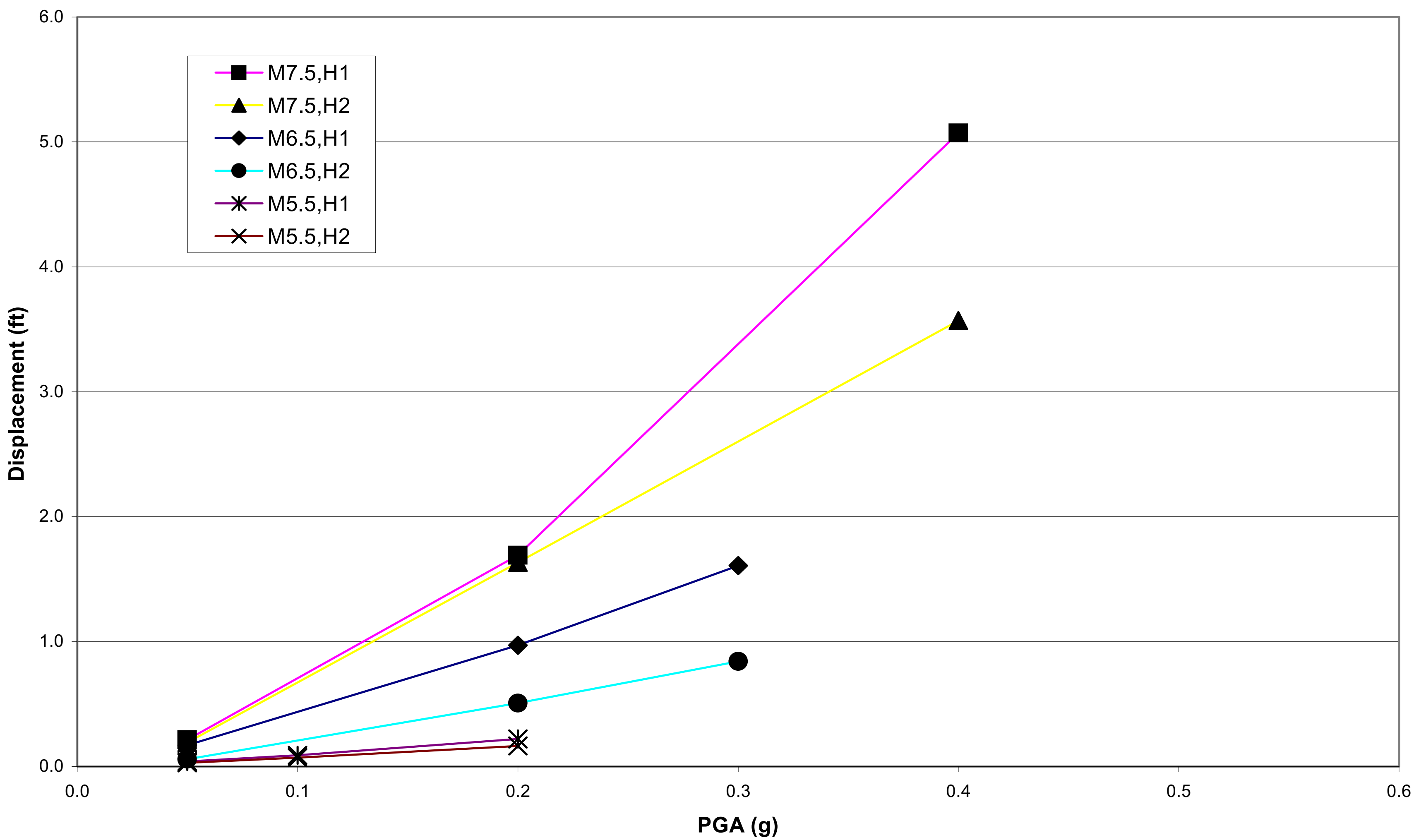
Legend

- Levee Fill
- Free Field Peat
- Under Levee Peat
- Sand
- Dense Sand

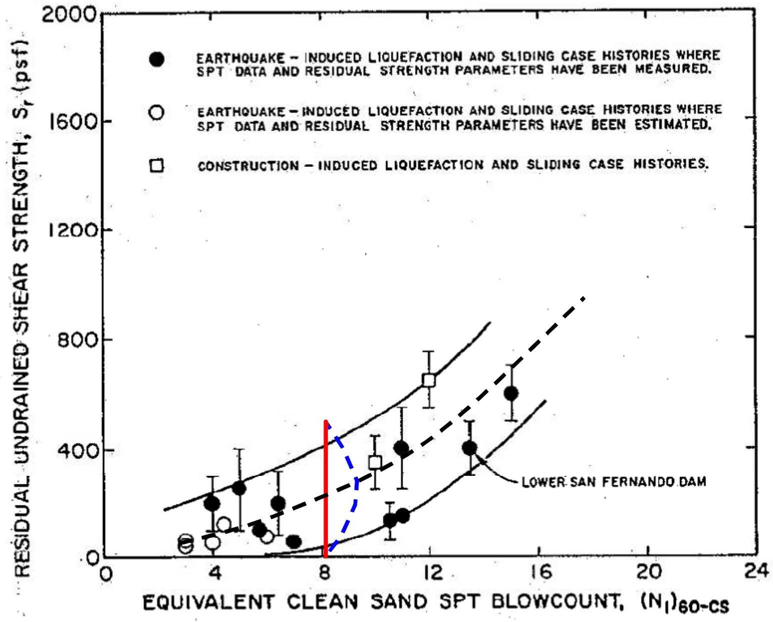
Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Model for Seismic Analysis Sherman Island - Station 650+00	Figure 6-61
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Sherman Island - Sta. 650+00 35 Feet of Peat	Figure 6-62
URS	Project No. 26815621		

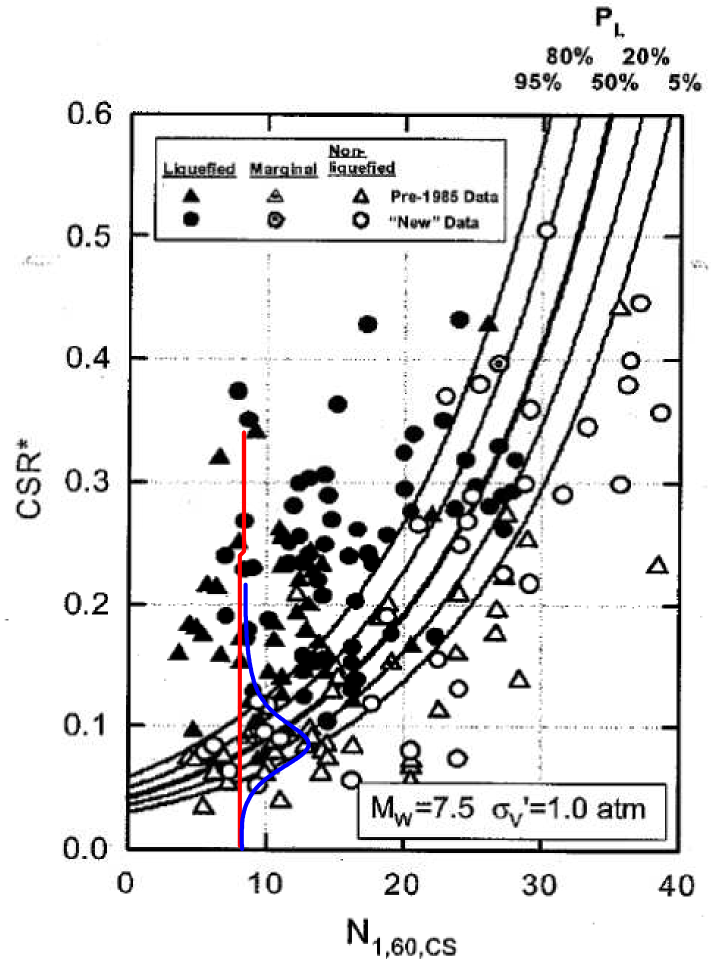


Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated FLAC Displacements Sherman Island - Sta. 650+00 35 Feet of Peat	Figure 6-63
URS	Project No. 26815621		



(1) Relationship Between $(N_1)_{60\text{-cs}}$ and Undrained Residual Shear Strength

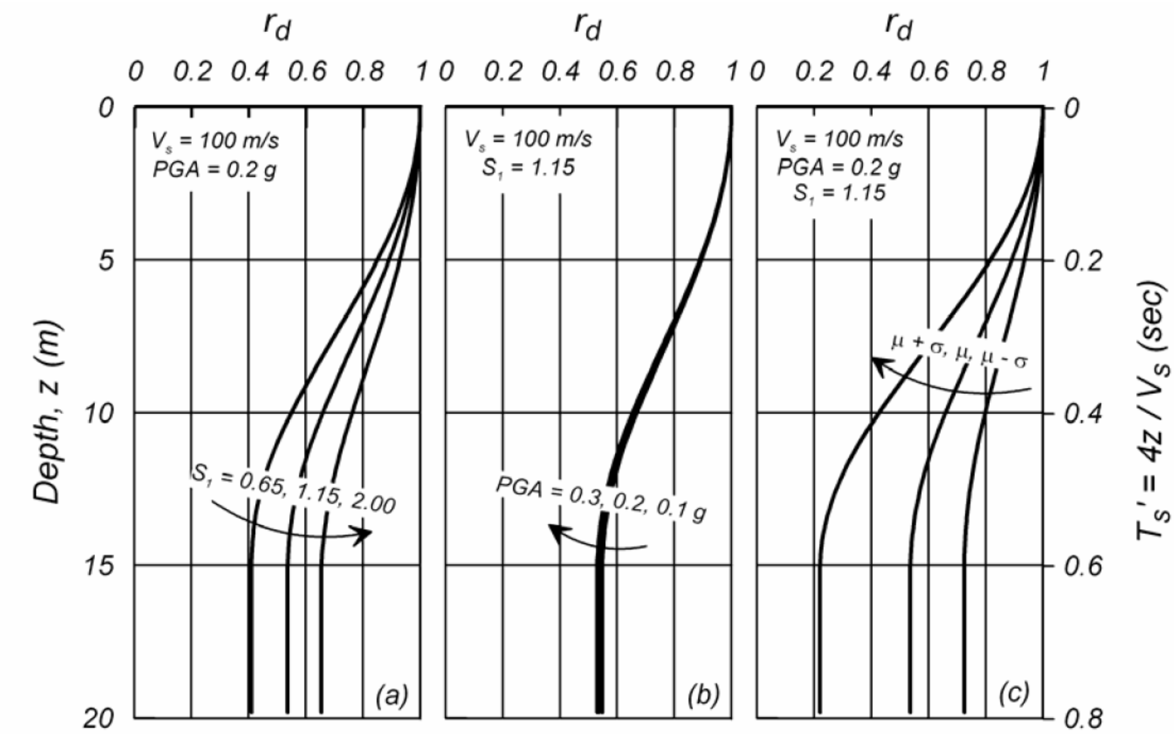
(Source: Seed and Harder 1990)



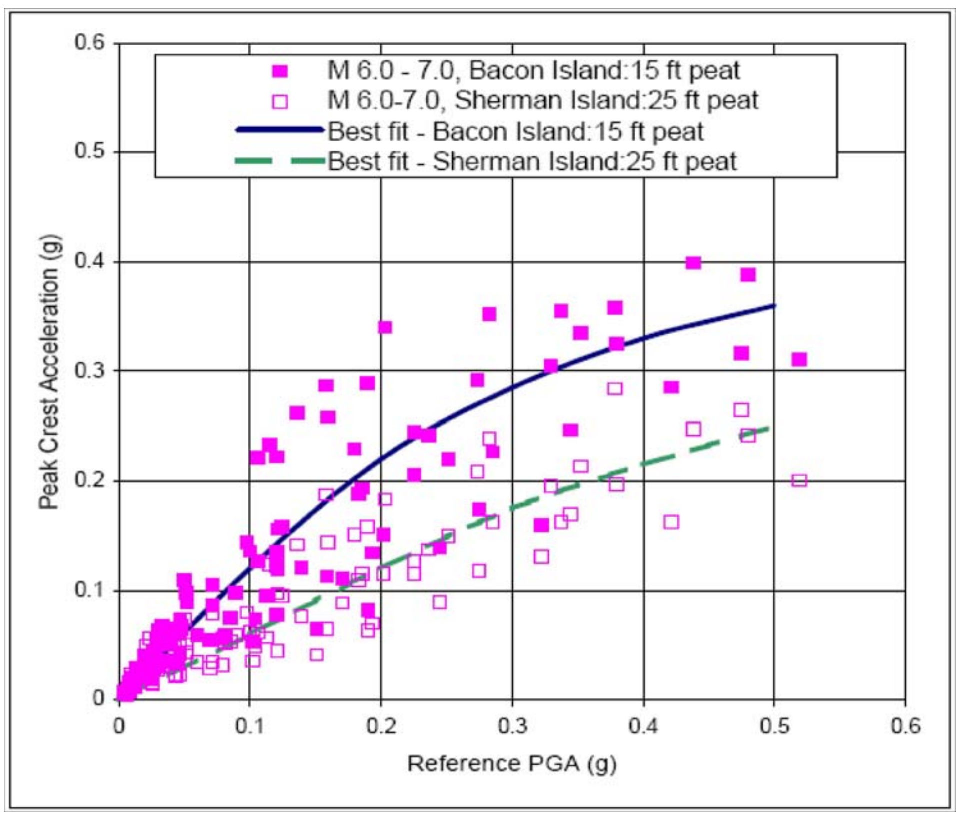
(2) Probabilistic SPT-Based Liquefaction Triggering Correlation

(Source: Seed et al. 2003)

Delta Risk Management Strategy (DRMS) Levee Fragility		Undrained Residual Shear Strength and Probabilistic Liquefaction Triggering Correlation	Figure 6-64a
URS	Project No. 26815621		

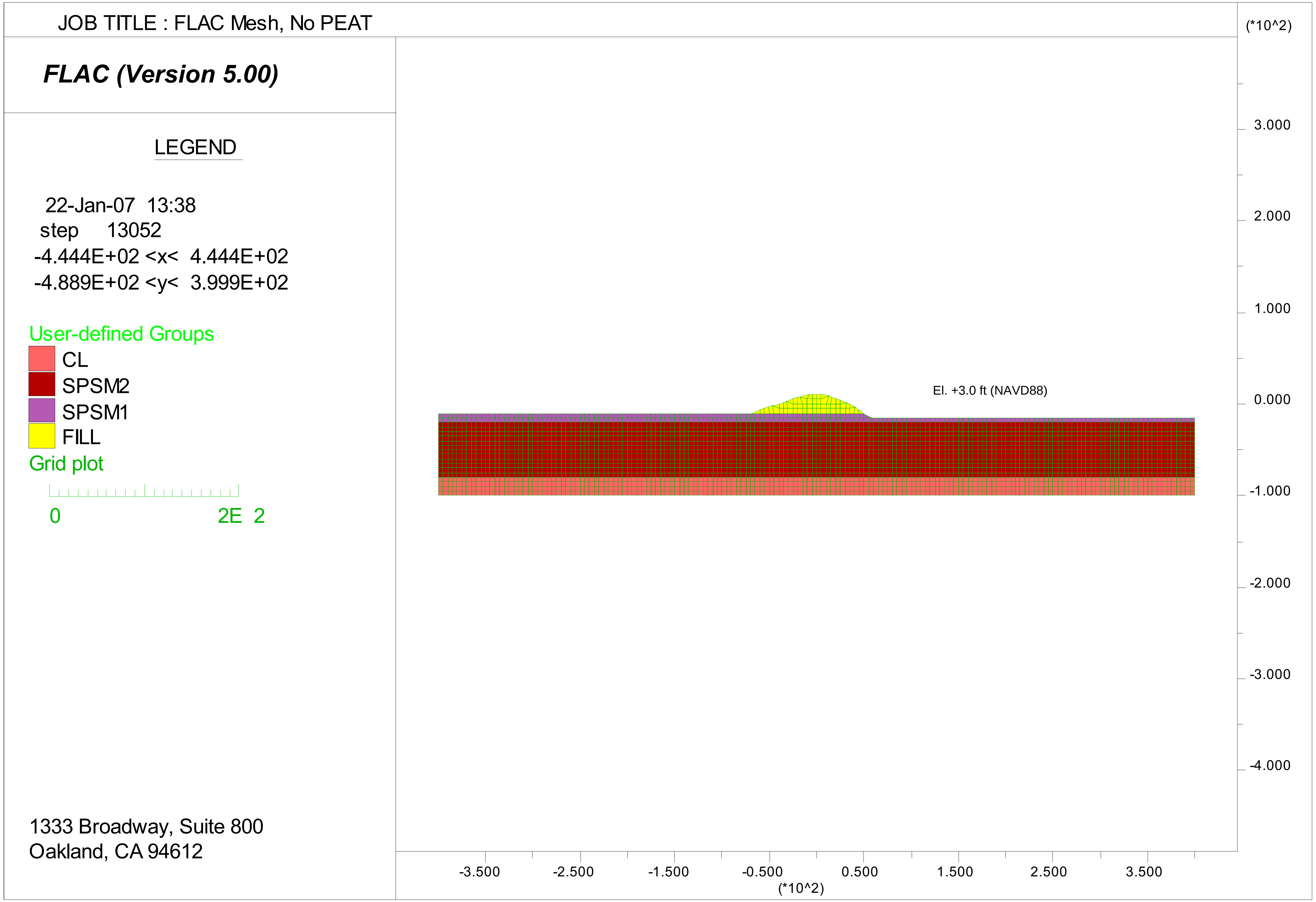


(1) r_d vs Depth (Tadahiro et al. 2007)

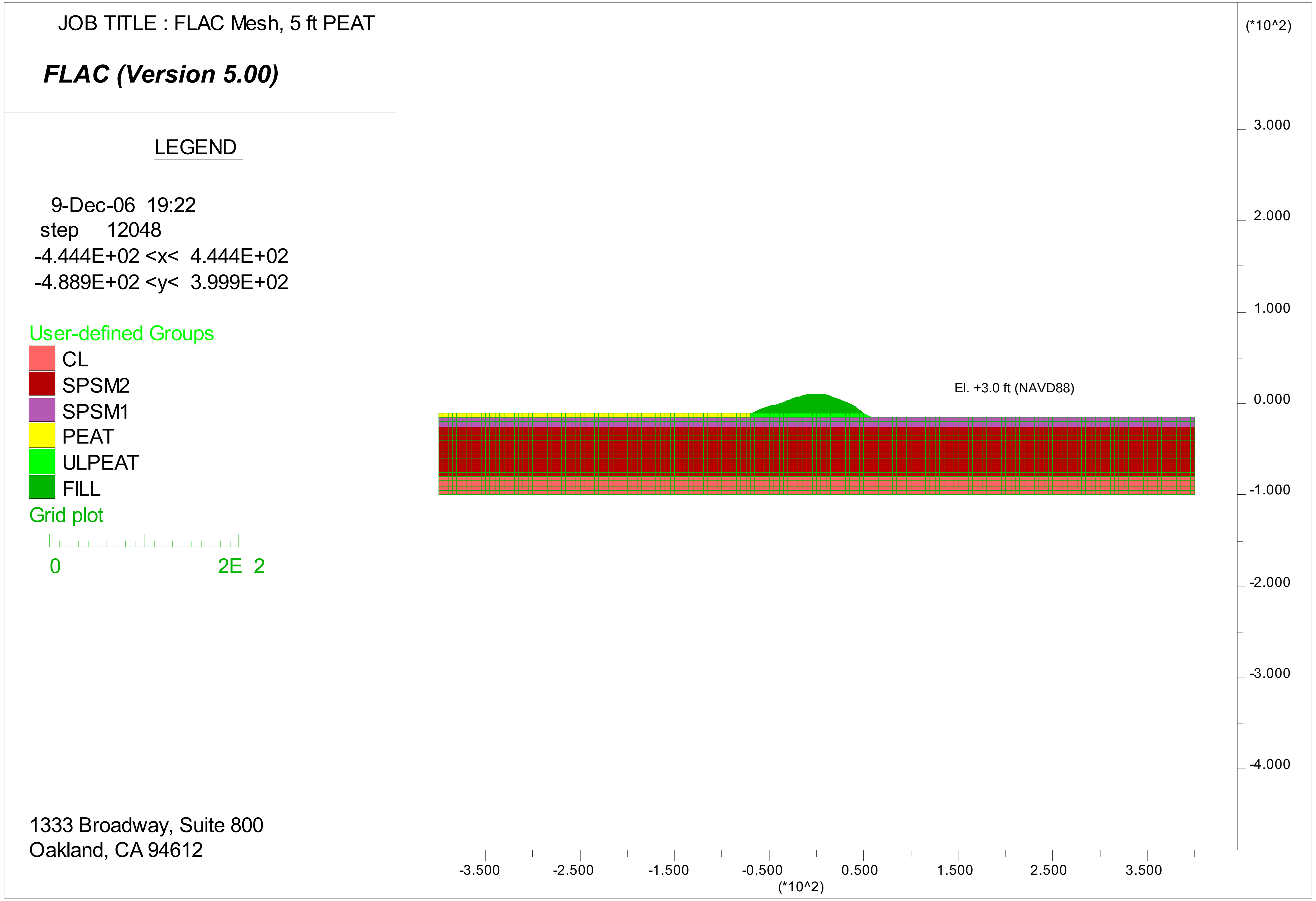


(2) Reference PGA vs Peak Crest Acceleration
(Data from Tadahiro et al. 2007)

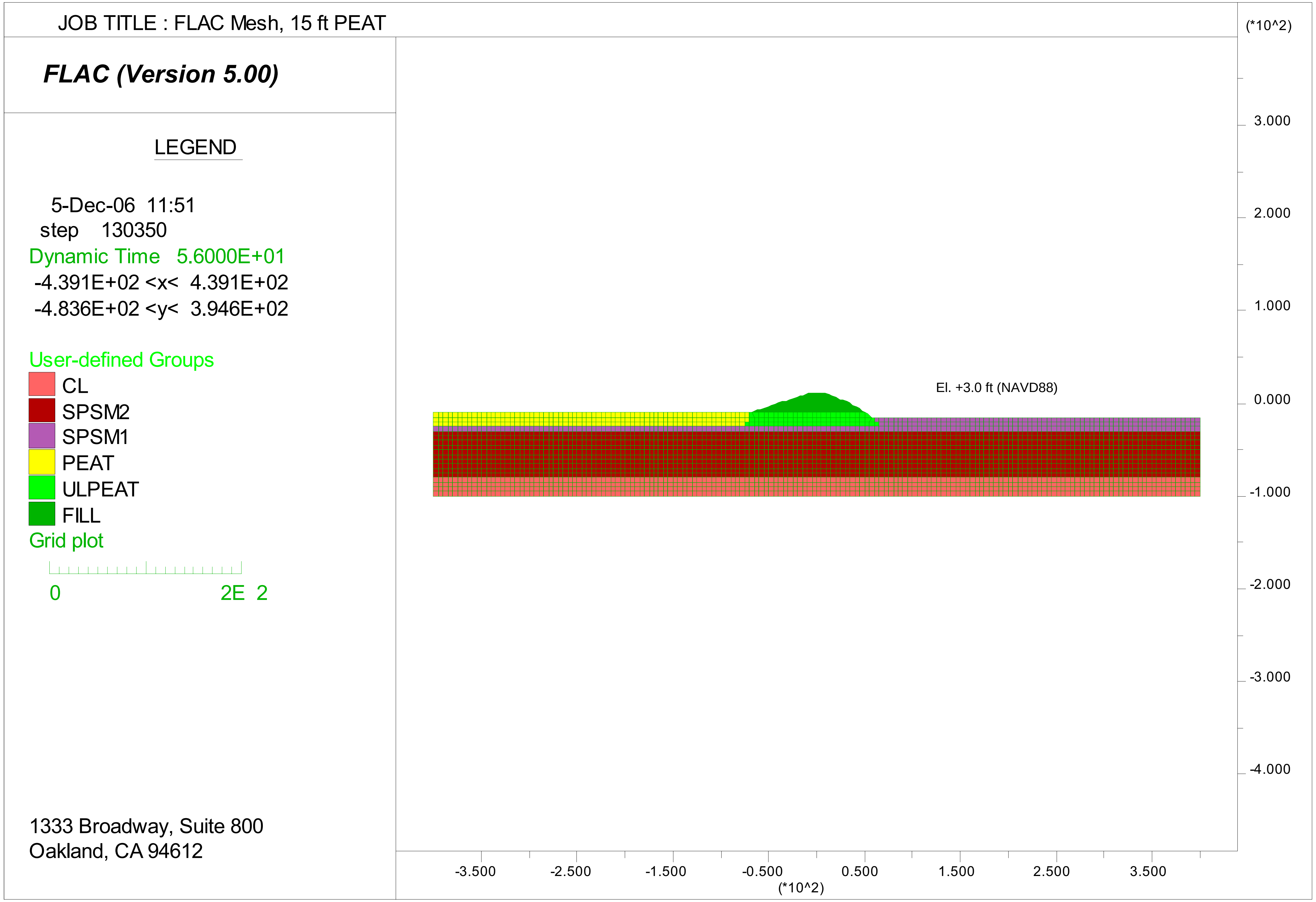
Delta Risk Management Strategy (DRMS) Levee Fragility		r_d vs Depth and Reference PGA vs Peak Crest Acceleration Relationships (Tadahiro et al. 2007)	Figure 6-64b
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility	FLAC Finite Element Model for Seismic Analysis Idealized Section - No Peat	Figure 6-65
URS — Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		FLAC Finite Element Model for Seismic Analysis Idealized Section - 5 ft Peat	Figure
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		FLAC Finite Element Model for Seismic Analysis Idealized Section - 15 ft Peat	Figure 6-67
URS	Project No. 26815621		

JOB TITLE : FLAC Mesh, 25 ft PEAT

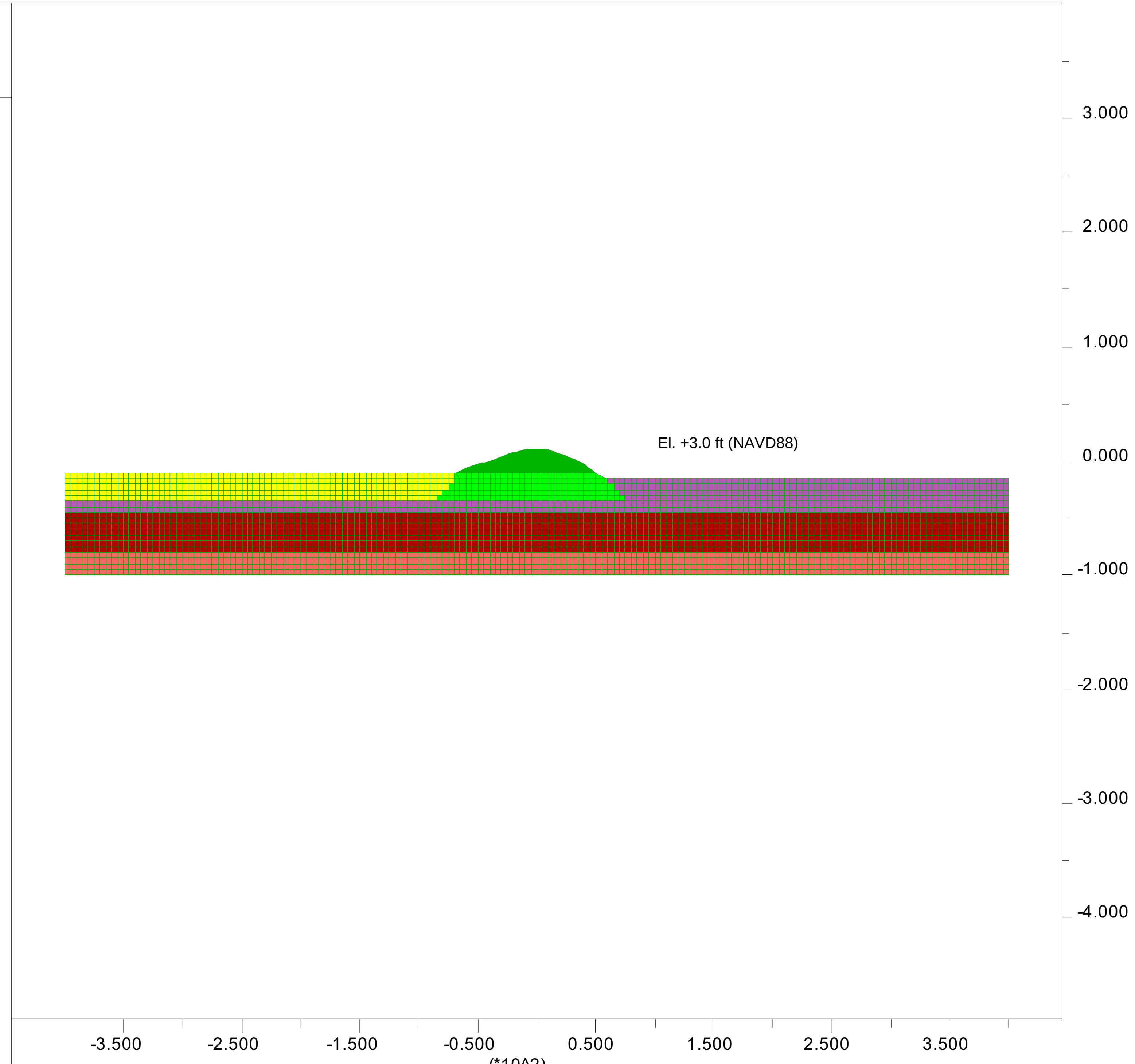
FLAC (Version 5.00)

LEGEND

9-Dec-06 18:58
step 11028
-4.444E+02 <x< 4.444E+02
-4.889E+02 <y< 3.999E+02

User-defined Groups
CL
SPSM2
SPSM1
PEAT
ULPEAT
FILL
Grid plot

0 2E 2



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Delta Risk Management Strategy (DRMS) Levee Fragility		FLAC Finite Element Model for Seismic Analysis Idealized Section - 25 ft Peat	Figure 6-68
URS	Project No. 26815621		

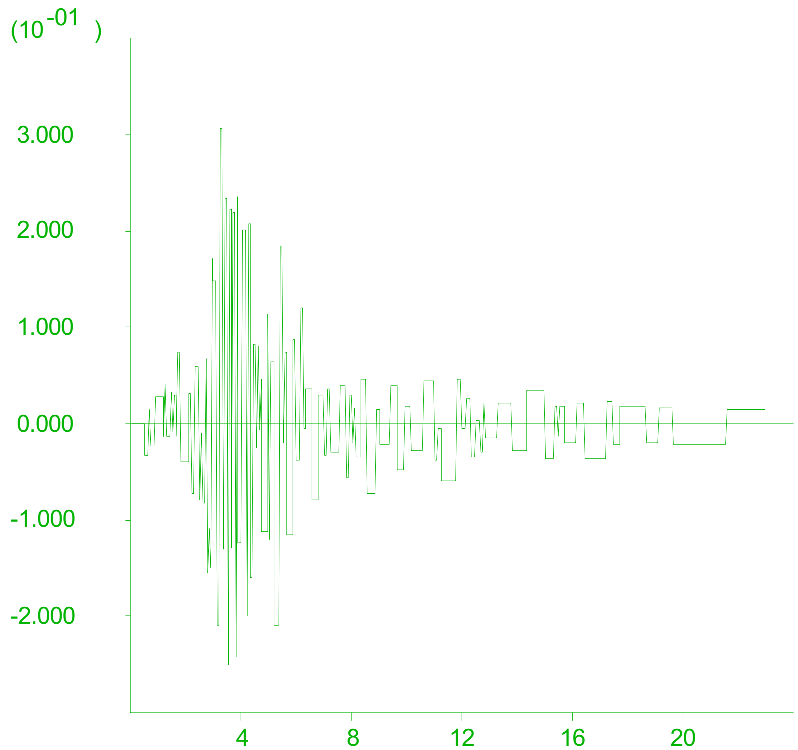
JOB TITLE : CSR Time History, Input Motion M5.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 18:42
step 62526
Dynamic Time 2.3000E+01

HISTORY PLOT
Y-axis :
68 sd_csr_zero (141, 17) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 5 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-69
URS	Project No. 26815621		

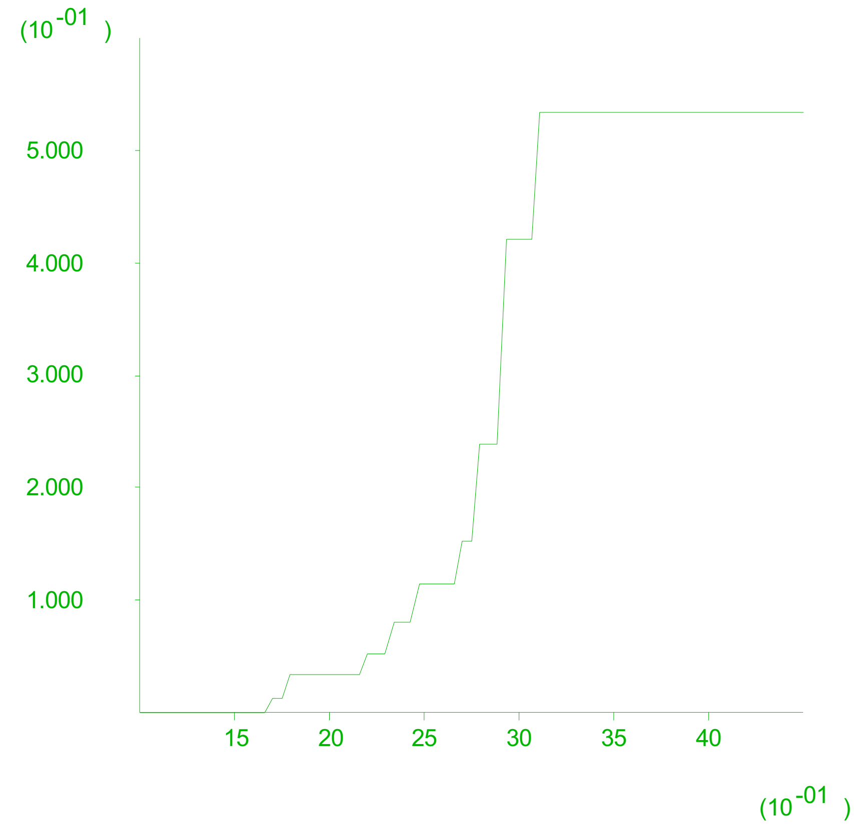
JOB TITLE : Pore Pressure Time History, Input Motion M5.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 18:42
step 62526
Dynamic Time 2.3000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 17) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility	Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 5 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-70
URS / Project No. 26815621		

JOB TITLE : CSR Time History, Input Motion M6.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 21:49
step 99815
Dynamic Time 4.0000E+01

HISTORY PLOT
Y-axis :
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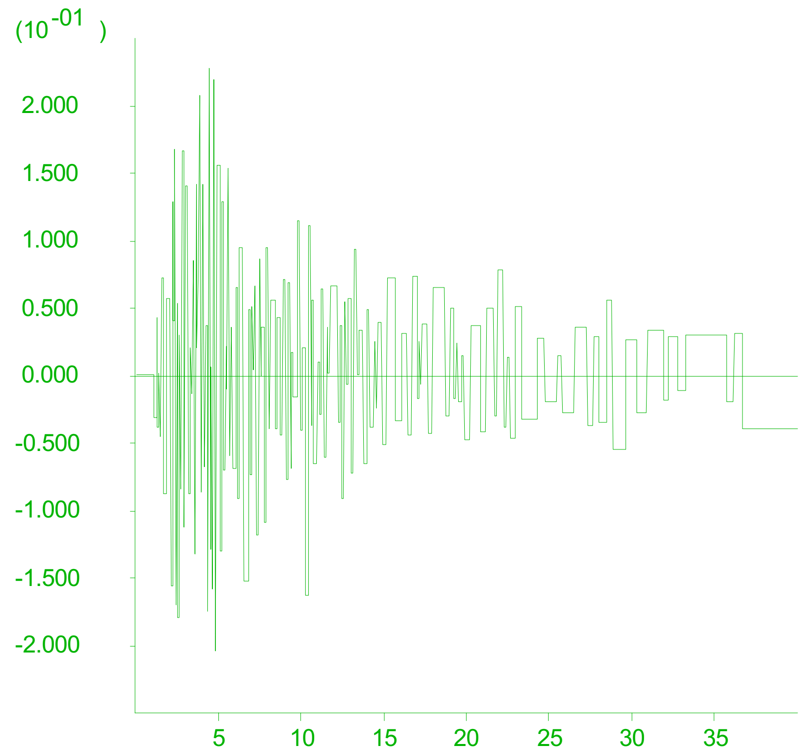
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 5 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-71
URS	Project No. 26815621		

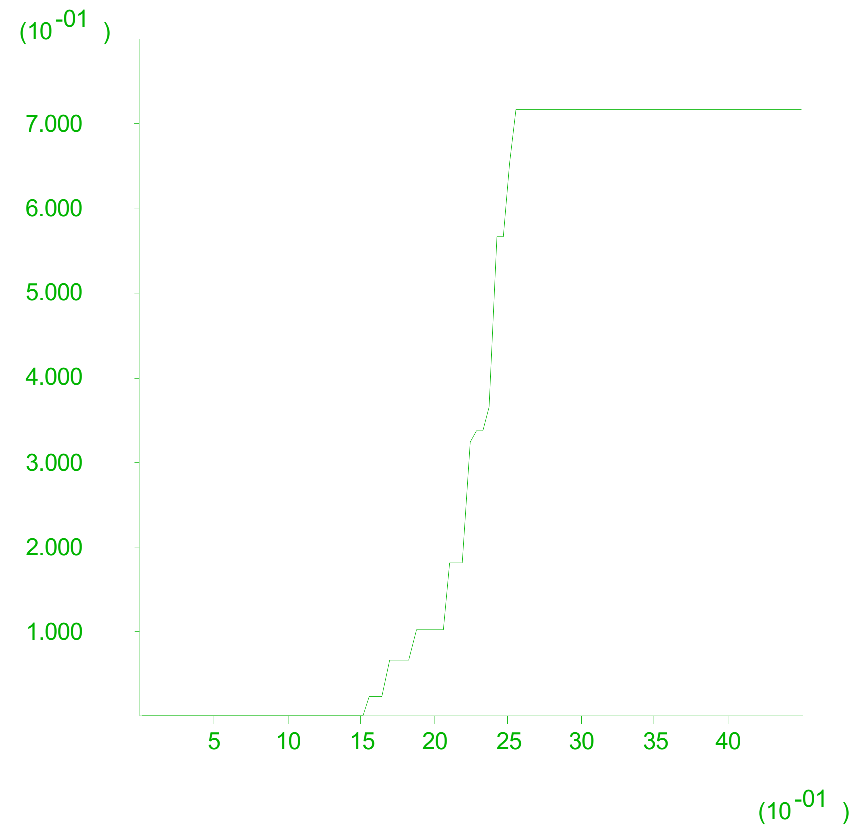
JOB TITLE : Pore Pressure Time History, Input Motion I65.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 21:49
step 99815
Dynamic Time 4.0000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 17) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 5 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-72
URS	Project No. 26815621		

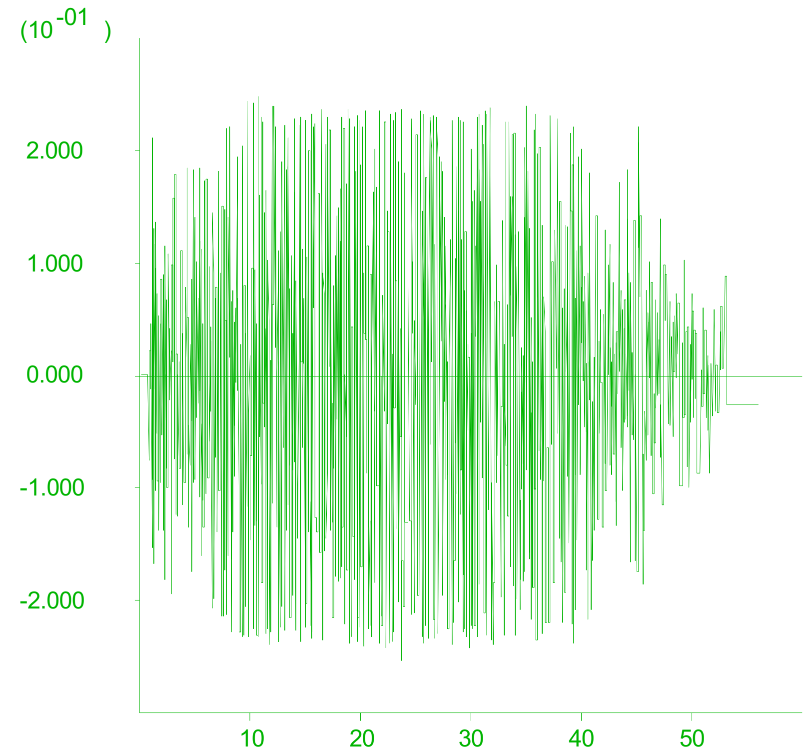
JOB TITLE : CSR Time History, Input Motion M7.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

10-Jan-07 2:35
step 134912
Dynamic Time 5.6000E+01

HISTORY PLOT
Y-axis :
68 sd_csr_zero (141, 17) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 5 ft Peat Input Motion M 7.5 H1, 0.2g	Figure 6-73
URS	Project No. 26815621		

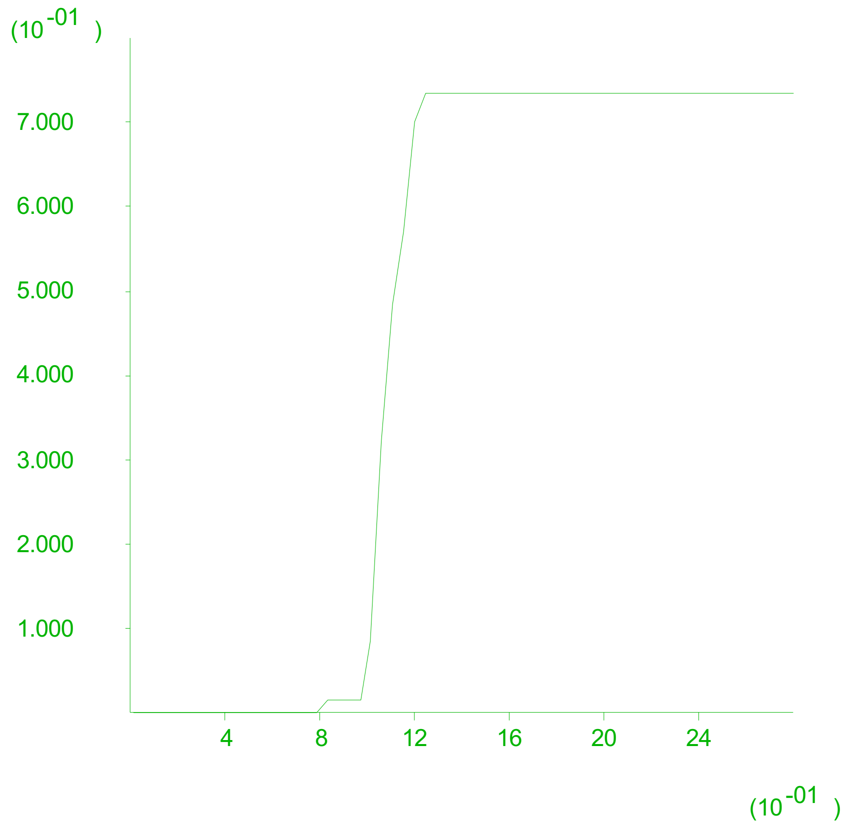
JOB TITLE : Pore Pressure Time History, Input Motion M7.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

10-Jan-07 2:35
step 134912
Dynamic Time 5.6000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 17) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 5 ft Peat Input Motion M 7.5 H1, 0.2g	Figure 6-74
URS	Project No. 26815621		

JOB TITLE : CSR Time History, Input Motion M5.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 23:18
step 59332
Dynamic Time 2.3000E+01

HISTORY PLOT
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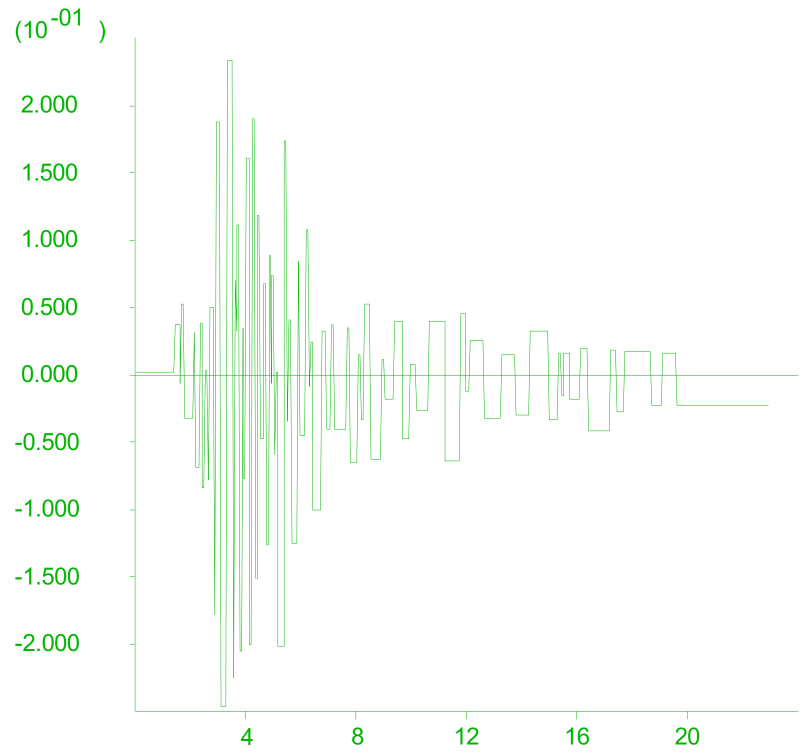
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 15 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-75
URS	Project No. 26815621		

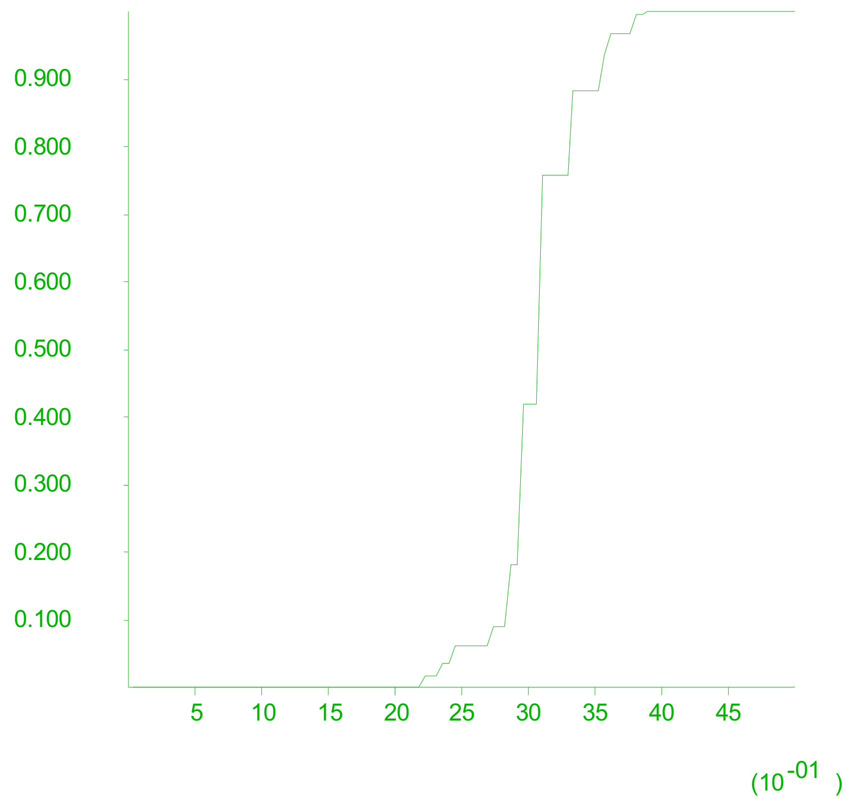
JOB TITLE : Pore Pressure Time History, Input Motion M5.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 23:18
step 59332
Dynamic Time 2.3000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 15) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 15 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-76
URS	Project No. 26815621		

JOB TITLE : CSR Time History, Input Motion M6.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 21:58
step 95763
Dynamic Time 4.0000E+01

HISTORY PLOT
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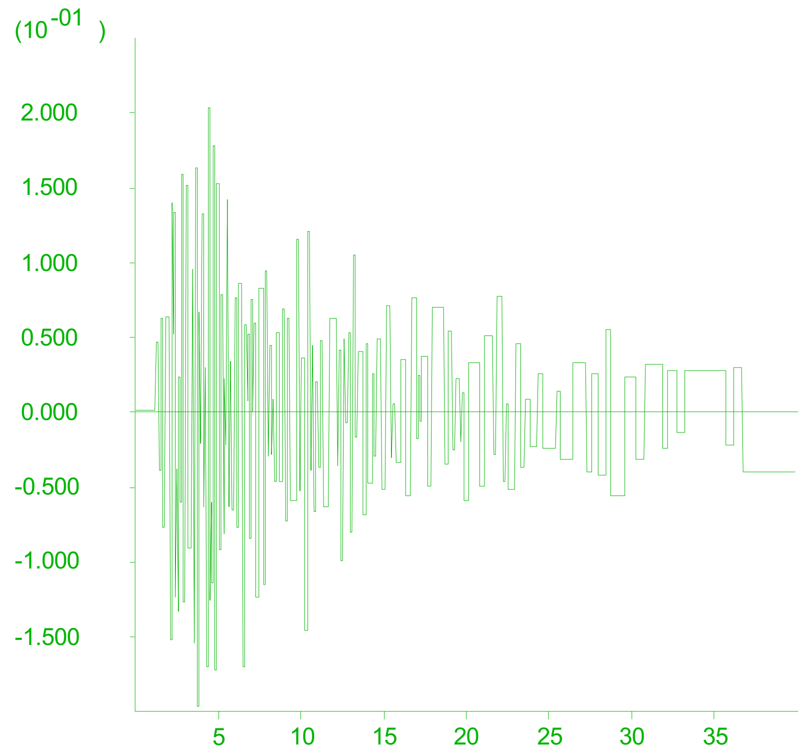
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 15 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-77
URS	Project No. 26815621		

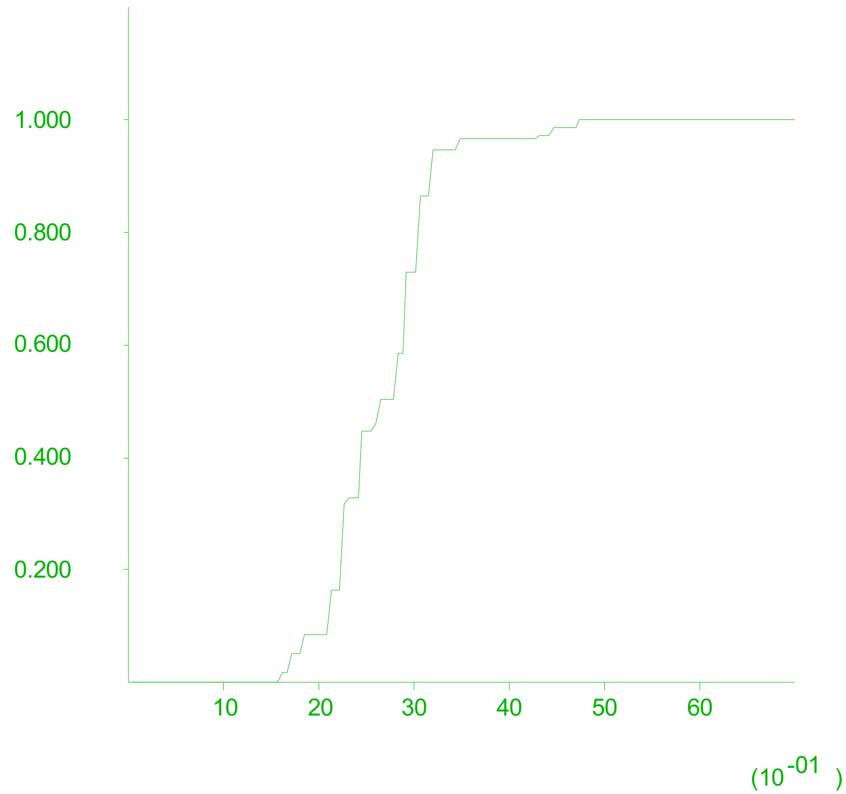
JOB TITLE : Pore Pressure Time History, Input Motion M6.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 21:58
step 95763
Dynamic Time 4.0000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 15) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 15 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-78
URS	Project No. 26815621		

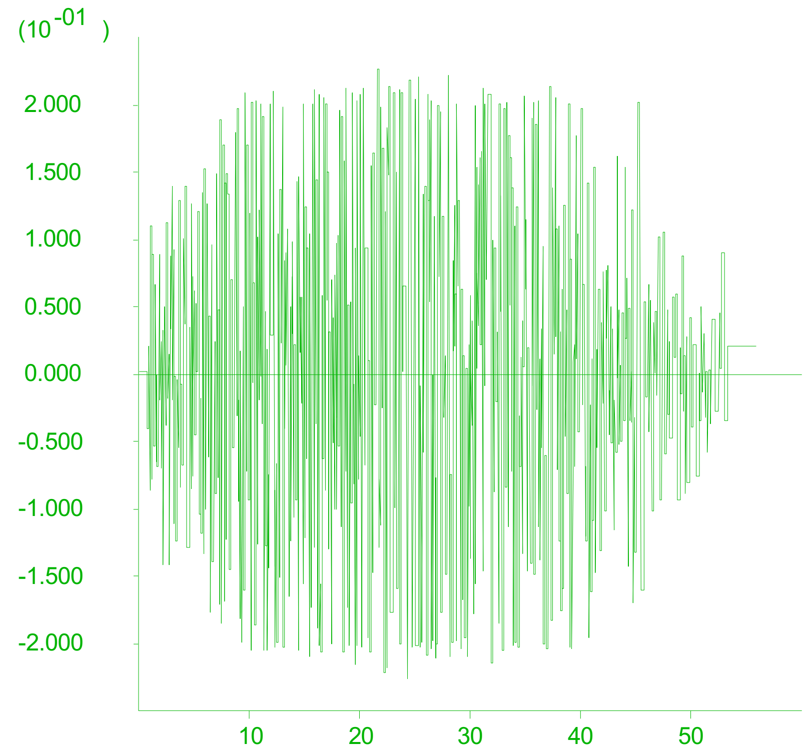
JOB TITLE : CSR Time History, Input Motion M7.5 H1 0.2g

FLAC (Version 5.00)

LEGEND

10-Jan-07 3:37
step 130051
Dynamic Time 5.6000E+01

HISTORY PLOT
Y-axis :
68 sd_csr_zero (141, 15) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 15 ft Peat Input Motion M 7.5 H1, 0.2g	Figure 6-79
URS	Project No. 26815621		

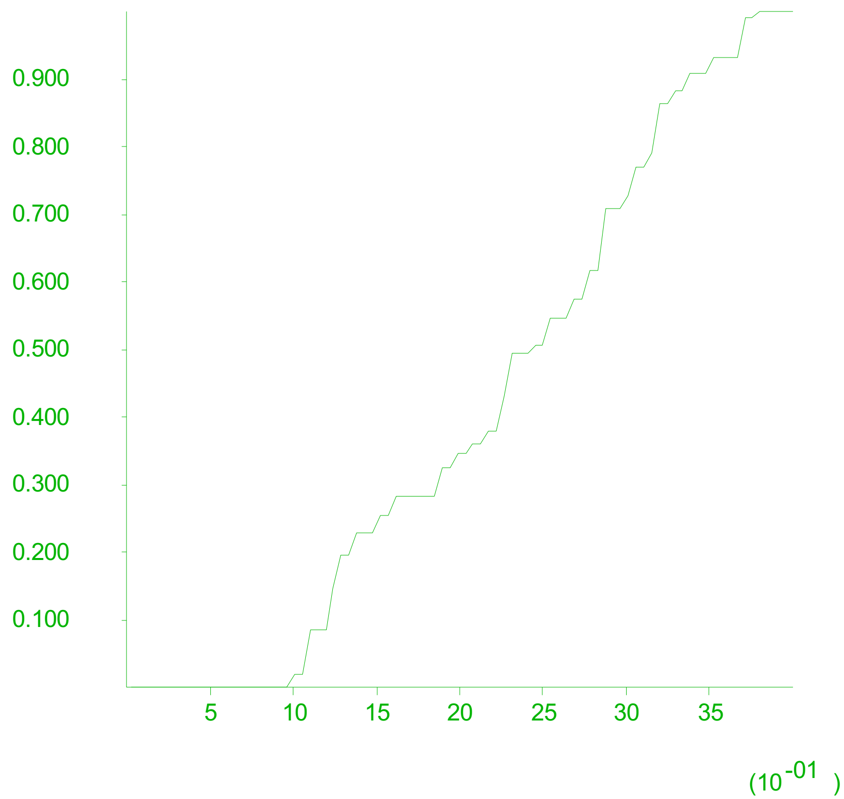
JOB TITLE : Pore Pressure Time History, Input Motion M7.5, H1 0.2g

FLAC (Version 5.00)

LEGEND

10-Jan-07 3:37
step 130051
Dynamic Time 5.6000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 15) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Pore Pressure Time History
at Liquefiable Sand Layer
Idealized Section - 15 ft Peat
Input Motion M 7.5 H1, 0.2g

Figure
6-80

JOB TITLE : CSR Time History, Input Motion M5.5 H1, 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 20:07
step 59058
Dynamic Time 2.3000E+01

HISTORY PLOT
Y-axis :
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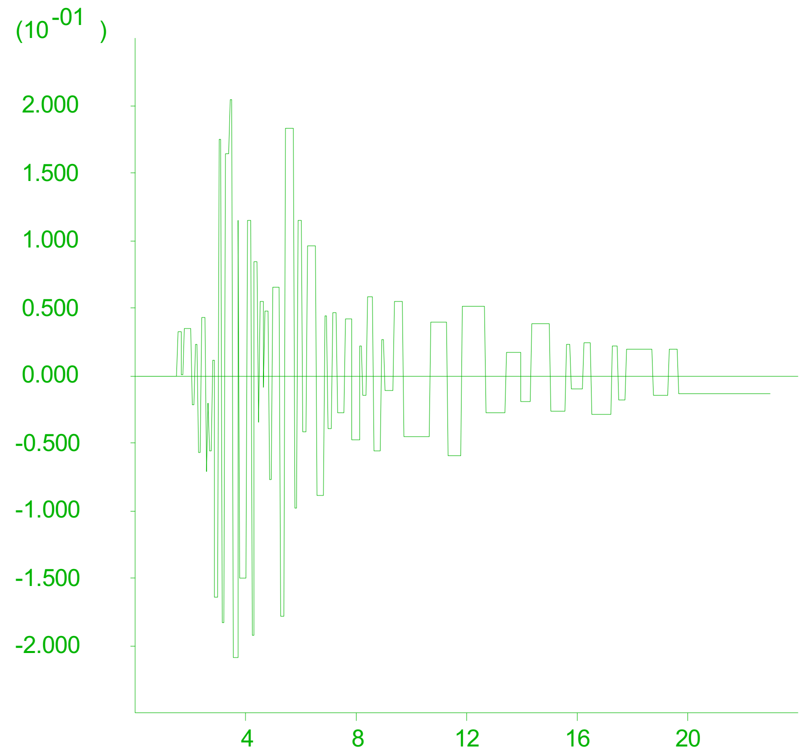
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 25 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-81
URS	Project No. 26815621		

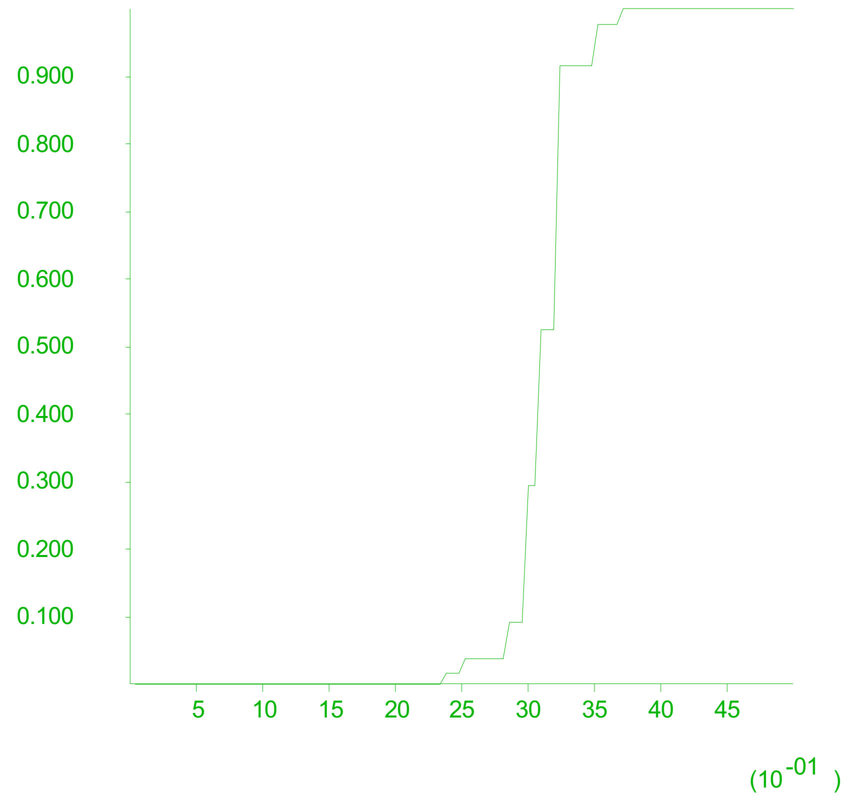
JOB TITLE : Pore Pressure Time History, Input Motion M5.5 H1, 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 20:07
step 59058
Dynamic Time 2.3000E+01

HISTORY PLOT
Y-axis :
67 sd_pore_pres (141, 13) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 25 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-82
URS	Project No. 26815621		

JOB TITLE : CSR Time History, Input Motion M6.5 H1, 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 23:49
step 94557
Dynamic Time 4.0000E+01

HISTORY PLOT
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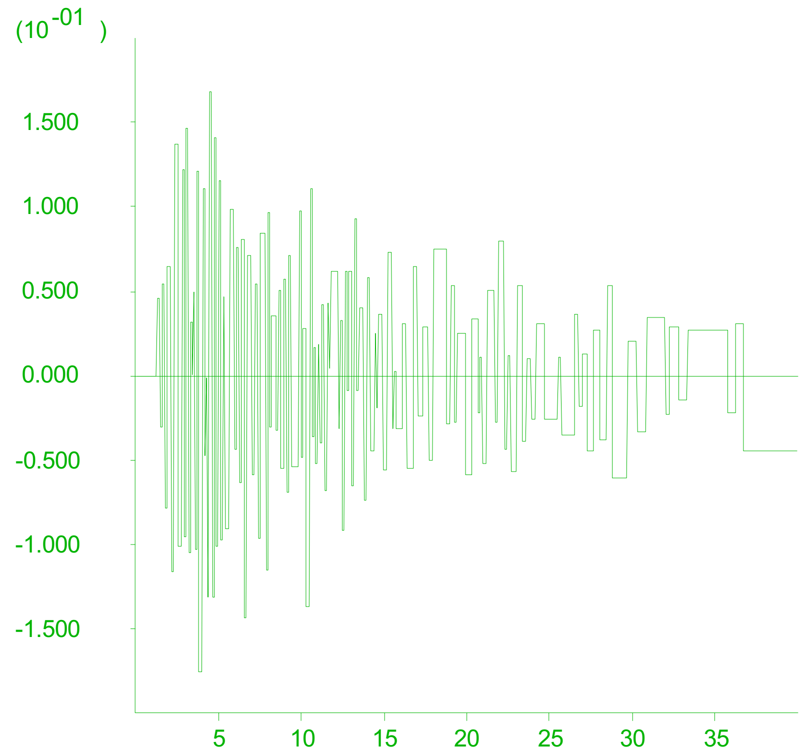
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		CSR Time History at Liquefiable Sand Layer Idealized Section - 25 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-83
URS	Project No. 26815621		

JOB TITLE : Pore Pressure Time History, Input Motion M6.5 H1, 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 23:49
step 94557
Dynamic Time 4.0000E+01

HISTORY PLOT
Y-axis :
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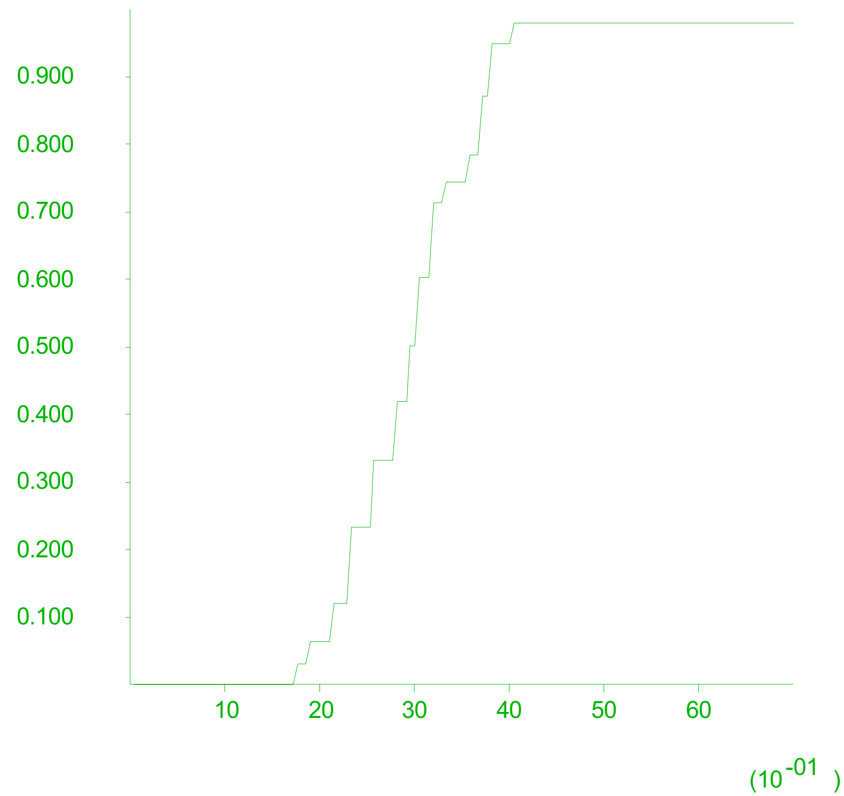
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS) Levee Fragility		Pore Pressure Time History at Liquefiable Sand Layer Idealized Section - 25 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-84
URS	Project No. 26815621		

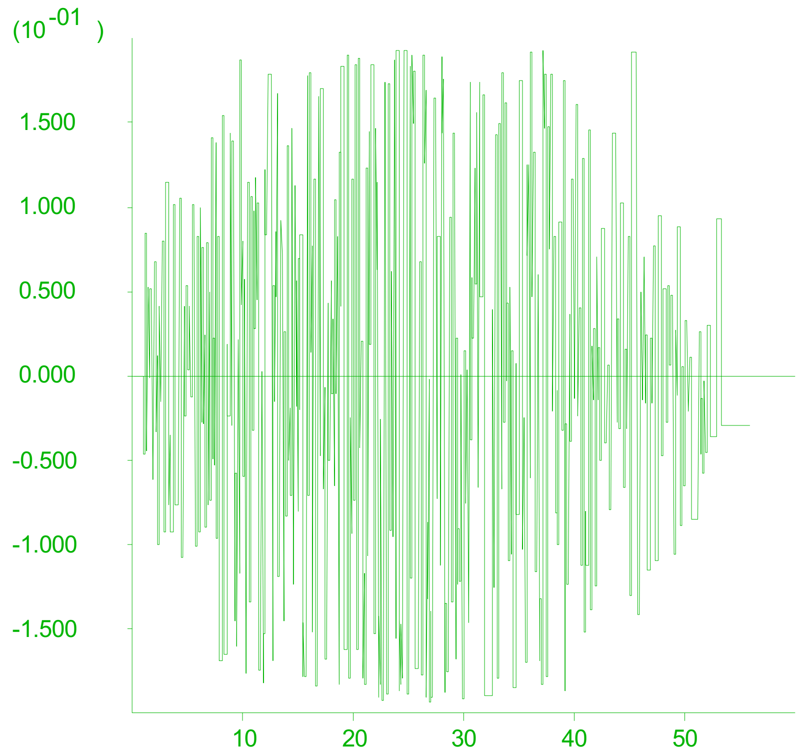
JOB TITLE : CSR Time History, Input Motion M7.5 H1, 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 5:27
step 127967
Dynamic Time 5.6000E+01

HISTORY PLOT
Y-axis :
68 sd_csr_zero (141, 13) PRP
X-axis :
1 Dynamic time



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Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

CSR Time History
at Liquefiable Sand Layer
Idealized Section - 25 ft Peat
Input Motion M 7.5 H1, 0.2g

Figure
6-85

JOB TITLE : Pore Pressure Time History, Input Motion M67; H1, 0.2g

FLAC (Version 5.00)

LEGEND

9-Jan-07 5:27
step 127967
Dynamic Time 5.6000E+01

HISTORY PLOT
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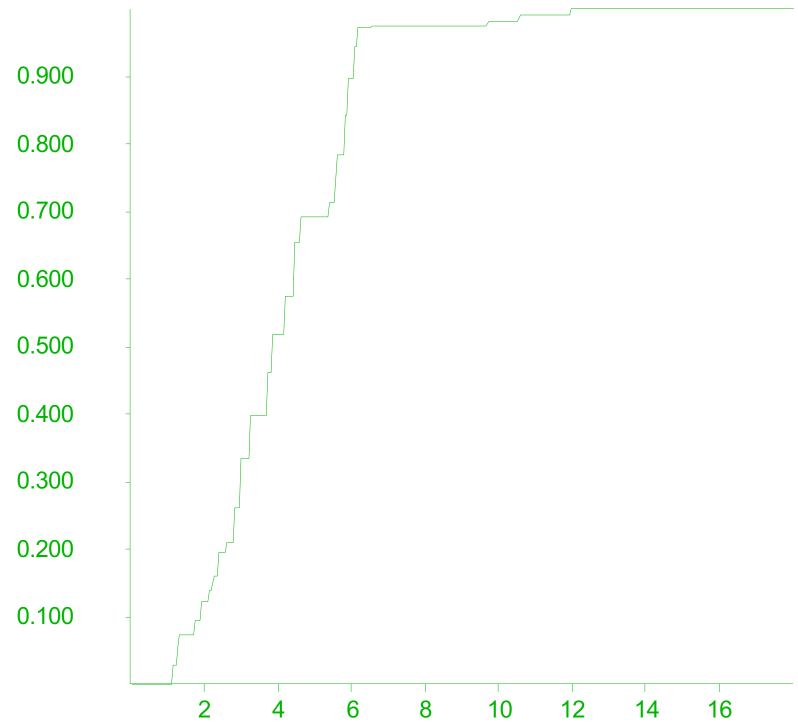
X-axis :
1 Dynamic time



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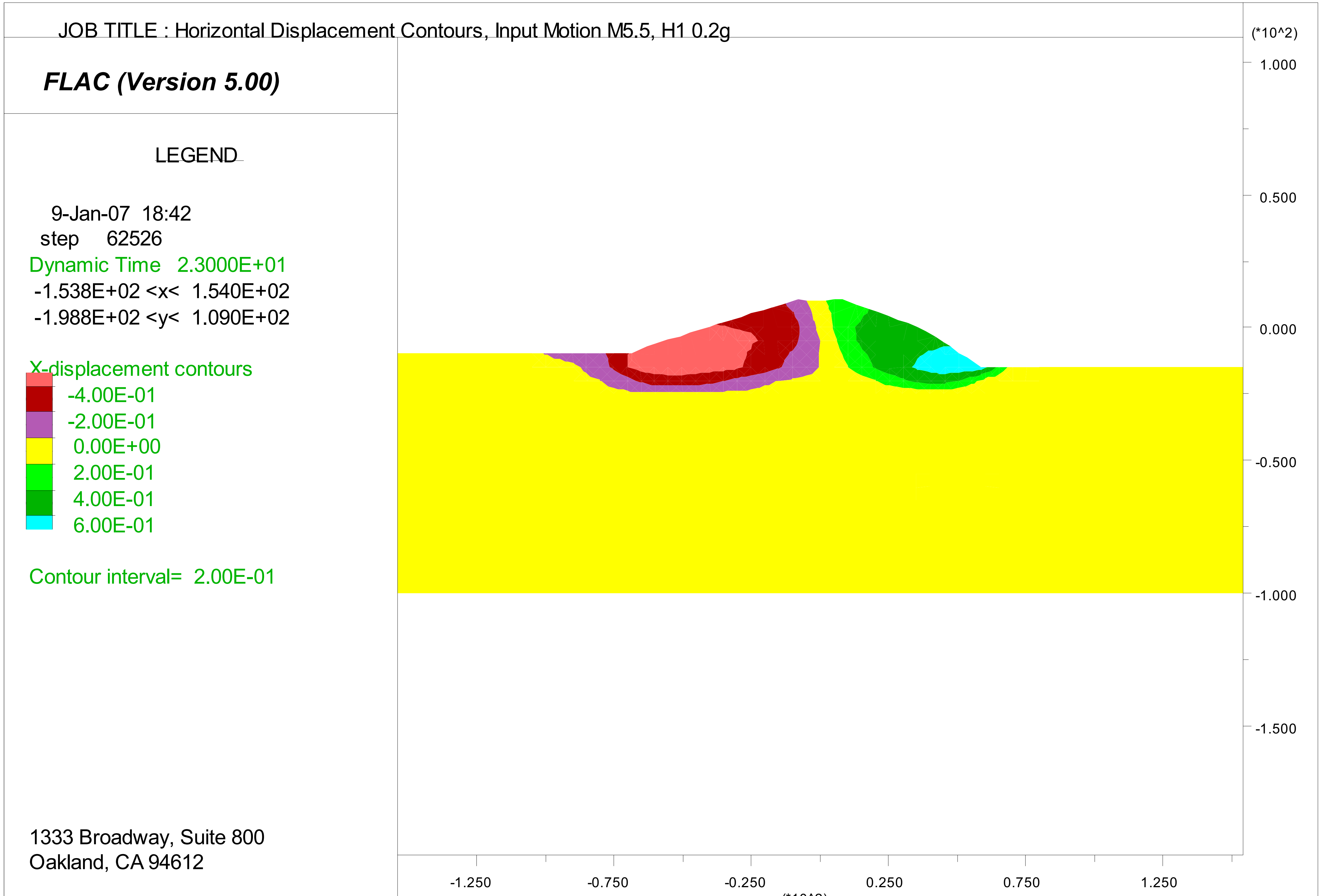
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

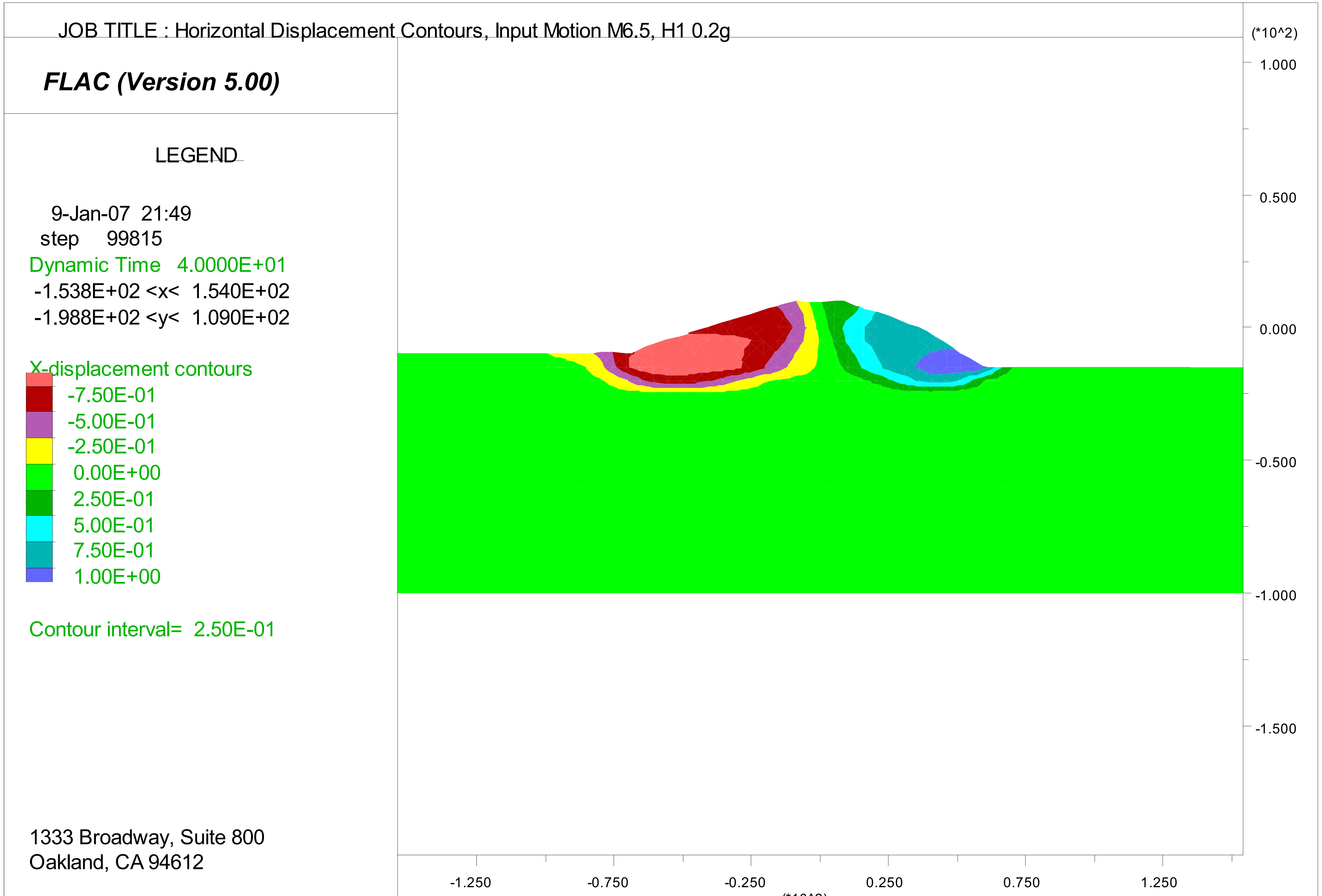
Project No. 26815621

Pore Pressure Time History
at Liquefiable Sand Layer
Idealized Section - 25 ft Peat
Input Motion M 7.5 H1, 0.2g

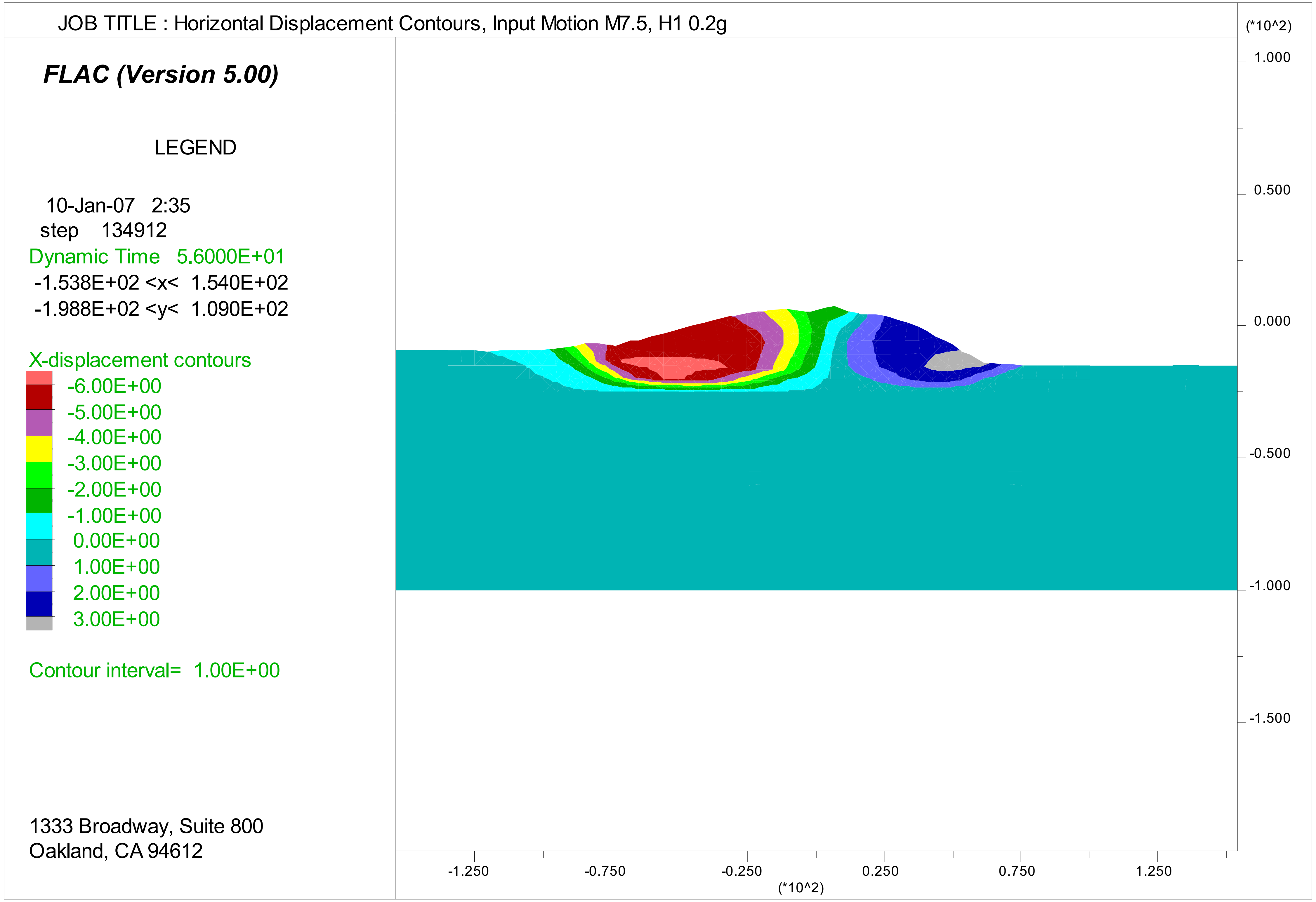
Figure
6-86



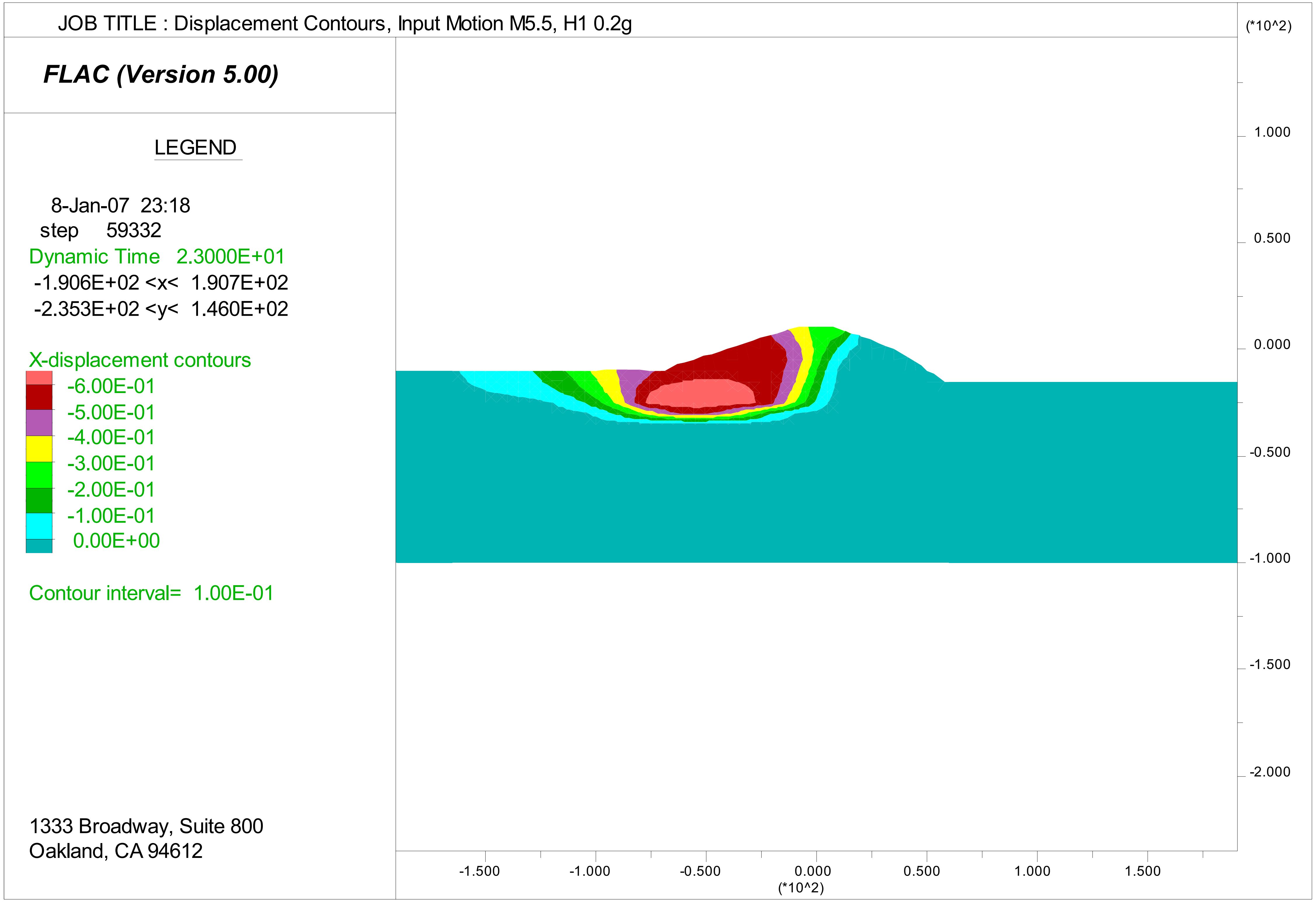
Delta Risk Management Strategy (DRMS) Levee Fragility		Displacement Contours Idealized Section - 5 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-87
URS	Project No. 26815621		



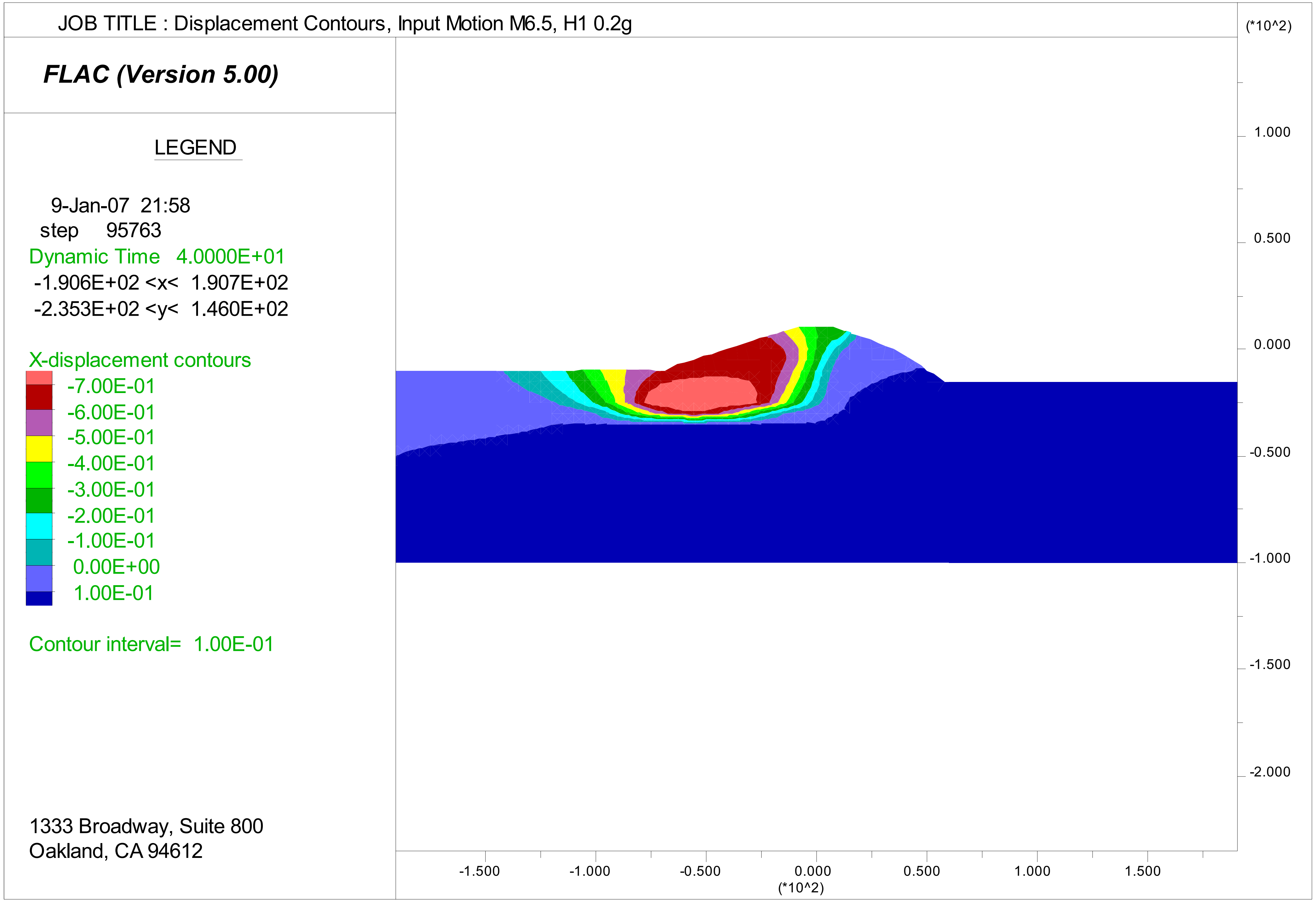
Delta Risk Management Strategy (DRMS) Levee Fragility		Displacement Contours Idealized Section - 5 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-88
URS	Project No. 26815621		



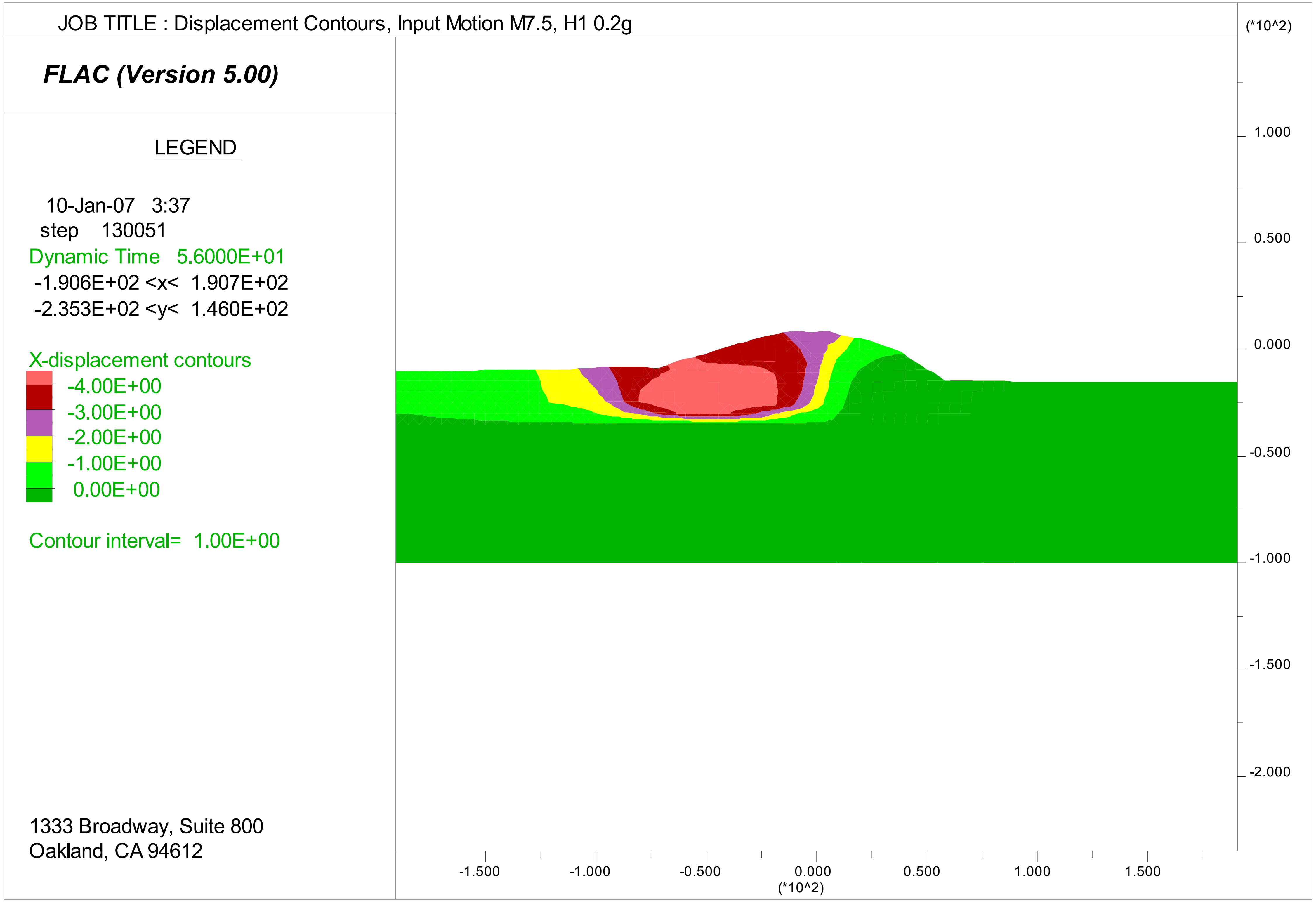
Delta Risk Management Strategy (DRMS) Levee Fragility	Displacement Contours Idealized Section - 5 ft Peat Input Motion M 7.5 H1, 0.2g	Figure 6-89
URS — Project No. 26815621		



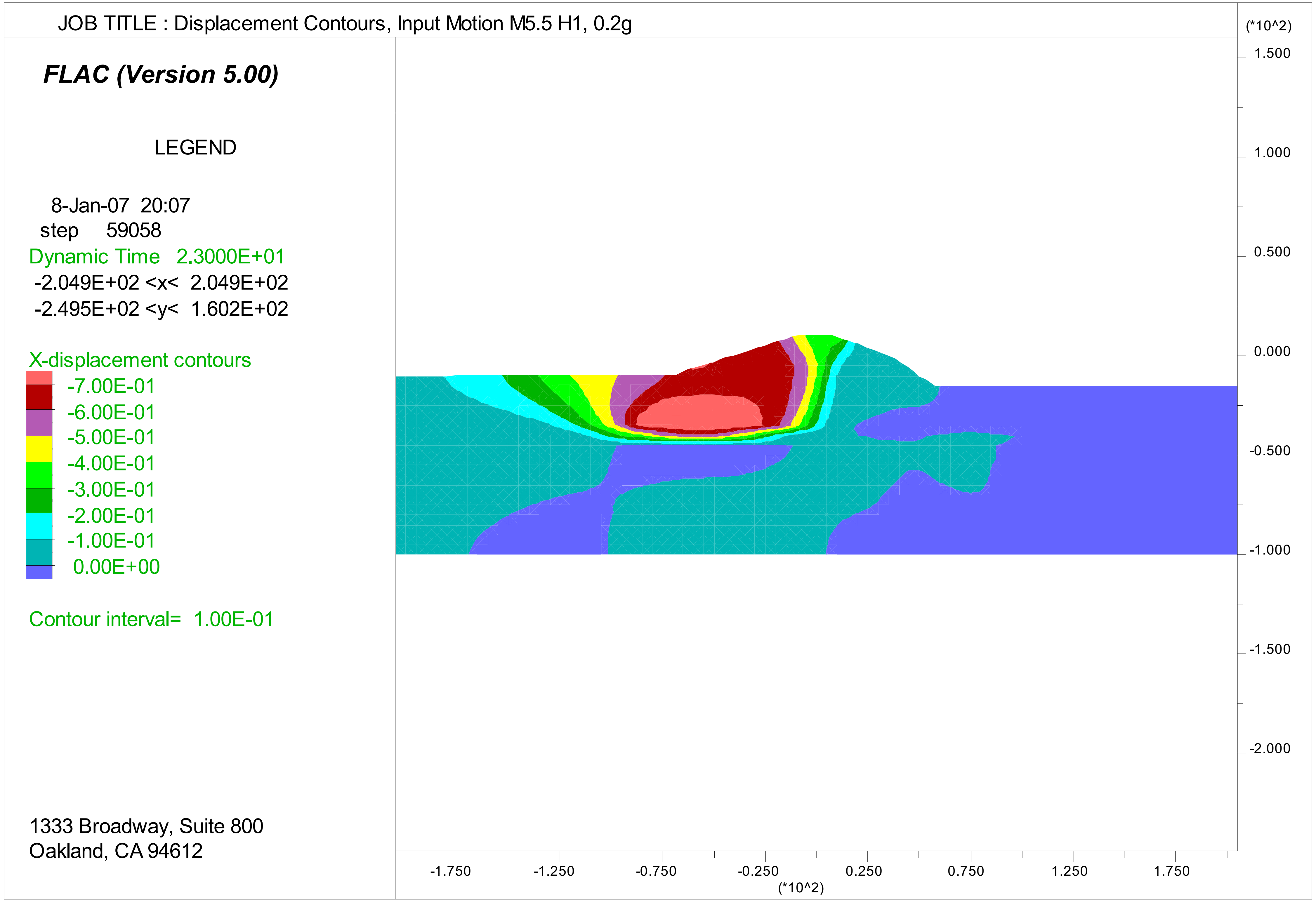
Delta Risk Management Strategy (DRMS) Levee Fragility		Displacement Contours Idealized Section - 15 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-90
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Displacement Contours Idealized Section - 15 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-91
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Displacement Contours Idealized Section - 15 ft Peat Input Motion M 7.5 H1, 0.2g	Figure 6-92
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility	Displacement Contours Idealized Section - 25 ft Peat Input Motion M 5.5 H1, 0.2g	Figure 6-93
URS — Project No. 26815621		

JOB TITLE : Displacement Contours, Input Motion M6.5 H1, 0.2g

FLAC (Version 5.00)

LEGEND

8-Jan-07 23:49
step 94557
Dynamic Time 4.0000E+01
-2.049E+02 <x< 2.049E+02
-2.495E+02 <y< 1.602E+02

X-displacement contours
- -8.00E-01
- -7.00E-01
- -6.00E-01
- -5.00E-01
- -4.00E-01
- -3.00E-01
- -2.00E-01
- -1.00E-01
- 0.00E+00

Contour interval= 1.00E-01

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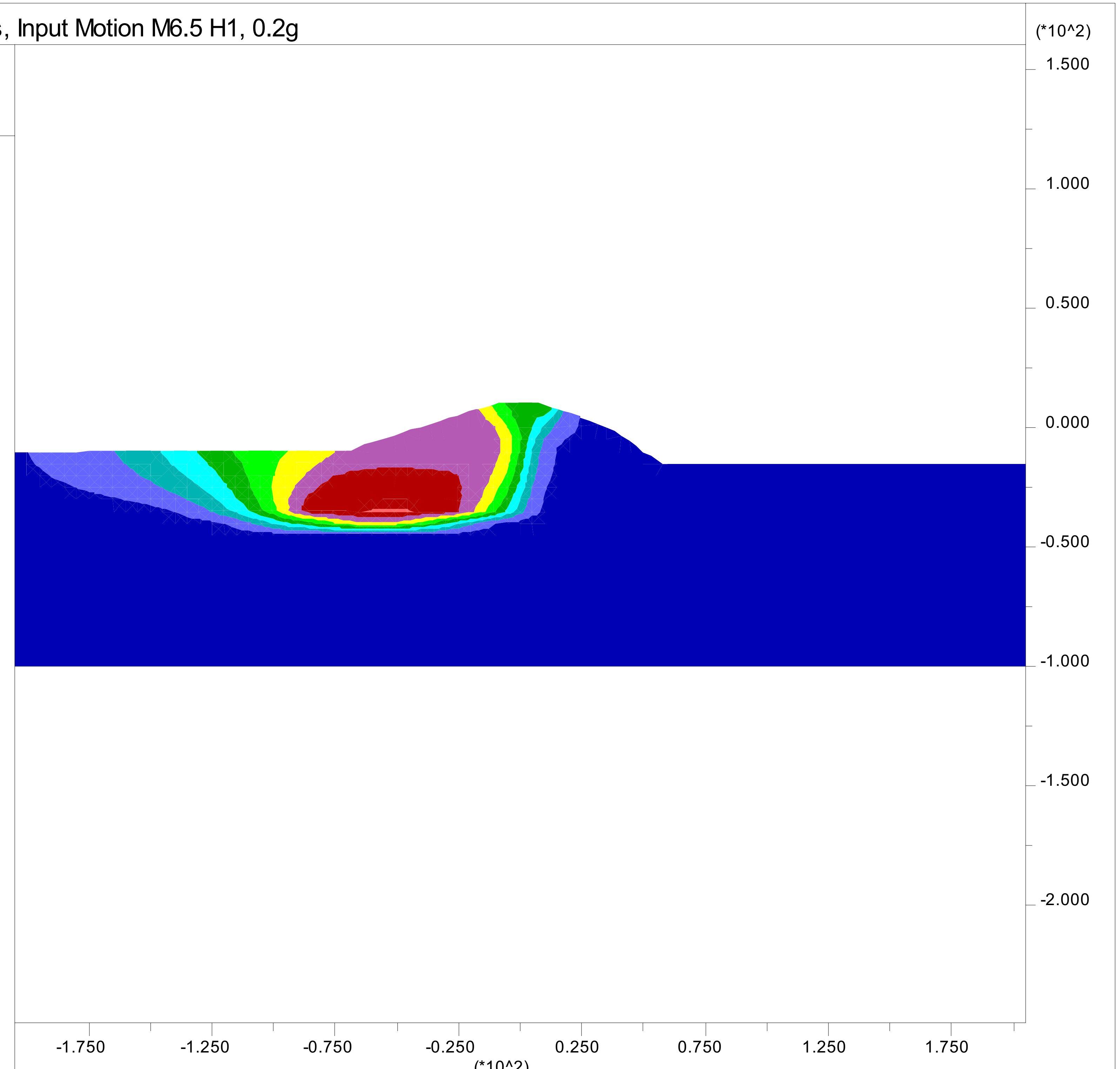
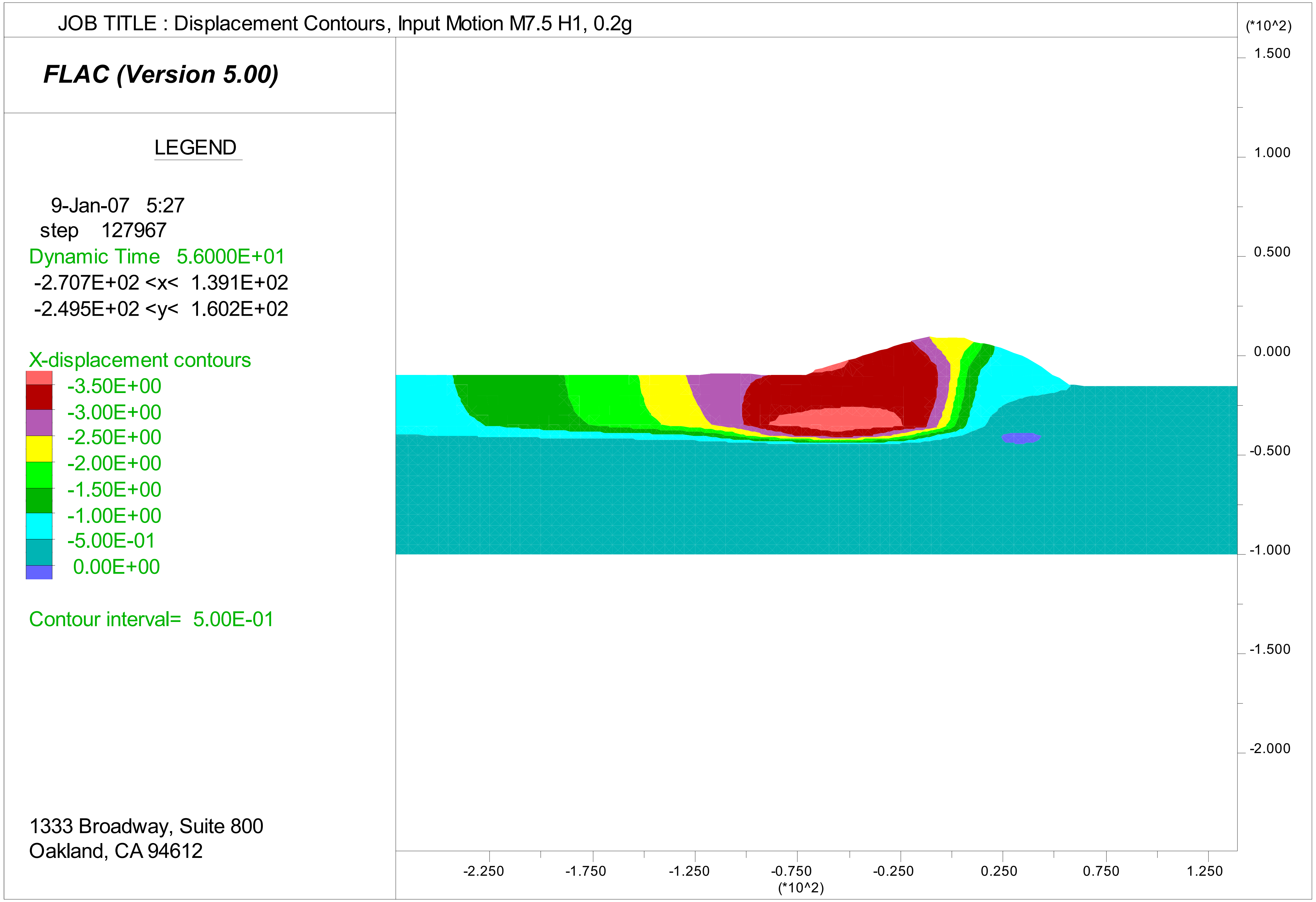
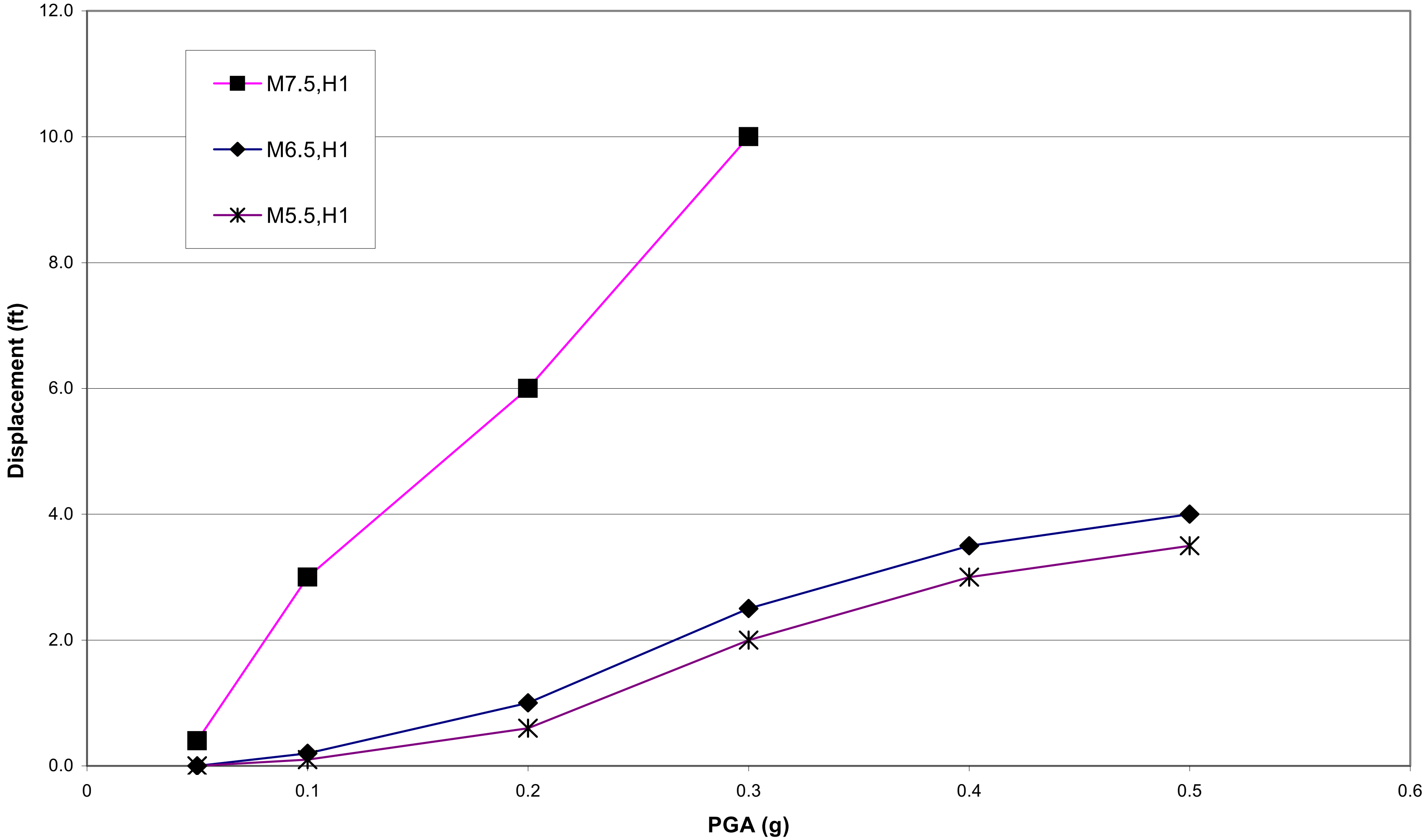


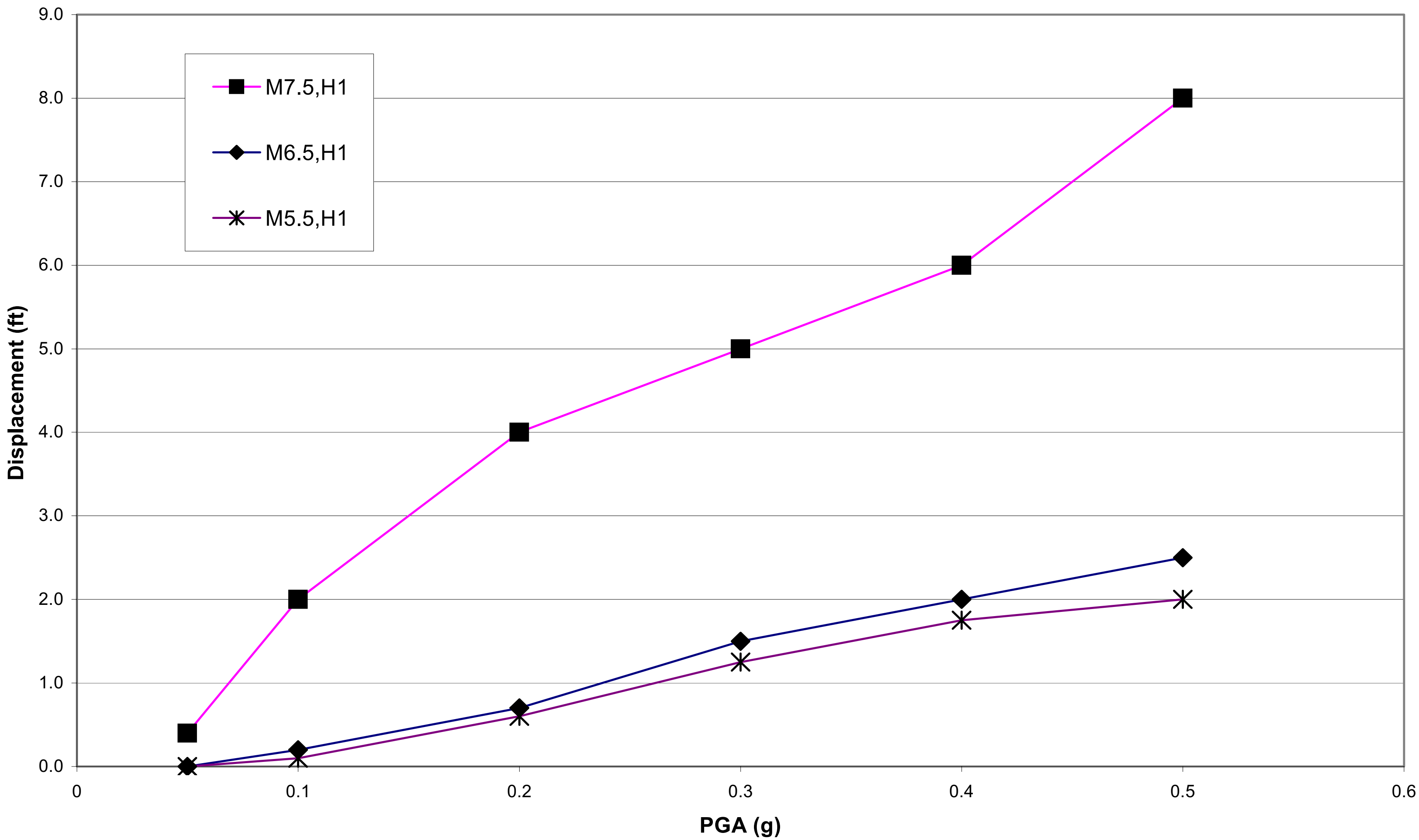
Delta Risk Management Strategy (DRMS) Levee Fragility		Displacement Contours Idealized Section - 25 ft Peat Input Motion M 6.5 H1, 0.2g	Figure 6-94
URS	Project No. 26815621		



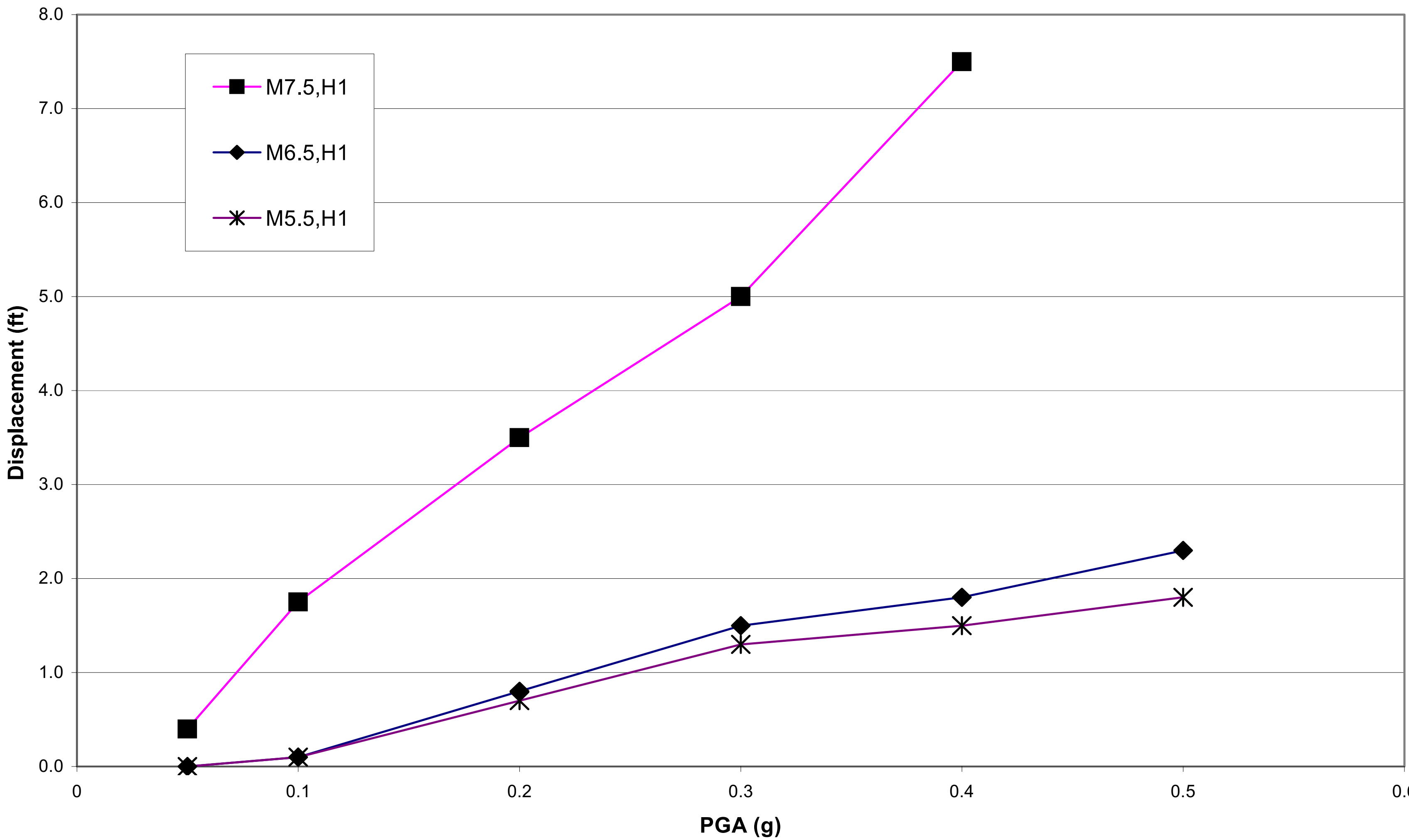
Delta Risk Management Strategy (DRMS) Levee Fragility	Displacement Contours Idealized Section - 25 ft Peat Input Motion M 7.5 H1, 0.2g	Figure 6-95
URS — Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated FLAC Displacements Idealized Section with Liquefiable Foundation Sand Layer 5 Feet of Peat	Figure 6-96
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated FLAC Displacements Idealized Section with Liquefiable Foundation Sand Layer 15 Feet of Peat	Figure 6-97
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated FLAC Displacements Idealized Section with Liquefiable Foundation Sand Layer 25 Feet of Peat	Figure 6-98
URS	Project No. 26815621		

JOB TITLE : Deformed Mesh, Liquefied Fill, Su = 230 psf

FLAC (Version 5.00)

LEGEND

27-Nov-06 18:59
step 10365
-9.464E+01 <x< 9.464E+01
-1.391E+02 <y< 5.014E+01

Grid plot

0 5E 1

Exaggerated Grid Distortion

Magnification = 1.000E+00
Max Disp = 1.001E+01

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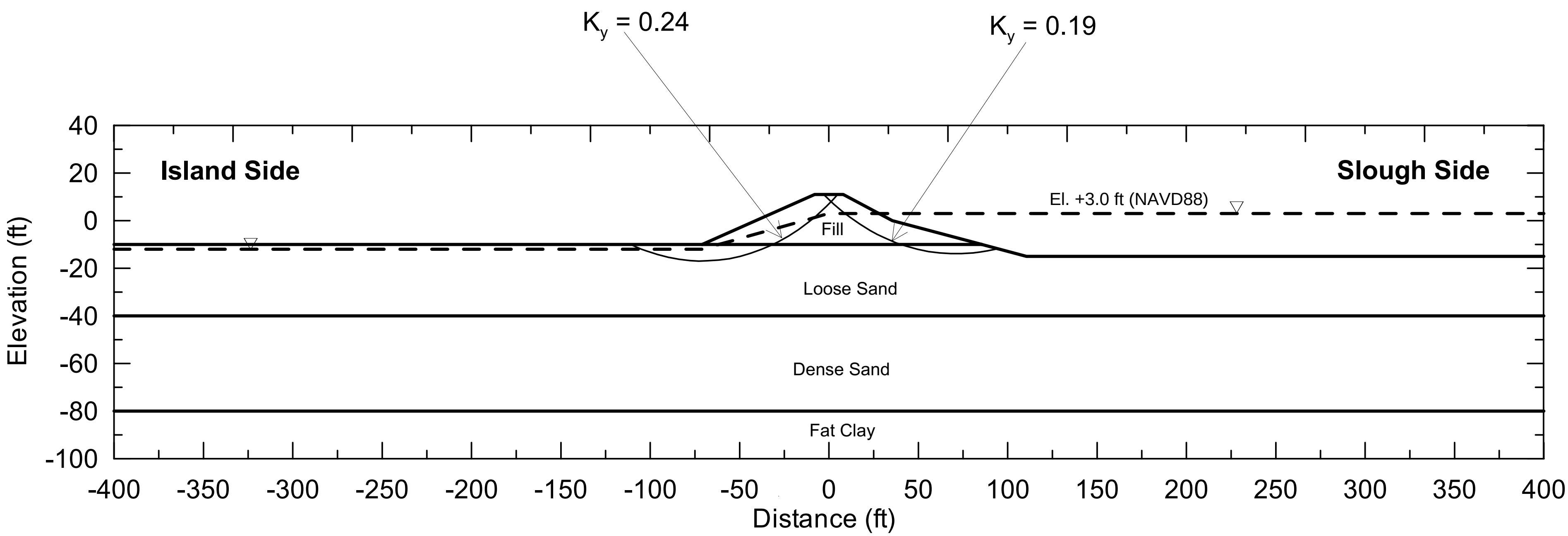
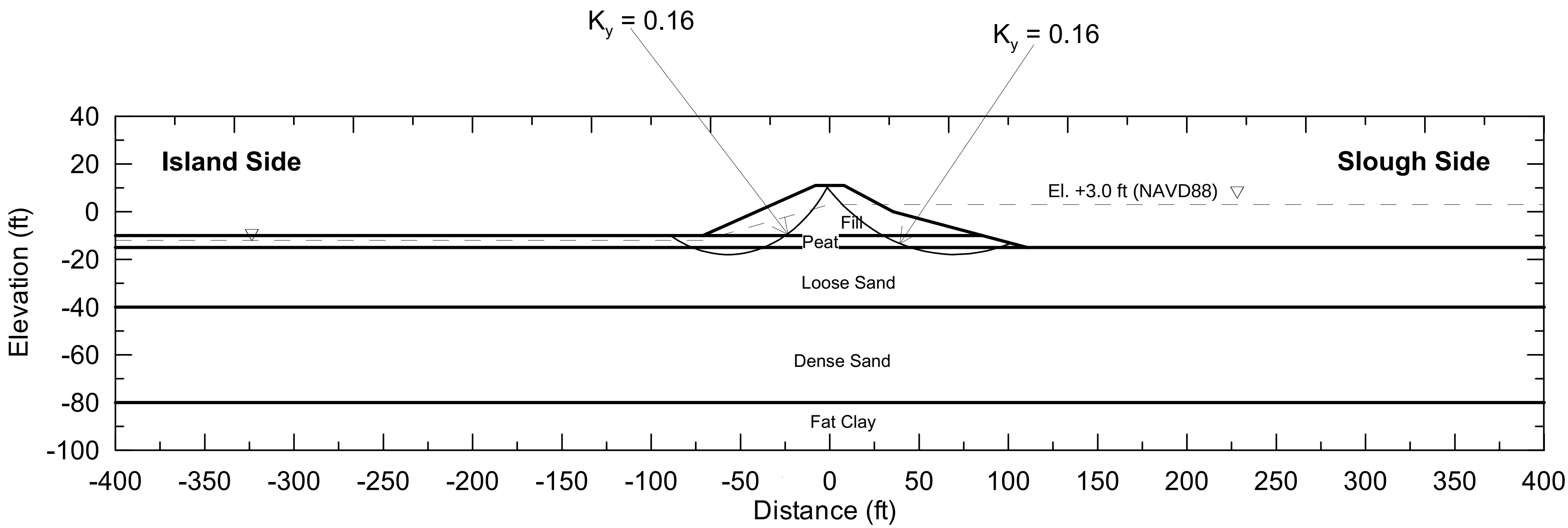
Delta Risk Management Strategy (DRMS) Levee Fragility		FLAC Deformed Mesh for Post Seismic Static Slumping Analysis Residual Strength of Embankment 230 psf	Figure 6-99
URS	Project No. 26815621		



Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Fill	115	30	50	-	-
Loose Sand	125	32	0	-	-
Dense Sand	125	38	0	-	-

Delta Risk Management Strategy (DRMS) Levee Fragility		Idealized Section Stability Analysis - Seismic No Peat	Figure 6-100
URS	Project No. 26815621		



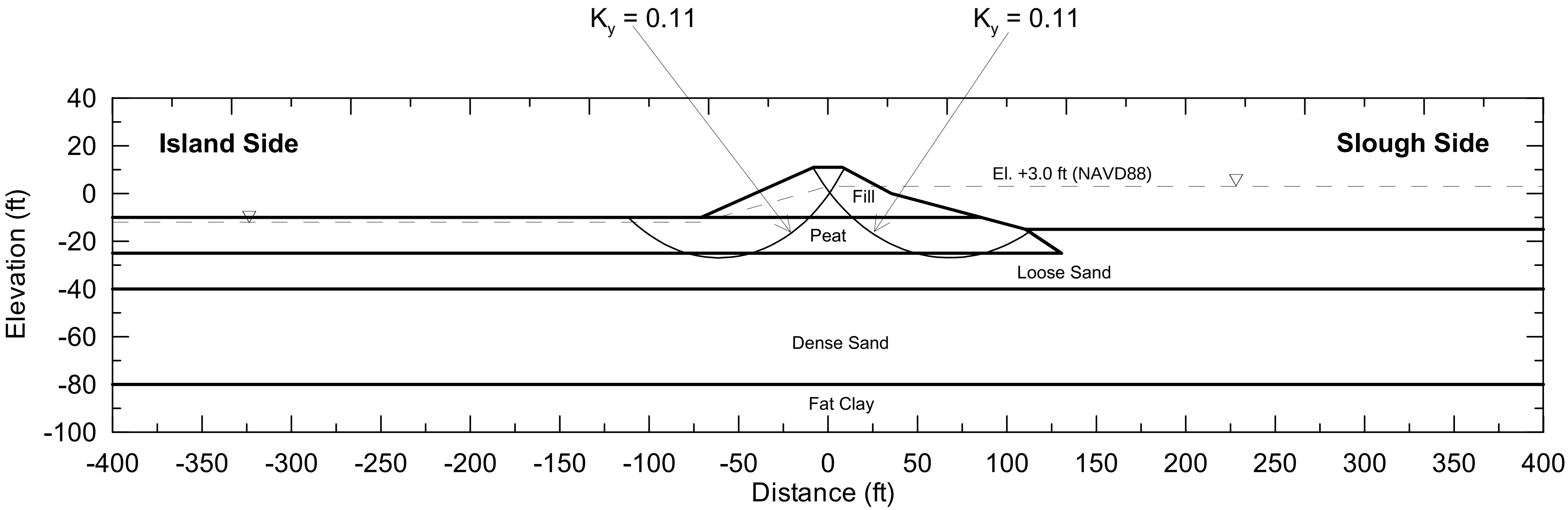
Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Fill	115	30	50	-	-
Peat	70	28	120	18	140
Loose Sand	125	32	0	-	-
Dense Sand	125	38	0	-	-

Delta Risk Management Strategy (DRMS)
Levee Fragility

URS | Project No. 26815621

Idealized Section
Stability Analysis - Seismic
5 Feet of Peat

Figure 6-101



Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Fill	115	30	50	-	-
Peat	70	28	120	18	140
Loose Sand	125	32	0	-	-
Dense Sand	125	38	0	-	-

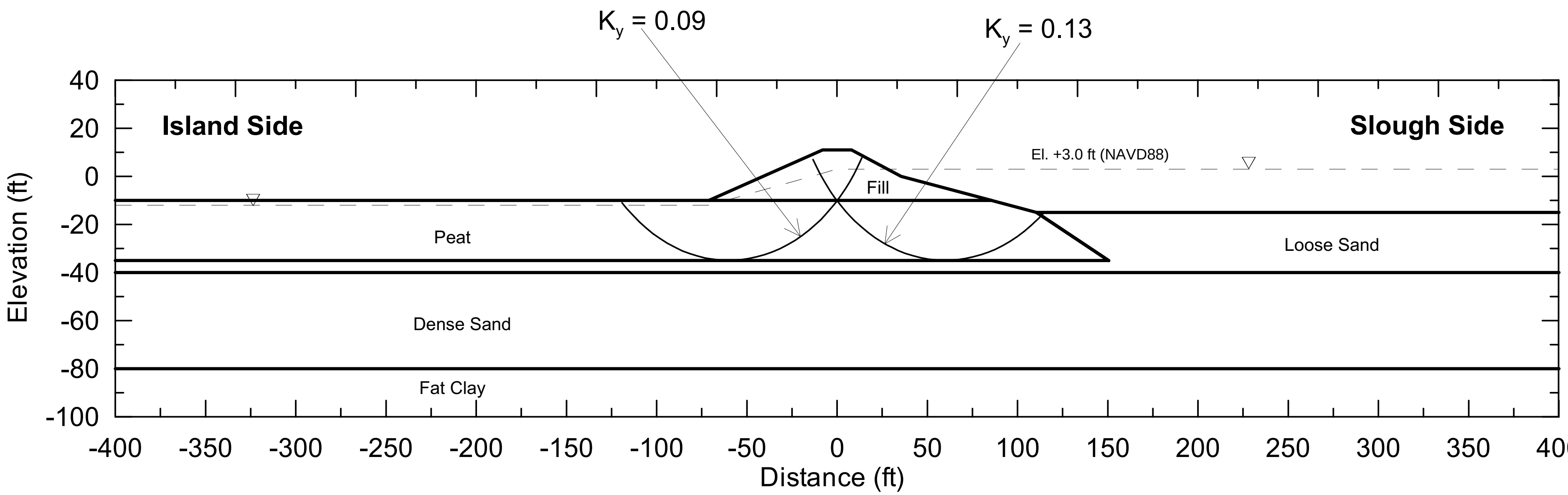
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

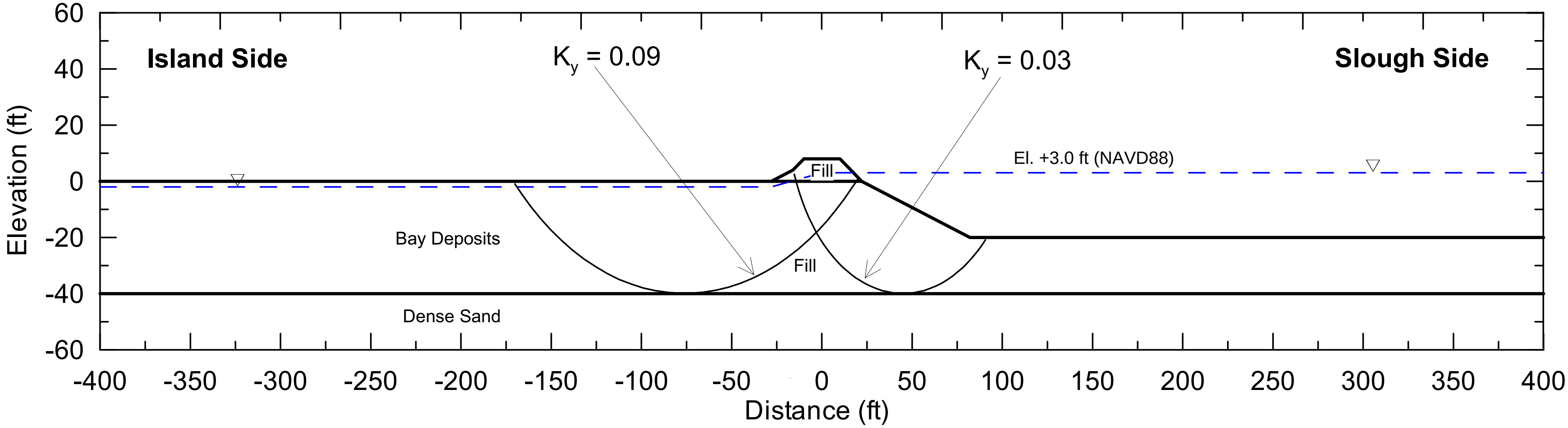
Idealized Section
Stability Analysis - Seismic
15 Feet of Peat

Figure
6-102



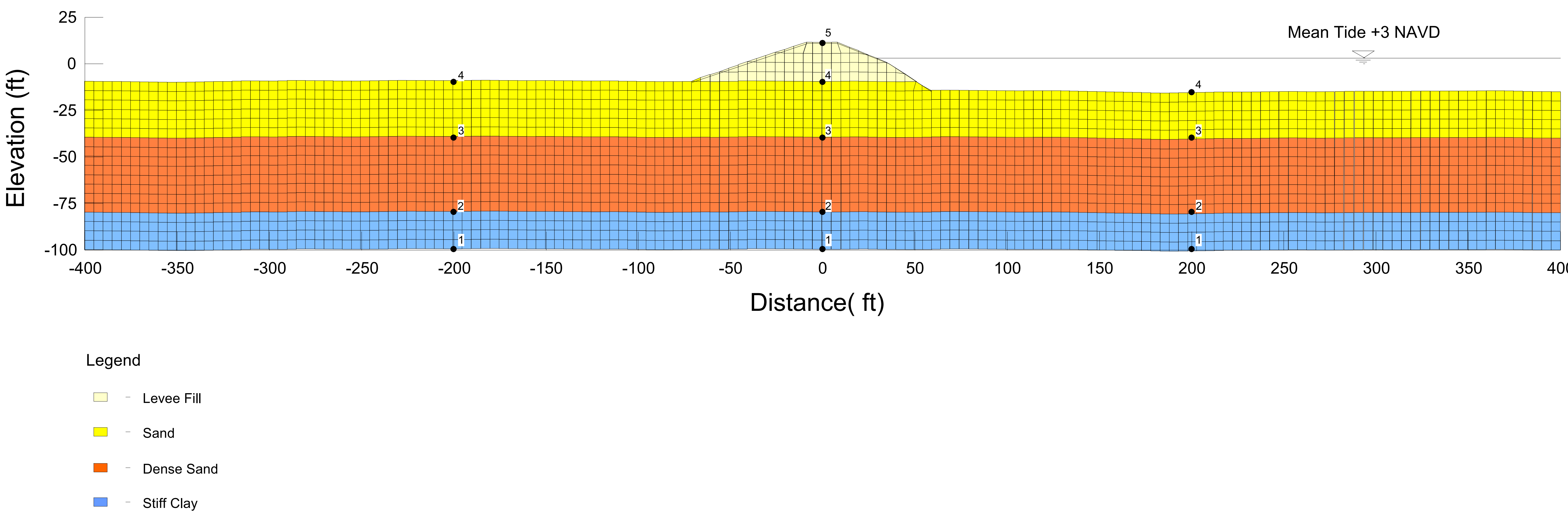
Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Fill	115	30	50	-	-
Peat	70	28	120	18	140
Loose Sand	125	32	0	-	-
Dense Sand	125	38	0	-	-

Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Idealized Section Stability Analysis - Seismic 25 Feet of Peat	Figure 6-103

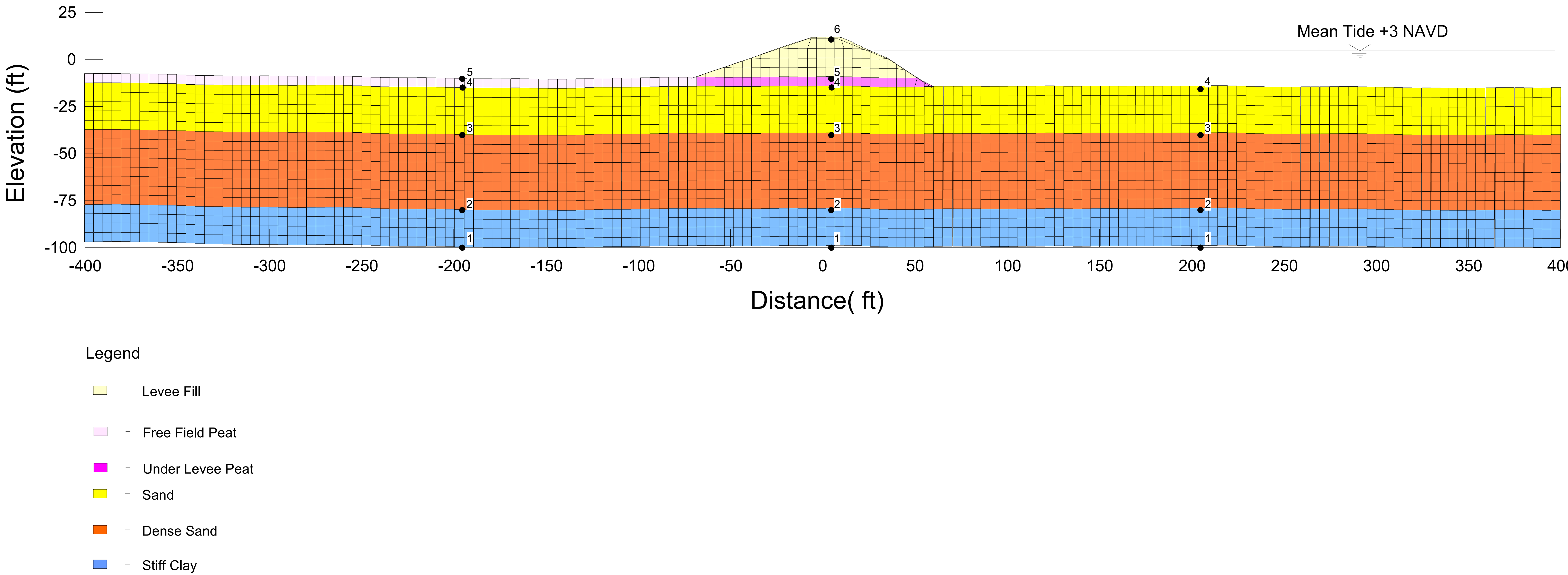


Type	Unit Weight (pcf)	ϕ'	c' (psf)	ϕ	c (psf)
Sandy Fill	115	30	50	-	-
Bay Deposit	110	0	300	0	300
Sand	125	38	0	-	-

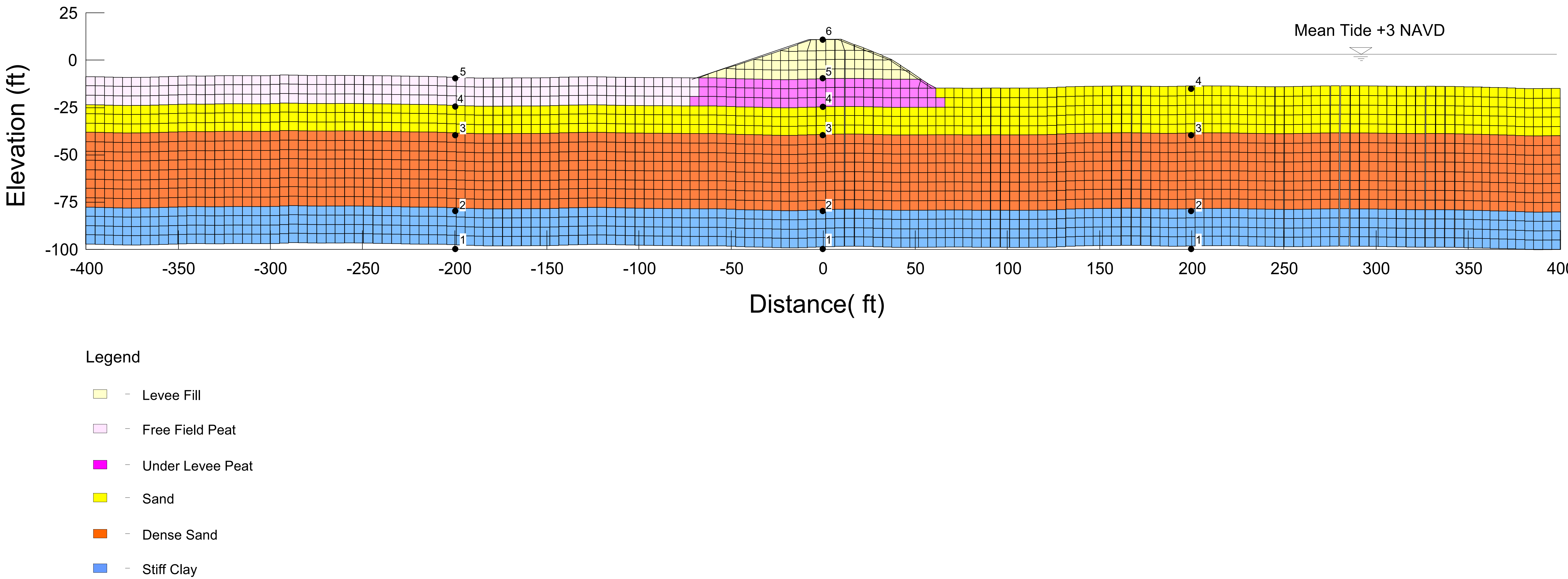
Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Idealized Section Stability Analysis - Seismic Suisun Marsh	Figure 6-104



Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Model for Seismic Analysis Idealized Section - No Peat	Figure 6-105
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Model for Seismic Analysis Idealized Section - 5 ft Peat	Figure 6-106
URS	Project No. 26815621		



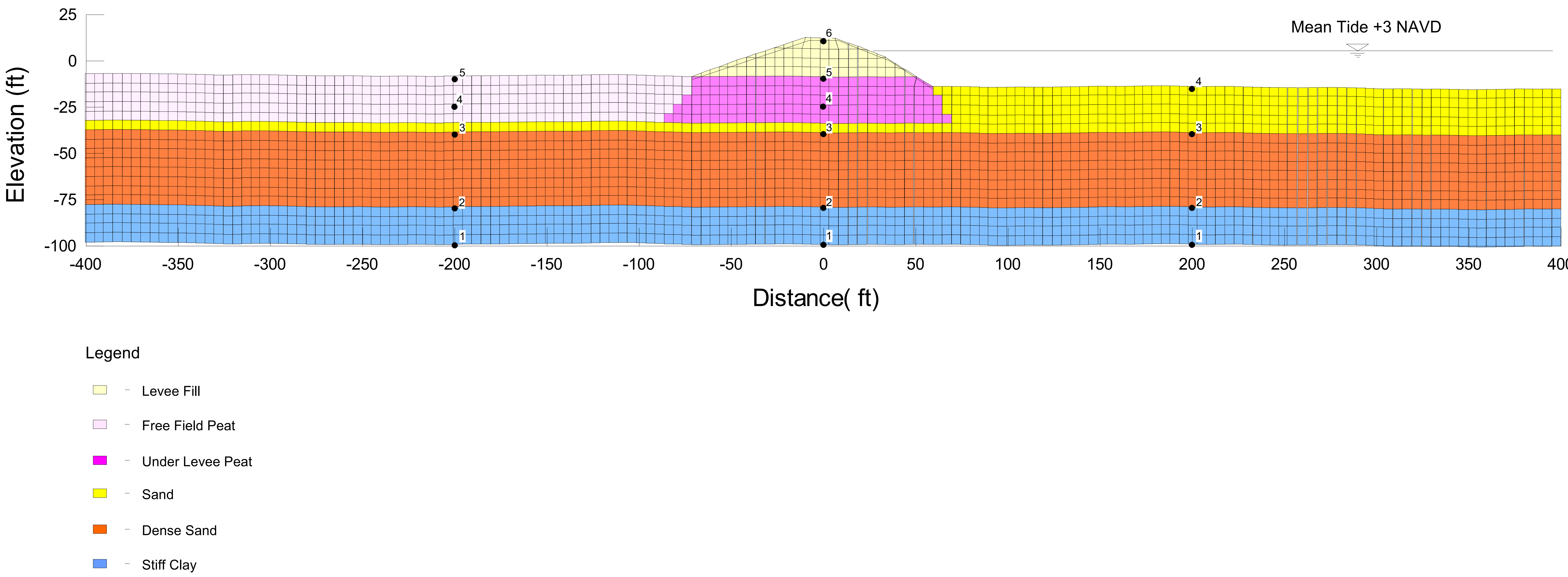
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Finite Element Model for Seismic Analysis
Idealized Section - 15 ft Peat

Figure 6-107



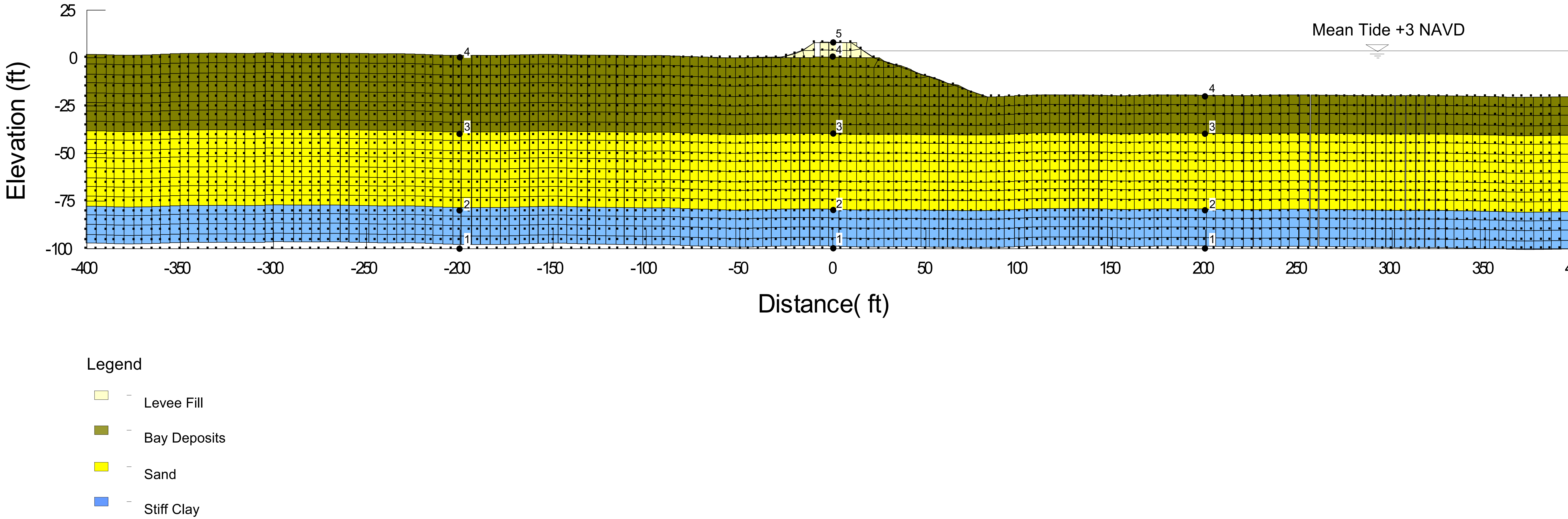
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Finite Element Model for Seismic Analysis
Idealized Section - 25 ft Peat

Figure
6-108



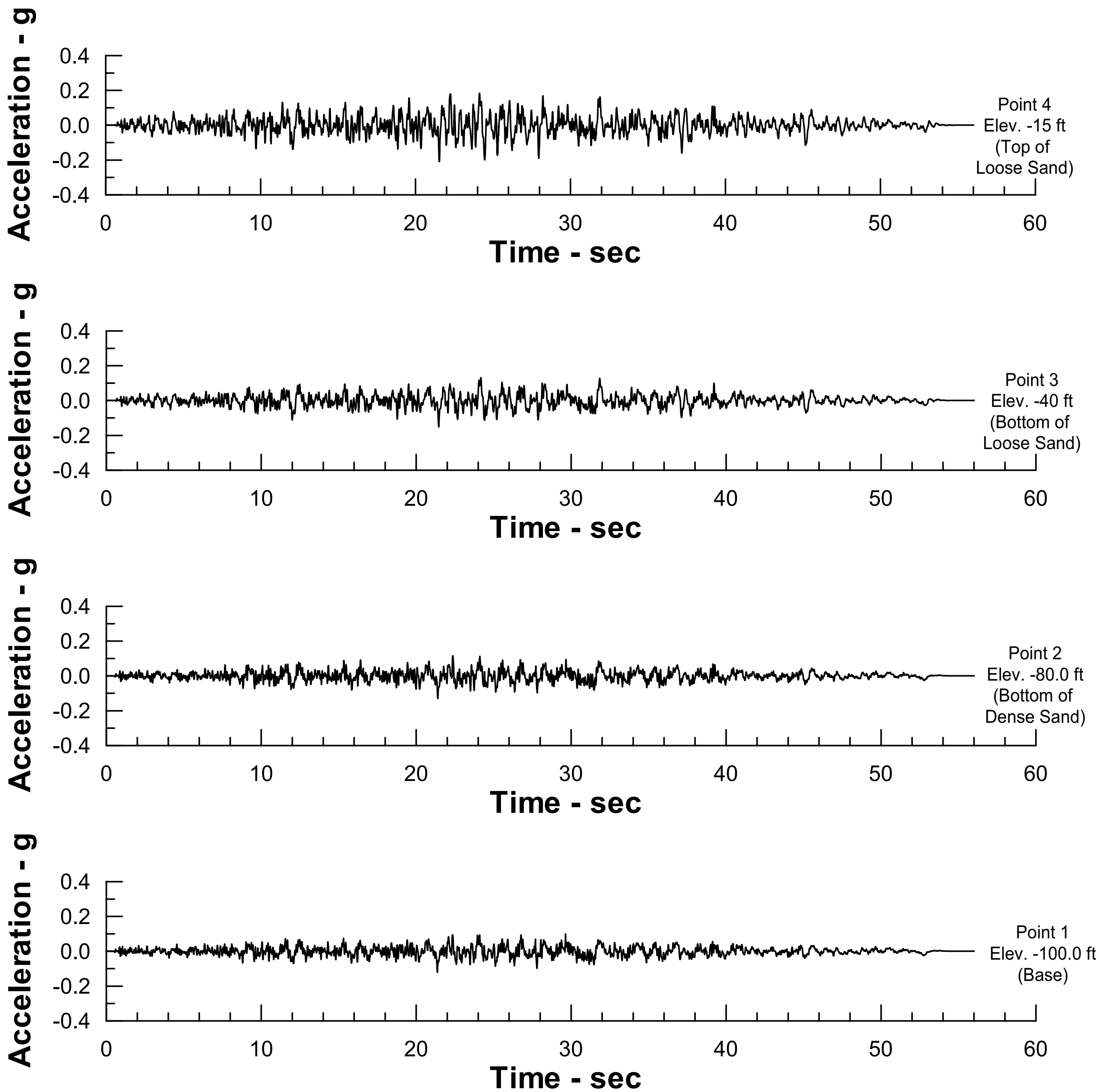
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

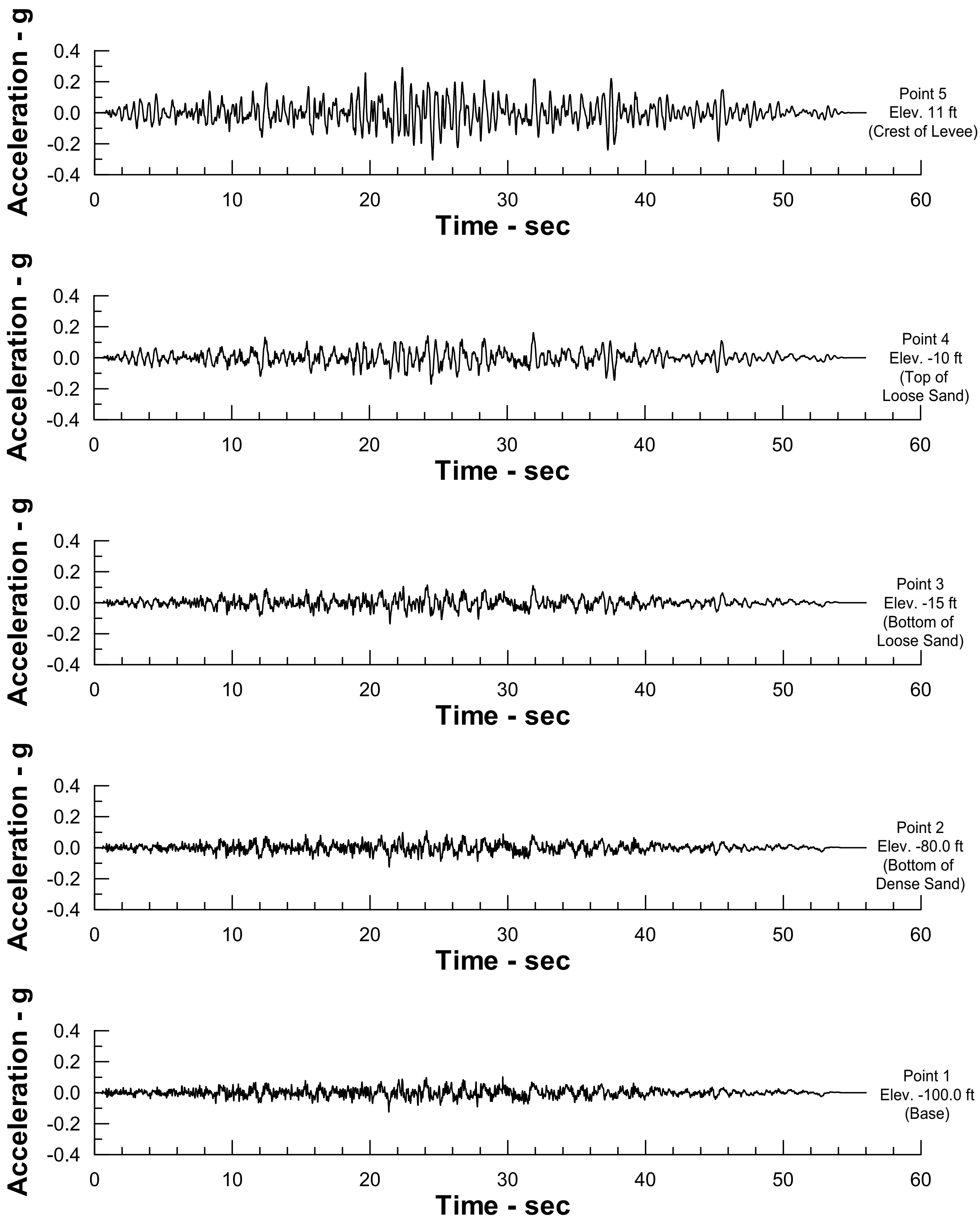
Project No. 26815621

Finite Element Model for Seismic Analysis
Suisun Marsh Section

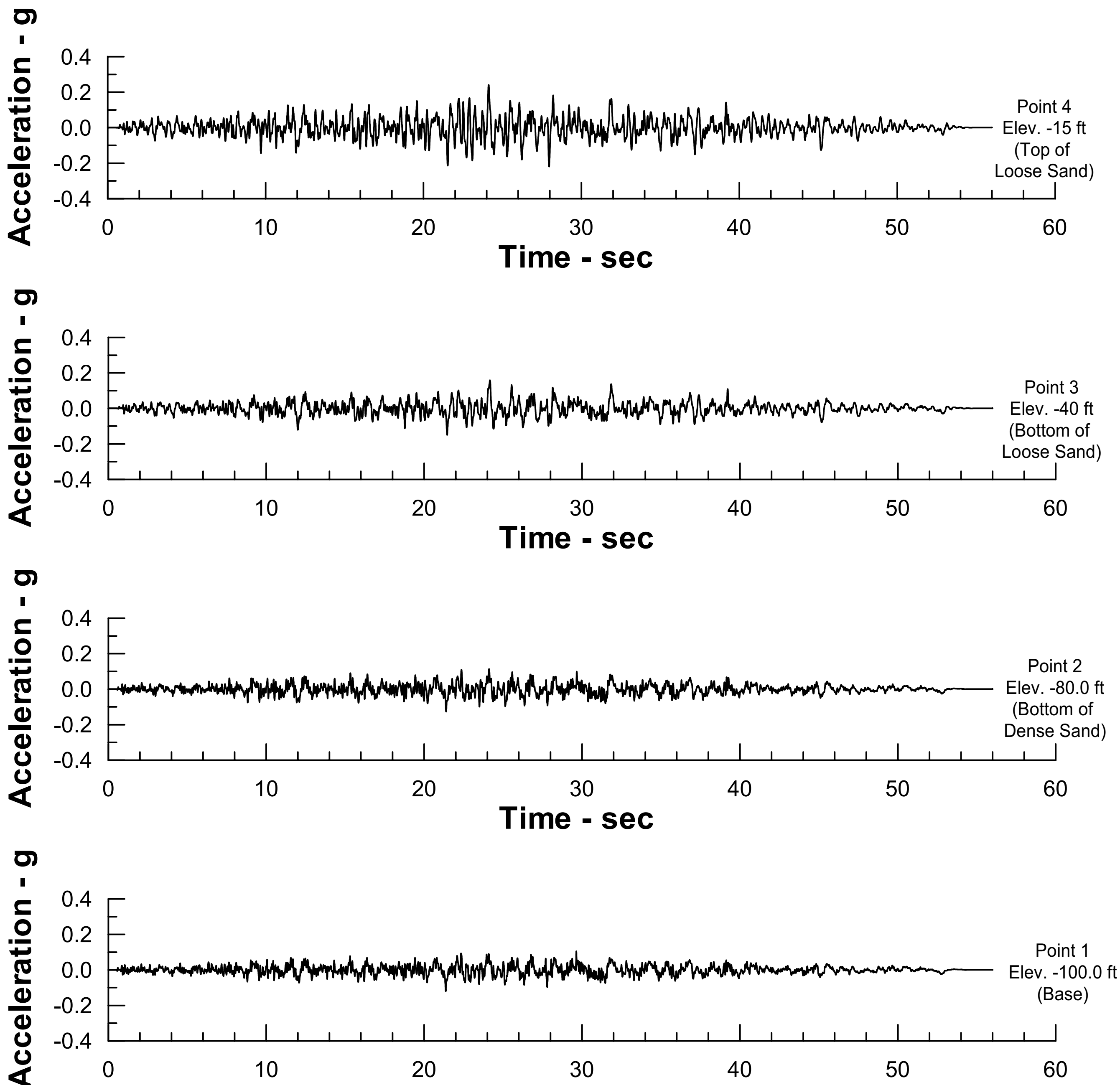
Figure
6-109



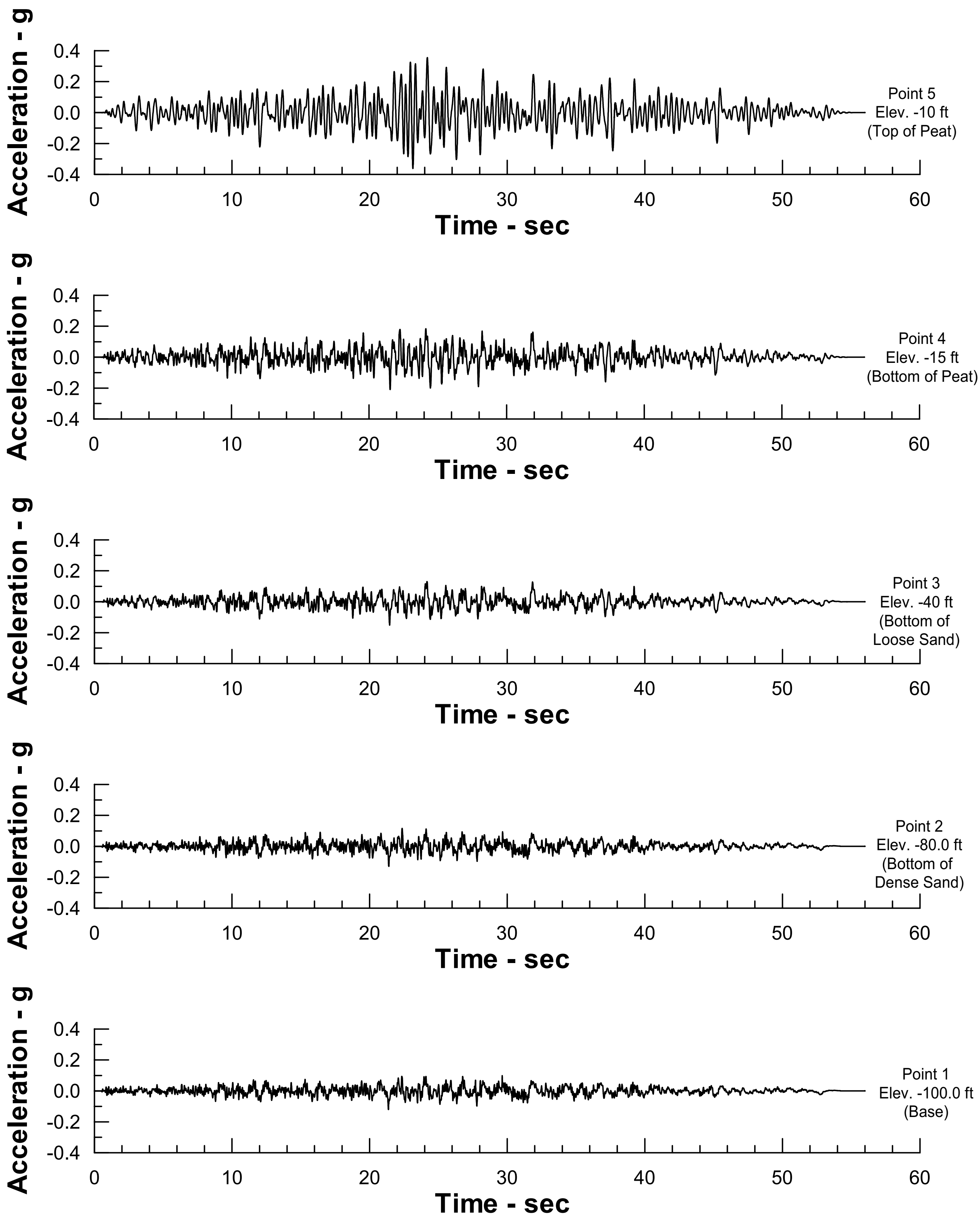
Delta Risk Management Strategy (DRMS) Levee Fragility URS Project No. 26815621	Horizontal Acceleration Time Histories Along Free Field Column: Island Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - No Peat	Figure 6-110



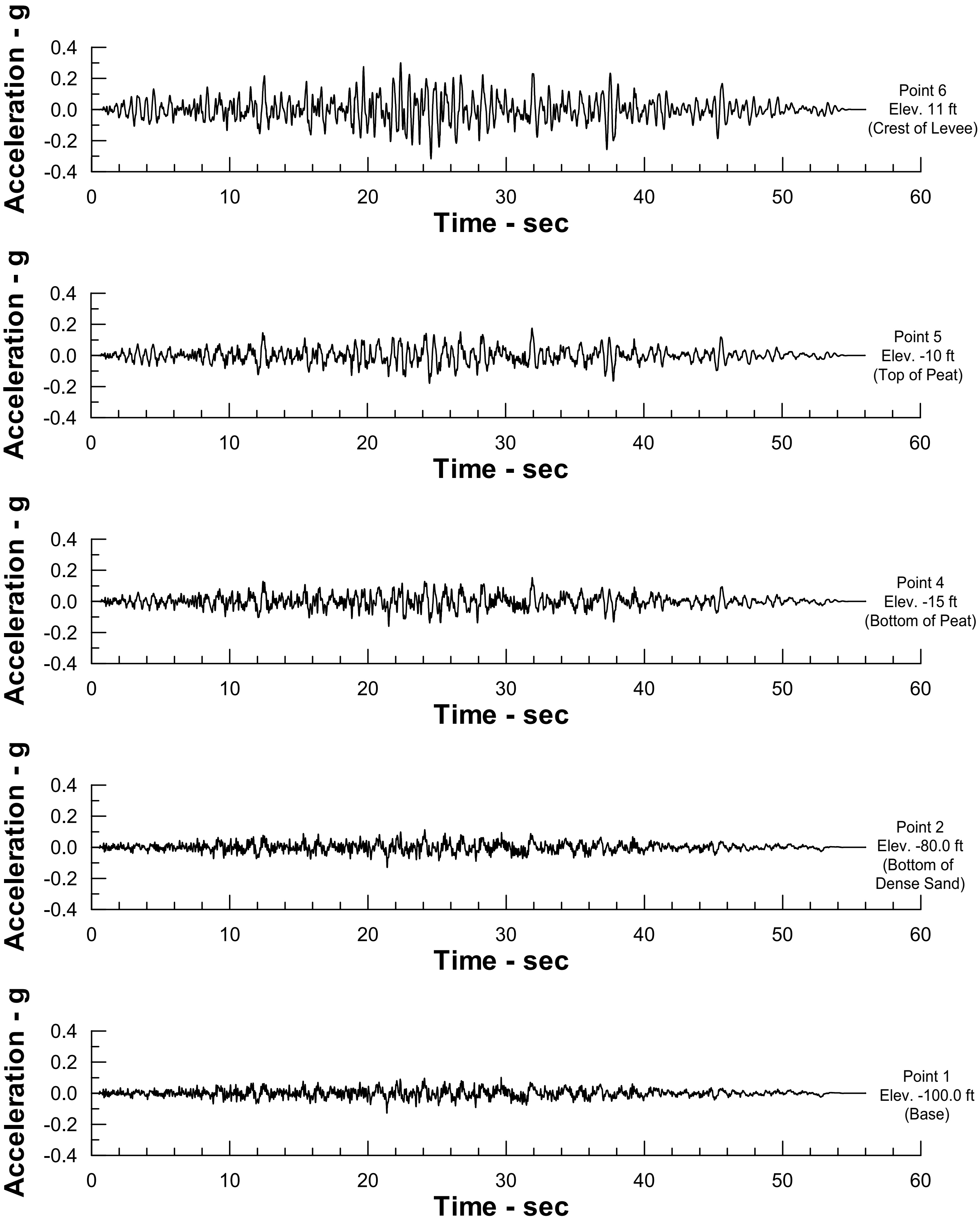
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along the Center Line of Levee (M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - No Peat	Figure 6-111
URS — Project No. 26815621		



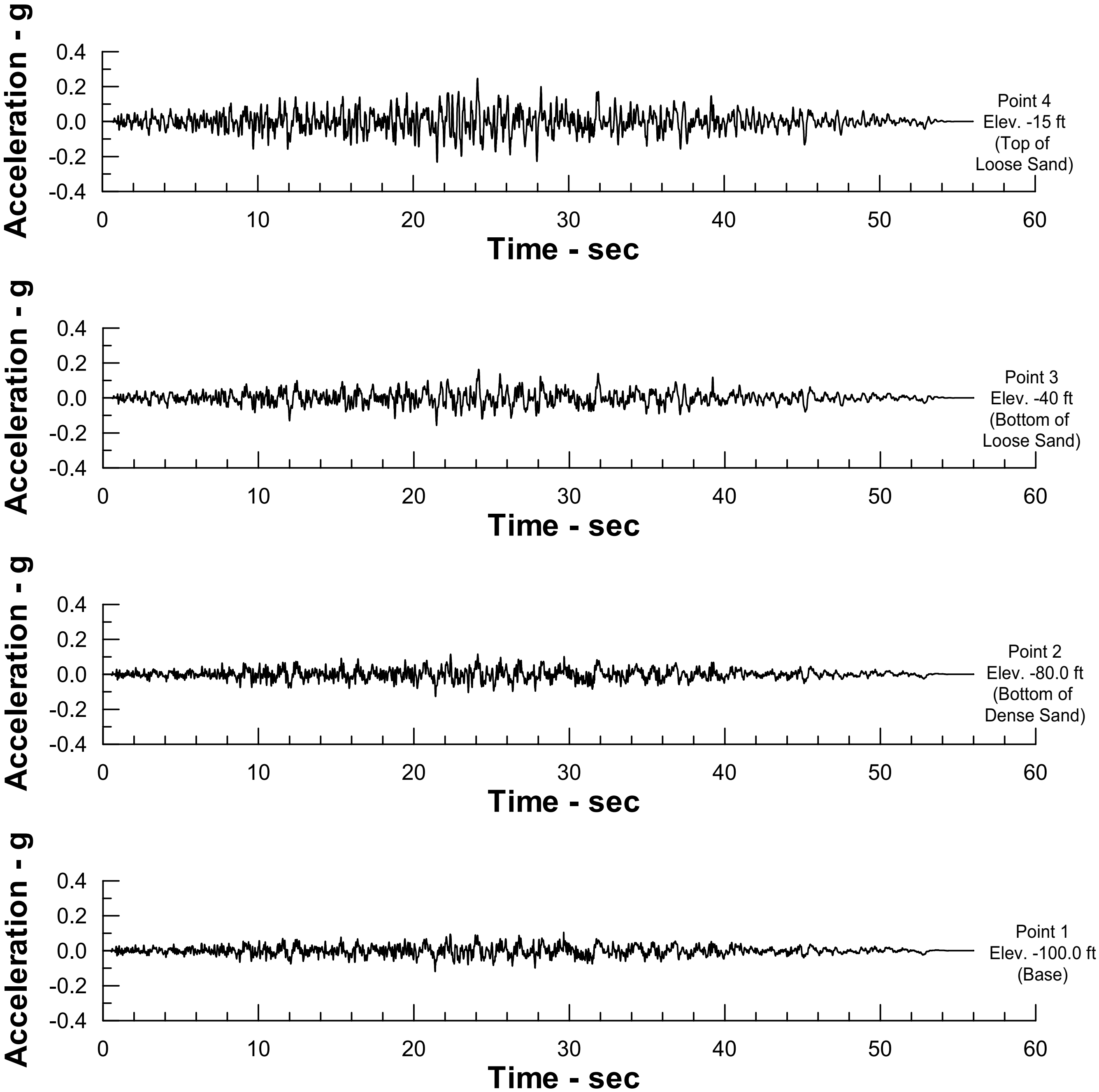
Delta Risk Management Strategy (DRMS) Levee Fragility		Horizontal Acceleration Time Histories Along Free Field Column: Water Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - No Peat	Figure 6-112
URS	Project No. 26815621		



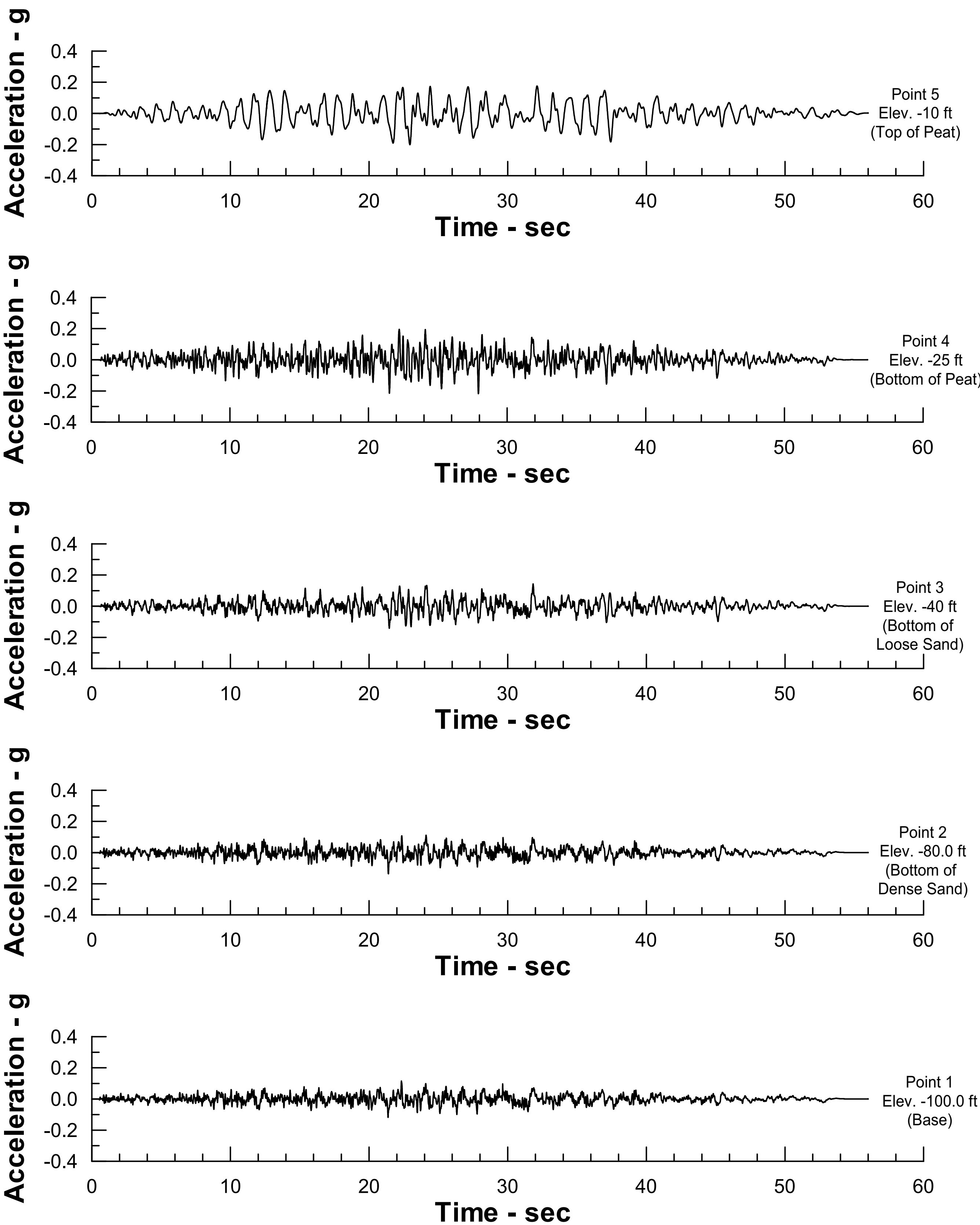
Delta Risk Management Strategy (DRMS) Levee Fragility		Horizontal Acceleration Time Histories Along Free Field Column: Island Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 5 Feet of Peat	Figure 6-113
URS	Project No. 26815621		



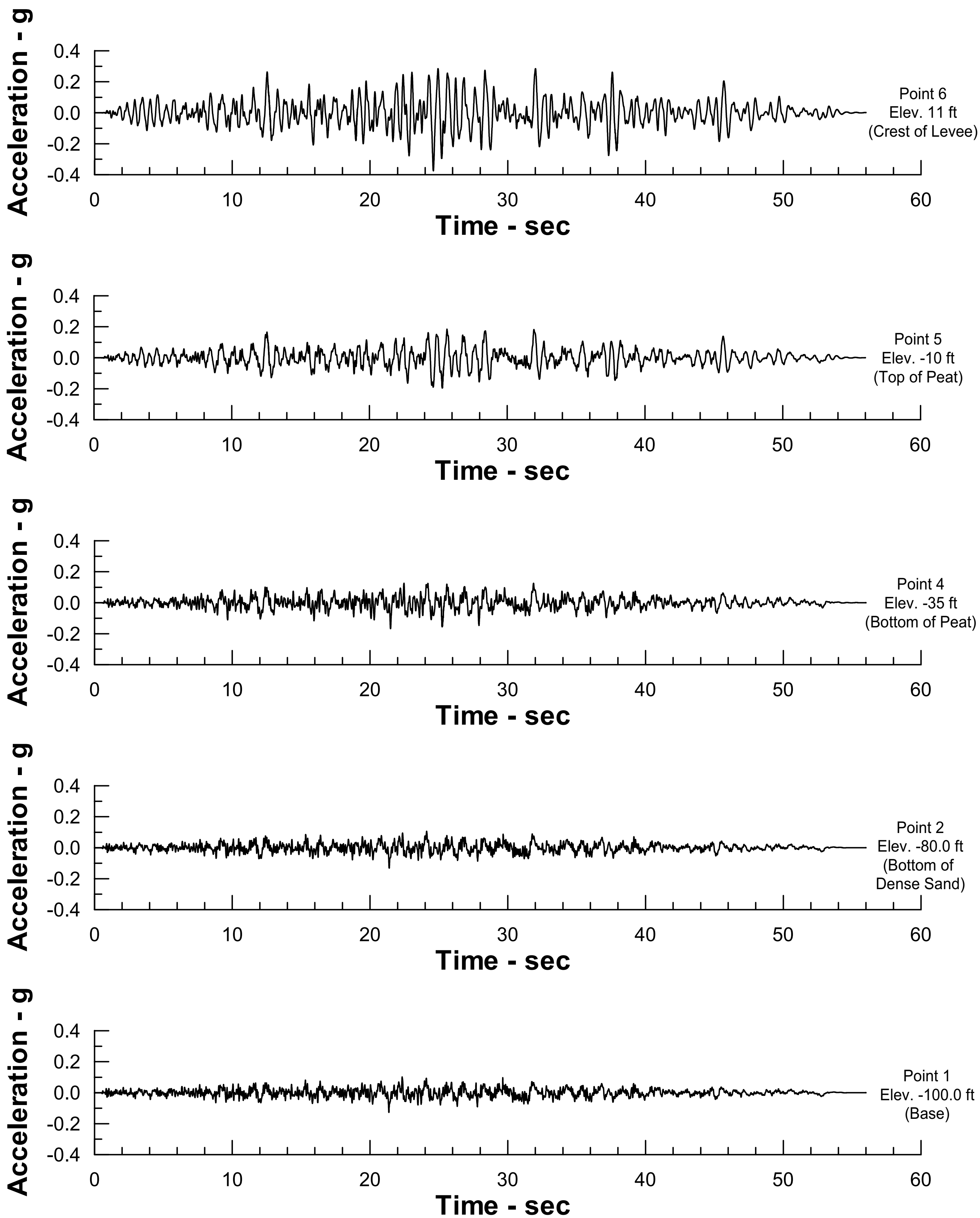
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along the Center Line of Levee (M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 5 Feet of Peat	Figure 6-114
URS Project No. 26815621		



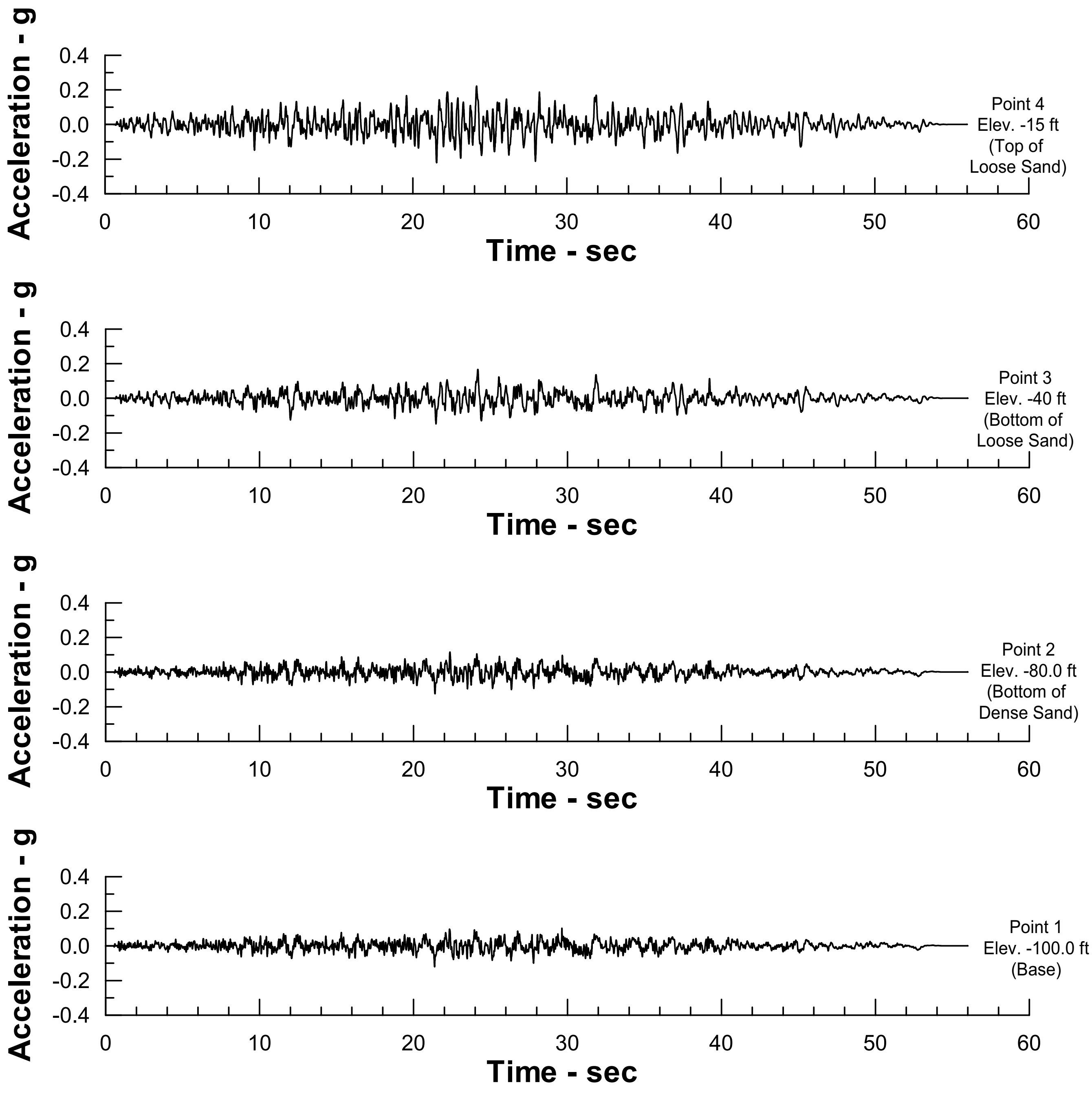
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along Free Field Column: Water Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 15 Feet of Peat	Figure 6-115
URS — Project No. 26815621		



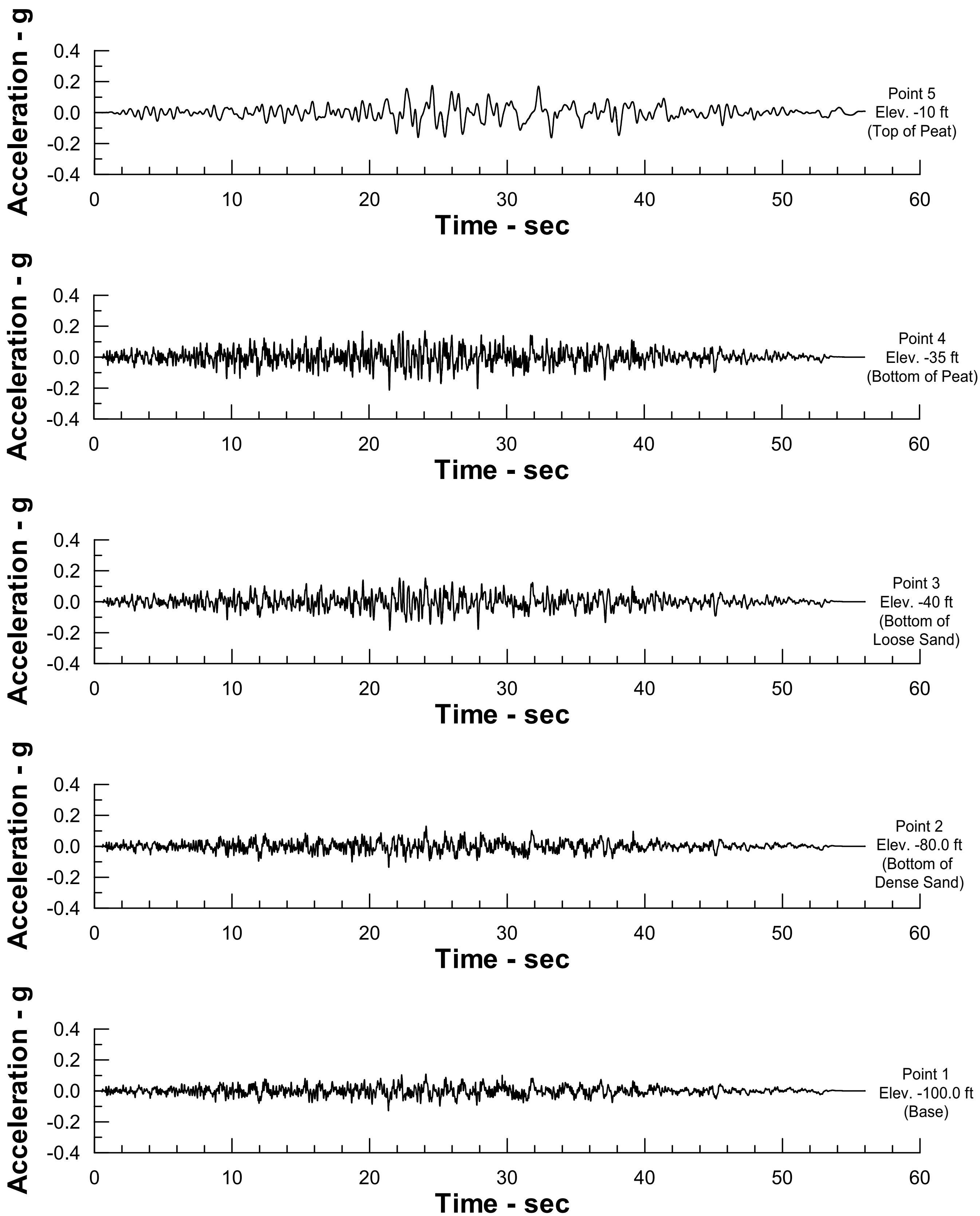
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along Free Field Column: Island Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 15 Feet of Peat	Figure 6-116
URS — Project No. 26815621		



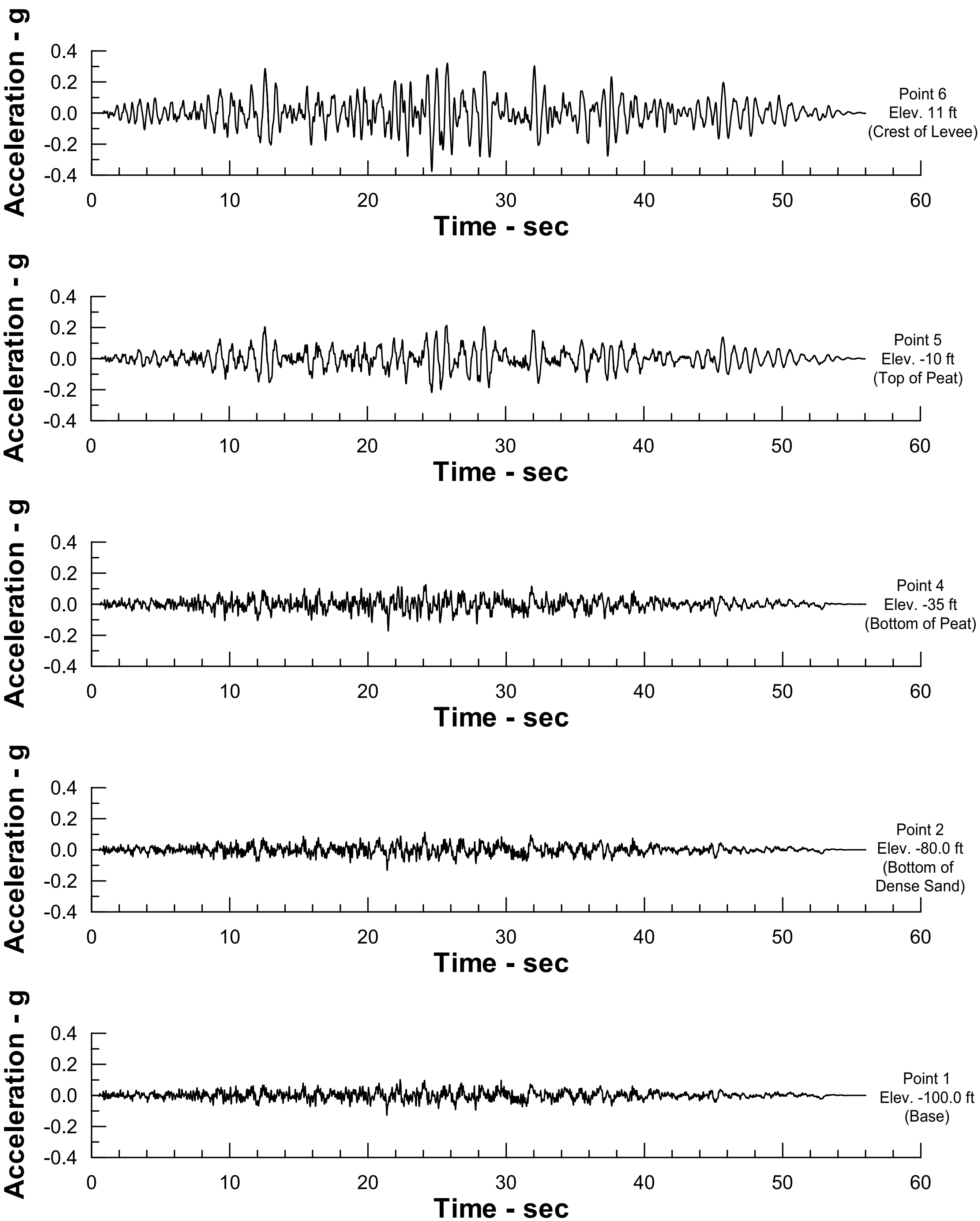
Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Horizontal Acceleration Time Histories Along the Center Line of Levee (M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 15 Feet of Peat	Figure 6-117



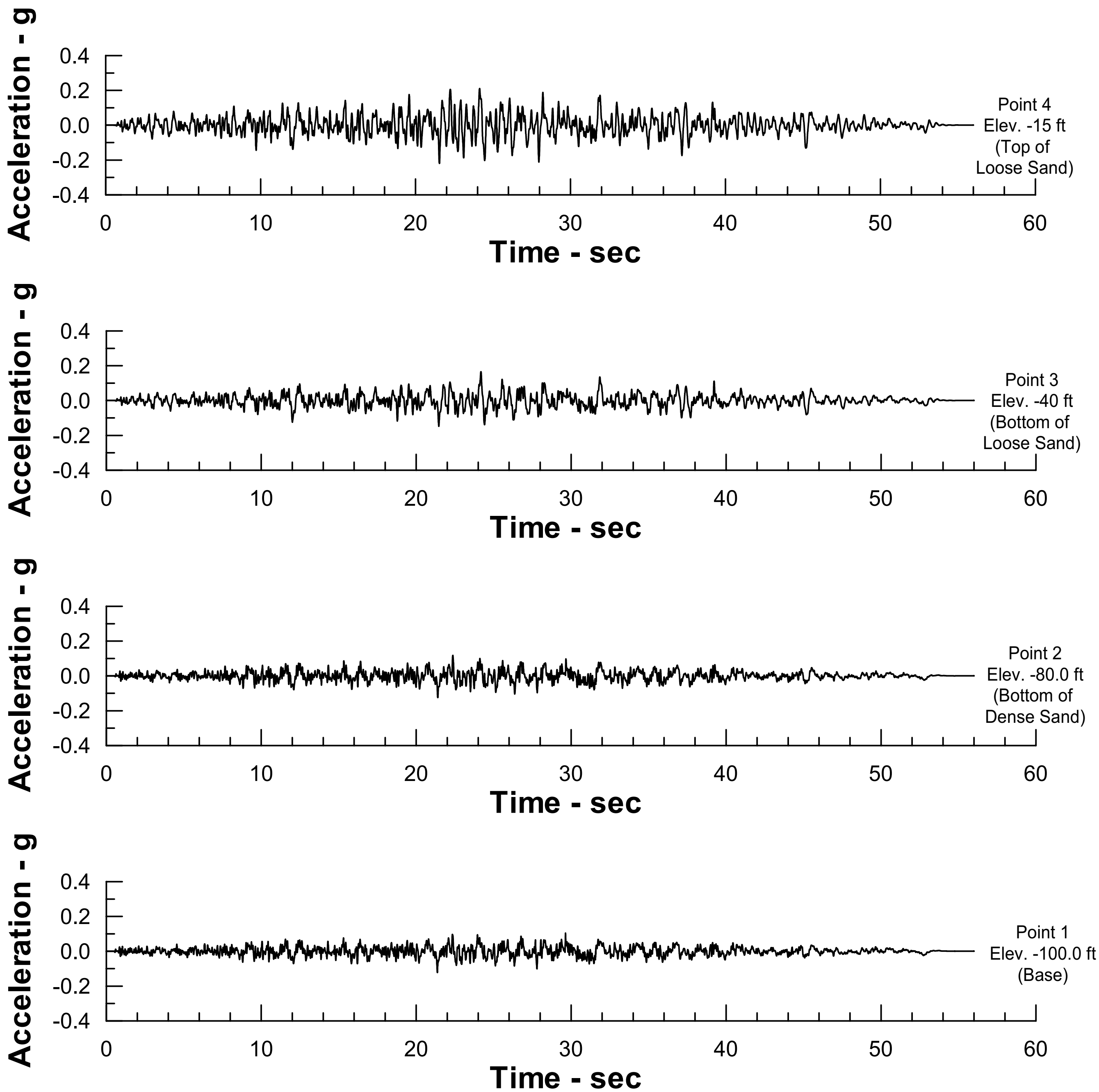
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along Free Field Column: Water Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 15 Feet of Peat	Figure 6-118
URS — Project No. 26815621		



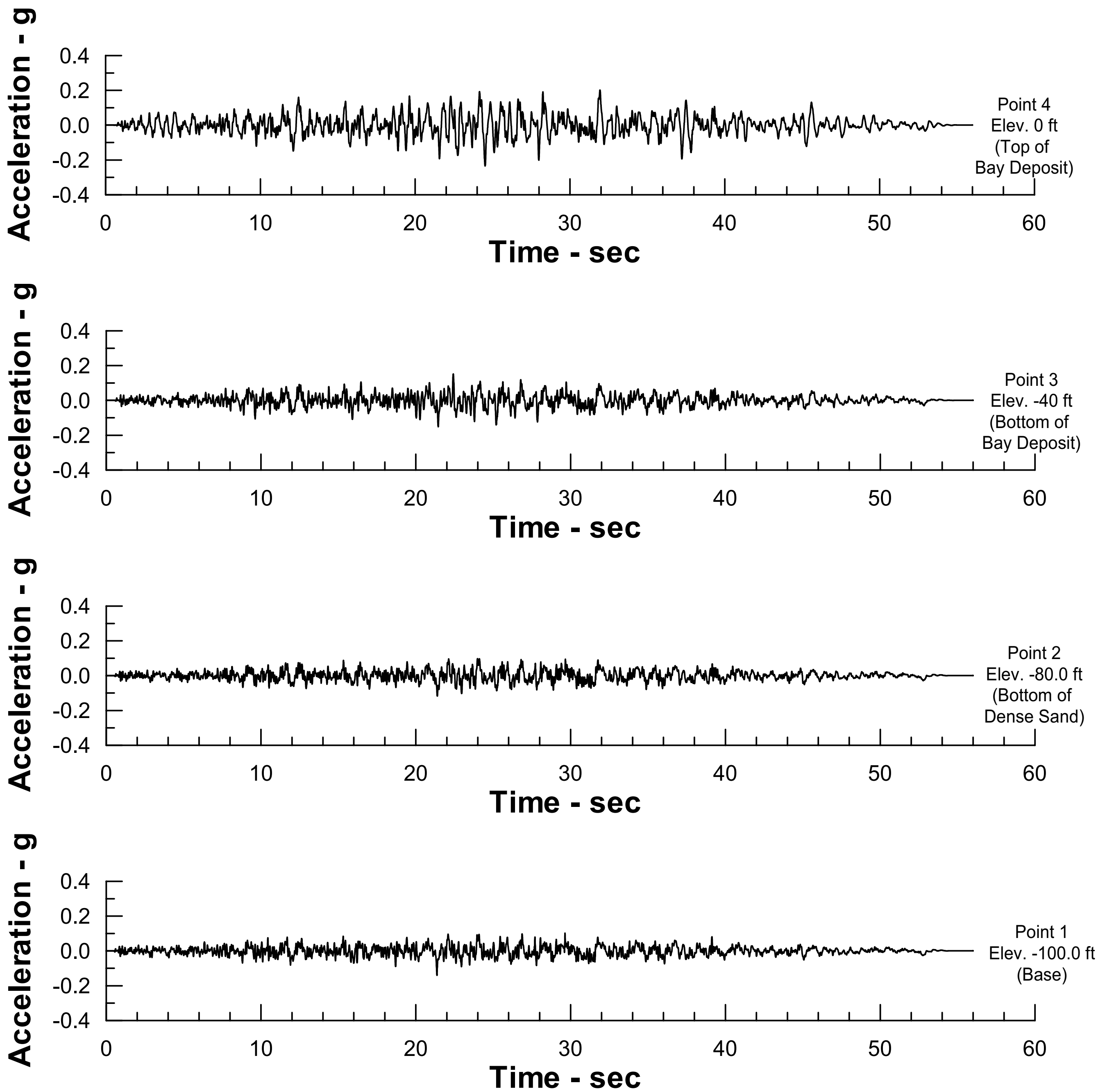
Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Horizontal Acceleration Time Histories Along Free Field Column: Island Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 25 Feet of Peat	Figure 6-119



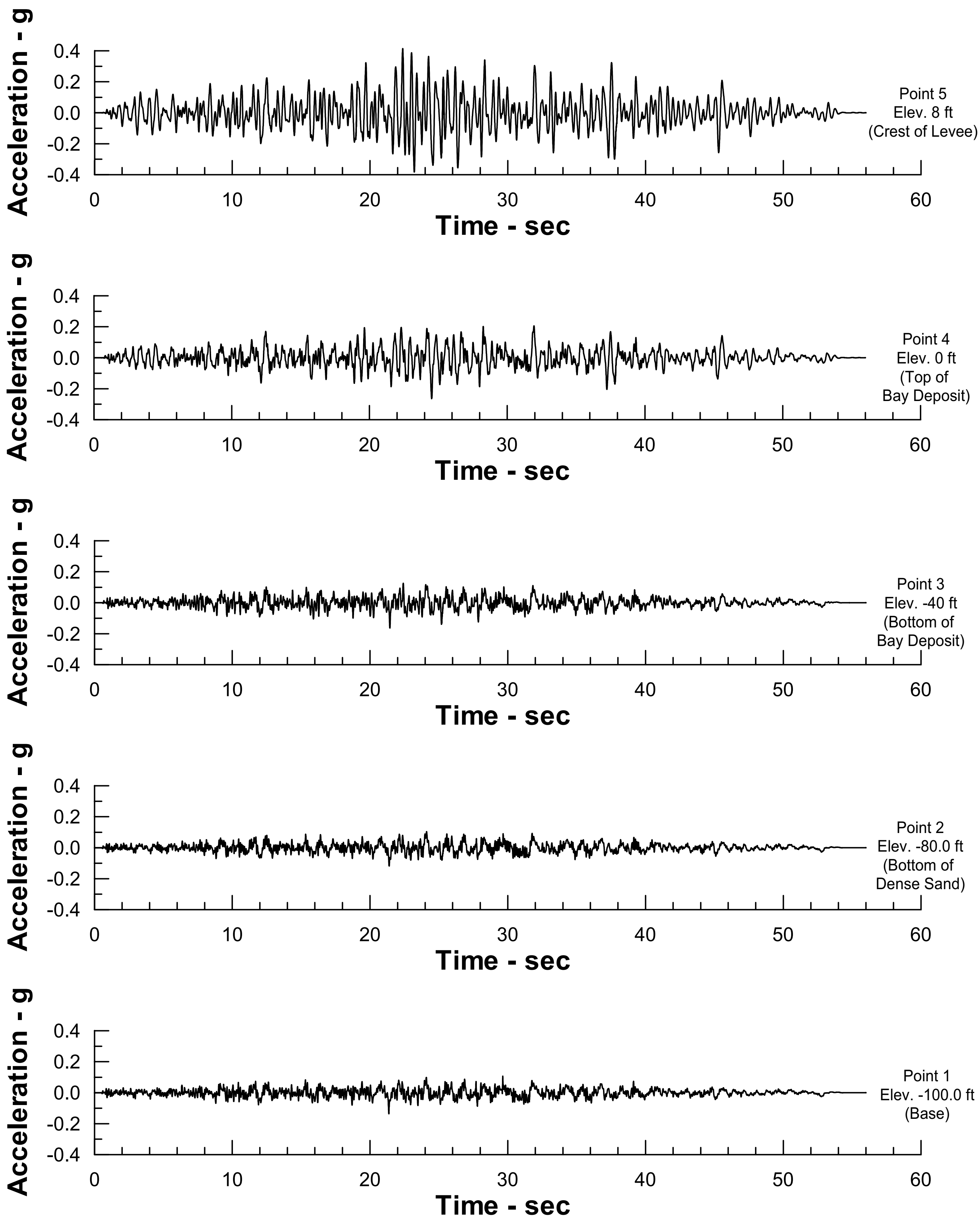
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along the Center Line of Levee (M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 25 Feet of Peat	Figure 6-120
URS Project No. 26815621		



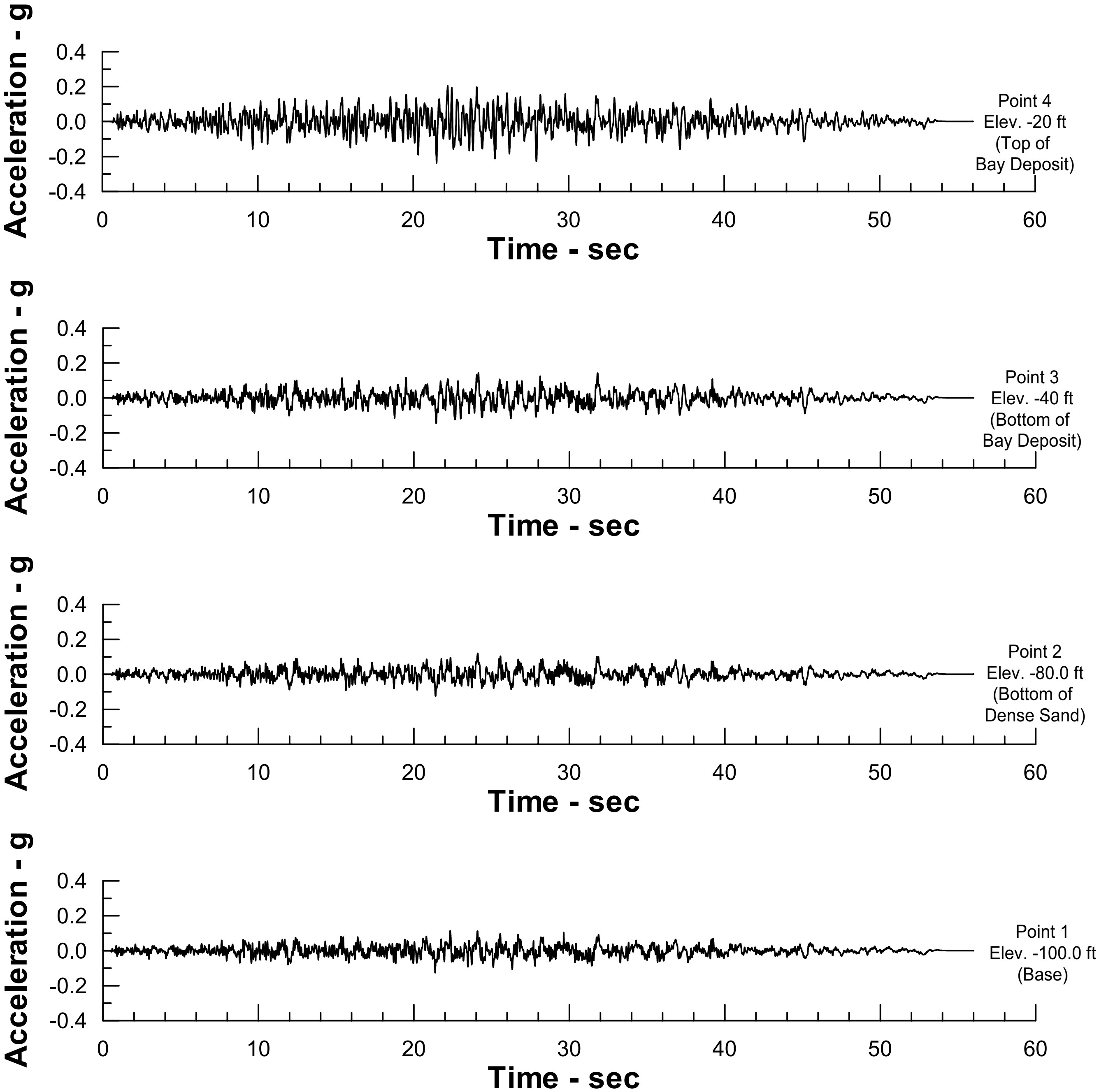
Delta Risk Management Strategy (DRMS) Levee Fragility		Horizontal Acceleration Time Histories Along Free Field Column: Water Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Idealized Section - 25 Feet of Peat	Figure 6-121
URS	Project No. 26815621		



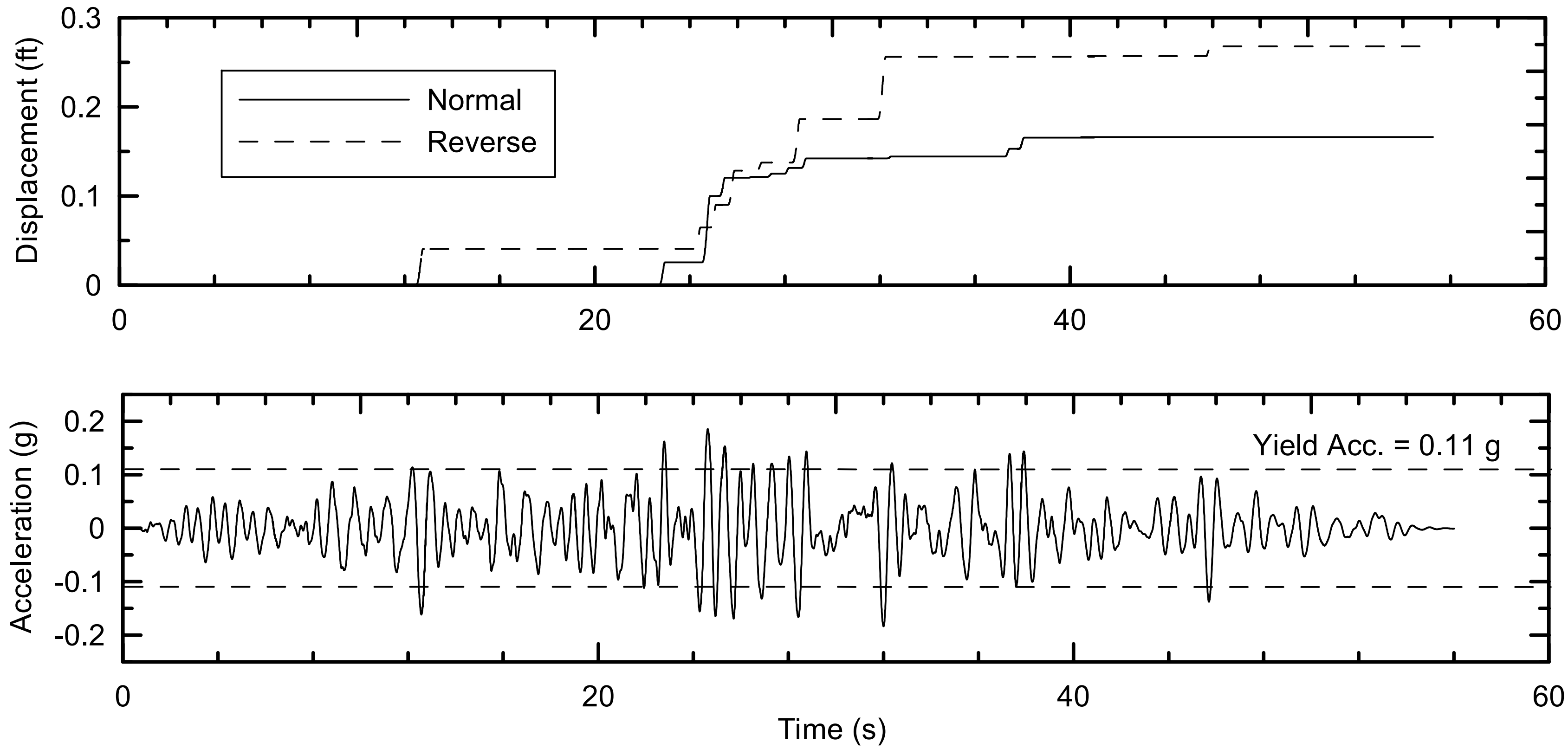
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along Free Field Column: Island Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Suisun Marsh Section	Figure 6-122
URS — Project No. 26815621		



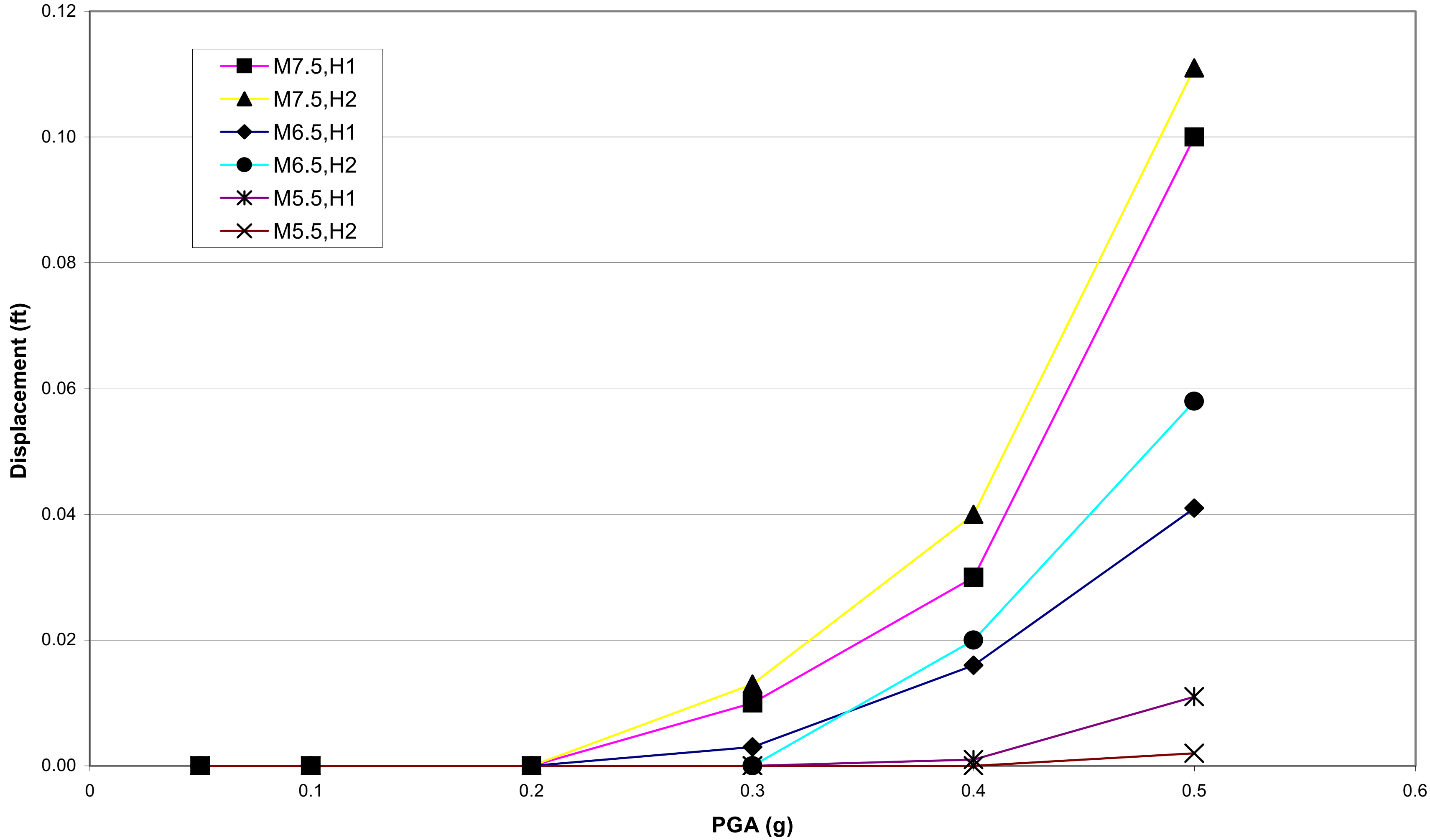
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along the Center Line of Levee (M 7.5 Horizontal-1 PGA 0.20g) Suisun Marsh Section	Figure 6-123
URS — Project No. 26815621		



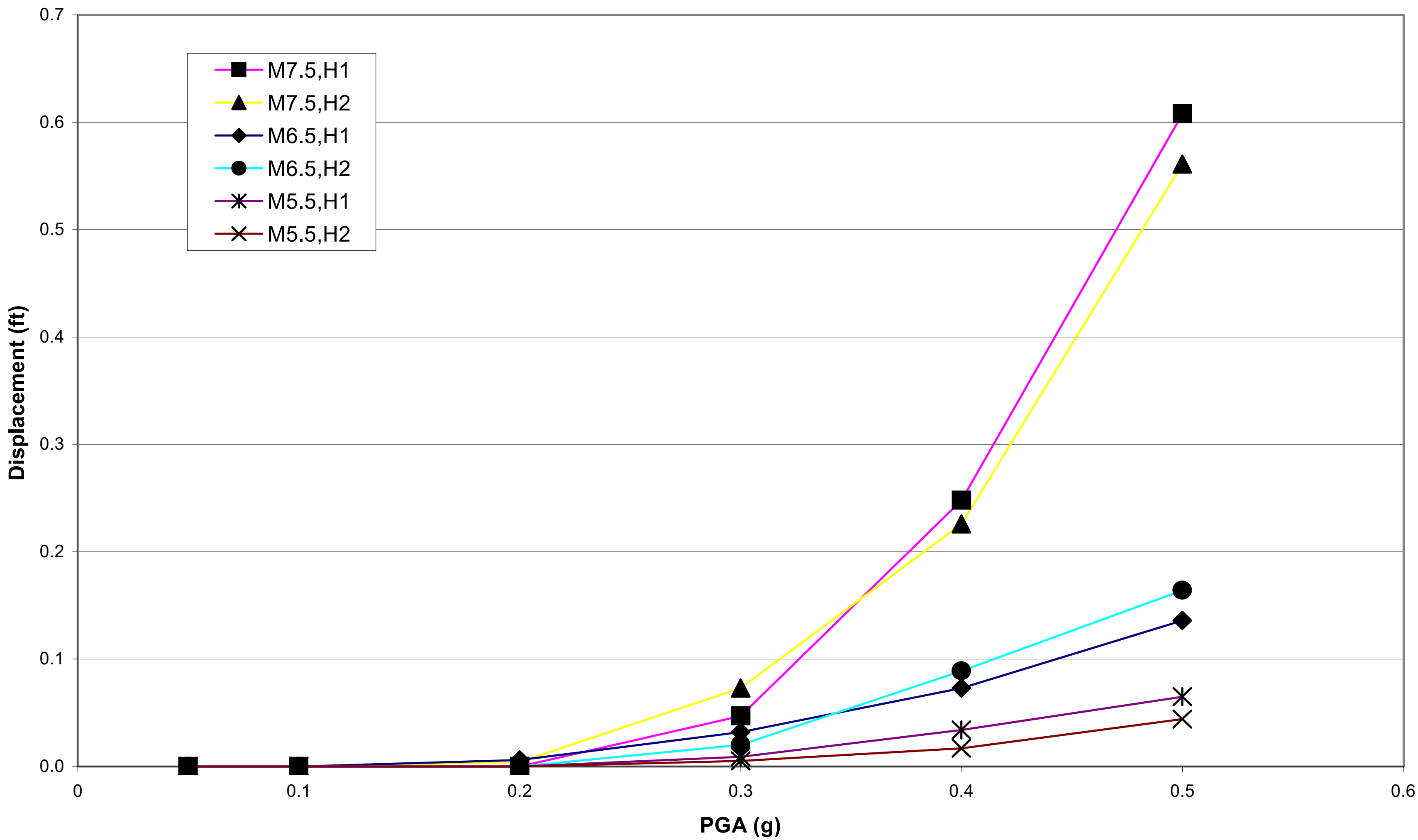
Delta Risk Management Strategy (DRMS) Levee Fragility	Horizontal Acceleration Time Histories Along Free Field Column: Water Side (Input Motion: M 7.5 Horizontal-1 PGA 0.20g) Suisun Marsh Section	Figure 6-124
URS — Project No. 26815621		



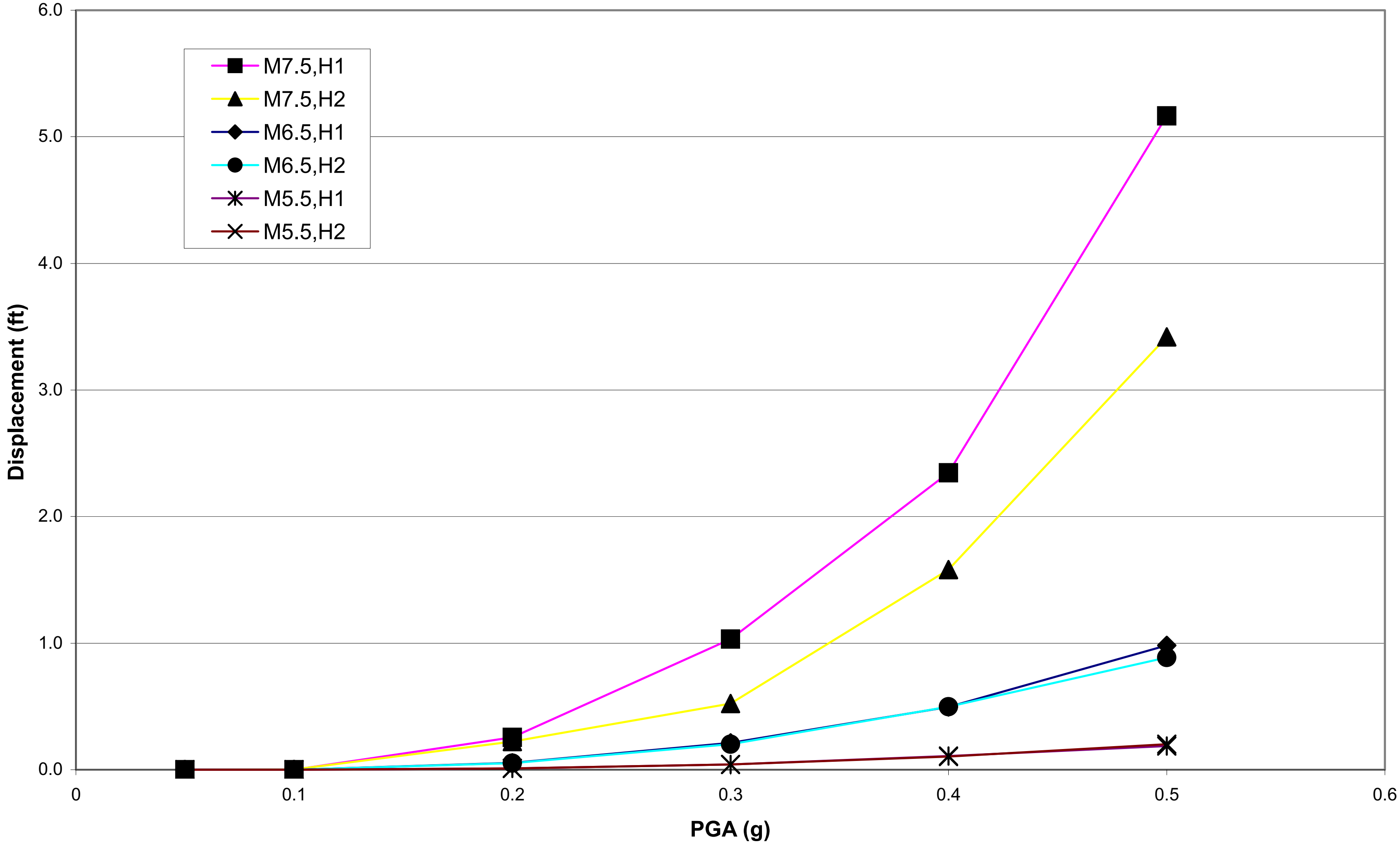
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements M7.5 Horizontal #1 Time History, 0.2g PGA Idealized Section 15 Feet of Peat	Figure 6-125
URS	Project No. 26815621		



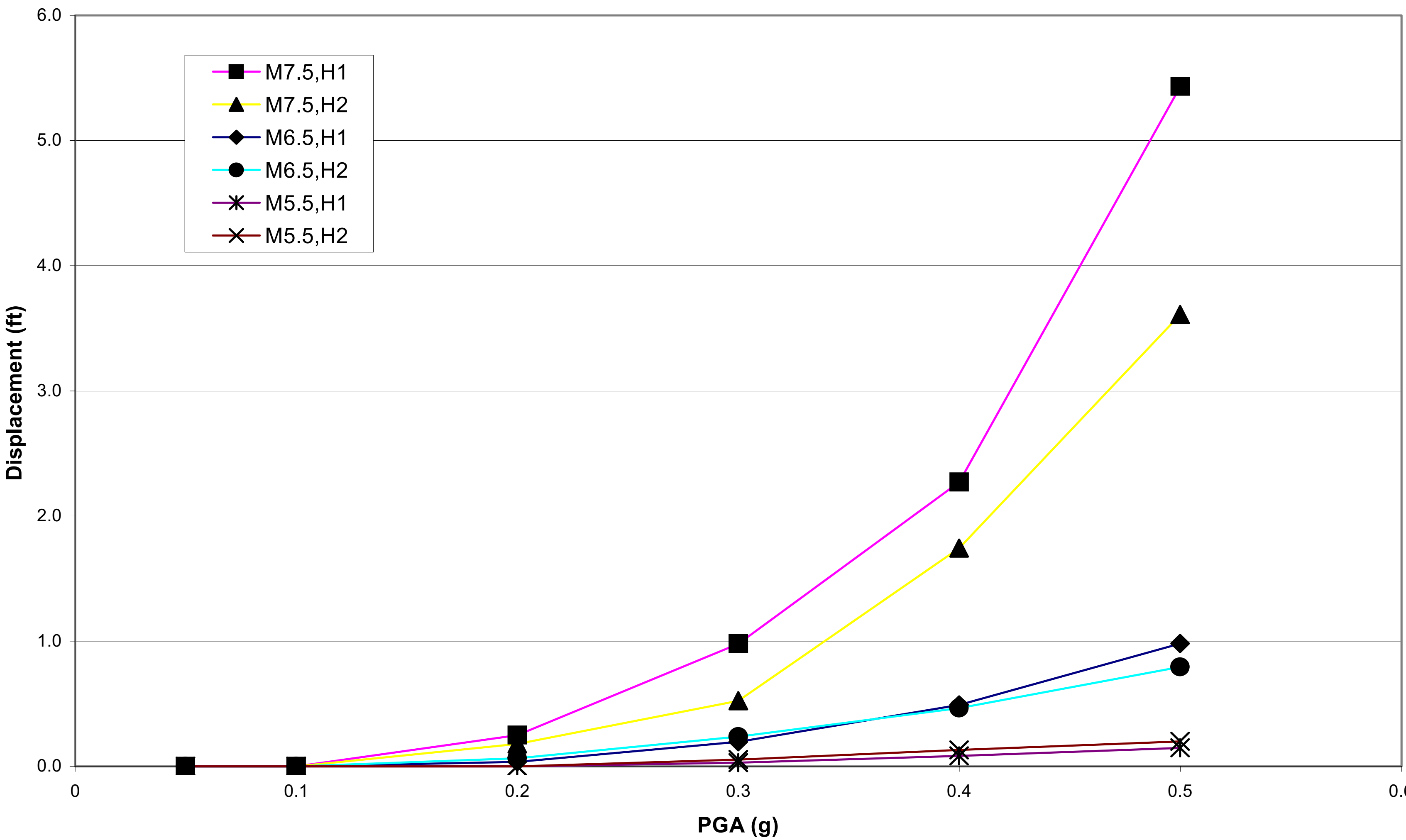
Delta Risk Management Strategy (DRMS) Levee Fragility	Calculated Newmark Displacements Idealized Section No Peat	Figure 6-126
URS — Project No. 26815621		



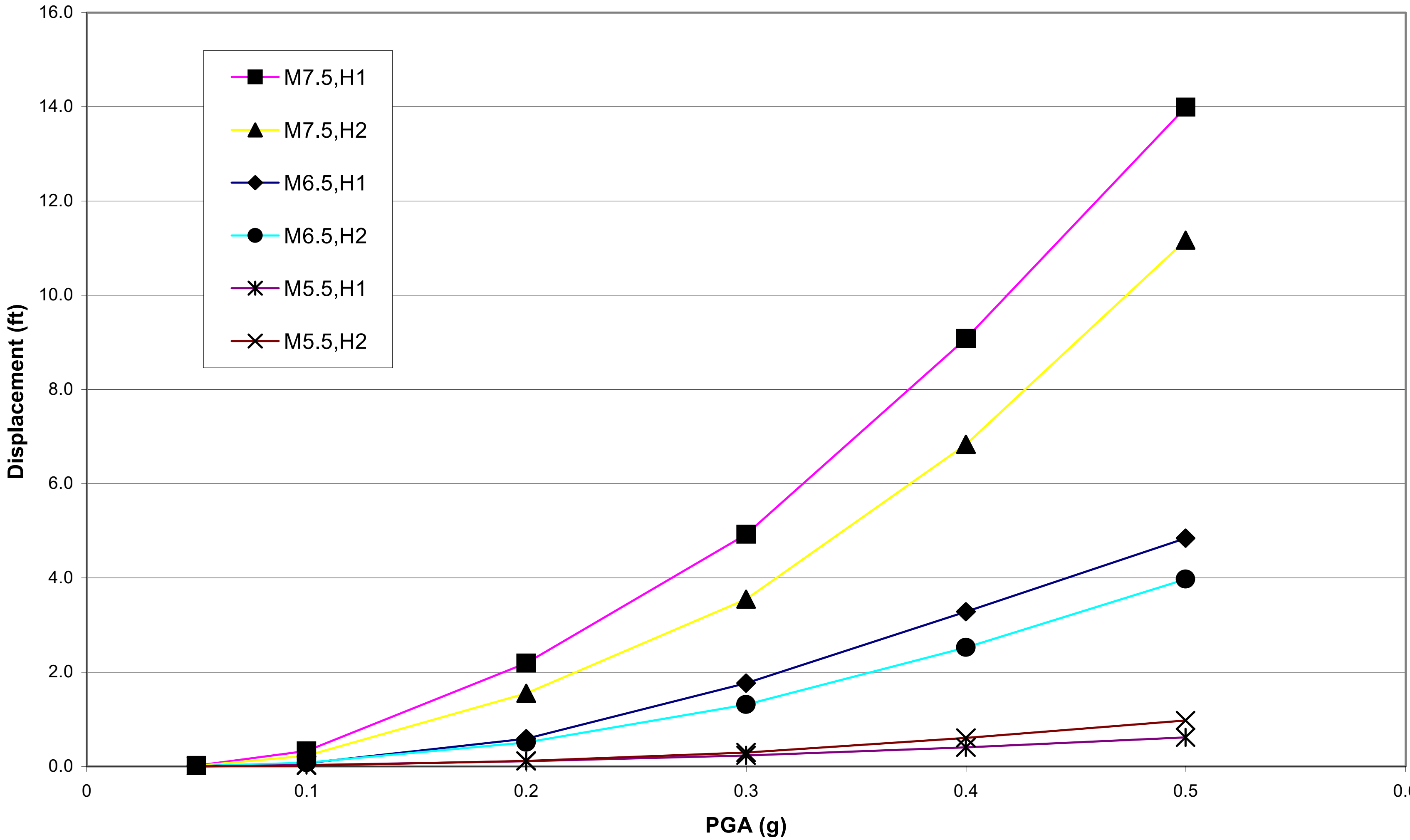
Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Calculated Newmark Displacements Idealized Section 5 Feet of Peat	Figure 6-127



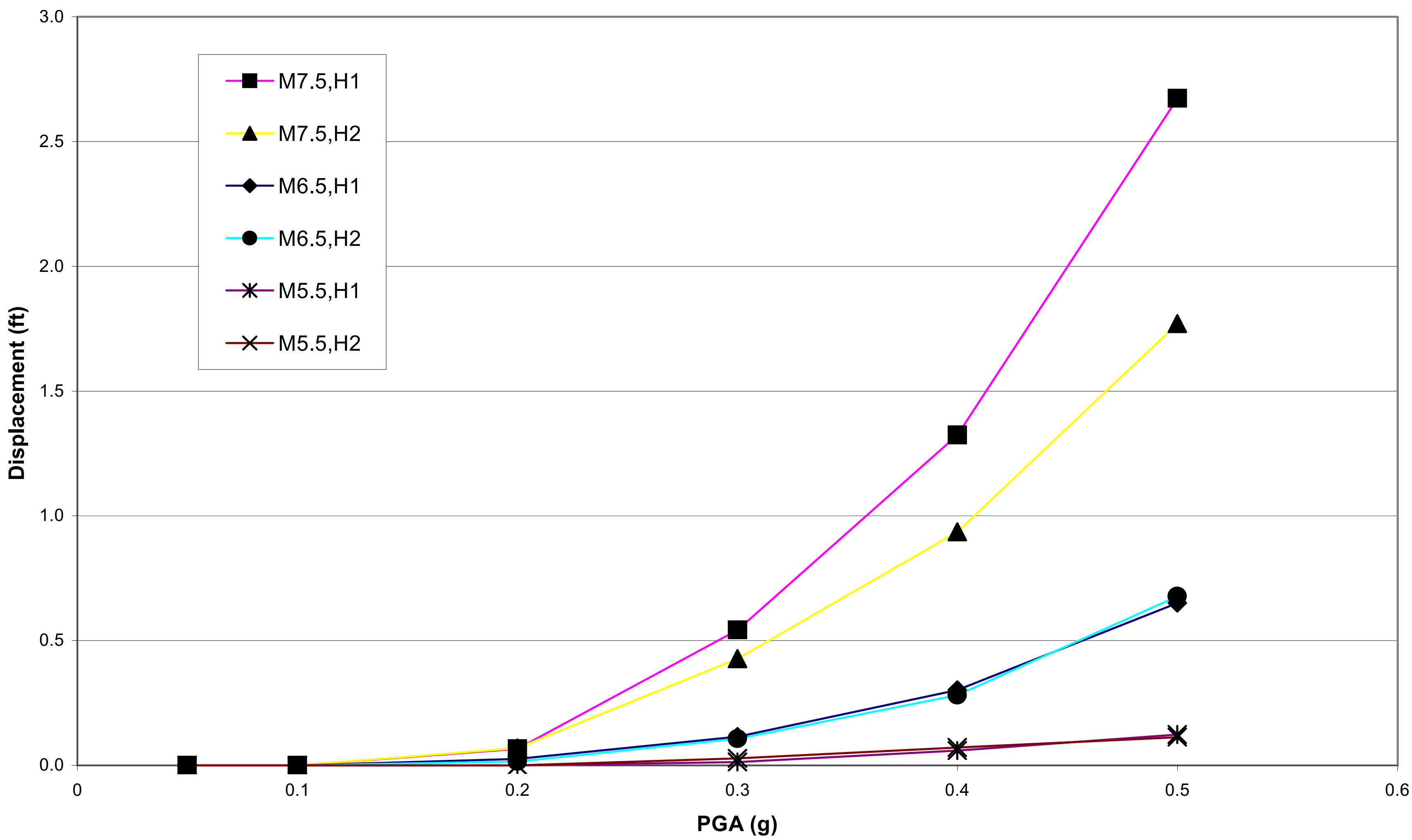
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section 15 Feet of Peat	Figure 6-128
URS	Project No. 26815621		



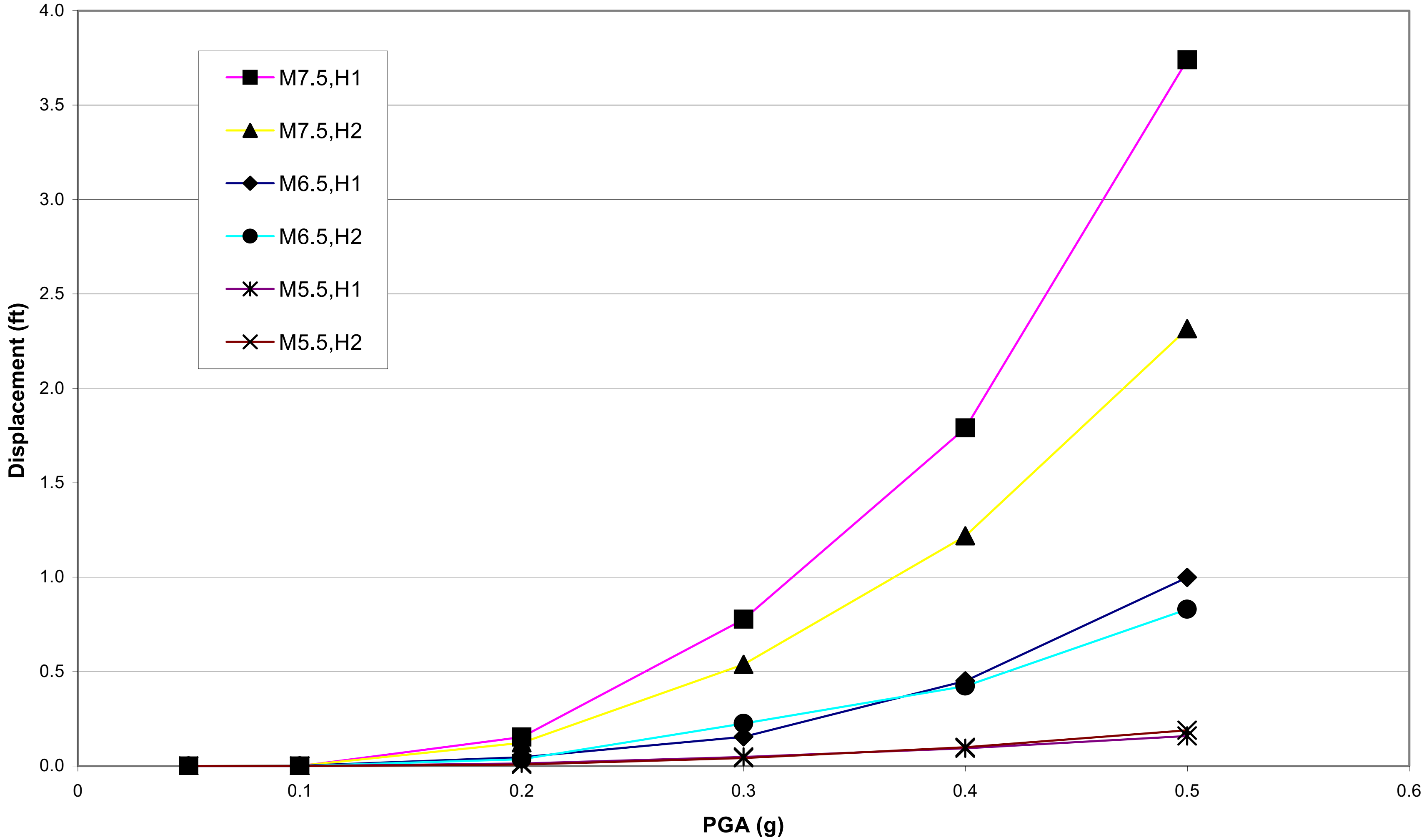
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section 25 Feet of Peat	Figure 6-129
URS	Project No. 26815621		



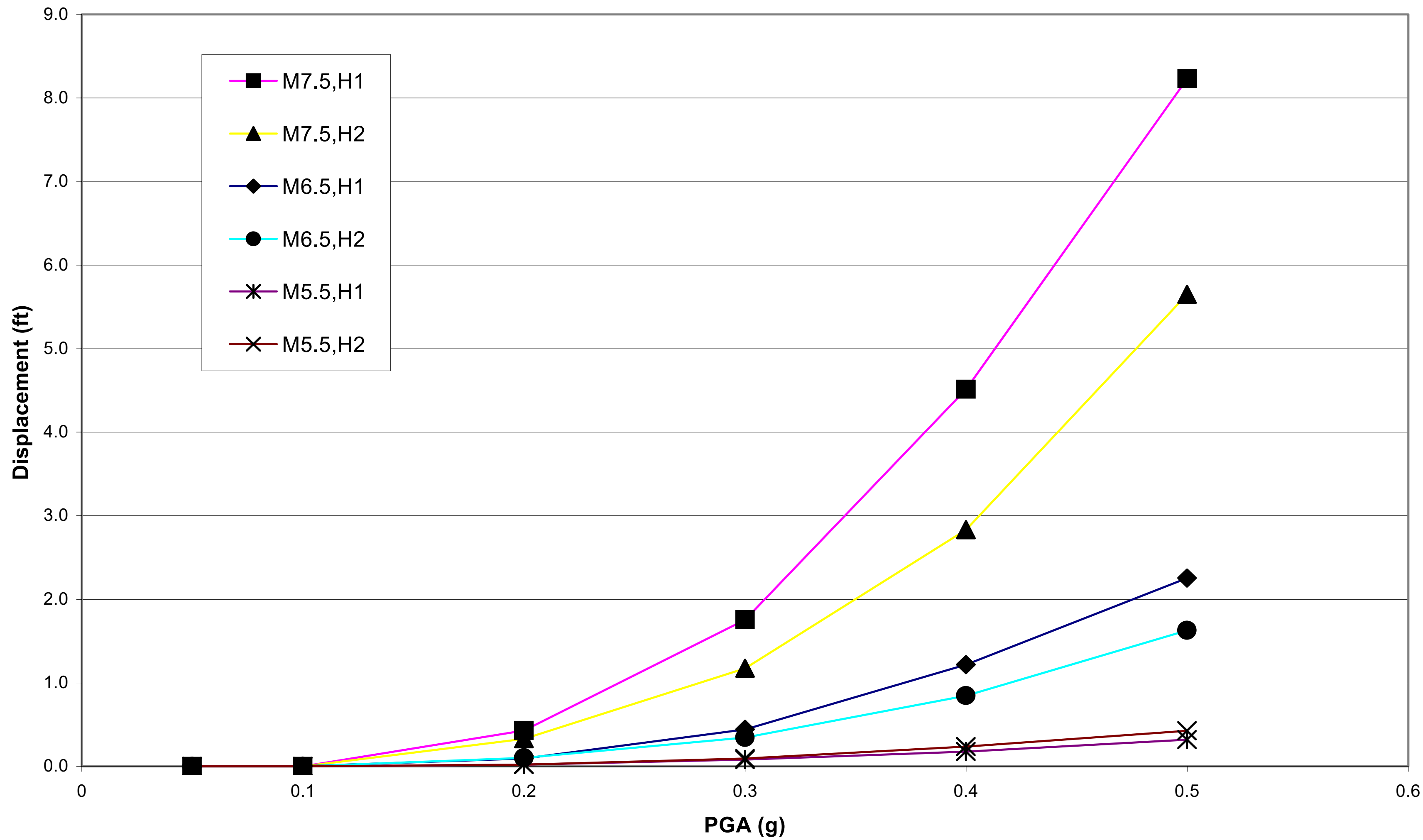
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section Suisun Marsh	Figure 6-130
URS	Project No. 26815621		



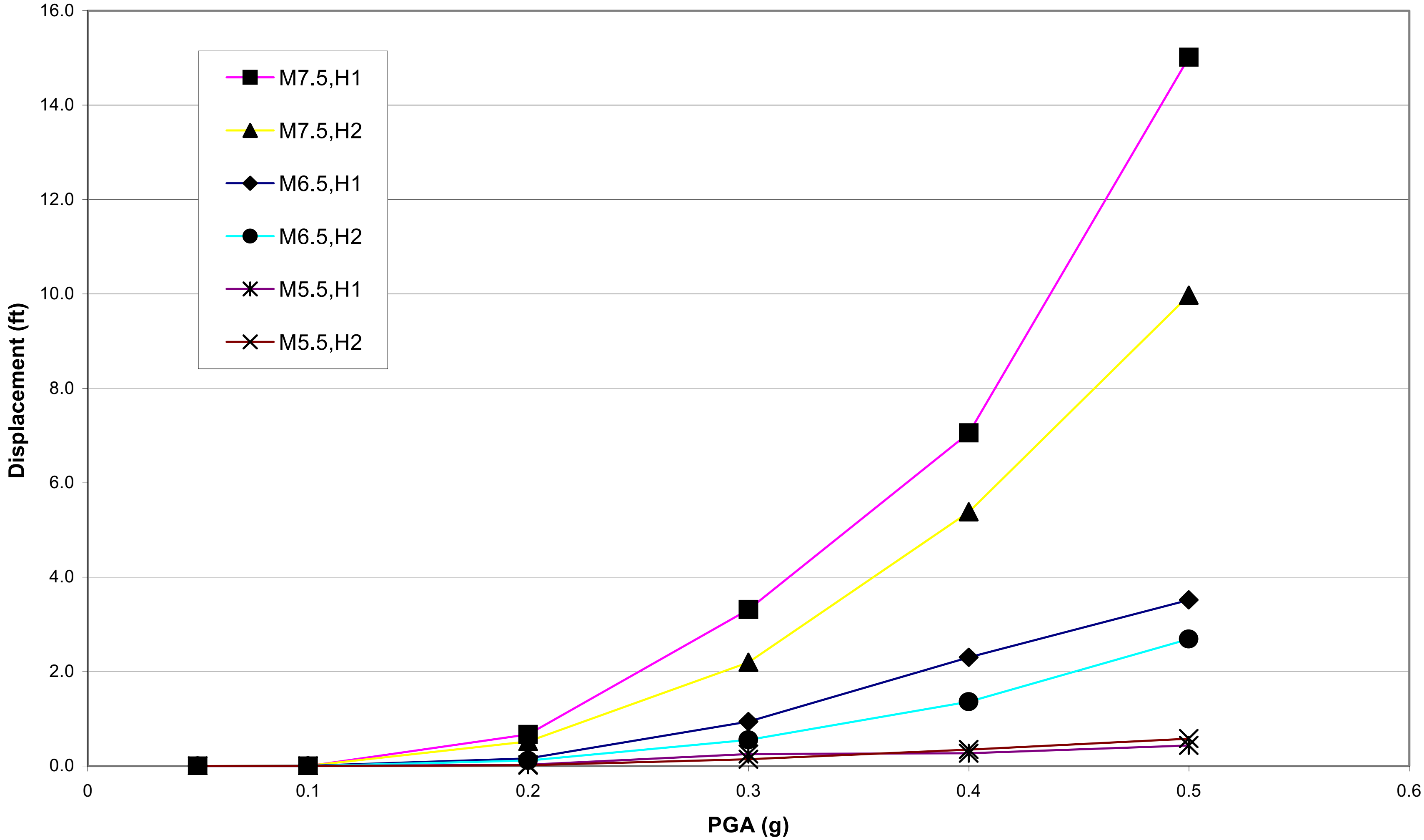
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section with Steep Water Side Slope No Peat	Figure 6-131
URS	Project No. 26815621		



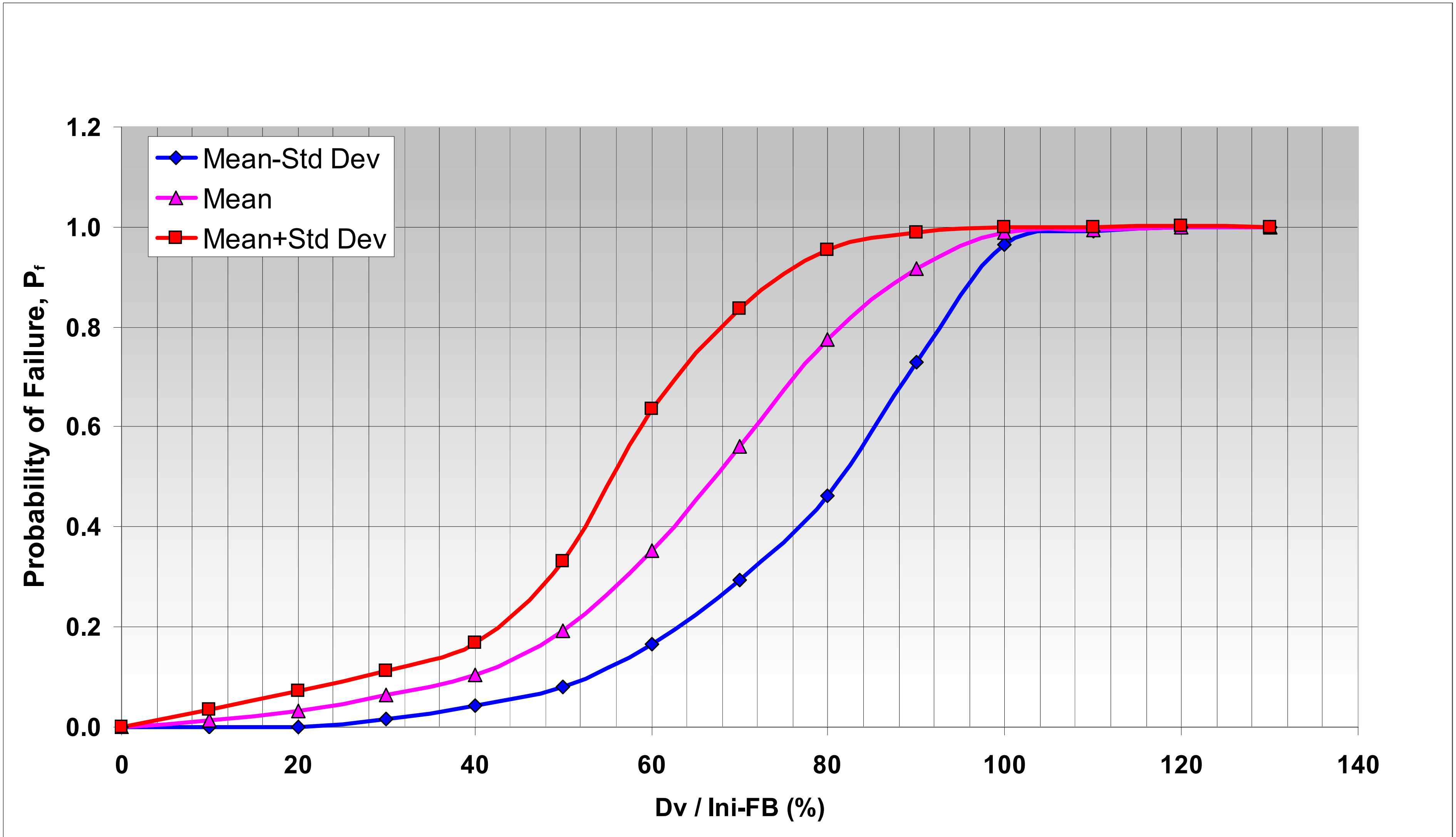
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section with Steep Water Side Slope 5 ft Peat	Figure 6-132
URS	Project No. 26815621		



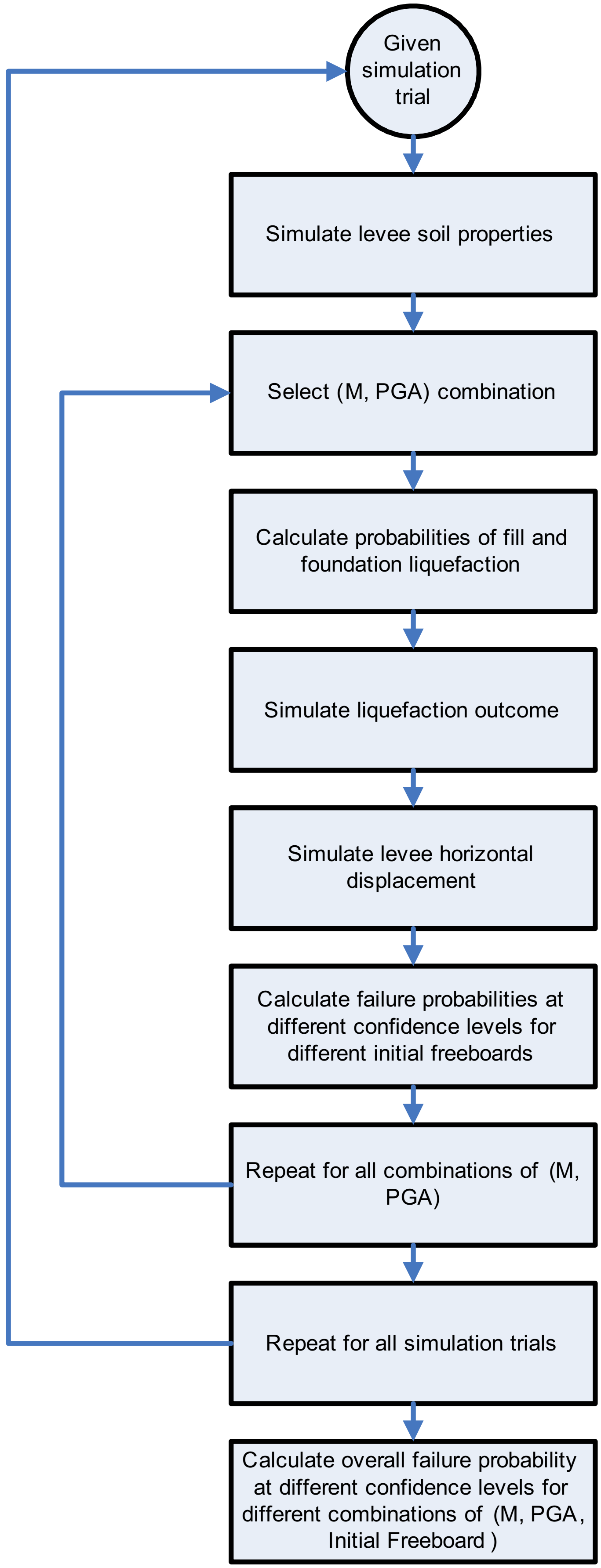
Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section with Steep Water Side Slope 15 ft Peat	Figure 6-133
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Calculated Newmark Displacements Idealized Section with Steep Water Side Slope 25 ft Peat	Figure 6-134
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Probability of Failure vs D_v / Ini-FB (Vertical Displacement / Initial Free Board)	Figure 6-135
URS	Project No. 26815621		



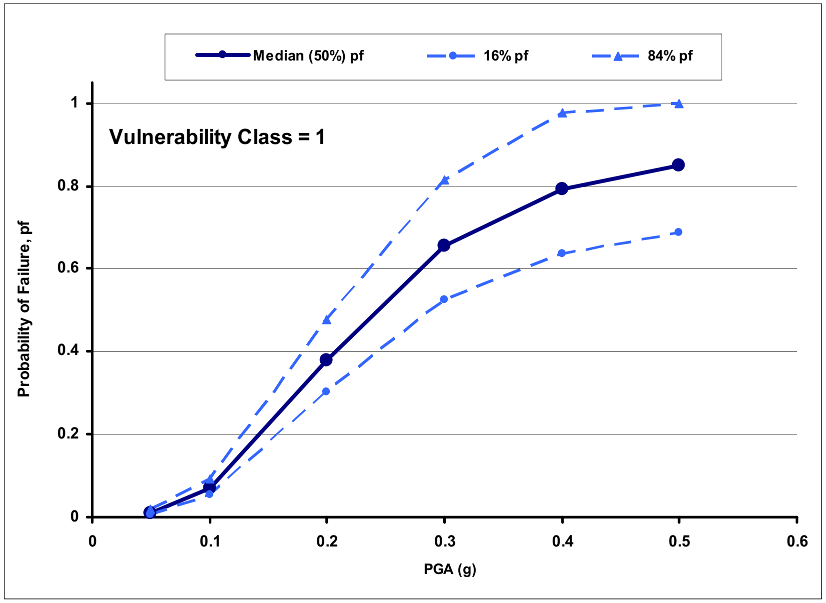
Delta Risk Management Strategy (DRMS)
Levee Fragility

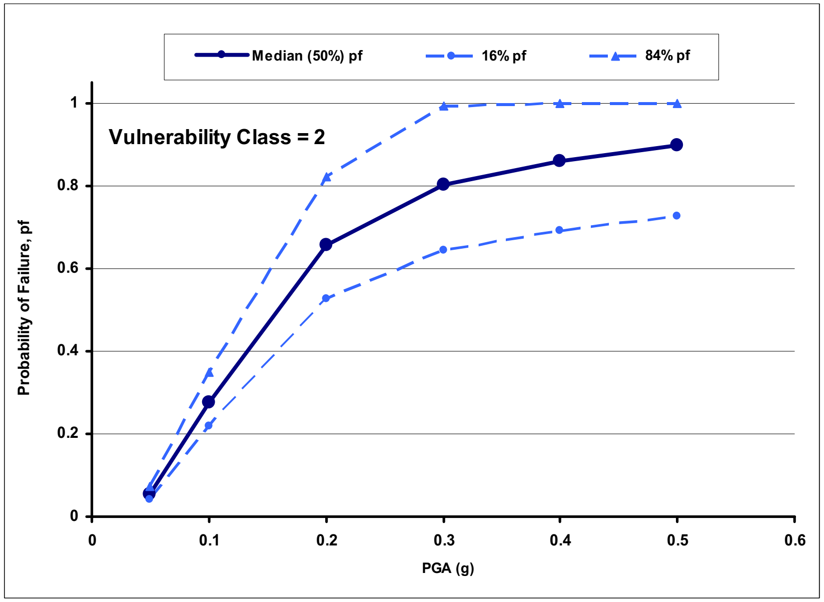
URS

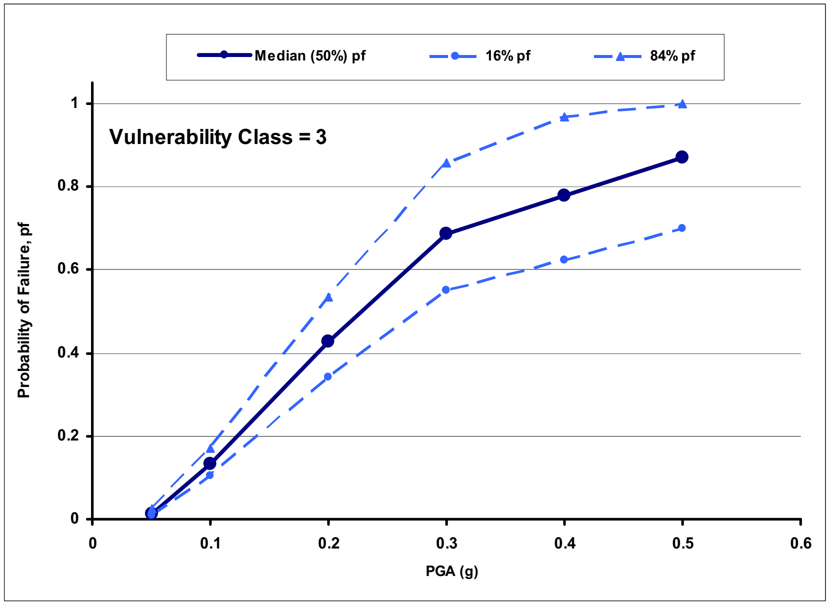
Project No. 26815621

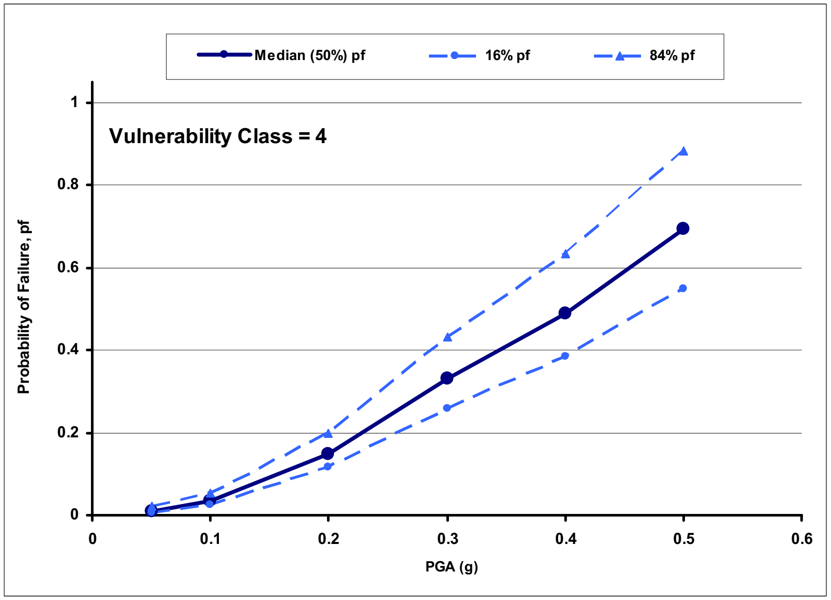
Flowchart of Key Steps in Monte Carlo simulation

Figure 6-136

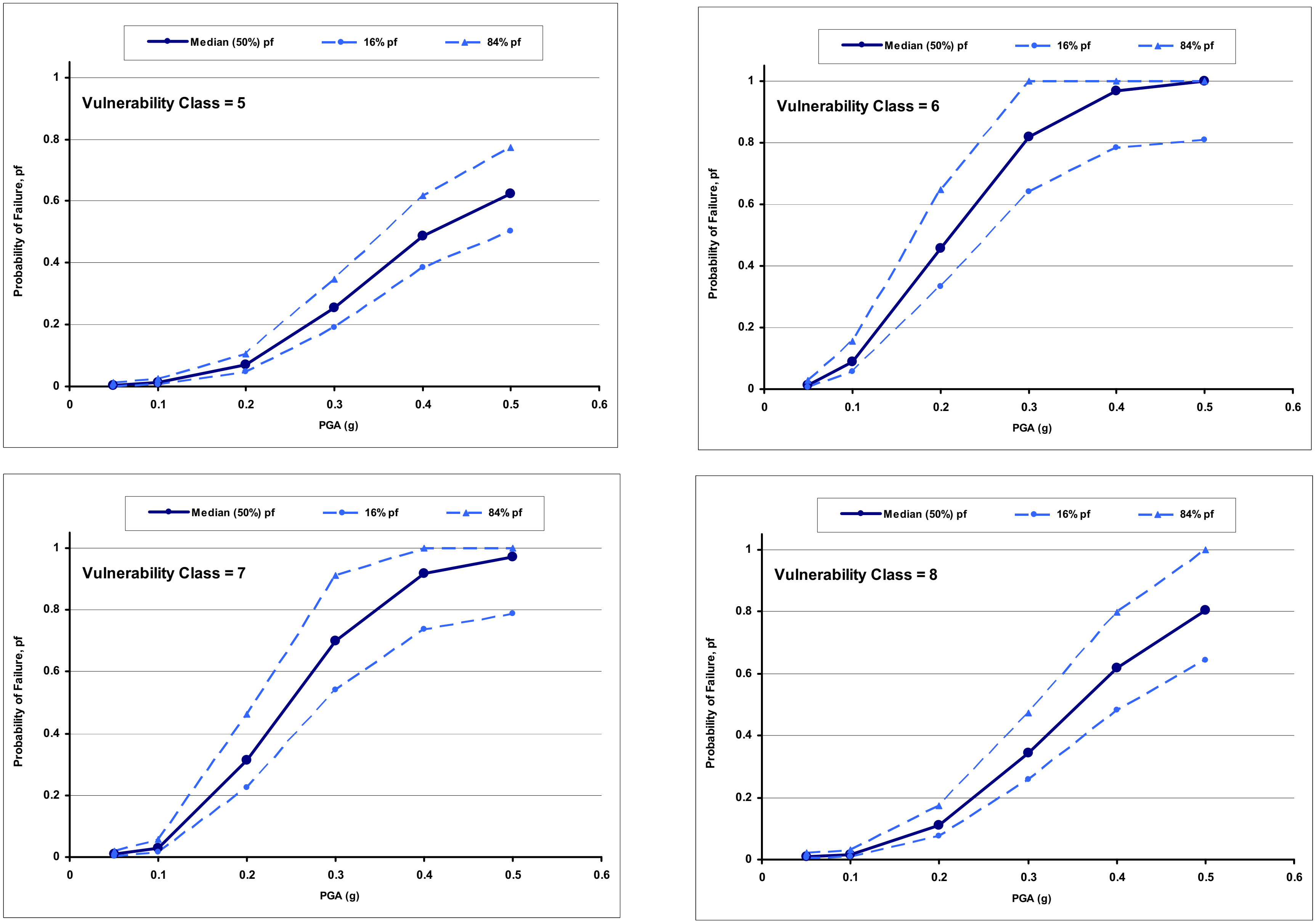




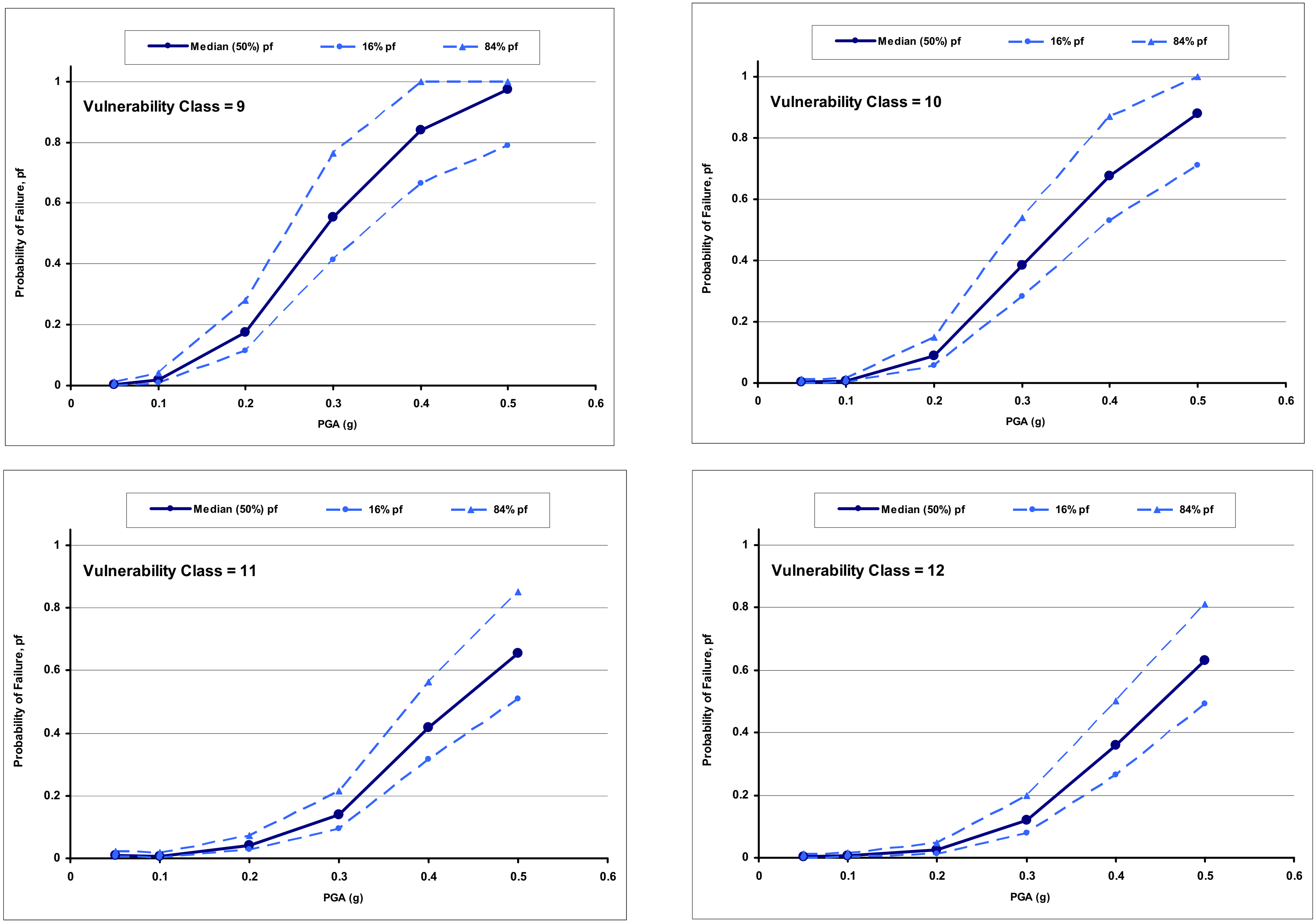




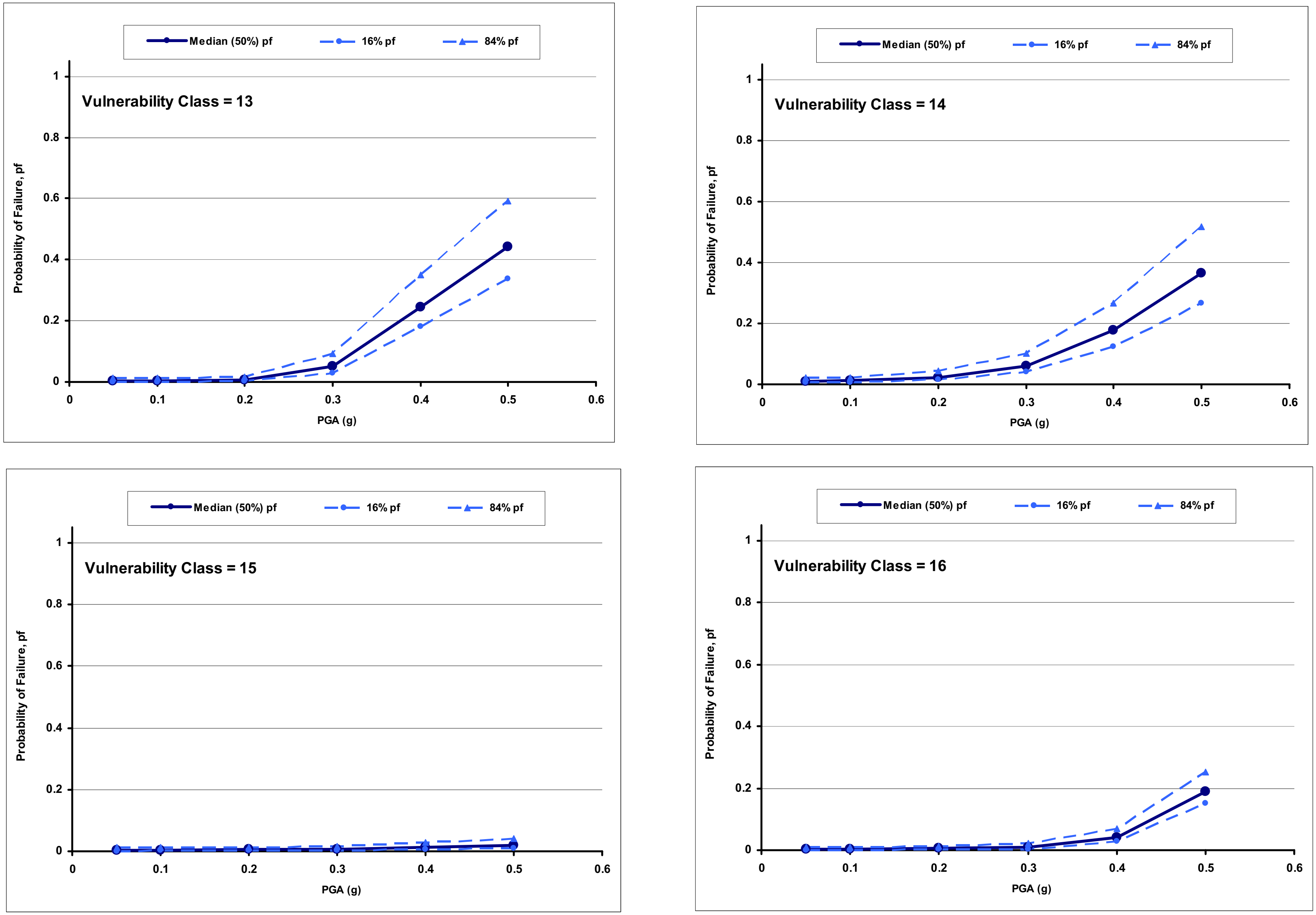
Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for M=6.5 and IFB=2 feet for Vulnerability Classes 1, 2, 3 and 4	Figure 6-137a
URS	Project No. 26815621		



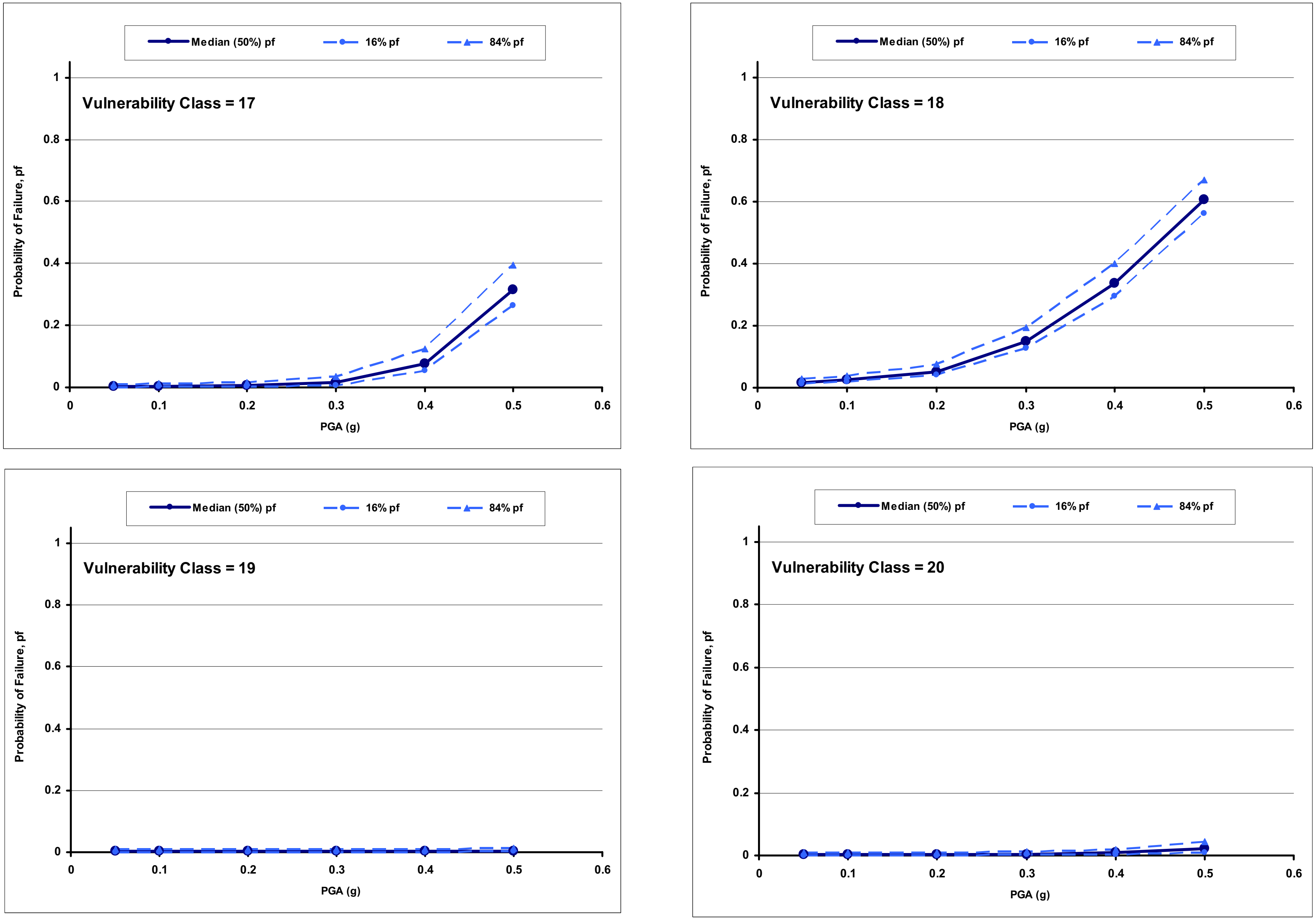
Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for M=6.5 and IFB=2 feet for Vulnerability Classes 5, 6, 7 and 8	Figure 6-137b
URS	Project No. 26815621		



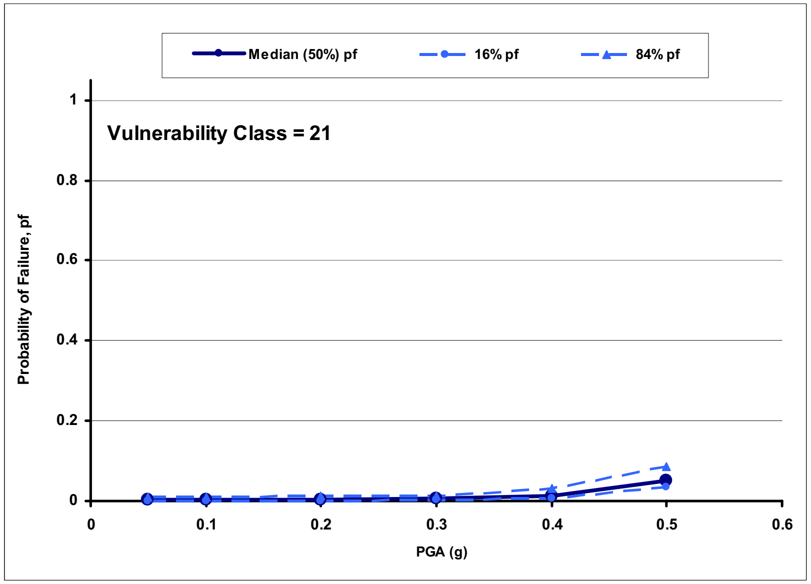
Delta Risk Management Strategy (DRMS) Levee Fragility	Estimated Failure Probability at 16%, 50%, and 84% confidence levels for M=6.5 and IFB=2 feet for Vulnerability Classes 9, 10,11 and 12	Figure 6-137c
URS — Project No. 26815621		

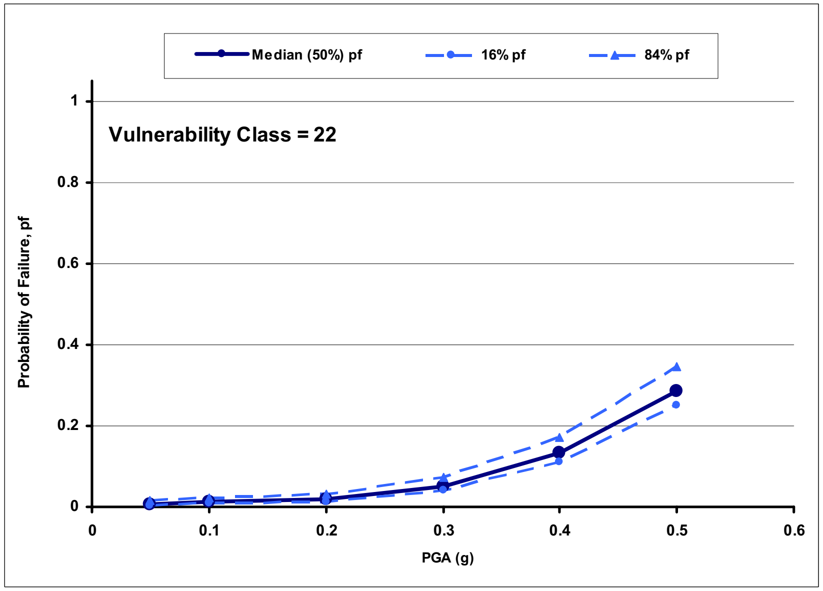


Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for M=6.5 and IFB=2 feet for Vulnerability Classes 13, 14,15 and 16	Figure 6-137d
URS	Project No. 26815621		

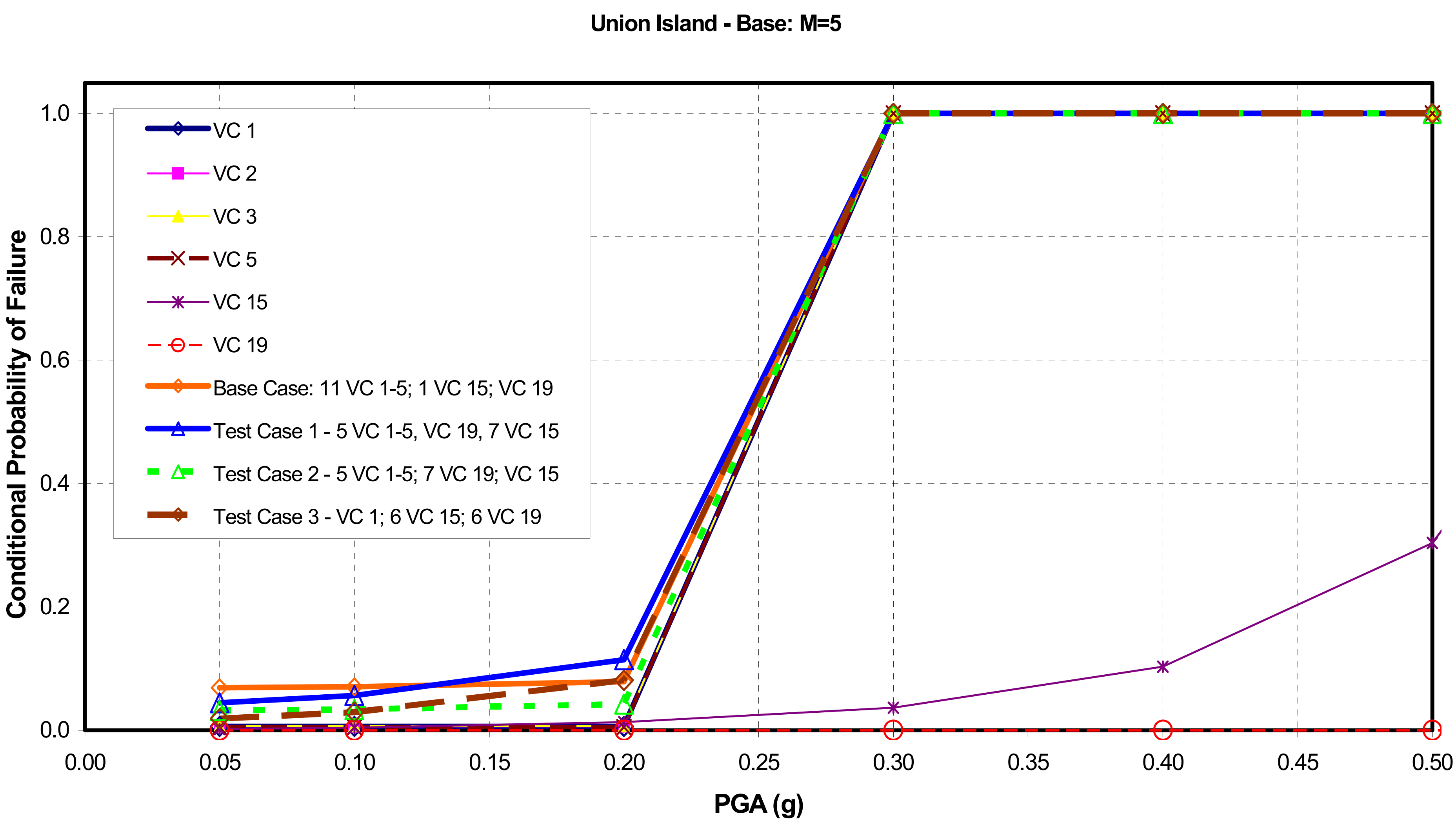


Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for M=6.5 and IFB=2 feet for Vulnerability Classes 17, 18,19 and 20	Figure 6-137e
URS	Project No. 26815621		

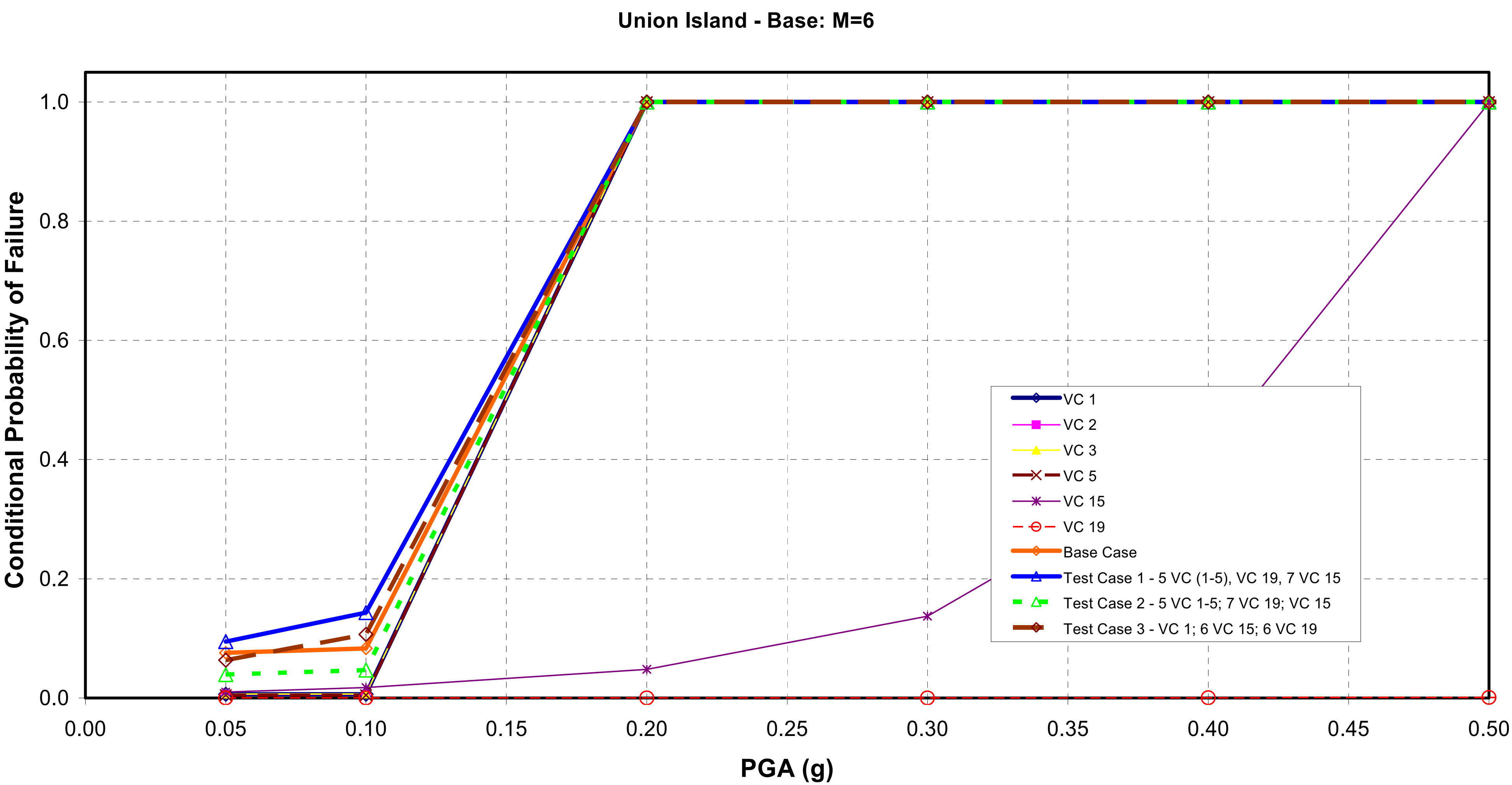




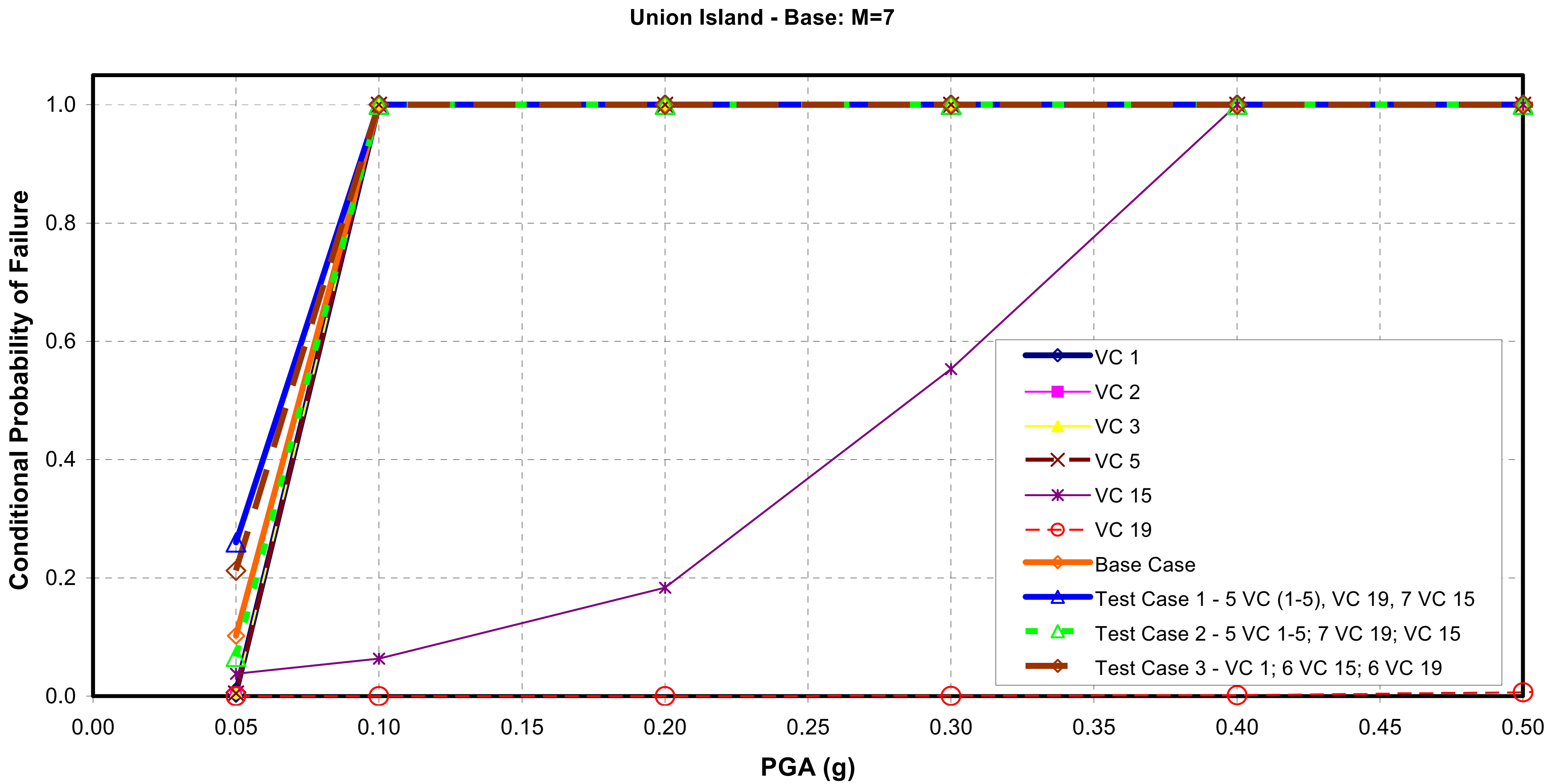
Delta Risk Management Strategy (DRMS) Levee Fragility	Estimated Failure Probability at 16%, 50%, and 84% confidence levels for M=6.5 and IFB=2 feet for Vulnerability Classes 21 and 22	Figure 6-137f
URS / Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Sensitivity of Island Fragility Curve to the Vulnerability Class Assignment of Levee Reaches Union Island, M=5	Figure 6-138a
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Sensitivity of Island Fragility Curve to the Vulnerability Class Assignment of Levee Reaches Union Island, M=6	Figure 6-138b
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Sensitivity of Island Fragility Curve to the Vulnerability Class Assignment of Levee Reaches Union Island, M=7	Figure 6-138c
URS	Project No. 26815621		

Appendix 6A
Step-by-Step Hand Calculation
for a Selected Vulnerability Class (VC-10),
Magnitude (M-6.5), and Free Board (2 feet)

Appendix 6A
Step-by-Step Hand Calculation for a Selected Vulnerability Class (VC-10), Magnitude (M-6.5), and Free Board (2 feet)

6A1.0 Introduction

The consulting team conducted the following calculation steps to determine the best-estimate values for use in the hand calculation. However, at each step the required simulations to represent the contribution of the uncertainties around the mean are highlighted for the reader but not calculated by hand to avoid making this simple document too cumbersome.

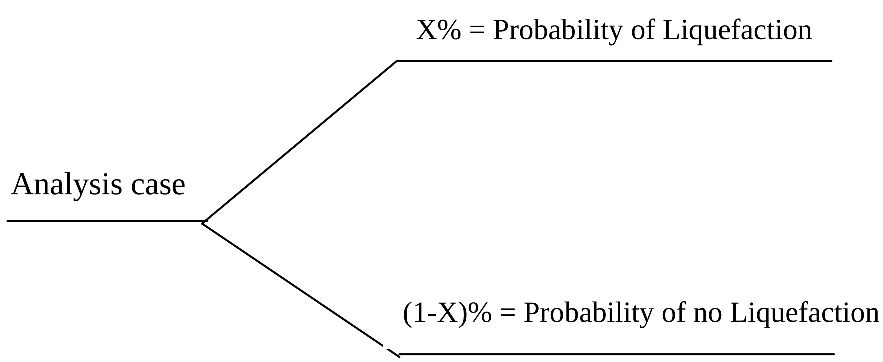
This example case represents the following conditions of Vulnerability Class 10 and loading values:

- Clayey levee fill (non liquefiable)
- **M** 6.5
- 2 feet of free-board
- Liquefiable foundation sand
- $N_{1\text{-}60\text{-}CS}$ = 5 to 10
- Peat thickness = 10' to 20'
- Reference PGA used: 0.2g, 0.3g, and 0.4g

Table 6-1 of the Seismology Technical Memorandum (URS/JBA 2007a) defines the vulnerability classes.

This particular class represents a cross section on the west side of Bacon Island near the northern corner of Palm Track. The figures in Attachment 6A-1 (at the end of this appendix) show a site plan/cross section and a drawing prepared during the original investigation.

The following logic tree approach is adopted for each vulnerability class to allow the representation of the probability of liquefaction and the probability of no liquefaction.



The contribution from the two branches to the failure probability is calculated in the following manner:

P_f(over all) = X% * P_f(displacement for branch X) + (1-X%)* P_f(displacement for branch (1-X)) (1)

6A1.1 Typical Cross Section

Figure 6A-1 shows a typical cross section.

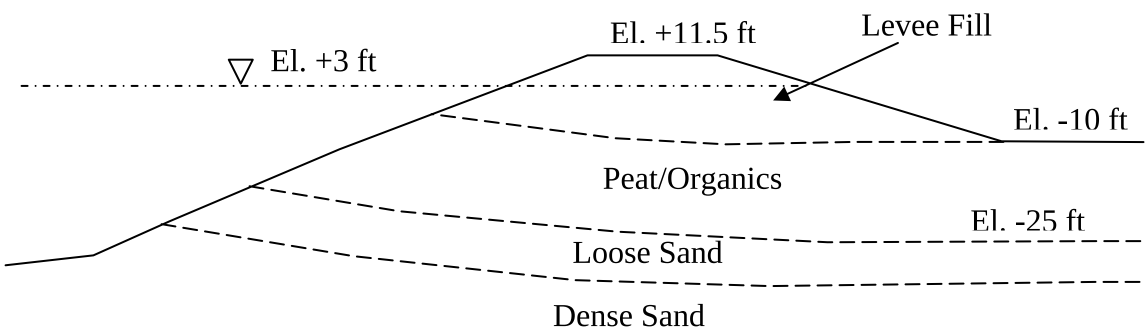


Figure 6A-1: Bacon Island – Cross Section No. 1

6A1.2 Basic Data

The crest and island floor elevations were corrected to account for subsidence and difference in datum from the original section shown in the attached site plan/cross section and site drawing.

- Crest elevation =11.5 ft (North American Vertical Datum of 1988 [NAVD88])
- Landside toe elevation = -10 ft (NAVD88)
- Levee fill: Silty/sandy clay
- Peat/organic thickness: 15 ft
- Magnitude: 6.5
- Fines content of the foundation loose sand = 15%

6A2.0 Step-1: Estimate Probability and Distribution of $N_{1\text{-}60\text{-}CS}$

For this class, the range of $\mathbf{N_{1\text{-}60\text{-}CS}}$ is between 5 and 10. For purposes of illustration, the consulting team chose the value of 8, as shown in Figure 6A-2, as being the closest to the best estimate. In the complete simulation, the range is fully sampled (100 points) for all $N_{1\text{-}60\text{-}CS}$ occurrences.

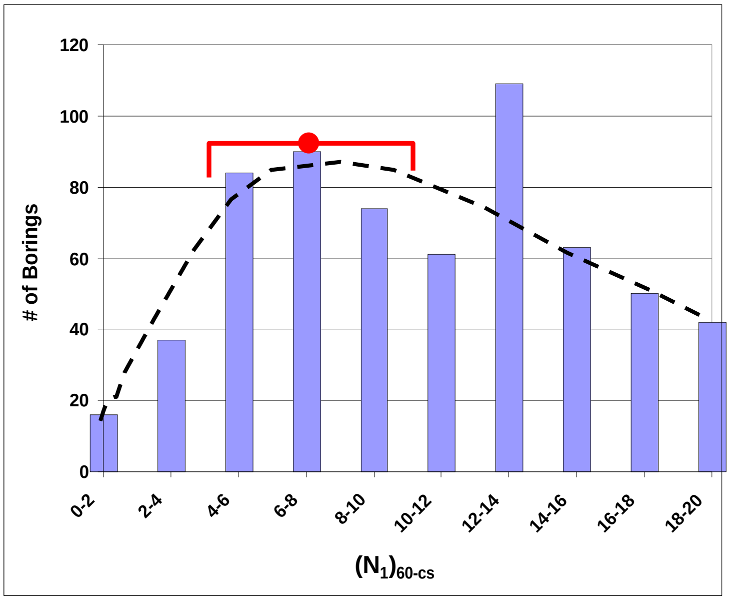


Figure 6A-2: $N_{1\text{-}60\text{-}CS}$ Distribution for Loose Foundation Sand with $N_{1\text{-}60\text{-}cs} < 20$

6A3.0 Step-2: Estimate Residual Shear Strengths (Sr)

The consulting team used the Seed and Harder (1990) relationship and estimated the range corresponding to the best estimate **$N_{1\text{-}60\text{-}CS}$**. For purposes of illustration, the team chose the best estimate value of Sr, which is 200 psf, as shown on Figure 6A-3. However, for the representation of the uncertainties, a range of Sr is used with FLAC to calculate the various deformation functions (deformation versus PGA).

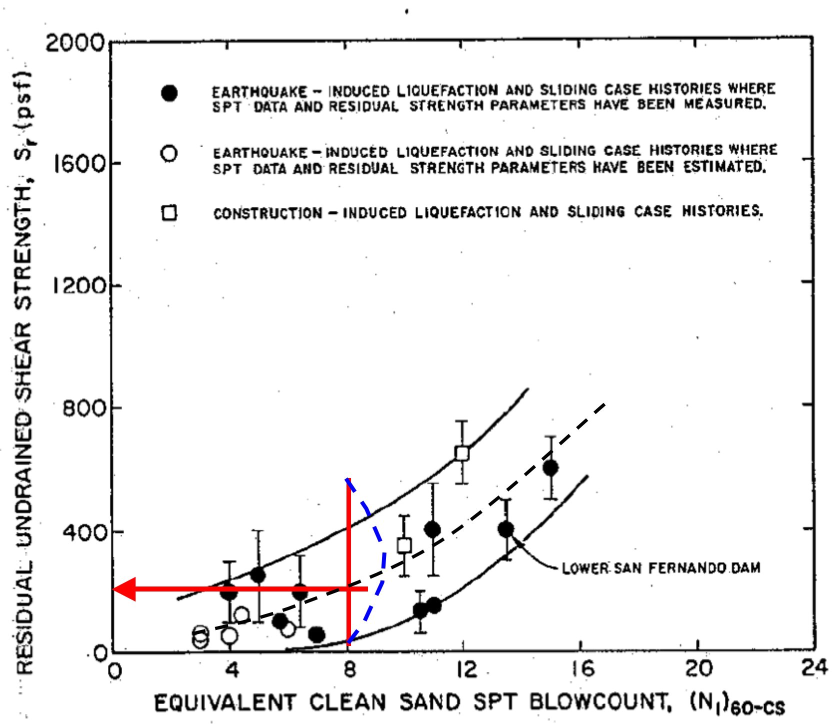


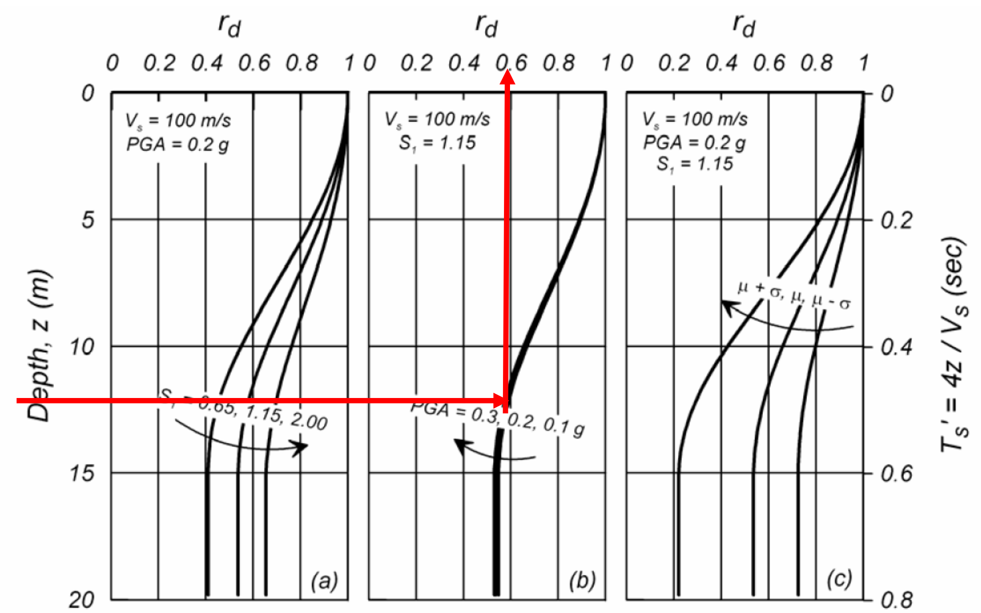
Figure 6A-3: Residual Shear Strength (Sr) VS ($N_{1\text{-}60\text{-}cs}$)
(Seed and Harder 1990)

6A4.0 Step-3: Calculate Cyclic Stress Ratio (CSR)

The team calculated r_d from Figure 6A-4, as shown below. As shown on the figure, r_d is equal to 0.6.

From Figure 6A-5, the team calculated the best-estimate peak crest accelerations (PCA) from the reference PGA (0.2g, 0.3g, and 0.4g). The PCAs are 0.22g, 0.28g, 0.33g, respectively. However, during the full analysis, the simulation accounts for the full range around the mean values.

From Equation (2), below, the team calculated the cyclic stress ratio (CSR).



Sur (psf)

Figure 6A-4: r_d vs Depth
(Tadahiro et al. 2007)

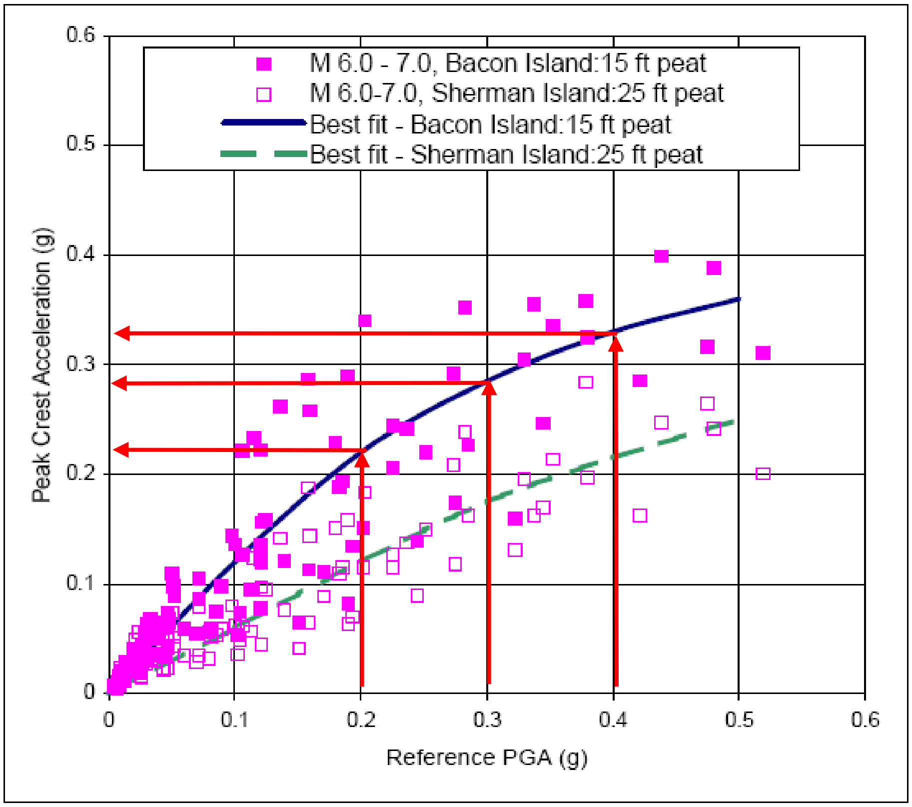


Figure 6A-5: Reference PGA versus Peak Crest Acceleration
(Data from Tadahiro et al. 2007)

Equation (3), below, of Section 6 of the Levee Vulnerability Technical Memorandum (URS/JBA 2008c) is not used for foundation CSR calculation; it is used for the liquefaction of the levee only. The conventional equation shown below is used to calculate the best estimate CSR for the three selected reference PGAs for liquefiable foundation sands.

CSR= 0.65 r_d (a_{max}/g) (Vertical total stress/Vertical effective stress)
= 0.65* 0.6*(a_{max}/g)* [(115* 21.5+70*15+125*2.5)/(115* 21.5+70*15+125*2.5-30.5*62.4)] (2)

CSR (PCA-0.22) = 0.16

CSR (PCA-0.28) = 0.22

CSR (PCA-0.33) = 0.26

6A5.0 Step-4: Calculate Probability of Foundation Liquefaction

Based on the values of CSR and the range of $N_{1\text{-}60\text{-}CS}$, the probability of liquefaction is estimated as shown in Figure 6A-6. The probability of liquefaction is automatically calculated from equation (3). For the three CSR values above, the probabilities of liquefaction are estimated to be 98 percent, 100 percent, and 100 percent for CSRs of 0.16, 0.22, and 0.26, respectively. Figure 6A-6 (for **M** 7.5) is provided only to illustrate the process of estimating the probability of liquefaction; Equation (3) is used instead.

After the probability of liquefaction is evaluated, the team went to logic diagram and applied values of X percent and (1 - X) percent for each CSR (or each PGA) value. In the current case, these values are:

X =98% and (1-X) =2%

X =100% and (1-X) =0%

X =100% and (1-X) =0%

For the case where the probability of no liquefaction is greater than zero, the team performed the same steps shown below and weight-averaged the probability of deformation contribution from both the 2 percent no liquefaction and the 98 percent liquefaction, as shown in Equation (1). For the no-liquefaction case, the team used corresponding deformation curves versus PGA, which are different from the liquefied foundation deformation curves.

As opposed to the best-estimate illustration provided here, the simulation will consider 500 point values distribution for each CSR and for the range of deformation.

$$P_L\left(N_{1,60}, CSR, M, \sigma_v', FC\right) = \Phi\left[-\frac{\begin{pmatrix} N_{1,60}\cdot(1+0.004\cdot FC) - 13.32\cdot\ln(CSR) - \\ 29.53\cdot\ln(M) - 3.70\cdot\ln(\sigma_v') \\ +0.05\cdot FC + 44.97 \end{pmatrix}}{2.70}\right] \qquad (3)$$

where

P_L = the probability of liquefaction in decimals (i.e., 0.3, 0.4, etc.)

$N_{1,60}$ = foundation $N_{1\text{-}60}$

CSR = cyclic stress ratio

M = earthquake magnitude

σ_v' = effective overburden stress

FC = fine contents

Φ = the standard cumulative normal distribution

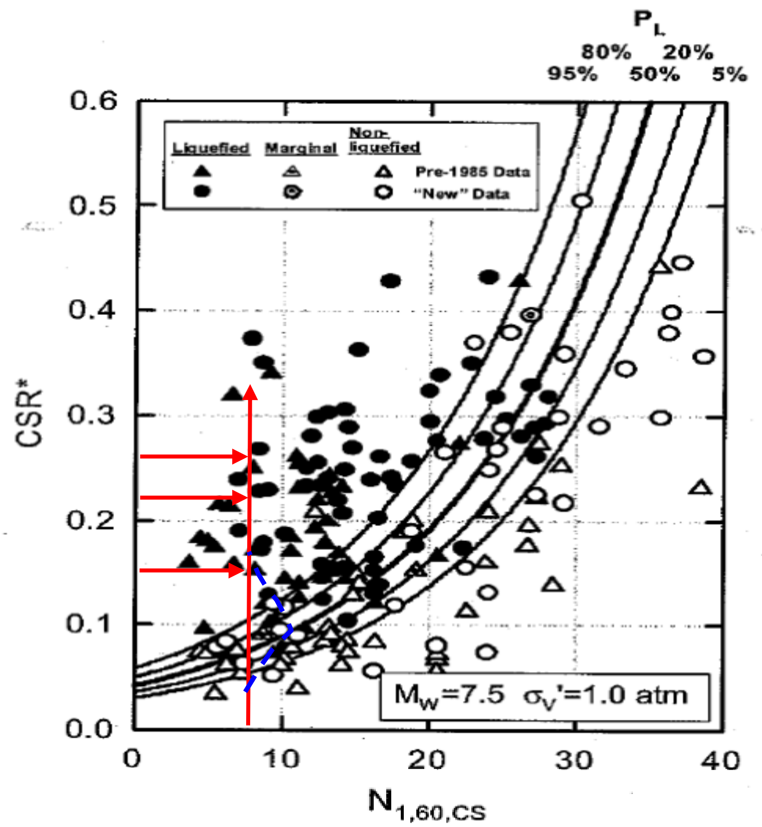


Figure 6A-6: Probabilistic SPT-Based Liquefaction Triggering Correlation
(Source: Seed et al. 2003)

6A6.0 Step 5: Calculate Deformations

The consulting team calculated deformations given PGA. For the three illustrative reference PGAs (0.2g, 0.3g, and 0.4g), we calculated the deformation from Figure 6A-7 (deformation curves for liquefiable foundations; other curves for other cases). The horizontal deformation curve corresponding to $N_{1\text{-}60\text{-}CS} = 8$, shown in Figure 6A-7 is used. The calculated best-estimate deformations for each PGA are approximately: 1.3 feet, 2. 5 feet, and 3.4 feet, respectively. However, the simulation will consider the entire range (500 points) of deformations for each PGA.

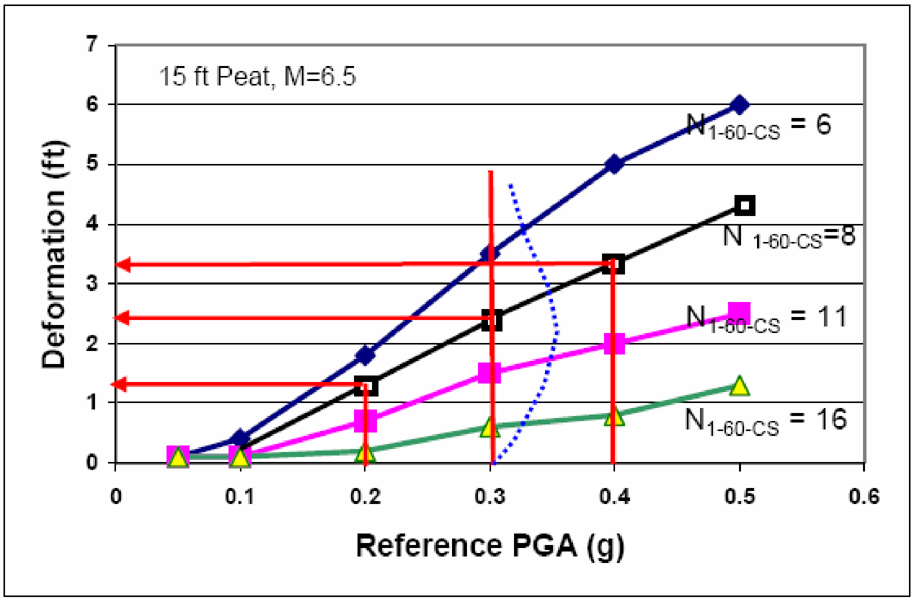


Figure 6A-7: Deformation versus Reference PGA for VC-10

6A7.0 Step 6: Calculate Probability of Levee Failure Given Deformation

For each deformation value, the team calculated the relative vertical deformation.

Dv/In-FB = ½. Dh/In-FB (initial freeboard is 2 feet for this case)

For 1.3 ft ⟶ Dv/In-FB = 0.325 or 32.5%

For 2.5 ft ⟶ Dv/In-FB = 0.625 or 62.5%

For 3.4 ft ⟶ Dv/In-FB = 0.85 or 85.0%

The probability of failure was calculated for each relative deformation. For this case, the best estimate probability values are approximately: 8 percent, 40 percent, and 85 percent for PGAs of 0.2g, 0.3g, and 0.4g, respectively, as shown Figure 6A-8. However, for each value of deformation (Figure 6A-7) a simulation for the full range of probabilities (500 points) is performed. For this case, the team used the best-estimate values shown with red dots in Figure 6A-8. These were then plotted in Figure 6A-9. The hand-calculated values are well within the confidence bounds. The difference in the value at 0.4g could be the result of the skewed distribution of the failure probability density function where the mean is higher then the median.

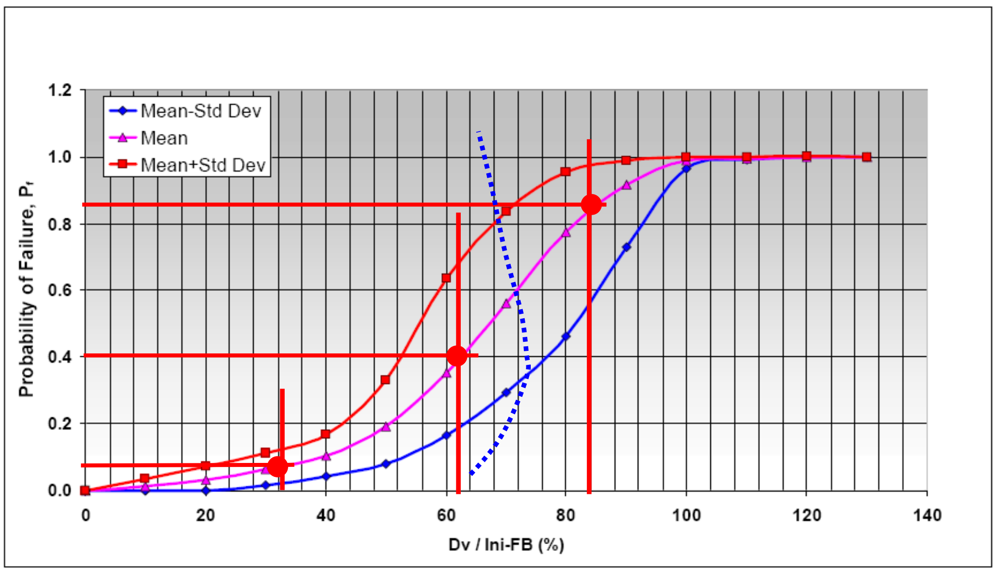


Figure 6A-8: Probability of Levee Failure versus Dv/Ini-FB

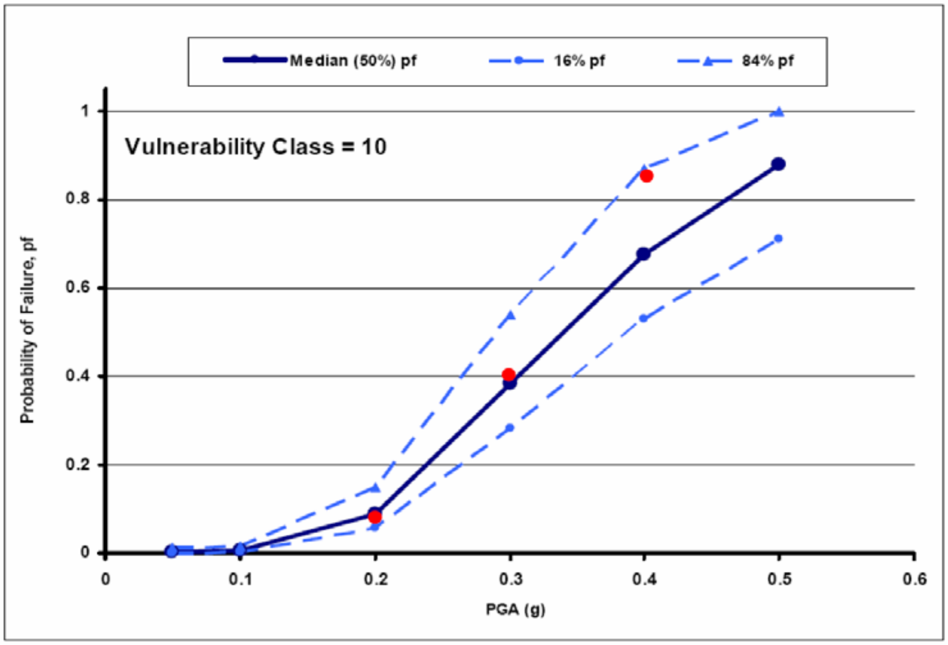


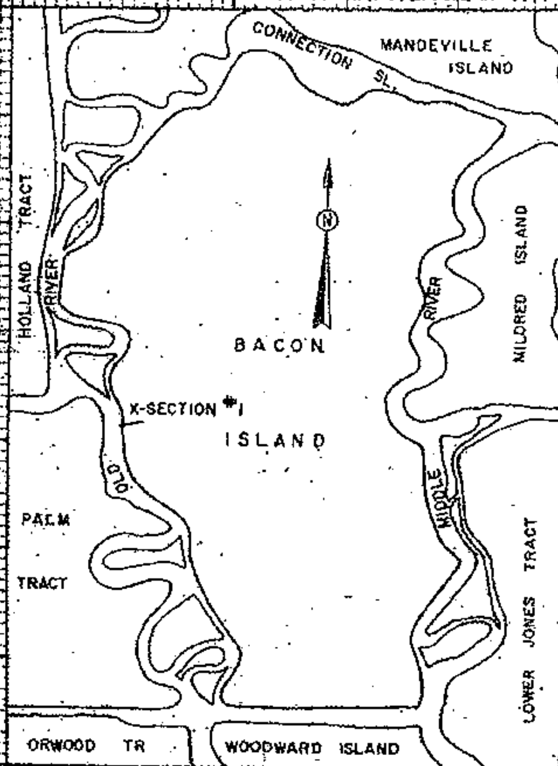
Figure 6A-9: Fragility Function for VC-10 and Best-Estimate Values

Site Plan/Cross Section No. 1 and Drawing

NOTES:

GRAPHIC LOGS ARE BASED ON VISUAL CLASSIFICATION
ALL BORINGS ARE ONE INCH DIAMETER EXCEPT WHERE NOTED
HAMMER WEIGHT: 1"-18 LBS.
2"-140 @ 175 LBS.

DRILLING DATES:
1" HOLES-NOV. 11, 1957 TO NOV. 18, 1957
2" HOLES-NOV. 18, 1957 TO DEC. 5, 1957
BARGE HOLE-APRIL 9, 1958



LOCATION MAP

LEGEND

BLOWS PER FOOT (P INDICATES PUSH, W INDICATES WASH)

DRY UNIT DENSITY IN POUNDS PER CUBIC FOOT

UNCONFINED COMPRESSIVE STRENGTH, K_c Kg/cm^2

UNCONFINED COMPRESSIVE STRESS AT 10% STRAIN, K_{10} Kg/cm^2

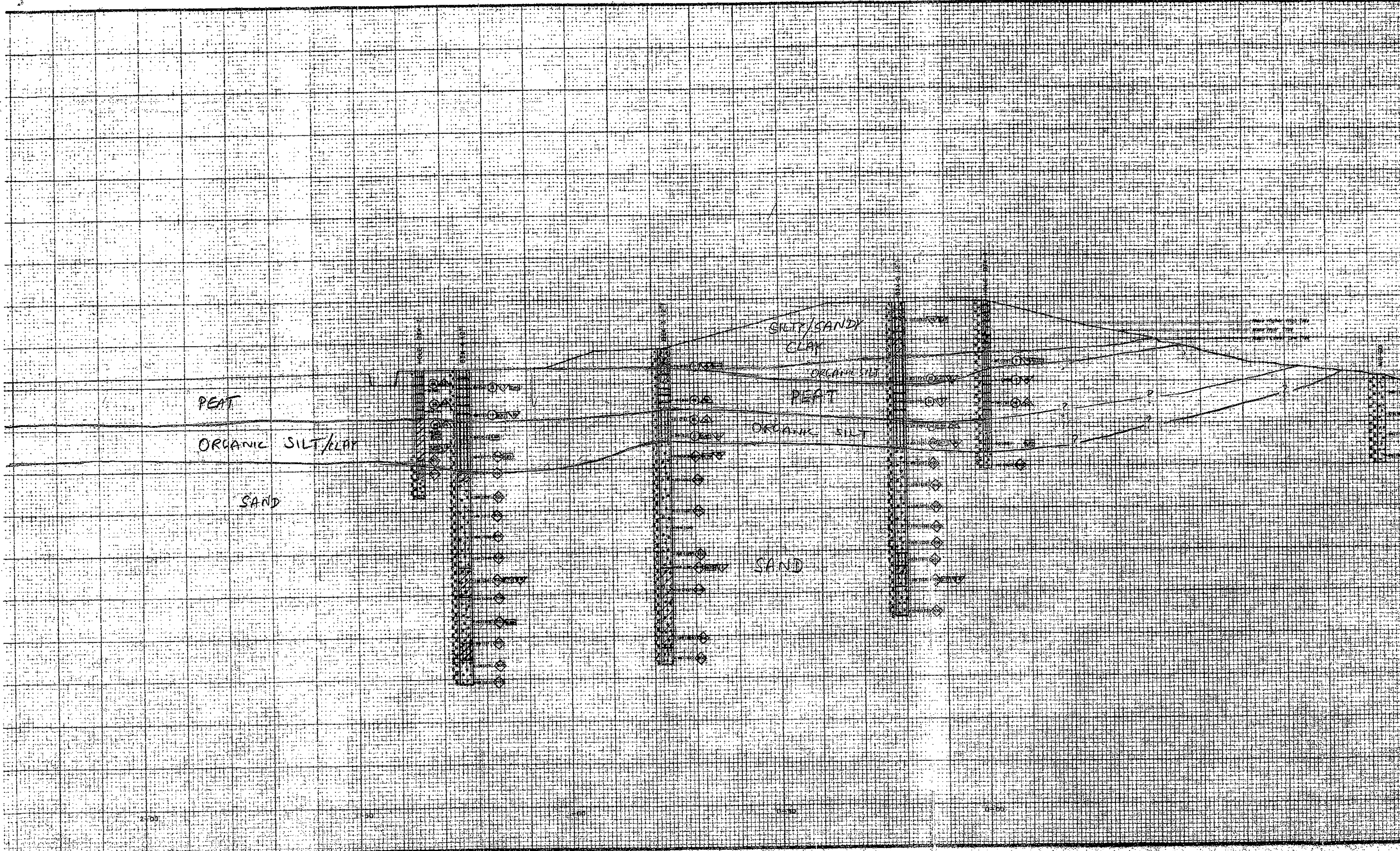
LOSS ON IGNITION IN PERCENT

MAXIMUM SIEVE SIZE RETAINING 50% OF SAMPLE BY WEIGHT, D_{50}

SPECIFIC GRAVITY

SILT	ORGANIC CLAY
PEAT	SILTY PEAT
CLAY	SILTY CLAY
SAND	SILTY SAND
ORGANIC SILT	SAND WITH SILT LENSES

BACON ISLAND CROSS SECTION NO 1


SILTY/SANDY
CLAY
ORGANIC SILT
PEAT
ORGANIC SILT
PEAT
ORGANIC SILT/CLAY
SAND
SAND

Tables

Figures

This section presents a summary of the analyses and results of the flood risk. Section 7.1 through 7.4 provide a summary of the flood risks from storm inflows and tides and estimate their corresponding stages throughout the Delta and Suisun Marsh. Section 7.5 presents the results of flood-related levee breaches and island flooding since 1900. Sections 7.6 though 7.14 discuss the flood-related failure modes and the procedures and method used to develop the levees' conditional probabilities of failure given flood stage. Section 7.15 summarizes the findings and observations of the flood risk analysis. Detailed discussion of the flood risk can be found in the Flood Hazard Technical Memorandum (TM) (URS/JBA 2008a), and historical levee failures and the levee vulnerability analyses are discussed in the Levee Vulnerability TM (URS/JBA 2008c).

7.1 DELTA INFLOW

Average daily inflows into the Delta are available from the California Department of Water Resources (DWR) website for the 50 water years (WYs) from October 1, 1955, through September 30, 2005 (WYs 1956 through 2005). These data include average daily inflows for all major streams entering the Delta and the total inflow into the Delta (DWR 2006). The major streams or stream groups included in the dataset are Sacramento River, Yolo Bypass, Cosumnes River, Mokelumne River, San Joaquin River, and miscellaneous streams. Flows in miscellaneous streams are primarily Calaveras River flows. The locations of the stations used in the analysis are shown on Figure 7-1. Measured average daily inflows into the Delta are summarized graphically on Figure 7-2. Figure 7-2a presents total inflows into the Delta for the period of record. Figure 7-2b presents inflows from Sacramento River and Yolo Bypass, the major contributors to total inflow (>80 percent). Figure 7-2c presents inflows from San Joaquin River, the third-largest contributor to total inflow (approximately 10 percent).

One of the objectives of these studies is to develop estimates of hydrologic characteristics of the Delta under current conditions in the tributary watersheds. Thus, it was necessary to examine the available Delta inflow data to determine if these data adequately reflect current watershed conditions or if the statistical characteristics of the data have significantly changed during the period of recorded data due to new reservoirs in the watersheds, developments in the watershed, land use changes, and other factors.

As shown on Figure 7-2, the period from approximately 1987 to 1993 had relatively fewer large flood inflow events than before 1987. This six-year period had below-average precipitation and is the longest period of below-average rainfall between 1955 and 2005. This pattern suggests that during the 50-year period of record, more drought years occurred in the recent period of record than in earlier years. It is, therefore, desirable to use the entire period of available inflow record to avoid or reduce any statistical bias caused by the recent drought years.

Several dams and reservoirs, developments, and other changes have been constructed in the watersheds tributary to the Delta, and the impacts of these changes on inflows into the Delta were reviewed in the DRMS studies. Construction of new dams and reservoirs in the tributary watersheds could be a large contributor to changes in characteristics of runoff to the Delta. However, as discussed in the following paragraphs and in more detail in the Flood Hazard TM (URS/JBA 2008a), it is believed that changes related to reservoirs and watershed developments are associated with water supply and environmental flow releases from the reservoirs and have minimal impact on flood inflows into the Delta.

Table 7-1 is a partial list of dams and reservoirs that have been constructed in the tributary watersheds. As shown in Table 7-1, the reservoirs behind Oroville and New Melones dams are two of the largest reservoirs constructed during the period of available inflow measurements. Analyses were made to determine if Oroville Dam and other watershed changes since construction of the dam had a significant impact on Delta inflows from Sacramento River and Yolo Bypass. Similar analyses were made with regard to San Joaquin River since construction of New Melones Dam.

As shown on Figure 7-2, the incremental addition of reservoirs in the Sacramento or San Joaquin River watersheds between the beginning of the Delta inflow record (1955) and the essential completion of reservoir construction in the watersheds (1968 for the Sacramento River, and 1978 for the San Joaquin River) did not have a noticeable impact on lowering annual peak day Delta inflows. Although new reservoirs constructed during the early years of the inflow record undoubtedly provided some incremental increase in flood protection (by reducing flows at and downstream from the new dams), it is possible that some of the flood attenuation provided by the new reservoirs may have occurred anyway due to floodplain storage, thereby reducing the apparent impact of the reservoirs on Delta inflows. This result is generally consistent with the results presented by Florsheim and Dettinger (2007), which showed that the pattern of levee breaks in the Delta was the same in the first half of the twentieth century (before major dam construction) as it was in the last half of the twentieth century (after major dam construction).

Table 7-2 summarizes the measured Delta inflows for three periods. For the Sacramento watershed, the periods are the pre-Oroville Dam period (1956–1968), the post-Oroville Dam period (1969–2005), and the entire period of record. For the San Joaquin River watershed, the periods are the pre- and post-New Melones Dam periods (1956–1979 and 1980–2005, respectively), and the entire period of record. Because no major storage projects have been developed on the Delta tributaries since construction of New Melones Dam, the post-New Melones Dam period is considered to represent current conditions. As shown in Table 7-2, the average number of days per year with high Delta inflows (>100,000 cubic feet per second [cfs]) from San Joaquin River is greater during current conditions in the watershed than before New Melones Dam was constructed, and the average number of days per year of low Delta inflows (<100,000 cfs) is less. This situation is contrary to what would be expected if New Melones Dam and reservoir had a significant impact on flood inflows. Similarly, Table 7-2 shows more high (>100,000 cfs) and fewer low (<100,000 cfs) total inflows into the Delta from the Sacramento River watershed since the construction of Oroville Dam.

A statistical analysis was performed to compare the annual peak day Delta inflows for the following stations between two potentially distinct periods:

- Sacramento River + Yolo Bypass: Before 1968 versus after 1968
- San Joaquin River: Before 1979 versus after 1979

The data were tested by Shapiro-Wilk W test and were found to be lognormally distributed. Also, the variances were approximately equal between the two periods. Hence, the parametric *t*-Test, using the log-transformed data, was used to test whether data from the aforementioned periods were different from each other.

The statistical results are presented in Table 7-3. The *p*-values of the *t*-Test were above 0.05, indicating that the annual peak day Delta inflows were not significantly different from each other for the two periods, at the 5 percent significance level (i.e., 95 percent confidence level). Therefore, it is reasonable to combine data from all years together for subsequent analysis.

In summary, it was concluded that the available 50-year period of record data (WYs 1956 through 2005) should be used for the DRMS studies without adjustment for the following reasons:

1. Use of the entire period of available inflow record will reduce any statistical bias caused by the 1987 to 1993 drought years.
2. During major flood events before new reservoir construction, some, if not most flood attenuations were provided by floodplain storage, thereby reducing the impact of new reservoirs on Delta inflows and tending to make the 50-year data set more homogeneous.
3. No major changes in the Sacramento River watershed have occurred since 1968; thus, 38 years of the 50-year period of record represent approximate current watershed conditions.
4. Eleven of the largest 15 annual peak day Delta inflows from the Sacramento River and Yolo Bypass occurred during approximate current watershed conditions (see Flood Hazard TM [URS/JBA 2008a] for discussion).
5. Most of the major reservoirs in the San Joaquin River watershed were completed by 1979, meaning over half of the annual peak day Delta inflows during the 50-year period of record occurred during approximate current watershed conditions.
6. Eight of the largest 15 annual peak day Delta inflows from San Joaquin River occurred during approximate current watershed conditions (see Flood Hazard TM [URS/JBA 2008a] for discussion).
7. Additions to reservoir storage in the San Joaquin River watershed may not have significantly changed inflows into the Delta during major flood events but instead only reduced the amount of floodplain storage that has historically occurred.
8. Analyses of the annual peak day inflow data indicate no statistically significant changes in the data during the period of record.
9. Adjustment of the 50-year inflow record to reflect current watershed conditions would require numerous assumptions regarding reservoir operations and, more important, assumptions regarding downstream levee failures and floodplain storage and would probably incur more error than would result from using the inflow record without adjustment.

Another consideration in the DRMS studies is the season of high inflows into the Delta. It is anticipated that repairing damages in the Delta, due to any cause, will be more difficult during the high-inflow season and the repairs likely will take longer. Additionally, the possible impacts on Delta exports caused by damages may be different depending upon the time of year that the damage occurs. Thus, hydrologic characteristics in the Delta during different inflow seasons were considered in the studies. Figure 7-3 presents average daily Delta inflow versus time of the year for the period of record inflows. As shown on Figure 7-3, high inflows begin near the end of December and last until approximately mid-April. Between April 15 and December 15 maximum daily inflows are less than 200,000 cfs, and most of the time maximum daily inflows are less than 100,000 cfs, with the exception of one flood that occurred during October 14–17, 1962. Thus, only two inflow seasons are considered in these studies: the high-inflow season (December 16 through April 15) and the low-inflow season (April 16 through December 15).

7.2 FLOW-FREQUENCY ANALYSIS

The magnitude of the Total Delta Inflow (TDI) for a hydrologic event of a given probability can be estimated from a frequency analysis of the measured annual peak inflow events. Table 7-4 summarizes the annual peak TDIs for each of the 50 WYs of record, the 50 high-inflow seasons in the period of record, and the 49 low-inflow seasons in the period of record.

A commonly accepted frequency distribution of hydrologic events is the Log Pearson Type III (LPIII) distribution. This frequency distribution is recommended by the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data published by the USGS (1982). LPIII uses three distribution parameters: mean, standard deviation, and skew. Annual probabilities were calculated by using the data in Table 7-4 to estimate the distribution parameters.

Results of the LPIII analyses are presented in Table 7-5, and on Figures 7-4, 7-5, and 7-6 for all WYs (all seasons), high-inflow seasons, and low-inflow seasons, respectively. The distributions of seasonal peak daily inflows into the Delta are compared to the all-seasons distribution on Figure 7-7. Table 7-6 presents the estimated parameters for each distribution.

The frequency analyses of Delta inflows described above was divided into 50 ranges or bins of TDI, with each bin assigned the annual probability for the midpoint of the bin. The bins are equally spaced in log-space. Estimates are provided for 5 different confidence limits ranging from 5 percent confidence that the inflow will not be exceeded to 95 percent confidence that the inflow will not be exceeded. The estimated probability of an inflow being in each of the 50 ranges is presented in Table 7-7 for each of the five confidence limits.

The 50 bins resulting from the above analysis represent the range of inflows likely to occur in the Delta (i.e., from 0 to 2,000,000 cfs). The Risk Analysis will use the flow from each bin in the risk analysis to cover the range of possible inflows. Each flow is associated with an annual probability that the flow will occur (the probabilities are included in Table 7-7). Because uncertainty exists in the estimate of the annual probability that a given flow will occur, the risk analysis will also associate a confidence bound with each annual probability.

7.3 DELTA INFLOW PATTERNS

Flood frequency as used in this risk assessment has a slightly different definition than the definition typically used in Delta flood studies. For purposes of the risk assessment, flood frequency in these studies provides a measure of the annual probability that the total inflow into the Delta will be equal or exceeded. Many different inflow patterns into the Delta can produce any selected annual probability of occurrence, each of which could have its own set of water surface elevations (WSEs) in the Delta. For example, four storm events in the period of record have peak total daily inflows to the Delta that exceeded the 10-year event. For the largest storm of record, February 1986, San Joaquin River was not a significant contributor to the storm event, and Cosumnes and Calaveras rivers were. For the second-largest storm, January 1997, both Cosumnes and San Joaquin rivers experienced extreme events, and Calaveras River did not. The third-largest storm occurred only on Sacramento River. Finally, for the fourth-largest storm, March 1983, an extreme event occurred only on San Joaquin River. The risk assessment needs to be able to account for all of these possible inflow patterns.

As described above, inflow to the Delta is from several sources, including the Yolo Bypass (Yolo), Sacramento River (Sac), Cosumnes River (CSMR), Mokelumne River (Moke), San Joaquin River (SJR), and miscellaneous streams (misc), primarily the Calaveras River. The sum of these sources of inflow is defined as the TDI. Given the variability of flows in the streams making up TDI, many combinations of flows that could account for any TDI observed are possible. This section describes a method for developing different combinations of Delta inflow patterns that could account for any selected TDI.

A somewhat arbitrary cutoff value of 80,000 cfs was selected to eliminate nonstorm event flow rates. A TDI of 80,000 cfs corresponds to a 50 percent confidence peak annual return period flow of less than two years.

Daily average flows in Sacramento River are not highly variable (the coefficient of variation is only 0.084) and that most of the variability is due to flows in Yolo Bypass. Flows in these two channels are not independent because the flows originate from the same watershed. Upstream of the City of Sacramento, when the stage in Sacramento River reaches the crest of Fremont Weir, flow in Sacramento River spills over the weir into Yolo Bypass. This spill condition occurs at a flow of about 55,000 cfs in Sacramento River, as measured below the weir. Most of the increase in flow above 55,000 cfs goes over the weir into Yolo Bypass. The Yolo Bypass Working Group et al. (2001) developed a relationship between flows in the Sacramento River below Fremont Weir and spills over the weir. The relationship indicates that it is necessary only to predict one of the stream flows (Sacramento River or Yolo Bypass), and the other stream flow can be estimated. For this reason, the method presented below is used to predict the sum of flow in Sacramento River and Yolo Bypass.

The methodology for estimating flow in any of the contributing tributaries to the Delta given a specified TDI is to use a logistic regression relationship for each contributing inflow. The regression was structured such that the flow predicted from the regression could never exceed the flow possible in the tributary. The dependence between relationships was maintained by applying only the relationship to that portion of the flow not yet explained by any previously used relationship.

Table 7-8 lists the results of the logistic regression. The low r^2 values result from the large variability in the data. However, even with these small correlations, the equations reproduce the mean values for the flow distributions.

Figure 7-8 shows the results for the Sacramento River plus Yolo Bypass Delta inflow. The correlation coefficient for the fit is 0.94.

In addition to the above results, a relationship between the flow in Sacramento River and Yolo Bypass is needed to separate these two flows from the total. The correlation coefficient for the fit is 0.65. Figure 7-9 shows the relationship.

Figure 7-10 presents the results for San Joaquin River. The regression equations provide a reasonable fit, thought it slightly under predicts the main body of the data, due to the small number of cases where the remaining flow is large and the fraction of flow in San Joaquin River is small (approximately 10 percent of values). These events represent cases where a storm occurred on the Cosumnes River, but not the San Joaquin River.

Figure 7-11 presents the results for the miscellaneous inflows. The fit has an r^2 value of 0.94.

Figure 7-12 shows the results for the Cosumnes River. The r^2 value for the fit is 0.96, though it underestimates the peak annual flows.

The regression relationships reproduce the mean and median of the data well, except for the median of Cosumnes River inflows. For most of the rivers, the mean flow is centered within the bulk of the observed flows (e.g., halfway between the 25th and 75th percentiles), whereas, for Cosumnes River, the mean is almost at the 75th percentile. This percentile implies that the distribution of inflows from Cosumnes River is more skewed than the inflows from other rivers and, therefore, the regression will not reproduce the median values as well. Figures 7-13 through 7-16 compare measured to predicted flow for the Sacramento River plus Yolo Bypass, San Joaquin River, miscellaneous inflows, and Cosumnes River, respectively. All of the figures show a very good fit between the measured and predicted flows, except for the San Joaquin River cases in which the flows in other streams exceeded the flow in San Joaquin River. These values do not fit the relationship and need to be captured as part of the uncertainty analysis.

7.4 DELTA WATER SURFACE ELEVATIONS

WSEs throughout the Delta that are associated with various flood magnitudes and inflow patterns are needed to estimate risks of levee failure due to overtopping and/or high water. Delta WSEs were estimated from data on historic water levels measured at selected Delta gauging stations. Water levels, or stages, at the selected gauging stations were then used to interpolate stages at intermediate locations in the Delta.

7.4.1 Data

Tide data used in these analyses are tide elevations measured at the Golden Gate Bridge (NOAA 2005). The Golden Gate Bridge tide station was chosen for its long record of unbroken tide data dating back approximately 150 years. Tide levels at the Golden Gate station are independent of inflows into the Delta, but provide a geographically relevant measure of tailwater conditions that influence water levels in the Delta.

The California Data Exchange Center (CDEC) provides information on an extensive hydrologic data collection network, including automatic river stage sensors in the Delta. River stage data are provided primarily from the stations maintained by DWR and the United States Geological Survey (USGS). This stage data can be downloaded from CDEC's website (http://cdec.water.ca.gov/).

Stage data, since 1984, are provided on an hourly basis. For some gauging stations, 15-minute stage levels have been recorded for some inflow events since 1995. Figure 7-17 shows the stage gauging station locations selected for use in these studies, and presents the period of record for hourly and event data for each station. Gauging stations were selected based on station location, and length and reliability of available record.

7.4.2 Data Review and Adjustments

Stage records for the selected gauging stations contained some inconsistent data significant enough to have an impact on the analysis results. To assist in evaluation of the stage data, plots of daily stage versus time were created for each measuring station. These plots provide a picture of the normal stage range and also show apparent inconsistencies in the data. The data records were evaluated and, when possible, adjusted to eliminate apparent invalid data. The data records were reviewed to adjust or eliminate the following inconsistent data:

- Changes in station datum
- Measured stages greater than flood stage
- Missing and known invalid data
- Constant stage measurements
- Invalid recording intervals
- Incomplete daily records
- Conversion of data to common datum

7.4.3 Regression Analysis of Water Surface Elevations

Once maximum daily stage data were reviewed, invalid records removed, and conversion to North American Vertical Datum 88 (NAVD88) datum estimated for each station, the daily stage data for flood inflows were matched to the corresponding maximum daily tide data and the mean daily inflow data. The resulting data set is a daily record of maximum daily stage (NAVD88), maximum daily tide, and mean daily inflow from each of the six tributary inflows into the Delta.

This study focuses on the threat from high stages occurring during flood events. Most of the inflow data in the data sets represent low-inflow nonflood events. To minimize bias in the statistical analyses of WSEs, the inflow data sets were reduced to include only high-inflow events. Based on review of the data it was judged that only TDI magnitudes greater than 57,000 cfs should be included in the regression analyses.

Using the data on maximum daily tide, mean daily inflow, and measured adjusted stages at the gauging stations, multiple regression analyses were made for each of the stage-measuring stations. The regression analyses were made to determine best fit coefficients. Details on the regression analysis are provided in the Flood Hazard TM (URS/JBA 2008a).

At each station the measured WSE was compared to the WSE calculated using the coefficients developed from the regression. Figure 7-18 compares the calculated stage with the measured stage at Venice Island. Similar comparisons for other stations are provided in Appendix A of the Flood Hazard TM (URS/JBA 2008a). In addition, the observed annual peak at each station is compared to the predicted annual peak for stations with four or more years of data. For most stations, the root mean square error is equal to 0.34 feet or less. Only two stations, Benson’s Ferry and Liberty Island, have root mean square errors greater than one foot.

7.5 DELTA LEVEES AND HISTORICAL FAILURES

Delta levees were constructed over the past 150 years largely by farmers and reclamation groups who used light equipment and local, uncompacted sediments and organic matters, and did little or no foundation preparation. Foundations are composed of a complex mélange of river sediments and organic (peat) materials consisting of coarse-grained sediments, including gravels and loose, clean sands to soft, fine-grained materials such as silts, clays, and organics, including fibrous peat. The levee material consists of interfingered layers of loose sands, soft silts and clays, and peat.

Since 1900, 158 islands have been flooded as a result of levee breaches in the Delta (not including failures in Suisun Marsh). Records on Suisun Marsh levee failures are incomplete and consequently not included in the historical failures database. Failures in Suisun Marsh are more frequent due to the lower crest elevations of it levees. During the winter of 2005-06, Simmons Wheeler, Honker Bay Club, Fay and Van Sickle islands flooded during a relatively mild winter storm. These frequent floods have caused multiple overtopping of the Suisun Marsh levees. In a few places, the levees have been lowered to allow tidal exchange and tidal wetland restoration. Table 7-9a lists the number of island/tract breaches and their corresponding years of occurrence. A limited (and recent) number of failures in Suisun Marsh are listed at the bottom of Table 7-9a. Figure 7-19 illustrates the number of times islands or tracts have breached since 1900. Table 7-9b provides a chronological list of flooded islands since 1900. Figure 7-20 identifies the locations (when available) of the levee breaches that resulted in island/tract flooding. Most breach locations have been mapped except for few cases where information was not available.

In recent years, the levees have been built up to contain larger floods and have been upgraded and maintained to meet certain engineering standards (freeboard and geometry). Part of the recent changes include: (a) raising levees to meet higher flood protection level; (b) raising levees to compensate for foundation consolidation and settlement; (c) raising levees to mitigate for the continued subsidence (peat and organic marsh deposits) as a result of farming practices; (d) improving/increasing maintenance to mitigate/contain the higher stresses on the levee system due to higher hydrostatic heads. A plot of island cumulative breach trend is presented on Figure 7-21 for the last 106 years. For the period between 1900 and 2006, the mean annual frequency of island flooding corresponds to about 1.31 for all events, excluding earthquakes. The trend of the mean annual frequency of levee failures is about 1.19 for the period from 1900 to 1949 compared to 1.36 for the period from 1950 to 2006, showing a relatively similar trend between the 50 years prior to 1950 and the 56 years since 1950.

Figure 7-22a shows the cumulative number of levee breaches resulting in island flooding since 1950, and Figure 7-22b shows the numbers of flooded islands per annum since 1950. The “sunny weather” island flooding events are not included in these numbers. Data cutoff at 1950 was intentionally selected to remove older historical events during which levee configurations were different from current levees. These more-recent years represent a better data set for comparison with results of the predictive levee vulnerability numerical models. One should recognize that, since 1950, the levee geometry and crest elevation continued, nonetheless, to change slowly with time.

Further examination of the data (Figure 7-22a) indicates a mean annual frequency of island failures of 1.39 for the period between 1980 and 2006, compared to 0.80 for the period between 1950 and 1980. These trends indicate that during the last 26 years, the Delta levees have experienced a higher rate of levee failure than the period between 1950 and 1980 (30 years), despite the increasing maintenance efforts and subvention programs shown in Figure 7-22c.

A plot of the mean daily total Delta inflow (since 1955, the earliest date of available records) is presented on Figures 7-22d and 7-2(a). The storms of records for that period are shown in Table 7-9c. Although the cumulative daily mean inflow is constant for the period between 1955 and 2006 (red line in Figure 7-2[a]), the last 26 years experienced a prolonged drought between 1987 and 1993. The total mean daily inflow graph shows larger total daily storm inflows during the winters of 1983, 1986 and 1997 than during the period between 1950 and 1980. The storm events associated with the high Delta inflows since 1980 correlate with the higher number of simultaneously flooded islands/tracts. These particular floods include events in 1980 (6 islands flooded), 1983 (11 islands flooded), 1986 (9 islands flooded), and 1997 (11 islands flooded), as shown in Table 7-9b. Higher storm events tend to cause a disproportionate number of simultaneous levee failures.

7.6 DEFINITION OF FAILURE MODES

Three potential modes of failure—under-seepage, through-seepage, and overtopping—are considered in this analysis. Erosion was not considered a main failure mode. The mode of failure associated with stream flow erosion and wind-wave induced erosion is addressed in the Wind-Wave Hazard TM (URS/JBA 2008g) and the Emergency Response and Repair TM (URS/JBA 2008d).

Under-seepage refers to water flowing under the levee through the foundation materials, often emanating from the bottom of the landside slope and ground surface and extending landward from the landside toe of the levee. Through-seepage refers to water flowing through the levee prism directly, often emanating from the landside slope of the levee. Both conditions can lead to failure by several mechanisms, including excessive water pressures causing foundation heave and slope instabilities, slow progressing internal erosion and piping leading to levee slumping. Overtopping failure occurs when the flood water level rises above the crest of a levee. The representation of the failure modes and the evaluation of the probability of levee failures for each mode are discussed in the remaining sections.

When empirical data exist, model development relies heavily on calibration again past performance. In this context, the analysis team devoted its initial effort in collecting information on the levee performance under flood hazards. The information collection included review of relevant and available reports, DWR GIS database, and interviews with local and state engineers. For most failures, information regarding the specific mode of failure, time and date of failure, and the water levels in the slough was either not available or incomplete, as discussed in Sections 2 and 4 of the Levee Vulnerability TM (URS/JBA 2008c). In cases of seepage-induced failures, the effort to attribute them to under-seepage or through-seepage cannot be made at this stage because of the absence of post-event detailed documentation.

7.7 PROBABILITY OF FAILURE DUE TO UNDER-SEEPAGE

This section describes the approach used to develop the fragility functions for the under-seepage mode of failure. The variables used to define the vulnerability classes should not be confused with the random variables that define the statistical variation of the parameters used to develop the probabilistic model to estimate the response of the levee and foundation conditions making a given class. The variable used to define the vulnerability classes are those spatial variables that can be discretized throughout the Delta and Suisun Mash regions to generate small enough “similar” reaches of levees and foundation that would have the same response if subjected to the same load. Within each class there is a range of random variables that are treated statistically to represent the aleatory uncertainties in the probabilistic model representation.

7.7.1 Definition of Vulnerability Classes

The area covered by the Delta and Suisun Marsh is very large, and the conditions of the levees and their foundations vary substantially across the region. Because of the extent of this variability of the levees and their foundations, the study area was divided into finer and "similar" zones. These zones are referred to as vulnerability classes (VCs). The VCs are defined as reaches of levees that would yield the same probability of failure when subjected to the same flood stage. The primary factors identified to potentially contribute to the definition of the VCs include:

- Blanket (peat/organic layer) thickness on the landside of the levee
- Slough width
- Sand aquifer thickness
- Presence of toe drainage ditches
- Presence of slough bottom sediment
- Slough bottom elevation
- Levee Geometry

The above list of potential parameters defining vulnerability classes was further examined to identify which parameters are clearly and readily distinguishable geographically (and, hence, will remain as parameters for defining VCs), and which should be treated as random variables due to the lack of clear geographic correlation. For this purpose, a sensitivity analysis was conducted to evaluate the effects of these factors. The sensitivity analyses were carried out using the seepage models for a typical cross-section with a 15-foot-thick peat layer.

Peat Thickness/Organic Soil-Blanket. The primary factor that affects the under-seepage conditions is the thickness of the peat and organic marsh deposits under and on the landside of the levee (blanket). This parameter is clearly distinguishable geographically and was mapped using the GIS models discussed in Section 2 of the Levee Vulnerability TM (URS/JBA 2008c). This variable was one of the primary parameters used to map the VCs into six bins of ranges of thicknesses. Further, within each bin, the peat thickness is considered as a random variable.

Slough Width. Slough width is clearly distinguishable geographically. A sensitivity analysis was conducted to evaluate the effects of slough width on the exit gradient for a range of values from 200 to 2,000 feet. The results are shown in Figure 7-23(a), assuming the presence of a drainage ditch, and in Figure 7-23(b), assuming the absence of a drainage ditch. Two curves are presented in each figure showing the trends associated with the presence or absence of slough sediments. Figure 7-23 shows that the exit gradient becomes insensitive to slough widths beyond 500 feet. As a result of these findings, the slough width was maintained as a parameter defining the vulnerability classes. To simplify the number of analysis cases, the slough width parameter was considered to have two possible outcomes: less than 500 feet, defined as "narrow slough," or larger than 500 feet, defined as "not narrow slough."

Aquifer Thickness. The effects of the aquifer thickness on the exit gradient on the landside of the levee were evaluated for a range of values from 5 to 55 feet. The results are shown in Figure 7-24(a), assuming the presence of a drainage ditch, and in Figure 7-24(b), assuming the absence of a drainage ditch. Two curves are presented in each figure showing the trends associated with the presence or absence of slough sediments. This analysis clearly shows that beyond 15 feet, the thickness of the aquifer has little effect on the exit gradient. Based on these findings it was assumed that the presence or absence of the sand aquifer below the peat/organic blanket was sufficient to carry out the under-seepage analysis, and that no further discretization of the thickness of the aquifer was necessary.

Drainage Ditches. Seepage gradients and pressure heads in the levee foundation can be affected significantly by the thickness of a low-permeability layer on the landside of a levee. This layer is often referred to as the blanket. The effectiveness of the blanket can be reduced by any removal of material, such as a drainage ditch. Because agriculture in the Delta requires water levels to be maintained below the ground surface (2 to 3 feet), fields are often surrounded by drainage ditches near the levee toes, which drain water to pump stations. Development of a comprehensive catalogue of agricultural ditches throughout the Delta was beyond the scope of this study and was not entered into the DRMS database at this time. However, the presence of ditches have a strong affect on the exit gradients and under-seepage, as shown in Figures 7-23, 7-24, and 7-25. It should be noted, however, that the effects of a drainage ditch on under-seepage are stronger for thinner blankets and become less important for thicker blankets. For example, if a 25-foot-thick blanket without a drainage ditch is stable with respect to under-seepage, a 30-foot thick blanket with a 5-ffot deep drainage ditch will also be stable. Consequently, it was decided to carry the analyses models for both instances assuming a 5-foot-deep drainage ditch when present in thin blankets (25 feet or less). Because the exact location of the drainage ditches is unknown at this time, the analysis was carried out assuming the presence of the drainage ditch to be random with 50 percent chance of being present.

Slough/River Channel Sediments. Flow regimes in the channel and sloughs generally cause scouring and movement of materials during high flows and deposition during low flows. As discussed in the Geomorphology TM (URS/JBA 2007c), the Delta can be divided into two generalized geomorphic provinces. In the northern portion of the Delta, where the river channel has higher gradients, higher flows, and higher velocities, much of the sediment that is transported and deposited is coarse-grained and relatively permeable. In the other portions of the Delta, especially those subject to tidal influences, river channel gradients and velocities are lower, leading to the transport and deposition of predominantly finer grained, lower permeability materials. These low-permeability materials can accumulate at the base of the river channel, often to great depths, and can act as a seepage barrier. There is some anecdotal evidence that dredging these “slough sediments” has led to increased seepage in the islands next to dredged channel. Development of a comprehensive catalogue of the location and thickness of fine-grained slough sediments is beyond the scope of this study. Because these sediments can affect the under-seepage gradients, models for levees with and without fine-grained sediments in the adjacent sloughs were developed and evaluated.

Figure 7-24 shows the results of analyses relating vertical exit gradient to the thickness of slough sediments for models with drainage ditch (Figure 7-24a) and without ditch (Figure 7-24b). Figure 7-24 also indicates that the slough sediments have a moderate impact on the computed vertical gradients. The calculated exit gradients are approximately 11 to 15 percent smaller when the slough sediments are present. The slough sediment is not a fixed parameter, and changes with time. During high-velocity flows, the slough sediment is removed, and during low-velocity flows, the reverse occurs. No continuous survey of slough bottoms is conducted regularly throughout the Delta. The analysis was then carried out assuming the presence of the slough sediments to be random and was assigned a 50 percent chance of being present.

Slough Bottom Elevation. Figure 7-26 presents the results of analyses relating vertical exit gradient to the bottom elevation of the slough for models with drainage ditch (Figure 7-26a) and without ditch (Figure 7-26b). As expected, Figure 7-26 indicates that the depth of the adjacent slough bottom does not have a significant effect on the exit gradient. This parameter was not further considered in the definition of the vulnerability classes.

Levee Geometry. The effects of the levee geometry on under-seepage is mostly controlled by levee crest elevation. The crest elevation was treated as a deterministic variable using the recent LiDAR survey (DWR 2007) as input data into the risk model for each reach and mile post. The model scans and reads the crest elevation at each levee reach and each mile-post where the analysis is performed. To simplify the rest of the analyses, the levee crest width and side slopes were assumed to be equal to the average values for the Delta and Suisun Marsh, respectively. These values are presented in Section 2 of the Levee Vulnerability TM (URS/JBA 2008c).

Conclusion. The above process was used to evaluate which factors contribute to the definition of the vulnerability and/or to the random nature of the Delta. The VCs for under-seepage were then defined as follows:

- Peat thickness/organic deposits - The peat/organic deposits were divided into six intervals representing the variation of the peat/organic thickness within the Delta region.

  1. No peat
  2. 0.1 to 5 feet
  3. 5.1 to 10 feet
  4. 10.1 to 15 feet
  5. 15.1 to 30 feet
  6. > 30 feet

- Slough width - Slough width was represented by two broad groups: less than 500 feet (narrow sloughs), and greater than 500 feet (not narrow sloughs).

Twelve VCs were developed to represent the levees in the Delta study region (VCs 1 through 12), and 12 VCs were developed to represent the levees in the Suisun Marsh area (VCs 13 through 24). Table 7-10 lists the VCs, their definitions, and the associated random variables. Figure 7-27 shows the distribution of the VCs in the study region.

7.7.2 Material Properties and Random Variables

7.7.2.1 Slough/River Water levels

A probabilistic model was developed to estimate the frequency of occurrence of various water stages in the Delta and Suisun Marsh sloughs and rivers (Flood Hazard TM [URS/JBA 2008a]). The model accounts for the combined effect of storm inflows and tides. The Flood Hazard TM estimates the probability of occurrence of various water stages in the Delta and Suisun Marsh. This section estimates the conditional probability of levee failures given flood stages.

7.7.2.2 Material Properties and Random Variables

The material properties used to describe and model the behavior of the various soils, included permeability values and their corresponding anisotropies, were obtained from laboratory test results from previous studies, published correlation relationships, and engineering judgment and experience. The selected parameters were then calibrated using actual levee performance during flood events at specific sites. The calibration of selected parameters is discussed in subsequent sections.

Numerous government, municipal, and private organizations were approached for information and data collection on the Delta and Suisun Marsh, as discussed in Section 2 of the Levee Vulnerability TM (URS/JBA 2008c). Except for few limited and site-specific investigations by others, no single study has conducted an extensive and comprehensive investigation of the peat and organic deposits throughout the Delta and Suisun Marsh. Tables 7-11 and 7-12 present summaries of reported vertical and horizontal permeability values of organic and sandy soils compiled by Harding Lawson Associates (HLA 1989, 1991, 1992) and others, as shown in Appendices A and B of the Levee Vulnerability TM (URS/JBA 2008c). These permeability values were obtained from laboratory tests and field pump tests. Also included in the tables are details of soil type, type of test, sample location, and other sampling details.

The reported permeability data for free-field peat/organic soils listed in Table 7-11 indicate that both horizontal and vertical laboratory-measured permeability values are approximately equal and on the order of 10^{-6} centimeters per second (cm/s). The Technical Advisory Committee (TAC) and the analysis team considered that the anisotropy should be higher than one, given the historical cycles of wetland vegetation growth and burial under sediment loads during run offs for the post ice-age sea-level rise period which started some 15,000 years ago. Further, these laboratory tests cannot support the TAC and analysis team’s observations of high seepage flows in many locations in the Delta during non-flood high-tides conditions. The team’s observations indicate that the horizontal permeability (k_h) of peat/organic soils is generally higher than the vertical permeability (k_v), especially if the peat is in a “free-field” condition, away from the consolidating loads of a constructed levee. Therefore, for the initial evaluations, the TAC members recommended using an anisotropy (k_h/k_v) of 10, with a k_h of 1×10^{-4} and a k_v of 1×10^{-5} cm/s, for “free-field” peat/organic soil to be calibrated against case histories.

Peat/organic materials lying beneath the levee showed lower permeability than the free-field peat (Table 7-11), due to the consolidating effect of the weight of a constructed levee. For the initial analyses, the TAC members recommended using horizontal and vertical permeability values of 1×10^{-5} and 1×10^{-6} cm/s, respectively, one order of magnitude lower than the permeability of free-field peat/organic soils.

The permeability values of mineral silts and sands are well-tested and documented. Vast data, including empirical correlations, laboratory and field-performance data, are available for assessing the permeability of sandy soils (designated as SP or SM materials in the unified soils classification system [USC] or ASTM-D2487). Table 7-12 contains results from both laboratory and field-pump tests from materials evaluated during previous Delta studies. These values are consistent with measurements and correlation relationships developed for these types of soils in other publications, including correlations from the United States Army Corps of Engineers (USACE) (1986, 1993), Terzaghi and Peck (1967), Freeze and Cherry (1979), and Cedergren

(1979). For the initial analyses, the TAC and analysis team members used values of horizontal permeability equal to 1×10^{-3} cm/s and a k_h/k_v ratio of 4 for these sandy materials.

As described above, low-permeability silt sediments deposited on slough bottoms can reduce the infiltration rate of water into underlying levee foundation materials, leading to beneficial reductions of seepage rates and water pressures below the levee. This phenomenon is often referred to as “entrance head losses.” To model this condition, the TAC members and analysis team used a horizontal permeability of 1×10^{-5} cm/s with a k_h/k_v ratio of 1 for these fine-grained slough sediments, based on the above-published correlation relationships.

The peat/organic deposits and the sand aquifer permeability values were considered as random variables. The remaining parameters were considered as deterministic variables because they have a second order effect on the under-seepage results.

7.7.3 Methodology for Developing Flood Fragility Functions

Figure 7-28 illustrates the three-step method followed in developing the flood-fragility functions for under-seepage analysis of each vulnerability class.

The first step involves the evaluation of **levee response functions** (Section 7.7.4), which estimate the exit gradient as a function of water surface elevation (Figure 7-28a). The exit gradients are evaluated using generalized geotechnical models presented throughout this section.

The second step involves the development of the **conditional probability of failure functions** (Section 7.7.5), which relate the conditional probability of a levee breach given an exit gradient (Figure 7-28b). This step relied solely on expert elicitation. The range of expert elicitation was used to quantify the epistemic uncertainty in the estimated probability of failure.

The third and final step involves the development of the **levee fragility functions**, which relate the probability of failure to slough WSE, or equivalently freeboard [= crest elevation – WSE] for each VC (Figure 7-28c). This step combines the levee response functions with the conditional probability of failure functions, using Monte Carlo simulations, to generate the fragility functions.

Before the levee response functions are presented, a discussion on the analysis method (Section 7.7.4.1), numerical model development (Section 7.7.4.2), comparison to simplified procedure (Section 7.7.4.3), validations against known seepage cases (Section 7.7.4.4), and comparisons to historical cases (Section 7.7.4.5) are addressed first.

7.7.4 Evaluation of Levee Response Functions

The levee response functions represent the levee ability to withstand the forces applied by the hydrostatic pressures on the channel bottom and levee water side slopes. The hydrostatic pressures will generate a flow path through the levee foundation substrates, and hydraulic gradients through those foundation layers. The hydraulic gradients represent the pressure head differential between two points along the flow path of the water, normalized by the length traveled by the water molecule between these two points.

The gradient is a measure of the force of the water velocity within each substrate that will try to move soil particles. Very often the word vertical exit gradient is used in conjunction with under-seepage. When the water, moving through the levee foundation reaches the ground surface on the landside of the levee, the vector direction of the gradient will point upward, and hence the reference to the “vertical exit gradient”. Under the levee, the water flows in a horizontal direction and consequently the vector of the gradient points to the horizontal direction. In other words, the vector of the gradient will point to the direction of the flow lines along which the water molecules travel from the river side until they exit on the landside of the levee.

When dealing with through-seepage, we often refer to horizontal or downward exit gradient. Similarly to the above definition, the water flow lines run parallel or downward (at varying angles) when they cross the levee fill. At the point of exit on the face of the landside slopes of the levees, the vectors of the exits gradients will point to horizontal or slightly downward directions (depending on which flow line is tracked) consistent with the flow lines.

7.7.4.1 Analysis Method and Model Development

Seepage analyses were conducted using a two-dimensional finite-element procedure (SEEP/W, Geo-Slope International Ltd. 2004) under steady-state flow conditions. The computer program SEEP/W allows for modeling multiple soil types, anisotropic hydraulic conductivity, irregular contacts between soil layers, and a variety of boundary conditions.

Boundary conditions in the steady-state analyses included constant head, no-flow, constant or variable flow, and infinite boundaries for modeling long landside basins.

Water levels in the low-lying Delta islands are maintained 2 to 3 feet below land surface by an extensive network of drainage ditches. Water collected by drainage ditches is pumped through or over the levees into the local stream channels. It is, therefore, reasonable to assume that steady-state seepage conditions exist in the tidal Delta. In the northern Delta and in the Delta fringes, flood waters may rise and drop so quickly that full steady-state conditions may not always develop in every area, especially if the foundation materials are of low permeability. In these locations, steady-state analyses may slightly overestimate seepage conditions; but because of the low permeability, these areas will not likely be vulnerable to significant under-seepage problems. Conversely, based on observations during past floods, most, if not all, of the levees experiencing under-seepage problems are founded on materials that are relatively permeable. In these cases, steady-state seepage analyses are appropriate.

7.7.4.2 Finite Element Model Details: Mesh Development and Boundary Conditions

Mesh development. Actual site data were used to develop idealized cross-sections at selected locations. The idealized cross-sections were then discretized into finite elements for performing seepage analysis using SEEP/W.

Boundary conditions. The following boundary conditions were used in all of the seepage models:

- To avoid boundary effects and to model conditions more accurately at the levee itself, the landside lateral boundary (left side of the models) was set approximately 1,000 feet from the levee crest.
- On the river/slough side (right side of the models), to portray seepage conditions below the mud line, the analysis sections were extended to the middle of the river, and a no-flow

boundary condition at the vertical face of the elements below the mud line was set as an axis of symmetry.

- A fixed, total-head-boundary condition was used to model the contact between the water and the riverbank and levee.
- Fixed, constant-head boundary conditions were used to model the drainage ditch water levels and was set to two feet below the top of the ditch.
- Fixed, head-boundary conditions were used to model far-field groundwater levels at the left boundary of the models. On the far-field left boundary, the water level was assumed to be at two feet below the ground surface.
- Other portions of the levee and the ground surface were modeled using "review nodes." The SEEP/W program assigns a flux-type boundary condition to all review nodes. After the heads are computed for all nodes, the head at the review node is modified if any have a computed head greater than the elevation of the node. Use of these nodes allows the water table to rise above or fall below the nodes, which leads to a more-accurate assessment of the location of the phreatic surface and allows seepage to flow at the free face.

Typical Finite element meshes are shown in Figures 7-53 and 7-54.

7.7.4.3 Model Results Comparison to Simplified Hand Calculations

After the seepage models were created and the material properties (i.e., permeability values) assigned, the seepage analyses were performed for steady-state conditions for different water levels in the slough/river. The results were used to evaluate average gradients, exit gradients, steady-state phreatic surface location, the total head distribution throughout the model, and flow paths. Special attention was given to calculate gradients at several key locations, including the landside levee toe for cases without drainage ditches, and directly below and away from the drainage ditch for cases with a ditch.

To confirm the validity of the finite element model results, exit gradients calculated from SEEP/W were compared to average gradients calculated using the simplified "blanket theory." The blanket theory is a semi-empirical, hand-calculation method developed by USACE (1956, 1999b) and calibrated against the past experience. The blanket theory uses performance data and measured seepage conditions from numerous sites in the Mississippi Valley combined with a theoretically based model, to develop predictions for under-seepage flow conditions, pressures, and failure potential as a function of flood-level. The sites evaluated in those studies and used to develop the blanket theory are characterized as having a relatively thin layer of relatively low-permeability soil (i.e., the blanket) overlying a more permeable material directly connected to the river. Expectedly, the results of the FEM model and the blanket theory are very similar and hence it was confirmed that the finite element model was producing comparable results. The blanket theory has been widely used by private consultants and USACE to evaluate seepage conditions and cross-check the results of finite-element seepage models in this region. The finite element model is more versatile in representing irregular geometries and was used to carry the rest of the analyses.

7.7.4.4 Initial Seepage Analyses (Calibration and Verification)

To perform a "reality check" on the model, and especially to better ground-truth the results and validate the material properties, several initial seepage analyses were performed using information from sites where data and past performance were readily available. This part of the analysis was conducted to confirm that results of the levee response functions model are reasonable, and consistent with the empirical observations.

Several analysis sections were derived from information contained in the 1956–1958 California Department of Water Resources Salinity Control Barrier study (DWR 1958). Specifically, cross-sections at Bradford Island, Sherman Island, and Terminous Tract were considered. The cross-sections and boring logs describing the subsurface material types from these sites are presented in Appendix A of the Levee Vulnerability TM (URS/JBA 2008c). Not every site had information regarding slough-side subsurface materials. For these sites, the peat/organic layer present on the landside was assumed to extend horizontally into the waterside, intersected only the bathymetric profile of the channel bottom. Cross-sections on Bouldin Island, Byron Tract, and Union Island were also developed using data obtained from USACE (1987), the Mark Group (1992), and DWR (1994), respectively.

Table 7-13 presents values of horizontal permeability and anisotropy ratios used in the initial analyses. The uncertainties associated with the subsurface material properties, in particular the permeability values of the blanket layer (often composed of peat/organic materials in the central Delta) and the underlying sandy soil strata, were evaluated by conducting statistical analyses using mean estimated and distribution around the mean.

Because of the similarity of the results from the above cases evaluated in the initial analyses, and to avoid too much redundancy on this subject, only the evaluation process and results from the analysis of Terminous Tract are presented herein. These results are considered representative of the other islands, mentioned above. Below is a bulleted list of basis data and assumptions used for the modeling of these initial (calibration/verification) analysis cases.

- An idealized soil profile was developed based on the cross-section and boring log information from the 1958 DWR report (for Terminus Island) and other reports for the other cases, which are presented in Appendix A of the Levee Vulnerability TM (URS/JBA 2008c). In some locations, additional information from adjacent deep borings was used to supplement any information gaps.
- Because subsidence of peat/organic soil has been an ongoing process in the Delta, the cross-section data from the 1956 study are likely under representing the current ground-surface conditions. The data is likely representative of the elevation at the bottom of the peat/organic layer and foundation sand layer. The topography of the cross-section was corrected using recently surveyed IFSAR topography data (DWR survey provided with the GIS database). To better evaluate current slope profiles below the slough water levels, bathymetric data available from the DWR GIS database were used.
- For the model cases with slough sediments, a 2-foot-thick silt sediment layer was assumed to exist at the bottom of the channel slough.
- An analysis cross-section was developed, based on the above data and interpretation, as illustrated in Figure 7-29.

- Using the above cross-section, a finite-element model was developed using SEEP/W. It was often difficult to confirm whether drainage ditches abutting the landside levee toe were present or had been filled in after problems were identified during the 1986 and 1997 floods. Therefore, models were developed for both “with ditch” and “without ditch” conditions, as illustrated in Figures 7-30 and 7-31.
- The models were then executed using three different slough water elevations: 0, +4, and +7 feet NAVD88, representing low-tide, high-tide, and flood-water-level conditions, respectively, as illustrated in Figures 7-32 through 7-37.

The results of these initial analyses are briefly summarized below and making reference to the appropriate figures and results.

Figures 7-32 through 7-34 show the total head distribution and vertical gradient contours for the “with ditch” condition for the three slough water elevations (0, +4, and +7 feet, respectively).

Figures 7-35 through 7-37 show the total head distribution and vertical gradient contours for the “without ditch” condition for the three slough water elevations (0, +4, and +7 feet, respectively).

For the “with ditch” condition, gradients at Point A, located directly below the ditch, are significantly higher than at Point B, located approximately 100 feet from the toe of the levee (Figures 7-32 through 7-34). Except for the gradient at the bottom of the ditch, the “with ditch” and “without ditch” models, produce approximately the same vertical gradients near the landside toe of the levee and at Point B 100 feet away from the toe of the levee (Figures 7-35 through 7-37). These results indicate that the presence of a ditch next to a levee has a significant impact on seepage conditions with exit gradient of 0.8 when water stage is near +7 feet elevation. For the same +7 feet water stage, the exit gradient is 0.4 without drainage ditch. The analysis of the lower water stages indicates no adverse conditions at Terminus Tract, supporting the historical performance of Terminus Tract which has experienced no failure since 1958.

To assess the contribution of the variation of the material properties around the mean values (uncertainties), the “with ditch” model as described below was analyzed:

- Mean-minus-one standard deviation value of permeability for the blanket layer (peat/organics)
- Mean-plus-one standard deviation value of permeability for the blanket layer (peat/organics)
- Mean-minus-one standard deviation value of permeability for the underlying higher permeability (SP/SM) foundation sand
- Mean-plus-one standard deviation value of permeability for the underlying higher permeability (SP/SM) foundation sand
- No slough sediment layer

The analysis results are summarized in Table 7-14 and presented in Figures 7-38 through 7-41. For comparison purposes, Table 7-14 also presents a summary of the results from analyses conducted for the “with ditch” and slough sediments case for the initial mean values of permeability, using estimated values of permeability for peat/organic or fine-grained blanket soils.

Table 7-14 and Figure 7-38 indicate that the blanket (peat) permeability has a direct and highly significant impact on computed gradients. Computed gradients increased by approximately 50 percent for a one standard deviation increase in permeability and decreased by approximately 50 percent for a one standard deviation decrease in permeability.

Table 7-14 and Figure 7-39 indicate that in the case of low-permeability sand for the model with sediments, the sand permeability has a less obvious impact on computed gradients. The computed gradients decreased by approximately 50 percent for an increase by one standard deviation and also decreased by less than 10 percent by decreasing the permeability by one standard deviation. In this situation, the sand layer is effectively “capped” on both the water entry on the slough side and water exit on the landside by the lower permeability of the slough sediment and blanket layer. Therefore, in the seepage model, these two impervious top layers have counteracting impacts, yielding a more-complex relationship and skewed distribution around the mean. Because of the strong contrast between the permeability of the blanket and the sand aquifer, the variation of the permeability of the sand was found to be of second-order effect (as long as its permeability is one to two log cycles below that of the blanket) and hence, the best estimate values only were used.

Table 7-14 and Figure 7-40 indicate that the presence of slough sediments has a potentially important impact on computed gradients. Computed gradients increased by about 25 percent when slough sediment is removed. Although slough sediment presence was found to be a potentially important and should be included as a random variable in the development of under-seepage fragility functions, unfortunately, confirmation of the presence of slough sediments at each location throughout the Delta was beyond the scope of this study. Because of this shortcoming, the slough sediment was modeled as random variable with 50 percent chance of being present. Slough sediments are more likely to exist in smaller channels and backwaters and less likely to exist in large, main flow, and dredged channels. Further assessment of the extent and thickness of slough sediments throughout the Delta is recommended.

Table 7-14 and Figure 7-41 indicate that the presence of a ditch has a potentially important impact on computed gradients at the ditch and little impact on computed gradients away from the ditch. Computed gradients increased by more than 100 percent near the levee when a ditch was present but increased by less than 5 percent about 100 feet away from the levee when a ditch was present. The ditch has the same impacts as the slough sediments on the exit gradient. Unfortunately, confirmation of the presence of ditches at each location throughout the Delta was beyond the scope of this study and could not be used as a deterministic feature during the development of the risk model. The presence of ditches is a potentially important factor and should be included in developing under-seepage fragility functions. In the best conditions, it must be modeled as a deterministic parameter defining the cross-section geometry for each vulnerability classes since it would be geographically defined. It should be noted however, that the presence of the drainage ditch becomes insignificant for cross-sections with peat thickness of 20 feet or more.

Findings from the initial analyses. Overall, the initial analyses for the selected specific cases in the Delta, indicate that calculated gradients are not showing adverse under-seepage conditions for normal water stages (excluding storm events) as expected. For the worst-case condition (mean-minus-one standard deviation blanket permeability, “with ditch” and slough water at +7 feet), the maximum computed vertical gradient is approximately 1.0, which is near the point of initiation of under-seepage problems. This is generally consistent with observed seeps and boils throughout the Delta during high-water events.

7.7.4.5 Comparisons with Areas with Known Seepage Problems

As previously discussed, approximately 74 levee failures have resulted in island flooding since 1950 (Figure 7-22a and 7-22b). A compilation of eyewitness accounts and documented reports of seepage problems in the Delta were recorded on a map, as shown in Figure 7-42. In general, the observations represent reliable empirical data to gage the seepage model results against (verification of fatal flows). The analysis team identified sites where known under-seepage problems could be used to compare to the seepage model results.

These sites included a number of reported sites of observed seepage problems. The under-seepage problems observed during the 1997 flood at the east levee of Grand Island and the under-seepage reported at Woodward Island after the Upper Jones Tract failure in June 2004 are discussed below.

Grand Island. Topographical data derived from IFSAR and bathymetric data sets (provided in the DWR GIS database) were used to develop the geometry of the cross-section at that site. No ditches exist next to the levee at the problem area based on private communication with Mr. Gilbert Cosio (Consulting engineer to local Reclamation Districts 2007). Subsurface data from nearby borings (stick logs), shown in Figure 7-43, were used to develop a representative cross-section for analysis. A cross-section representing the geometry and subsurface conditions during the 1997 flood was developed, as shown in Figure 7-44.

To evaluate water levels during the 1997 flood, flood elevation data were obtained from DWR monitoring station B91650 on the Sacramento River at Walnut Grove. The station is approximately 2 miles upstream and is the closest station to the site (see recorded water elevation at the time of the event in Figure 7-45). The distance is short enough that a water-level distance correction was not considered necessary. Based on these data, a water elevation of +16 feet was used in the seepage model. In addition, because the seepage problem was observed during a flooding event when the flow velocity in the slough would be higher than normal, it was assumed that slough sediment was not present.

Figure 7-46 presents the finite-element model and boundary conditions at the site. Analyses were performed for a blanket anisotropy of 10, 100, and 1,000. The results are presented in Figures 7-47, 7-48, and 7-49, respectively. Computed gradients near the landside toe and away from the toe (Point B) are also summarized in Table 7-15. The results of the analysis indicate that the exit gradient at the toe of the levee is approximately 0.4, 0.5 and 0.6 for k_h/ k_v, of 10, 100, and 1000, respectively. The results for anisotropy of 10 indicate that the calculated vertical exit gradient (i_{vert} = 0.4) would be insufficient to initiate an under-seepage problem during the 1997 flood. For an anisotropy of 100 the exit gradient was calculated to be i_{vert} = 0.5, value at which typical seepage start to become a concern. An anisotropy of 100 was then adopted for the next steps of the analysis. It should be noted, however, that the change in the vertical exit gradient is not very sensitive to the increased anisotropy of the blanket (0.4 to 0.6).

Woodward Island. The properties from the above analysis with an anisotropy of 100 were used at the observed seeps and boils site at the southeastern corner of Woodward Island. During the

June 3, 2004 breach of the Upper Jones Tract, the slough water was at elevation +6.85 feet (NAVD88). One of two boring logs at the southeastern corner shows the presence of an upper, about 5- to 7-foot thick, soft organic clay layer with more than 30 percent organic content overlaying a thick sand deposit. The levee landside toe was at elevation –7.5 feet. The analysis with no slough sediment and no drainage ditch, showed that the exit gradient at this location was estimated to be approximately 2.0, clearly confirming the observed sand boils and consistent with the model prediction (see Figure 7-60 at point A near the toe of the levee). During the Jones Tract failure, the breach caused high-flow velocities which scoured the channel extensively as reported in the repair and construction documents (provided by DWR 2004), and hence removed any recent silt deposits and exposed the sand layer.

Based on the above initial verifications and the results of this calibration, the values listed in Table 7-16 were adopted as representative conditions throughout the Delta, and were then used for the production runs.

7.7.4.6 Levee Response Functions for the Delta

To develop levee response functions representative of conditions throughout the Delta, seepage models with the range of subsurface conditions throughout the Delta were developed. Based on the previously discussed review of cross-section data (Section 2.0 of the Levee Vulnerability TM [URS/JBA 2008c]) and with the aid of the GIS mapping, levee geometries and subsurface conditions were developed for each vulnerability class.

As shown on the peat/organics thickness map (Figure 7-50), the thickness of a landside blanket layer varies throughout the Delta. Levee reaches with ranges of thickness from no peat to over 35 feet were developed from the GIS model. For each of these reaches, “with ditch” and “without ditch” models were considered. Figure 7-51 shows a typical cross-section for a “with ditch” model and a 25-foot-thick peat layer. Figure 7-52 shows a typical cross-section for a “without ditch” model and a 25-foot-thick peat layer.

Based on the depth of the channels and sloughs (-25 feet to -34 feet elevation within the central western Delta) and the high velocity flows in the confined channel, it was assumed that the peat/organic layer (blanket) terminates below the waterside toe of the slope as the channels are incised. To model the landside downward slope of the ground surface away from most Delta levees, a slope of approximately 500H:1V, away from the levee, was used based on the general topographic contour maps of the interior of the islands. If the section was modeled with drainage ditch, the ditch was modeled as 5 feet deep and approximately 100 feet away from the levee centerline or near the toe, whichever is more distant. When slough bottom sediment was considered, a 2-foot-thick layer was used.

Figures 7-53 and 7-54 present typical finite element models used to estimate seepage conditions as a function of flood water levels and to develop fragility curves. Typical results from these models are presented in Figures 7-55 through 7-58, showing only the “with ditch,” with slough sediments, and slough water at elevation +4 feet, for peat/organic deposit thickness of 5 feet, 15 feet, 25 feet, and 35 feet, respectively.

Figures 7-59a and 7-59b present the computed vertical gradients (below the ditch and 100 feet from the ditch, respectively) versus water level (from +0 feet to levee crest elevation) for a levee founded on a 5-foot-thick blanket layer with a ditch. Maximum vertical gradients are found below the ditch, which cuts completely through the peat layer. This is a special case for this series of models. In this situation, the ditch completely pierces the blanket layer and acts as a drain to the underlying sandy layer. While seepage flow rates into the ditch may be high, the pressures in the sand layer are greatly relieved, lowering the gradients to subcritical levels (i.e., <~0.24), particle movement is still a concern.

In contrast, for the model with a 5-foot-thick blanket layer and without a ditch (Figures 7-60a and 7-60b), the gradients at the toe (Figure 7-60a) and away from the toe (Figure 7-60b) show a substantial increase in the calculated vertical gradients (1.2 to 2.4 and 1.0 to 2.0, respectively). For this condition, the exit gradients are mostly above 1.0, indicating a state of active failure. Separate fragility curves for both “with ditch” and “without ditch” have been produced for the mean and standard deviations.

Figures 7-61a, 7-61b, 7-62a, and 7-62b present the computed vertical gradients for 15-foot-thick blanket layer as a function of river/slough water levels for “with ditch” and “without ditch,” respectively. The results indicate that the vertical gradient under the ditch increased to values ranging from 0.8 to 1.6 as a function of higher water levels (Figure 7-61a), effectively representing the average gradient through a 10-foot-thick blanket. Conversely, the vertical gradients calculated for “without ditch” are smaller and range from 0.4 to 0.9 near the toe (Figure 7-62a) and 0.3 to 0.8 away from the toe (Figure 7-62b).

The same calculations were conducted for blanket thicknesses of 25 and 35 feet, as shown in Figures 7-63 through 7-66. Generally, the results indicate that the vertical gradients are below 0.8 for “with ditch” and below 0.6 for “without ditch.” Therefore, blankets with 25 feet or more in thickness have less potential for under-seepage failures. It was also noted that the 84th percentile of the vertical gradients were constrained to values very close to the mean. Beyond a certain contrast between the sand and the blanket permeability coefficients, the vertical gradients become insensitive to further reduction of peat/organic permeability. or conversely further increase in the permeability of the aquifer

7.7.4.7 Levee Response Functions for Suisun Marsh

The available information indicates that the levees in the Suisun Marsh area have special characteristics that should be accounted for slightly differently than those in the main Delta. Most importantly, these levees are smaller and typically hold back lower flood levels. The landside ground elevation is also different from the Delta. The interior land elevations are much higher than the Delta and have not subsided much. Separate models were, therefore, developed to evaluate the relationships between flood levels and computed gradients.

Appendix A of the Levee Vulnerability TM (URS/JBA 2008c) contains cross-sectional and subsurface information on levees in the Suisun Marsh area. Figure 7-67 presents a typical cross-section for Suisun Marsh. Based on a review of available data, this cross-section was estimated to be representative of the conditions throughout Suisun Marsh. In a similar fashion to the process used for the main Delta, a model based on this section was developed and evaluated for a series of subsurface conditions and water levels. Figure 7-68 presents a typical finite element model of Suisun Marsh levees. Figure 7-69 presents the calculated values of head and gradient using this model and a water surface elevation of +4 feet (although the calculations were run for a full range of water elevations from 0 to +8 feet).

As with the Delta levees, sensitivity of the model to changing conditions was also evaluated. Figure 7-70 shows the relationship between computed vertical gradient as a function of blanket thickness and water level. All cases were run “without ditch” and 2-foot-thick slough sediment. Figure 7-70 indicates that the calculated gradients for Suisun Marsh are much smaller than those calculated for the main Delta. For example, the calculated vertical gradients for the 5-foot-thick blanket range from 0.4 to 1.1 for Suisun Marsh compared to 1.2 to 2.4 for the main Delta. The foremost reason for the difference with the main Delta is the higher surface elevation of the interior island floors in Suisun Marsh. Under-seepage at Suisun Marsh appears to be of lesser concern than for the main Delta, except for irregularities (sand seams, cracks, burrowing animal holes, etc.).

7.7.5 Evaluation of Conditional Probability Failure Functions

The second step in the development of a fragility curve was to relate the predicted vertical gradient to a probability of failure. To complete this step, an expert elicitation process was used.

Members of the levee vulnerability team experienced with characteristics of the Delta and the experts from the Technical Advisory Committee were given a summary of the background work and data, model development methodology, and model results showing the computed gradients as a function of water levels and blanket permeability for each vulnerability class. The team of experts was also asked to consider the following assumptions in developing their opinion:

1. The objective behind the development of the conditional probability of failure curves is to characterize the likelihood that internal erosion and piping will progress to the point of full failure (breaching).
2. High water persists for one or more days with tides causing fluctuation.
3. In some cases, partial erosion degradation may already exist as a result of previous events.
4. Consider two options in the evaluation: (1) no human intervention to contain or mitigate the forming seeps and boils, and (2) human intervention.

The group of experts participating in the elicitation process included:

- Professor Ray Seed (UC Berkeley)
- Dr. Leslie Harder (DWR)
- Mr. Michael Driller (DWR)
- Dr. Ulrich Luscher (URS Consultant)
- Mr. Michael Ramsbotham (USACE)
- Mr. Gilbert Cosio (MBK)
- Mr. Kevin Tillis (Hultgren-Tillis)
- Mr. Edward Hultgren (Hultgren-Tillis)
- Dr. Said Salah-Mars (URS - Facilitator)

First the experts were briefed on the methodology and development process of the models discussed above in few briefing and questions and answers sessions. The experts were then asked to independently develop estimates of failure probability as a function of vertical gradient for the case of no human intervention, using the model results and assumptions provided above. Each expert submitted their recommendations separately. The experts were then asked to estimate failure probability for the same situation but using human intervention.

The proposed curves by the experts were treated a individual statistical values equally weighted and used to generate mean and standard deviations, representing the epistemic uncertainties for this failure mode.

Figure 7-71 is a summary of the exercise results assuming no human intervention. As shown, the mean value of the probability of failure is less than 50 percent for computed vertical gradients of less than 0.8. Probabilities of failure are expected to be greater than 80 percent when the vertical gradient is greater than approximately 1.1. This value is in general agreement with values suggested by USACE (1999b).

Figure 7-72 presents a summary of the results of the same exercise assuming human intervention. A comparison of Figure 7-71 with Figure 7-72 indicates that the panel believes that human intervention, assuming available emergency response resources, can significantly reduce the probability of levee failures**,** as indicated by the significant shift of the mean curve to the right of the graph in Figure 7-72.

During high flood stage when wind waves crash over the levee crest, emergency repair vehicles cannot access the crest roads. However, at lower flood stage, when levee crests are safe, emergency repair vehicles can access the levee crest to repair erosion damage, cracking, and levee slumps related to developing seepage or other problems. The experts recommend using two conditional probability-of-failure functions in the following manner: (1) use the “no human intervention” curve for the high flood stage with freeboard less than 2 feet, and (2) use the “with human intervention” curve for flood stage corresponding to more than 2 feet of freeboard.

7.7.6 Evaluation of Fragility Functions

The third and final step in developing levee fragility functions was to evaluate the under-seepage fragility functions, which was done by combining the levee response functions with the conditional probability of failure functions through Monte Carlo simulation. The levee fragility functions relate the probability of failure to slough water surface elevation (or in terms of freeboard [= crest elevation – WSE]) for each vulnerability class (Figure 7-28c). This step was performed using Monte Carlo simulations. The random variables used in the simulation are listed in Table 7-10 and described below.

- VCs 1 and 2 represent no-peat areas in the Delta. In the development of under-seepage fragility curves for these classes, presence of ditch and sediment were treated as random input variables.
- VCs 3 through 12 represent areas that have peat/organic blanket layer in the Delta. In the development of under-seepage fragility curves for these classes, presence of ditch, presence of sediment, peat thickness, and peat permeability were treated as random input variables.

- VCs 13 and 14 represent no-peat areas in the Suisun Marsh. In the development of under-seepage fragility curves for these classes, presence of sediment was treated as a random input variable.
- VCs 15 through 24 represent areas that have peat/organic blanket layer in the Suisun Marsh region. In the development of under-seepage fragility curves for these classes, presence of sediment, peat thickness, and peat permeability were treated as random input variables.
- Levee geometry and water level for a given flood event were treated as deterministic parameters. The model was run for a full range of water levels varying from the toe to the crest of the levee. In the overall risk analysis, the water level is treated probabilistically as discussed in the Flood Hazard TM (URS/JBA 2008a).

The vertical gradient versus water level curves (Figures 7-59 through 7-66 and Figure 7-70) are combined with the probability of failure versus gradient curves (Figures 7-71 or 7-72) to produce the probability of failure versus water level (or freeboard = crest elevation – water level) for the entire Delta and Suisun Marsh for each VC. The calculated under-seepage fragility functions for the Delta and Suisun Marsh region are shown in Figures 7-73a through 7-73f. The resulting curves will be used as input in the flood risk model.

7.8 PROBABILITY OF FAILURE DUE TO THROUGH-SEEPAGE

Calculation of through-seepage have yielded very low exit gradients through the levee landside slopes. The finite element models used to estimate exit gradients on the landside slope of the levees indicate that the exit horizontal gradients are on the order of 0.12 under flood stage condition (2 feet of freeboard).

This calculated exit gradient can easily be verified with a simple hand calculation. For a typical levee geometry consisting of a 20-foot-wide crest, 20 feet high, with 2.5H:1V and 3.5H:1V slopes on the waterside and landside, respectively, the water column will be 18 feet, leaving a 2-foot freeboard. The simplified one-dimensional flow equation for a sandy levee yields a horizontal exit gradient at the landside toe of the levee of approximately DH/DL=18/140=0.128.

The standard definition of critical gradient, and the safe-design gradient of 0.3 or less, do not apply in this case, where the horizontal flows through the levee tend to move the near-surface particles horizontally and down the landside slope of the levee. Unlike moving particles upward against gravity (as in the case of under-seepage), the seeping water through the levee will move particles horizontally with more ease and under a much-smaller gradient.

Because the analysis models show horizontal exit gradients values much smaller than 0.3, there were no standard procedures that establish failure probabilities as a function of exit gradient. The analysis team turned to expert elicitation and local knowledge to develop a procedure by which through-seepage levee failure prediction can be made for the Delta. Through-seepage failures are known to occur in the Delta by the local practicing engineers and researchers in that field.

The mechanism of through-seepage is known to evolve in a slow and progressive fashion as discussed below and illustrated with pictures of forming boils in Figure 7-74. We have observed many instances of unthreatening seeps and boils in the Delta and the Sacramento Basin as a whole (Bouldin Island 1983, Staten Island 2007, Sacramento River in the Natomas area 1986, Sacramento Bypass South levee 1998), where fine particles are moved slowly and progressively over time, eroding the levee sandy fill of its finer particles.

As the finer particles are moved, the permeability of the levee increases, and flow velocities increases. This process takes time to develop, erodes fines with each high stage cycle, but will ultimately create a quasi-stable levee which will experience slumping and cracking (Staten Island, July 2007), and rapid erosion of the landside levee slope (Sacramento Bypass south levee, January 1998, and Sacramento River, Natomas area, 1986).

Because of the difficult nature of developing a reliable numerical model to predict through-seepage failures, the analysis team and the TAC recommended adopting the assumption that the annual frequency of failures by through-seepage is equal to that of under-seepage, based on their observations and long-standing experience with the Delta levees.

7.9 PROBABILITY OF FAILURE DUE TO OVERTOPPING

Water surface elevations were estimated based on in-Delta flows, tide condition, and wind set-up. A fragility curve was defined to assess the probability of overtopping as a function of freeboard as shown in Figure 7-75.

Overtopping failure occurs when the floodwater level rises above the crest of a levee and erode the levee to the point of breaching. The factors used to estimate the probability of failure by overtopping are levee crest elevation, the frequencies of floodwater levels above the levee crest and the conditional probability of levee failure (breaching) as a function of the water height over the crest.

The probability of failure due to overtopping increases from zero (when the water level is at or below the levee crest), to one when the water level is at two feet above the levee crest. Figure 7-75 illustrates the fragility function assumed for the overtopping failure mode. Some amount of overflow can occur without complete failure of the levee. Human intervention can also prevent failure due to overtopping by raising the crests with sandbags during high-water periods and wind action.

The flood levels for current and future years (in 50, 100, and 200 years) were developed in the Flood Hazard TM (URS/JBA 2008a) and the Climate Change TM (URS/JBA 2008b). The results of the probability of overtopping are combined with the probability of failure due to under-seepage and through-seepage and are presented in Section 13.

7.10 PROBABILITY OF FAILURE DUE TO WIND/WAVE

During non flood and non seismic conditions, the wind-wave action on the exterior slopes of the levees was not explicitly considered in the analysis. Excluding floods and earthquakes, and considering the existing waterside slope protection with rip rap and the human intervention, this particular hazard was considered relatively insignificant and, hence, was not considered explicitly. Furthermore, because these potential failures would occur during periods of no flood and no seismic conditions, they were implicitly included in the empirical data compiled for the normal failure conditions also referred to as “sunny-day failures” and discussed in Section 9.

However, when islands are flooded, the wind-wave action on the non protected interior slopes and the resulting erosion of the interior of the levees are represented in the risk model, and are addressed in the Wind-Wave Hazard TM (URS/JBA 2008g) and the Emergency Response and Repair TM (URS/JBA 2008d).

7.11 SPATIAL MODELING OF PHYSICAL RESPONSE OF LEVEES TO FLOOD EVENTS

Section 7.7 described the geotechnical model used to assess seepage gradients of individual levees in different vulnerability classes subjected to a given flood scenario, and the model to assess the probability of a breach of a levee reach given the estimated seepage gradient. To assess the risk of simultaneous, multiple levee failures under a given flood, the simultaneous physical behavior of all levees in the study area subjected to a specified flood event also needs to be modeled. Such a model needs to account for the spatial continuity of levees and define how levees within and across levee reaches are likely to behave in a given flood event.

This section first provides an overview of the spatial physical model of representing levees around different islands, and describes the key assumptions made in modeling the spatial behavior of levees during a flood event.

The geotechnical fragility model described in Section 7.7.6 provides a procedure to estimate the probability of under-seepage failure on individual reaches of an island. This procedure needs to be extended for estimating the probability of under-seepage failure of an island. The approach is based on the concept of the "weakest link," that is, the first failure of a system would occur at the weakest link. This assumption is appropriate for a linear system such as levees. It would not be known with certainty which levee reach is the weakest link. It is reasonable to assume that each reach has some probability of being the weakest link, and that probability is proportional to the vulnerability of the reach, as reflected in its conditional failure probability. That is, a reach with a higher failure probability would be more vulnerable to a failure, and would have a greater chance of being the weakest link and failing first. Using this assumption, the probability that each reach on an island is the weakest link is first estimated by making this probability proportional to the reach failure probability. This estimation can then be used to calculate the joint probability that a given reach would be the weakest link and would fail. This joint probability is summed over all reaches to estimate the probability of failure of the island.

This approach will honor three essential criteria: (1) It will be invariant with regard to the reach length. That is, regardless if an island is divided into 10 reaches or 100 reaches, the result would be the same. (2) It will preserve the concept of the weakest link. That is, the probability of island failure would not be simply an average value over all reaches. (3) Each reach will contribute to the overall probability of island failure. That is, the probability of island failure will not be controlled by a single reach that has the maximum failure probability. This approach simply reflects the fact that it is not known with certainty which reach is the weakest link; each reach could be the weakest link, with some probability, and could fail first.

Let

f_{ijk} = conditional under-seepage failure probability of j-th reach on i-th island for k- th flood event

$f_{i.k}$ = conditional under-seepage failure probability of i-th island for k-th flood event

w_{ijk} = probability that j-th reach on i-th island is the "weakest" link for k-th event (that is, the link that would fail first under the given event)

w_{ijk} is calculated as follows:

$$w_{ijk} = f_{ijk} / \Sigma(f_{ijk}) \quad (1)$$

The conditional under-seepage failure probability of the i-th island for k-th event is calculated taking into account the probability that each reach could be the weakest link and the conditional under-seepage failure probability of that reach for k-th event. Thus, $f_{i.k}$ is calculated from:

$$fi.k = \Sigma_j (w_{ijk} f_{ijk}) \quad (2)$$

7.12 ISLAND FAILURE PROBABILITY UNDER MULTIPLE FAILURE MODES

The previous section was used to estimate the probability of an island failure in under-seepage for a given flood event. The probability of an island failure due to through-seepage was assumed to be equal to the probability of failure due to under-seepage, as discussed in Section 7.8. The probability of an island failure due to overtopping was estimated using the procedure described in Section 7.9 (i.e., using the fragility curve for overtopping). Overall probability of an island failure due to any of these three failure modes was calculated as follows:

$$P_f \text{ (island)} = 1- ((1-P_{fUS}) \times (1-P_{fTS}) \times (1-P_{fOT})) \quad (3)$$

where,

P_f (island) = Probability of an island failure

P_{fUS} = Probability of an island failure in under-seepage

P_{fTS} = Probability of an island failure in through-seepage

P_{fTS} = Probability of an island failure in overtopping

7.13 PROBABILITY OF DAMAGE BUT NO BREACH

For the flood induced failure there is no condition of ,"damage but no breach" as with earthquake induced failures. The only secondary damage considered in the analysis is the interior slope erosion under wind/wave action when the island is flooded. The erosion of the landside slopes of flooded islands is discussed in the emergency response and repair section (Section 10).

7.14 LENGTH EFFECTS ON PROBABILITY OF LEVEE FAILURES

The procedure presented above for the estimation of an island failure probability does not account for the effect of length of levees within each island. A simplified procedure was developed using historical island failures in the Delta islands to adjust the probability of failure considering the length of each island perimeter levee under consideration. To develop this simplified procedure, islands that have breached multiple times in the past were reviewed. Venice Island breached 8 times in the past 100 years, and was considered as the reference case where all contributing effects (including length) are included. Hence, the length effect is developed as a simple hyperbolic scaling function as described in Equation (4). This scaling factor (SF) is used to adjust the probability of failure of any given island.

$$SF = 1 + (L_i - L_r)/L_n \quad (4)$$

where

L_i = length of an island under consideration

L_r = length of a referenced island

L_n = length of the longest island in the study area

The above equation, when applied to two islands with perfectly equal fragility functions and subjected to exactly the same load, would indicate that the longer island will have a slightly higher probability of failure and conversely for a smaller island. The logic would lead to say that a similar island with twice the levee length of the first island will have twice the probability of failure than the first. Although logical, we found that the 100-year record of Delta island flooding cannot support it. A more attenuated relationship as proposed above was considered more reasonable by the analysis team and was adopted. The typical range of SF is about 0.7 to 1.7 for the Delta. 0.7 corresponds to an island with one mile of perimeter levee and 1.7 corresponds to an island with 42 miles of perimeter levees such as Grand Island which has 3.5 times longer perimeter levees than Venice Island.

7.15 SUMMARY OF FINDINGS AND OBSERVATIONS

7.15.1 General Observations

- About 158 islands have flooded in the Delta since 1900, and about 74 since 1950. The Suisun Marsh levees have lower elevation than those of the Delta and are prone to more frequent failures. The rate of island flooding in Suisun Marsh cannot be quantified because of absence of historical data going back to 1900.
- The Delta offers numerous case histories (although with incomplete details) for calibrating the levee flood-induced failure model. These case histories helped ground-truth the model used and the results.
- We observed that not all the details of historical flood events are recorded or available. It is recommended that failures in the Delta be fully documented in a formal and comprehensive way that covers the necessary details to reconstruct the events and verify them numerically. This documentation will provide increased validity to future modeling exercises.
- The data to collect should include, at a minimum, the following: the storm event date, the storm time, the type of storm, the Delta inflow measurements, the water stage readings before, during, and after the event, the crest elevation at the failure point (if failure occurred), visual observations (seeps, boils, ponding water, erosion, overtopping, etc.), when the initiating conditions started and their type , a description of the flood fight, if any, and the actions taken.
- Field notes are essential in documenting the events and observations. These should be recorded and entered into the database that has been started in the context of this study.

- These observations will also help provide valuable information on the types of failure modes and, at a minimum, will allow the development of an empirical model to represent through-seepage failures.

7.15.2 Findings

- Because of the large contrast between the permeability of the organic/peat deposits and the pervious foundation sand layer, the uncertainties around the mean permeability values of the sand layer do not contribute substantially to the overall model uncertainties.
- Blankets of 15 feet or less in thickness have the highest impacts on under-seepage.
- The drainage ditch contribution to under-seepage is significant for blankets of 15 feet or less in thickness.
- Blankets of 20 feet or more in thickness are not impacted by the presence of a drainage ditch, which is assumed to be 5 feet-deep or less.
- The presence or absence of slough sediments has a significant impact on under-seepage. However, it is difficult to map the presence, thickness, and composition of slough sediments knowing that their state is changing with flow velocities and channel dredging. This parameter is highly variable with time.
- Other contributors to under-seepage and through-seepage cannot be formally accounted for or explicitly modeled. These contributors include random and elusive weaknesses in the levees and their foundations (burrowing animals, human activities, weak zones, etc.). We believe that these "weak links" are more pronounced in non engineered levees.
- The use of empirical models and the calibration of the models against observations help account implicitly for these pre-existing and difficult-to-investigate conditions.

Tables

Table 7-1 Partial List of Major Dams and Reservoirs in Tributary Watersheds to the San Francisco Bay-Delta

Dam Name	Watercourse	Tributary of	Reservoir	Year Original Construction Completed	Reservoir Capacity (acre-feet)
East Park	Little Stony Creek	Sacramento River	East Park	1910	
Daguerre Point	Yuba River	Sacramento River		1910	
Cache Creek	Cache Creek	Sacramento River	Clear Lake	1914	
Capay Diversion Dam	Cache Creek	Sacramento River		1914	
Stony Gorge	Stony Creek	Sacramento River	Stony Gorge	1928	
Pardee	Mokelumne River	San Joaquin River	Pardee	1929	210,000
Englebright	Yuba River	Sacramento River		1941	
Friant	San Joaquin River	San Joaquin River	Millerton Lake	1942	520,000
Shasta	Sacramento River	Sacramento River	Shasta Lake	1945	4,552,000
Martinez	off-stream storage		Martinez	1947	
Keswick	Sacramento River	Sacramento River	Keswick	1950	
Sly Park	Sly Park Creek	American / Sacramento River	Jenkinson Lake	1955	
Mormon Island Auxiliary Dam	Blue Ravine	American / Sacramento River	Folsom Lake	1956	
Folsom	American River	Sacramento River	Folsom Lake	1956	1,010,000
Tulloch	Stanislaus River	San Joaquin River	Tulloch	1957	68,000
Monticello	Putah Creek	Sacramento River	Lake Berryessa	1957	
Comanche	Mokelumne River	San Joaquin River	Comanche	1963	431,000
Whiskeytown	Clear Creek	Sacramento River	Whiskeytown Lake	1963	
Spring Creek Debris Dam	Spring Creek	Sacramento River	Spring Creek	1963	
Red Bluff (Diversion)	Sacramento River	Sacramento River	Lake Red Bluff	1964	
New Hogan	Calaveras River	San Joaquin River	New Hogan	1931, 1964	325,000
Los Banos (Detention)	Los Banos Creek	San Joaquin River	Los Banos	1965	

Table 7-1 Partial List of Major Dams and Reservoirs in Tributary Watersheds to the San Francisco Bay-Delta

Dam Name	Watercourse	Tributary of	Reservoir	Year Original Construction Completed	Reservoir Capacity (acre-feet)
Little Panoche (Detention)	Little Panoche Creek	San Joaquin River	Little Panoche	1966	
San Luis	San Luis Creek	Delta - Mendota Canal	San Luis	1967	
O'Neill	San Luis Creek	Delta - Mendota Canal	O'Neill Forebay	1967	
Contra Loma	off-stream storage		Contra Loma	1967	
Oroville	Feather River	Sacramento River	Lake Oroville	1968	3,537,580
New Exchequer	Merced River	San Joaquin River	Lake McClure	1926, 1968	1,026,000
New Bullards Bar	Yuba River	Sacramento River	New Bullards Bar	1969	
New Don Pedro	Tuolumne River	San Joaquin River	New Don Pedro	1923, 1971	2,030,000
Buchanan	Chowchilla River	San Joaquin River	Eastman Lake	1975	150,000
Indian Valley	N Fork Cache Creek	Sacramento River	Indian Valley	1976	300,600
New Melones	Stanislaus River	San Joaquin River	New Melones	1979	2,400,000
Sugar Pine	N Shirttail Creek	American / Sacramento River	Sugar Pine	1981	
Hidden	Fresno River	San Joaquin River	Hensley Lake		90,000
Almanor	N Fork Feather River	Sacramento River			

Table 7-2 Summary of Delta Inflows

Sacramento + Yolo Bypass Inflows	WY 1956 - 1968, pre-Oroville Dam	WY 1969 - 2005, ~Existing Conditions	WY 1956 - 2005, Period of Record
Average Daily Inflow, cfs	26,430	28,671	28,088
Avg. Annual Precip., inches[1]	17.4	18.1	18
Max. Annual Precip., inches	27.7	34.5	35
Inflow Range	**Number of Inflows in Q-Range**		
0-100K	4564	12924	17488
100K-200K	152	466	618
200K-300K	28	96	124
300K-400K	3	19	22
400K-500K	2	5	7
>500K	0	4	4
sum =	4749	13514	18263
Inflow Range	**No. of Days per Year With Inflows in Q-range**		
0-100K	351.1	349.3	349.8
100K-200K	11.7	12.6	12.4
200K-300K	2.2	2.6	2.5
300K-400K	0.2	0.5	0.4
400K-500K	0.2	0.1	0.1
>500K	0.0	0.1	0.1
sum =	365.3	365.2	365.3

San Joaquin River Inflows	WY 1956 - 1979, pre-New Melones Dam	WY 1980 - 2005, ~Existing Conditions	WY 1956 - 2005, Period of Record
Average Daily Inflow, cfs	4,416	4,809	4,416
Avg. Annual Precip., inches[2]	13.9	14.9	14.3
Max. Annual Precip., inches	25.9	27.5	27.5
Inflow Range	**Number of Inflows in Q-range**		
0-10K	8037	8270	16307
10K-20K	393	697	1090
20K-30K	247	336	583
30K-40K	74	171	245
40K-50K	15	22	37
>50K	0	1	1
sum =	8766	9497	18263
Inflow Range	**No. of Days per Year With Inflows in Q-range**		
0-10K	334.9	318.1	326.1
10K-20K	16.4	26.8	21.8
20K-30K	10.3	12.9	11.7
30K-40K	3.1	6.6	4.9
40K-50K	0.6	0.8	0.7
>50K	0.0	0.0	0.0
sum =	365.3	365.3	365.3

[1] Precipitation data from the Sacramento Airport, Station 47630.

[2] Friant Government Camp.

Table 7-3: Statistical Analysis of Annual Peak Inflows

Annual Peak Delta Inflows - Sacramento River & Yolo		
Annual Peak Inflows - Statistical Parameters	**WY 1956 - 1967, pre-Oroville Dam**	**WY 1968 - 2005, ~Existing Conditions**
No. of Years	12	38
Mean	188,164	160,107
Standard Deviation	128,500	140,928
Minimum	51,250	13,703
Median	137,681	108,106
Maximum	441,865	612,301
Distribution	Lognormal	
Statistical Test	t-Test (lognormal, equal variances)	
2-sided p-value	0.304	
Statistical Difference	No	

Annual Peak Delta Inflows - San Joaquin River		
Annual Peak Inflows - Statistical Parameters	**WY 1956 - 1978, pre-New Melones Dam**	**WY 1979 - 2005, ~Existing Conditions**
No. of Years	23	27
Mean	7,402	10,431
Standard Deviation	8,674	9,587
Minimum	960	1,280
Median	4,690	5,700
Maximum	41,700	41,800
Distribution	Lognormal	
Statistical Test	t-Test (lognormal, equal variances)	
2-sided p-value	0.227	
Statistical Difference	No	

Table 7-4 Annual Peak Delta Inflows (cfs), 1956-2005

Water Year	Water Year Oct. 1 to Sept. 30	High Runoff Season Dec 16 to Apr 15	Low Runoff Season Oct 1 to Dec 15, Apr 16 to Sep 30
1956	383,322	383,322	80,086
1957	127,125	127,125	77,800
1958	278,826	278,826	127,867
1959	122,938	122,938	18,357
1960	142,860	142,860	21,479
1961	52,585	52,585	35,461
1962	157,492	157,492	35,160
1963	350,859	350,859	232,438
1964	62,010	62,010	42,188
1965	470,122	470,122	90,923
1966	64,384	64,384	38,415
1967	237,831	237,831	115,781
1968	92,407	92,407	25,433
1969	283,710	283,710	86,471
1970	383,921	383,921	26,488
1971	118,608	110,400	118,608
1972	36,664	36,664	22,654
1973	222,801	222,801	43,742
1974	276,092	276,092	123,106
1975	127,364	127,364	44,033
1976	34,593	30,651	34,593
1977	14,908	14,908	12,438
1978	174,450	174,450	70,752
1979	101,046	101,046	27,774
1980	339,008	339,008	33,394
1981	64,268	64,268	33,434
1982	238,395	238,395	197,768
1983	422,213	422,213	127,334
1984	351,622	351,622	169,189
1985	49,820	44,937	49,820
1986	661,272	661,272	48,018

Table 7-4 Annual Peak Delta Inflows (cfs), 1956-2005

Water Year	Water Year Oct. 1 to Sept. 30	High Runoff Season Dec 16 to Apr 15	Low Runoff Season Oct 1 to Dec 15, Apr 16 to Sep 30
1987	44,060	44,060	26,604
1988	42,023	42,023	28,941
1989	77,384	77,384	30,508
1990	38,654	38,654	23,052
1991	56,926	56,926	13,399
1992	57,349	57,349	13,870
1993	143,649	143,649	54,362
1994	34,770	34,770	29,893
1995	387,177	387,177	176,174
1996	207,020	207,020	98,021
1997	561,989	561,989	130,890
1998	323,012	323,012	112,420
1999	141,418	141,418	69,997
2000	168,766	168,766	43,293
2001	57,684	57,684	18,567
2002	108,335	108,335	39,772
2003	93,766	93,766	71,627
2004	186,184	186,184	34,270
2005	96,699	73,956	96,699

Table 7-5 Results of Log Pearson Type III Frequency Analyses

Probability	Inflows For Various Percent Confidence That The Inflow Will Not Be Exceeded												
	CL = 99%	CL = 97.5%	CL = 95%	CL = 90%	CL = 80%	CL = 60%	CL = 50%	CL = 40%	CL = 20%	CL = 10%	CL = 5%	CL = 2.5%	CL = 1%
All Seasons Inflow													
0.5000	183,628	174,123	167,003	159,301	150,600	139,862	135,551	131,292	121,982	115,391	110,149	105,728	100,438
0.2000	417,743	384,177	362,404	340,001	316,076	288,481	280,047	267,913	246,965	232,973	222,322	213,661	205,125
0.1000	646,984	583,006	543,290	503,306	461,634	414,947	402,011	381,158	347,674	325,861	309,564	296,514	284,711
0.0500	925,781	819,574	755,468	691,963	626,943	555,619	536,997	505,080	455,965	424,523	401,337	382,966	367,245
0.0400	1,026,698	904,163	830,738	758,322	684,543	604,074	583,366	547,383	492,578	457,658	431,996	411,722	394,606
0.0250	1,257,855	1,096,264	1,000,731	907,312	813,021	711,305	685,788	640,424	572,582	529,736	498,454	473,871	453,614
0.0200	1,376,716	1,194,262	1,087,010	982,520	877,483	764,716	736,715	686,503	611,966	565,071	530,929	504,158	482,312
0.0100	1,784,960	1,527,536	1,378,571	1,234,957	1,092,240	941,059	904,505	837,586	740,151	679,497	635,677	601,532	574,362
0.0050	2,255,260	1,906,317	1,707,080	1,516,767	1,329,544	1,133,535	1,087,120	1,000,928	877,353	801,129	746,428	704,032	670,944
0.0020	2,978,735	2,480,798	2,200,802	1,936,227	1,679,002	1,413,366	1,351,820	1,236,059	1,072,812	973,177	902,221	847,564	805,745
0.0010	3,607,958	2,974,111	2,621,311	2,290,391	1,971,236	1,644,691	1,570,048	1,428,709	1,231,467	1,111,939	1,027,254	962,289	913,176
0.0005	4,312,097	3,520,576	3,084,102	2,677,476	2,288,198	1,893,304	1,804,086	1,634,300	1,399,532	1,258,192	1,158,523	1,082,350	1,025,346
0.0001	6,257,320	5,006,780	4,330,189	3,708,698	3,122,771	2,538,809	2,409,770	2,162,386	1,826,400	1,626,823	1,487,440	1,381,729	1,304,080
High Inflow Season													
0.5000	181,568	172,677	165,544	157,831	149,124	138,385	134,031	129,820	120,522	113,944	108,714	104,307	99,311
0.2000	413,058	384,136	362,145	339,533	315,401	287,591	276,906	266,882	245,805	231,739	221,037	212,338	202,824
0.1000	639,727	585,479	545,194	504,669	462,468	415,235	397,502	381,085	347,276	325,268	308,836	295,684	281,518
0.0500	915,397	825,972	760,721	696,137	630,079	557,696	530,974	506,465	456,730	424,919	401,476	382,913	363,125
0.0400	1,015,182	912,153	837,341	763,625	688,596	606,861	576,822	549,344	493,801	458,443	432,477	411,975	390,180
0.0250	1,243,746	1,108,170	1,010,641	915,363	819,299	715,802	678,096	643,769	574,902	531,453	499,753	474,855	448,526
0.0200	1,361,275	1,208,309	1,098,719	992,060	884,962	770,130	728,451	690,588	614,872	567,283	532,662	505,531	476,903
0.0100	1,764,939	1,549,465	1,396,870	1,249,918	1,104,061	949,770	894,360	844,316	745,139	683,467	638,948	604,280	567,919
0.0050	2,229,964	1,938,146	1,733,590	1,538,429	1,346,685	1,146,245	1,074,926	1,010,841	884,829	807,192	751,524	708,407	663,418
0.0020	2,945,324	2,529,142	2,240,895	1,968,875	1,704,783	1,432,499	1,336,657	1,251,046	1,084,220	982,528	910,174	854,479	796,708

Table 7-5 Results of Log Pearson Type III Frequency Analyses

	Inflows For Various Percent Confidence That The Inflow Will Not Be Exceeded												
Probability	**CL = 99%**	**CL = 97.5%**	**CL = 95%**	**CL = 90%**	**CL = 80%**	**CL = 60%**	**CL = 50%**	**CL = 40%**	**CL = 20%**	**CL = 10%**	**CL = 5%**	**CL = 2.5%**	**CL = 1%**
0.0010	3,567,490	3,037,795	2,673,925	2,333,085	2,004,848	1,669,586	1,552,438	1,448,212	1,246,349	1,124,182	1,037,709	971,422	902,933
0.0005	4,263,731	3,602,278	3,151,331	2,731,820	2,330,828	1,924,779	1,783,850	1,658,929	1,418,332	1,273,682	1,171,779	1,093,960	1,013,845
0.0001	6,187,136	5,141,778	4,440,231	3,796,821	3,191,257	2,588,905	2,382,741	2,201,376	1,856,069	1,651,259	1,508,377	1,400,104	1,289,453
Low Inflow Season													
0.5000	68,727	65,878	63,574	61,061	58,198	54,623	53,160	51,736	48,561	46,287	44,462	42,911	41,138
0.2000	139,955	131,575	125,144	118,473	111,284	102,898	99,645	96,576	90,066	85,675	82,306	79,549	76,513
0.1000	207,931	192,620	181,139	169,485	157,226	143,338	138,074	133,174	122,995	116,301	111,264	107,208	102,812
0.0500	290,229	265,260	246,858	228,475	209,477	188,403	180,547	173,303	158,476	148,897	141,785	136,120	130,045
0.0400	320,067	291,342	270,273	249,319	227,768	204,001	195,181	187,069	170,532	159,899	152,032	145,783	139,102
0.0250	388,659	350,886	323,437	296,368	268,789	238,708	227,642	217,513	197,019	183,960	174,362	166,780	158,715
0.0200	424,091	381,448	350,586	320,264	289,499	256,103	243,863	232,684	210,139	195,828	185,340	177,074	168,302
0.0100	546,819	486,453	443,268	401,289	359,189	314,108	297,761	282,918	253,258	234,632	221,091	210,485	199,300
0.0050	690,367	607,903	549,521	493,307	437,513	378,485	357,283	338,130	300,165	276,549	259,496	246,215	232,282
0.0020	916,000	796,528	712,991	633,460	555,491	474,173	445,288	419,355	368,429	337,098	314,656	297,288	279,181
0.0010	1,117,030	962,759	855,816	754,796	656,598	555,188	519,441	487,483	425,124	387,048	359,923	339,023	317,321
0.0005	1,347,193	1,151,399	1,016,766	890,518	768,770	644,191	600,590	561,764	486,453	440,790	408,423	383,584	357,892
0.0001	1,999,908	1,678,991	1,462,024	1,261,661	1,071,627	880,862	815,089	756,991	645,681	579,164	532,504	496,990	460,544

Table 7-6 Parameters Used in Log Pearson Type III Distribution

Season	Mean	Standard Deviation	Skew	Weighted Slew
All	5.12	0.383	-0.194	0.223
High	5.11	0.387	-0.184	-0.216
Low	4.72	0.325	0.0645	-0.0323

Weighted skew is a function of the generalized skew (-0.3000) and Mean Square Error of Generalized Skew (see p. 13, of Bulletin 17B)

Table 7-7 Inflow Ranges (Bins) and Confidence Limit Probabilities for the High Inflow Season - Year 2000

						50% Confidence Limit		80% Confidence Limit		20% Confidence Limit		95% Confidence Limit		5% Confidence Limit	
Bin #	**LN (Lower Value)**	**LN (Upper Value)**	**Lower Value**	**Upper Value**	**Designated Bin Value[(1)]**	**Proabability of Exceedence**	**Probability of Being in Bin**	**Proabability of Exceedence**	**Probability of Being in Bin**	**Proabability of Exceedence**	**Probability of Being in Bin**	**Proabability of Exceedence**	**Probability of Being in Bin**	**Proabability of Exceedence**	**Probability of Being in Bin**
			0	30,045		1.000		1.000		1.000		1.000		1.000	
1	10.310438	10.581243	30,045	39,389	34,717	0.940	0.060	1.000	0.000	1.000	0.000	1.000	0.000	1.000	0.000
2	10.581243	10.852048	39,389	51,640	45,514	0.865	0.072	0.970	0.030	1.000	0.010	1.000	0.000	0.970	0.030
3	10.852048	11.122853	51,640	67,701	59,670	0.780	0.084	0.911	0.059	1.000	0.025	1.000	0.000	0.920	0.050
4	11.122853	11.393658	67,701	88,757	78,229	0.685	0.095	0.817	0.094	0.900	0.060	0.830	0.100	0.840	0.080
5	11.393658	11.664463	88,757	116,362	102,560	0.565	0.105	0.673	0.144	0.800	0.100	0.680	0.150	0.735	0.105
6	11.664463	11.935268	116,362	152,553	134,458	0.445	0.113	0.498	0.175	0.650	0.154	0.530	0.220	0.617	0.118
7	11.935268	12.206073	152,553	200000	176,277	0.353	0.121	0.299	0.190	0.402	0.174	0.248	0.220	0.490	0.127
8	12.206073	12.476878	200,000	262,204	231,102	0.225	0.120	0.174	0.125	0.284	0.180	0.138	0.150	0.360	0.130
9	12.476878	12.747683	262,204	343,754	302,979	0.130	0.095	0.103	0.080	0.168	0.116	0.078	0.082	0.235	0.125
10	12.747683	13.018488	343,754	450,669	397,212	0.076	0.060	0.053	0.051	0.106	0.075	0.036	0.042	0.145	0.090
11	13.018488	13.289293	450,669	590,835	520,752	0.038	0.038	0.023	0.030	0.060	0.046	0.014	0.022	0.085	0.060
12	13.289293	13.560098	590,835	774,597	682,716	0.017	0.021	0.009	0.014	0.030	0.030	0.004	0.010	0.047	0.038
13	13.560098	13.830903	774,597	1,015,511	895,054	0.006	0.011	0.003	0.006	0.014	0.016	0.001	0.003	0.025	0.023
14	13.830903	14.101708	1,015,511	1,331,355	1,173,433	0.002	0.004	0.001	0.002	0.005	0.008	0.0002460	0.001	0.012	0.013
15	14.101708	14.372513	1,331,355	1,745,432	1,538,394	0.001	0.002	0.000	0.001	0.002	0.003	0.0000415	0.000	0.005	0.007
16	14.372513	14.643318	1,745,432	2,288,296	2,016,864	0.000	0.000	0.000	0.000	0.001	0.001	0.0000044	0.000	0.002	0.003
17	14.643318	14.914123	2,288,296	3,000,000	2,644,148	0.000	0.000	0.000	0.000	0.000	0.000	0.0000005	0.000	0.001	0.001
						Totals =	**1.000**		**1.000**		**0.9994**		**0.9998**		**0.9994**

(1) Designated Bin Value is average of Lower & Upper Value.

Table 7-8 Results of Logistic Regressions

River	a (Slope)	b (Intercept)	r^2	Standard Error of Regression
Sacramento + Yolo Bypass	.563	-5.21	0.054	0.530
San Joaquin River	0.430	-4.173	0.075	0.709
Miscellaneous Flows	0.379	-4.453	0.071	0.665
Cosumnes River	1.116	-9.670	0.358	0.714

	Table 7-9a Islands/Tracts Flooded Since 1900			
	Location		**Years**	**No. Of Failures**
1	Bacon	Island	1938	1
2	Big Break	Island	1927	1
3	Bishop	Tract	1904	1
4	Brack	Tract	1904	1
5	Byron	Tract	1907	1
6	Coney	Island	1907	1
7	Donlon	Island	1937	1
8	Edgerly	Island	1983	1
9	Grand	Island	1955	1
10	Holland	Tract	1980	1
11	Little Holland	Tract	1963	1
12	Lower Roberts	Island	1906	1
13	Mandeville	Island	1938	1
14	Mc Donald	Island	1982	1
15	Medford	Island	1936	1
16	Palm	Tract	1907	1
17	Rd 1007	Tract	1925	1
18	Shima	Tract	1983	1
19	Union	Island	1906	1
20	Upper Jones	Tract	2004	1
21	Upper Roberts	Tract	1950	1
22	Walthall	Tract	1997	1
23	Wetherbee	Lake	1997	1
24	Bradford	Island	1950-1983	2
25	Cliftoncourt	Tract	1901-1907	2
26	Empire	Tract	1950-1955	2
27	Fabian	Tract	1901-1906	2
28	Fay	Island	1983-2006	2
29	Glanville	Island	1986-1997	2
30	Ida	Island	1950-1955	2
31	McMullin Ranch	Tract	1997-1950	2
32	Middle Roberts	Island	1920-1938	2
33	Rhode	Island	1938-1971	2
34	Sargent Barnhart	Tract	1904-1907	2
35	Staten	Island	1904-1907	2
36	Terminous	Tract	1907-1958	2
37	Victoria	Island	1901-1907	2
38	Webb	Tract	1950-1980	2
39	Little Mandeville	Island	1980-1986-1994	3
40	Ryer	Island	1904-1907-1986	3
41	Franks	Tract	1907-1936-1938	3

Table 7-9a Islands/Tracts Flooded Since 1900				
	Location		**Years**	**No. Of Failures**
42	Little Franks	Tract	1981-1982-1983	3
43	Lower Jones	Tract	1906-1907-1980-2004	3
44	Mildred	Island	1965-1969-1983	3
45	Mossdale Rd17	Tract	1901-1911-1950	3
46	Paradise	Junction	1920-1950-1997	3
47	Pescadero	Tract	1938-1950-1997	3
48	River Junction	Junction	1958-1983-1997	3
49	Stewart	Tract	1938-1950-1997	3
50	Twitchell	Island	1906-1907-1908	3
51	Tyler	Island	1904-1907-1986	3
52	Bethel	Island	1907-1908-1909-1911	4
53	Bouldin	Island	1904-1907-1908-1909	4
54	Jersey	Island	1900-1904-1907-1909	4
55	Quimby	Island	1936-1938-1950-1955	4
56	Shin Kee	Tract	1938-1958-1965-1986	4
57	Brannan-Andrus	Island	1902-1904-1907-1909-1972	5
58	Sherman	Island	1904-1906-1909-1937-1969	5
59	Dead Horse	Island	1950-1955-1958-1980-1986-1997	6
60	McCormack-Williamson	Tract	1938-1950-1955-1958-1964-1986-1997	7
61	New Hope	Tract	1900-1904-1907-1928-1950-1955-1986	7
62	Prospect	Island	1963-1980-1981-1982-1983-1986-1995-1997	8
63	Venice	Island	1904-1906-1907-1909-1932-1938-1950-1982	8
	Number of Delta Flooded Islands/Tracts			**158**
	Honker Bay Club	Island	2006	1
	Grizzly	Island	1983-1998	2
	Simmons Wheeler	Island	2005-2006	2
	Van Sickle	Island	1983-1998-2006	3
	Suisun Marsh		Incomplete record only few recent data points available	**NA**

Table 7-9b Chronologic List of Flooded Islands Since 1900

Island Flooded	Year	Island Flooded	Year
TERMINOUS	1907	HOLLAND	1980
CLIFTONCOURT	1907	LITTLE MANDEVILLE	1980
SARGENT BARNHART	1907	LOWER JONES	1980
STATEN	1907	WEBB	1980
VICTORIA	1907	DEAD HORSE	1980
FRANKS	1907	PROSPECT	1980
RYER	1907	LITTLE FRANKS	1981
TWITCHELL	1907	PROSPECT	1981
TYLER	1907	LITTLE FRANKS	1982
BETHEL	1907	MC DONALD	1982
BRANNAN-ANDRUS	1907	VENICE	1982
BOULDIN	1907	EDGERLY	1983
JERSEY	1907	SHIMA (2)	1983
NEW HOPE	1907	FAY	1983
VENICE	1907	GRIZZLY WEST	1983
BETHEL	1908	BRADFORD	1983
BOULDIN	1908	VAN SICKLE (2)	1983
BRANNAN-ANDRUS	1909	LITTLE FRANKS (U)	1983
BETHEL	1909	MILDRED (U)	1983
BOULDIN	1909	VAN SICKLE	1983
SHERMAN	1909	PROSPECT (2)	1983
VENICE	1909	RIVER JUNCTION	1983
MOSSDALE RD17	1911	GLANVILLE	1986
BETHEL	1911	RYER	1986
MIDDLE ROBERTS	1920	SHIN KEE	1986
PARADISE JUNCTION	1920	DEAD HORSE (2)	1986
RD 1007	1925	LITTLE MANDEVILLE	1986
BIG BREAK	1927	PROSPECT	1986
NEW HOPE	1928	MC CORMACK-WILLIA (2)	1986
VENICE	1932	NEW HOPE	1986
MEDFORD	1936	TYLER (2)	1986
FRANKS	1936	LITTLE MANDEVILLE (U)	1994

Table 7-9b Chronologic List of Flooded Islands Since 1900

Island Flooded	Year	Island Flooded	Year
QUIMBY	1936	PROSPECT	1995
DONLON	1937	DEAD HORSE	1997
SHERMAN	1937	MC CORMACK-WILLIA	1997
BACON	1938	PROSPECT	1997
MANDEVILLE	1938	MCMULLIN RANCH	1997
MIDDLE ROBERTS	1938	PARADISE JUNCTION	1997
RHODE	1938	RIVER JUNCTION	1997
PESCADERO	1938	WALTHALL (2)	1997
STEWART	1938	WETHERBEE	1997
FRANKS	1938	GLANVILLE	1997
SHIN KEE	1938	PESCADERO	1997
QUIMBY	1938	STEWART TRACT	1997
MC CORMACK-WILLIA	1938	GRIZZLY	1998
VENICE	1938	VAN SICKLE	1998
BRADFORD	1950	UPPER JONES	2004
EMPIRE	1950	SIMMONS WHEELER	2005
IDA	1950	HONKER BAY CLUB	2006
WEBB	1950	FAY ISLAND	2006
PESCADERO	1950	SIMMONS WHEELER	2006
STEWART	1950	VAN SICKLE	2006

Table 7-9c Annual Peak Day Delta Inflows of Record (WY 1956 Through 2005)

Water Year	Date, WY Peak Inflow Day	Peak Day Sacramento River, cfs	Peak Day Yolo Bypass, cfs	Peak Day Cosumnes River, cfs	Peak Day Mokelumne River, cfs	Peak Day Misc. Streams, cfs	Peak Day San Joaquin River, cfs	Peak Day Total Inflow, cfs	Average 5-day Peak Inflow, cfs	Ratio: Avg. 5-day Peak to Peak Day	5-Day Inflow Vol. Up Through Peak Day, ac-ft	5-Day Inflow Vol. Up Through Peak Day, ac-ft
1986	February 20, 1986	113,000	499,301	15,600	4,490	14,981	13,900	661,272	551,714	0.83	4,501,390.41	1,571,520
1997	January 3, 1997	113,000	395,140	19,200	4,250	5,699	24,700	561,989	493,338	0.88	3,641,896.86	959,768
1965	December 25, 1964	98,600	343,265	11,500	150	2,607	14,000	470,122	382,948	0.81	2,673,209.26	2,281,874
1983	March 4, 1983	83,100	274,300	6,490	3,350	13,173	41,800	422,213	381,167	0.90	3,127,846.61	797,068
1995	March 13, 1995	96,100	266,562	6,340	2,440	1,635	14,100	387,177	336,016	0.87	2,229,883.64	741,241
1970	January 25, 1970	93,000	255,600	5,970	4,330	3,821	21,200	383,921	362,105	0.94	3,304,076.03	455,516
1956	December 23, 1955	90,200	249,600	34,100	2,180	4,032	3,210	383,322	276,247	0.72	1,571,520.00	1,131,743
1984	December 28, 1983	92,700	221,988	7,010	3,840	7,484	18,600	351,622	305,986	0.87	2,345,680.66	1,190,319
1963	February 2, 1963	94,400	230,107	17,300	3,260	1,962	3,830	350,859	202,799	0.58	1,190,318.68	399,078
1980	February 22, 1980	94,100	202,145	9,190	1,730	11,543	20,300	339,008	303,426	0.90	2,285,049.92	2,673,209
1998	February 8, 1998	86,800	193,521	6,130	2,930	7,331	26,300	323,012	305,585	0.95	2,823,322.31	596,854
1969	January 27, 1969	87,000	134,770	10,600	4,160	5,480	41,700	283,710	259,060	0.91	2,608,720.66	1,807,500
1958	February 26, 1958	85,500	174,510	6,140	1,650	3,276	7,750	278,826	245,784	0.88	2,281,874.38	798,413
1974	January 20, 1974	94,200	165,350	4,360	2,250	1,642	8,290	276,092	251,157	0.91	1,960,831.74	2,608,721
1982	February 17, 1982	98,000	103,742	11,700	3,030	14,203	7,720	238,395	175,241	0.74	1,041,399.67	3,304,076
1967	February 1, 1967	90,100	132,590	6,060	93	918	8,070	237,831	211,254	0.89	1,807,499.50	923,631
1973	January 19, 1973	92,700	112,559	6,790	1,910	2,472	6,370	222,801	196,152	0.88	1,728,842.98	337,839
1996	February 23, 1996	86,800	93,818	2,900	2,840	5,262	15,400	207,020	193,127	0.93	1,647,205.29	1,728,843
2004	February 28, 2004	73,800	105,288	1,500	326	1,050	4,220	186,184	177,486	0.95	1,594,216.86	1,960,832
1978	January 18, 1978	75,000	85,024	5,100	114	5,062	4,150	174,450	158,930	0.91	1,310,340.50	1,126,078
2000	February 28, 2000	81,700	63,375	5,010	2,010	3,071	13,600	168,766	156,851	0.93	1,446,424.46	325,369
1962	February 16, 1962	70,100	68,679	7,520	547	2,826	7,820	157,492	137,722	0.87	1,131,742.81	122,450
1993	March 28, 1993	82,300	53,026	3,280	431	662	3,950	143,649	136,829	0.95	1,300,621.49	1,310,340
1960	February 10, 1960	69,100	67,482	3,280	156	712	2,130	142,860	108,434	0.76	741,240.99	838,080
1999	February 11, 1999	85,400	31,150	3,630	2,770	6,568	11,900	141,418	124,608	0.88	991,787.11	2,285,050
1975	March 26, 1975	73,800	36,228	6,340	895	3,171	6,930	127,364	118,869	0.93	1,126,078.02	525,396
1957	March 7, 1957	79,200	36,361	4,050	1,800	1,024	4,690	127,125	112,424	0.88	959,767.93	1,041,400
1959	February 20, 1959	67,300	46,902	1,830	662	1,404	4,840	122,938	105,502	0.86	797,067.77	3,127,847
1971	December 5, 1970	73,200	32,983	5,880	1,230	1,675	3,640	118,608	108,748	0.92	923,631.07	2,345,681
2002	January 6, 2002	65,567	34,528	725	194	3,097	4,224	108,335	91,437	0.84	802,131.57	461,516
1979	February 24, 1979	71,300	5,170	2,660	1,260	7,856	12,800	101,046	95,445	0.94	838,080.00	4,501,390
2005	May 22, 2005	74,100	6,668	1,590	2,090	151	12,100	96,699	90,974	0.94	769,348.76	331,279
2003	January 3, 2003	65,300	25,560	261	211	154	2,280	93,766	83,057	0.89	751,933.88	291,814
1968	February 25, 1968	66,200	18,648	1,350	838	1,251	4,120	92,407	88,976	0.96	798,412.56	578,604
1989	March 27, 1989	73,500	26	1,820	7	11	2,020	77,384	68,450	0.88	578,604.30	293,407
1966	January 10, 1966	53,600	4,085	377	436	536	5,350	64,384	61,741	0.96	596,854.21	398,339
1981	January 31, 1981	51,900	5,096	759	72	741	5,700	64,268	60,686	0.94	525,395.70	495,923
1964	January 23, 1964	52,200	2,841	2,780	624	455	3,110	62,010	54,099	0.87	399,078.35	1,300,621
2001	March 9, 2001	46,200	4,425	483	289	627	5,660	57,684	53,441	0.93	505,557.02	237,051
1992	February 17, 1992	46,800	2,456	1,290	177	1,516	5,110	57,349	53,943	0.94	495,923.31	2,229,884
1991	March 27, 1991	46,900	3,260	1,310	119	2,027	3,310	56,926	49,859	0.88	398,338.51	1,647,205
1961	February 14, 1961	49,500	1,750	228	111	36	960	52,585	51,222	0.97	455,516.03	3,641,897
1985	November 30, 1984	41,200	3,408	511	762	439	3,500	49,820	47,470	0.95	461,516.03	2,823,322
1987	March 16, 1987	38,000	1,686	840	91	443	3,000	44,060	40,764	0.93	331,279.34	991,787
1988	January 7, 1988	37,200	3,245	203	46	49	1,280	42,023	39,287	0.93	291,814.21	1,446,424
1990	January 16, 1990	36,900	25	284	45	30	1,370	38,654	33,325	0.86	293,406.94	505,557
1972	December 28, 1971	31,100	192	1,440	96	406	3,430	36,664	35,424	0.97	337,838.68	802,132
1994	February 10, 1994	29,900	1,686	190	150	64	2,780	34,770	29,317	0.84	237,050.58	751,934
1976	December 8, 1975	30,600	48	53	297	15	3,580	34,593	33,457	0.97	325,368.60	1,594,217
1977	January 5, 1977	13,700	3	76	37	12	1,080	14,908	13,128	0.88	122,449.59	769,349

Table 7-10 Vulnerability Classes for Under-Seepage Analyses

Geographic Region	Vulnerability Class Index	Peat Thickness (ft)	Slough Width	Random Input Variables
Delta	1	0	Narrow	Ditch, Sediment
	2	0	Not Narrow	Ditch, Sediment
	3	0.1-5	Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	4	0.1-5	Not Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	5	5.1-10	Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	6	5.1-10	Not Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	7	10.1-15	Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	8	10.1-15	Not Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	9	15.1-30	Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	10	15.1-30	Not Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	11	>30	Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
	12	>30	Not Narrow	Ditch, Sediment, Peat Thickness, Peat Permeability
Suisan Marsh	13	0	Narrow	Sediment
	14	0	Not Narrow	Sediment
	15	0.1-5	Narrow	Sediment, Peat Thickness, Peat Permeability
	16	0.1-5	Not Narrow	Sediment, Peat Thickness, Peat Permeability
	17	5.1-10	Narrow	Sediment, Peat Thickness, Peat Permeability
	18	5.1-10	Not Narrow	Sediment, Peat Thickness, Peat Permeability
	19	10.1-15	Narrow	Sediment, Peat Thickness, Peat Permeability
	20	10.1-15	Not Narrow	Sediment, Peat Thickness, Peat Permeability
	21	15.1-30	Narrow	Sediment, Peat Thickness, Peat Permeability
	22	15.1-30	Not Narrow	Sediment, Peat Thickness, Peat Permeability
	23	>30	Narrow	Sediment, Peat Thickness, Peat Permeability
	24	>30	Not Narrow	Sediment, Peat Thickness, Peat Permeability

Table 7-11 Reported Permeability Data for Organic Soils
(Source: HLA 1989, 1992)

Soil Type	k_h (cm/s)	k_v(cm/s)	Type of test	Location	Sampling detail
Black peat (PT) with fat clay	2.4×10^{-7}	-	Lab test	Levee, Bacon Island	1988, Sample depth = 22 ft
Black peat (PT) with fat clay	7.2×10^{-7}	-	Lab test	Levee, Web Tract	1988, Sample depth = 25 ft
Black Peat (PT)	4.7×10^{-6}	1.3×10^{-6}	Falling head lab test	Wilkerson Dam-Test fill, Bouldin Island	1989, Sample depth = 9 ft
Black Peat (PT)	5.5×10^{-6}	7.6×10^{-8}	Falling head lab test	Wilkerson Dam-Test fill, Bouldin Island	1989, Sample depth = 9 ft
Black Silty Peat (PT)	1.5×10^{-6}	2.1×10^{-6}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 4 ft
Black Silty Peat (PT)	-	7.5×10^{-7}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 5 ft
Black Silty Peat (PT)	1.9×10^{-6}	9.7×10^{-7}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 11 ft
Black Silty Peat (PT)	2.6×10^{-6}	1.8×10^{-7}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 10 ft
Black Silty Peat (PT)	8.8×10^{-7}	1.5×10^{-6}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 5 ft
Brown elastic silt w/ peat (MH)	1.2×10^{-6}	3.2×10^{-7}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 8 ft
Black organic silt (OH) contains peat		5.7×10^{-7}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 15 ft

Table 7-12 Reported Permeability Data for Sandy Soils and Silt (Source: HLA 1989, 1991, 1992)

Soil Type	k_h (cm/s)	k_v(cm/s)	Type of test	Location	Sampling detail
Gray Silty sand (SM), fine to medium grained	2.2×10^{-5}	-	Lab test	Levee, Bacon Island	1988, Sample depth = 40 ft
Gray Silty sand (SM), fine to medium grained	3.3×10^{-4}	-	Lab test	Levee, Web Tract	1988, Sample depth = 45 ft
Brown silty sand (SM)	3.9×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown silty sand (SM)	1.2×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown poorly graded sand (SP)	6.9×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Washed sample
Brown poorly graded sand (SP)	8.6×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Washed sample
Brown silty graded sand (SP)	3.9×10^{-3}	-	Falling head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown sand (SP)	6.4×10^{-3}	-	Falling head lab test	Barrow pit, Bouldin Island	1991, Washed sample
Brown silty sand (SM)	6.8×10^{-5}	-	Falling head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown silty sand (SM)	1.1×10^{-5}	-	Falling head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown poorly graded sand (SP)	5.6×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, washed sample
Brown poorly graded sand (SP)	4.6×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Washed sample
Brown sand w/ silt (SP-SM)	1.1×10^{-3}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown sand w/ silt (SP-SM)	1.2×10^{-4}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, Natural sample
Brown poorly graded sand (SP)	1.0×10^{-3}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, washed sample
Brown poorly graded sand (SP)	1.9×10^{-3}	-	Constant head lab test	Barrow pit, Bouldin Island	1991, washed sample
Brown silty sand (SM)	2.4×10^{-5}	-	Constant head lab test	Test Fill, Bouldin Island	1991, natural sample
Brown silty sand (SM)	1.1×10^{-6}	-	Falling head lab test	Test Fill, Bouldin Island	1991, natural sample
Brown poorly graded sand (SP)	7.5×10^{-4}	-	Constant head lab test	Test Fill, Bouldin Island	1991, washed sample
Brown poorly graded sand (SP)	1.1×10^{-3}	-	Constant head lab test	Test Fill, Bouldin Island	1991, washed sample
Poorly graded sand (SP), very fine to fine grained, contains some silt	5.4×10^{-3}	-	Field pump test	Holland Tract	1989, Pumping rate = 30 GPM, Depth = 20 ft
Poorly graded sand (SP), very fine to fine grained, contains some silt	6.4×10^{-3}	-	Field pump test	Holland Tract	1989, Pumping rate = 30 GPM, Depth = 30 ft
Blue gray silty sand (SM, fine grained)	1.4×10^{-1}	-	Field pump test	McDonald Island	1989, Pumping rate = 215 GPM
Blue-gray elastic silt (MH)	3.1×10^{-6}	3.8×10^{-6}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 20 ft
Blue-gray sandy silt (ML)	-	3.9×10^{-7}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 25 ft
Blue-gray silt (ML)	-	1.1×10^{-5}	Falling head lab test	Wilkerson Dam-Bouldin Island	1989, Sample depth = 20 ft

Table 7-13 Permeability Coefficients Used for Initial Seepage Analysis

Material	k_h (cm/s)			k_h/k_v
	Mean - σ	Mean	Mean + σ	
Fill				
CL-ML (fill)	-	1×10^{-5}	-	4
SM (fill)	-	1×10^{-3}	-	4
Peat & Organics				
Free Field	1×10^{-5}	1×10^{-4}	1×10^{-3}	10
Under Levee	1×10^{-6}	1×10^{-5}	1×10^{-4}	10
Other Foundation Soils				
Sand (SM/SP)	5×10^{-4}	1×10^{-3}	5×10^{-3}	4
ML	-	1×10^{-4}	-	4
CL	-	1×10^{-6}	-	4
Sediment (at slough bottom)	-	1×10^{-5}	-	1

Table 7-14 Initial Analysis Results for Terminous Tract

Slough Water Elevation (ft) [NAVD88]	Analysis Case-Permeability	Ditch		No Ditch		Remarks
		i_y below ditch (Point A)	Ave. i_y at Point B	i_y (near toe)	Ave. i_y at Point B	
0	k_{mean}	0.46	0.17	0.22	0.178	model with sediment
4	k_{mean}	0.64	0.24	0.30	0.249	model with sediment
7	k_{mean}	0.75	0.29	0.36	0.301	model with sediment
0	$k_{(mean-\sigma)peat}$	0.57	0.25			model with sediment
4	$k_{(mean-\sigma)peat}$	0.82	0.38	-	-	model with sediment
7	$k_{(mean-\sigma)peat}$	1	0.47			model with sediment
0	$k_{(mean+\sigma)peat}$	0.26	0.05			model with sediment
4	$k_{(mean+\sigma)peat}$	0.36	0.07	-	-	model with sediment
7	$k_{(mean+\sigma)peat}$	0.42	0.08			model with sediment
0	$k_{(mean-\sigma)\ sand}$	0.44	0.14			model with sediment
4	$k_{(mean-\sigma)\ sand}$	0.6	0.20	-	-	model with sediment
7	$k_{(mean-\sigma)\ sand}$	0.7	0.24			model with sediment
0	$k_{(mean+\sigma)\ sand}$	0.25	0.07			model with sediment
4	$k_{(mean+\sigma)\ sand}$	0.41	0.15	-	-	model with sediment
7	$k_{(mean+\sigma)\ sand}$	0.52	0.21			model with sediment
0	k_{mean}	0.58	0.22			model without sediment
4	k_{mean}	0.79	0.31	-	-	model without sediment
7	k_{mean}	0.94	0.38			model without sediment

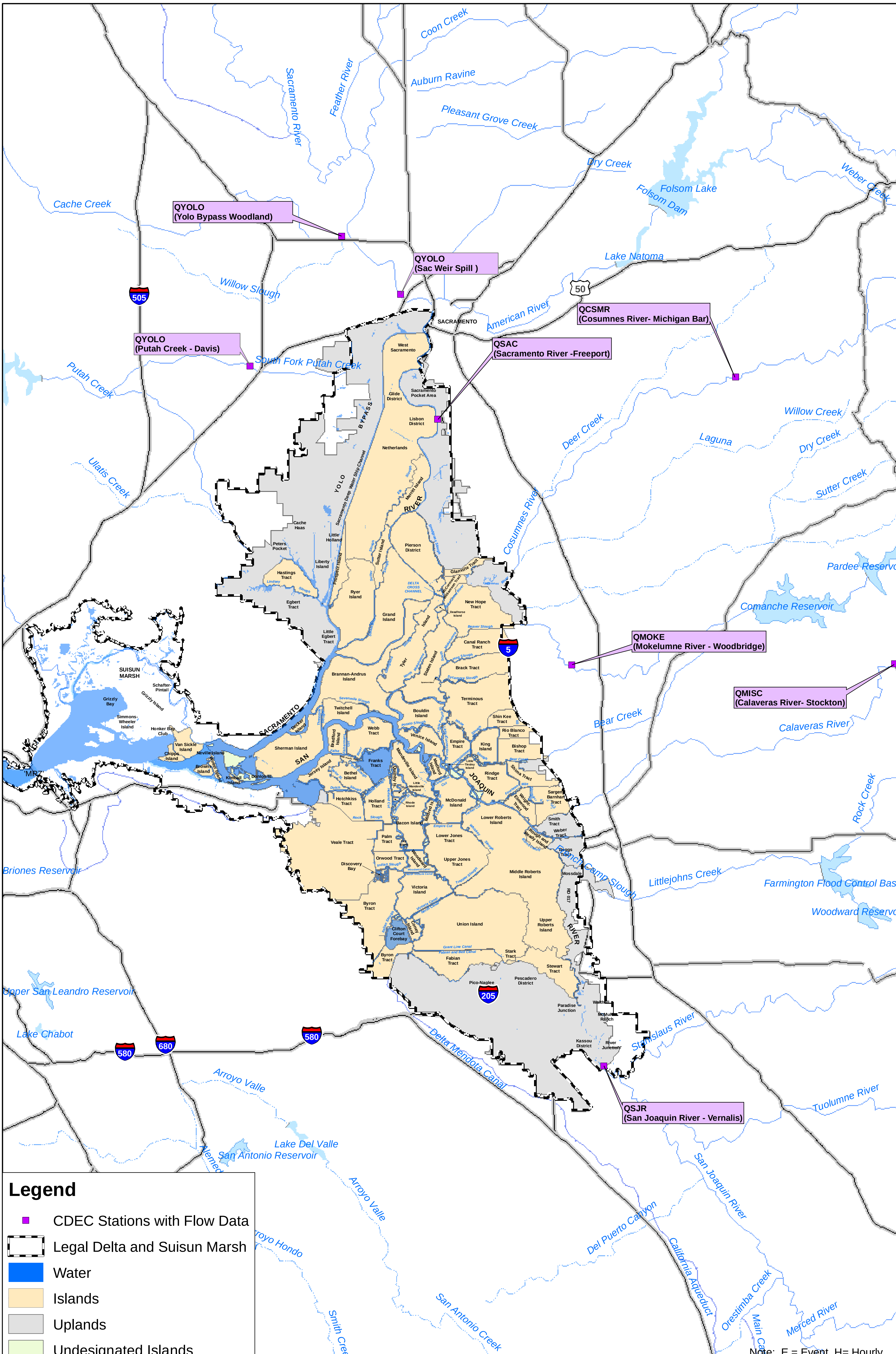
Table 7-15 Estimated Vertical Gradients for Grand Island Under-seepage Problem

(k_h/k_v)peat	Analysis Case: No Ditch & No Sediment	
	Ave. i_y near toe	Ave. i_y at Point B
10	0.42	0.26
100	0.59	0.50
1000	0.63	0.56

Table 7-16 Evaluated Permeability Coefficients Used for Model Analyses

Material	k_h (cm/s)			k_h/k_v
	Mean - σ	Mean	Mean + σ	
Fill				
SM (fill)	-	1×10^{-3}	-	4
Peat & Organics				
Free Field	1×10^{-5}	1×10^{-4}	1×10^{-3}	100
Under Levee	1×10^{-6}	1×10^{-5}	1×10^{-4}	100
Other Foundation Soils				
Sand (SM/SP)	-	1×10^{-3}	-	4
CL	-	1×10^{-6}	-	4
Sediment (at slough bottom)	-	1×10^{-5}	-	1

Figures



URS

DRMS	Flow Stations Used with Flood Hazard Analysis	Figure 7-1
26815431		

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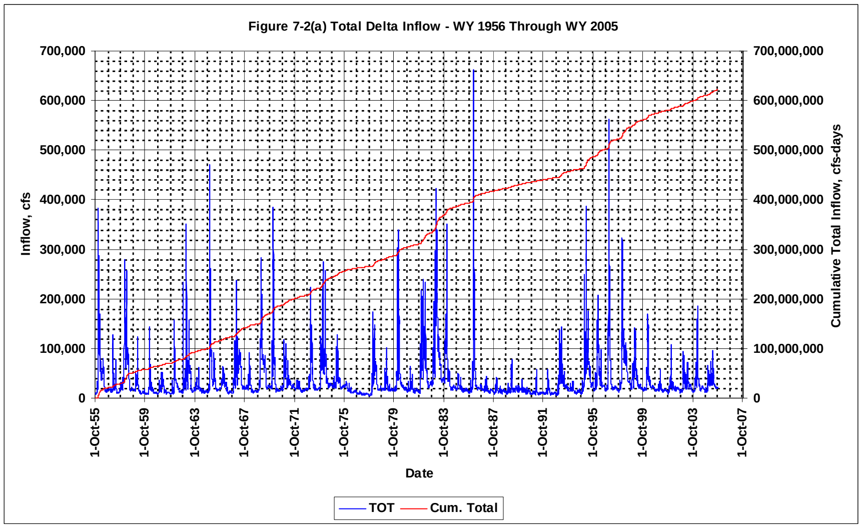
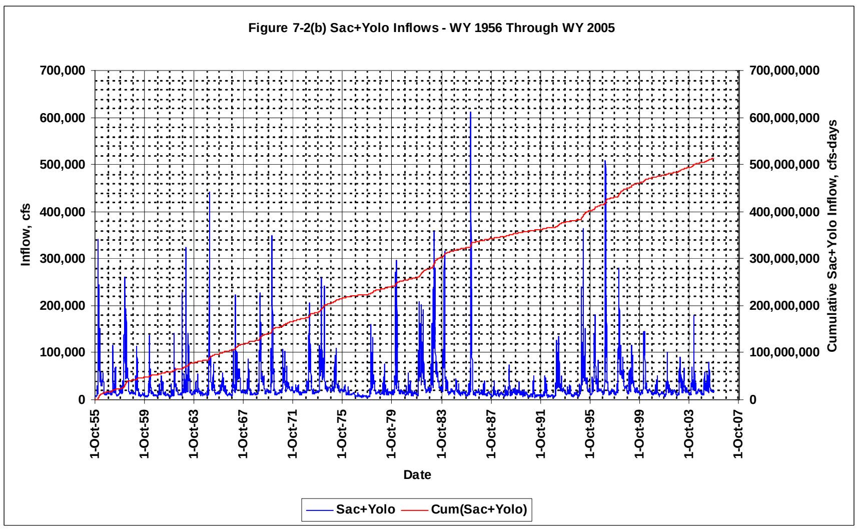
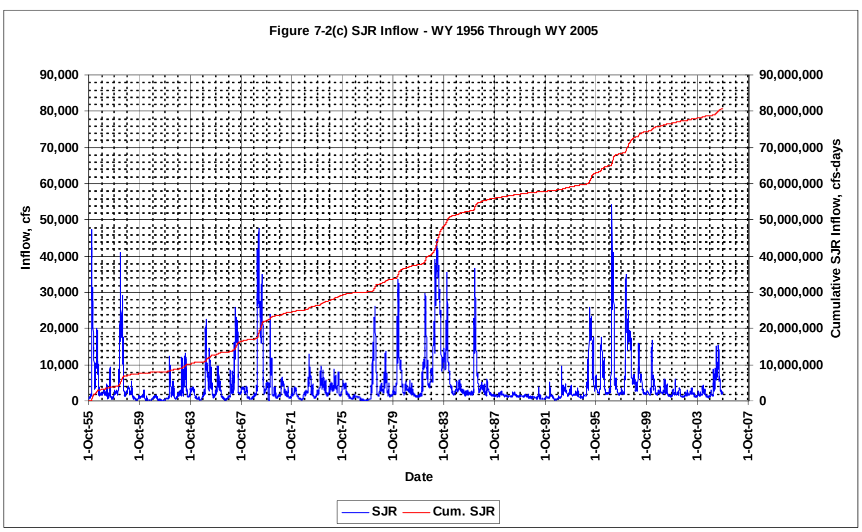
Figure 7-2 Historical Delta Inflows







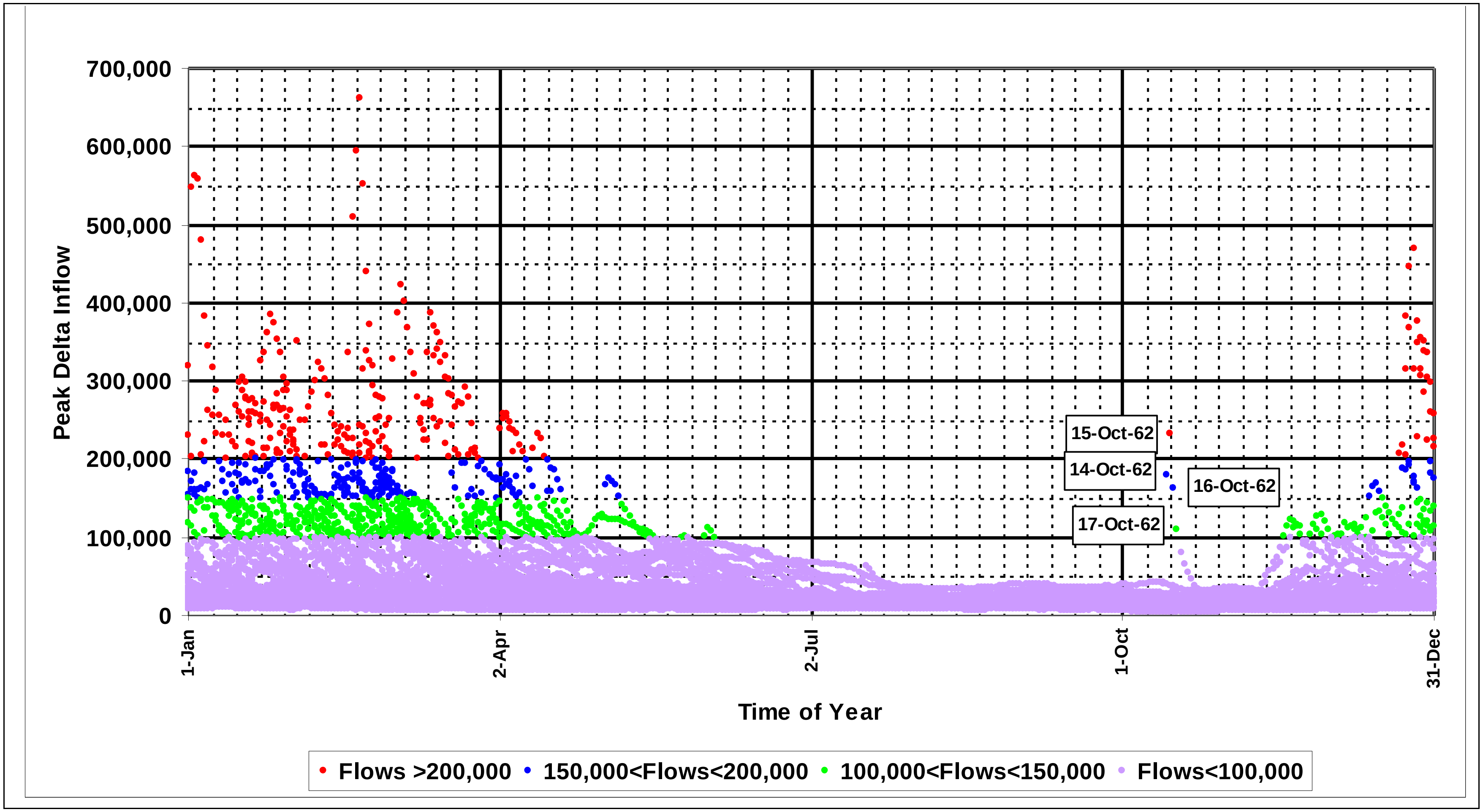


Figure 7-3 Temporal Distribution of Peak Delta Inflows

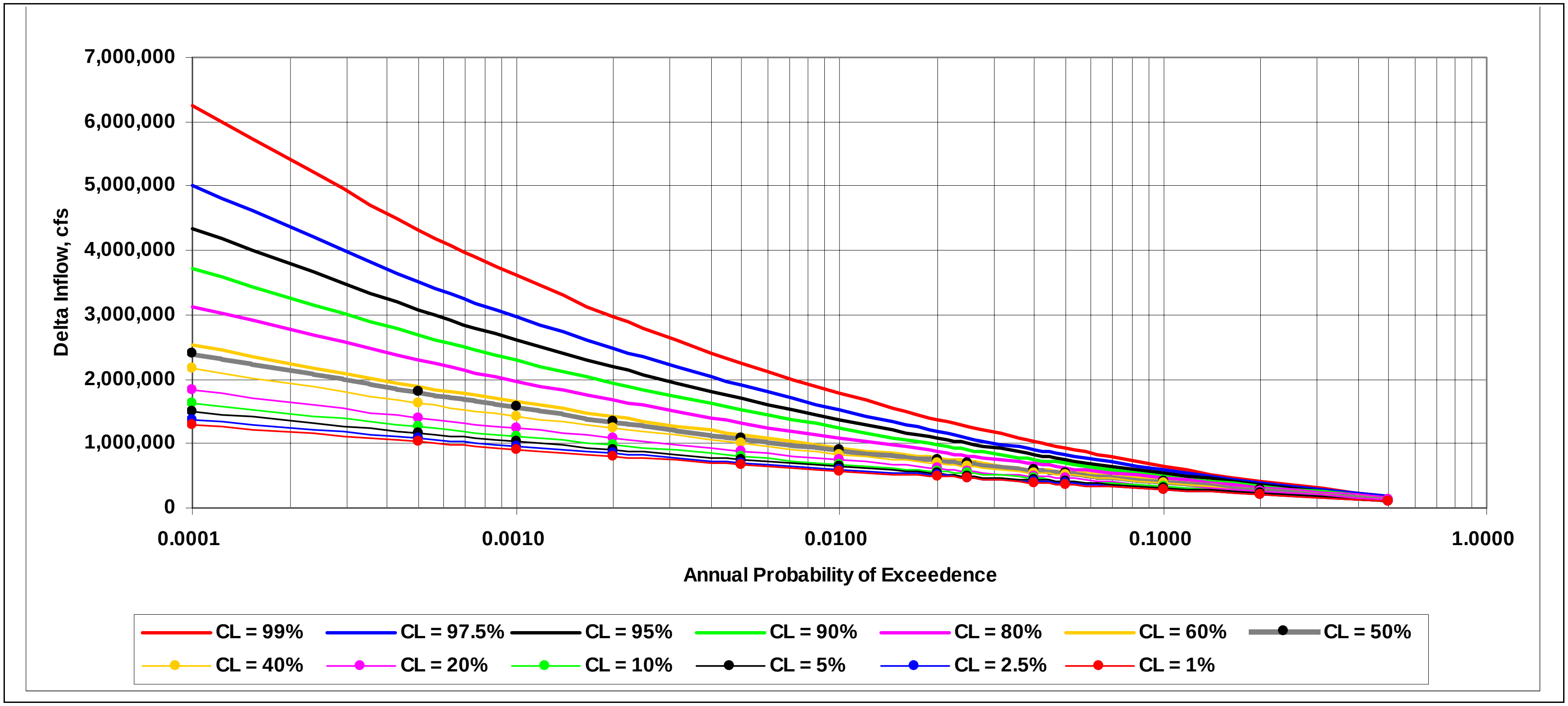


Figure 7-4 All Seasons Flow Frequency

(CL – Confidence Limit %)

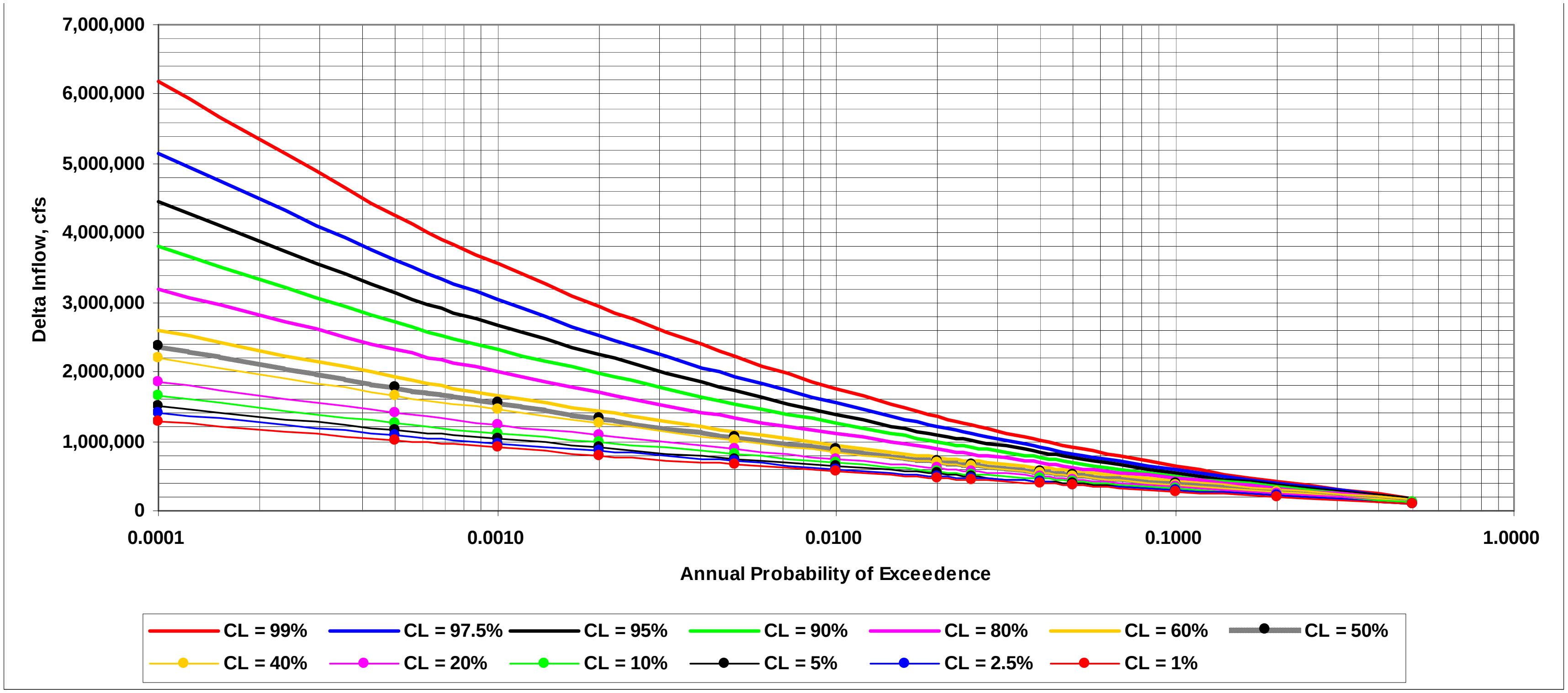


Figure 7-5 High Runoff Season – Inflow Frequency

(CL = Confidence Limit %)

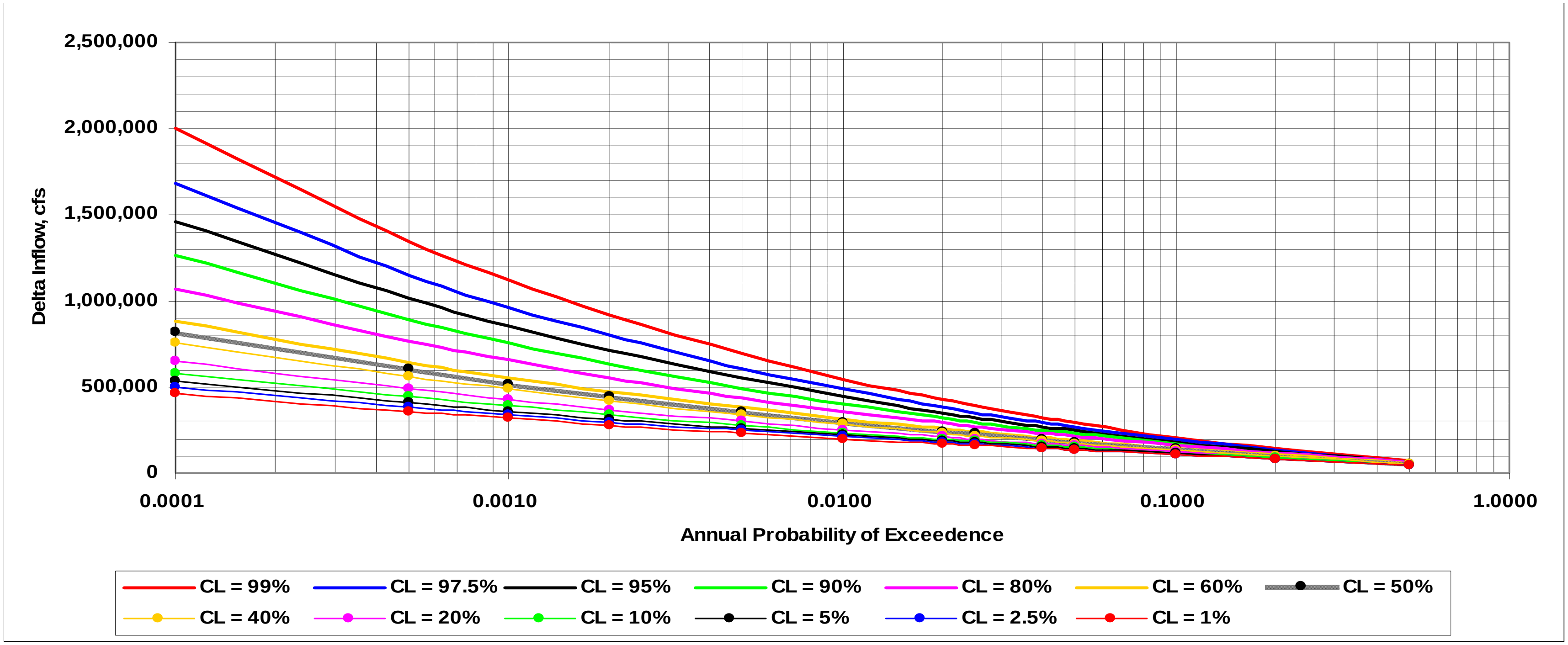


Figure 7-6 Low Runoff Season – Inflow Frequency

(CL = Confidence Limit %)

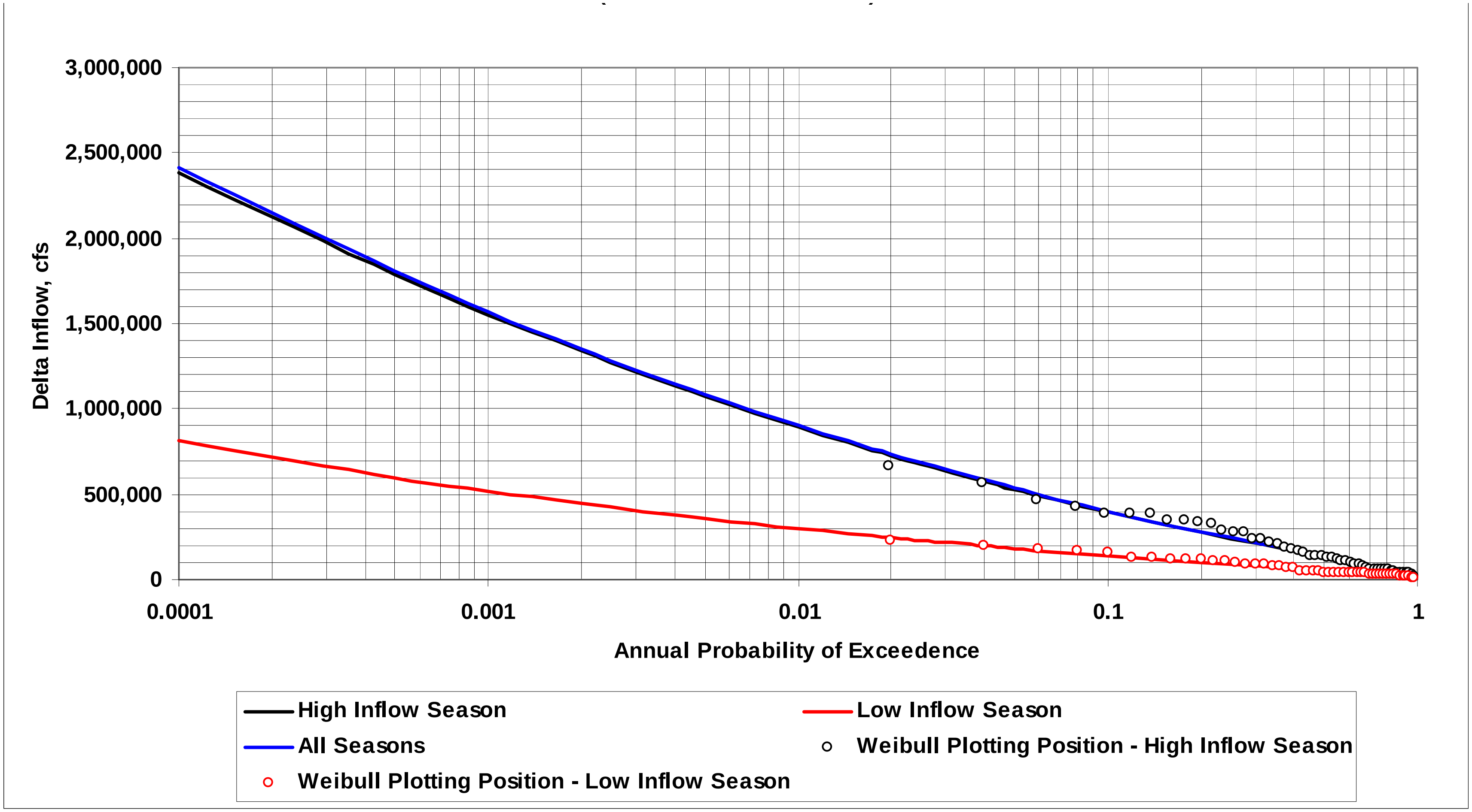


Figure 7-7 Comparison Between Inflow-Frequency Curves, CL = 50%

(CL = Confidence Limit %)

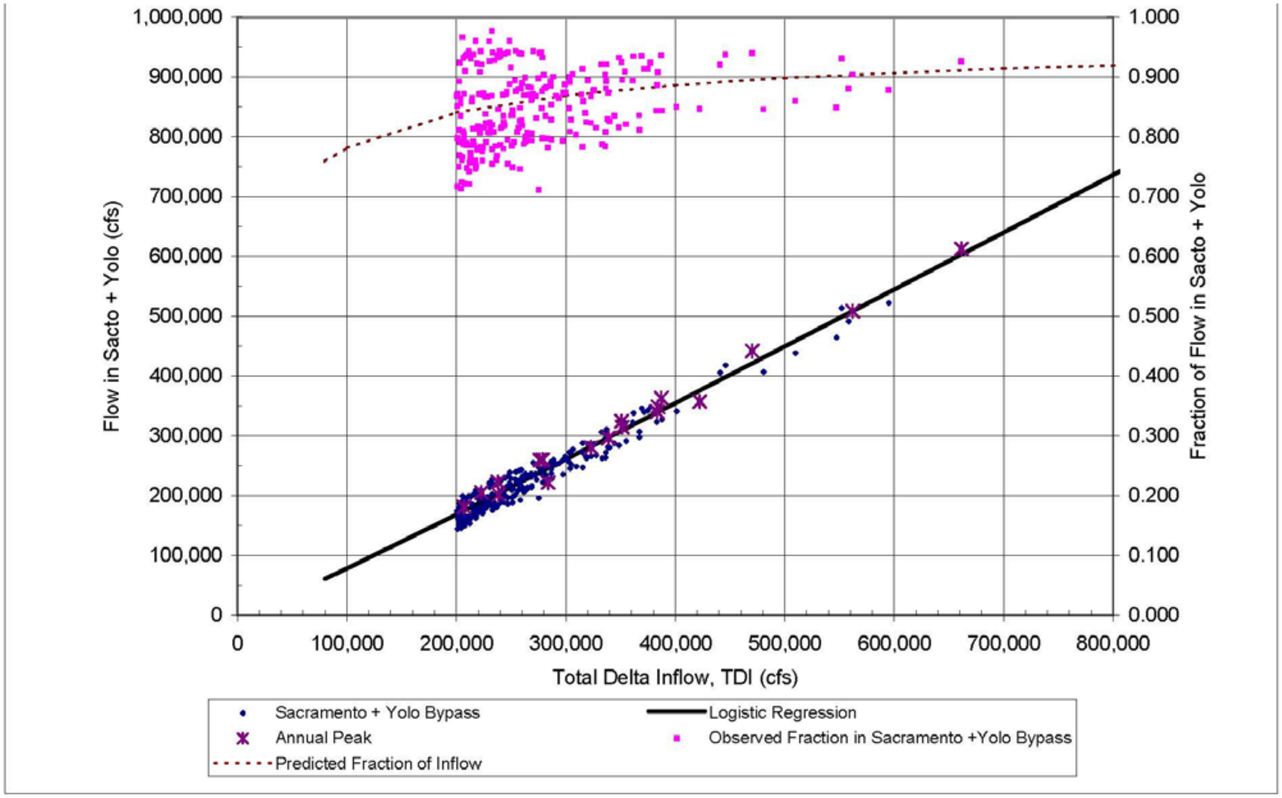


Figure 7-8 Flow in Sacramento River Plus Yolo Bypass Versus Total Delta Inflow

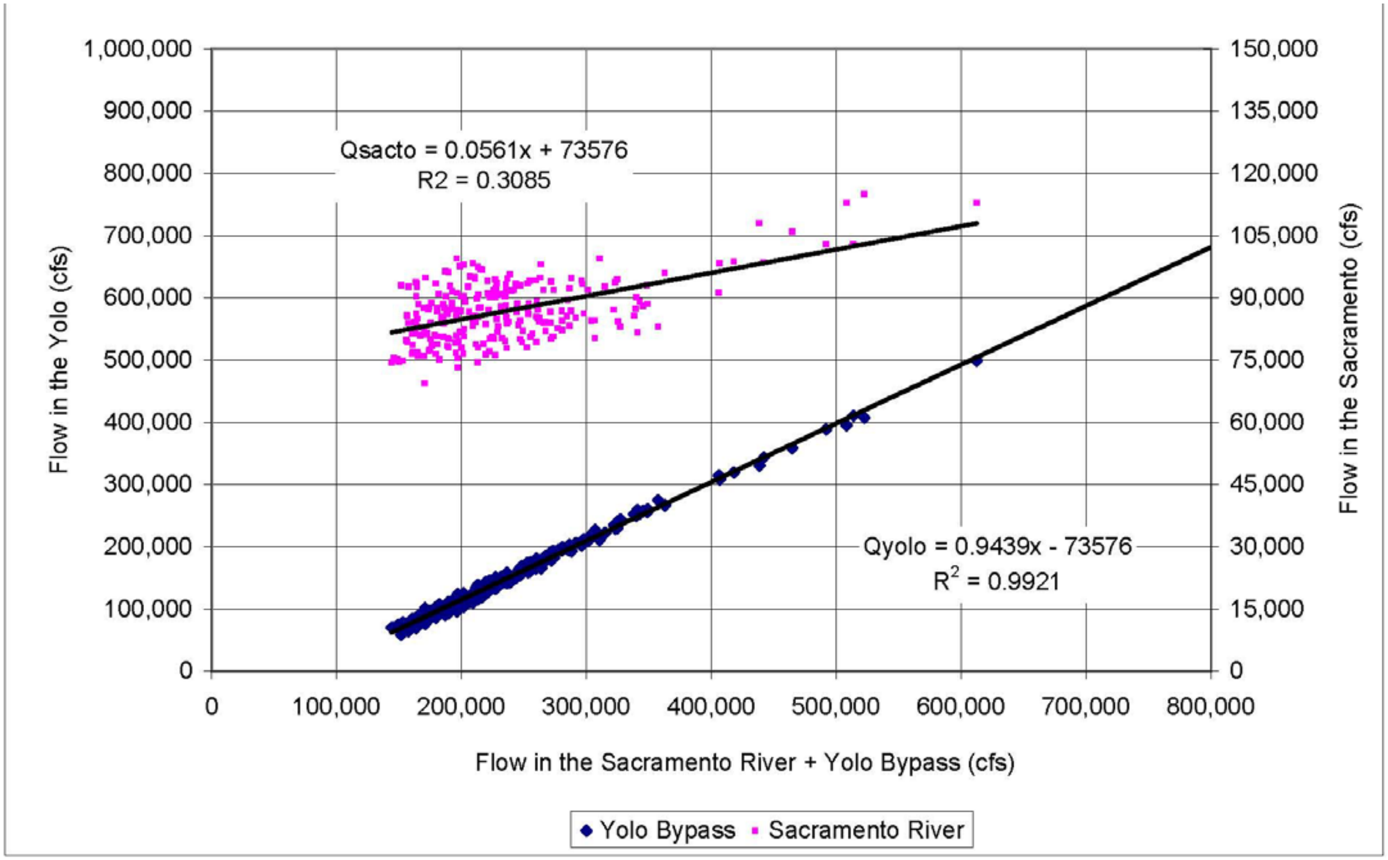


Figure 7-9 Relationship Between Flow in Yolo Bypass and Total Flow in the Sacramento River

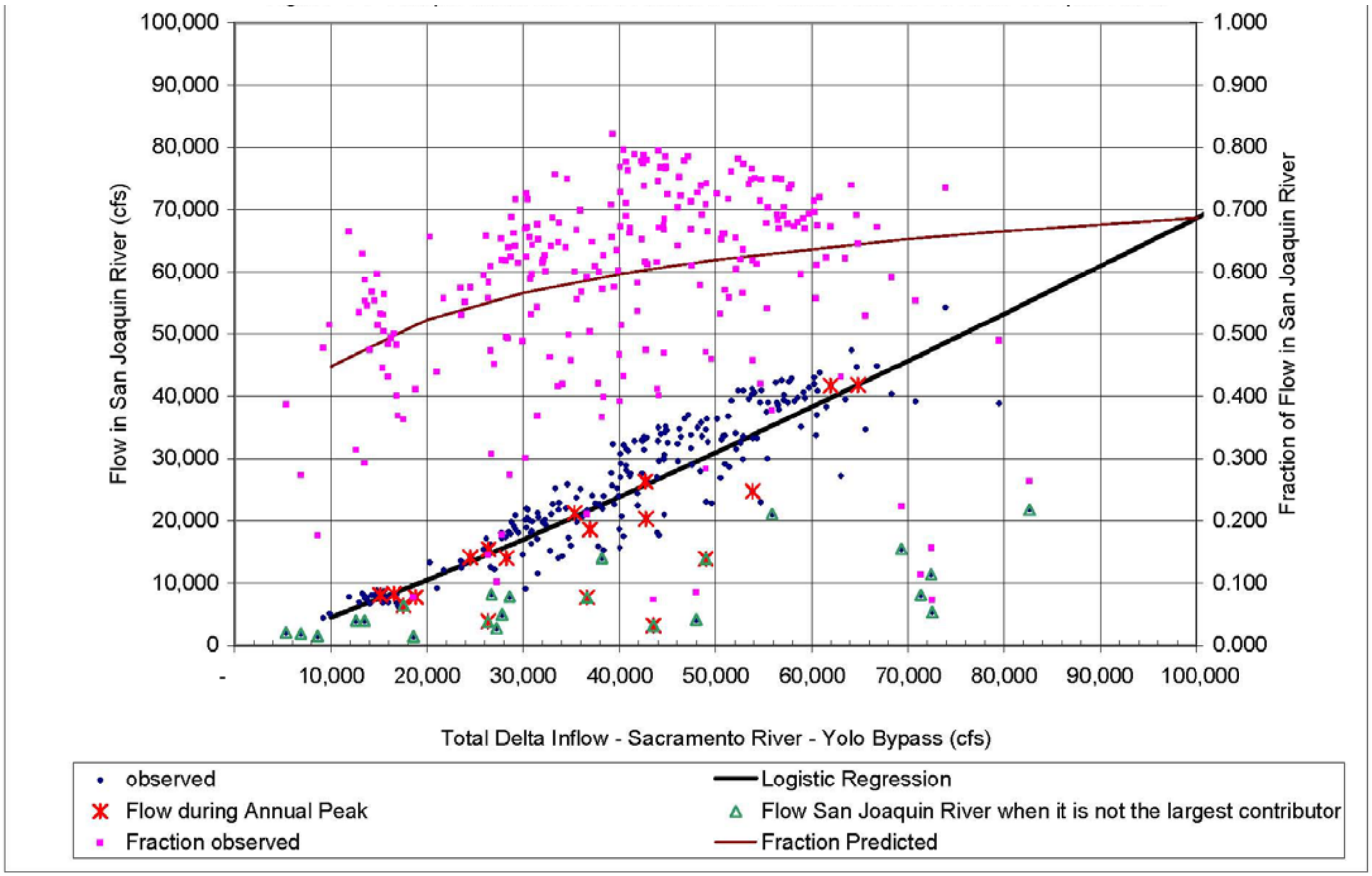


Figure 7-10 Comparison Between Predicted and Observed Flow in San Joaquin River

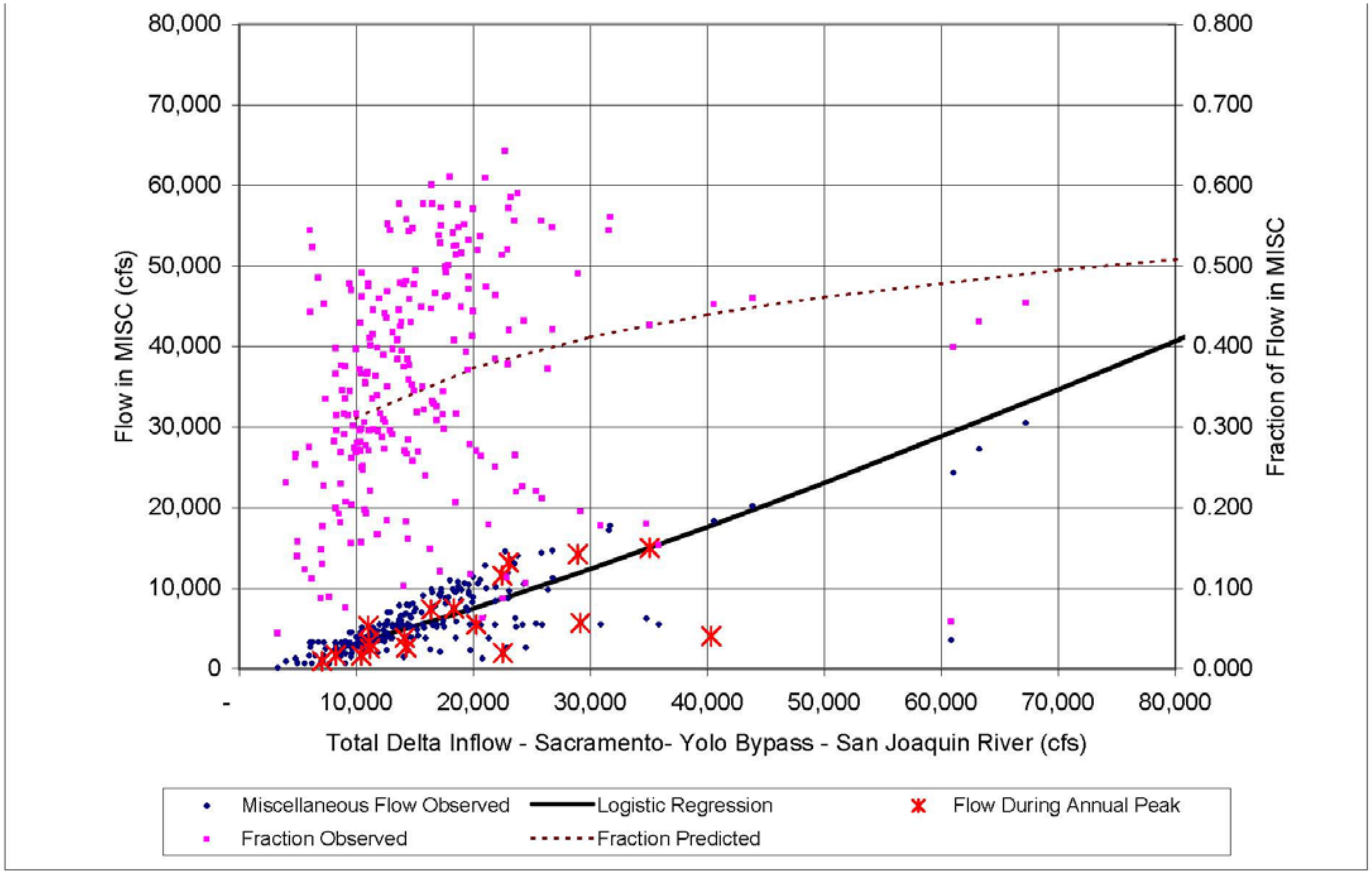


Figure 7-11 Comparison Between Predicted and Observed Flows in MISC Inflow

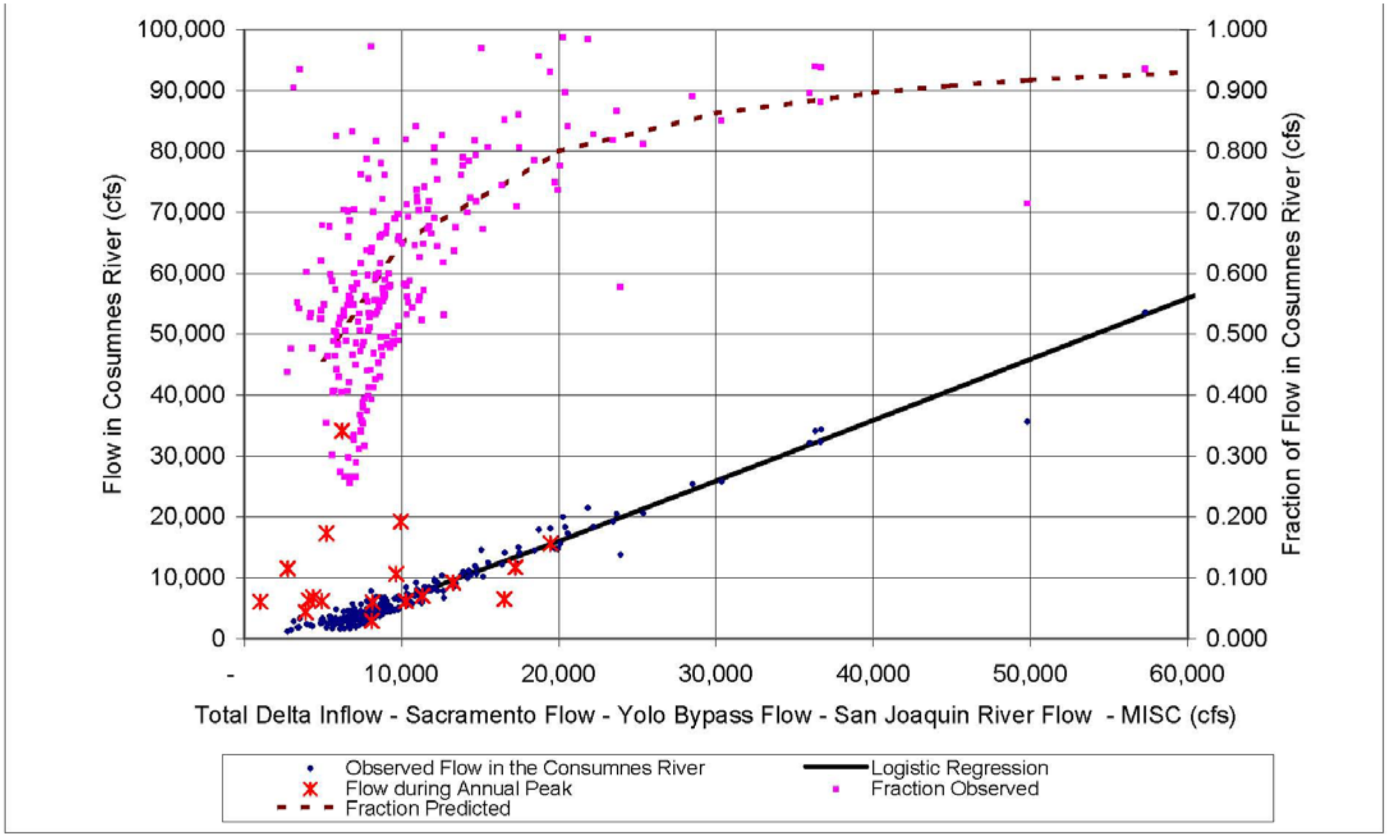


Figure 7-12 Comparison Between Predicted and Observed Flows in the Cosumnes River

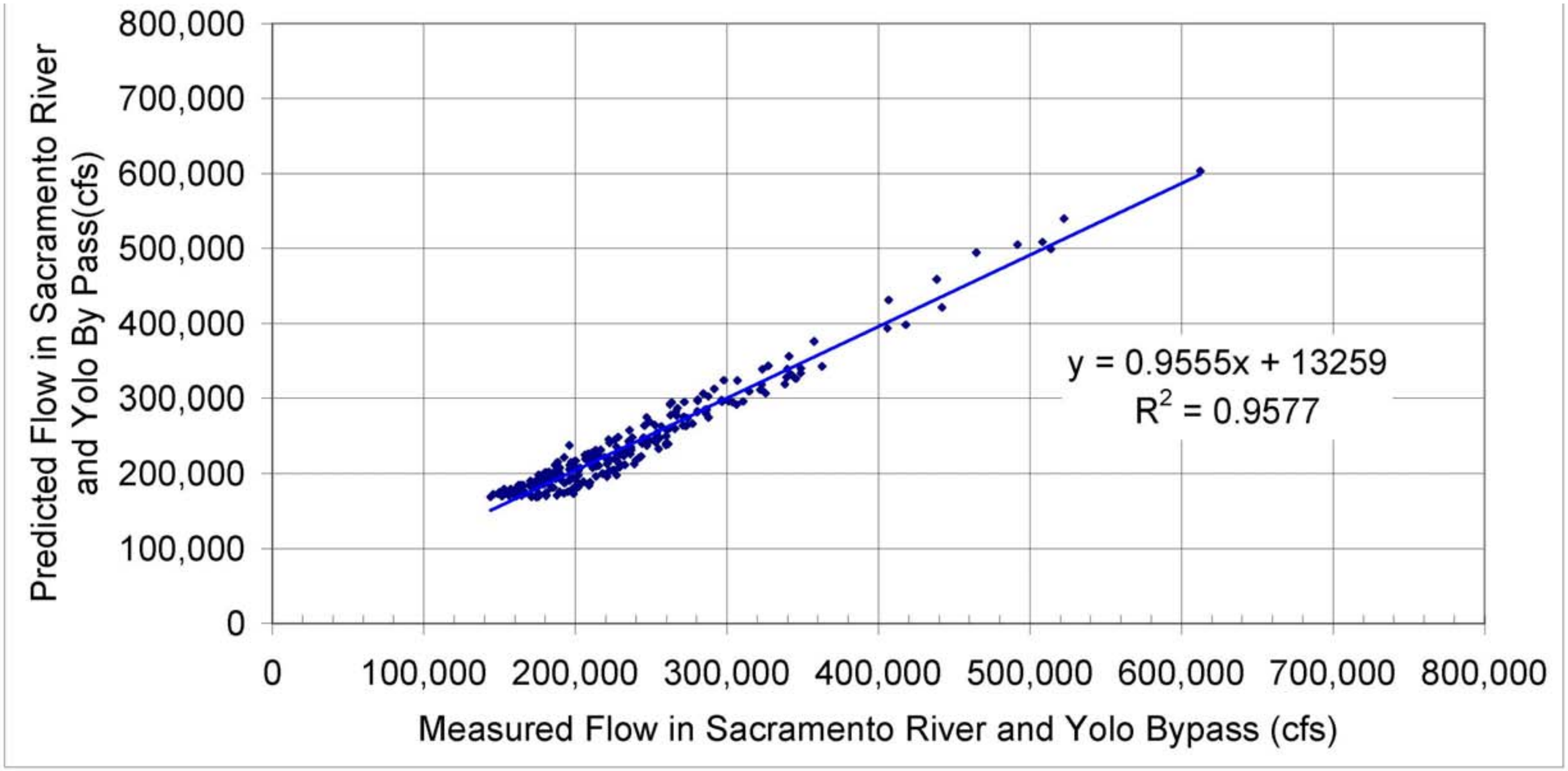


Figure 7-13 Comparison Between Measured and Predicted Flows in the Sacramento River and Yolo Bypass

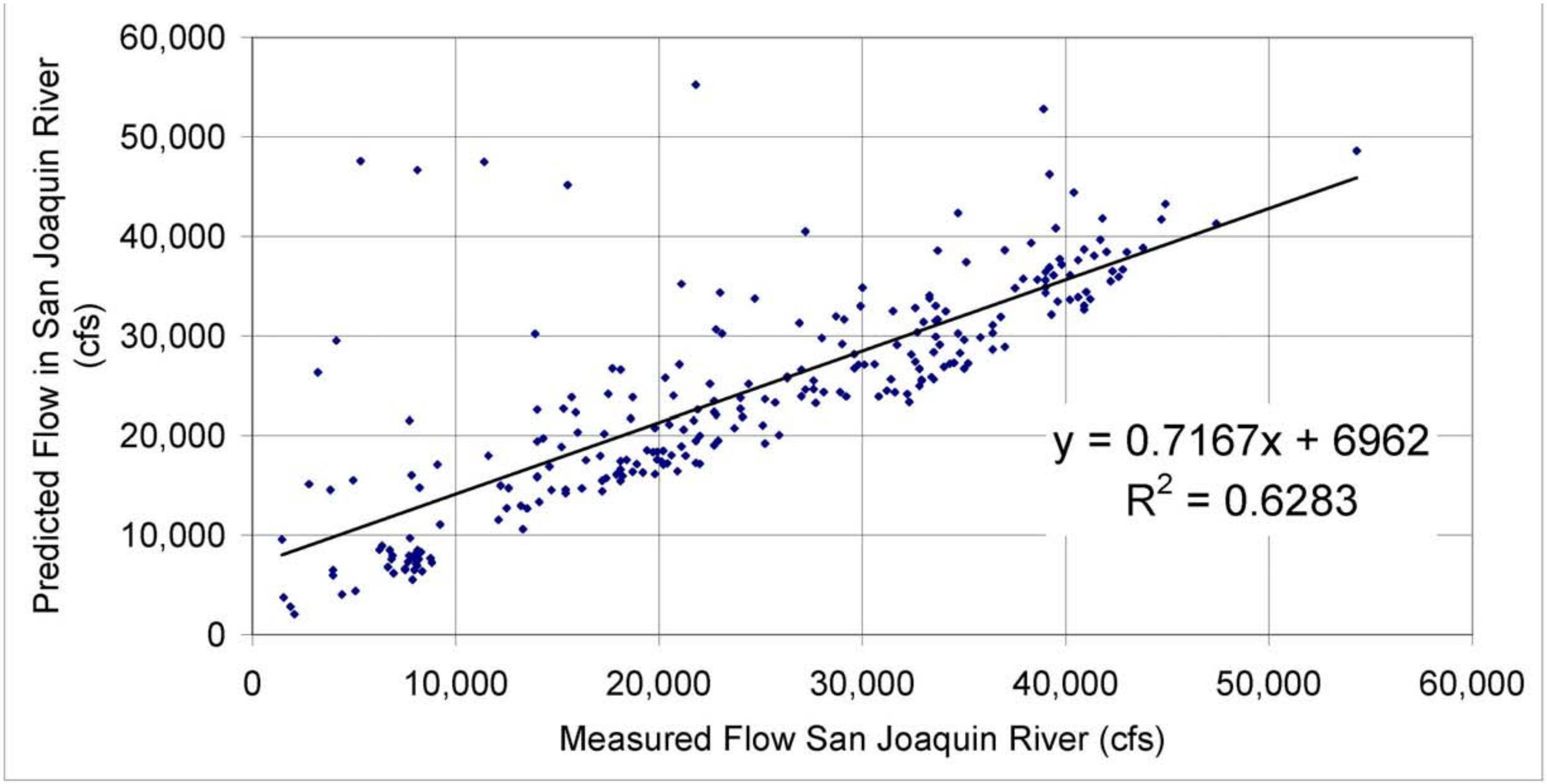


Figure 7-14 Comparison Between Measured and Predicted Flows in the San Joaquin River

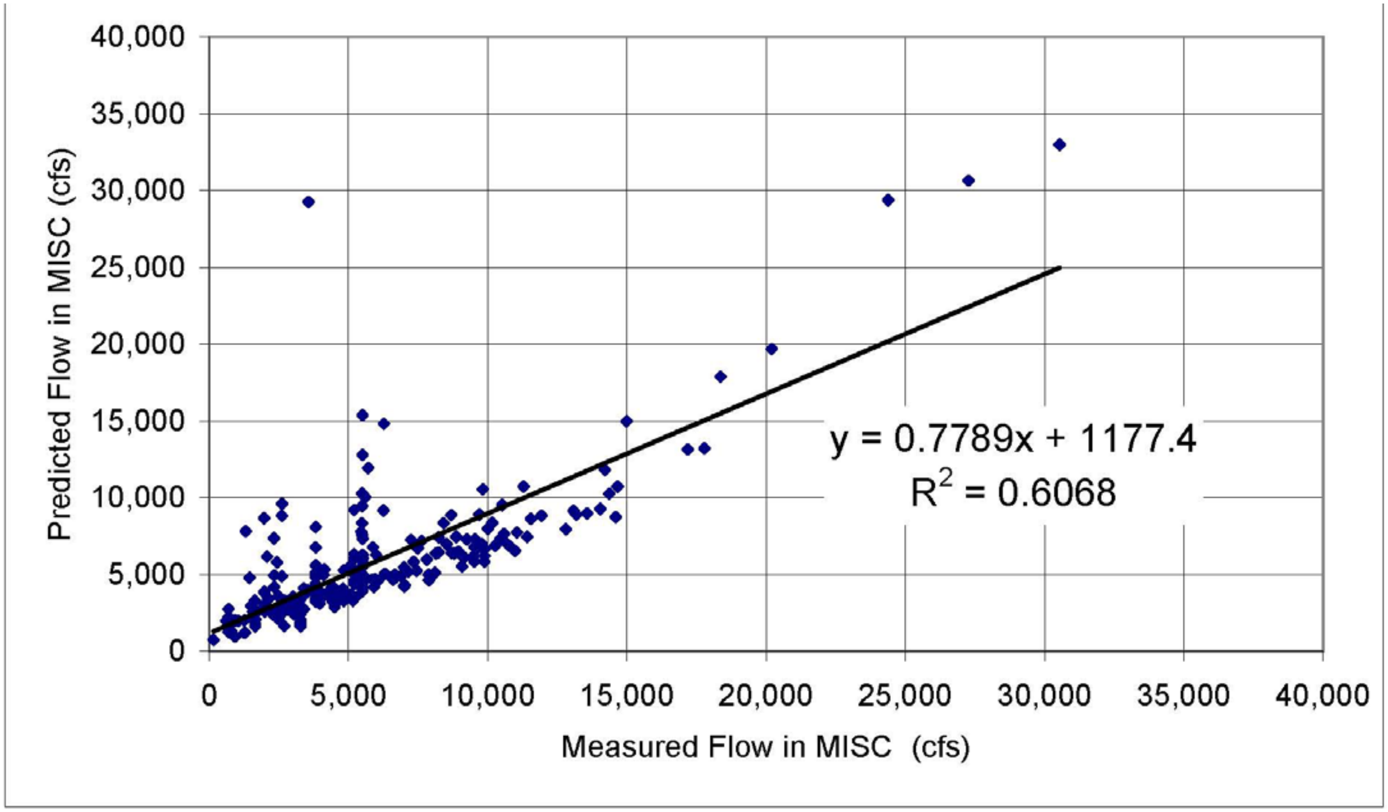


Figure 7-15 Comparison Between Predicted and Measured Flows in the Miscellaneous Inflows

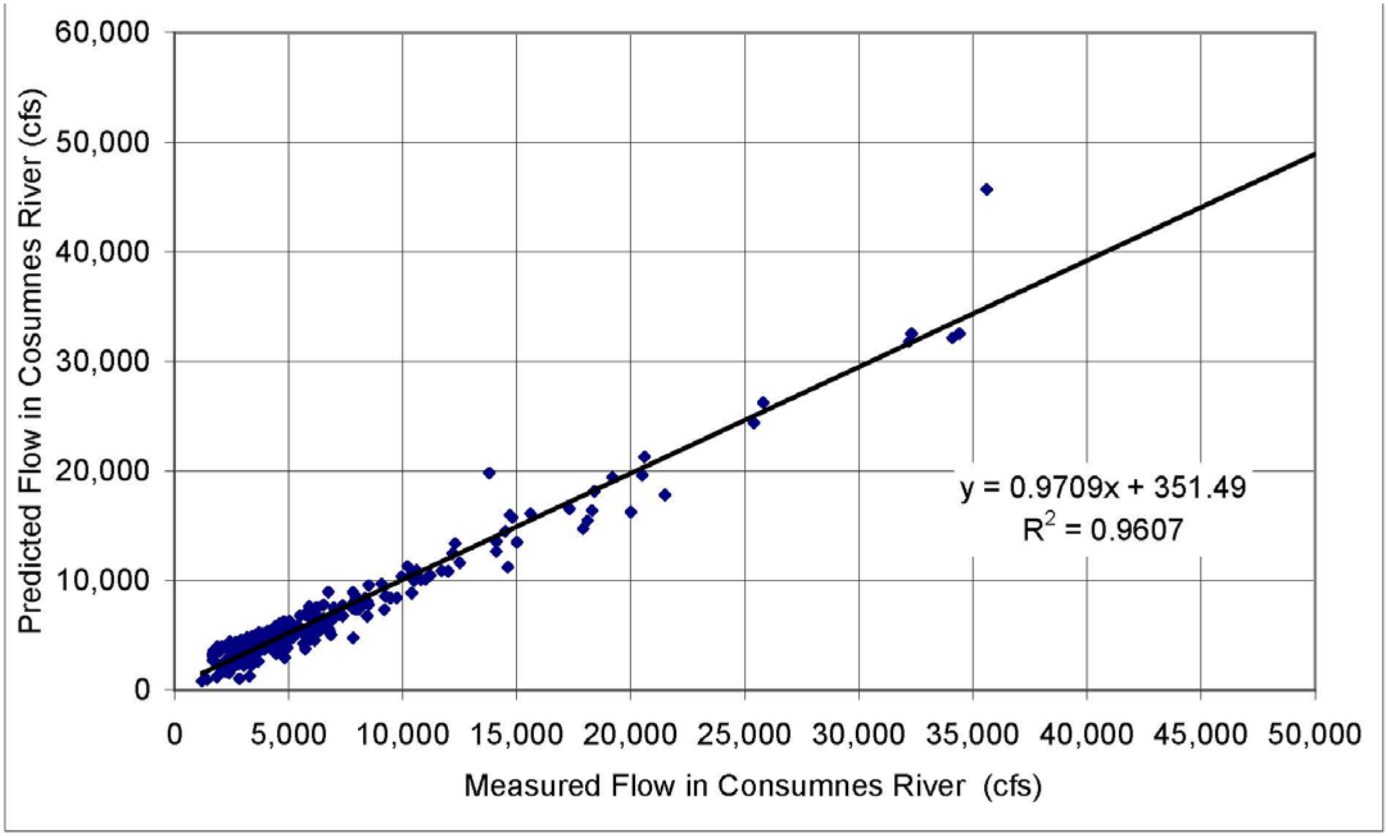
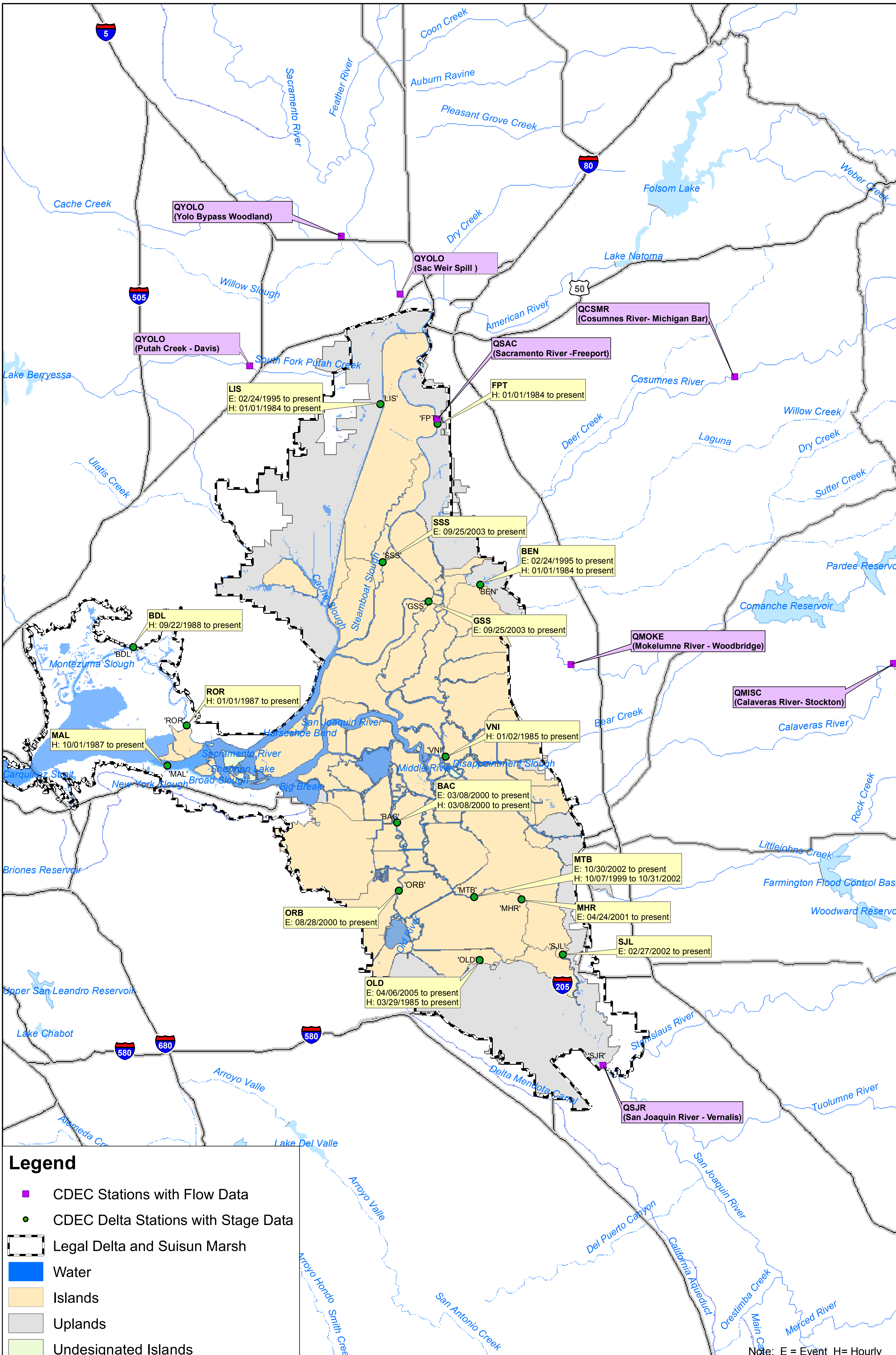


Figure 7-16 Comparison Between Predicted and Measured Flows in the Cosumnes River



URS	DRMS	Stations Used for Regression Analyses	Figure 7-17
	26815431		

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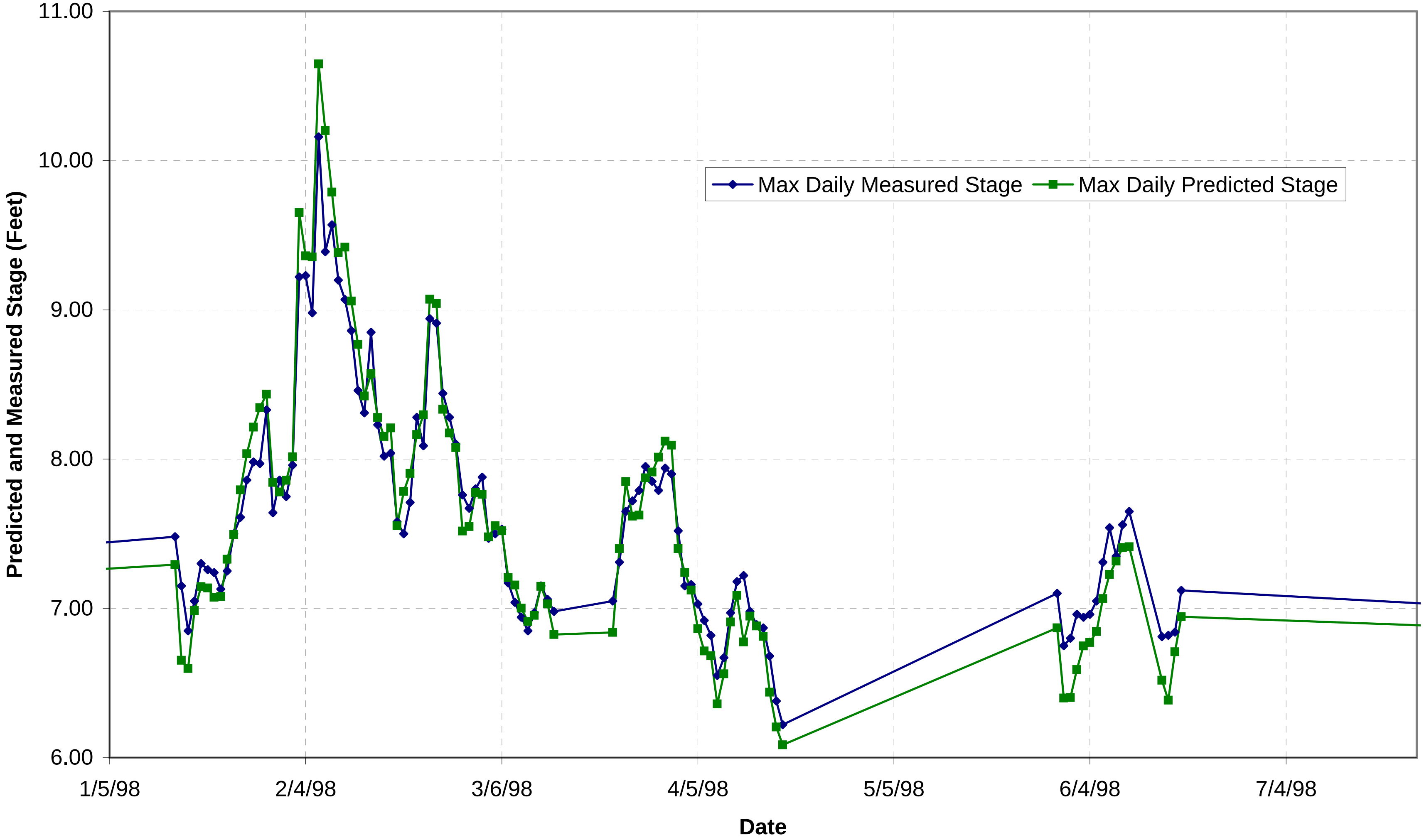
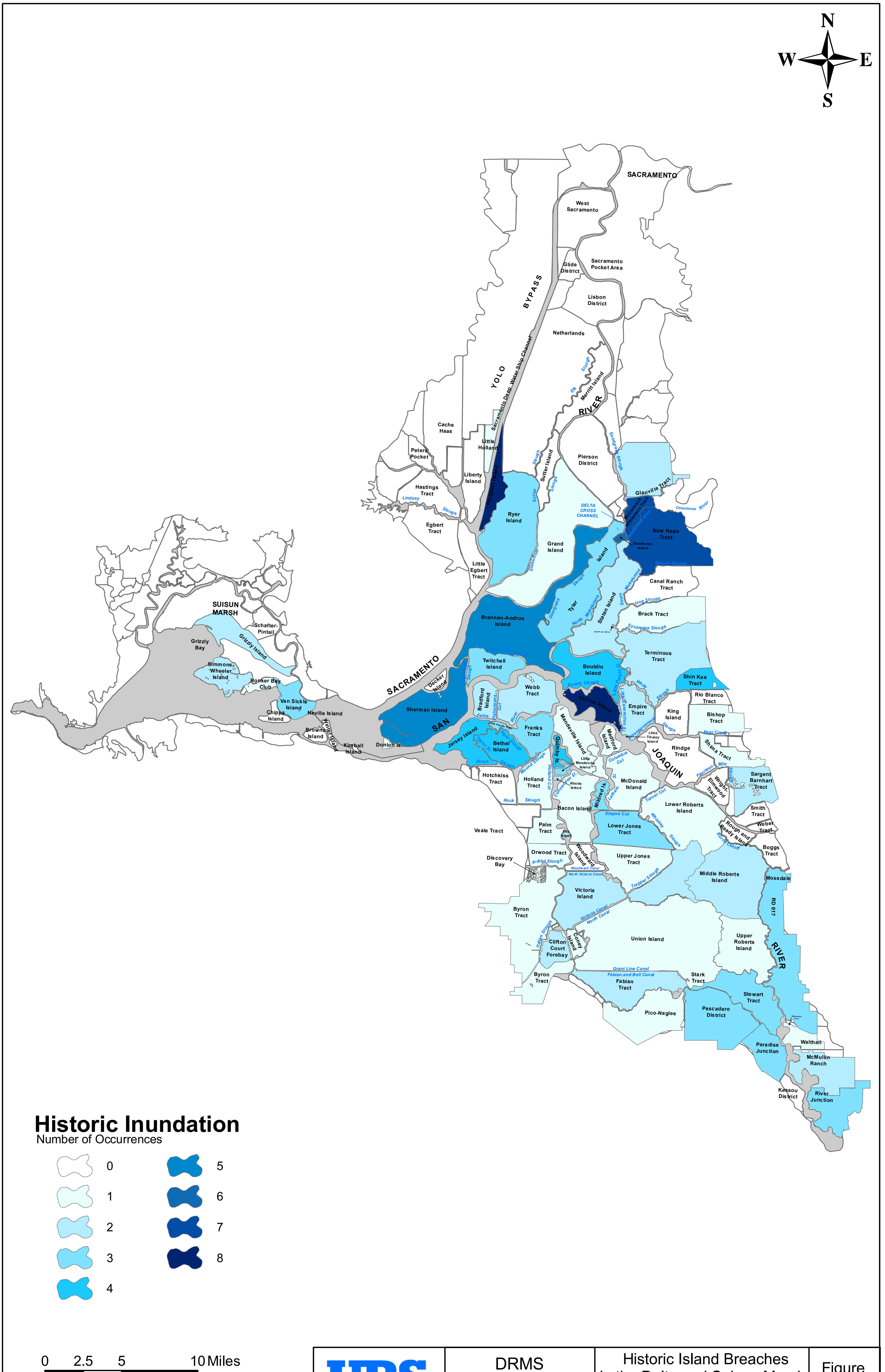
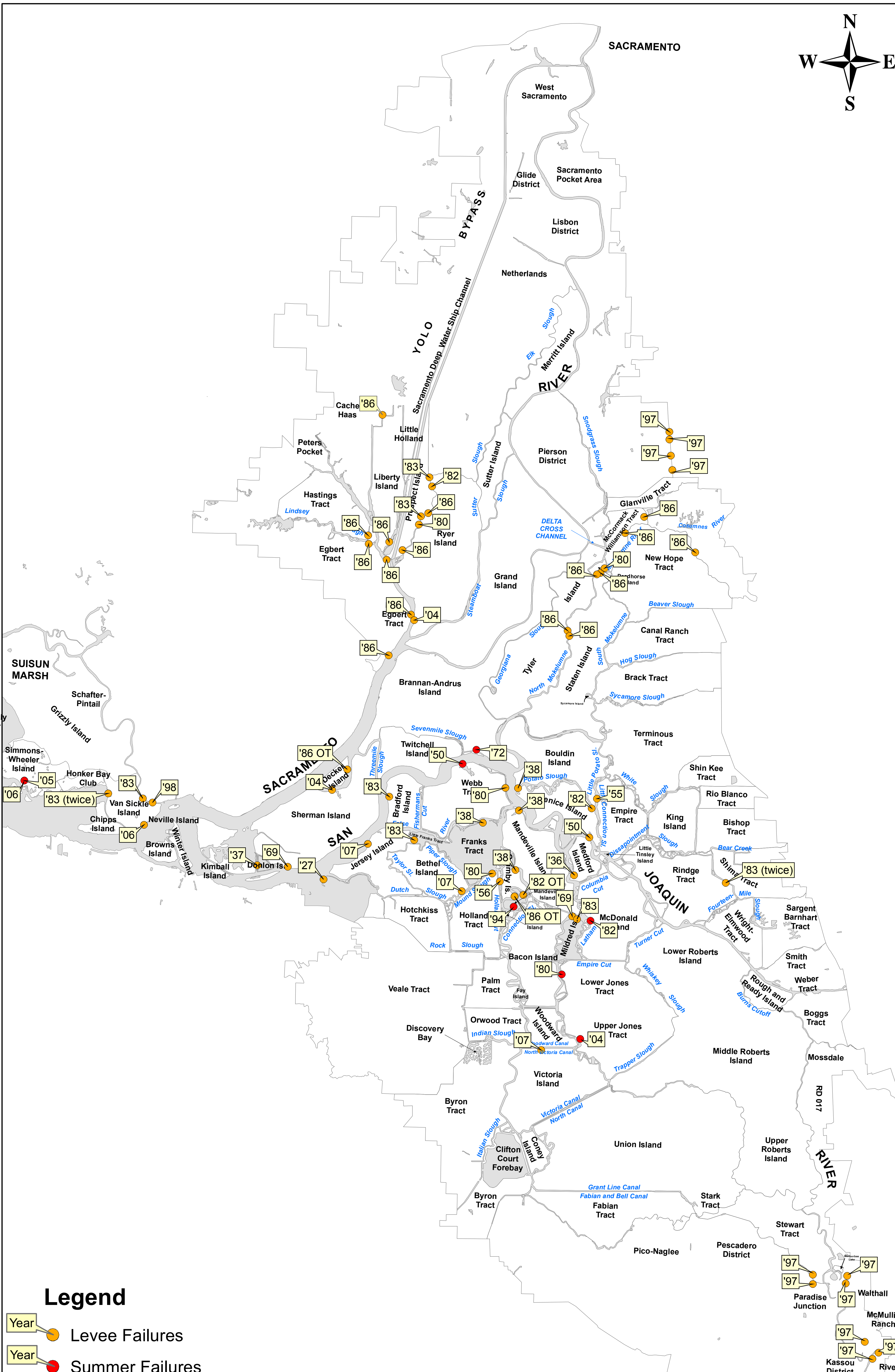
Figure 7-18 Venice Island (VNI)
Predicted and Measured vs. Date
1/5/1998 - 7/4/1998





URS	DRMS	Historic Island Breaches in the Delta and Suisun Marsh Since 1900	Figure 7-19
	26815431		



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Locations of Levee Failures

Figure 7-20

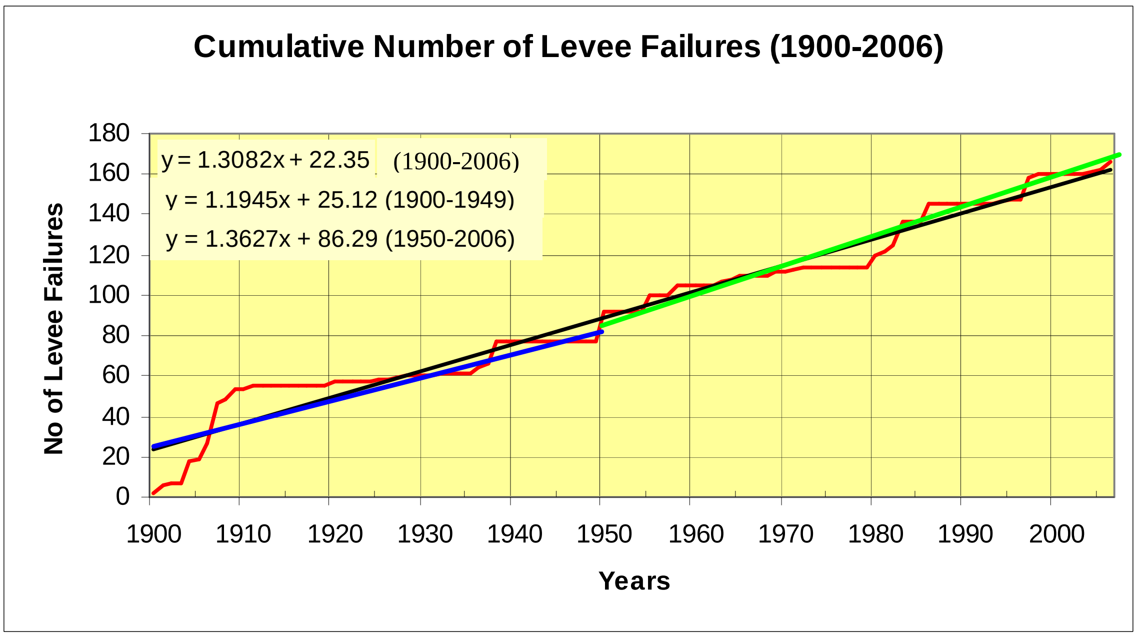


Figure 7-21 Cumulative Number of Levee Failures Since 1900

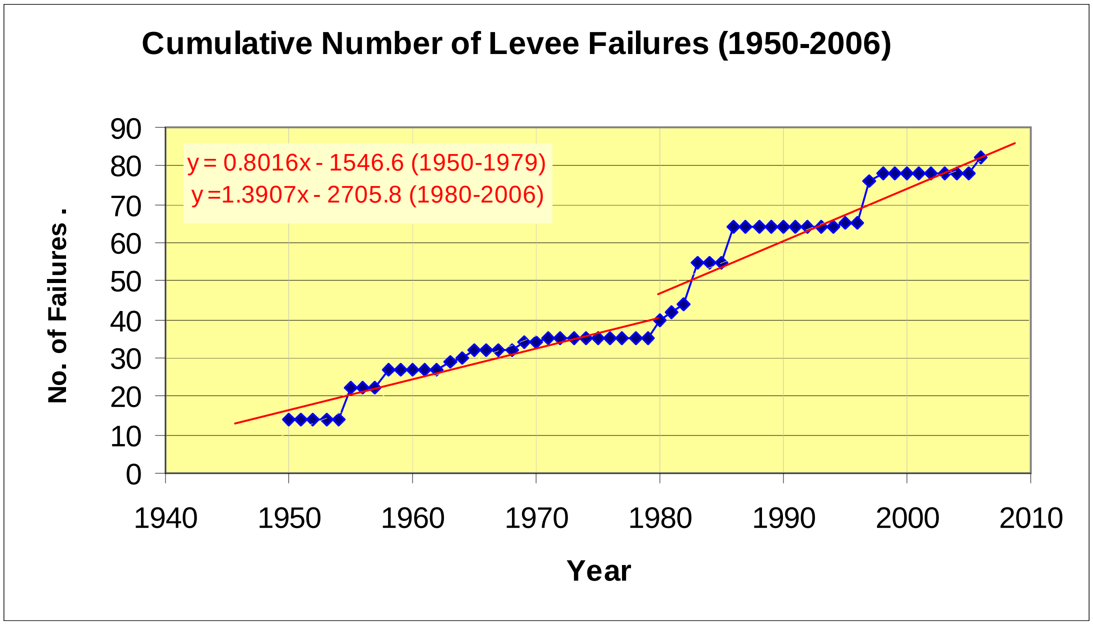


Figure 7-22a Cumulative Number of Levee Failures Since 1950

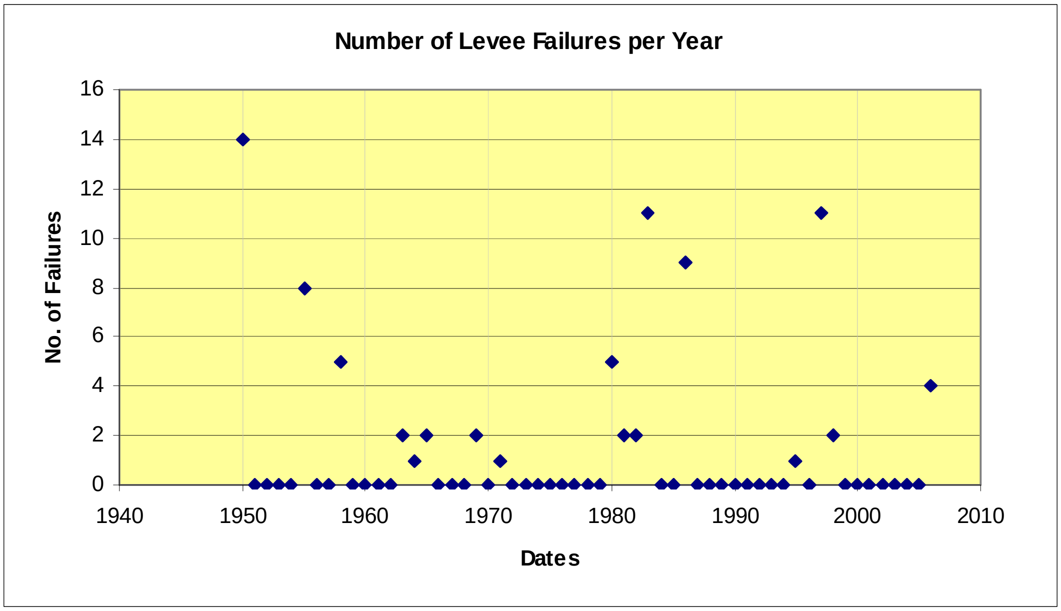


Figure 7-22b Number of Levee Failures per Year Since 1950

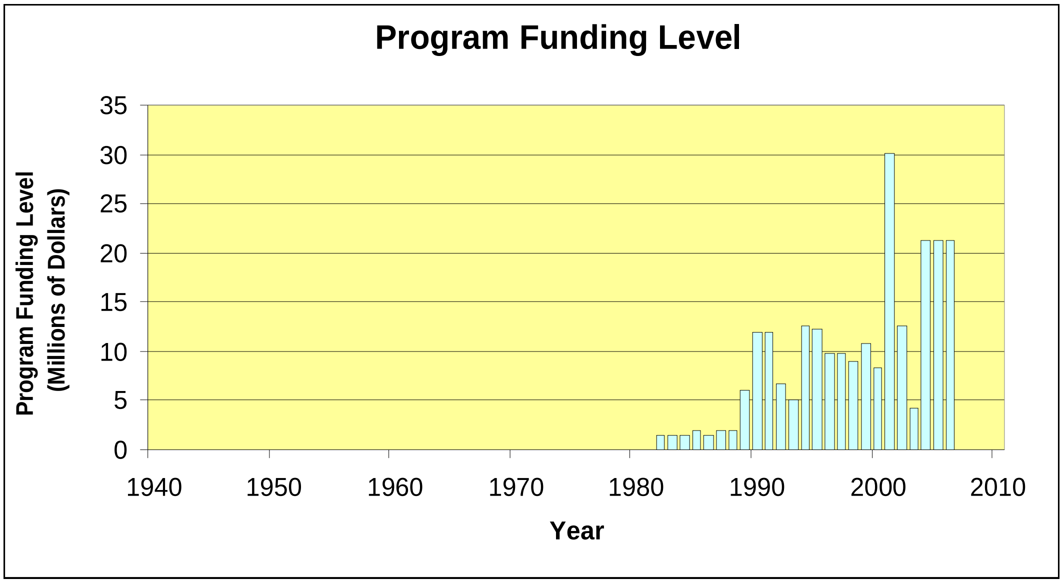


Figure 7-22c Program Funding Level

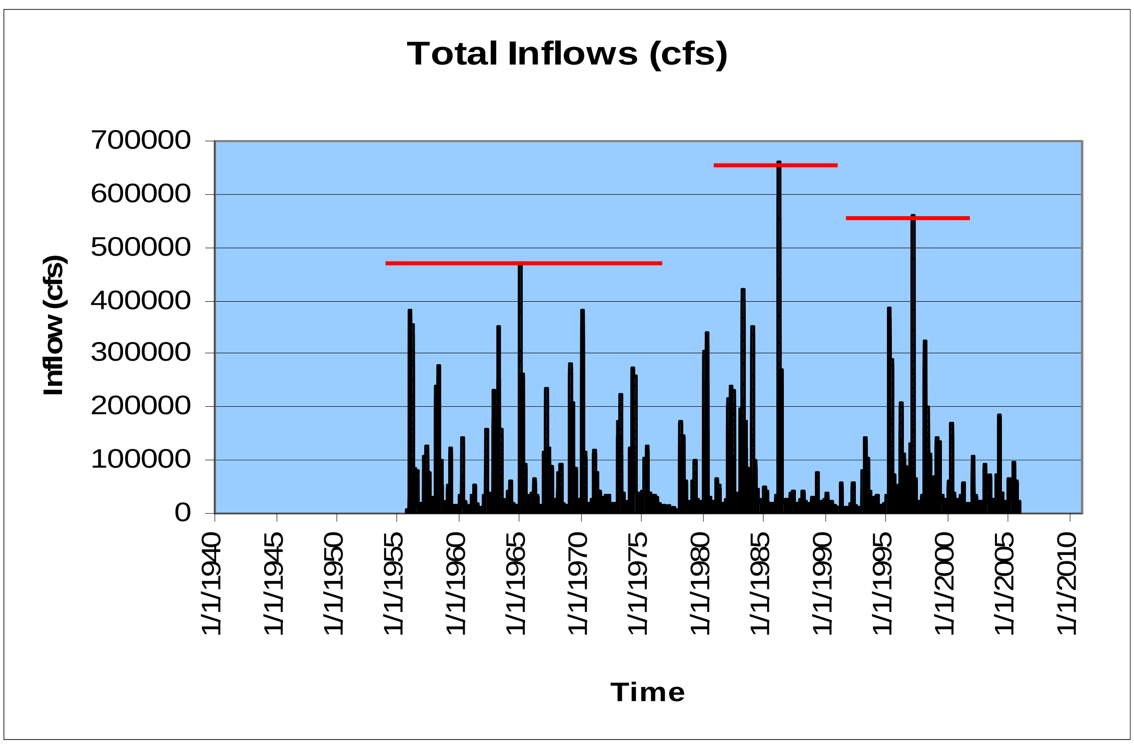
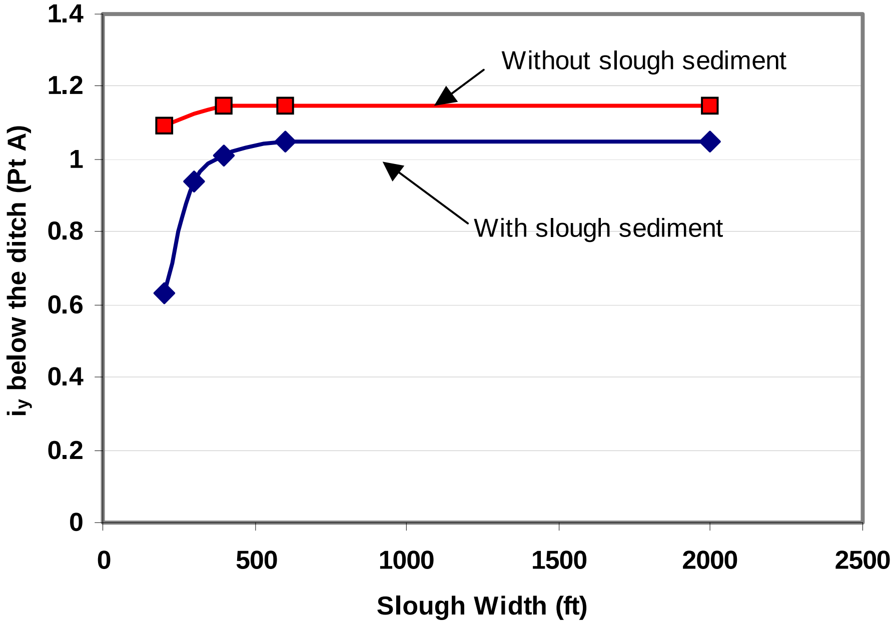
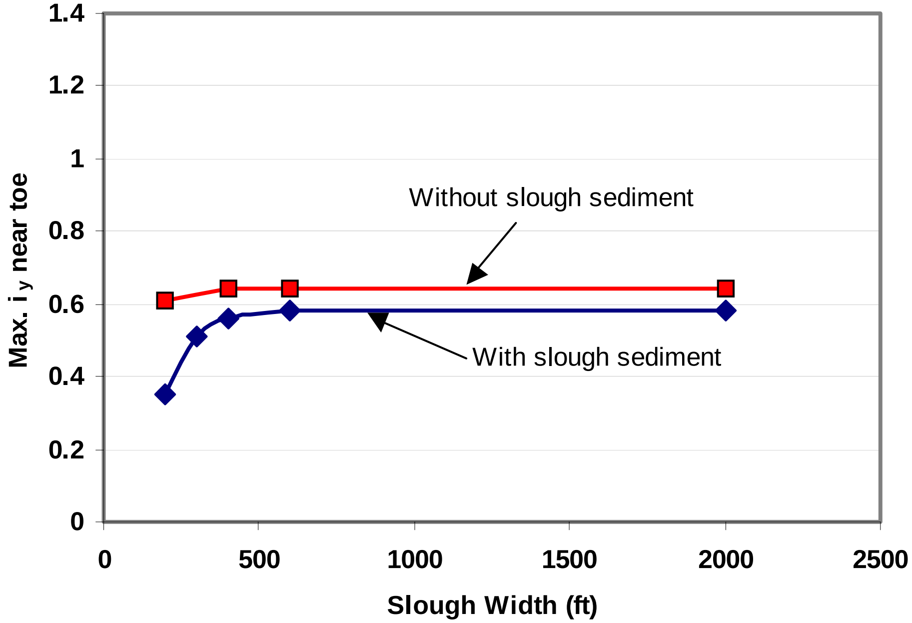


Figure 7-22d Total Delta Inflows (cfs) Since 1955

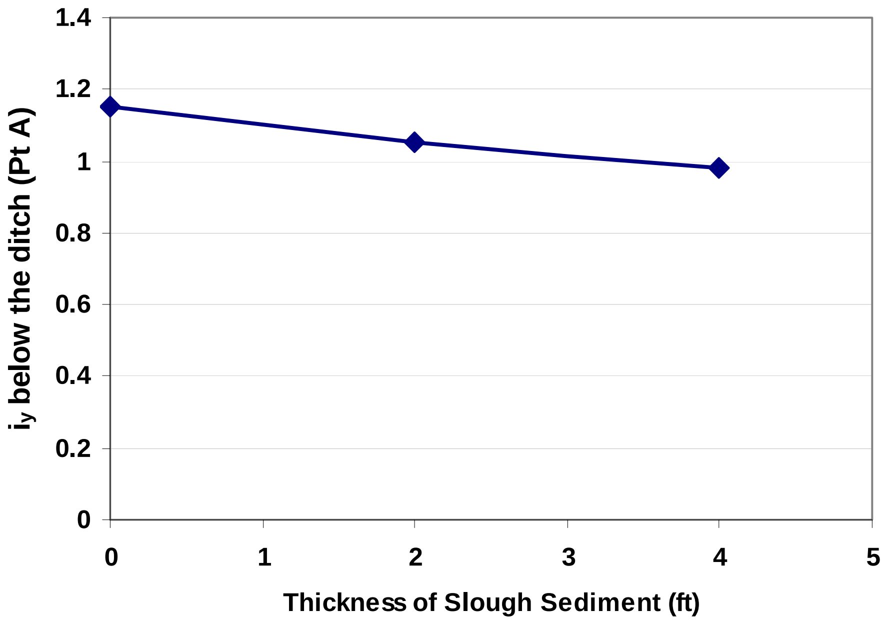


(a) Model with Ditch

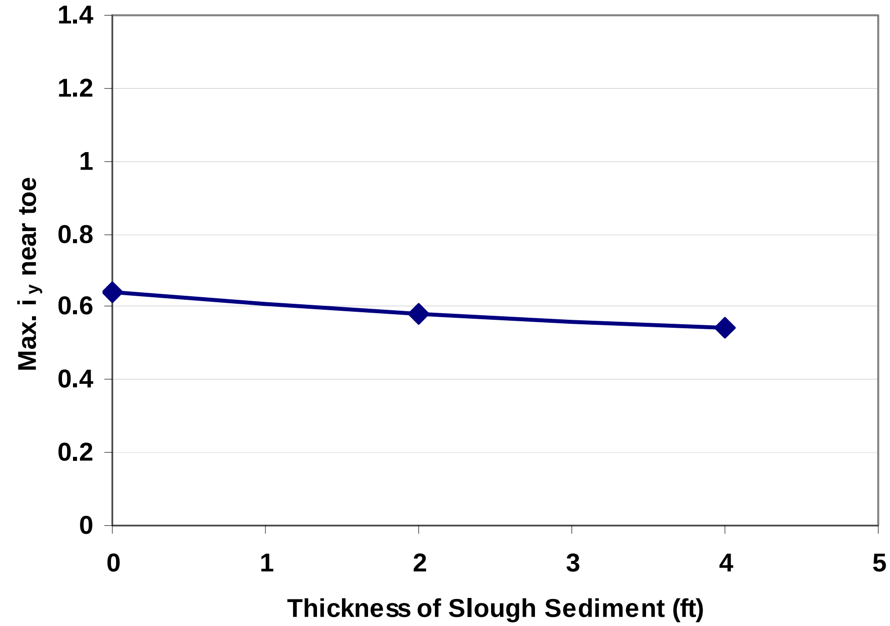


(b) Model without Ditch

Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Effect of Slough Width on Vertical Gradient	Figure 7-23

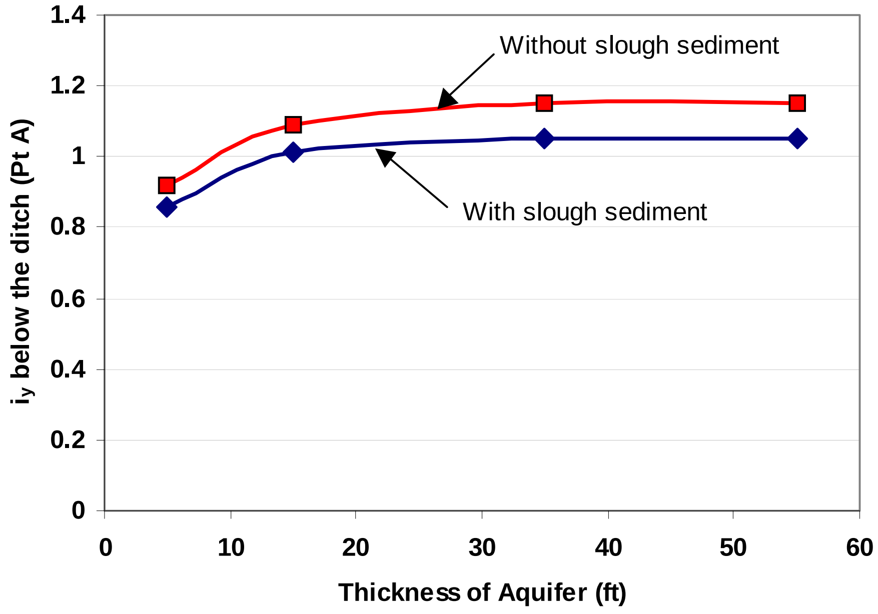


(a) Model with Ditch

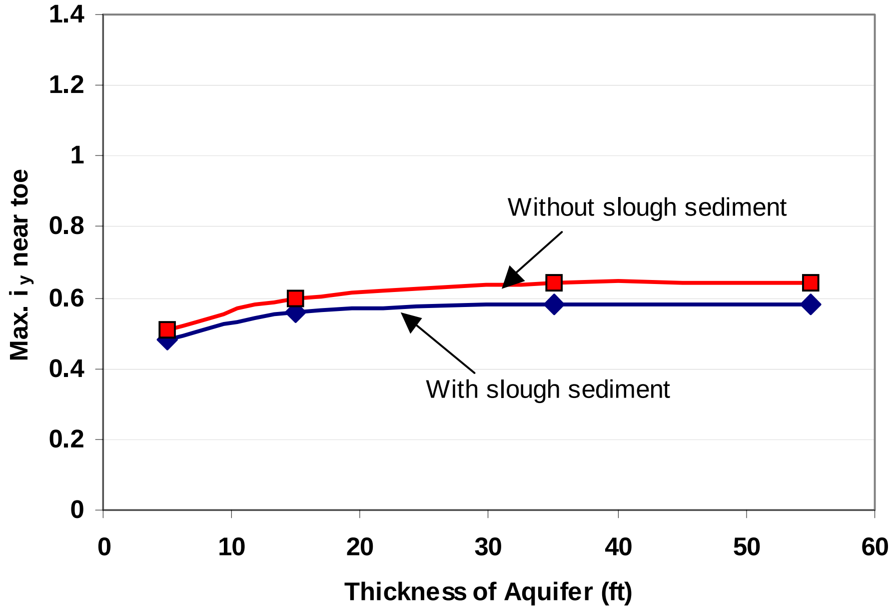


(b) Model without Ditch

Delta Risk Management Strategy (DRMS) Levee Fragility		Effect of Slough Sediment Thickness on Vertical Gradient	Figure 7-24
URS	Project No. 26815621		

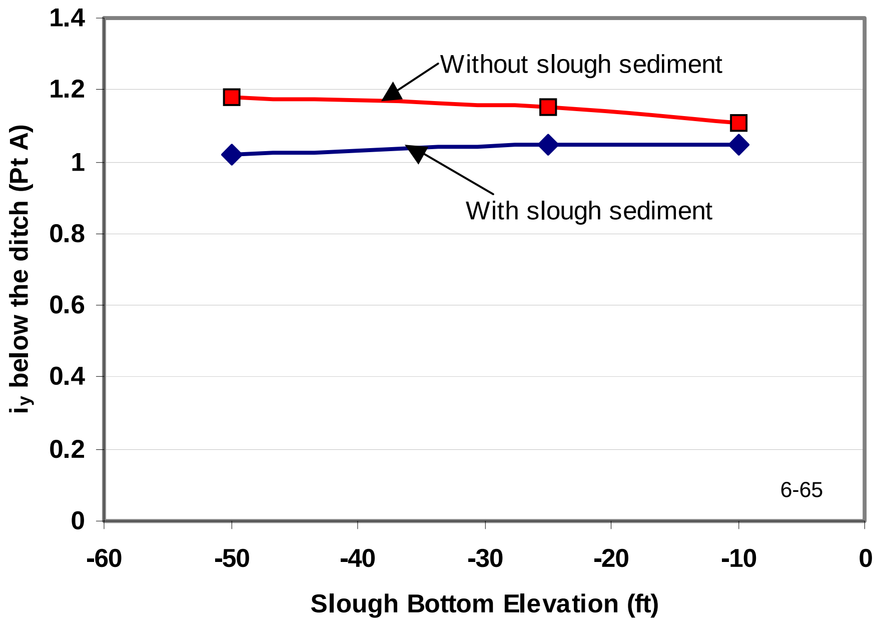


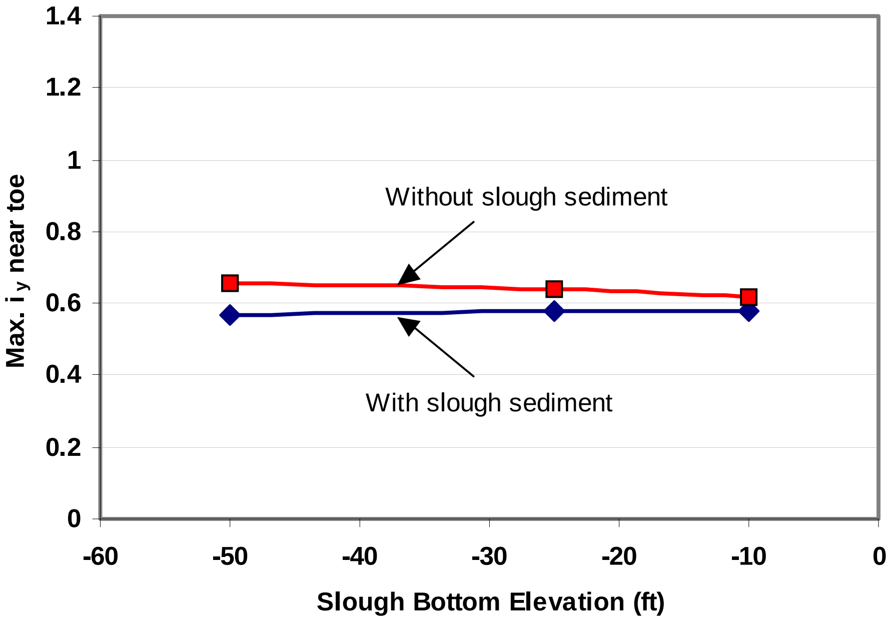
(a) Model with Ditch



(b) Model without Ditch

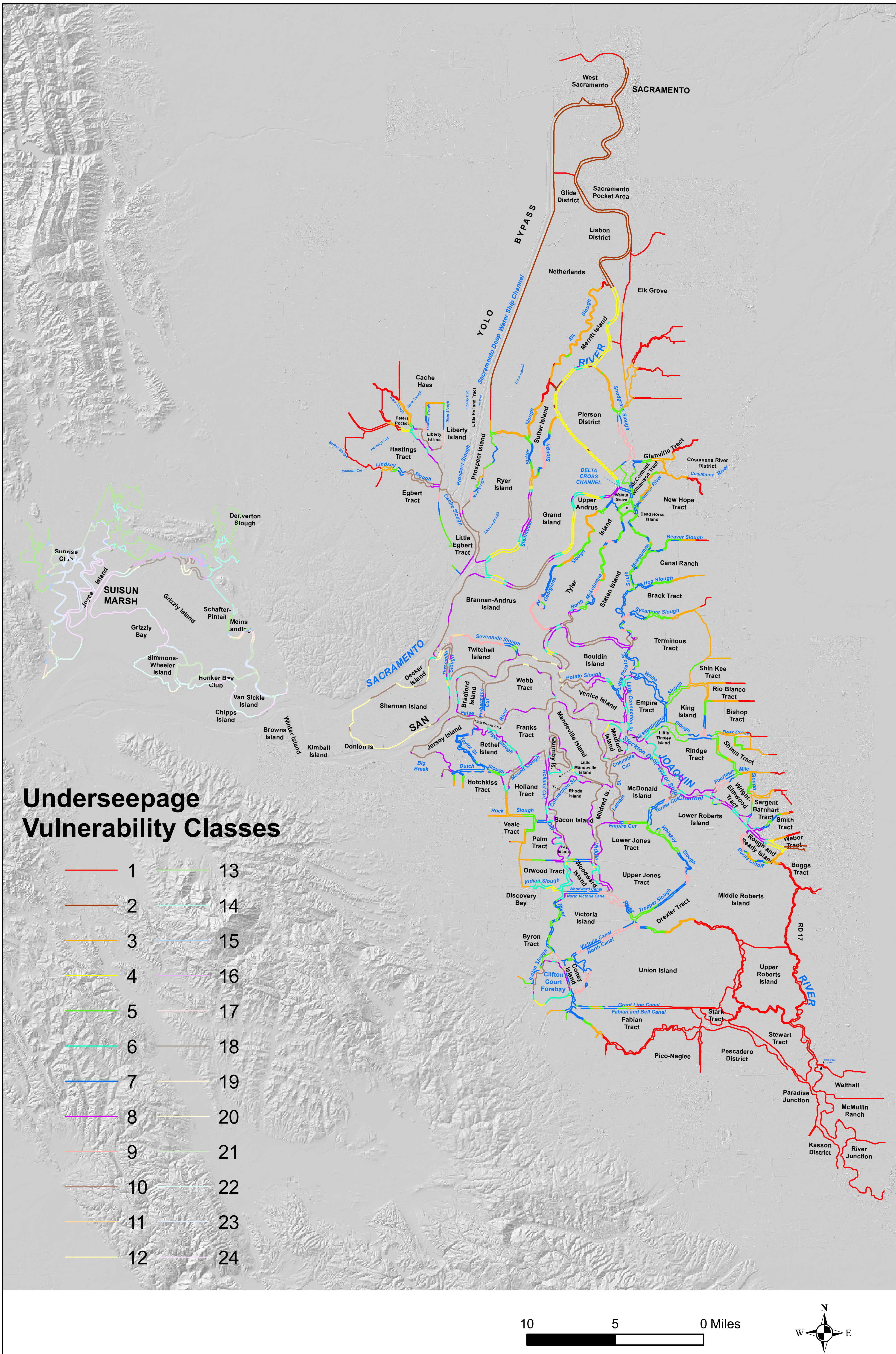
Delta Risk Management Strategy (DRMS) Levee Fragility		Effect of Aquifer Thickness on Vertical Gradient	Figure 7-25
URS	Project No. 26815621		





Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility	Effect of Slough Bottom Elevation on Vertical Gradient	Figure 7-26
URS — Project No. 26815621		

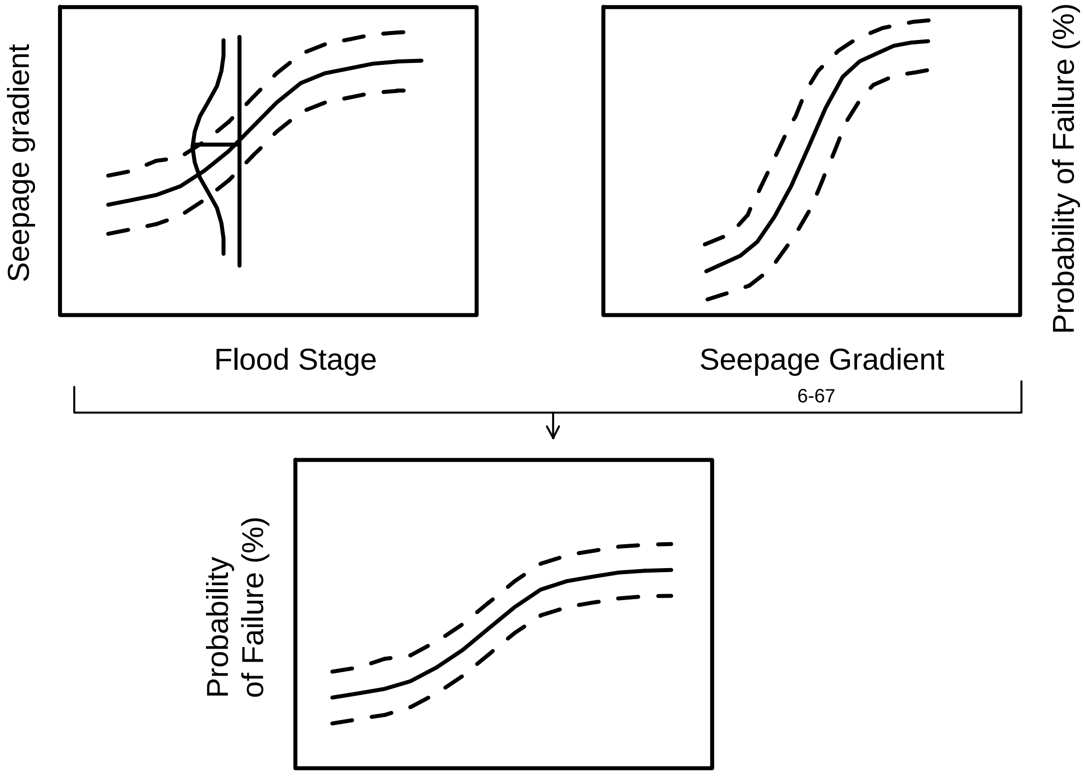


URS	Delta Risk Management Strategy (DRMS)	SPATIAL DISTRIBUTION OF UNDER-SEEPAGE VULNERABILITY CLASSES	Figure 7-27
	26815621		

P:\GIS\GIS_Phase_II_Project_Files\MXD\Analysis\Levee Geometry\Underseepage Vulnerability Classes 040708.mxd - 4/7/2008 @ 11:04:00 AM

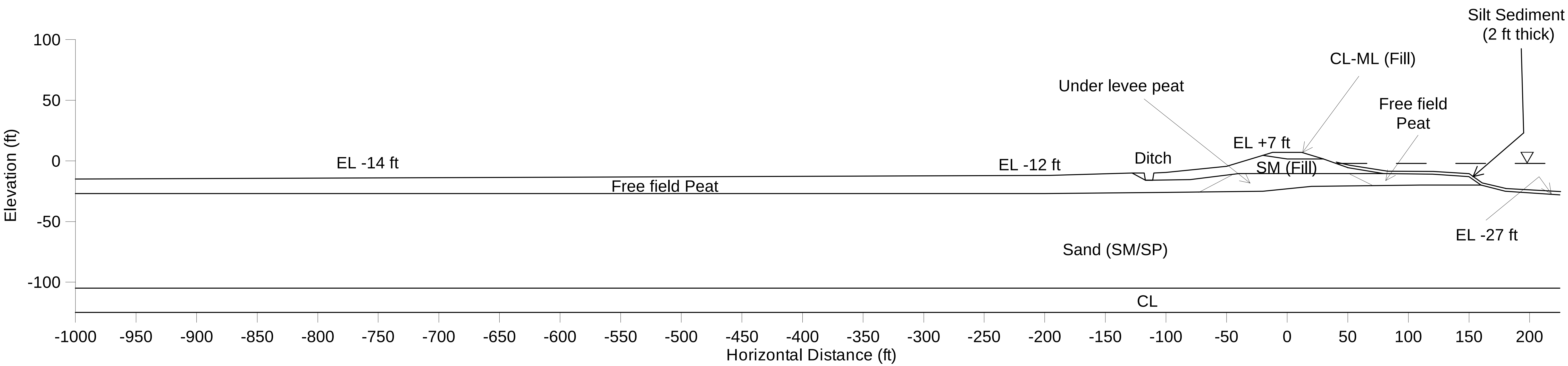
URS Corporation, Oakland, CA, douglas_wright

For Vulnerability Class i,



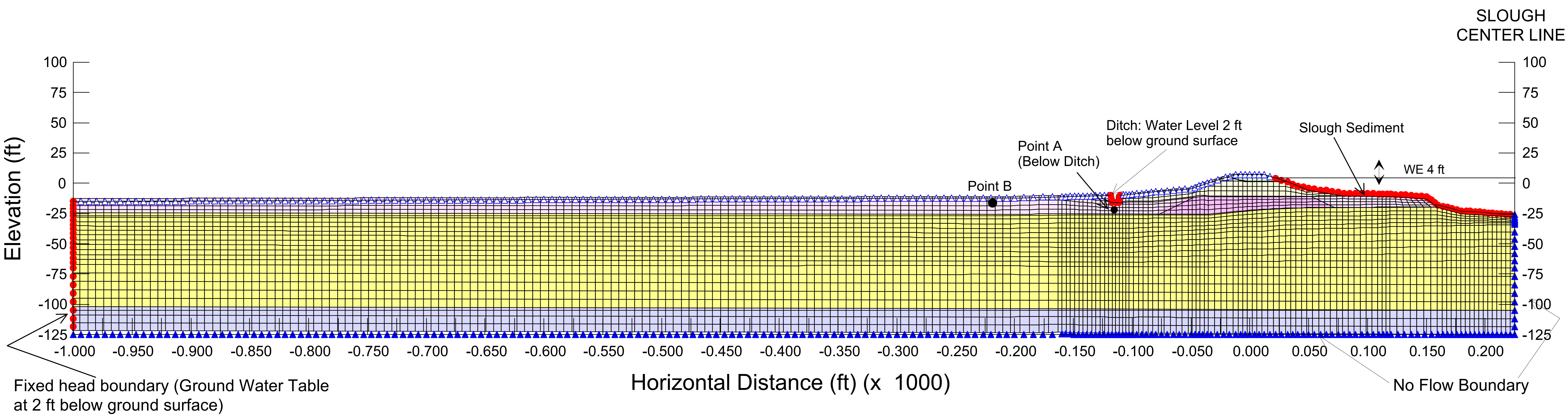
(c)

Delta Risk Management Strategy (DRMS) Levee Fragility		Probability of Failure versus. Flood Stage	Figure 7-28
URS	Project No. 26815621		



Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Idealized Soil Profile - Terminous Tract	Figure 7-29
URS	Project No. 26815621		



Legend

Boundary Conditions

- No flow
- Fixed head
- Review

Material Type

- CL-ML (Levee Fill)
- Sandy Levee Fill
- Free Field Peat
- Under Levee Peat
- Sand (SP/SM)
- Clay
- Slough Sediment

Hydraulic conductivities used for preliminary seepage analysis

Material	k_h (cm/s)			k_h/k_v
	Mean - σ	Mean	Mean + σ	
Fill				
CL-ML (fill)	-	1×10^{-5}	-	4
SM (fill)	-	1×10^{-3}	-	4
Peat & Organics				
Free Field	1×10^{-5}	1×10^{-4}	1×10^{-3}	10
Under Levee	1×10^{-6}	1×10^{-5}	1×10^{-4}	10
Other Foundation Soils				
Sand (SM/SP)	5×10^{-4}	1×10^{-3}	5×10^{-3}	4
ML	-	1×10^{-4}	-	4
CL	-	1×10^{-6}	-	4
Sediment (at slough bottom)	-	1×10^{-5}	-	1

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

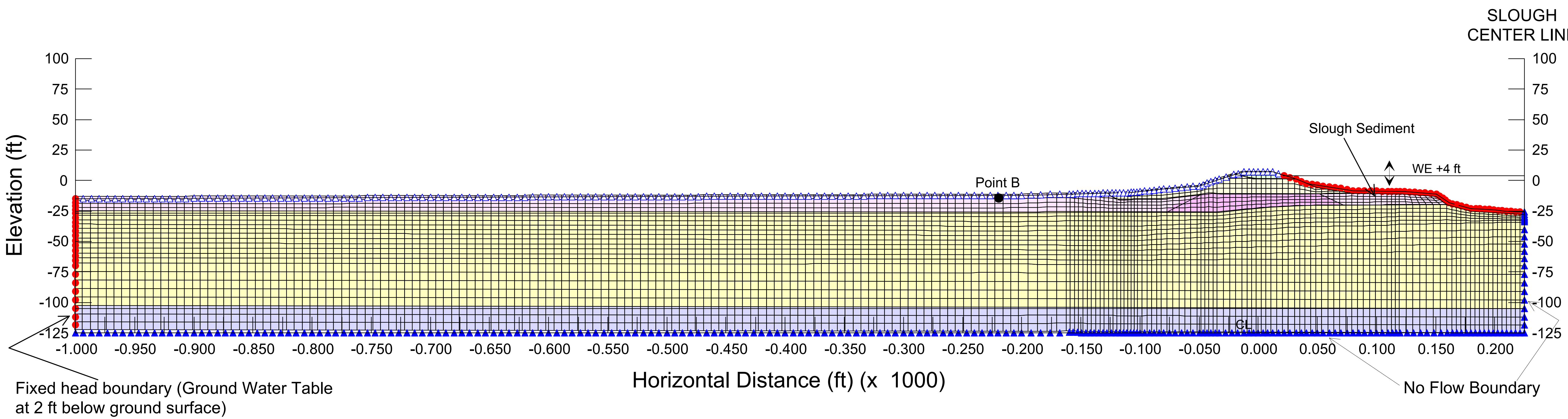
Delta Risk Management Strategy (DRMS)
Levee Fragility

URS

Project No. 26815621

Finite Element Mesh and Boundary Conditions - Model with Drainage Ditch Terminous Tract

Figure 7-30



Legend

Boundary Conditions

- ▲ – No flow
- ● – Fixed head
- △ – Review

Material Type

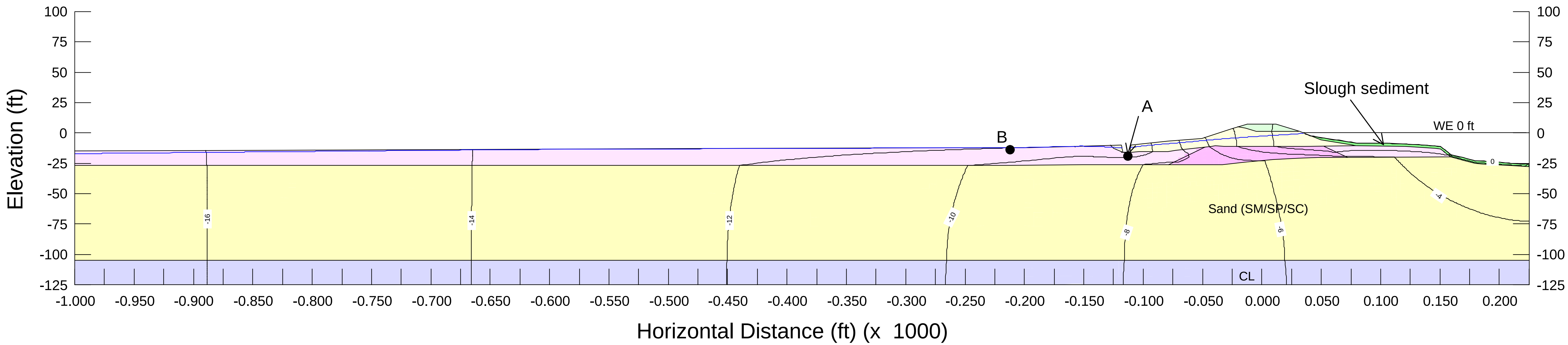
- CL-ML (Levee Fill)
- Sandy Levee Fill
- Free Field Peat
- Under Levee Peat
- Sand (SP/SM)
- Clay
- Slough Sediment

Hydraulic conductivities used for preliminary seepage analysis

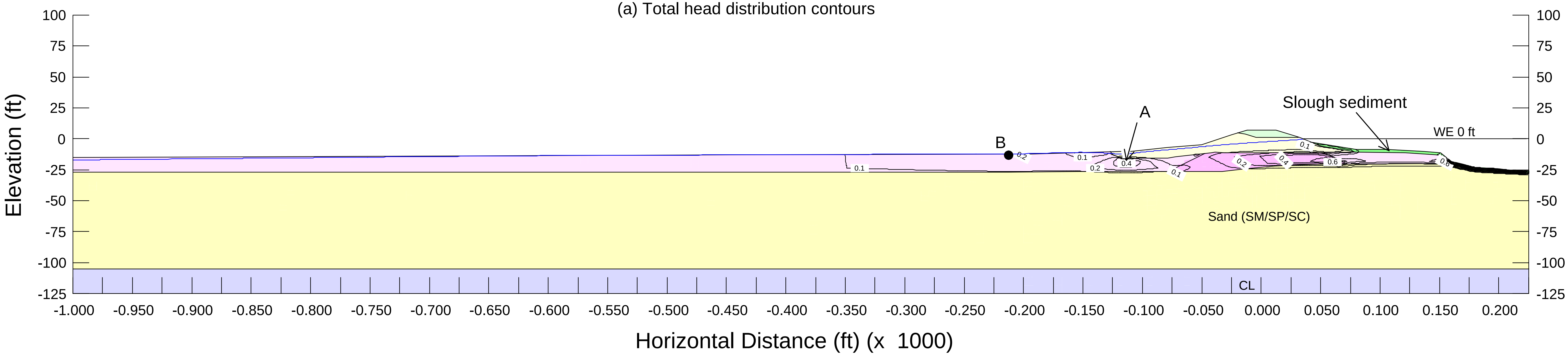
Material	k_h (cm/s)			k_h/k_v
	Mean - σ	Mean	Mean + σ	
Fill				
CL-ML (fill)	-	1×10^{-5}	-	4
SM (fill)	-	1×10^{-3}	-	4
Peat & Organics				
Free Field	1×10^{-5}	1×10^{-4}	1×10^{-3}	10
Under Levee	1×10^{-6}	1×10^{-5}	1×10^{-4}	10
Other Foundation Soils				
Sand (SM/SP)	5×10^{-4}	1×10^{-3}	5×10^{-3}	4
ML	-	1×10^{-4}	-	4
CL	-	1×10^{-6}	-	4
Sediment (at slough bottom)	-	1×10^{-5}	-	1

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Mesh and Boundary Conditions - Model without Drainage Ditch Terminous Tract	Figure 7-31
URS	Project No. 26815621		



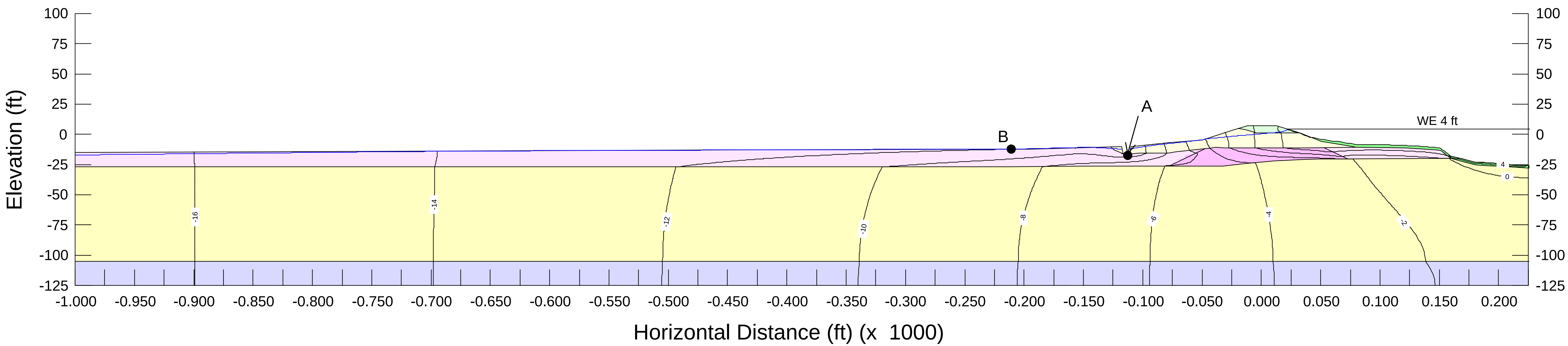
(a) Total head distribution contours



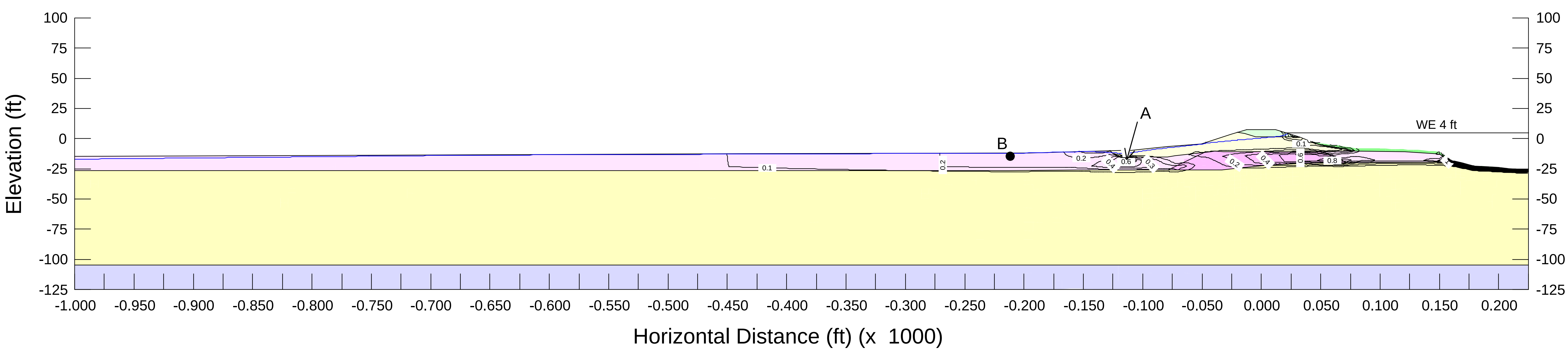
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head and Vertical Gradient Contours for Slough Water EL: 0 ft Terminous Tract	Figure 7-32
URS	Project No. 26815621		



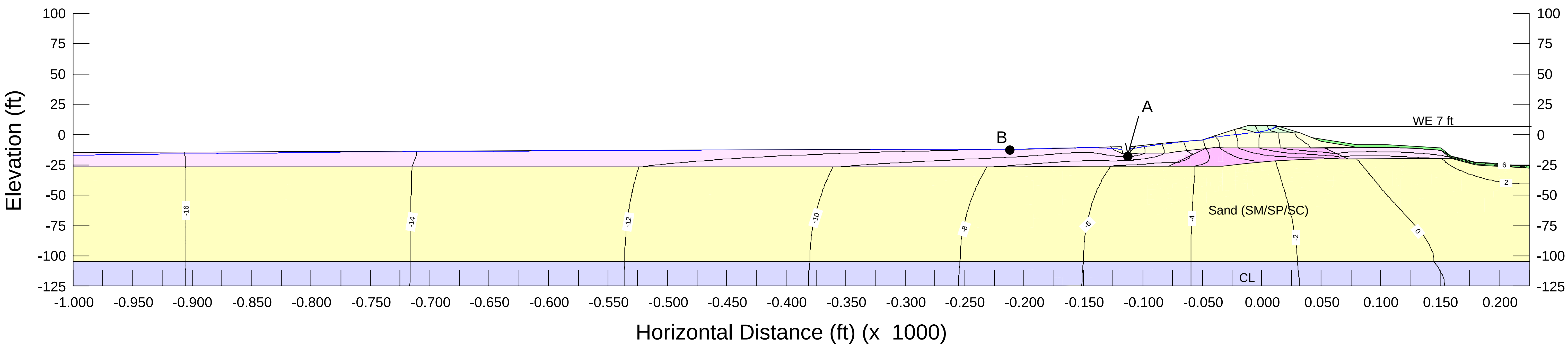
(a) Total head distribution contours



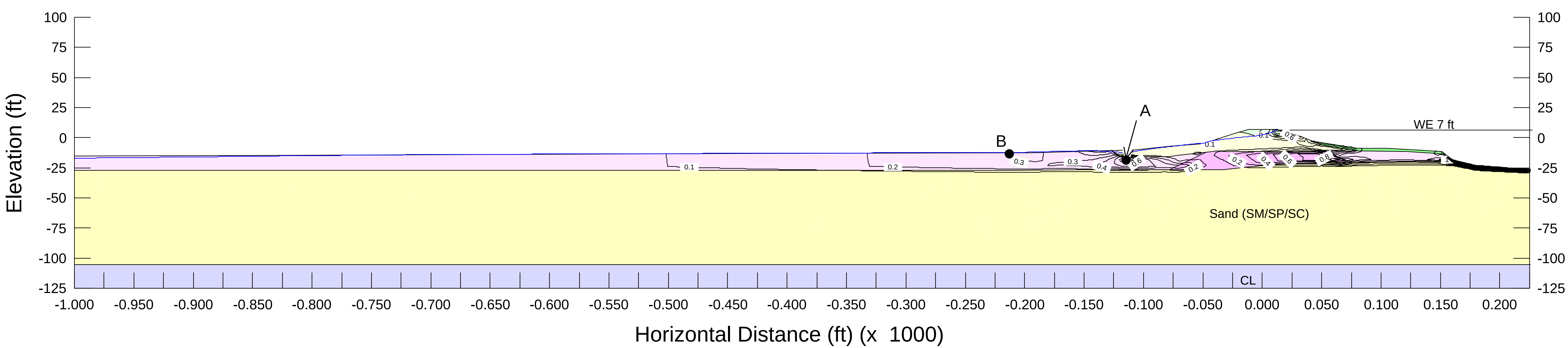
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head and Vertical Gradient Contours for Slough Water EL: +4 ft Terminous Tract	Figure 7-33
URS	Project No. 26815621		



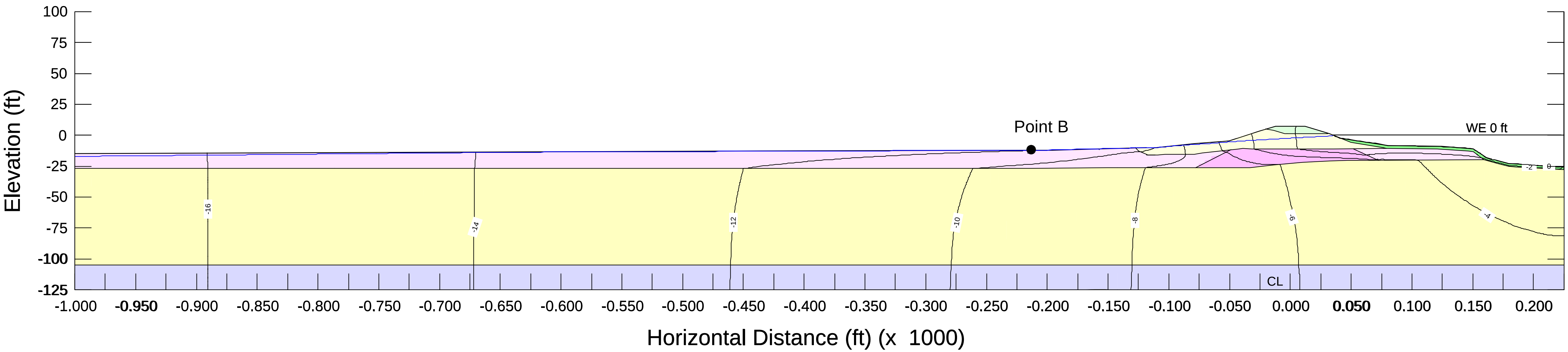
(a) Total head distribution contours



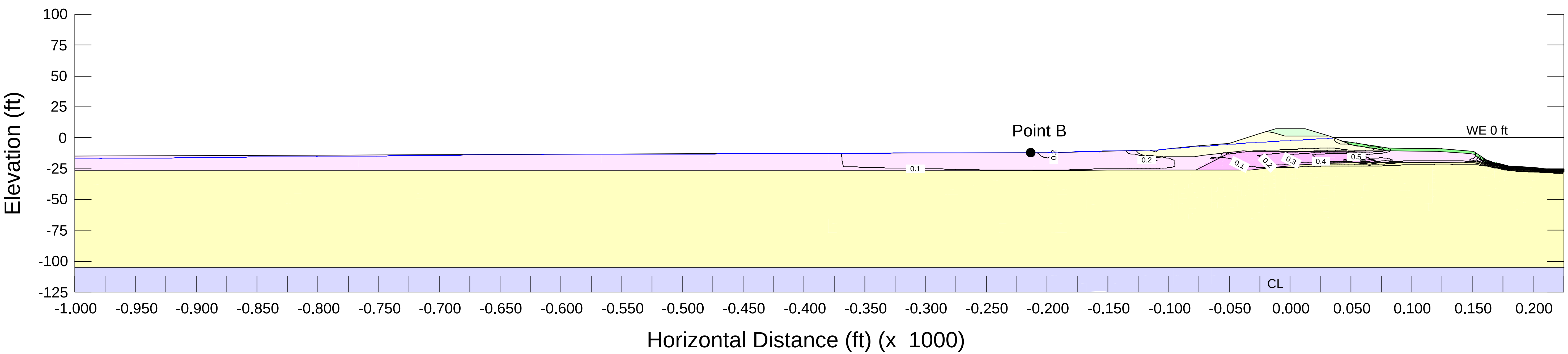
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head and Vertical Gradient Contours for Slough Water EL: +7 ft Terminous Tract	Figure 7-34
URS	Project No. 26815621		



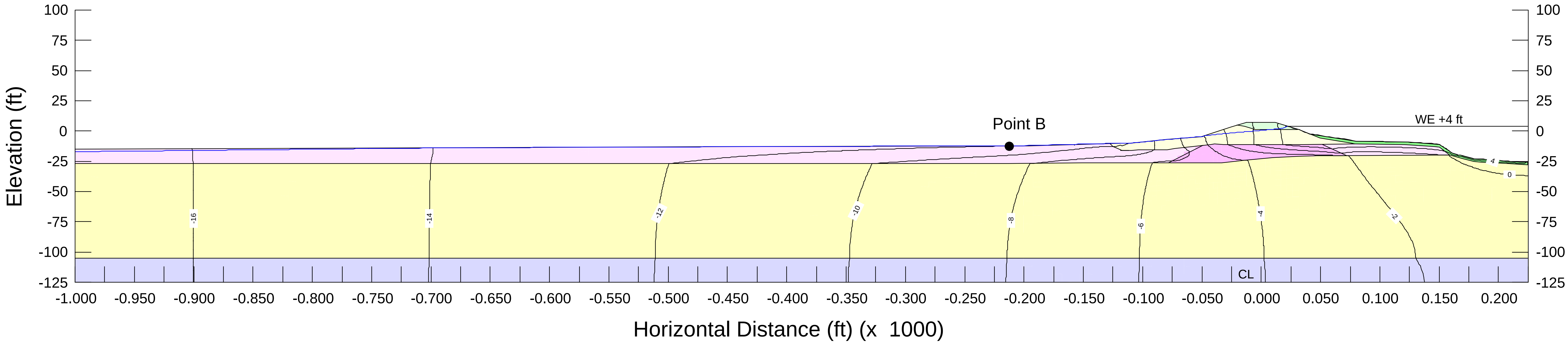
(a) Total head distribution contours



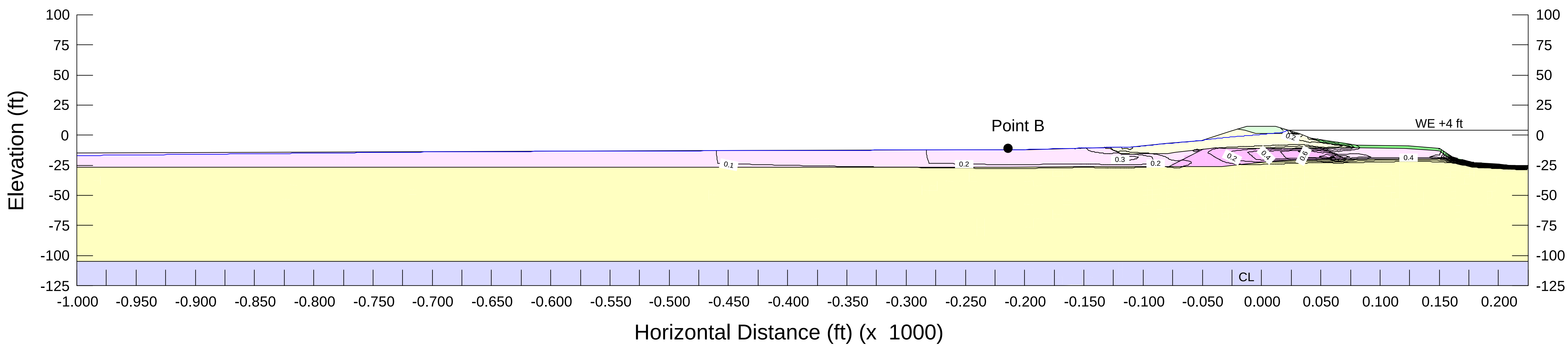
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head and Vertical Gradient Contours for Slough Water EL: 0 ft - Model without Drainage Ditch Terminous Tract	Figure 7-35
URS	Project No. 26815621		



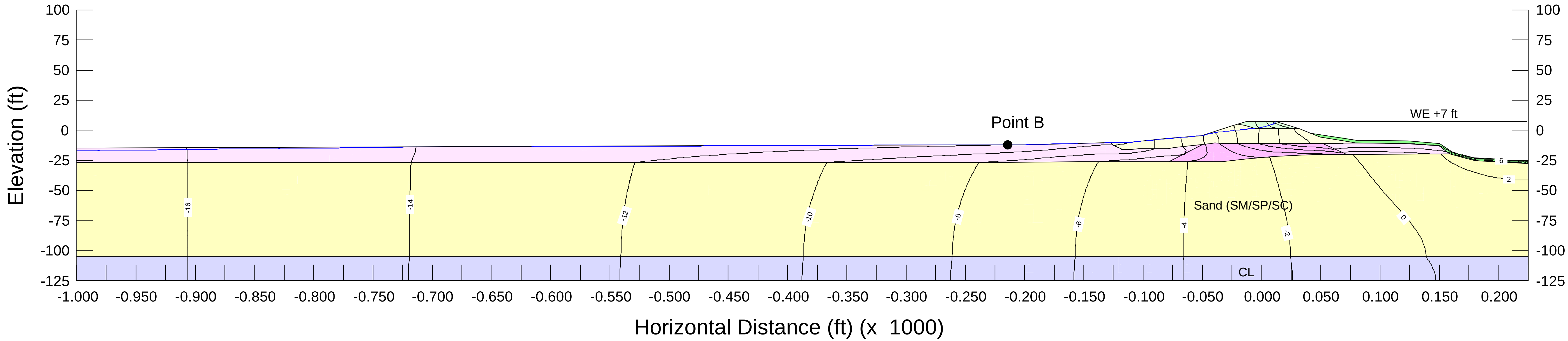
(a) Total head distribution contours



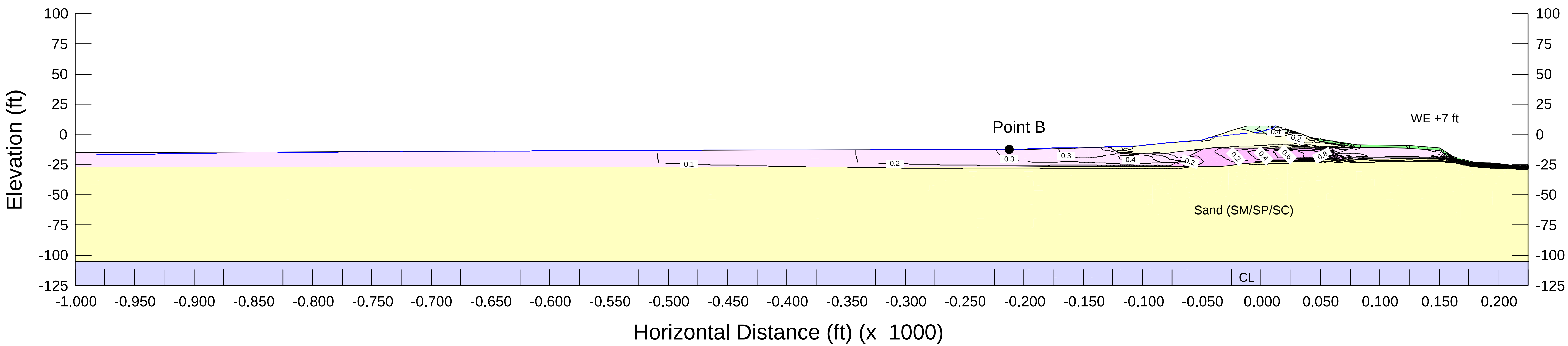
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head and Vertical Gradient Contours for Slough Water EL: +4 ft - Model without Drainage Ditch Terminous Tract	Figure 7-36
URS	Project No. 26815621		



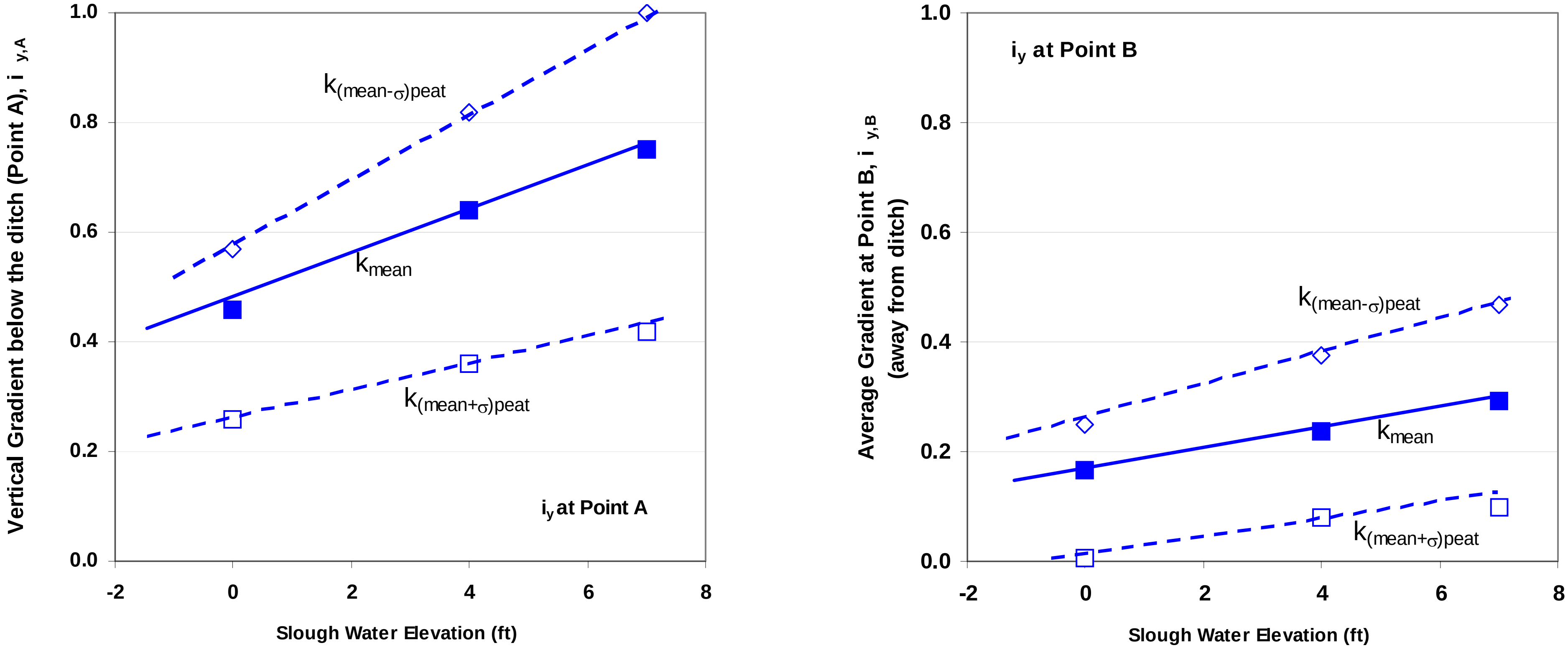
(a) Total head distribution contours



(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

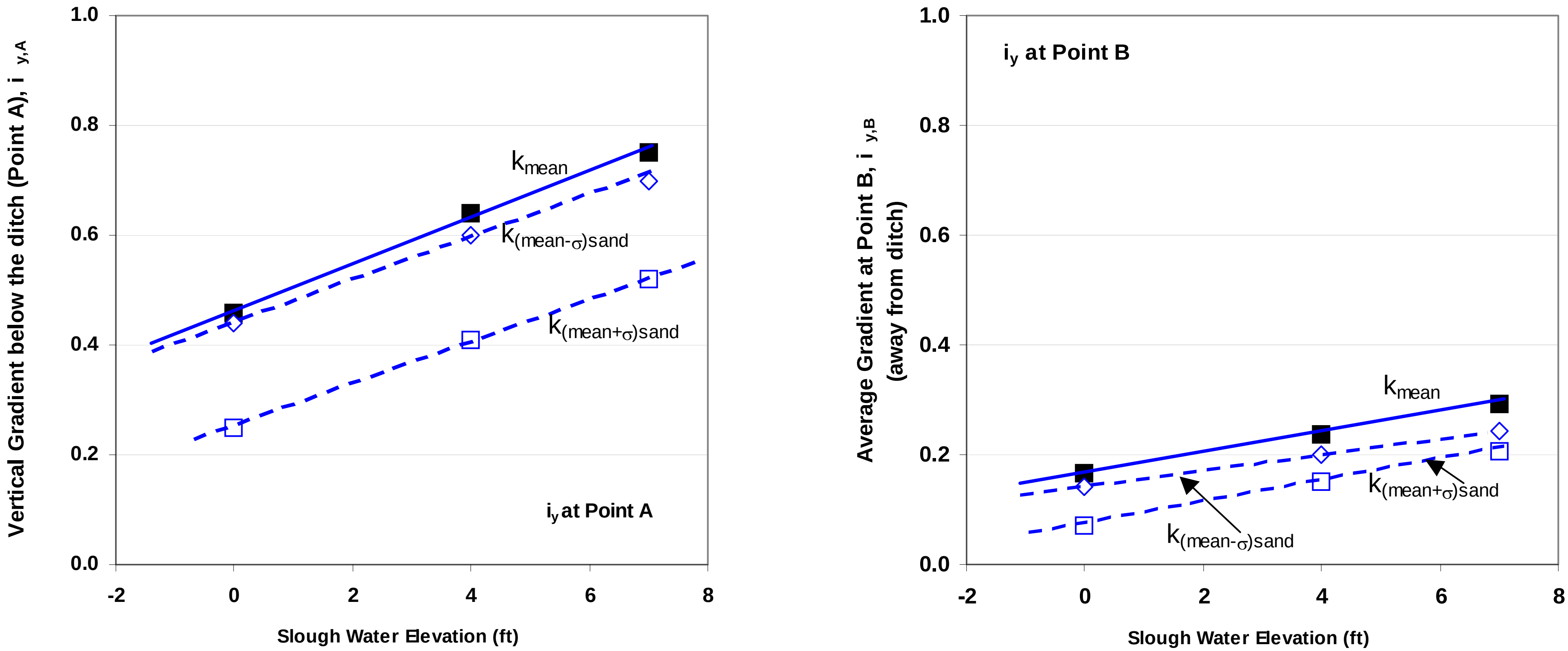
Delta Risk Management Strategy (DRMS) Levee Fragility	Total Head and Vertical Gradient Contours for Slough Water EL: +7 ft - Model without Drainage Ditch Terminous Tract	Figure 7-37
URS / Project No. 26815621		



Note:

1. Gradients were calculated for seepage model with ditch and 2 ft silt sediment deposit at slough bottom.
2. All elevations are referenced to NAVD88 (NAVD88 = NGVD29 + 2.5 ft)

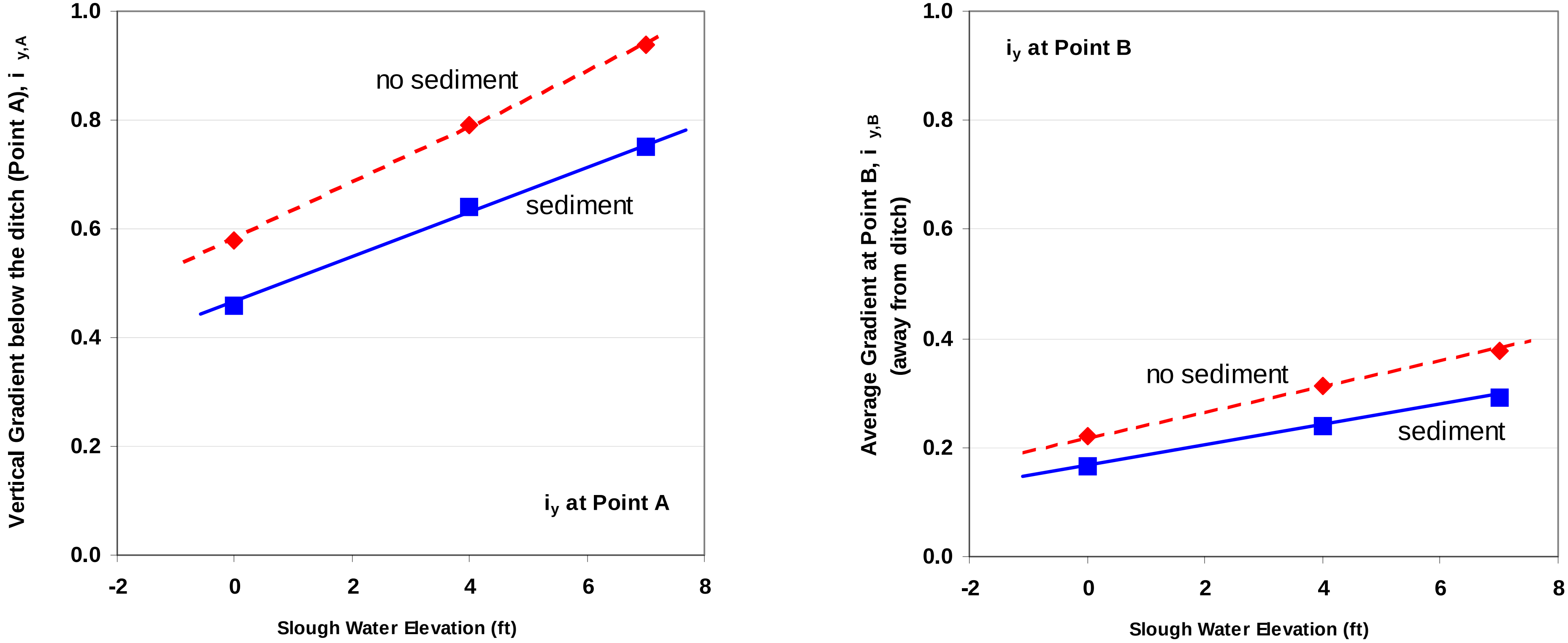
Delta Risk Management Strategy (DRMS) Levee Fragility	Effect of Permeability of Peat Initial Analysis -Terminous Tract	Figure 7-38
URS — Project No. 26815621		



Note:

1. Gradients were calculated for seepage model with ditch and 2 ft silt sediment deposit at slough bottom.
2. All elevations are referenced to NAVD88 (NAVD88 = NGVD29 + 2.5 ft)

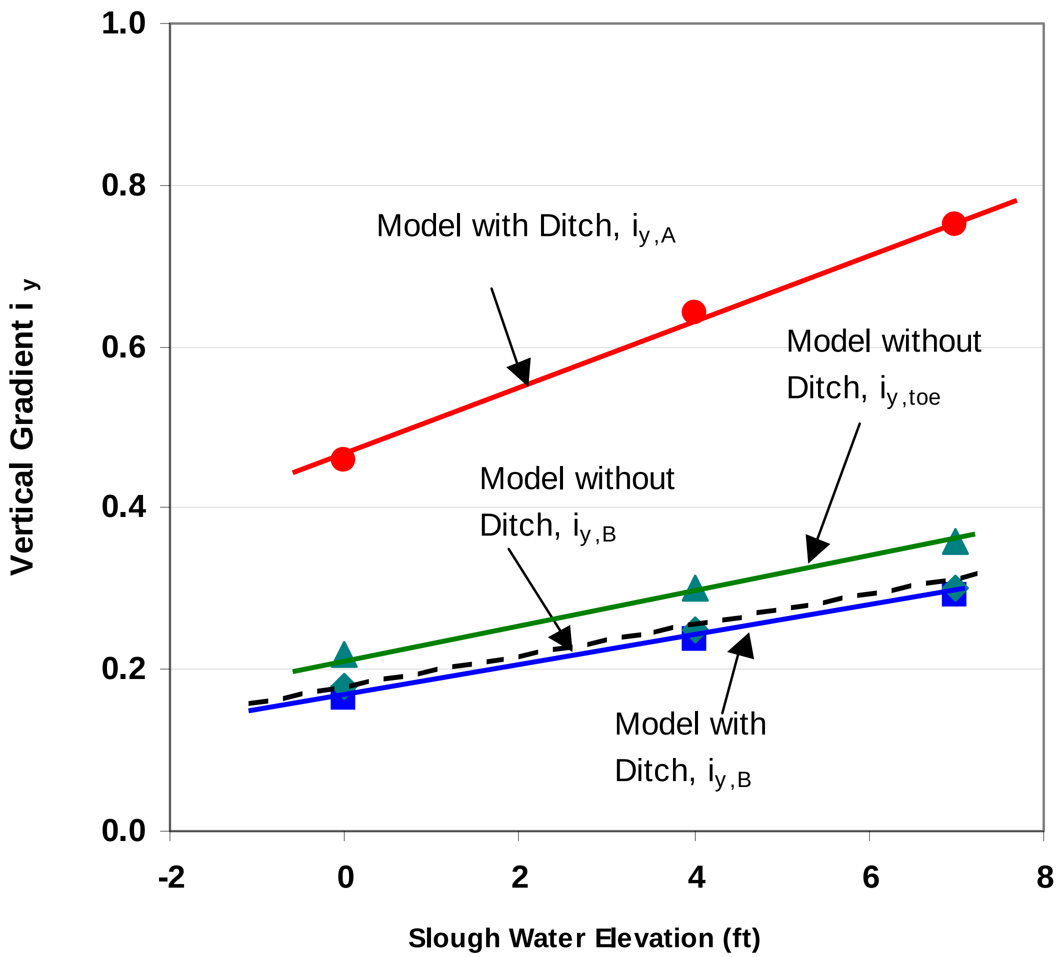
Delta Risk Management Strategy (DRMS) Levee Fragility		Effect of Permeability of Sand Aquifer Initial Analysis -Terminous Tract	Figure 7-39
URS	Project No. 26815621		



Note:

1. Gradients were calculated for seepage model with ditch.
2. All elevations are referenced to NAVD88
   (NAVD88 = NGVD29 + 2.5 ft)

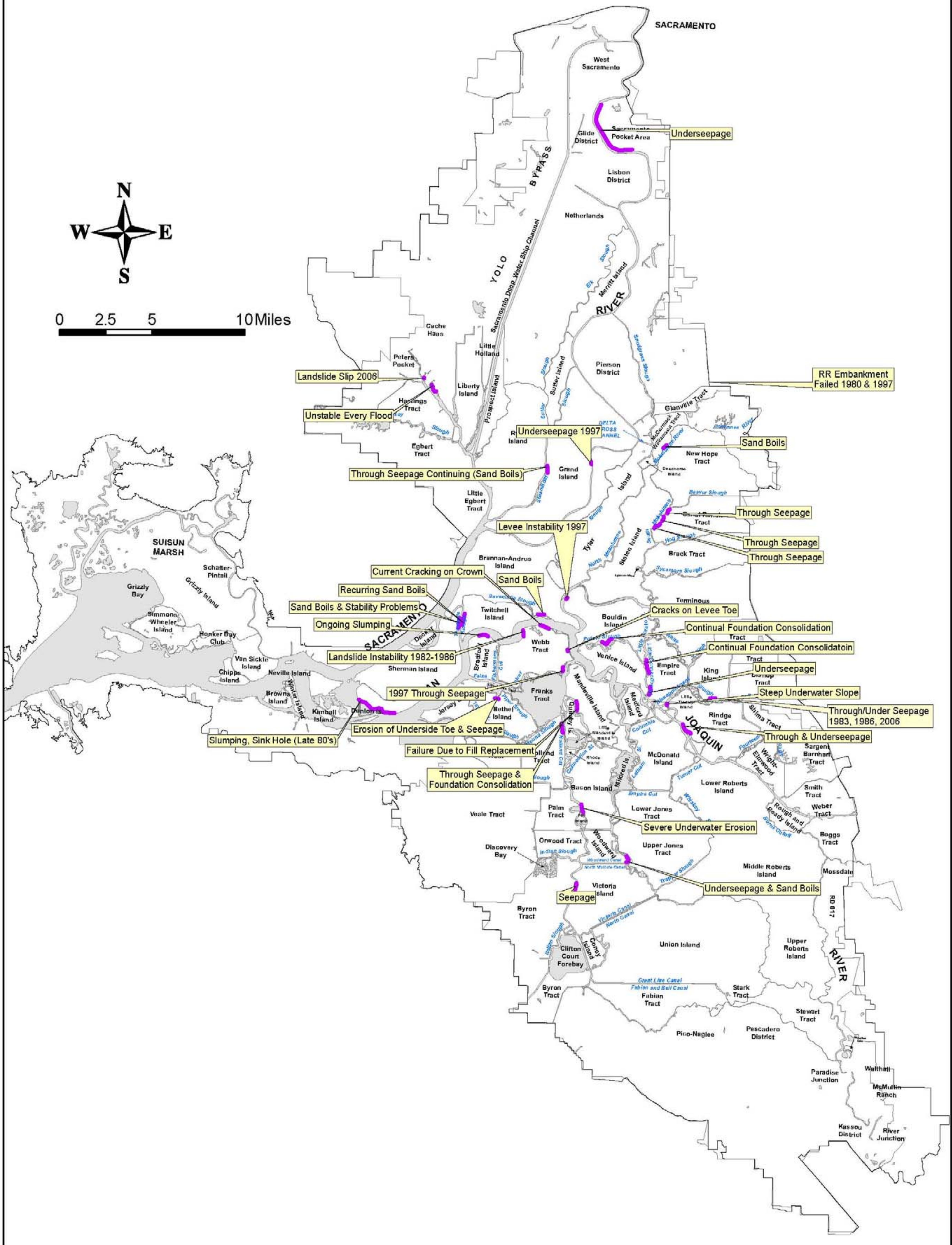
Delta Risk Management Strategy (DRMS) Levee Fragility		Effect of Slough Sediment Initial Analysis -Terminous Tract	Figure 7-40
URS	Project No. 26815621		



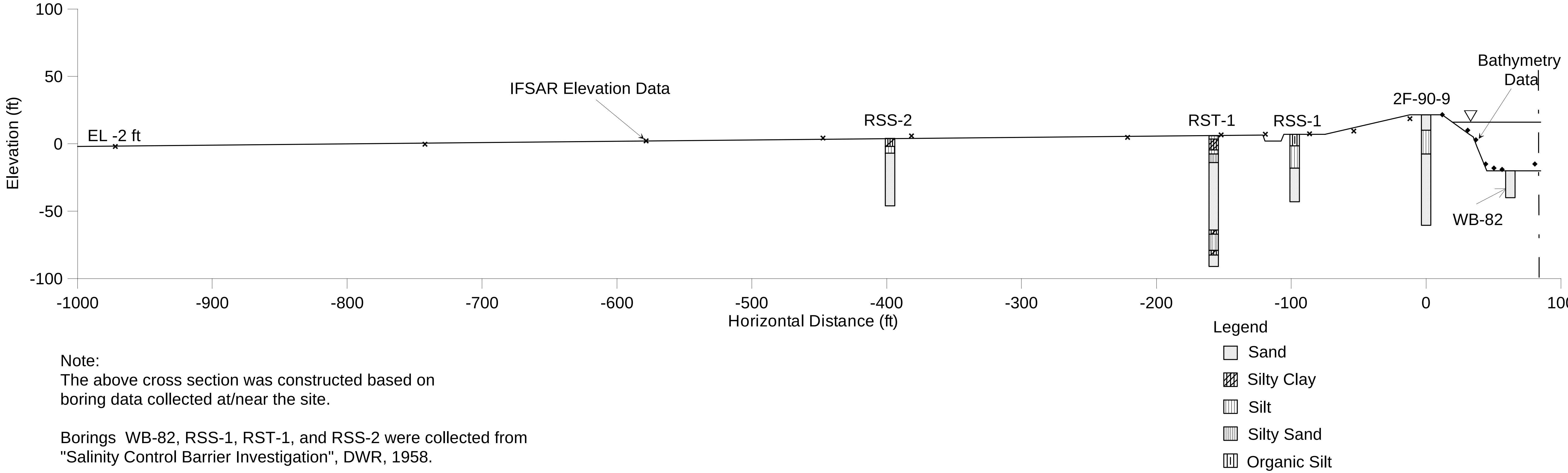
Note:
Gradients were calculated for seepage model with
2 ft silt sediment deposit at slough bottom.

Elevations are referenced to NAVD88

Delta Risk Management Strategy (DRMS) Levee Fragility	Effect of Drainage Ditch Initial Analysis -Terminous Tract	Figure 7-41
URS — Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility	Reported Problem Areas	Figure 7-42
URS — Project No. 26815621		



Note:
The above cross section was constructed based on boring data collected at/near the site.

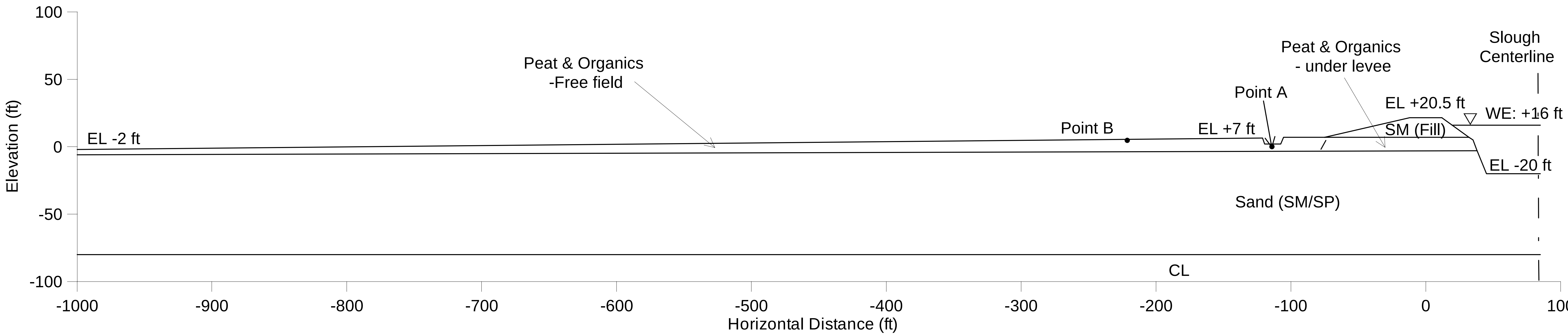
Borings WB-82, RSS-1, RST-1, and RSS-2 were collected from "Salinity Control Barrier Investigation", DWR, 1958.

Boring 2F-90-9 was collected from "Sacramento River Flood Control System Evaluation, Lower Sacramento Area", COE, 1993.

Based on boring RSS-1 and Organic Thickness Map, it was conservatively assumed that the top foundation layer has 10 ft thick peat/organic material.

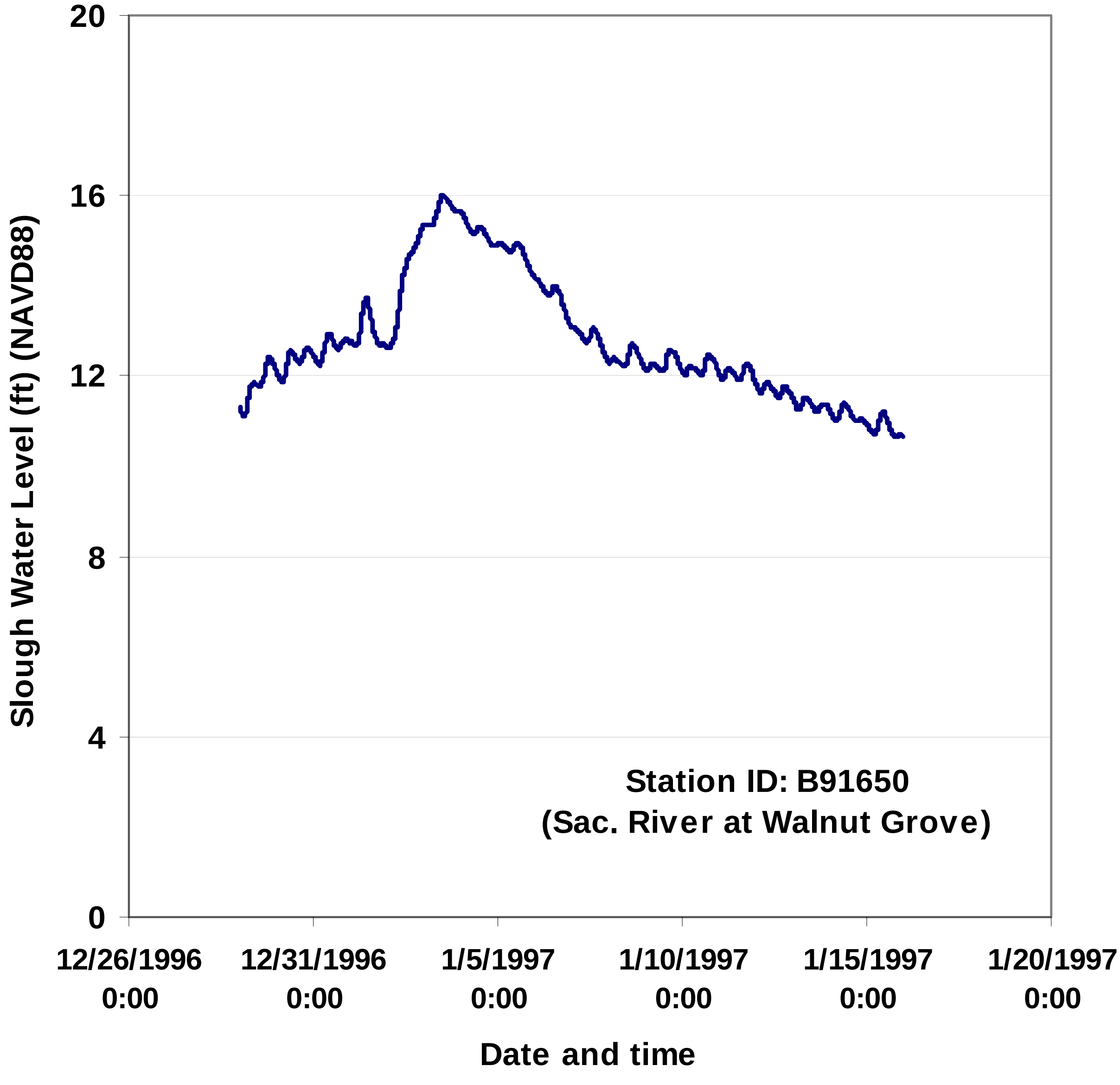
All elevations are referenced to NAVD88 (NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Topography and Boring Data Grand Island	Figure 7-43
URS	Project No. 26815621		

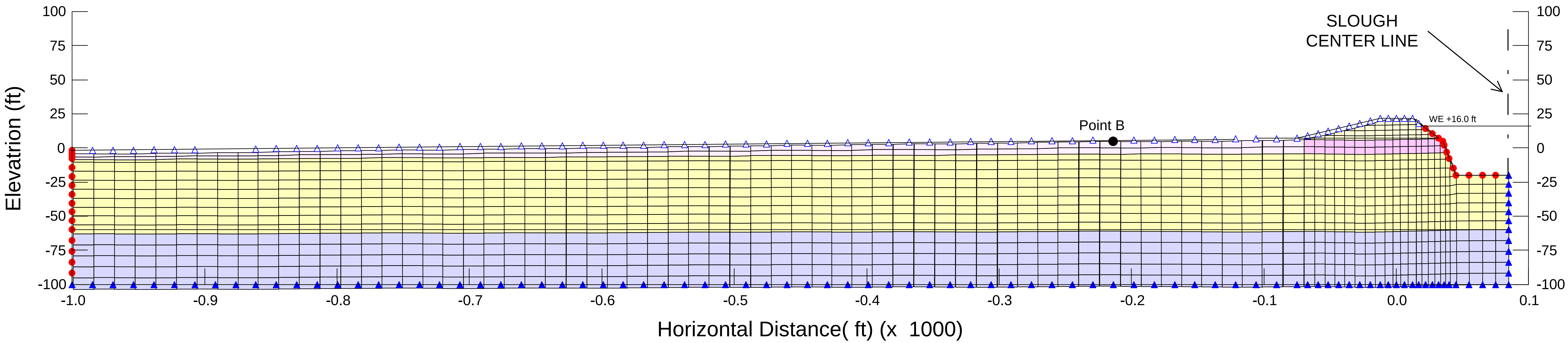


Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)
Water Elevation: +16 ft (NAVD88)

Delta Risk Management Strategy (DRMS) Levee Fragility		Idealized Cross-section Grand Island	Figure 7-44
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Monitored Slough Water Level at Walnut Grove Station (ID:91650)	Figure 7-45
URS	Project No. 26815621		



Seepage Model without Ditch

Legend

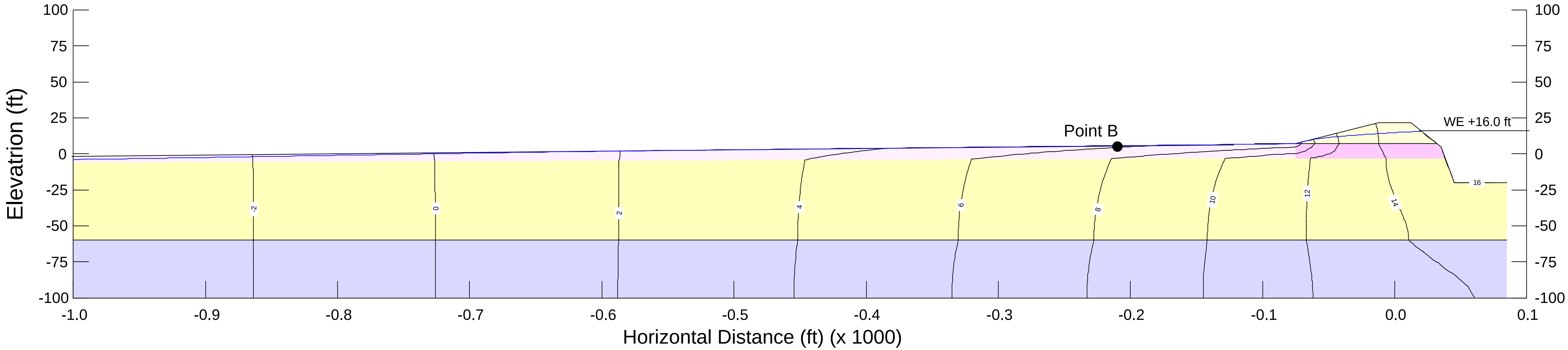
Boundary Conditions

- No flow
- Fixed head
- Review

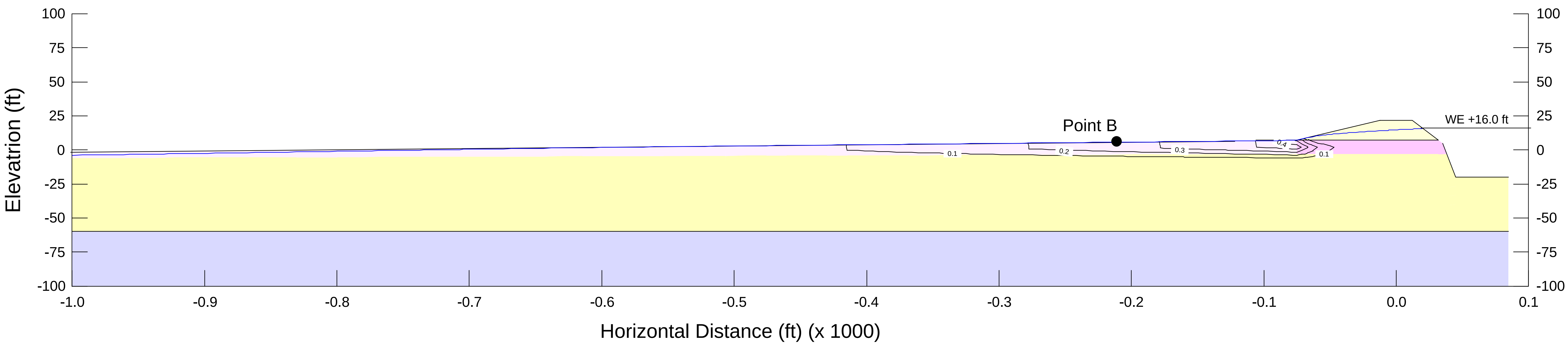
Material Type

- Sandy Levee Fill
- Free Field Peat
- Under Levee Peat
- Sand (SP/SM)
- Clay

Delta Risk Management Strategy (DRMS) Levee Fragility	Finite Element Mesh and Boundary Conditions Grand Island Underseepage Problem	Figure 7-46
URS Project No. 26815621		



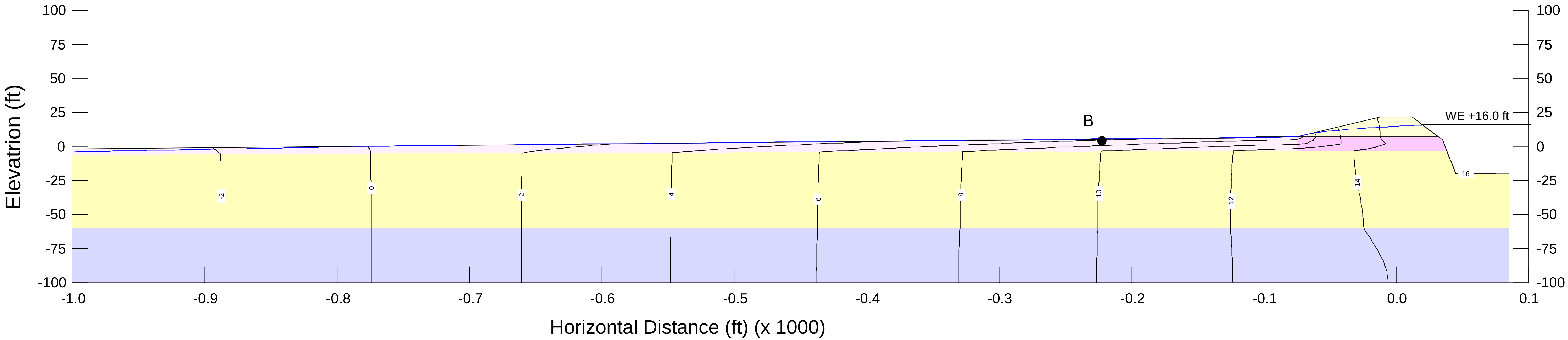
(a) Total head distribution contours



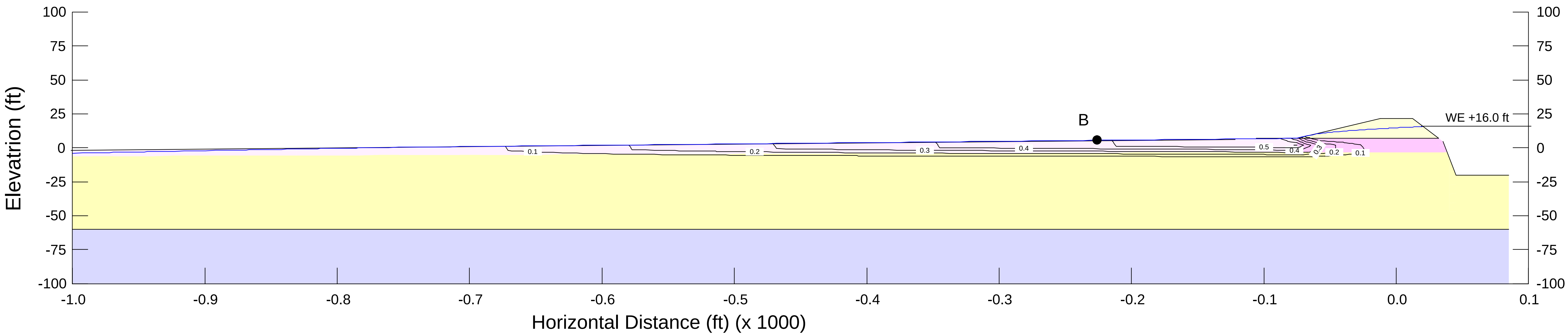
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility	Total Head & Vertical Gradient Contours for $(k_h/k_v)_{peat}$ = 10 Grand Island Underseepage Problem	Figure 7-47
URS — Project No. 26815621		



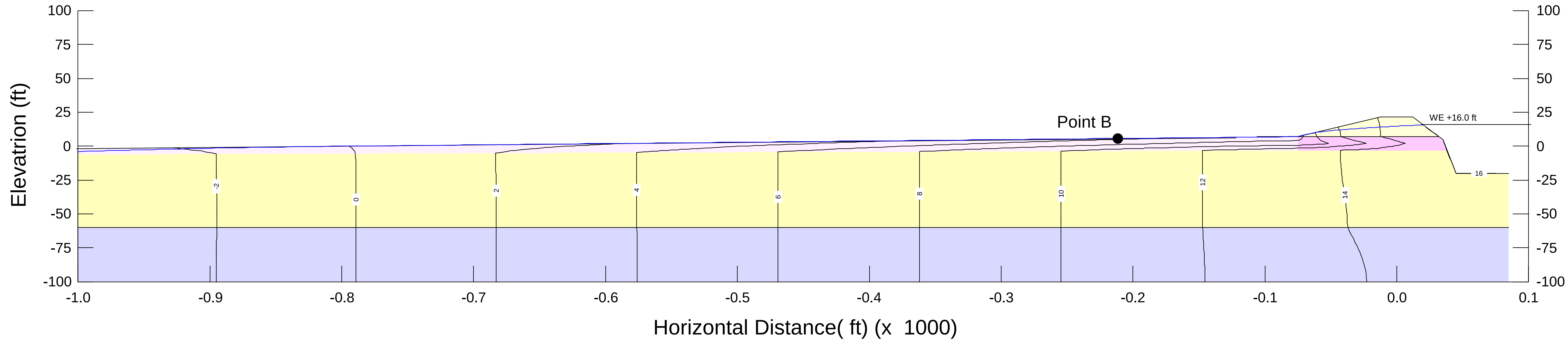
(a) Total head distribution contours



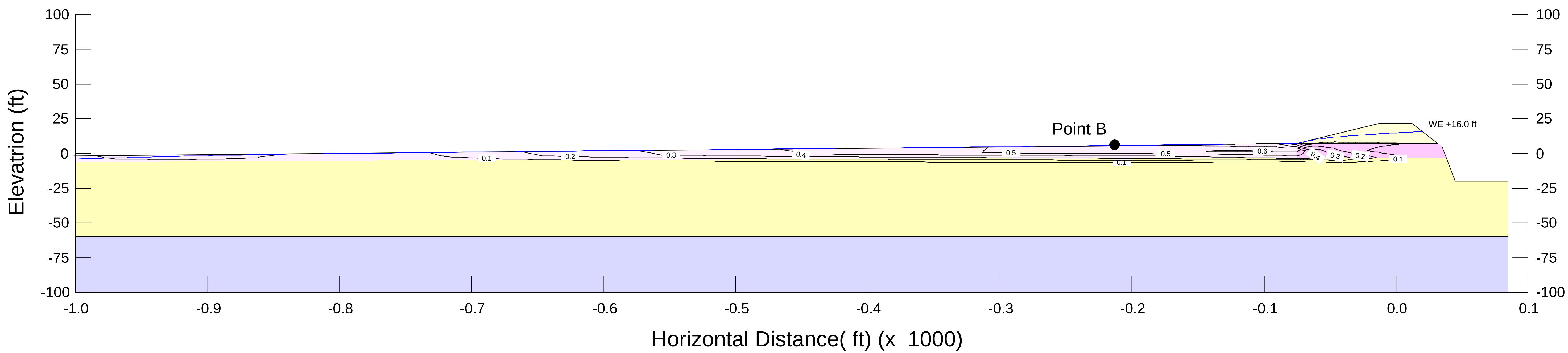
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88

Delta Risk Management Strategy (DRMS) Levee Fragility	Total Head & Vertical Gradient Contours for $(k_h/k_v)_{peat}$ = 100 Grand Island Underseepage Problem	Figure 7-48
URS — Project No. 26815621		



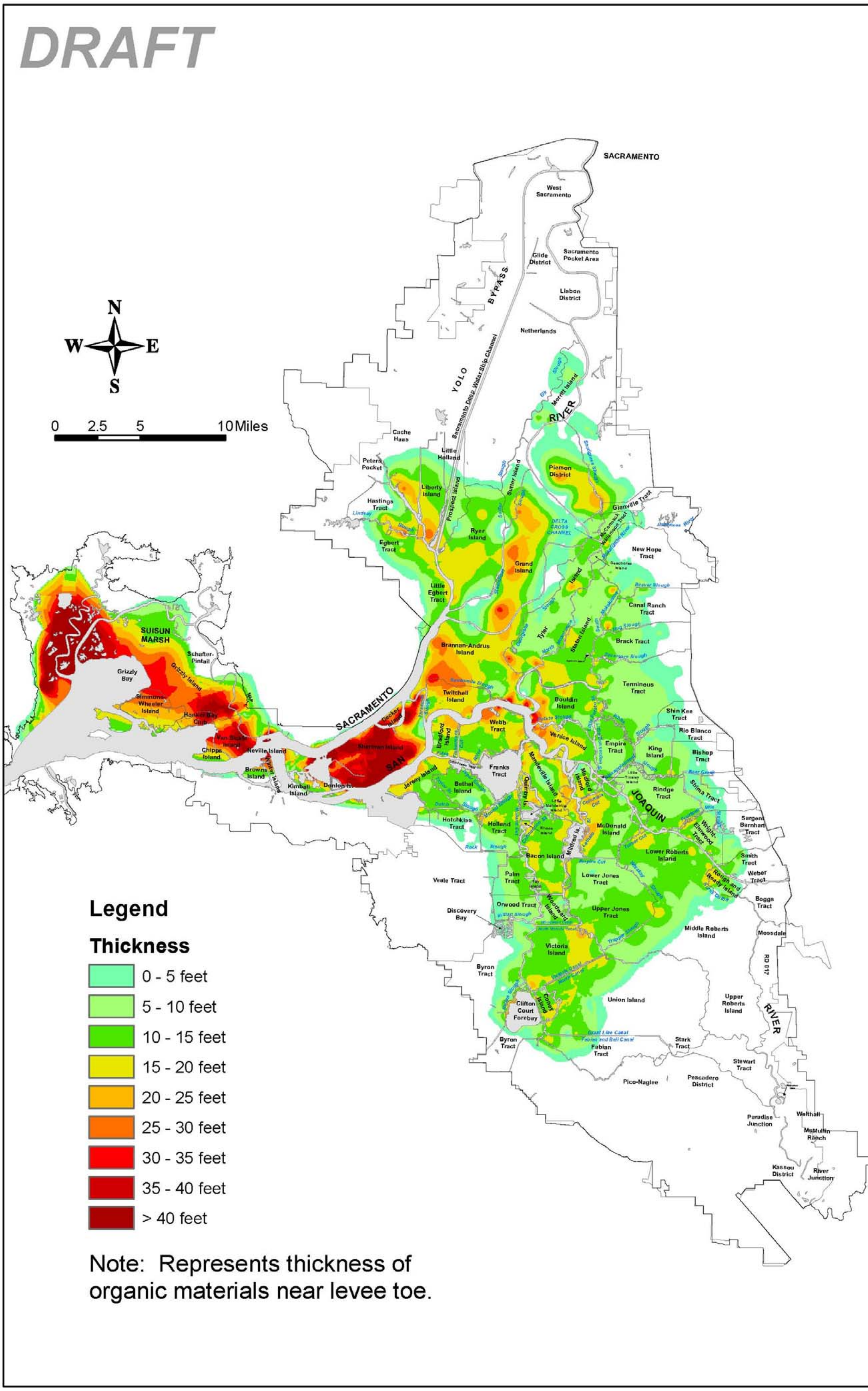
(a) Total head distribution contours



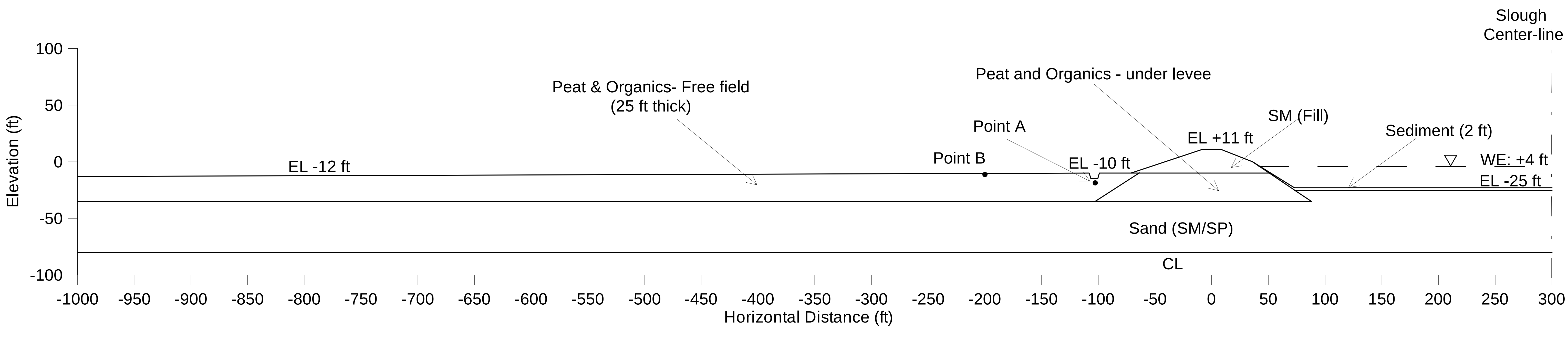
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head & Vertical Gradient Contours fro $(k_h/k_v)_{peat}$ = 1000 Grand Island Underseepage Problem	Figure 7-49
URS	Project No. 26815621		



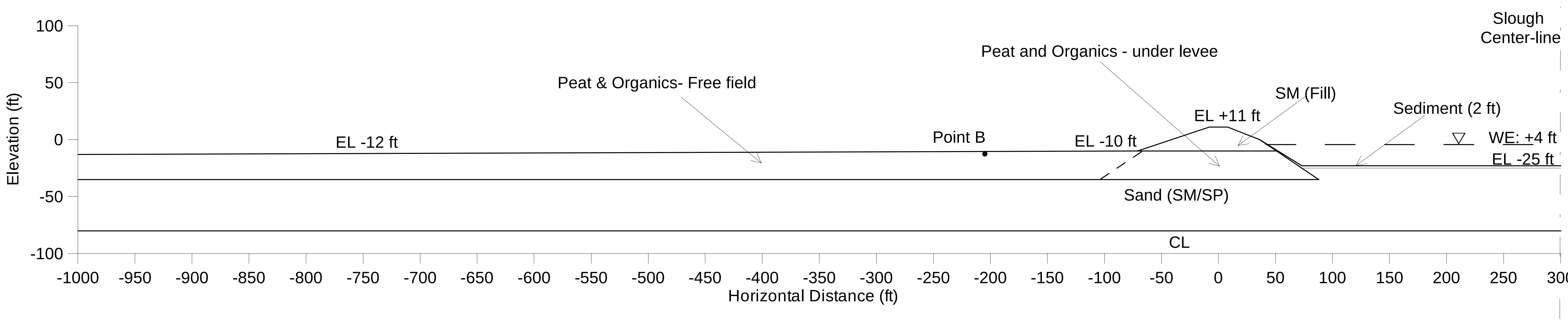
Delta Risk Management Strategy (DRMS) Levee Fragility		Thickness of Organic Materials	Figure 7-50
URS	Project No. 26815621		



Note:
Typical cross section with drainage ditch and slough sediment
Landside slope: 3:1
Waterside slope: 2.5:1 from crest to EL 0 ft, and then 1.5:1
Crest width: 16 ft

All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

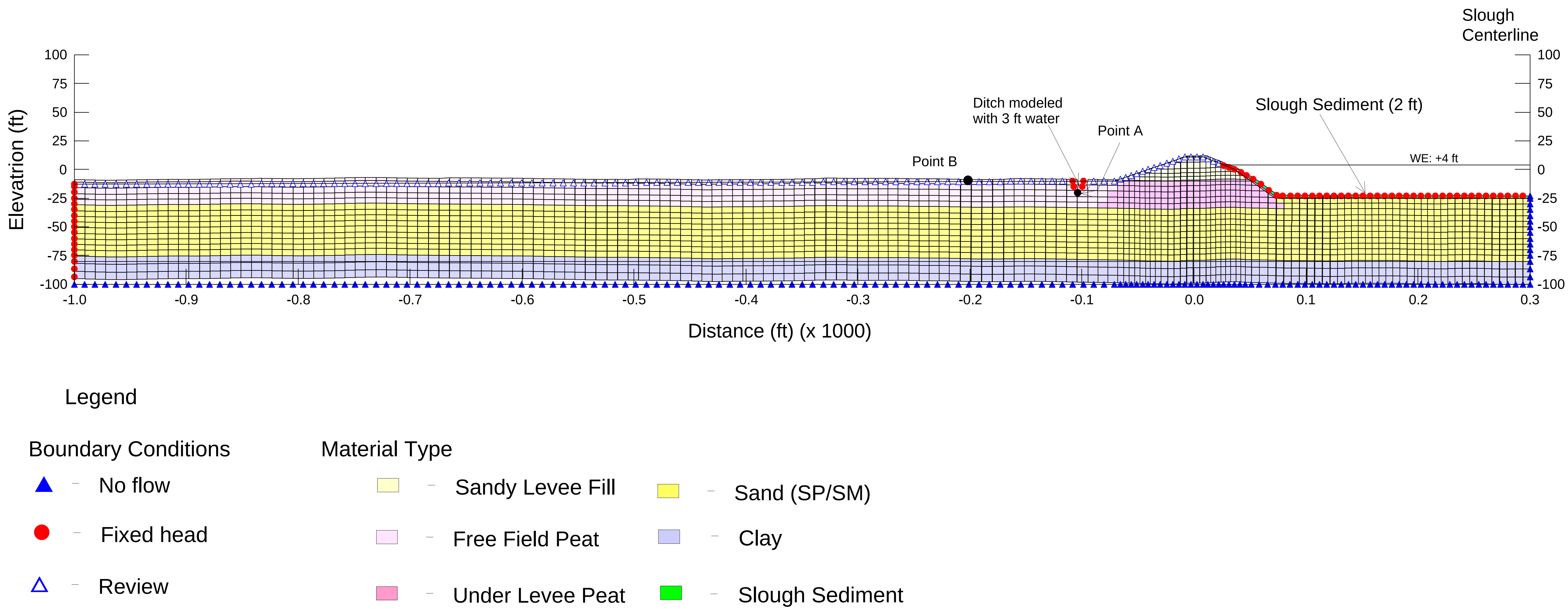
Delta Risk Management Strategy (DRMS) Levee Fragility	Typical Cross Section with Drainage Ditch and 25 ft Peat & Organic Layer	Figure 7-51
URS — Project No. 26815621		



Note:
Model without drainage ditch and with slough sediment
Landside slope: 3:1
Waterside slope: 2.5:1 from crest to EL 0 ft, and then 1.5:1
Crest Width: 16 ft

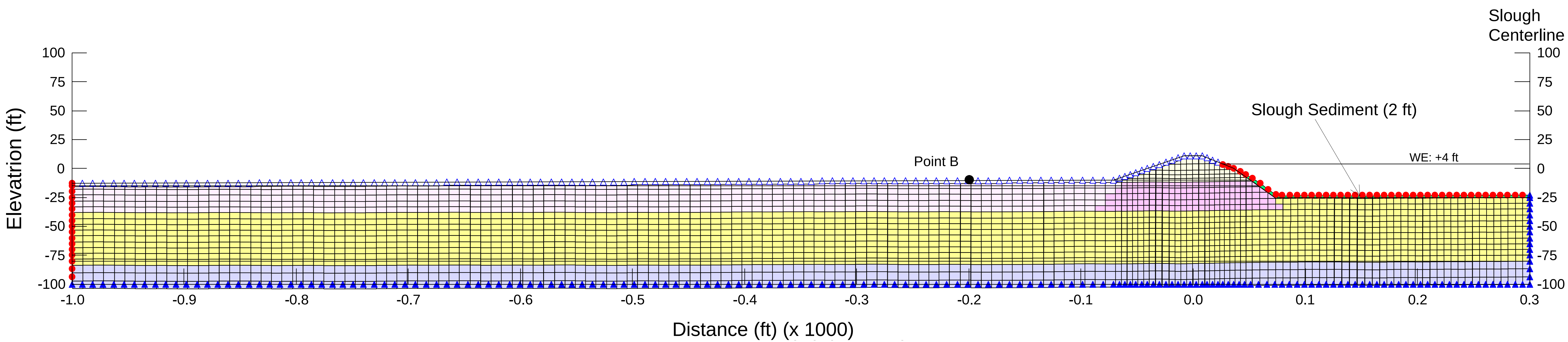
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Cross Section without Drainage Ditch and 25 ft Peat & Organic Layer	Figure 7-52
URS	Project No. 26815621		



Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Mesh & Boundary Conditions Typical Cross Section with Drainage Ditch and 25 ft Peat & Organic Layer	Figure 7-53
URS	Project No. 26815621		



Legend

Boundary Conditions

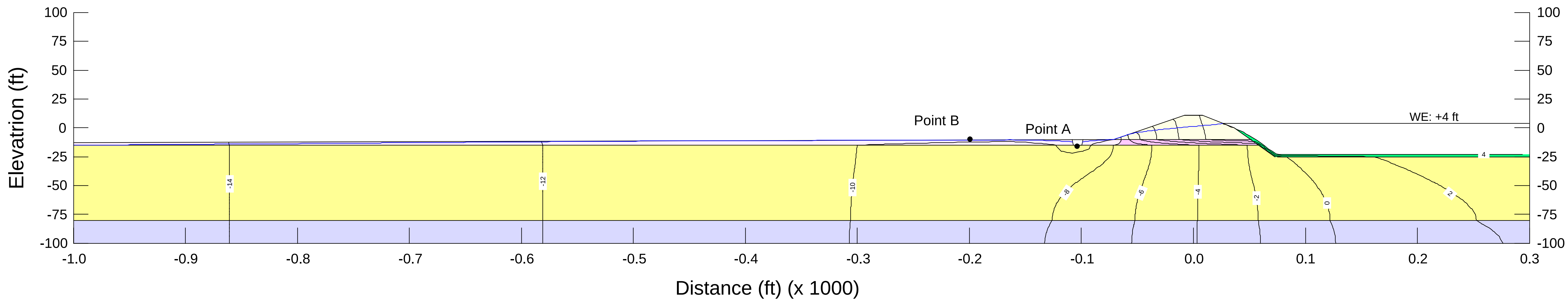
- No flow
- Fixed head
- Review

Material Type

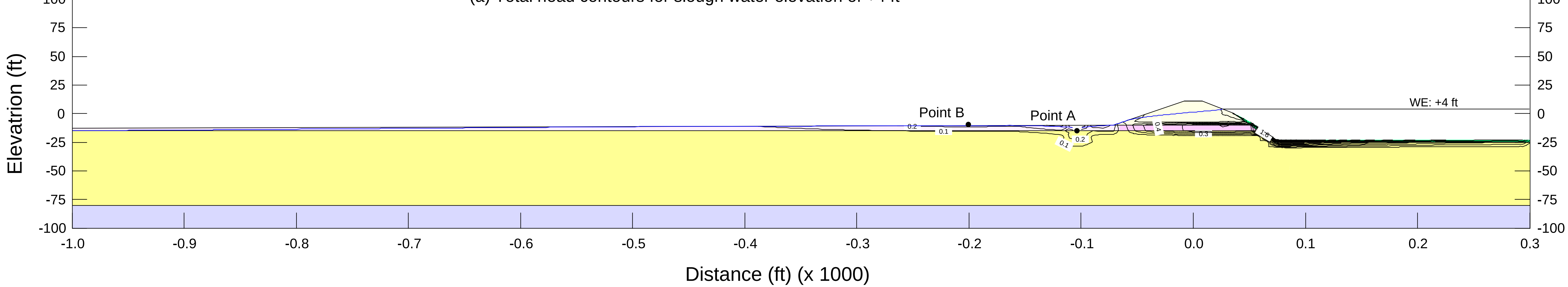
- Sandy Levee Fill
- Free Field Peat
- Under Levee Peat
- Sand (SP/SM)
- Clay
- Slough Sediment

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Mesh & Boundary Conditions Typical Cross Section witout Ditch and 25 ft Peat & Organic Layer	Figure 7-54
URS	Project No. 26815621		



(a) Total head contours for slough water elevation of +4 ft

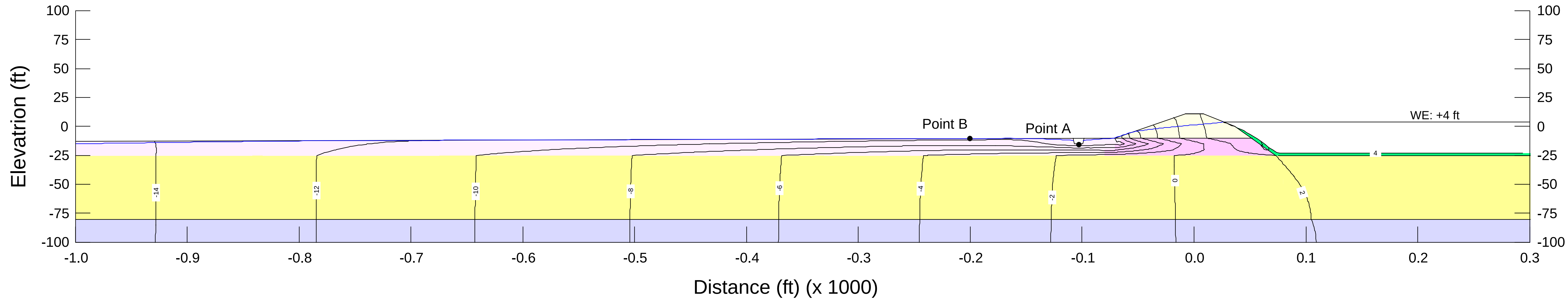


(b) Vertical exit gradient contours for slough water elevation of +4 ft

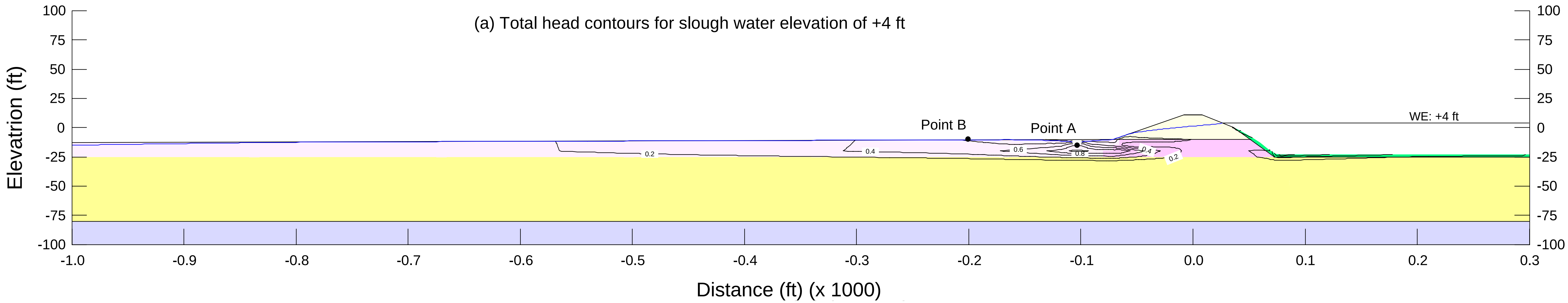
Note:
Analysis CAse:
Mean Permeability values, 5 feet peat/organics, model with drainage ditch and with slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head & Vertical Gradient Contours Typical Cross Section with Drainage Ditch for 5 ft Peat	Figure 7-55
URS	Project No. 26815621		



(a) Total head contours for slough water elevation of +4 ft

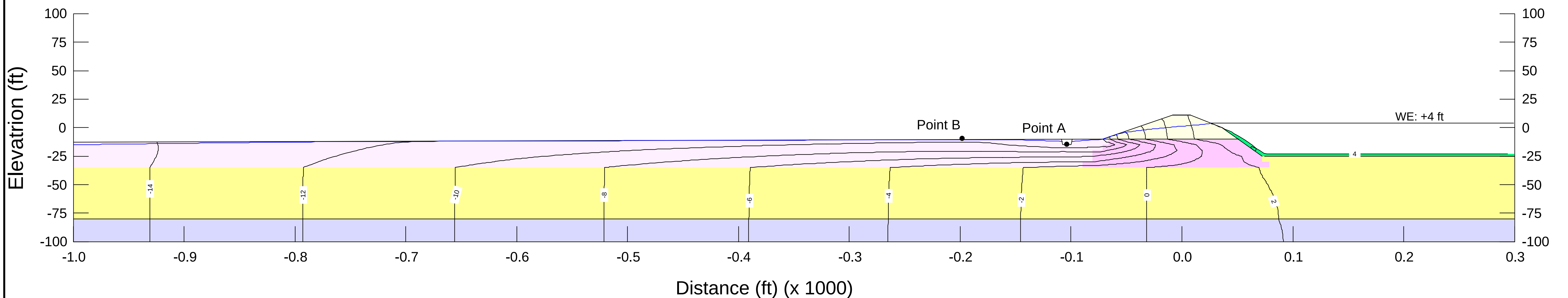


(b) Vertical exit gradient contours for slough water elevation of +4 ft

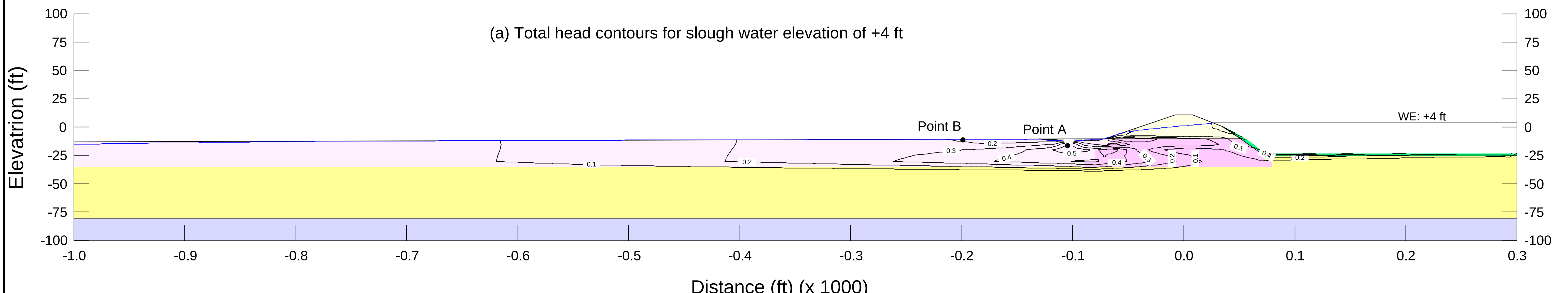
Note:
Analysis CAse:
Mean Permeability values, 15 feet peat/organics, model with drainage ditch and with slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head & Vertical Gradient Contours Typical Cross Section with Drainage Ditch for 15 ft Peat	Figure 7-56
URS	Project No. 26815621		



(a) Total head contours for slough water elevation of +4 ft

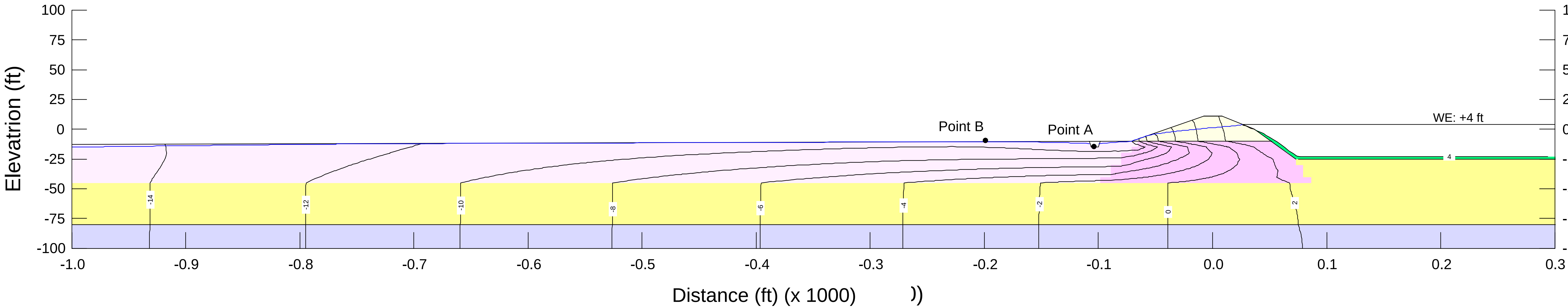


(b) Vertical exit gradient contours for slough water elevation of +4 ft

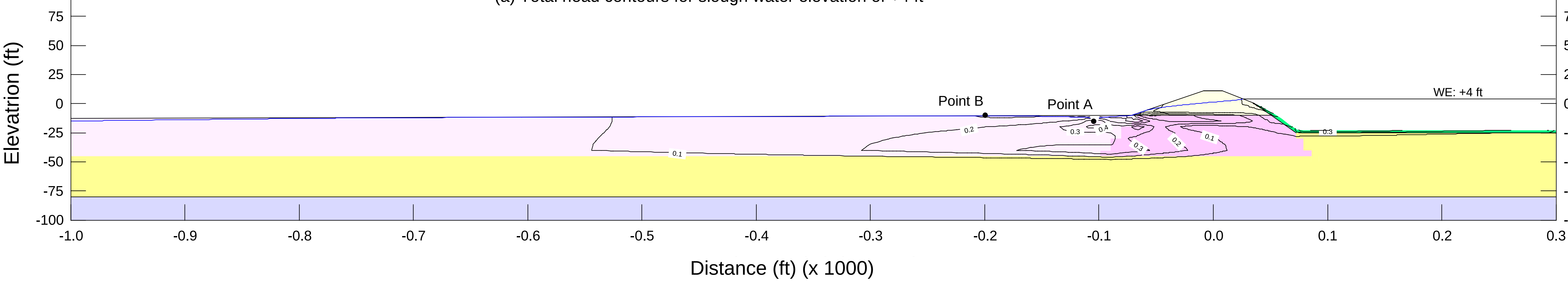
Note:
Analysis CAse:
Mean Permeability values, 25 feet peat/organics,
model with drainage ditch and with slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head & Vertical Gradient Contours Typical Cross Section with Drainage Ditch for 25 ft Peat	Figure 7-57
URS	Project No. 26815621		



(a) Total head contours for slough water elevation of +4 ft

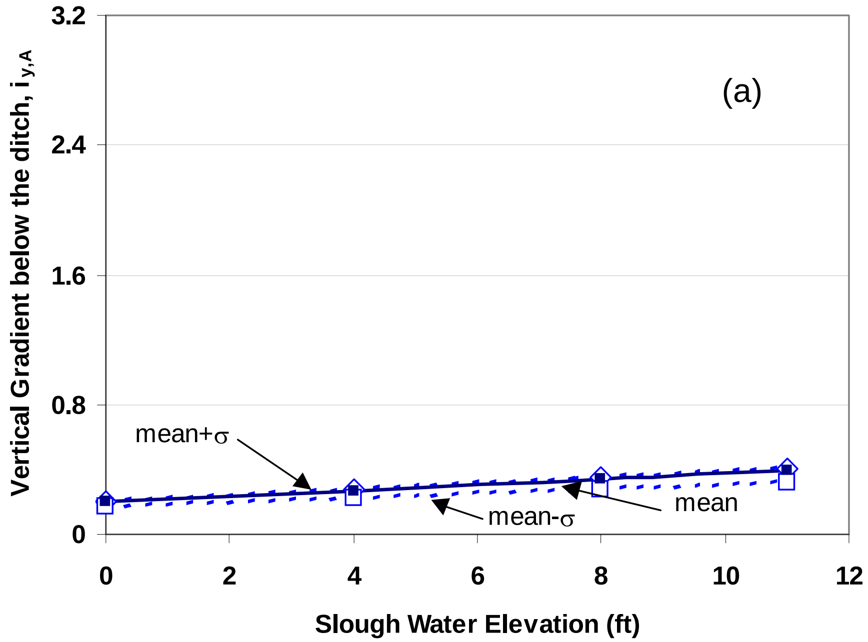


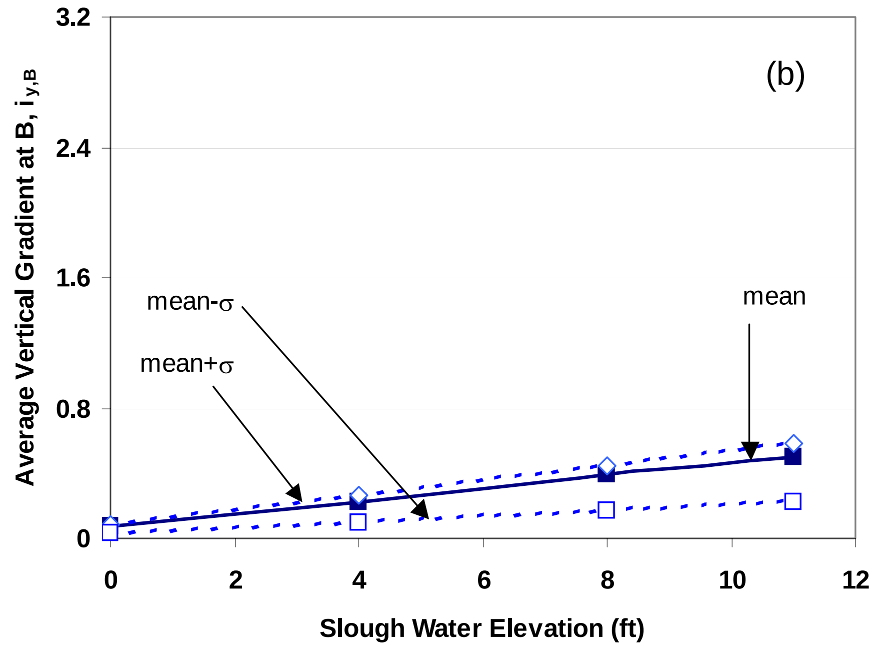
(b) Vertical exit gradient contours for slough water elevation of +4 ft

Note:
Analysis CAse:
Mean Permeability values, 35 feet peat/organics, model with drainage ditch and with slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Total Head & Vertical Gradient Contours Typical Cross Section with Drainage Ditch for 35 ft Peat	Figure 7-58
URS	Project No. 26815621		

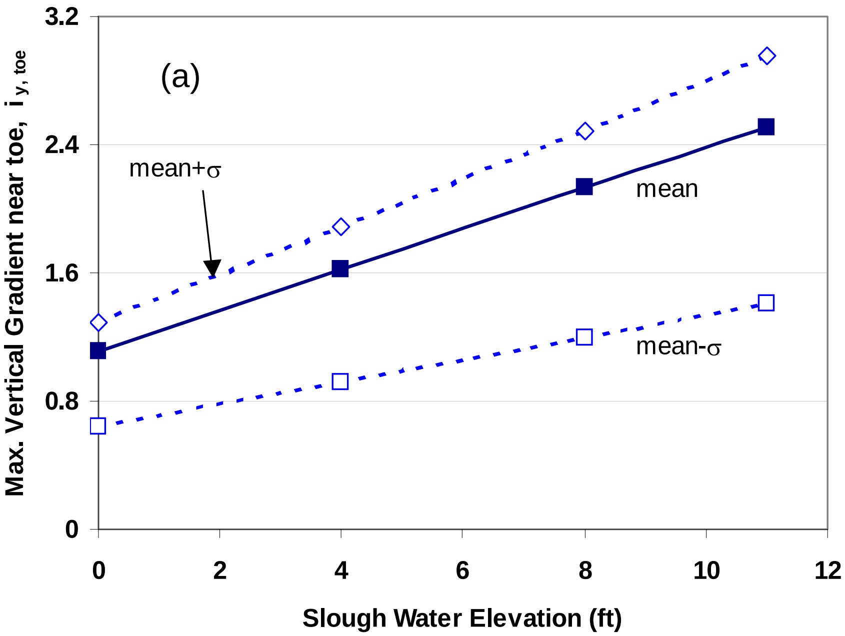


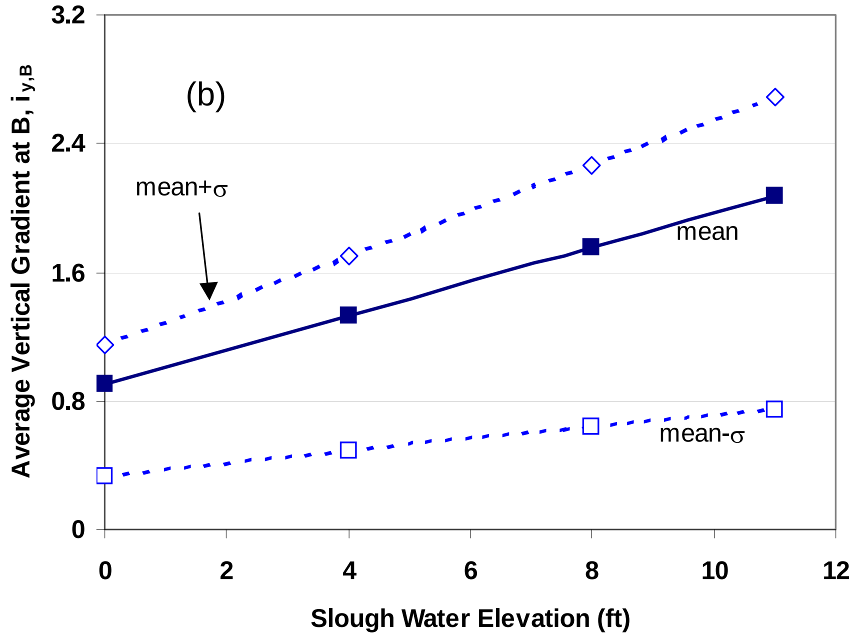


Note:
Analysis model: Typical cross section for Delta, 5 ft peat & organic layer, model with drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 5 ft Peat/Organics - Typical Cross Section with Ditch	Figure 7-59
URS	Project No. 26815621		

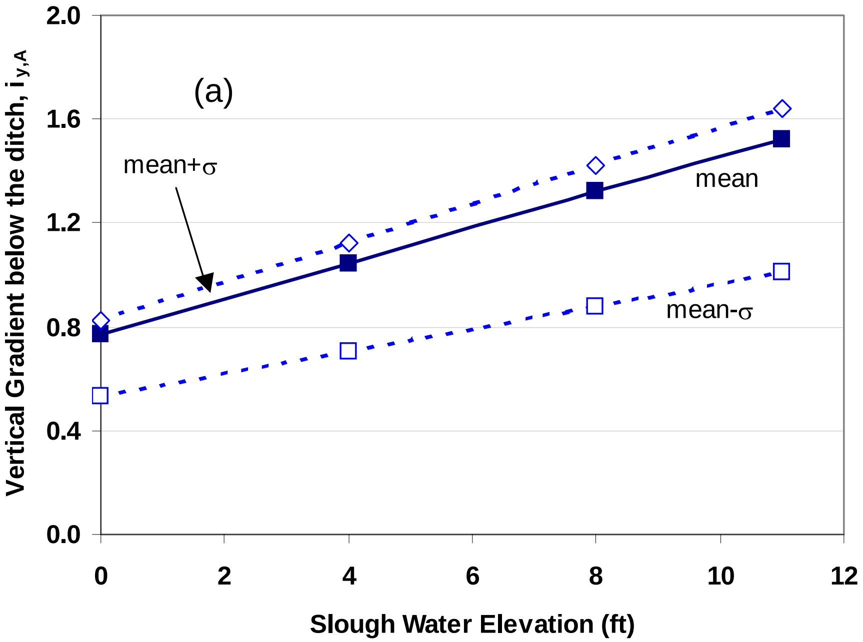


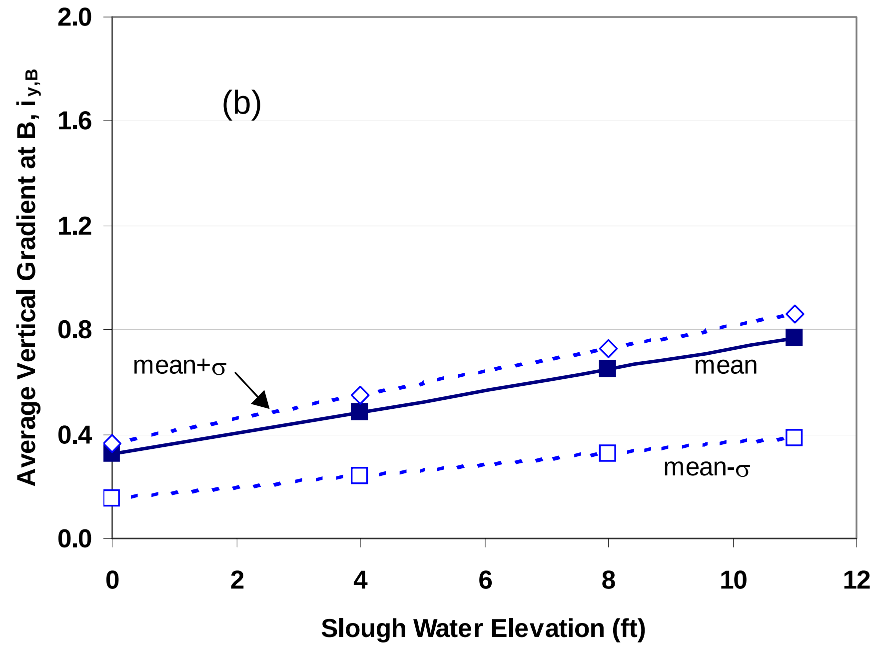


Note:
Analysis model: Typical cross section for Delta, 5 ft peat & organic layer, model without drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility	Vertical Gradients for 5 ft Peat/Organics - Typical Cross Section without Ditch	Figure 7-60
URS — Project No. 26815621		

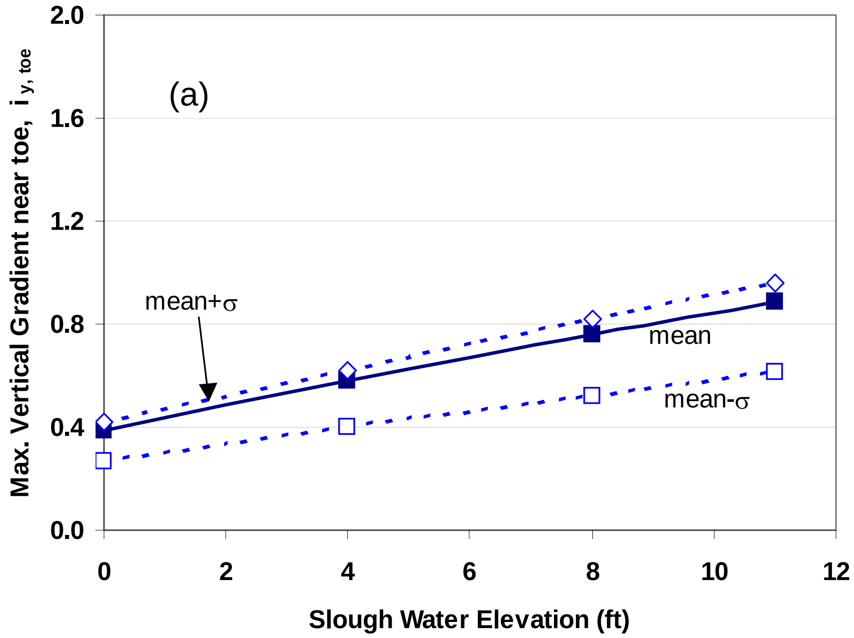


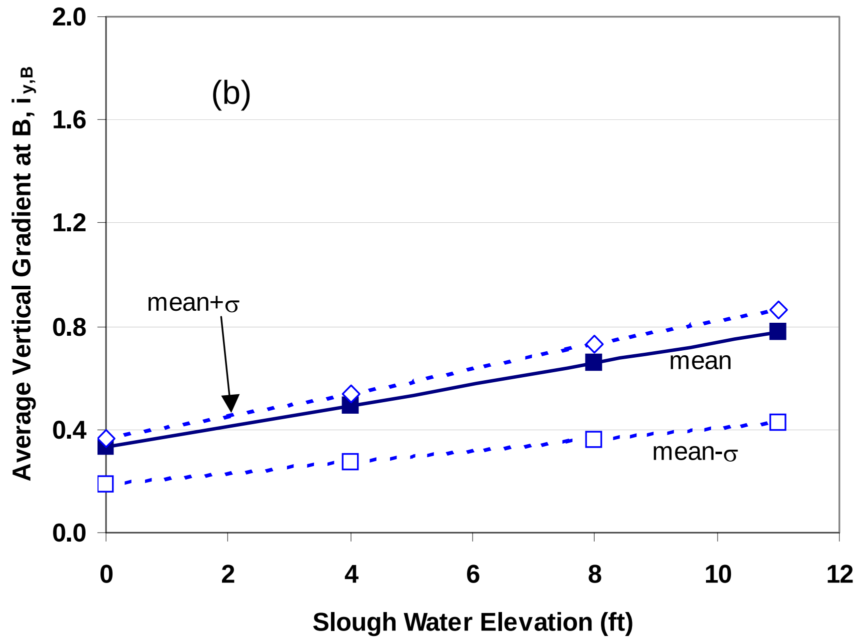


Note:
Analysis model: Typical cross section for Delta, 15 ft peat & organic layer, model with drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 15 ft Peat/Organics - Typical Cross Section with Ditch	Figure 7-61
URS	Project No. 26815621		

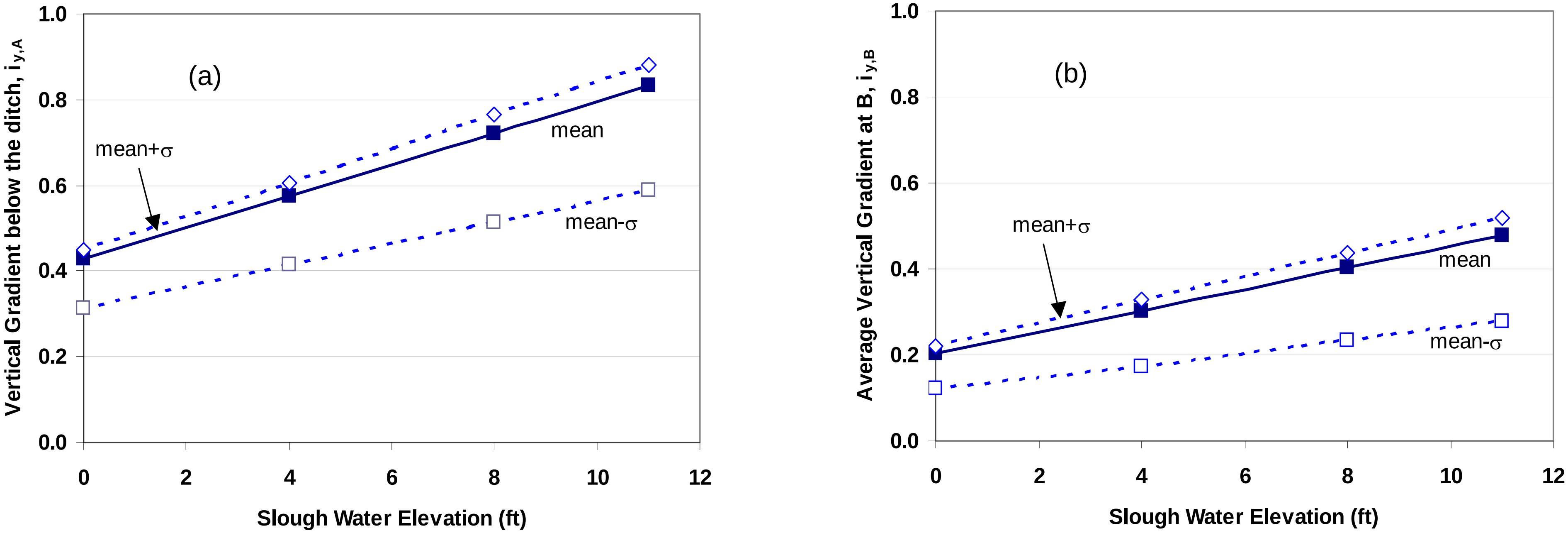




Note:
Analysis model: Typical cross section for Delta, 15 ft peat & organic layer, model without drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

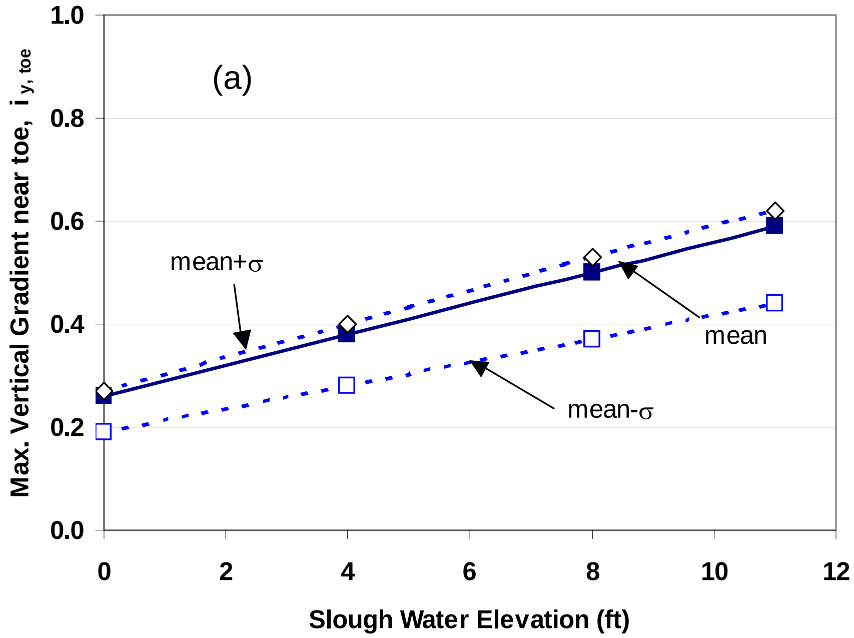
Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 15 ft Peat/Organics - Typical Cross Section without Ditch	Figure 7-62
URS	Project No. 26815621		

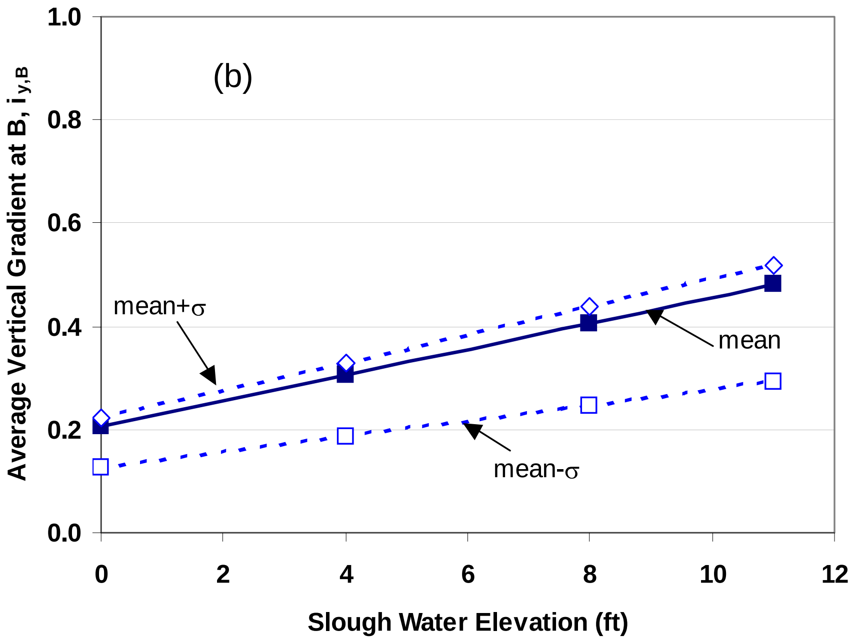


Note:
Analysis model: Typical cross section for Delta, 25 ft peat & organic layer, model with drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 25 ft Peat/Organics - Typical Cross Section with Ditch	Figure 7-63
URS	Project No. 26815621		

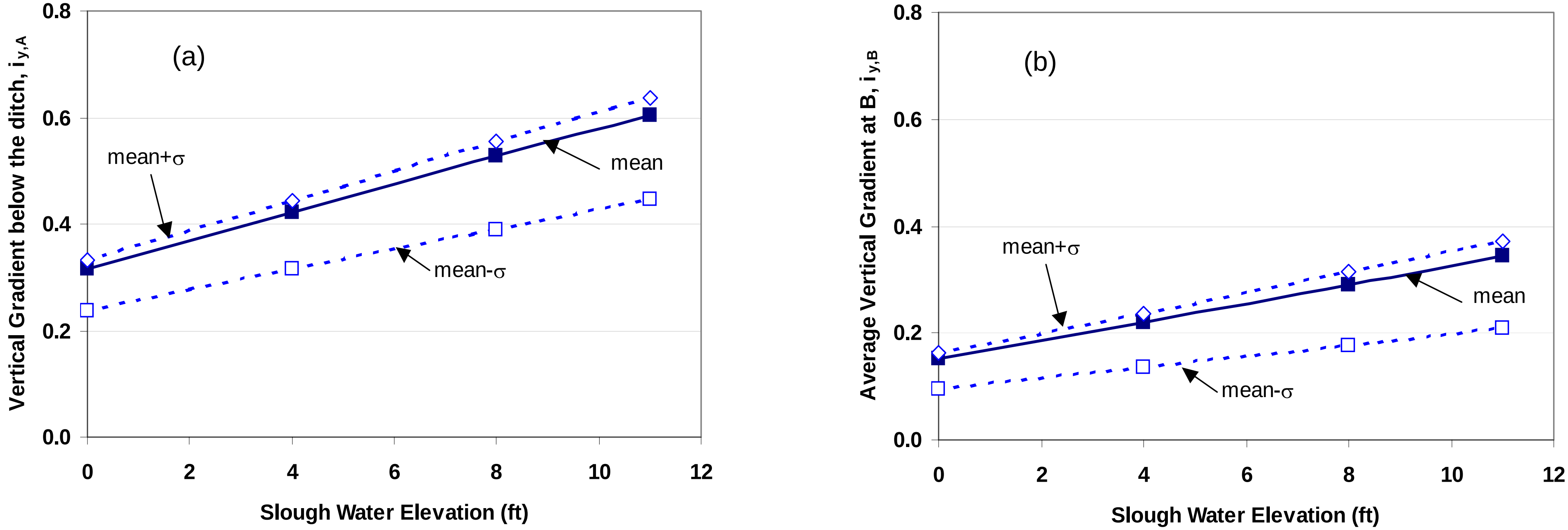




Note:
Analysis model: Typical cross section for Delta, 25 ft peat & organic layer, model without drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

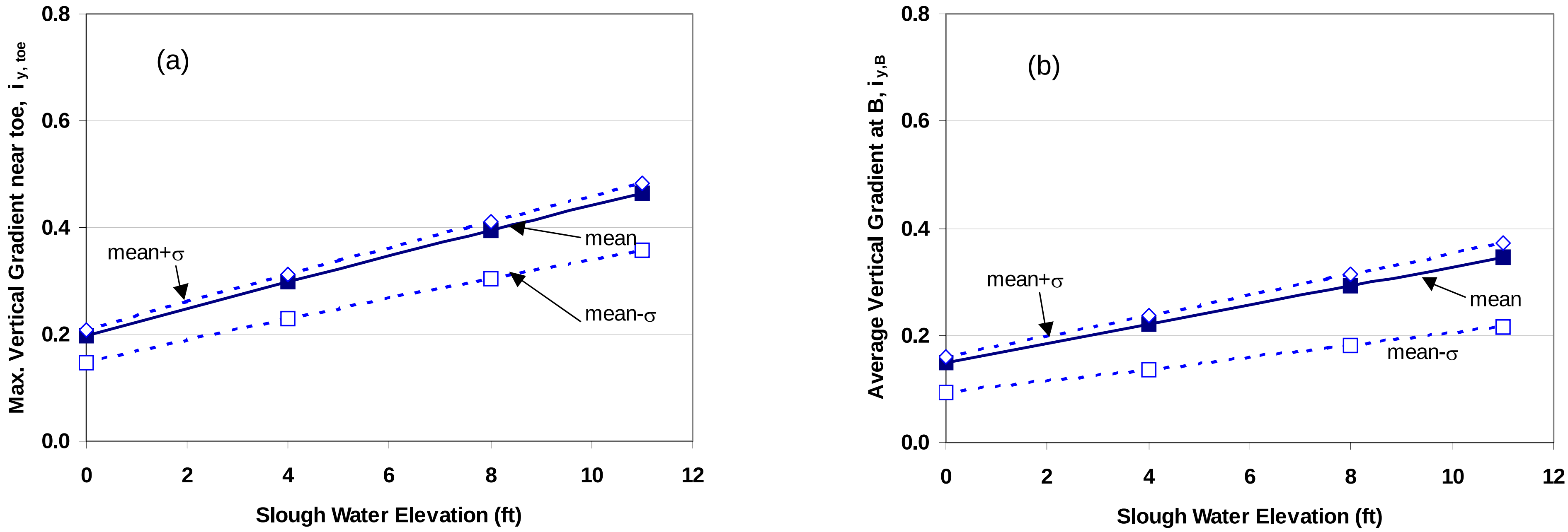
Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 25 ft Peat/Organics - Typical Cross Section without Ditch	Figure 7-64
URS	Project No. 26815621		



Note:
Analysis model: Typical cross section for Delta, 35 ft peat & organic layer, model with drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

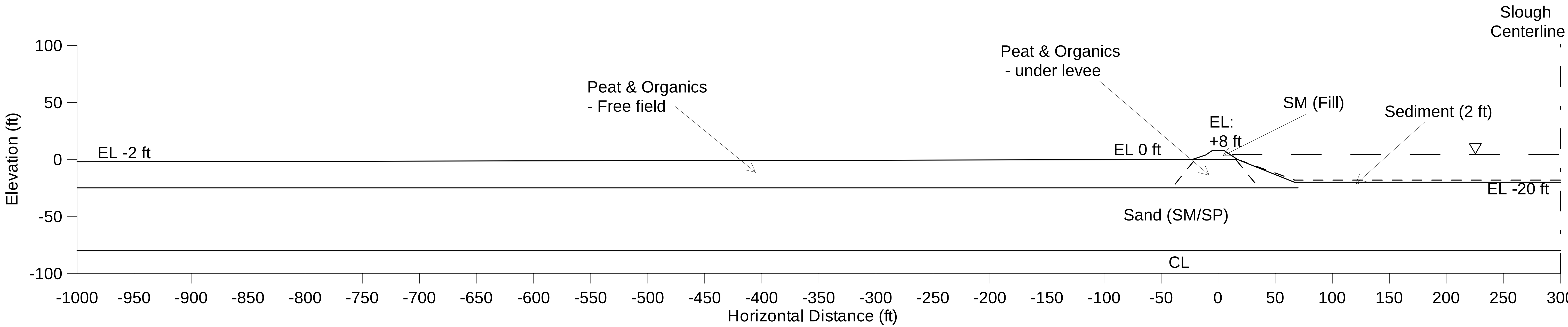
Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 35 ft Peat/Organics - Typical Cross Section with Ditch	Figure 7-65
URS	Project No. 26815621		



Note:
Analysis model: Typical cross section for Delta, 35 ft peat & organic layer, model without drainage ditch and slough sediment

All elevations are referenced to NAVD88
(NAVD88 = NGVD29+2.5 ft)

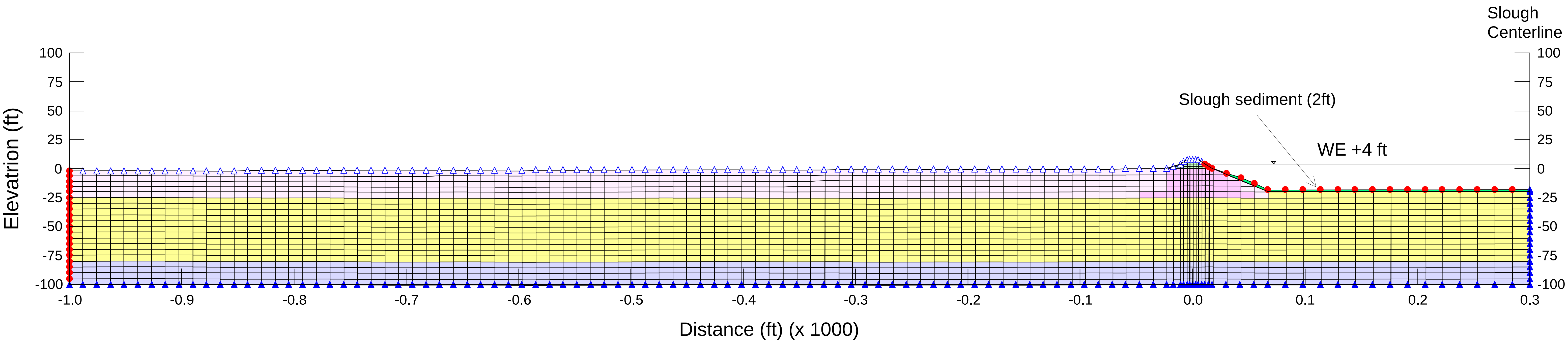
Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 35 ft Peat/Organics - Typical Cross Section without Ditch	Figure 7-66
URS	Project No. 26815621		



Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Levee Geometry
Crest elevation +8 ft
Landside slope - From levee crest to EL+4 ft:1.5H:1V, followed by 3H:1V
Waterside slope - From levee crest to EL0 ft:1.5H:1V, followed by 2.5H:1V

Delta Risk Management Strategy (DRMS) Levee Fragility		Typical Cross Section for Suisun Marsh Levees	Figure 7-67
URS	Project No. 26815621		



Legend

Boundary Conditions

- No flow
- Fixed head
- Review

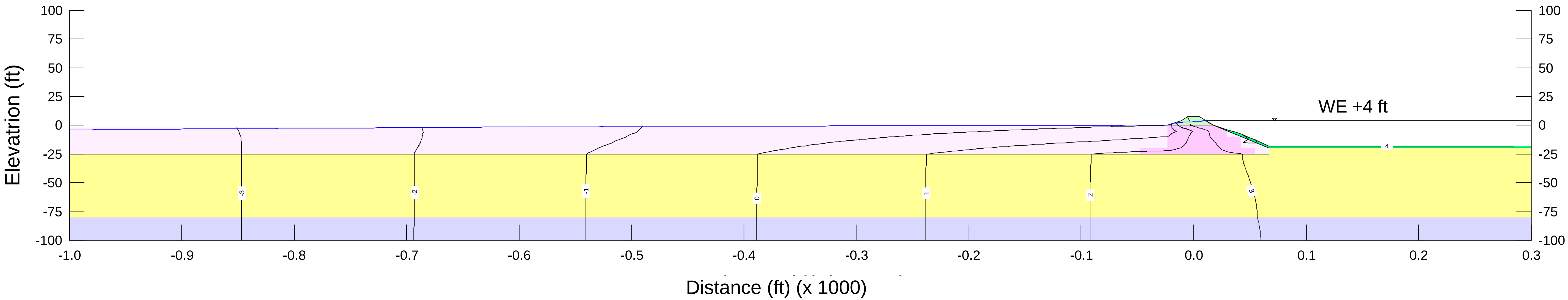
Material Type

- Sandy Levee Fill
- Free Field Peat
- Under Levee Peat
- Sand (SP/SM)
- Clay
- Slough Sediment

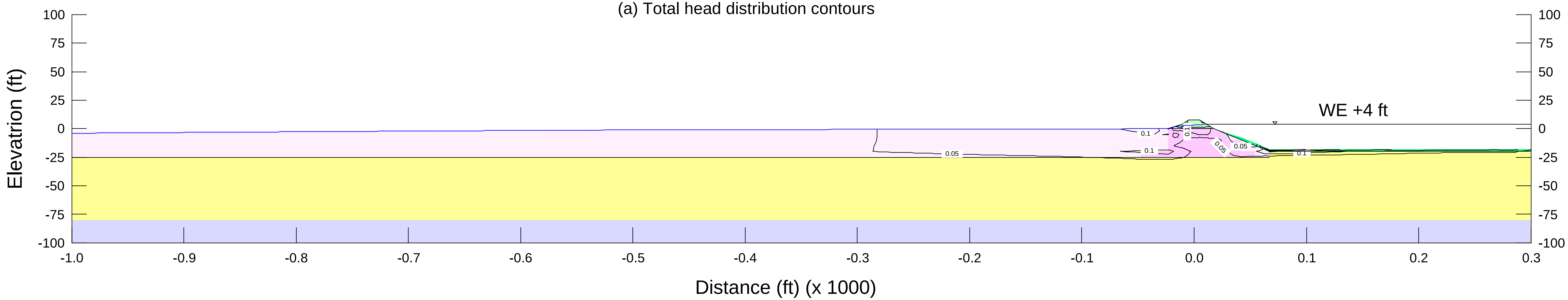
Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Model: Typical cross section for Suisun Marsh
with 25 ft peat & organics
(Case- with slough sediment and without ditch)

Delta Risk Management Strategy (DRMS) Levee Fragility		Finite Element Mesh & Boundary Conditions Typical Cross Section for Suisun Marsh	Figure 7-68
URS	Project No. 26815621		



(a) Total head distribution contours



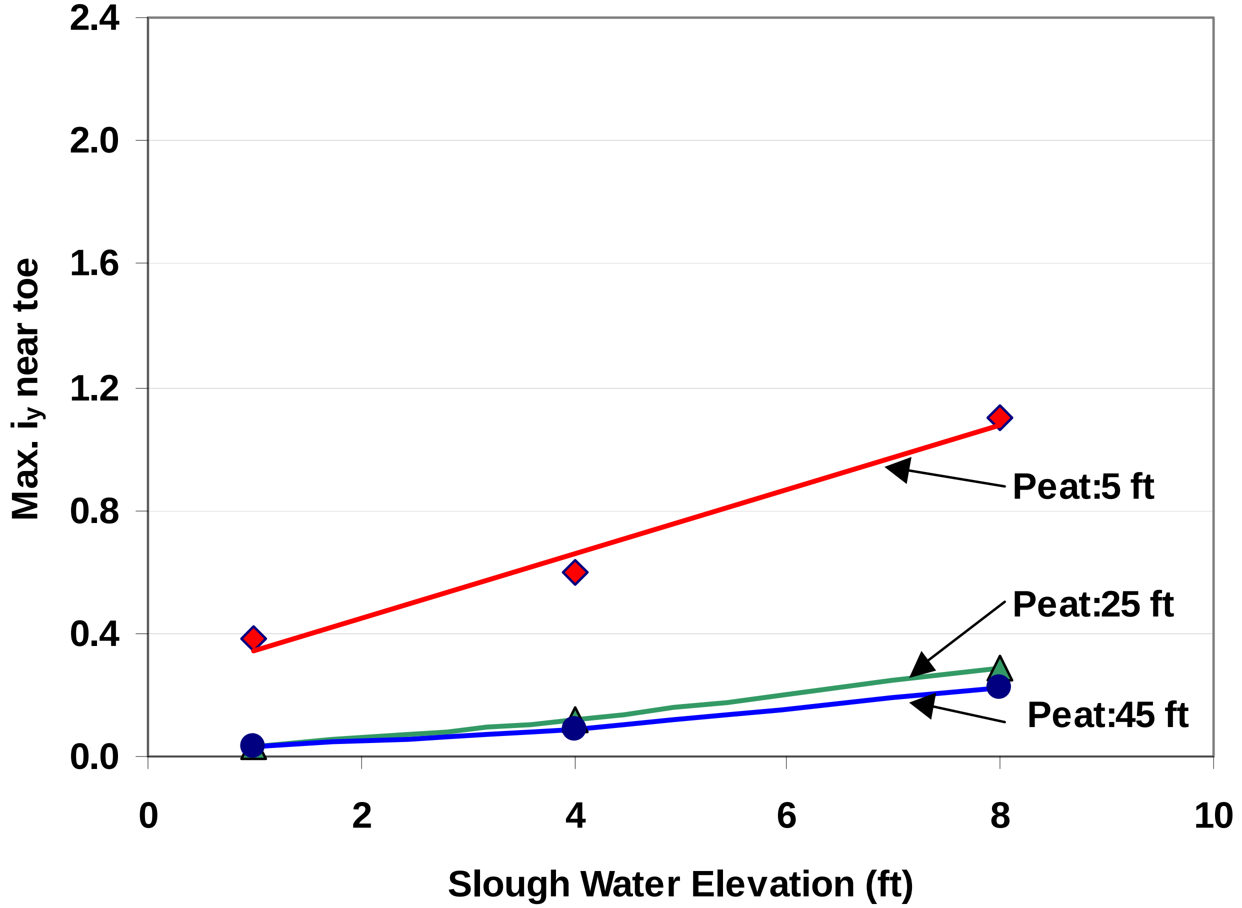
(b) Vertical gradient contours

Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Analysis Case: Mean permeability veaues, Slough Water Elevation +4 ft,
Peat and Organic Thickness 25 ft, Model without Ditch , and
2 ft silt sediment presents at slough bottom

For Suisun Marsh,
Mean High Tide ~ +5.5 ft
Mean Low Tide ~ +0.3 ft

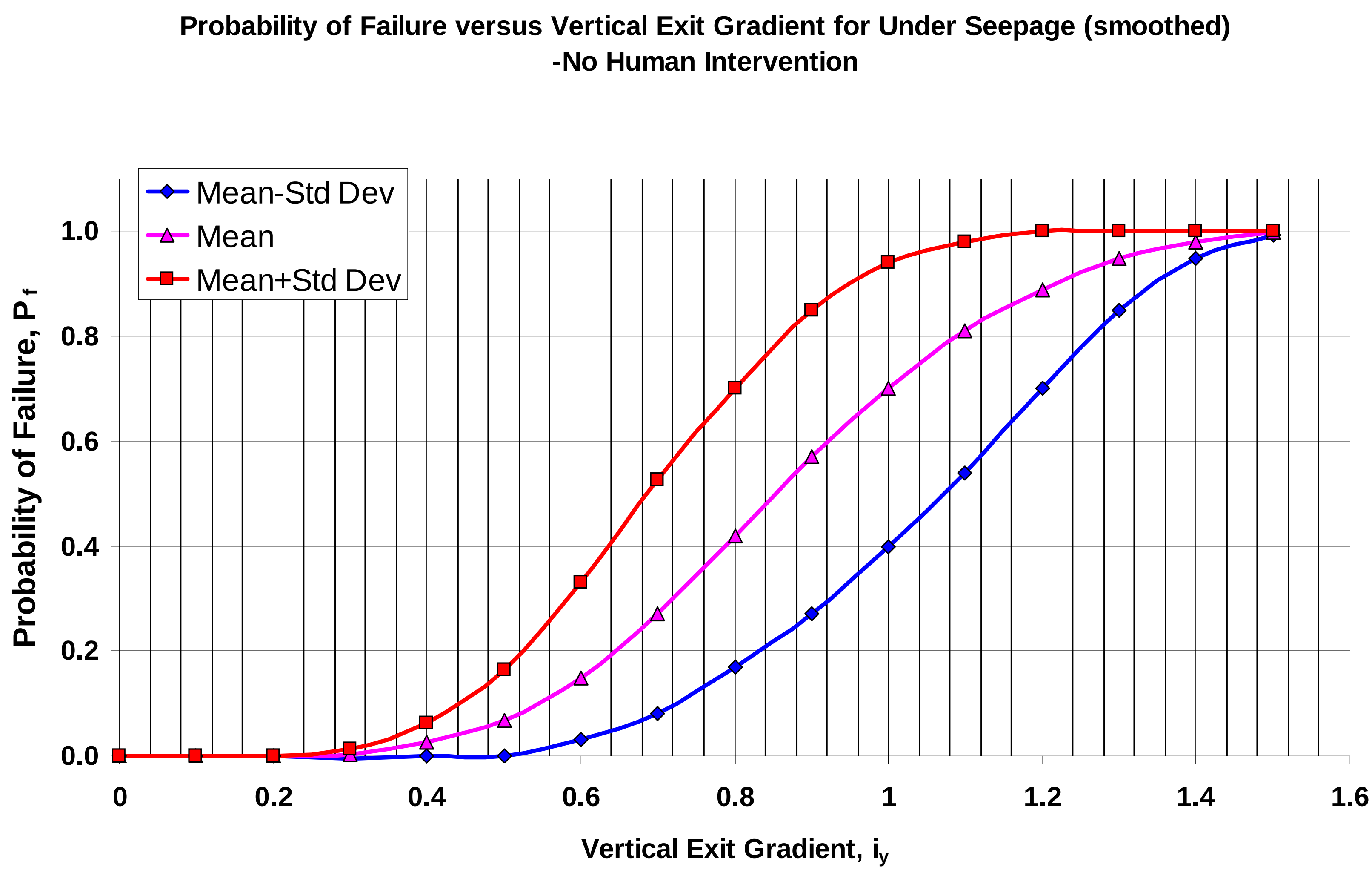
Delta Risk Management Strategy (DRMS) Levee Fragility URS — Project No. 26815621	Total Head & Vertical Gradient Contours for 25 ft Peat & Organics Typical Cross Section for Suisun Marsh	Figure 7-69



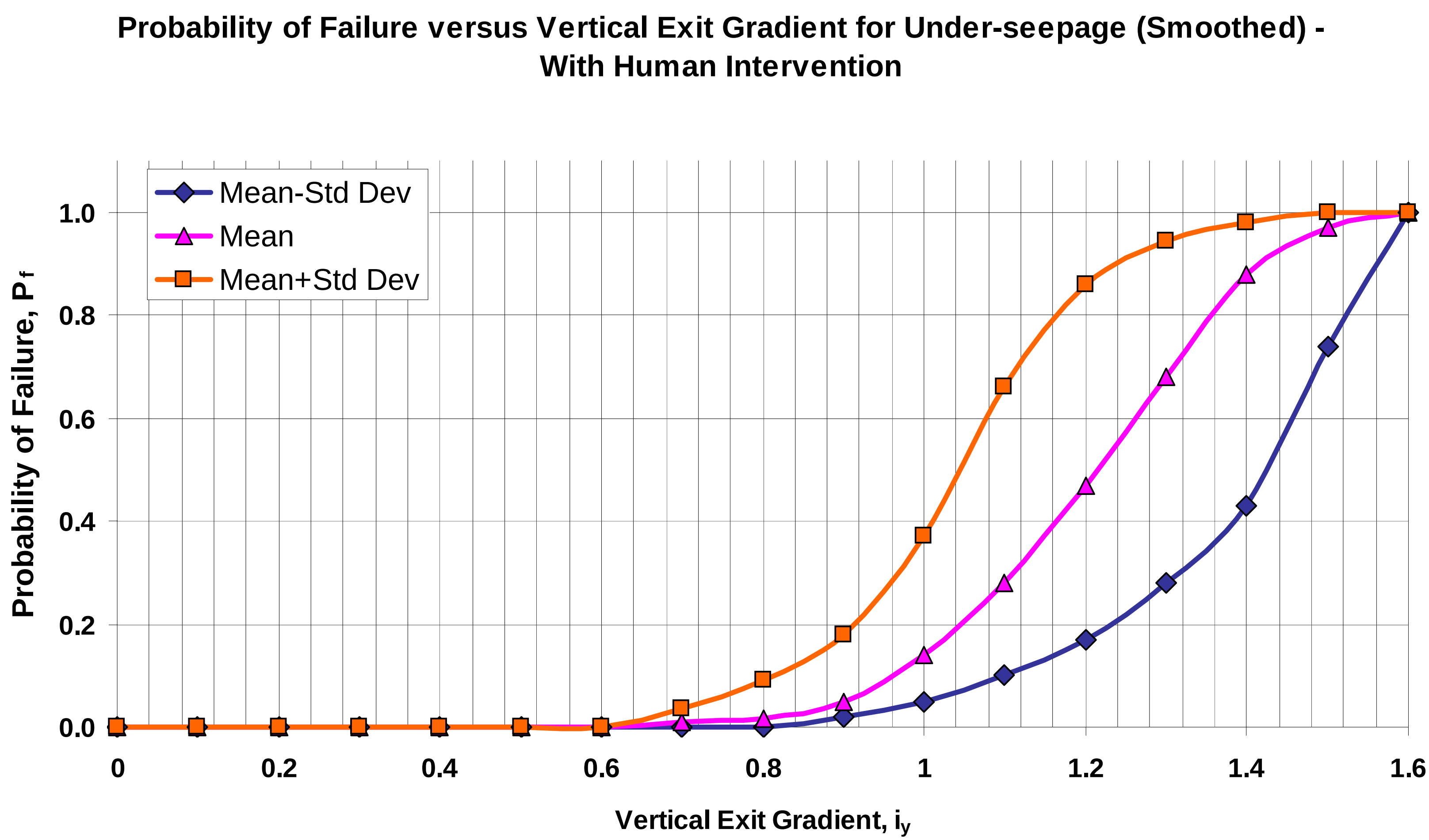
Note:
All elevations are referenced to NAVD88
(NAVD88 = NGVD29 + 2.5 ft)

Analisis Case: Model without ditch and with slough sediment

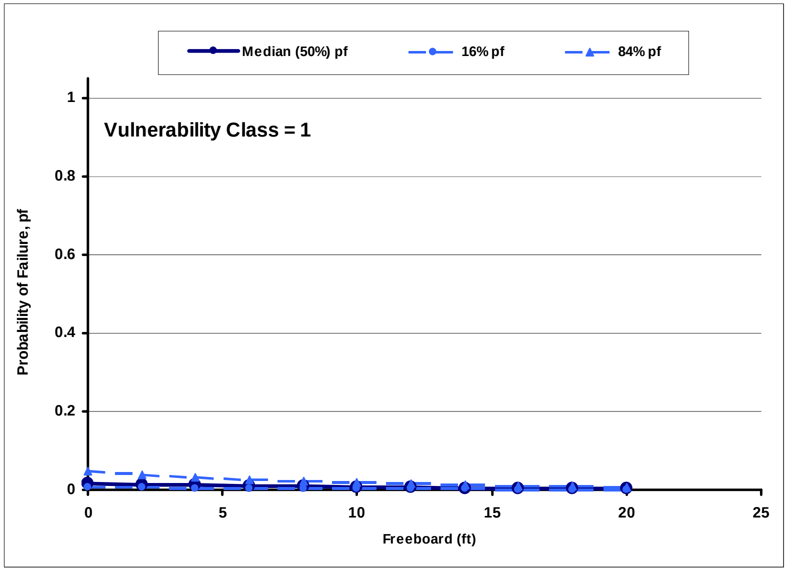
Delta Risk Management Strategy (DRMS) Levee Fragility		Vertical Gradients for 5, 25, and 45 ft Peat/Organics Typical Cross section for Suisun Marsh	Figure 7-70
URS	Project No. 26815621		

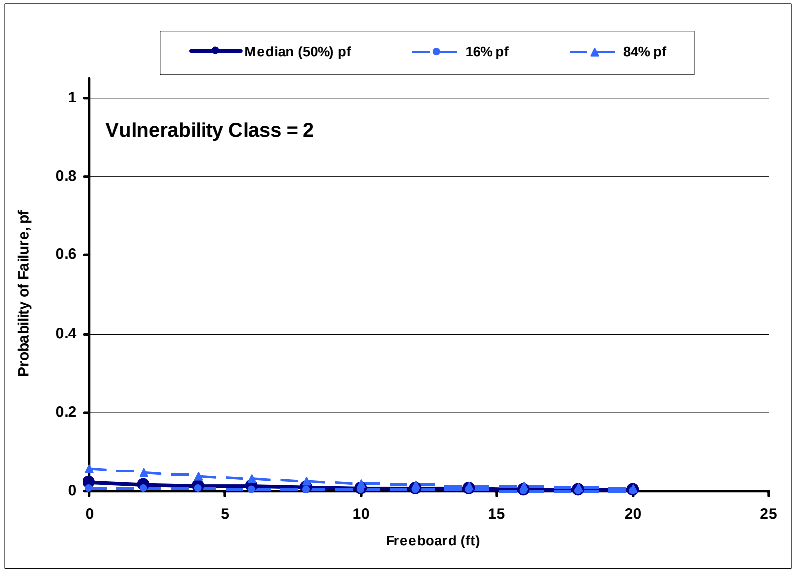


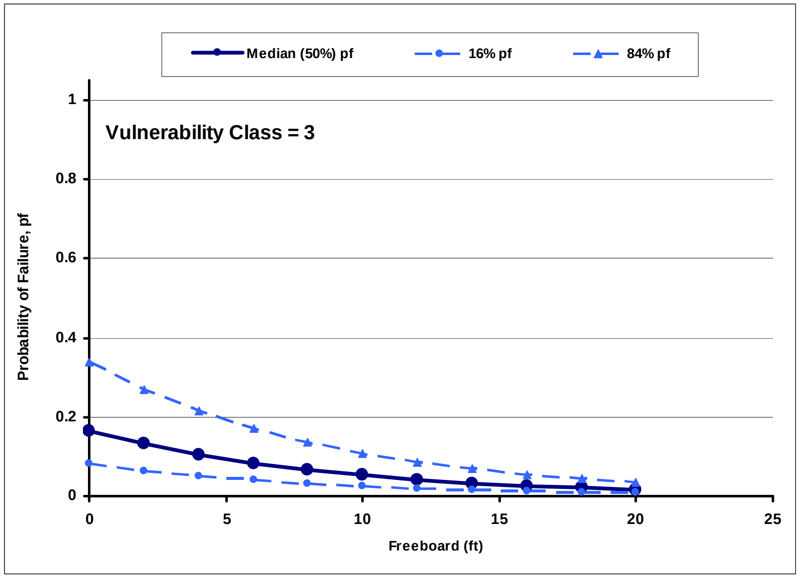
Delta Risk Management Strategy (DRMS) Levee Fragility		Probability of Failure versus Exit Gradient -No Human Intervention	Figure 7-71
URS	Project No. 26815621		

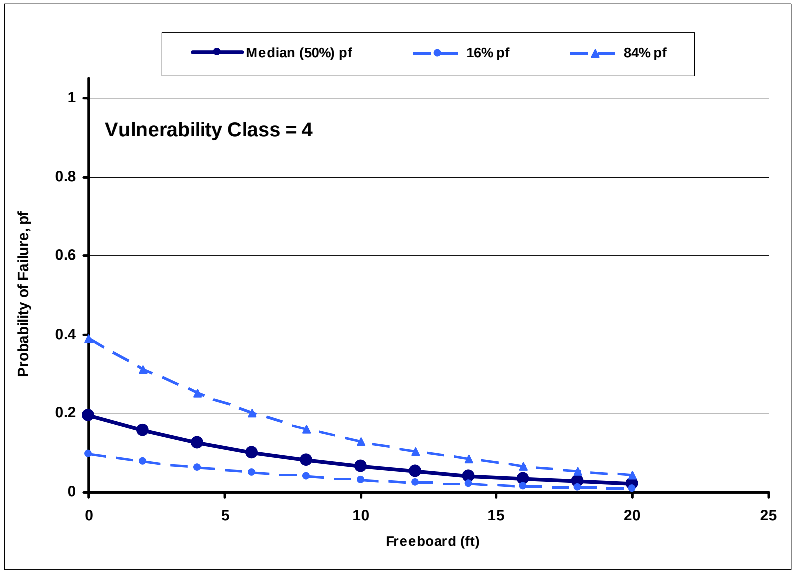


Delta Risk Management Strategy (DRMS) Levee Fragility	Probability of Failure versus Exit Gradient - With Human Intervention	Figure 7-72
URS — Project No. 26815621		

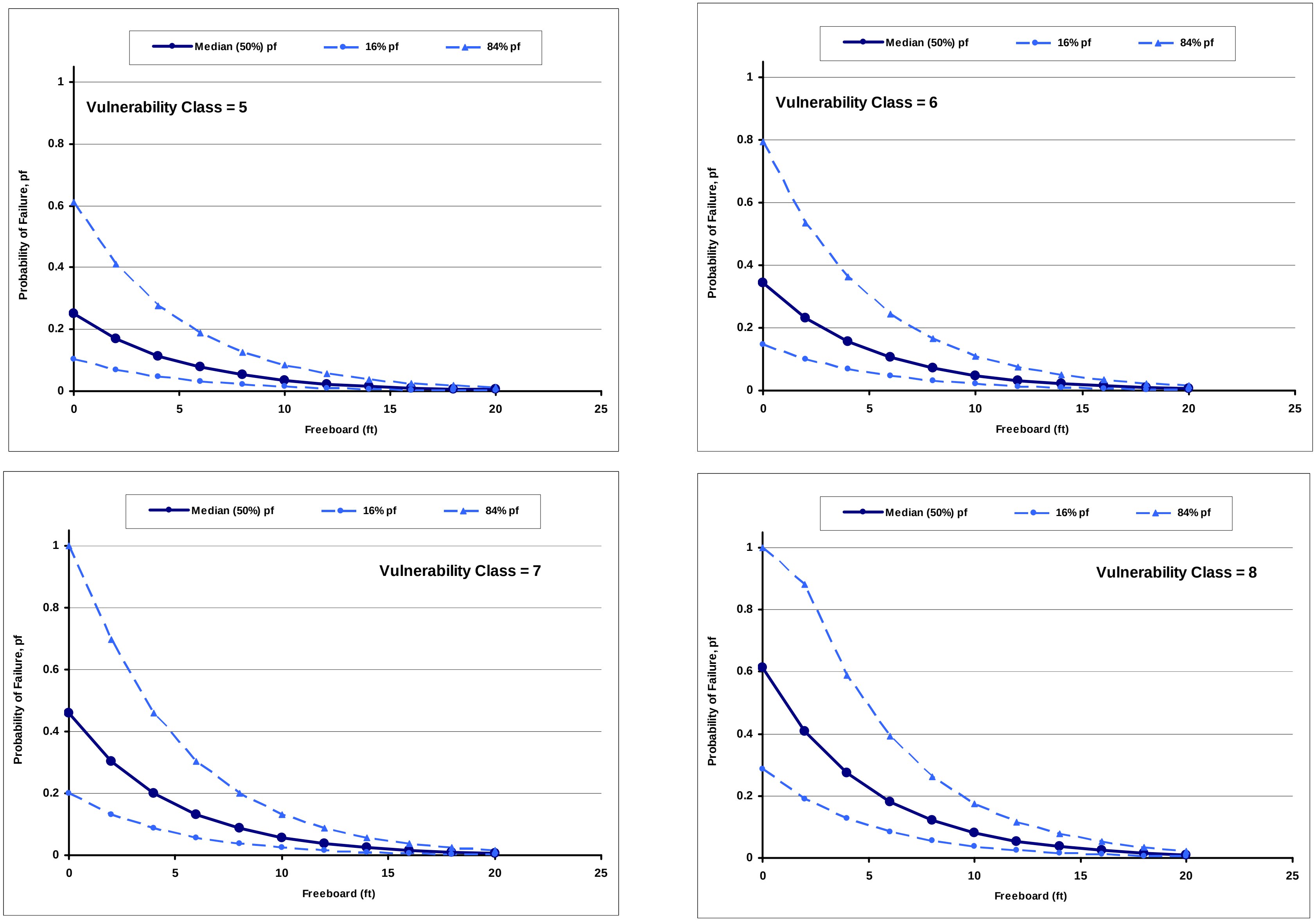




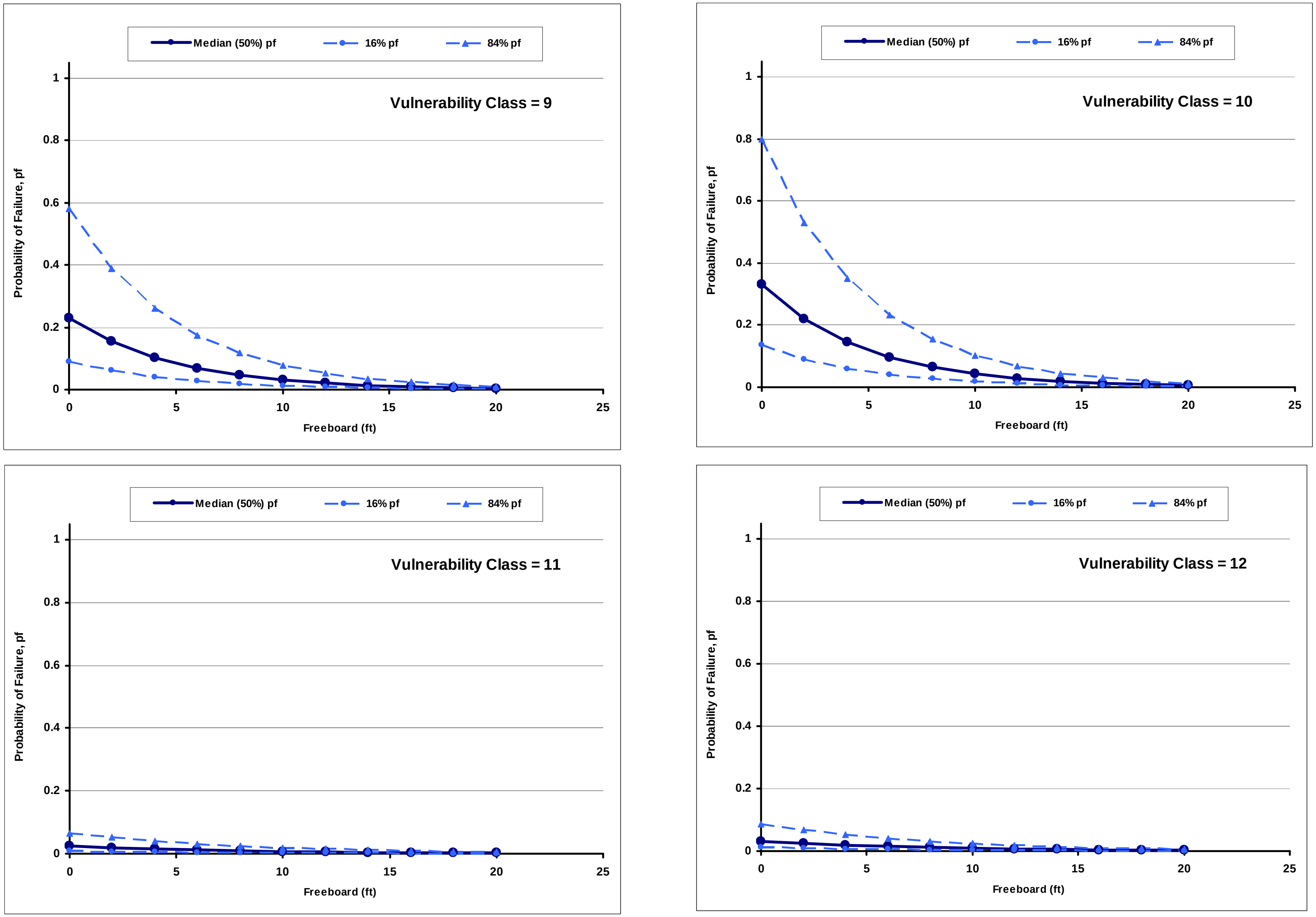




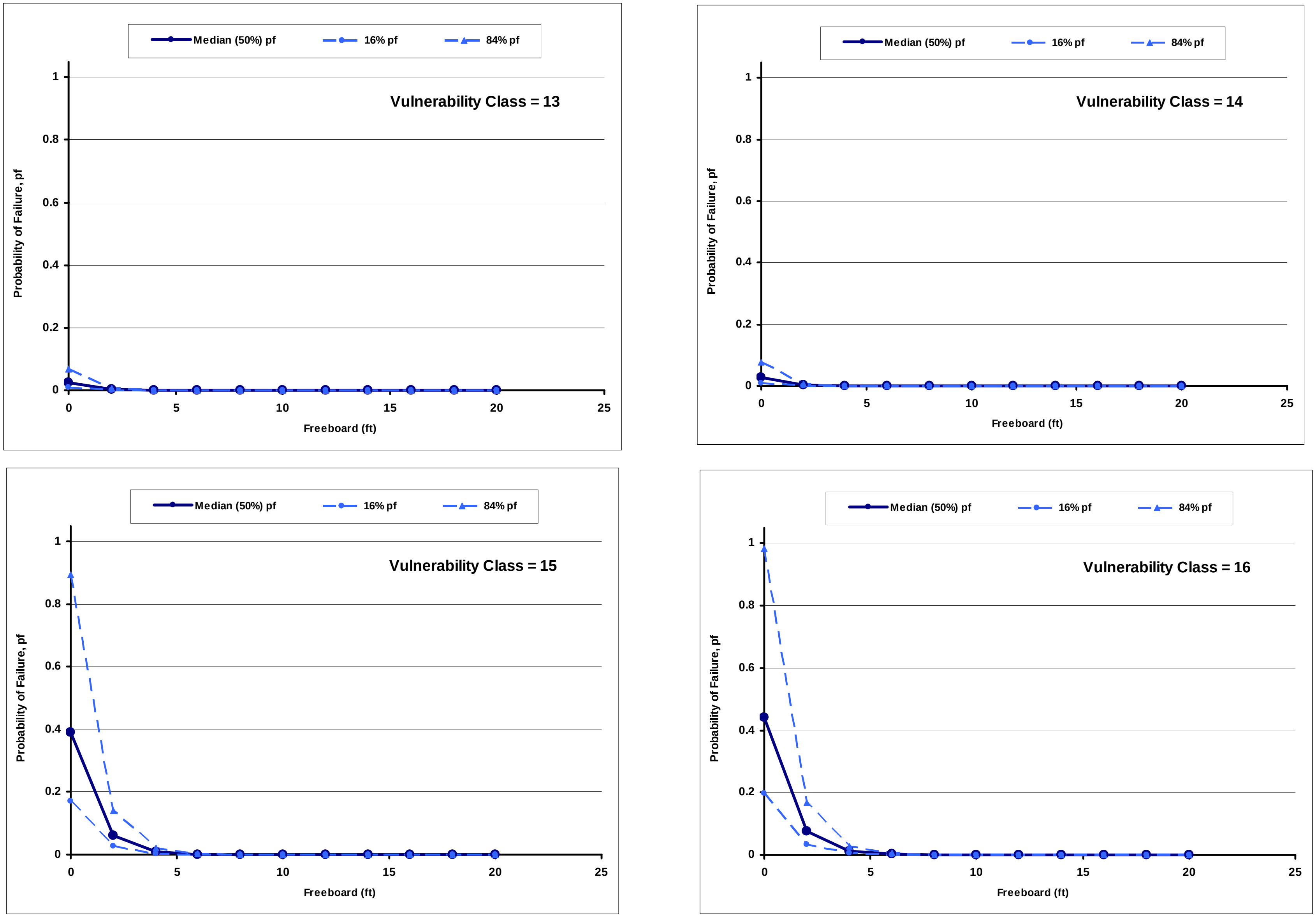
Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for Under-seepage Vulnerability Classes1, 2, 3 and 4	Figure 7-73a
URS	Project No. 26815621		



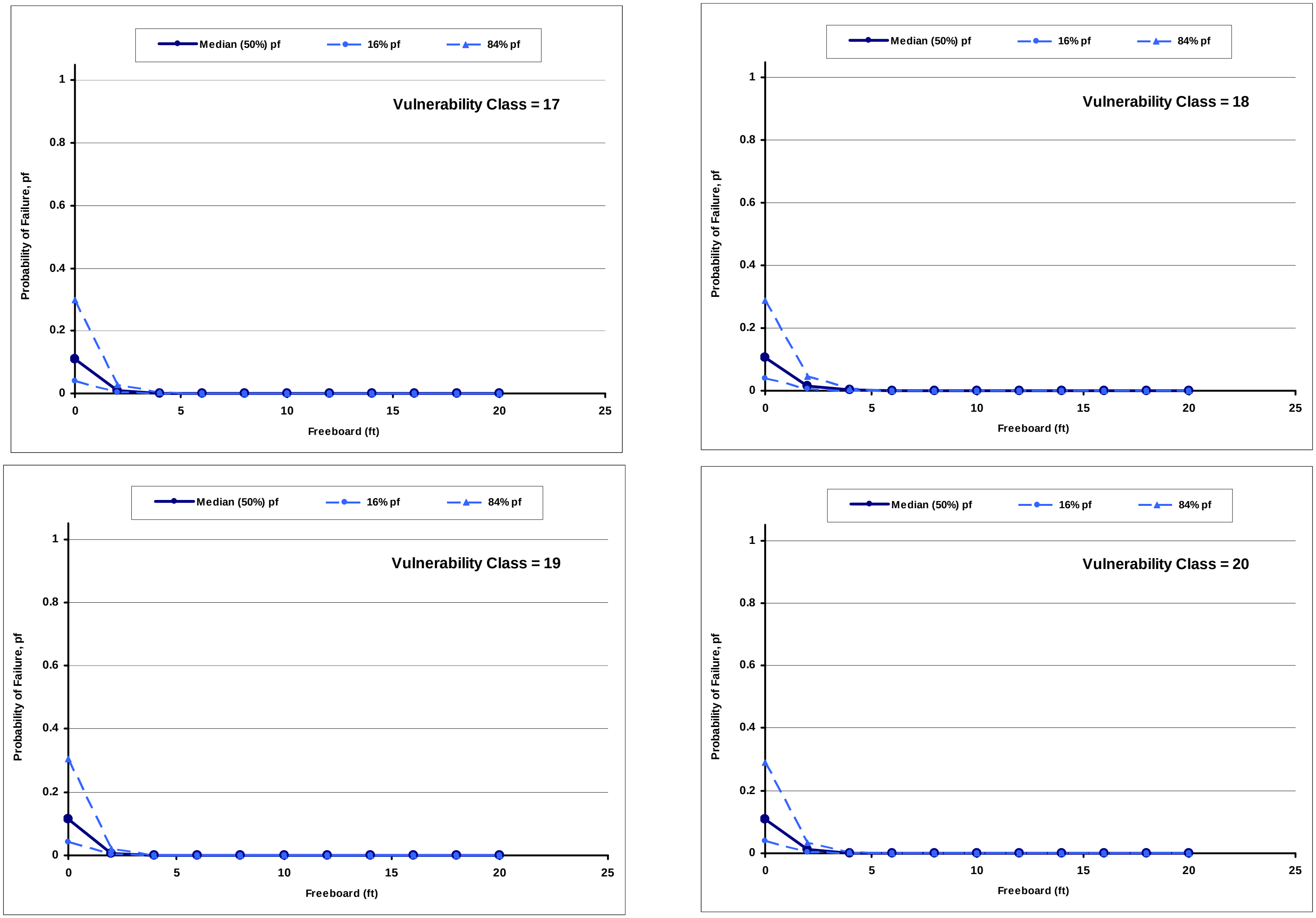
Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for Under-seepage Vulnerability Classes 5, 6, 7 and 8	Figure 7-73b
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for Under-seepage Vulnerability Classes 9,10, 11 and 12	Figure 7-73c
URS	Project No. 26815621		



Delta Risk Management Strategy (DRMS) Levee Fragility	Estimated Failure Probability at 16%, 50%, and 84% confidence levels for Under-seepage Vulnerability Classes 13,14, 15 and 16	Figure 7-73d
URS — Project No. 26815621		



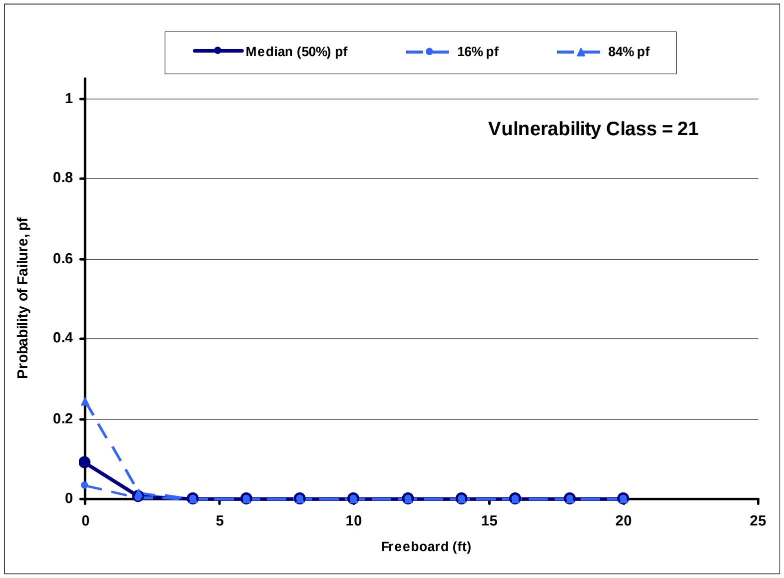
Delta Risk Management Strategy (DRMS)
Levee Fragility

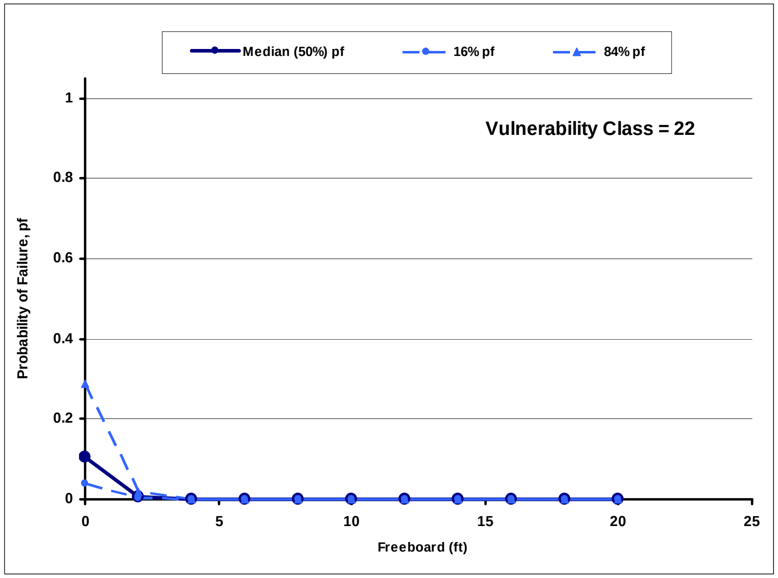
URS

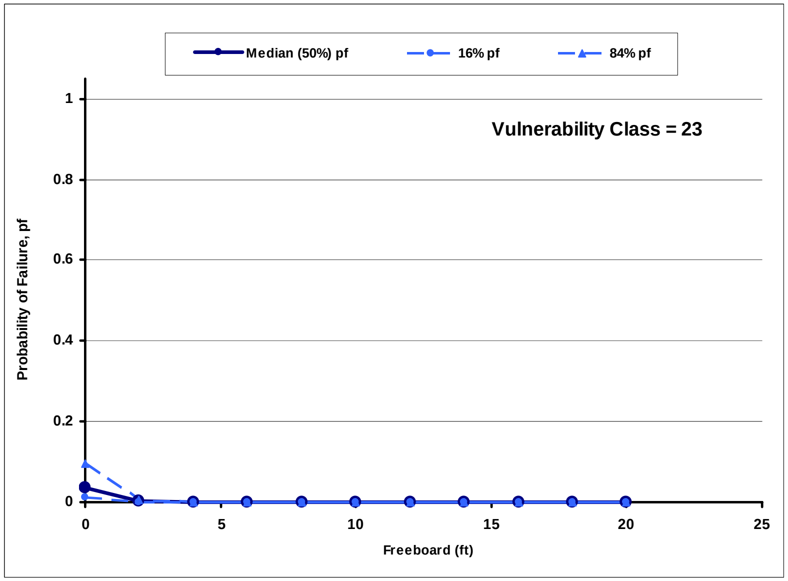
Project No. 26815621

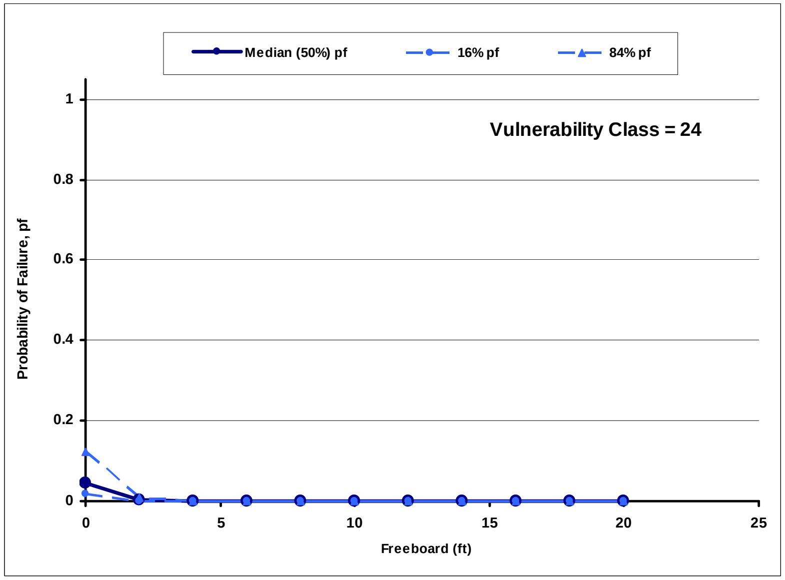
Estimated Failure Probability
at 16%, 50%, and 84% confidence levels
for Under-seepage
Vulnerability Classes 17,18, 19 and 20

Figure
7-73e









Delta Risk Management Strategy (DRMS) Levee Fragility		Estimated Failure Probability at 16%, 50%, and 84% confidence levels for Under-seepage Vulnerability Classes 21,22, 23 and 24	Figure 7-73f
URS	Project No. 26815621		

Landside toe through-seepage erosion, Sacramento Bypass South Levee (Jan. 2008)

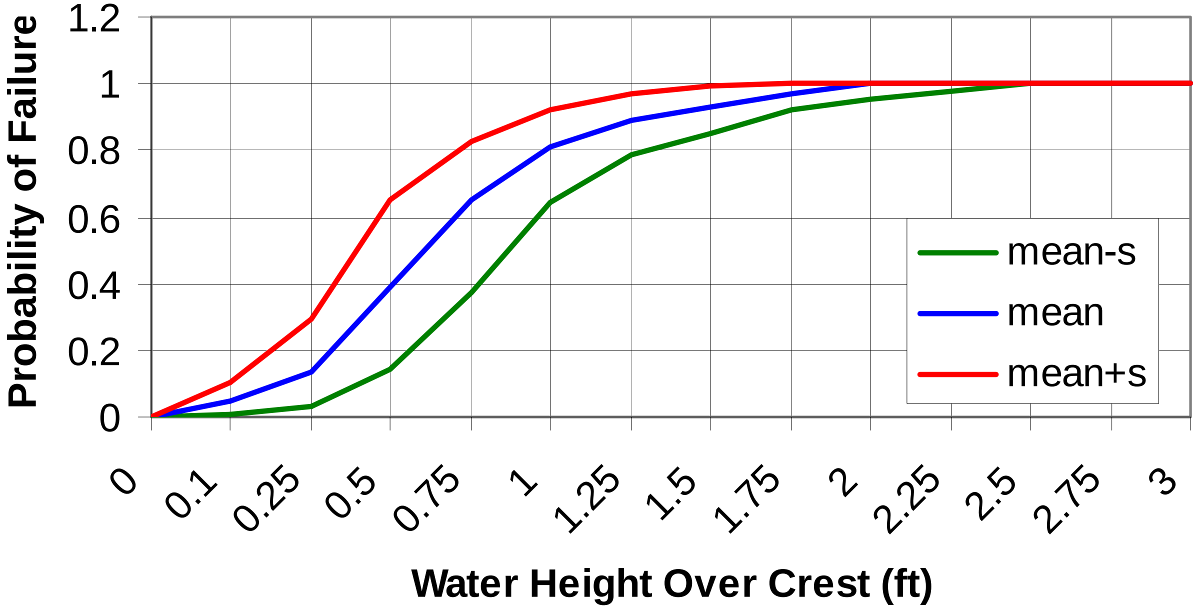
Boil on landside slope, Bouldin Island, Delta (Feb. 1983)

Tension crack at levee crest, Staten Island, Delta (Jul. 2007)

Landside through-seepage erosion, Sac. River at Natomas Highway (Jan. 1986)

Boil on landside levee bench, Staten Island, Delta (Jul. 2007)

Figure 7-74 Through-Seepage Case Histories



Delta Risk Management Strategy (DRMS) Levee Fragility		Probability of Failure versus Water Height over the Crest - Overtopping Failure Mode	Figure 7-75
URS	Project No. 26815621		

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In the event of a levee failure (due to any initiating event) winds blowing over the length of the flooded island would generate waves that have the potential to erode the inner slope (inboard side) of the levee, which are not armored. Inboard levee erosion could cause secondary levee breaches to form.

This section presents an analysis of wind and the corresponding wind waves to use in erosion and risk calculations. A complete description of the wind and wave analysis, including the datasets that were used, and the methodology and results of the analysis is presented in detail in the Wind-Wave Hazard Technical Memorandum (TM) (URS/JBA 2008g).

8.1 INTRODUCTION

As described in Section 4, wind waves pose a potential hazard to Delta levees. In the risk analysis wind-waves are recognized as a potential hazard, but are not evaluated as an independent initiating event that leads to levee failure (see Sections 4.4.4 to 4.4.6). Wind waves and their effects are considered in conjunction with other initiating events that result in levee failure and island flooding. Waves generated on flooded islands lead to erosion of the interior, unprotected slopes of levees, and may cause secondary breaches. Erosion of levee interiors adds to the cost and timing of levee repairs and island recovery, which could be significant in the case of a multiple island levee failure event.

This section describes the analysis of wind and wind-waves in the Delta. The results of this analysis were used as input to the levee erosion model described in Section 10 and used in the levee emergency response and repair analysis (see the discussion in Sections 4 and 10).

To evaluate the wind and wind-wave hazards in the Delta, wind data were collected from multiple locations in and around the Delta region. The wind data were analyzed to estimate the probability of extreme winds and their patterns, seasonal wind occurrences, and a range of wave conditions that may be caused by these winds. A complete description of the wind and wind-wave analysis is given in the Wind-Wave Hazard TM (URS/JBA 2008g).

Although wind setup, wave transmission past levees due to wave overtopping, and the joint probability of high winds/wind waves and high water levels (residuals or storm surges) can be important in the analysis of wind-wave generation, they were considered secondary in regard to their effect on the risk analysis, so were not included. The primary use of the wave data to the risk analysis is in the estimate of the cost of emergency response. The processes just named are not primary drivers in determining those costs.

8.2 METHOD

Winds and wind-waves were analyzed separately. The wind analysis addresses both extreme winds that occur infrequently and typical winds that on average occur throughout each year and season. Extreme winds were analyzed using a probabilistic model of extreme wind events that models the temporal and spatial patterns of winds across the Delta and Suisun Marsh region. For typical winds, the percent occurrence of wind speeds was analyzed in multiple directions (wind roses) for two seasons (fall-winter and spring-summer) and multiple locations (identified later).

The approach to the wind-wave portion of the analysis is deterministic rather than probabilistic. Wind-wave height, period, power, and runup were estimated for a range of wind speeds and open-water fetch lengths. Deep water wave conditions were assumed and wave transformations were not addressed in this analysis. A discussion on the validity of the deep-water assumption is provided in the Wind-Wave Hazard TM (URS/JBA 2008g). When the water is too shallow for deep water conditions to apply, wave energy is partially dissipated by bottom friction; therefore, for a given wind speed, wave heights and periods would be less than in deep water. Thus, assuming deep water wave heights and periods for shallow water conditions provide a conservative estimate of wind-wave conditions (USACE 2006).

8.2.1 Extreme Wind Analysis Method

Wind data for the Delta and surrounding region are available from National Oceanic and Atmospheric Administration/National Weather Service (NOAA/NWS), the California Department of Water Resources (DWR), and the California Irrigation Management Information System (CIMIS). Wind stations are shown on Figure 8-1 and available wind data are summarized in Table 8-1. Only a few wind stations are actually located in the Delta and Suisun Marsh and these stations are located on the periphery (see Figure 8-1).

Agencies that collect wind data use different data collection and quality control procedures. Gaps in wind data were assessed as part of this analysis and are described in the Wind-Wave Hazard TM (URS/JBA 2008g). The height of the wind gage at each station and the sampling interval over which winds are measured vary by station and agency. The wind speed data were corrected to a 10-meter height and for a 1-minute averaging period using the procedure described in the Coastal Engineering Manual (CEM) (USACE 2003) to give a consistent set of regional wind data.

As described in Section 4, the assessment of the potential for levee failures due to hazards that may affect a large geographic region during a single event (i.e., large earthquake), is an important component of the risk analysis for a spatially distributed system such as the Delta[1]. In this context,, the probabilistic wind analysis considers the occurrence of regional extreme wind events that can occur over the spatial dimensions of the Delta, rather than an evaluation of the probability of extreme winds at a particular location independent of other locations, as typically considered in wind hazard studies. Therefore, wind data and synoptic charts were analyzed in terms of regional wind patterns (meteorologies) that cause high winds. These data were obtained from the National Centers for Environmental Prediction (NCEP 2006), North American Regional Reanalysis data, and NOAA Central Library U.S. Daily Weather Maps Project (2006a). The analysis identified three meteorologies that cause high winds:

- **Pacific Low:** an extra-tropical low pressure storm system moving from the Pacific through or to the north of the San Francisco Bay-Delta region, generally causing high winds from the southeast before frontal passage (and also from the southwest to west after frontal passage and sometimes prior to southeast frontal winds) in the Delta.

[1] At the start of the DRMS study, it was anticipated that a complete spatial and temporal characterization of the wind and wind wave hazard in the Delta would be required in the risk analysis. Later, it was determined this would not be the case. As a result, the full scope of the spatial-temporal wind model was not used in the analysis.

- **Polar Front:** a high pressure cold front extending from the polar region and Canada coupled with a low-pressure system over the southern Great Basin, generally causing high winds from the north in the Delta.
- **Sea Breeze:** thermal pressure gradient between a cold high pressure area over the Pacific and a warm low pressure area inland. Sea breezes generally cause high winds from the west through the straits and over the coastal range and diverge to the northeast and southeast in the Delta.

To model the probability of regional high-wind events, events for each meteorology in the measured regional wind data record were identified. These events were ranked by the highest peak wind speed measured at a wind station. The data generally showed that, during these events, wind speeds were relatively high throughout the Delta and Suisun region. For a given event, regional wind speeds were typically highest at Travis, the site of the former Air Force base. Travis was selected as the reference station to represent the regional probability of extreme wind events. For each meteorology, an extreme value analysis was performed on peak annual wind speeds measured at Travis (i.e., using high wind events only). The analysis resulted in estimates of extreme "meteorological" wind events and their probabilities for Pacific Lows, Polar Fronts, and Sea Breezes.

To evaluate the spatial distribution of wind patterns (speed and direction) throughout the study area, coincident wind data collected at other locations were compared to those collected at Travis. Then, wind data were scaled relative to the Travis data.

Winds were estimated at un-gauged locations throughout the study area by interpolation. For each meteorology, a spatial scaling pattern for wind speed and direction was developed. Using triangulation, wind speeds were interpolated throughout the region for the highest peak wind events measured in each year.

Wind direction for several measured high wind events were interpolated using the Winds on Critical Streamline Surfaces (WOCSS) model (Ludwig et al. 1991). The WOCSS model was also tested for wind speed interpolation, but linear interpolation was selected as a more appropriate scheme. The wind speed and direction fields were interpolated for multiple events to estimate typical (mean) patterns of: (1) (normalized) wind speed and (2) direction.

The normalized wind speed patterns and wind direction patterns developed for the meteorologies were used as the spatial scaling patterns. The variability in these patterns was accounted for in the probabilistic model.

Empirical probability distributions were developed for the direction, duration, and month of occurrence of measured high wind events. These distributions were used to characterize these parameters for extreme wind events.

8.2.2 Wind-Wave Analysis Methods

Simple parametric models for wind-wave generation and wave runup (USACE 1984, 2003; TAW 2002) were used to develop "look-up tables" for wind-wave height, period, power, and runup. Each look-up table is arranged by wind speed and fetch length. The range in wind speed covers seasonal and extreme winds, and the range in fetch lengths covers possible fetches in Delta sloughs and islands and Suisun Marsh. The specifics of wind-wave conditions depend on island shape and fetch orientation, water depth, bed friction, and vegetation. For purposes of this analysis, site-specific assessments to delineate fetches, estimate water depths, or characterize bed and vegetation types were not performed. The look-up tables developed as part of this analysis are based on deep water conditions to represent Delta sloughs and flooded islands. Because shallow water (relative to the wave length) limits wind-wave growth (USACE 1984, 2003), the use of deep-water waves in the model is conservative.

8.3 EXTREME WIND PROBABILITY MODEL

To model the regional occurrence of extreme wind events, a probabilistic extreme wind probability model (model) was developed. The model was implemented for the Delta and Suisun Marsh region using the collected wind data.

8.3.1 Wind Model Formulation

The wind model for the Delta is given by the following expression:

$$P(S(\underline{x}) > s(\underline{x}), \theta(\underline{x}), d, t \mid m_i) \qquad (8\text{-}1)$$

where

$P(\ )$ = annual probability of exceedance distribution

$\underline{x}$ = vector of geographic locations where the wind is defined

$S(\underline{x})$ = wind speed at location $\underline{x}$

$\theta(\underline{x})$ = wind direction at location $\underline{x}$

d = event duration

t = time of year

m_i = meteorological event type (meteorology)

Equation 8-1 calculates the probability of wind events in the Delta and Suisun Marsh occurring in a direction and duration for a given period of the year. Different meteorologies are assumed to be independent.

Reference wind speed distribution. Given the occurrence of a meteorology m_i, a probability distribution of wind speeds for a reference location, Travis, was determined. This distribution can be expressed:

$$P(S_R > s \mid m_i) \qquad (8\text{-}2)$$

where

S_R = the wind speed at a reference location

Spatial wind speed distribution. An occurrence of a wind event at the Travis reference location will be accompanied by an associated pattern of coincident winds throughout the Delta. These spatial patterns of winds throughout the Delta are spatially correlated because they are associated with the same wind event and meteorology. The coincident wind speeds can be expressed:

$$S(\underline{x}, m_i) = S_R(m_i)\, u(\underline{x}, m_i) \qquad (8\text{-}3)$$

where

$u(\underline{x}, m_i)$ = spatial pattern of normalized wind speeds (with respect to the reference location and wind speed, S_R) in the Delta and Suisun Marsh, and defined as a function of meteorology

Given the occurrence of a wind speed at the reference location, the spatial pattern of wind speed will be random and can be expressed:

$$P(u(\underline{x}, m_i)) \quad (8\text{-}4)$$

The distribution of this random variability of the spatial wind speed pattern with respect to the reference station can be modeled by a lognormal distribution. The distribution parameters are:

$\mu(\underline{x}, m_i)$ = the mean of the natural logarithm of the normalized wind speeds at location $\underline{x}$

$\sigma(\underline{x}, m_i)$ = the standard deviation of the natural logarithm of the normalized wind speeds at location $\underline{x}$; the variability of the spatial wind speed pattern is assumed to be perfectly correlated in space

The review of wind speed data at the stations analyzed showed a high degree of correlation of the observed winds in the region[2]. From the perspective of assessing risk, assuming the wind speeds are perfectly correlated over the dimensions of the Delta is conservative.[3]

The lognormal distributions of the spatial wind speed pattern variability are truncated to account for the fact that real wind speed values are limited and may not reach extreme values in the distribution tails. Depending on location, the distributions were truncated to two or three standard deviations ($\pm 2\sigma$ or $\pm 3\sigma$), which spans most of the empirical data distribution. The joint probability distribution of the independent parameters of reference wind speed (S_R) and the spatial wind speed variability (u) was then integrated to get a single-parameter exceedance probability distribution for wind speed at a particular location.

The exceedance probability of wind speeds at locations throughout the Delta (x) is a function of the wind speed at the reference location (SR) and the random variability of the spatial wind speed pattern (u). The combination of these two random variables can be used to derive the probability distribution on wind speed at any location in the Delta and Suisun Marsh:

$$P(S(\underline{x}) > s(\underline{x}) \mid m_i) = P(S_R * u(\underline{x}) > s(\underline{x}) \mid u(x), m_i)\, P(u(\underline{x}) \mid m_i) \quad (8\text{-}5)$$

Spatial wind direction distribution. For each meteorology, a probability mass function (PMF) on wind speed direction was determined from observations. This distribution is expressed:

$$P(\theta(\underline{x}) \mid m_i) \quad (8\text{-}6)$$

where

$\theta(\underline{x})$ = the wind direction for a given event at location $\underline{x}$.

The spatial pattern of wind directions can be denoted:

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[2] As part of this analysis, a correlation analysis (estimation of the variances and covariances) was not carried out. As a result, the distances over which correlations are very high is not known.

[3] As noted previously, the spatial-temporal probabilistic model of wind speeds was not used in the risk analysis.

$\theta(\underline{x}, m_i) = h(\underline{x}, m_i) + \eta(\underline{x}_m, m_i)$ (8-7)

where

$h(\underline{x}, m_i)$ = mean spatial wind direction pattern in the Delta and Suisun Bay, defined as a function of meteorology, m_i

$\eta(\underline{x}_m, m_i)$ = random variability of wind direction relative to the mean spatial wind direction pattern, represented as a PMF at:

$\underline{x}_m$ = the location of the wind station nearest to $\underline{x}$.

The wind direction distributions represent the direction of the peak wind speed (peak wind direction) for a given event, but do not model the temporal variation of wind direction within an event. This simplification can be mitigated somewhat by the way the method is applied. The wind direction distributions (η in Equation 8-7, represented as PMFs) can be applied to give the probability of wind events with peak wind speeds occurring over a range of directions. These distributions represent the variability of the peak wind direction from the mean wind direction at the wind stations.

These distributions can also be used to represent the variability of wind direction at other locations near the stations. In this case, the distributions can be applied to the local mean wind direction at another location, as estimated from the mean spatial wind direction patterns (*h* in Equation 8-7). Additionally, the directional variability of winds and wind waves can be addressed using directional spreading functions (e.g., see Goda [1985]). An alternative simplified approach is to select the direction corresponding with the longest fetch for a given location and meteorology if, for example, that wind-wave direction might produce the greatest erosion.

The Pacific Low meteorology includes both southeasterly winds (typically pre-frontal winds) and westerly winds (typically following passage of a cold front). Hence, to represent both wind conditions, wind speeds for Pacific Low events should be considered for two wind directions. For Pacific Low wind events, the duration of the wind event, discussed below, can be split between the direction of the prefrontal wind speed and the direction of subsequent winds from the southwest to west. A reasonable assumption is that winds are southeasterly for half the duration and westerly for half the duration.

Wind duration distribution. Observational data can be used to determine a PMF of wind event duration for different meteorological types, which can be expressed as:

$P(S(\underline{x}), d \mid m_i)$ (8-8)

where

d = wind speed duration above a given threshold (in hours) for a given wind event.

Although the analysis of wind event duration showed that wind speed and wind event duration may be partially correlated, wind event duration was characterized independently of wind speed as a simplifying assumption. The simplified PMF of wind event duration can then be denoted:

$P(d \mid m_i)$ (8-9)

Timing of an event within a year. The timing of a wind event (for a given meteorology) within a year can be denoted by a PMF:

$P(t \mid m_i)$ (8-10)

where

t = the month of occurrence of a wind event

Probability of wind events. The probability of wind events can be determined from a combination of the various elements identified above. The probability of winds generally in the Delta and Suisun Marsh for events of a given meteorology can be expressed as follows:

$$P(S(\underline{x}) > s(\underline{x}), \theta(\underline{x}), d, t \mid m_i) = P(S(\underline{x}) > s(\underline{x}) \mid m_i)\, P(\theta(\underline{x}) \mid m_i)\, P(d \mid m_i)\, P(t \mid m_i) \qquad (8\text{-}11)$$

Uncertainty. Given that epistemic uncertainty exists in the elements of the model, uncertainty exists in the estimate of the probability of wind events, (S(x), θ(x), d). Based on an analysis of these uncertainties and propagating them through the analysis, the uncertainty can be denoted:

$$\{P(S(x) > s(x), \theta(x), d|m_i)_j, p_j\} \qquad (8\text{-}12)$$

where

p_j = the probability weight associated with the jth wind model

The model was implemented by sorting data for high wind events by wind meteorology, fitting extreme value probability distributions to the reference wind speed data, developing spatial wind patterns and distributions, and developing empirical probability distributions of wind event duration and month of occurrence.

8.3.2 Wind Characterization

As identified previously, three meteorologies cause winds with relatively consistent seasonal and directional patterns. The following meteorologies were identified:

- Pacific Low
- Polar Front
- Sea Breeze

The meteorology classification of each peak annual event was checked against wind speed and direction patterns at Travis, Sacramento, and Stockton and the time of year of each event. For events in which this information did not conform to the general pattern for the meteorology, synoptic charts were checked to confirm or re-classify the event meteorology. The peak wind speed and direction for certain events appeared to be erroneous. These wind events were not included in the extreme wind data sets, as a quality control measure.

The time series of wind directions and wind event duration for Pacific Lows are complex. Wind directions during Pacific Low events may shift from southeast to west at a given location as the storm front moves through the region. During Pacific Low wind events, high wind speeds typically occur for a duration of about 12 hours. A Pacific Low storm system may have multiple storm fronts or may be a series of storms. Thus, these 12-hour wind events may be preceded or followed by wind events of similar duration in which the peak wind speed is less. Analyzing the time series of wind events and series of multiple events was not evaluated in this study.

Wind data were characterized by the following parameters:

Reference Wind Speed Distribution

Travis was selected as the reference wind station because it has the longest data record and the wind speed at Travis is often the highest during high wind events (i.e., winds speeds at Travis are higher than at other stations for more than 80 percent of the peak annual wind events from 60 years of data record). As the spatial wind speed patterns are normalized, any station could be chosen as the reference station, and the results are not expected to vary significantly according to the station selection.

Two different probability distributions were tested for the reference wind speed:

1. Gumbel (Extreme Value Type I) Distribution
2. Generalized Extreme Value Distribution (GEV)

The distributions were fit to annual maximum wind speed data for each meteorology. Figure 8-2 shows the results for the GEV distribution for the three meteorologies.

Spatial Wind Distribution

The WOCSS model was tested as a method for spatially interpolating wind speed and direction for this study. Triangulation was selected as a wind speed interpolation method over the WOCSS model. The WOCSS model results were used to interpolate wind direction patterns and develop a spatial wind direction pattern.

The WOCSS model interpolates wind speed and direction in space using an inverse distance interpolation scheme between data points (wind stations) and imposes physical constraints on the interpolation to account for the effects of topography and atmospheric layering (Ludwig et al. 1991; Ludwig and Sinton 1998). The physical principles of the WOCSS model are intended primarily to account for complex physical terrain and atmospheric stratification. The physical principles are based on a two-dimensional nondivergence constraint to force flow interaction with topography and atmospheric layers. The WOCSS model is not an atmospheric model and does not solve differential equations for the conservation of momentum.

Figure 8-3 shows the mean and standard deviation of the wind spatial distribution model for the three meteorologies.

Spatial Wind Speed Distribution

Wind speed exceedance probability distributions were developed at selected locations throughout the Delta and Suisun Marsh region using normalized spatial wind speed patterns, applying these patterns to scale the reference wind speed distributions in space, and accounting for the variability in the spatial wind speed patterns.

Spatial Wind Direction Distribution

Wind direction exceedance probability distributions were developed at locations throughout the Delta and Suisun Marsh region using mean spatial wind direction patterns and PMFs of wind direction at each NWS station.

For each wind event modeled with WOCSS (9 hours modeled per event), the wind direction results were averaged to give a spatial map of wind direction for each event. For the five events modeled for each meteorology, the wind event direction maps were averaged to give mean spatial wind direction patterns for each meteorology. These results are shown in Figure 8-4.

Duration

The duration of wind speeds above 11 meters per second (m/s) were evaluated with respect to wind speed for the peak annual wind events from each meteorology. Wind event duration and wind speed appear to be partially correlated for Polar Fronts and Sea Breezes, but not for Pacific Lows. This difference could be explained by the fact that Polar Fronts and Sea Breezes may be characterized by meteorological conditions (i.e., pressure systems) that persist for more than a day, whereas Pacific Low storm systems may tend to move through the region within a day.

PMFs of wind event duration were calculated for each meteorology using wind data from the reference station (Travis), without consideration of wind speed. The duration PMFs are shown in Figure 8-5 for each meteorology. If the potential correlation with wind speed is not included as a simplifying assumption, the wind event duration PMFs could be applied to wind speed exceedance distributions at any location to give distributions of wind event duration and wind speed exceedance. This application may tend to underestimate the probability of longer duration events associated with higher wind speeds, and overestimate the probability of longer durations for lower, but more frequent wind speeds.

The wind event durations can be applied by assuming wind speeds increase from 11 m/s to the estimated peak wind speed, and then decreases back to 11 m/s over the event duration. For Pacific Lows, this assumption may not account for multiple storm fronts or a series of storm fronts, as the analysis approach only represents peak annual wind events and does not model stochastic processes involving multiple storms. Seasonal wind data include the full series of winds throughout the year. Additional discussion of the duration of Pacific Low events is included above.

Month of Occurrence

PMFs for the month of occurrence of peak annual wind events from each meteorology were calculated using wind data at the reference station (Travis). The PMFs for month of occurrence for each meteorology are given in Figure 8-6. The wind speed exceedance distributions (or other distributions) at a particular location can be multiplied by the probability of occurrence for a month to give the probability of a wind event (wind of a given speed) occurring during a given month.

Seasonal Winds

WRPLOT was used to create seasonal wind roses for the fall-winter season (October to March), spring-summer season (April to September), and the entire year for the period from 1997 to 2005 at each wind data station. The wind roses give the percent occurrence of wind speeds (from low to high) in eight compass directions. For other DRMS analyses using the seasonal wind rose data at a given location, the wind rose for the nearest NWS station can be used, as the NWS data are consistent and are expected to provide the most reliable data.

8.4 WIND-WAVE ANALYSIS

Wind-wave calculations were performed to develop look-up tables for wind-wave height and period, wave power, and wave runup. These look-up tables can be used to estimate deep-water wind-wave heights and periods, power, and runup for seasonal or extreme winds and any fetch of interest in other DRMS analyses.

8.4.1 Wind-Wave Generation

Wind-wave heights and periods were calculated for a range of fetch lengths and wind speeds using the procedures and parametric deepwater wave equations for fetch-limited wave growth from the Shore Protection Manual (USACE 1984).

Wind speeds estimated in the wind analysis are based on wind speed data measured over land (and are corrected to a 10-m wind gage height and 1-minute averaging period). The overland wind speeds were increased by a factor of 1.2 to estimate wind speeds over water, based on corrections provided in the CEM. The CEM recommends a correction factor of 1.2 for fetches less than 10 miles (16,000 meters). For longer fetches, the CEM gives this correction factor as a function of wind speed based on a Great Lakes study and provides additional correction factors for air-sea temperature difference and the stability of the atmospheric boundary layer. The factor of 1.2 was used for all fetches for consistency and simplicity.

For fetch-limited wave growth conditions in sheltered waters, the wind blows steadily in a constant direction for a sufficient amount of time to achieve steady-state fetch-limited wave conditions. Wind-wave generation requires a sustained input of wind energy. The adjusted 1-minute average wind speeds represent sustained winds with durations of 1 minute. The duration of the sustained wind speed that gives steady-state fetch-limited wave conditions may be longer (or shorter) than 1 minute. For each 1-minute wind speed estimate, wind speeds corresponding to a range of durations using Shore Protection Manual equations were calculated and these combinations of wind speed-duration were tested in the wave growth equations.

An automated computer code was used to find the wind-speed duration combination giving fetch limited conditions. The code calculates the duration for the highest wind speed-shortest wind duration combination to see if the calculated duration is sufficient to develop a fetch limited condition. If not, the code selects the next wind speed and repeats the calculation.

When the calculated duration for a given wind speed and fetch length is greater than the corresponding wind duration, the corresponding wind stress factor is used to calculate deep-water wave heights and periods, considered to be the largest fetch-limited condition. The results are included in tables found in Appendix A of the Wind-Wave Hazard TM (URS/JBA 2008g) for wind speeds above the highest estimated wind speed of interest (35 m/s, which has an exceedance probability of less than 0.002 for all meteorologies and fetch lengths beyond the longest fetch length, 21 km from east to west across Suisun Marsh).

8.4.2 Wave Power

Wave power is a measure of the rate of wave energy transmitted to a surface, such as a coastal structure or levee. As defined in the CEM, wave power refers to “the average wave energy flux per unit wave crest width transmitted across a vertical plane perpendicular to the direction of wave advance." Wave power is an indicator of potential work done toward levee erosion and generally provides an indication of intensity. Given that waves are dissipated over time and space, the actual work done on a surface depends on the shape of that surface and hence the antecedent wave conditions. Erosion is affected by the sequence of wave power, water levels, and event duration, and is more accurately modeled in terms of a time series of waves and erosion.

8.4.3 Wave Runup

Potential wave runup height is the height above the still water level that a wave breaking on a structure slope will reach as it travels up the slope, assuming the slope extends above the runup height. The actual wave runup height or elevation depends on the water level and structure crest elevation, which may limit runup height. However, potential wave runup is an indicator of water velocity on the structure slope, wave overtopping of the structure, and the potential for erosion of both the outboard levee slope and inboard levee slope (due to wave overtopping and head-cutting).

For each combination of wave height and period in the wind-wave generation look-up table, potential wave runup heights were calculated using the TAW method (2002) as described in the *Guidelines for Coastal Flood Hazard Analysis and Mapping for the Pacific Coast of the United States* (FEMA 2005a).

The TAW method and other wave runup methods give the wave runup height that is exceeded 2 percent of the time during a given wave event. This 2 percent wave runup height was calculated for each wind-wave height and period. The 2 percent wave runup height is otherwise not related to the probability of a given wind speed or wind-wave condition. Wave runup height calculated from the TAW method includes the super-elevation of the still water level due to wave setup (static and dynamic) caused by the wave conditions input into the equation. Note that in real situations, larger waves can break farther offshore of the slope and induce greater setup, which can in turn increase the local wave height and wave runup height elevation. The analysis accomplished here assumes the hindcast wave impinges on the slope and the wave runup includes all wave setup.

Wave runup heights were calculated for two structure slopes:

- 1 vertical to 1.5 horizontal (1:1.5) to represent relatively steep upper slopes of outboard and inboard levees that typically result in relatively high wave runup heights
- 1 vertical on 5 horizontal (1:5) to represent less steep lower slopes or average (composite) slopes of inboard levees

The TAW method includes wave runup reduction factors for surface roughness, the influence of a berm, oblique wave incidence, and structure permeability. FEMA (2005a) and TAW (2002) provide guidance on estimating wave runup reduction factors. These reduction factors were not included in wave runup calculations, and assumed smooth levee surfaces, the absence of a berm, perpendicular wave attack, and an impermeable structure (i.e., all reduction factors equal to one). For armored levees, a roughness reduction factor of 0.55 to 0.6 can be applied for levees with one layer of rock armoring, where the rock diameter (D) is one to three times the significant wave height (H_s / D = 1 to 3) (FEMA 2005a).

Table 8-1 Summary of Delta and Suisun Bay Wind Data

Agency	Data Type/QC	Station	Years of Record
NOAA/NWS	Wind Speed & Direction (daily)	Concord Buchanan	1973-2006
		Concord	1973-2006
		Livermore	1978-2006
		Sacramento	1948 - 2006
		Stockton	1941-1946, 1948-1955, 1963-2006
		Travis	1943-1970, 1973-2006
		Oakland	1943 only
NOAA NDBC	Wind Speed, Direction & Gust (hourly)	Port Chicago	1994-present
DWR	Wind Direction & Velocity	Antioch	1983 - 2006
		Mallard	1984 - 2006
		Martinez	1983 - 2006
		Rio Vista	1983 - 2006
CIMIS	Wind Speed & Direction (hourly)	Dixon	1994-2006
		Hastings	1995-2006
		Lodi	2000-2006
		Twitchell	1997-2006

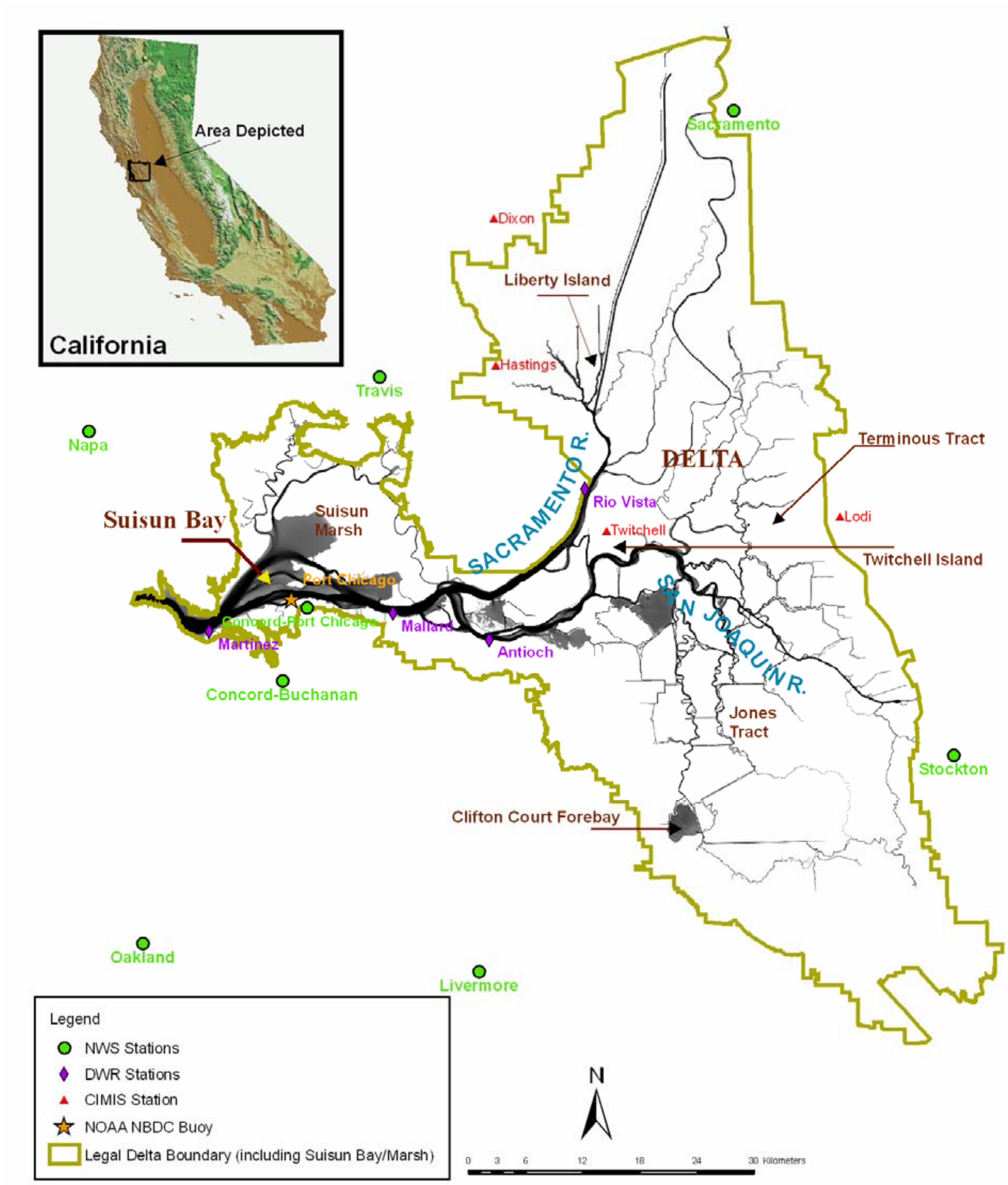

Figure 8-1 Site Map Wind Stations

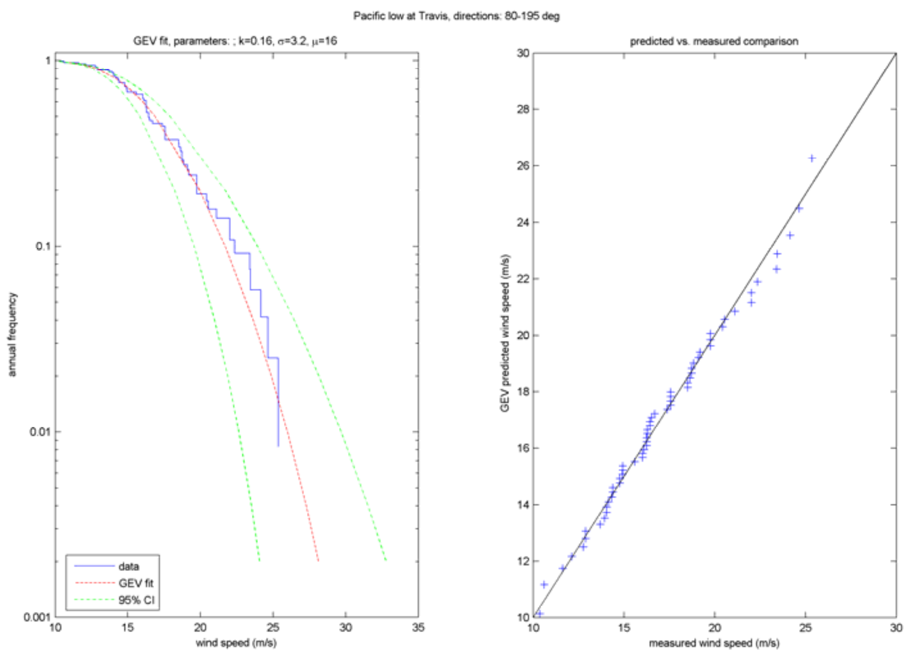

Figure 8-2a Wind Speed Distributions for Travis for Pacific Lows

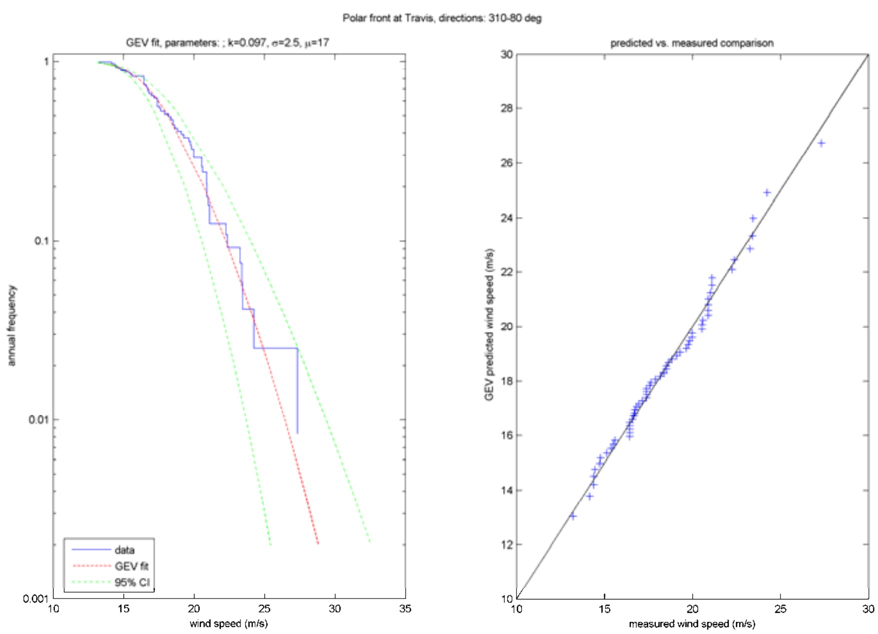

Figure 8-2b Wind Speed Distributions for Travis for Polar Fronts

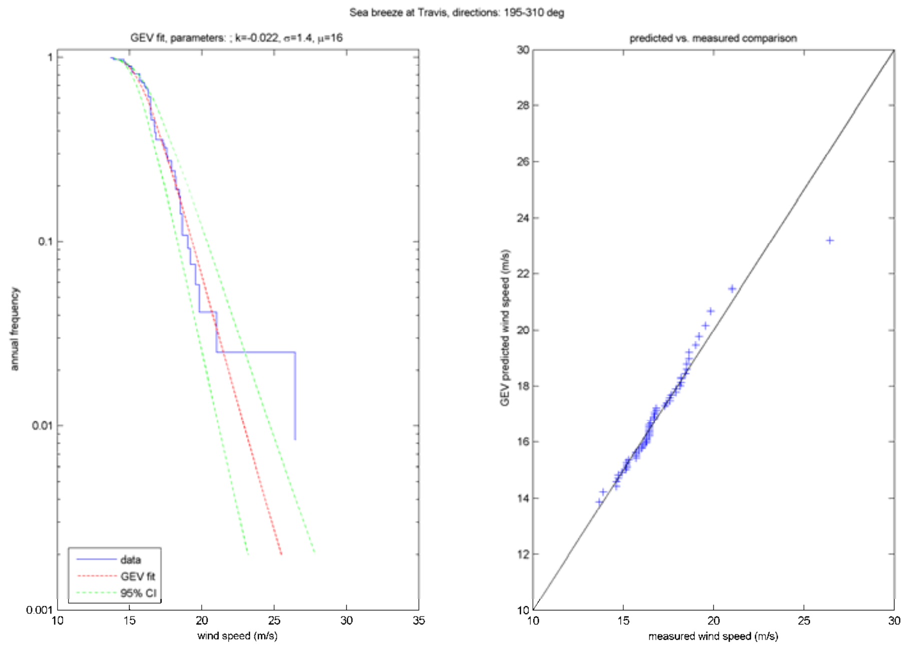

Figure 8-2c Wind Speed Distributions for Travis for Sea Breezes

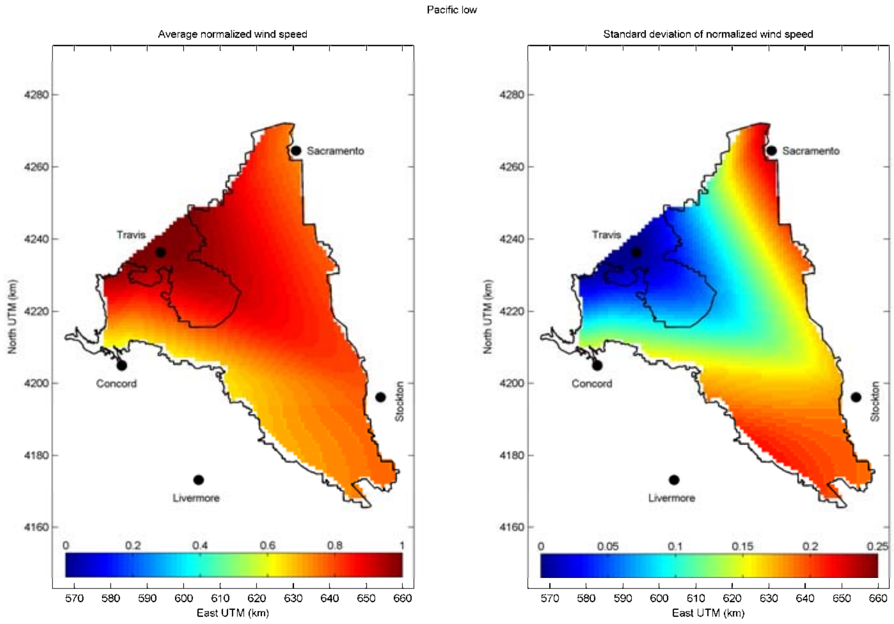

Figure 8-3a Spatial Wind Pattern, Mean and Standard Deviation for Pacific Lows

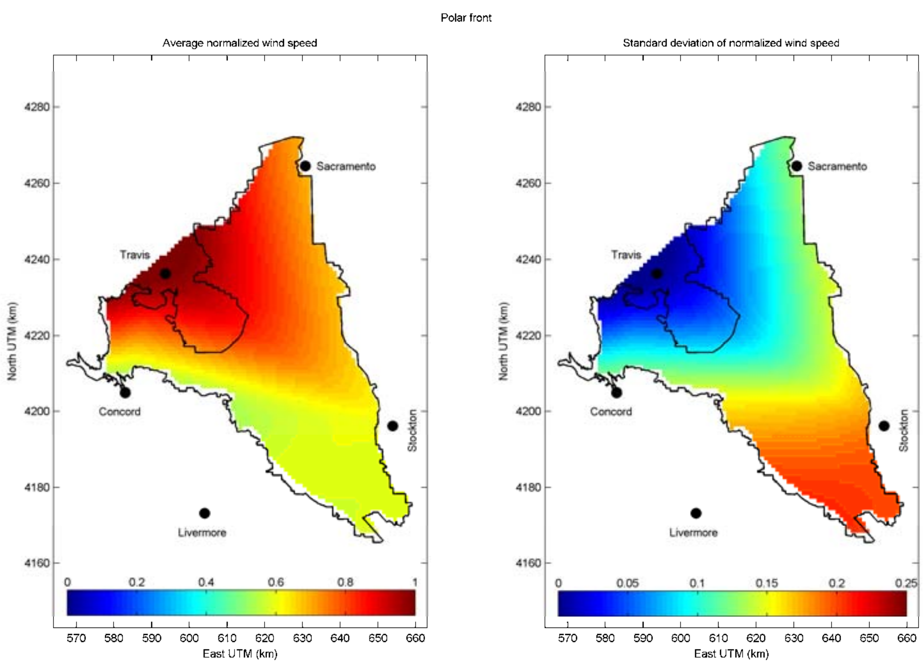

Figure 8-3b Spatial Wind Pattern, Mean and Standard Deviation for Polar Fronts

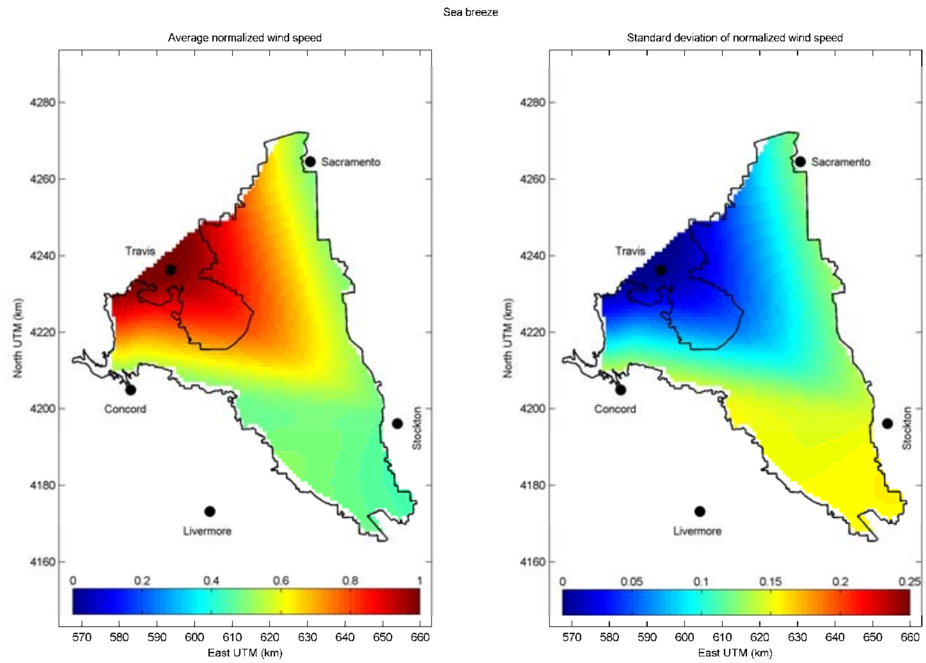

Figure 8-3c Spatial Wind Pattern, Mean and Standard Deviation for Sea Breezes

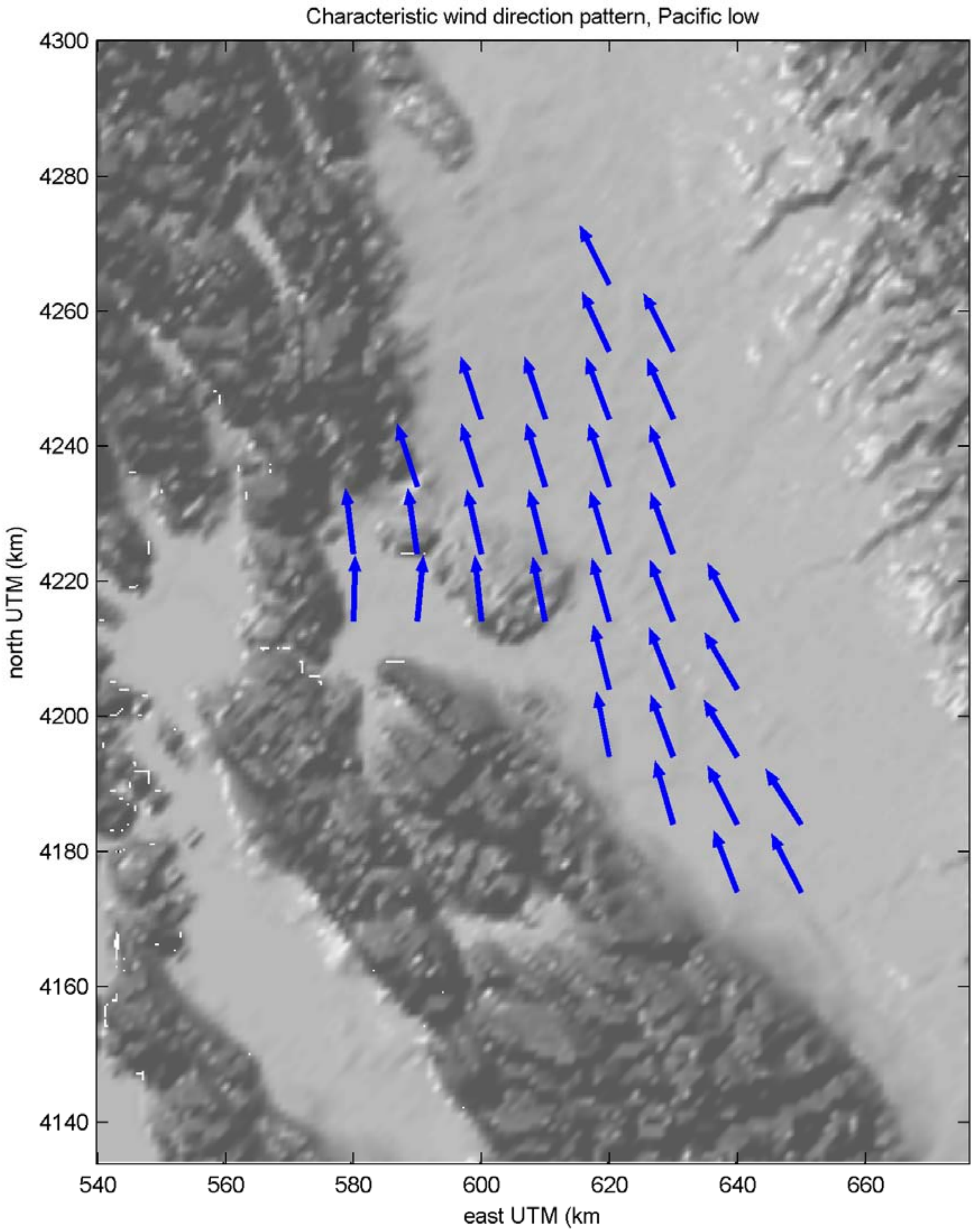

Figure 8-4a Spatial Mean Wind Direction Patterns for Pacific Lows

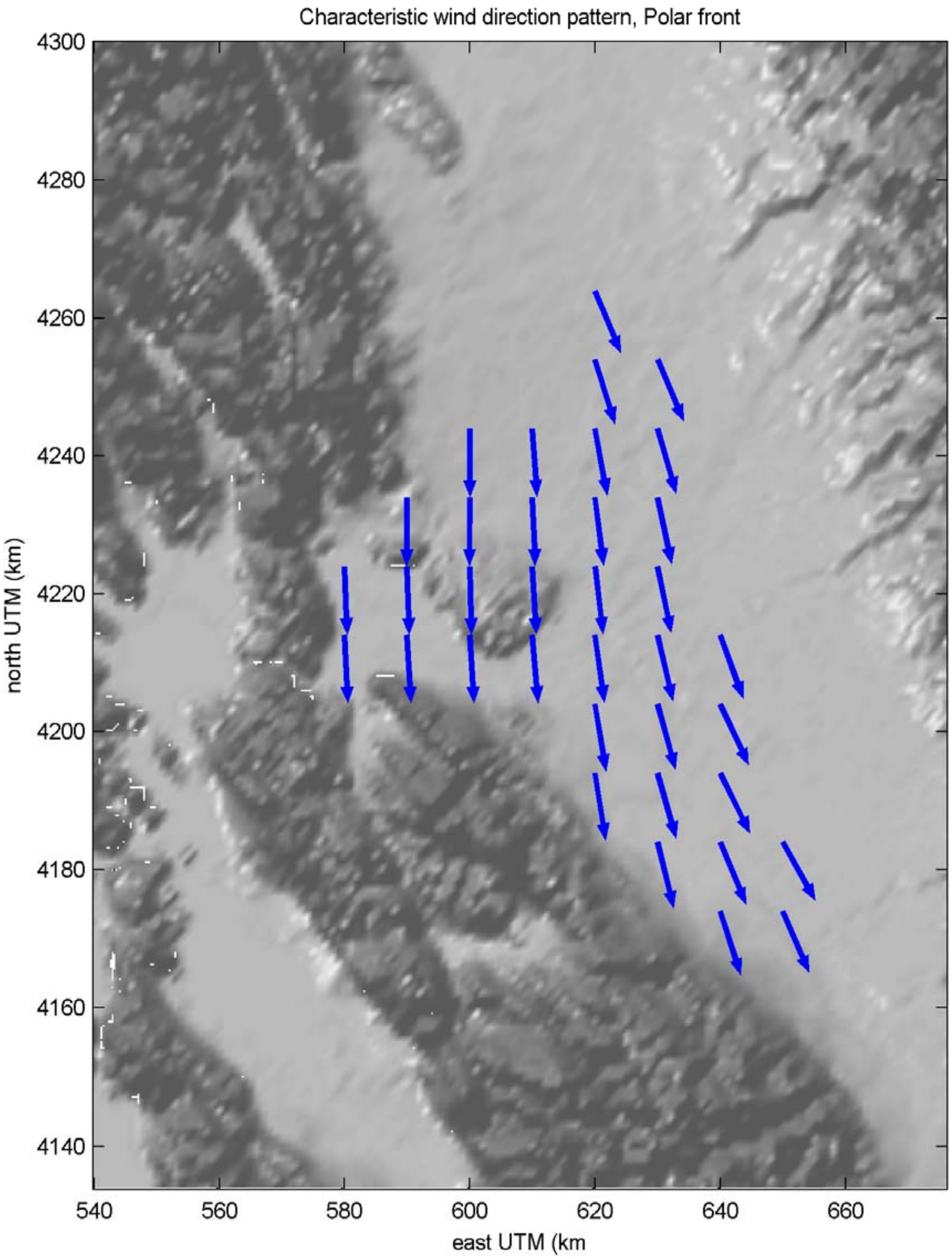

Figure 8-4b Spatial Mean Wind Direction Patterns for Polar Fronts

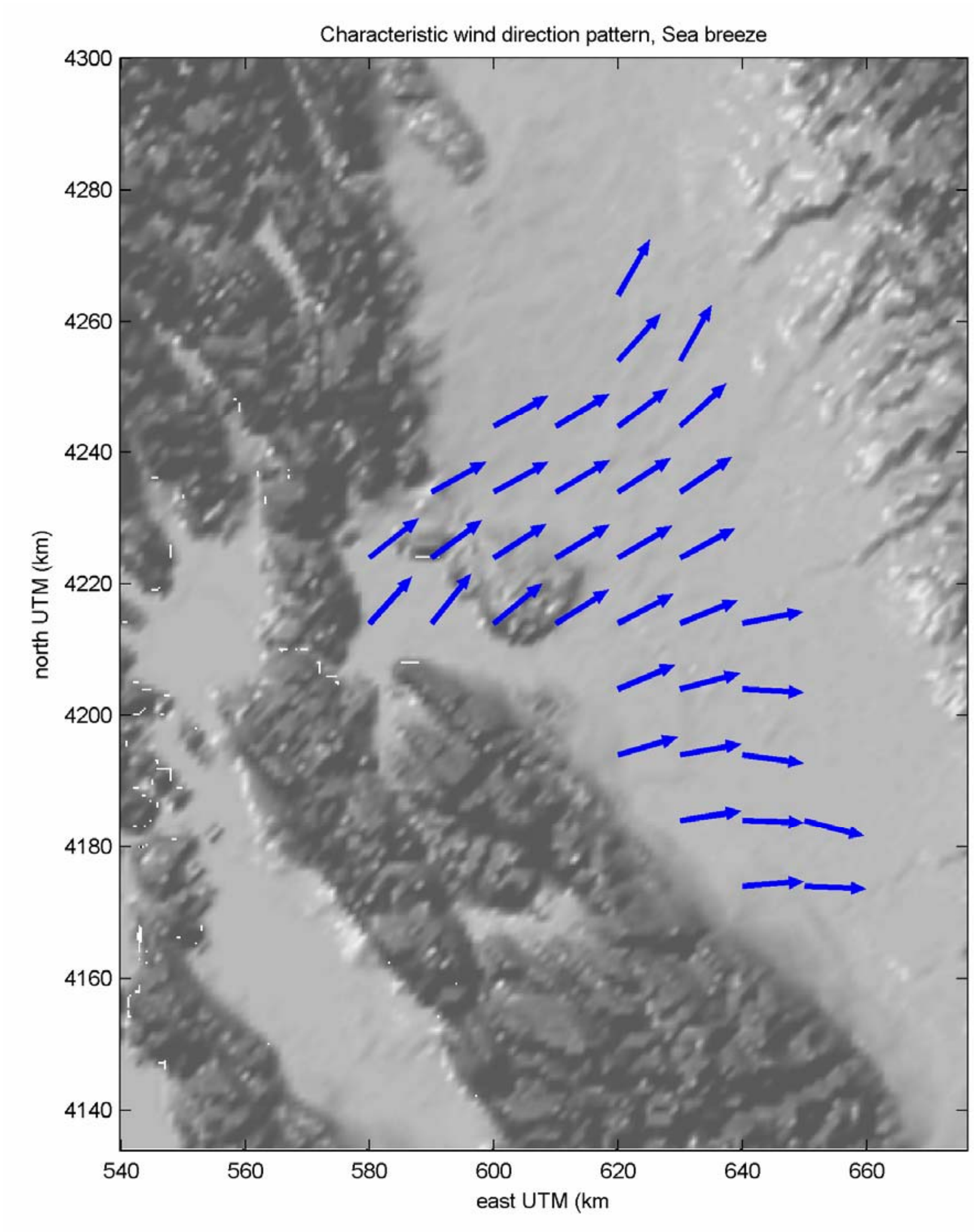

Figure 8-4c Spatial Mean Wind Direction Patterns for Sea Breezes

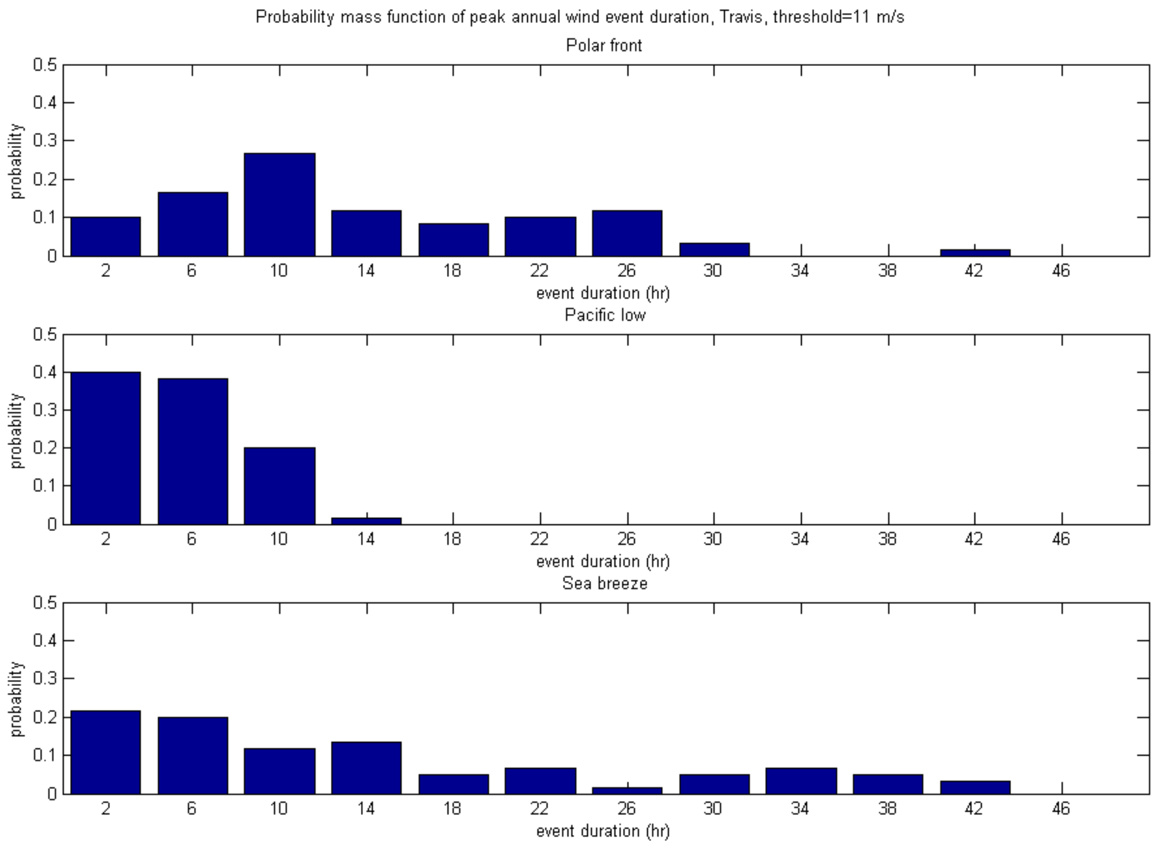

Figure 8-5 Wind Speed Duration for Each Meteorology

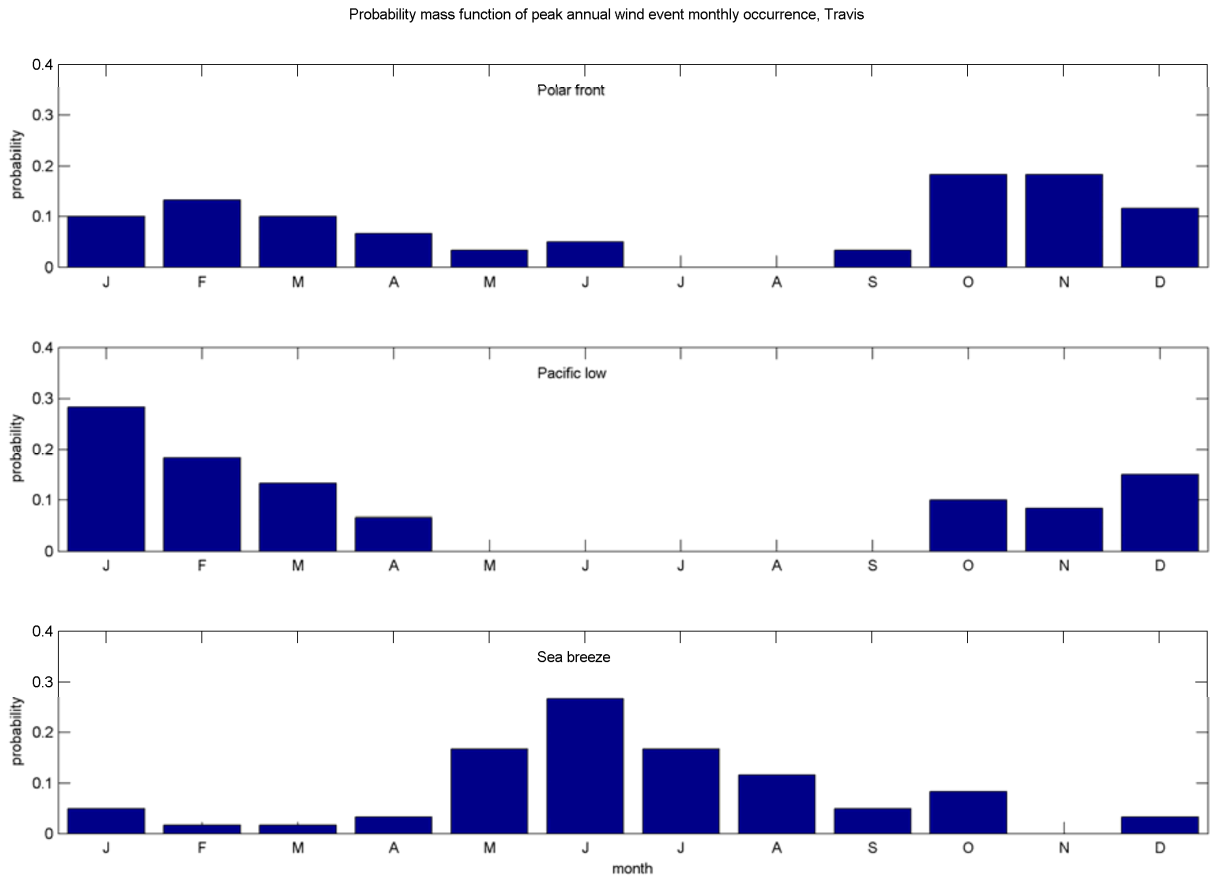

Figure 8-6 Probability Mass Function for the Month of Occurrence of Winds Associated with Each Meteorology Type

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9.1 ASSUMPTIONS AND DEFINITIONS

Sunny-day failures are levee breaches that are not flood or seismic related. Historical data were used to estimate the rate at which the levee breaches occurred during non-flood and non-seismic conditions. These failures typically occur between the end of the late snowmelt from the Sierras, in late May, and the beginning of the rainy season, in early October. Sunny-day failures are addressed separately from flood-induced failures to differentiate between winter and summer events. Aside from seismic events, factors that can cause Delta levee failures in the summer period are different than the factors that can cause winter failures.

Levee failures resulting from flood hazard are discussed in Section 7 of this report. Factors that influence water stage frequencies during winter include the following hydrologic conditions: historical storms, storm surges, snow melt, rainfall and runoff, tides, and their combined effects.

Water stage frequencies associated with the summer, are controlled by tides and remote oceanic storm surges. Therefore, frequencies of failure for the two seasons are different, kept separate, and compared against historical observations for each season.

9.2 HISTORICAL INFORMATION

To estimate the sunny-day annual frequency of failures, the consulting team used the historical record of summer-time levee failures in the Delta since 1950. In this period, eight levee failures were recorded during summers that resulted in island flooding. Data prior to 1950 were not used because the information needed, such as water level, crest elevation, and failure mode, is either nonexistent, sparse, or lacks the necessary details to fully document failure conditions. Furthermore, levees prior to 1950 were much smaller than today's levees.

Table 9-1 summarizes the information collected about sunny-day island flooding. Water levels in the nearby sloughs were obtained from gauge station historical records operated and maintained by the California Data Exchange Center (CDEC). Levee crest elevations were obtained from the Interferometric Synthetic Aperture Radar (IFSAR) data in the Geographic Information System files that the California Department of Water Resources (DWR) provided. Post-failure investigation reports are not available to provide detailed descriptions of the causes of the levee failures. The information provided in the column titled "Conditions at Time of Failure or Assumed Failure Mode" of Table 9-1 is anecdotal and relies on limited available data and communication with DWR personnel and the reclamation districts' engineers.

Figure 9-1 shows the levee crest elevations versus the water stage (North American Vertical Datum of 1988 [NAVD88]) for seven of the eight levee breaches at the time of failure. Figure 9-2 shows the approximate locations of the breaches. A close examination of the data indicates that failures occurred during "unusual" high-tide conditions. An unusual high tide could be caused by offshore storm surges arriving in the Delta, planetary conditions resulting in higher gravitational pull from the concurrent alignment of the sun and the moon, or a combination of the two.

At Simmons-Wheeler in July 2005, the water rose above the crest of the levee at Suisun Marsh and overtopping may have caused the levees to fail. However, other eyewitness reports indicate also that the levee failure at Simmons-Wheeler may have been caused by rapid drawdown during a period of receding water levels.

Post-failure reports indicate that excavation activities at the landside toes of the levee may have caused the failure of Brannan Andrus Island in June 1972. At MacDonald Island in August 1982, the levee may have been breached as a result of dredging on the waterside toe of the levee. However, that information has not been confirmed in any written report. Generally, these failure events may be the result of a combination of high tide and pre-existing internal levee and foundation weaknesses caused by burrowing animals, internal compounded erosion of the levee and foundation through time, and human interventions such as dredging or excavation at the toe of the levee.

Burrowing animal activities and pre-existing weaknesses in the levees and foundation are the key weak links leading to levee failures. This is the case whether or not the failures occur during a high-tide condition. Most practicing engineers, scientists, and maintenance personnel in the Delta and Suisun Marsh believe that rodents are prolific in the Delta and use levees for burrowing. As a result, they cause undue weaknesses by creating a maze of internal and interconnected galleries of tunnels.

Underseepage and through-levee seepage are slow processes that tend to work through time by removing fines from levee and foundation material during episodes of high river levels. Cumulative deterioration through the years can lead to foundations ultimately failing by means of uncontrollable internal erosion that leads to slumping and cracking of levees.

Sunny-day levee failures all occurred during higher-than-typical daily high tides. The typical daily high tides over a 24-hour cycle in summer conditions are generally around elevation +5 feet (NAVD88) in the central-west Delta, and about +5.6 feet in Suisun Marsh (DWR 1995b). Water elevations at the times of the summer levee failures, as shown in Figure 9-1, were generally around elevation +6 feet (NAVD88) or higher.

9.3 ESTIMATION OF FREQUENCY OF SUNNY-DAY FAILURES

The frequency of historical sunny-day failures of levees in the Delta and Suisun Marsh was determined from the records of six such failures recorded in the Delta and two sunny-day failures in Suisun Marsh. Assuming 911 miles of Delta levees within the Mean Higher High Water (MHHW) boundary, a failure rate of 1.06×10^{-4} /year/levee-mile or 0.0969 failure/year was estimated using the least square linear fit to the six data points for the Delta shown in Figure 9-3. The standard deviation around the linear trend line is 0.47.

Assuming 75 miles of Suisun Marsh exterior levees within the MHHW boundary, a failure rate of 4.76×10^{-4} /year/levee-mile or 0.036 failure/year was estimated. The data points for the Suisun Marsh are too few to conduct a statistical regression analysis (trend line and standard deviation). The trend for Suisun Marsh is estimated to be an average of two failures over 55 years, and the standard deviation is assumed to be the same as for the Delta, short of any other information.

Because of having incomplete information on the exact causes of the sunny-day levee failures at each location and, therefore, the DRMS project team was unable to map out the various conditions leading to sunny-day failures by specific area in the Delta and Suisun Marsh. The project team assumed that the recurrence models of sunny-day failures have uniform probabilities throughout the Delta and Suisun Marsh, respectively. These two failure rates will be applied to all levees in the two areas within the MHHW boundary, assuming the uniform probabilities shown in the preceding two paragraphs.

Table 9-1 Sunny-Day Failures

Island/Tract	Year	Month	Day	Conditions at Time of Failure or Assumed Failure Mode	Water Level (NAVD88)	Levee Crest (NAVD88)
Webb Tract	1950	Jun	2	High tide, stability	6.1	10.8
Brannan-Andrus Island	1972	Jun	22	Excavation at landside toe	6.2	10.8
Lower Jones Tract	1980	Sep	26	Seepage and rodent activities	6	11
McDonald Island	1982	Aug	23	Seepage from dredging at waterside toe	5.48	11.5
Little Mandeville	1994	Aug	2	High tide, abandoned	6.1	11.5
Upper Jones Tract	2004	Jun	3	High tide, underseepage, and rodent activity	6.85	11
Simmons-Wheeler (Suisun Marsh)	2005	Jul	20	High tide, breach occurred between two water control structures; beaver activities suspected	7.51	7.3
Sunrise Duck Club (Suisun Marsh)	1999	Jul	NA	High tide and possible beaver activities	NA	5 to 6

NAVD88 = North American Vertical Datum of 1988

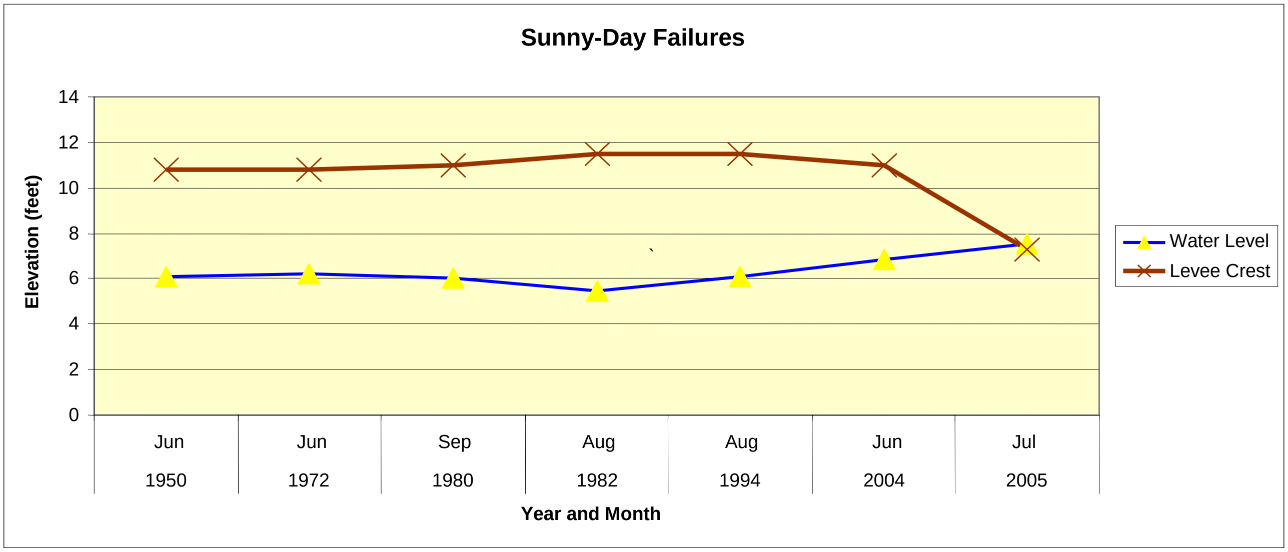
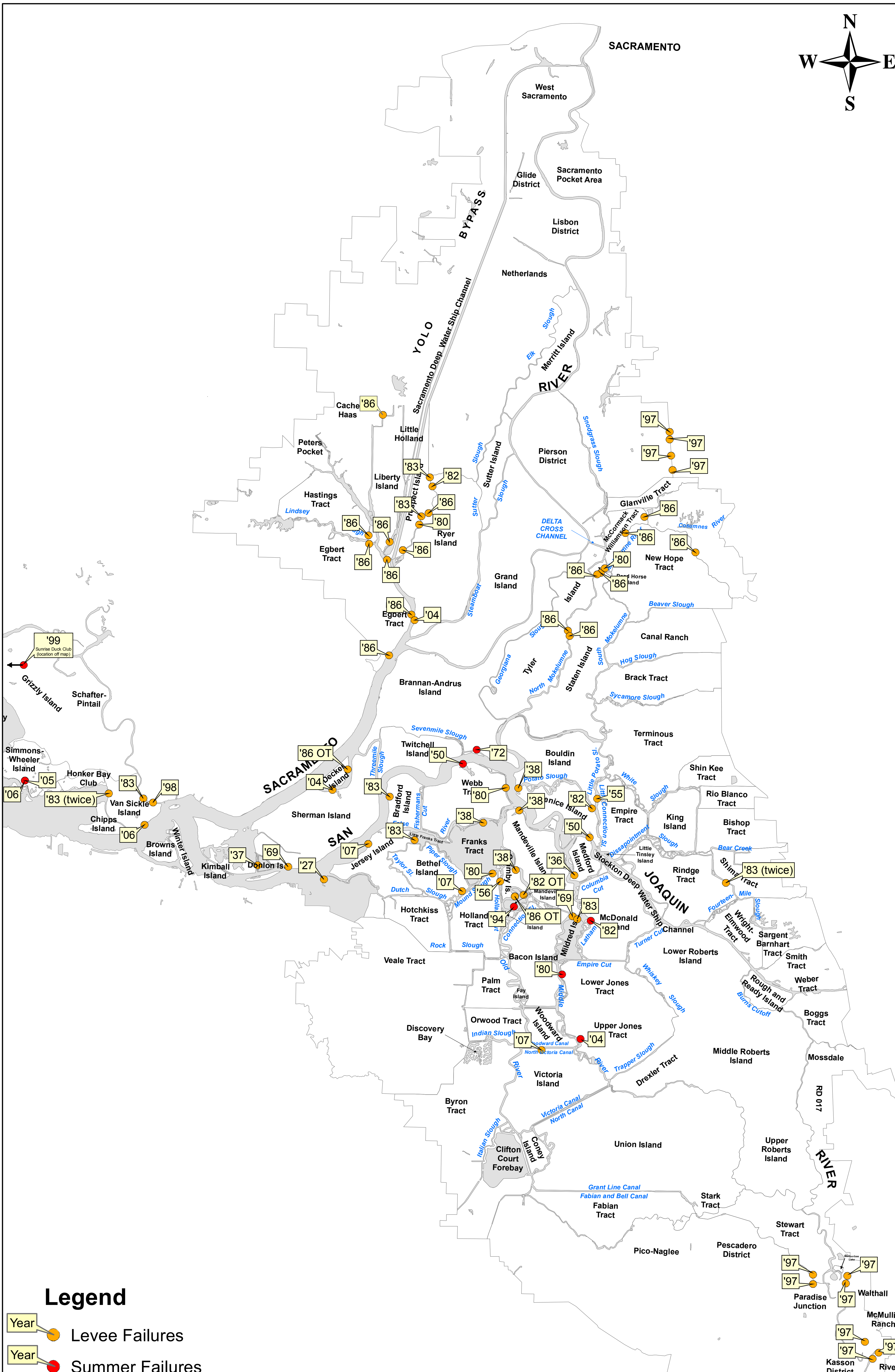


Figure 9-1 Water Stage versus Crest Elevation at Sunny-Day Failure Locations



URS	DRMS 26815431	Locations of Levee Failures	Figure 9-2

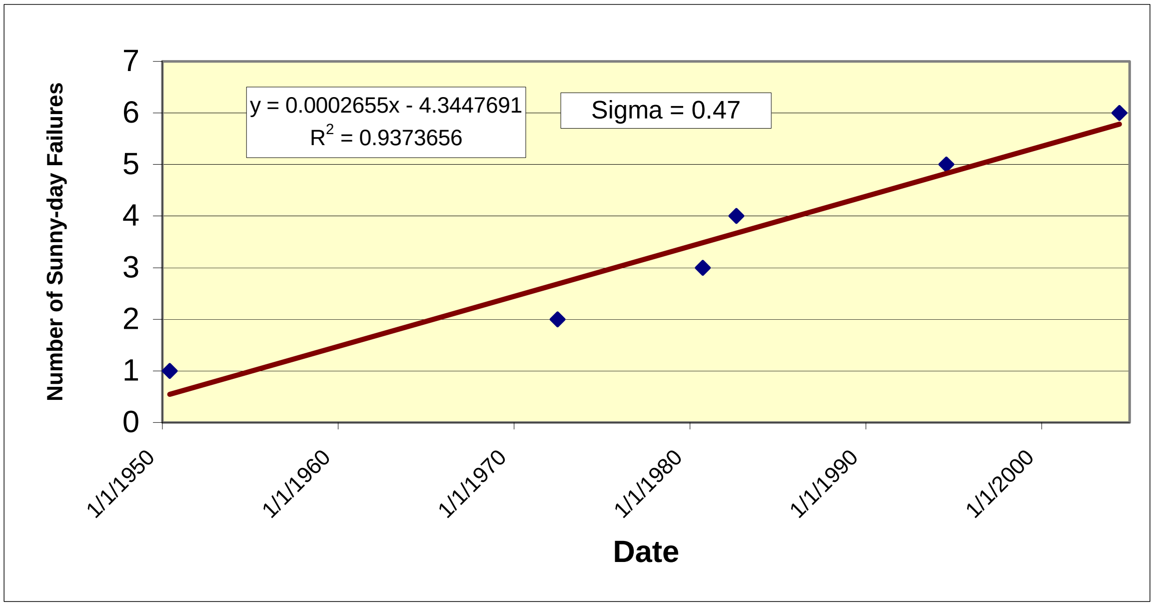


Figure 9-3 Cumulative Number of Sunny-Day Failures and Trend Line for the Delta

(Note: The slope of the trend line in the graph is based on days, not years)

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When a levee failure event occurs, including those that involve multiple breaches on a number of islands, repair activities will be initiated to close the breach(es) and recover the island(s). The objective of the emergency response and repair (ER&R) part of the risk analysis is to estimate the time and material required, and the associated costs, to repair damaged and breached levees and dewater flooded islands.

The Emergency Response and Repair Technical Memorandum (TM) (URS/JBA 2008d) presents a detailed description of the ER&R analysis. The ER&R model has been developed using past Delta levee repair experience of the California Department of Water Resources (DWR), contractors, and local quarries.

Because an emergency response plan was not available to define a business-as-usual (BAU) approach to levee repair for the events that are modeled in the risk analysis, the development of the ER&R model required that a BAU approach be defined. Also, the Delta Risk Management Strategy (DRMS) consulting team conducted assessments based on interviews with contractors, quarry officials, etc., to estimate the resources (e.g., quarry production) that could be used in the ER&R analysis to analyze the response to levee failures in the Delta.

10.1 LEVEE FAILURE SEQUENCES

Levee failures and/or non-breach damage to levees in the Delta could result from earthquakes, floods, and normal (sunny-day) events. Hydrologic events and earthquakes can result in multiple levee failures on multiple islands as a result of a single event (e.g., single earthquake). In the case of an earthquake, there will also be non-breach levee damage (see Section 6 and the Levee Vulnerability TM [URS/JBA 2008c]) that must be repaired as part of the effort to recover an island.

As described in Section 4, a levee failure event may involve (depending on the initiating event and details of the sequence) the following:

- One or more levees may fail on one or possibly multiple islands.
- In the case of a seismic event, possible non-breach damage (with no levee failures and therefore no island flooding) may occur on some islands. These islands will require levee repair, but not dewatering.
- The repair of an island that is flooded will involve the following:
    - Closure of the levee breach
    - Placement of rock on levee interior slopes and possible repair of levee interiors as a result of erosion due to wind waves
    - Repair of non-breach damage (in the case of a seismic event)
    - Dewatering of the island
- Once a flooded island is closed and non-breach seismic damage is repaired, the island is dewatered.

The repair of failed and damaged levees and the dewatering of flooded islands are the first steps in the process of recovering from a levee failure event. At the same time, the timing of levee breach closures and the dewatering of islands is a continuation of the levee failure sequence because of the effect that open islands have on the hydrodynamic response of the Delta after the initiating event (e.g., the earthquake that caused the levee failures).

10.2 EMERGENCY LEVEE REPAIR ANALYSIS

When levee failures occur, the method of repair involves the placement of rock to stabilize the damaged levees and to close breaches. This approach, based on past experience (BAU) includes capping of breach ends to stabilize the breach before attempts are made to close it. Once the breach ends are capped, the breach and scour hole are filled with rock until closure is achieved. In addition, capping of the waterside slope is often required to limit seepage through the repaired sections. Due to wind waves that are generated on the flooded island, placement of erosion protection on the interior levee slopes is required.

10.2.1 Levee Emergency Response and Repair Model

When a levee failure event occurs in the Delta, one or multiple islands may be flooded, and in the case of a seismic event there may be a number of islands whose levees have experienced damage, but have not failed. The ER&R model is a time simulation model that tracks the repair activities (described later) on each island, until all of the repairs have been completed and the islands dewatered. Repair activities that are tracked in time in the analysis include:

- Levee breach growth prior to capping
- Cumulative levee interior erosion on flooded islands
- Quarry rock production rates which increase during the period of repair
- Rock and soil placement rates for breach capping, breach closure, interior erosion protection and repair, and non-breach damage repair
- Repairs and dewatering costs

Figure 10-1 shows a schematic of the elements of the DRMS levee emergency response and repair approach. Elements of the analysis are summarized in the following paragraphs.

Figure 10-2 shows a schematic of the timeline of repairs for a levee failure sequence. The timeline illustrates the progression of levee repairs, ongoing damage, and quarry production.

Levee Failure Sequence. A levee failure event (sequence) is defined in terms of:

- Islands that are flooded as a result of a levee failure
- Number and location of the breaches on each island
- Location (identified by levee reach/sector) and length of non-breach damage in the case of an earthquake on each flooded island
- Damaged, but non-flooded islands
- Location (identified by levee reach/sector) and length of non-breach damage in the case of an earthquake on each non-flooded island
- Time of year the event occurs (month)

A sequence is also defined by the type of water year, which is important for the hydrodynamic and water analysis part of the risk analysis (see Sections 4 and 11).

Repair Types and Business as Usual. In the ER&R analysis, the response to levee damage and breaching is divided into a series of repair types:

- RT1 – repair non-breach damage on non-flooded islands
- RT2 – protect the levee interior slopes on a flooded island against wind-wave damage, or repair damage if it has already occurred
- RT3 – repair non-breach damage on a flooded island
- RT4 – stabilize breached levees by capping the levee ends at the breach
- RT5 – breach closure
- RT6 – island dewatering

These repairs are carried out for all islands that are defined in a sequence. As part of the ER&R analysis, repair types can be prioritized, eliminated (not performed), etc. from one island to the next.

In the DRMS Phase 1 analysis all six repair types could be carried out for all islands, and would be selected as dictated by the damage on the island. This is the BAU approach to responding to levee failures in the Delta. It should be recognized that other sequences of repair or extent of repair, after a major event in the Delta, could be different from the proposed sequence of emergency repair proposed here.

Island Priority and Work Order Priorities for Levee Repair. For a given levee failure sequence, islands are assigned a priority. The island priority system used in the DRMS Phase 1 analysis is described in Section 10.4. As resources become available for a particular repair type, repairs begin on the island next on the priority list.

The repairs that are required on an island are prioritized in a work order that is generated for each island. The work order repair priorities for flooded islands are; 1) RT4, 2) RT5, 3) RT3, 4) RT2, and 5) RT6. Note, due to the varying availability of equipment resources and the completion of different repair types on islands that have higher priority, repairs of a given type may not be carried out in the priority listed above. For instance, if equipment becomes available to initiate interior levee slope protection and repair (RT2) because the work on other islands has been completed, these repairs are initiated on the island next in line for repairs.

For islands that are not flooded but have non-breach damage, RT1 repairs are carried out.

Quarry Production. The San Rafael Rock Quarry (SRRQ), the major source for rock and marine delivery, has a certain production capability. Based on discussions with the Dutra Group (owners of the SRRQ), an assessment was made to determine, in the case of a major event in the Delta, what production levels could be achieved to meet the repair demands in the Delta. As described in the Emergency Response and Repair TM (URS/JBA 2008d), the Dutra Group provides estimates of the quarry production and delivery capacities that can be achieved. The increased capacities depend on the level of demand and include construction of a docking facility in San Rafael to increase loading and delivery capacity.

ER&R Analysis Results. There are two primary outputs that are generated by the ER&R analysis. The first is the estimated cost of the levee repair and island dewatering. This result is an input to the economic consequence analysis (see Fig. 10-1). The second result is the location of island breaches and the timing of their closure. This information serves as input to the Water Analysis Module (URS/JBA 2007e), which estimates the hydrodynamic response of the Delta to the levee failure event (see Figure 10-1).

10.2.2 Analysis Conditions and Business as Usual

Following the BAU approach to the Phase 1 analysis, the SRRQ is the source of rock required for breach repairs and the only source of material for marine-based activities. The SRRQ, located in San Rafael, California, and owned by The Dutra Group, is the primary supplier of quarry products for the Delta. Consequently, the SRRQ has the ability to respond in a timely manner in an emergency to directly load barges with product for delivery to the Delta.

Placement of erosion protection and repair of erosion damage can be carried out from land, if access permits. In this case, material is sourced from local quarries. Although BAU practices are summarized above, it is recognized that no failure of many islands (20 or more) at the same time has yet occurred to provide an experience base to define a usual or typical approach to emergencies involving tens of flooded islands in the Delta[1].

In the analysis, it is assumed an emergency response plan is in place including necessary pre-event preparedness[2]. As the magnitude of a levee failure event increases, the effect of a lack of emergency preparedness (in the context of the Phase 1 analysis and BAU) on the overall repair durations diminishes. Therefore, the model does not quantitatively account for such emergency preparedness preparations beyond the assumption that such preparations enable the model to meet the SRRQ production rates.

When a major event in the Delta occurs in which there are multiple levee failures and islands flooding, a number of factors will come into play that will determine how the emergency is managed and as a result what the eventual impact will be. These factors include the decisions that will be made by the governor and others in the chain command with respect to priorities that will be set, the range of emergency powers that will be exercised, the allocation of resources, the potential suspension of regulations (i.e., environmental regulations, local noise restrictions near the SRRQ, etc.),repair priorities, etc. The DRMS consulting team established the following conditions based on BAU for the ER&R analysis:

- It is assumed all flooded or damaged islands will be repaired after an event.
- Within days of a sequence of failures, local regulations will be eased or set aside to allow the SRRQ to operate on a 24-hour basis.

[1] Alternative rock sources will be considered in Phase 2 as a potential approach for enhanced emergency response.

[2] In fact this is not the case. However, for purposes of conducting the analysis, it is the basis from which the analysis is carried out. Delays and uncertainties associated with decision-making during an emergency in the Delta (the need to establish repair priorities; the political influences that may factor into the decision-making process; difficulties in establishing contracts with suppliers, etc.) are not modeled.

- Sufficient transportation equipment (i.e., deck barges, scows, and tugs) will be made available immediately to support initial material production rates, so that material supply capacity remains the constraint.[3]
- Resources (i.e., materials, equipment, and trained labor) are assumed to be available and will not be compromised by demands outside the Delta that occur as a result of the same seismic or flood event. Damage that occurs to assets other than levees will not put a demand on resources required to support levee breach repairs. This may be unconservative in the case of a major seismic event in the Bay Area (e.g., an earthquake on the San Andreas Fault) that causes significant damage to infrastructure systems (port facilities, bridges, etc.) that require marine equipment, etc. Even for these events, the governor may give priority to levee repair and restoring the Delta, such as in the case of a drought. For events that are more local to the Delta (e.g., an earthquake on the Southern Midland Fault), this assumption is reasonable.
- The effect of earthquake aftershocks which could potentially damage levees or compromise repair operations is not considered in the risk analysis (see Section 4).
- No constraints exist for dewatering resources. The need for pumps and related material (e.g., piping) to dewater an island is not required immediately following a levee failure since dewatering will start after breaches have been closed and damaged levees are stabilized (in the case of a seismic event) which will take a minimum of 3-4 weeks typically. As a result time is available to procure pumps, etc. With highway and rail transportation available in the region and the country, the geographic accessibility for dewatering resources is at least continent wide. Further, experience from the response to Hurricane Katrina indicates pumping resources world-wide can be made available (Times-Picayune 2005) in a timely manner.

These conditions, which are based on BAU, are a reasonable basis on which to define the bounds of the analysis and to establish a baseline measure of risk.

10.3 ONGOING DAMAGE

In the period following a levee failure event, damage will continue to accumulate until repairs have been made. This damage includes erosion of exterior levee slopes, potential levee overtopping due to flooding, interior levee erosion on flooded islands as a result of wind waves, and erosion of breach ends as a result of flows into and from islands during tidal exchanges. Prevention of ongoing damage (such as remediation of damaged sections of levee, capping of breached levee ends, and interior levee protection) is one element of the emergency response to levee failures. Each source of ongoing damage is discussed briefly in the following subsections.

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[3] This condition is based on the discussions with Dutra staff, the analyst's familiarity with Dutra's fleet and with other marine equipment generally active in the Bay Area. It also considers equipment available from other West Coast locations, given a mobilization period, to support increased production rates later in the repair period.

10.3.1 Exterior Damage

In the case of slumped levee sections (which may occur as a result of a seismic event) on a flooded island, overtopping from the exterior (from an episodic storm) will not result in further breaches, since equal heights of water occur on both sides of the levee. However, exterior damage could occur as a result of waves breaking on the crest instead of on the riprap, as a result of an exterior episodic event. This type of damage would be eroding (similar to interior slope erosion) over a short period of time, since it is episodic. Thus, it is likely not an important factor (it adds a little more to the material requirement of the already damaged levee section) and is, therefore, not included in the analysis.

10.3.2 Breach Growth

Breached levee sections will grow in length over time. A review of historic breaches in the Delta, and in particular those that have not been closed indicates that breach growth in the short term is not significant and therefore this source of continuing damage was not included in the analysis.

10.3.3 Wind-Wave Erosion

Wind-wave erosion on the levee's interior slopes will act on the intact and damaged levee sections throughout the repair period. This erosion manifests itself as additional (continuing) damage on an island (e.g., the Jones Tract failure in 2004). During a given levee failure event, rock will be required to add rip rap to provide erosion protection on levee interiors and/or to repair erosion damage that occurs.

The wave erosion that could occur following a levee failure event is random, due to the stochastic nature of winds (direction, duration, and velocity). In the DRMS analysis, levee erosion occurs following each levee failure event. The rate of erosion was estimated from a simulation that models the randomness of winds and waves in the Delta. The result is a set of mean erosion curves for each island that accumulates the amount of erosion until levee interior protection/repairs are carried out (see the Emergency Response and Repair TM for a more detailed description of the analysis [URS/JBA 2008d]).

The elements of the levee interior slope erosion model are illustrated in Figure 10-3 and are summarized in the following:

- Sets of mean erosion curves that predict the amount of erosion as a function of time are defined for each island sector (each island is subdivided into eight sectors, each consisting of 45 compass degrees)[4].
- With each day that passes following flooding of an island, erosion damage is accumulated on the intact and damaged levee sections of each island sector, based on wind and wave forces as generated by the wind/wave module (see Section 8).

[4] The levee reaches that are modeled in the analysis are mapped into the eight sectors on each island. The approach of modeling the islands by eight sectors is conservative, since the erosion model is applied to every foot of levee in the sector, which will not be the case since the winds will not directly impact every foot of the levee in the most detrimental direction for every event (i.e., wind waves will not approach every foot of the levee in a sector at 90 degrees, which is what is assumed in the analysis).

- Erosion occurs at the same rate along the entire levee perimeter of each island sector (as noted earlier, this is conservative).
- Erosion continues to act on the levee width (which is different for intact vs. damaged/slumped levee sections) at mean higher high water (MHHW). When the levee's width has been eroded down to a threshold level of 6 feet, it is assumed that the remaining portion of the levee fails, and the entire levee cross section above mean lower low water (MLLW) collapses and must be replaced for that specific levee segment.
- Accumulation of interior levee erosion damage on an island stops when the levee section fails (as defined above) or when laying of rock for protection of the levee interior is commenced. The amount of rock laid is based on the amount required for the layer of protection plus the amount required to replace the eroded section that has been accumulated to that point.

10.3.4 Secondary Breaches on Non-flooded Islands

When a seismic event occurs, levee reaches on an island may be damaged, but not breached. Due to the damage that has occurred on these non-flooded islands (crest slumping and loss of freeboard, embankment disruption), the damaged levees could fail at a later time, as a result of a storm event that causes overtopping and subsequent breach. Depending on the levee failure sequence (the number of islands involved and the extent of damage that must be repaired), the repair period could extend many months or years. As the exposure of non-flooded islands (that have not been repaired) increases, the probability that an island will experience high water levels due to flooding and/or episodic wave events that could lead to overtopping, levee failure and island flooding increases as well.

Factors that contribute to the potential for subsequence failure of non-flooded islands include:

- Timing of levee repairs and their completion (following the event)
- The extent of the non-breach damage that has occurred on an island (e.g., 500 feet or 5000 feet of damaged levee)
- Probability of experiencing high-water elevations and/or episodic wave events that erodes damaged levee sections resulting in a breach, overtops the levee, or causes a piping failure through the damaged embankment.
- The potential for local efforts to successfully initiate levee protection efforts (rock placement, visquine placement, sandbagging, etc. that avoids a possible failure.

Each of these events is random (stochastic) in nature. In the ER&R analysis, a simplified model is used to estimate the probability that damaged, non-flooded island will fail.

10.4 PRIORITIZING REPAIRS

Deciding on the relevant factors and relative priorities for allocating scarce resources to levee repairs in an emergency situation depends on the location and magnitude of the levee failure event (i.e., the number of levee failures that occurred and the number of islands involved). As part of the levee emergency response and repair analysis some structure for making these decisions is required to guide the order of repairs that must be made.

This section discusses the factors considered to establish a BAU approach to levee repair. It is worth noting that actual priorities set in a real emergency will undoubtedly prove to be different considering the situation that must be addressed.

Purpose. The purpose of the prioritization approach is to allocate levee repair resources for a levee failure event. In the analysis, once an island is designated for repair, all repairs that are required are made for that island.

Objective. The objective that has been established for this priority system is very broad. The system is to allocate resources to island repairs in a way that best responds to the interests of the state (given BAU). The system developed attempts to be clear, unambiguous, and workable.

Factors, The factors considered in the priority system include the following:

- Flooded state – i.e., is an island or tract already flooded or is it in danger of flooding?
- Population – What is the population of the island or tract?
- Infrastructure – What infrastructure is flooded (or threatened) and what are the impacts?
- Export Salinity Impact – What is the relative impact of this island or tract (or group of areas) on salinity at the export pumps and on the ability to export?

For each of these factors, the islands (analysis zones) are ordered going from most important to least important. The order for a factor is fixed; it does not vary from levee failure sequence to sequence.

Repairs for Flooded Islands. The sequence of repairs for flooded islands is presented below:

- Cap all breach ends
- Control ongoing interior damage
- Close the breach
- Repair non-breach damage
- Pump out the island

The proposed repair sequence is based on experience with emergency response in the Delta. The highest priority is to control ongoing damage. Thus, marine repair resources are allocated to capping and interior protection first on all islands (as long as they can be used effectively). Then they move on to breach closure and island pump out on an island priority basis.

Repairs for Non-flooded Islands. Repairs are made on damaged non-flooded islands as the top priority. Thus, RT1 is the top priority for all "significant" islands.

Significant Islands. In this analysis, "Significant" islands are defined on the basis of population, infrastructure, and flooding volumes/locations that impact salinity relative to water export. The list of "significant" islands (or analysis areas) is provided in Table 10-1. All "significant" islands are addressed by this priority system in Categories A and B, as explained below.

Prioritization of Levee Repairs. Three priority categories are established as follows:

- A – Islands/areas threatened but not yet flooded
- B – Islands/areas already flooded

- C – All islands/areas not addressed by Categories A or B (Delta and Suisun Marsh islands not listed in Table 10-1)

For a given levee failure sequence involving a series of flooded and/or damaged islands, each island is placed in one of the above categories. The highest priority is given to Category A, then B, then C.

Within a category, islands are ranked based on the factors identified above (e.g., population, etc.). This ordering is used to define the island priority and the work order for individual repair types that are input to the analysis. The levee emergency response and repair model uses the island and work order priorities that are set (as defined by A1 through A16; see Table 10-2 for the list of priorities) in the order specified. If no assignment is found in Priority Category A (threatened but not flooded) the search continues in Priority Category B (islands already flooded). Finally, model considers Priority Category C (islands that were not included in A or B).

Population. The population categories were established based on the estimated 2005 population. Where population data were not readily available, estimates were based on the number of households as estimated by the DRMS economic consequence evaluation team. Four population groups were defined: 10,000 or more, 5,000 but less than 10,000, 1,000 but less than 5,000, and 500 but less than 1,000. Areas with less than a population of less than 500 were not considered to have population preference. Island priorities based on population are given in Table 10-3. Within each group, islands are listed in priority order.

Infrastructure. In the case of islands that have flooded, much of the critical infrastructure can be put back into service before an island is repaired and pumped out. This situation is true for interstate highways, electrical transmission lines, the Mokelumne Aqueduct, and the railroad. Thus, the only infrastructure items that enter into a decision on which flooded island should be repaired next are as follows:

- State highways (12, 4, and 16)
- Natural gas storage and retrieval (McDonald Tract)

Since traffic can be rerouted around the impassable area, the state highways generally do not get a high priority (for flooded islands). For non-flooded islands, the presence of a state highway is considered to be associated with a higher priority.

The DRMS economic consequences evaluation team analyzed the effect of infrastructure damage and downtime to business (see the Economic Consequences TM [URS/JBA 2008f]) and found that the loss of gas storage and retrieval on McDonald Tract would not have a major regional impact, so it does not receive a high priority except where flooding might be prevented.

When an island has been damaged, but not flooded, the infrastructure priority is based on preventing damage to:

- Mokelumne Aqueduct
- State highways
- Railroads
- MacDonald Island's natural gas storage and retrieval facility

Infrastructure priority groups are listed in Table 10-4. Within each group, islands are listed in priority order.

Salinity. The salinity priority categories are based on the DRMS and other hydrodynamic calculations that have been performed using the RMA Bay-Delta model (RMA 2005), After reviewing the available hydrodynamic calculations, the DRMS consulting team set priorities for individual islands that, when flooded with saline waters, would be most disruptive to water exports. Hydrodynamic calculations indicate that salinity intrusion deep into the southern Delta must be avoided if possible by defending threatened south Delta islands (JBA 2005). These calculations found that south Delta islands were the dominant interference for water exports. As a result, if salinity intrusion on these islands occurs, levee repairs to the southern Delta islands is given the top salinity priority.

Based on a review of the available hydrodynamic calculations involving multiple islands flooding and alternative levee repair sequences, a prioritization for levee repairs and salinity importance was set. The south Delta islands are addressed as Old River first, then Middle River, and then San Joaquin River. Next, the islands in the western Delta are important. Lastly, islands in the eastern and northern Delta are considered. Modeling experience suggests the eastern and northern islands that are flooded do freshen while the southern, central, and western Delta islands are repaired. The salinity priority groups are listed in Table 10-5. Within each group, islands are listed in priority order.

Within the three factors considered (population, infrastructure, and salinity), population and infrastructure are given higher priority when an area is unflooded and damage might be prevented than would be the case when the flooding has already occurred.

Within each priority category (A and B) the relative priority given to population versus infrastructure versus salinity is based on a subjective consideration of the categories' overall "interest to the state."[5] When flooding might be prevented on a threatened (damaged island), the highly populated areas are given a high priority. Thus, areas with 5,000 or more residents get highest consideration. At the same time it is important to avoid disrupting the state's water supply and also to prevent damage to other infrastructure. Thus, these factors dominate (and compete for resources) where the goal is to prevent further flooding (flooding on non-flooded islands). A salinity group comes next, then an additional population group, an infrastructure group and so forth.

When flooding has occurred on an island(s), the "state's interest" gives a high priority to repairs that restore the state's water supply. At the same time, there is also a competing interest to restore flooded islands that have large populations. To meet these needs, a portion of the marine-based repair resources is allocated to areas with populations of 5,000 or more. Otherwise, full attention is devoted to the repair of islands important to restoration of water exports in priority order.

Table 10-6 presents the island/area priority order that results for non-flooded (Category A) and flooded (Category B) islands/areas addressed as "significant."

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[5] The priority system that is implemented in the levee emergency response and repair analysis is a mechanism for carrying out the analysis. It is based only on general principles discussed with DWR during the course of the project. The priority system that is implemented is a starting point for carrying out the risk analysis (a means of establishing a baseline), given the fact an emergency response plan and a priority system do not exist.

For the islands and tracts not listed above (Category C), priority is assigned on the basis of island acreage.

10.5 IMPLEMENTING LEVEE ER&R IN THE DELTA

The ER&R model is used to estimate the time and material required to recover from levee failure(s). It estimates the time to repair islands and associated costs to stabilize damage levee section, prevent further damage, close breaches, and dewater flooded islands following levee failure(s). Given a sequence that identifies a set of levee breaches and/or damage throughout the Delta, the ER&R model makes an assessment of the ability to respond.

As discussed in Section 10.2, a number of factors will affect the repair of levees after a major event. These factors range from the lack of an emergency response plan that includes a strategy for undertaking the repairs to the response of state leaders to an emergency in the Delta. In this context, the ER&R model provides a starting point for evaluating risks and examining the role of emergency response strategies. Assumptions have been made to carry out the emergency response, because no detailed emergency response plans exists for the Delta and the region as whole that covers the issues listed below:

- After a major seismic event in the Bay Area, barge navigation will be interrupted if bridges have collapsed. In the ER&R analysis no interruption to barge navigation are considered.
- The time required to put contracts into place with companies that will participate in the levee repairs, which could vary from event to event, have not been addressed.
- If the SRRQ is required to obtain permits to increase their production (such as the construction of a second loading facility, it is unknown if this can be done in a timely manner, or if the permitting requirements can be waived. The potential impact of delays due to regulatory or other requirements as they might effect the SRRQ production and delivery have not been considered in the ER&R analysis.
- It may take longer than 180 days (a threshold assumed in the analysis) to bring other sources of material on line. The State will have to make the decision when to call in help from non-local sources, such as Catalina Island, Canada, or Mexico.
- After a seismic event numerous projects may compete for the same resources. The State will have to make the call on prioritization of competing projects. We assumed that some of the needed material and equipment will not be readily available.

Actual results for repair times and repair costs are presented in Section 13, which addresses specific cases that are used to develop risk results from several different levee breach events.

Table 10-1 Significant Islands for Repair Prioritization

(Based on Population, Infrastructure, and Volume/Salinity)

Bacon Island	Rough & Ready Island
Bethel Island	Ryer Island
Bishop Tract	Sacramento Pocket Area (196)
Bouldin Island	Sargent-Barnhart Tract 2 (188)
Brack Tract	Sherman Island
Bradford Island	Shima Tract
Brannon-Andrus Island	Shin Kee Tract
Byron Tract 1 (127)	SM-124 (Suisun Marsh, Southwest of Suisun City)
Byron Tract 2 (128)	Staten Island
Canal Ranch	Sutter Island
Coney Island	Terminous Tract 2 (87)
Discovery Bay	Twitchell Island
Empire Tract	Tyler Island 1 (Walnut Grove; 62)
Fabian Tract	Tyler Island 2 (63)
Grand Island	Union Island 1 (117)
Hastings Tract 2	Veale Tract 2 (129)
Holland Tract	Venice Island
Hotchkiss Tract 1 (108)	Victoria Island
Jersey Island	Webb Tract
Jones Tract (Upper and Lower)	West Sacramento North
King Island	West Sacramento South 1
Mandeville Island	Woodward Island
McDonald Tract	Wright Elmwood Tract (190)
Medford Island	Wright-Elmwood/Sargent-Barnhart Tract (191)
Netherlands 3 (142)	Zone 126 (Pico Naglee, north Tracy)
New Hope Tract	Zone 148 (E of Sac River near Hood)
Orwood Tract (20)	Zone 157 (Smith Tract, West Stockton)
Palm Tract (16)	Zone 158 (Weber Tract, West Stockton)
Pierson District 1 (149)	Zone 159 (Boggs Tract, West Stockton)
Quimby Island	Zone 185 (Northwest Stockton)
RD 17 Mossdale (Lathrop Area)	Zone 197 (E of Sac River N of Hood)
Ringe Tract	Zone 37 (North Shore Suisun Bay near Benicia Bridge)
Rio Blanco Tract	Zone 68 (Little Egbert Tract)
Roberts Island (Middle, 154/Lower, 106)	Zone 70 (Egbert Tract)
	Zone 76 (Freeport-Franklin)

Note: It is assumed all flooded or damaged islands will be repaired after an event.

Table 10-2 Priority Group Order for Unflooded and Flooded Islands

Priority Group Order – Islands That Are Threatened But Not Yet Flooded	Priority Group Order – Flooded Islands
A1 – Population A (>/= 10,000)	B1 – Flooded Population Areas A & B
A2 – Population B (>/= 5,000)	B2 – Salinity 1
A3 – Salinity 1	B3 – Salinity 2
A4 – Infrastructure A	B4 – Salinity 3
A5 – Population C (>/= 1,000)	B5 – Salinity 4
A6 – Salinity 2	B6 – Salinity 5
A7 – Infrastructure B	B7 – Infrastructure B
A8 – Population D (>/= 500)	B8 – Population C
A9 – Salinity 3	B9 – Population D
A10 – Salinity 4	B10 – Infrastructure D
A11 – Infrastructure C	B11 – Salinity 6
A12 – Infrastructure D	B12 – Salinity 7
A13 – Salinity 5	B13 – Salinity 8
A14 – Salinity 6	
A15 – Salinity 7	
A16 – Salinity 8	

Table 10-3 Population Priority Groups (Islands/Areas in Priority Order)

Population A (>/= 10,000) Zone 196 (South Sacramento/pocket) ***Population B (>/= 5,000 but < 10,000)*** West Sacramento North Zone 157 (Smith Tract, West Stockton) Wright-Elmwood Tract/Sargent-Barnhart Tract (West Stockton) Zone 76 (Freeport-Franklin) Sargent-Barnhart Tract 2 (West Stockton) Discovery Bay ***Population C (>/= 1,000 but < 5,000)*** RD 17 Mossdale (Lathrop Area) Shima Tract (Northwest Stockton) Zone 159 (Boggs Tract, West Stockton) Zone 185 (Northwest Stockton) West Sacramento South 1	***Population C (cont.)*** Zone 158 (Weber Tract, West Stockton) Bethel Island Brannon-Andrus Island SM-124 (Suisun Marsh, SW of Suisun City) Grand Island New Hope Tract Netherlands ***Population D (>/= 500 but < 1,000)*** Hotchkiss Tract Zone 126 (Pico Naglee, north Tracy) Zone 37 (North Shore Suisun Bay near Benicia) Roberts Island (Middle, 154/Lower, 106) Pierson District Terminous Tract Tyler Island 1 Union Island

Table 10-4 Infrastructure Priority Groups (Islands/Areas in Priority Order)

Infrastructure A (Mokelumne Aqueduct, if island is not already flooded)	***Infrastructure B (cont.)***
Orwood	*Hwy 160* (cont.)
Woodward	Brannon-Andrus Island
Jones Tract	Grand Island
Roberts (Middle/Lower)	Sutter Island
Wright-Elmwood/Sargent-Barnhart	Pierson District
Infrastructure B (State Highways)	Zone 148
Hwy 12	Zone 197
Brannon-Andrus	Sacramento Pocket Area (196)
Bouldin	***Infrastructure C (Railroad, if island is not already flooded)***
Terminous	
Hwy 4	
Byron	Boggs Tract (159)
Victoria	***Infrastructure D (Natural Gas Storage and Retrieval)***
Roberts (Middle/Lower)	McDonald Tract
Hwy 160	
Sherman Island	

Table 10-5 Salinity Priority Groups (Islands/Areas in Priority Order)

Salinity 1 (Old River Corridor, South to North)	***Salinity 4 (West Delta)***
Union	Twitchell
Victoria	Bradford
Fabian	Jersey
Coney	Sherman
Byron 2	***Salinity 5 (San Joaquin River – Upstream*** South to North)
Byron 1	Rough & Ready
Woodward	Wright Elmwood
Orwood	Wright Elmwood / Sargent Barnhart
Palm	RD17 Mossdale
Bacon	***Salinity 6 (North Delta)***
Veale	Terminous
Holland	Staten
Hotchkiss	Tyler 2
Bethel	Grand
Quimby	Ryer
Salinity 2 (Middle River Corridor, South to North)	Little Egbert
Roberts (Middle/Lower)	Egbert
Jones	Hastings 2
McDonald	Pierson
Mandeville	Sutter
Salinity 3 (San Joaquin Corridor, Southeast to Northwest)	Netherlands
Ringe	***Salinity 7 (East Delta A)***
King	Brack
Empire	Canal Ranch
Medford	New Hope
Venice	***Salinity 8 (East Delta B)***
Bouldin	Shima
Brannon-Andrus	Bishop
Webb	Rio Blanco
	Shin Kee

Table 10-6 Resulting Island/Area Prioritization

Category A – Unflooded	Category B – Flooded
Sacramento Pocket Area (196)	Sacramento Pocket Area (196)
West Sacramento North	West Sacramento North
Zone 157 (Smith Tract, West Stockton)	Zone 157 (Smith Tract, West Stockton)
Wright-Elmwood/Sargent-Barnhart Tract (191)	Wright-Elmwood/Sargent-Barnhart Tract (191)
Zone 76 (Freeport-Franklin)	Zone 76 (Freeport-Franklin)
Sargent-Barnhart Tract 2 (188)	Sargent-Barnhart Tract 2 (188)
Discovery Bay	Discovery Bay
Union Island 1 (117)	Union Island 1 (117)
Victoria Island	Victoria Island
Fabian Tract	Fabian Tract
Coney Island	Coney Island
Byron Tract 2 (128)	Byron Tract 2 (128)
Byron Tract 1 (127)	Byron Tract 1 (127)
Woodward Island	Woodward Island
Orwood Tract (20)	Orwood Tract (20)
Palm Tract (16)	Palm Tract (16)
Bacon Island	Bacon Island
Veale Tract 2 (129)	Veale Tract 2 (129)
Holland Tract	Holland Tract
Hotchkiss Tract 1 (108)	Hotchkiss Tract 1 (108)
Bethel Island	Bethel Island
Quimby Island	Quimby Island
Jones Tract (Upper and Lower)	Roberts Island (Middle, 154/Lower, 106)
Roberts Island (Middle, 154/Lower, 106)	Jones Tract (Upper and Lower)
RD 17 Mossdale (Lathrop Area)	McDonald Tract
Shima Tract	Mandeville Island
Zone 159 (Boggs Tract, West Stockton)	Ringe Tract
Zone 185 (Northwest Stockton)	King Island
West Sacramento South 1	Empire Tract
Zone 158 (Weber Tract, West Stockton)	Medford Island
Brannon-Andrus Island	Venice Island
SM-124 (Suisun Marsh, Southwest of Suisun City)	Bouldin Island
Grand Island	Brannon-Andrus Island
New Hope Tract	Webb Tract
Netherlands 3 (142)	Twitchell Island
McDonald Tract	Bradford Island
Mandeville Island	Jersey Island
Bouldin Island	Sherman Island
Terminous Tract 2 (87)	Terminous Tract 2 (87)
Sherman Island	Grand Island
Sutter Island	Sutter Island
Pierson District 1 (149)	Pierson District 1 (149)
Zone 148 (E of Sac River near Hood)	Zone 148 (E of Sac River near Hood)
Zone 197 (E of Sac River N of Hood)	Zone 197 (E of Sac River N of Hood)
Zone 126 (Pico Naglee, north Tracy)	Rough & Ready Island
Zone 37 (North Shore Suisun Bay near Benicia Bridge)	Wright Elmwood Tract (190)
Tyler Island 1 (Walnut Grove; 62)	RD 17 Mossdale (Lathrop Area)
Ringe Tract	Shima Tract
King Island	Zone 159 (Boggs Tract, West Stockton)
Empire Tract	Zone 185 (Northwest Stockton)

Category A – Unflooded	Category B – Flooded
Medford Island	West Sacramento South 1
Venice Island	Zone 158 (Weber Tract, West Stockton)
Webb Tract	SM-124 (Suisun Marsh, Southwest of Suisun City)
Twitchell Island	New Hope Tract
Bradford Island	Netherlands 3 (142)
Jersey Island	Zone 126 (Pico Naglee, north Tracy)
Rough & Ready Island	Zone 37 (North Shore Suisun Bay near Benicia Bridge)
Wright Elmwood Tract (190)	Tyler Island 1 (Walnut Grove; 62)
Staten Island	Staten Island
Tyler Island 2 (63)	Tyler Island 2 (63)
Ryer Island	Ryer Island
Zone 68 (Little Egbert Tract)	Zone 68 (Little Egbert Tract)
Zone 70 (Egbert Tract)	Zone 70 (Egbert Tract)
Hastings Tract 2	Hastings Tract 2
Brack Tract	Brack Tract
Canal Ranch	Canal Ranch
Bishop Tract	Bishop Tract
Rio Blanco Tract	Rio Blanco Tract
Shin Kee Tract	Shin Kee Tract

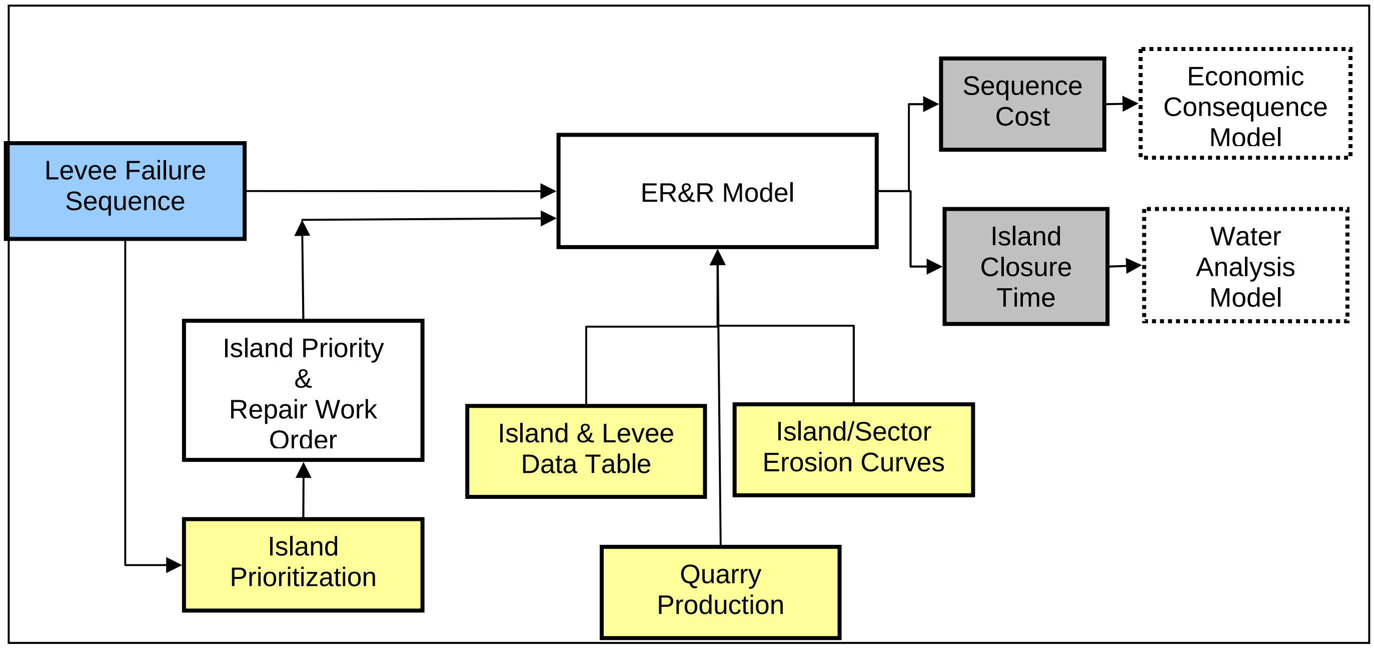

Figure 10-1 DRMS Levee Emergency Response and Repair Approach

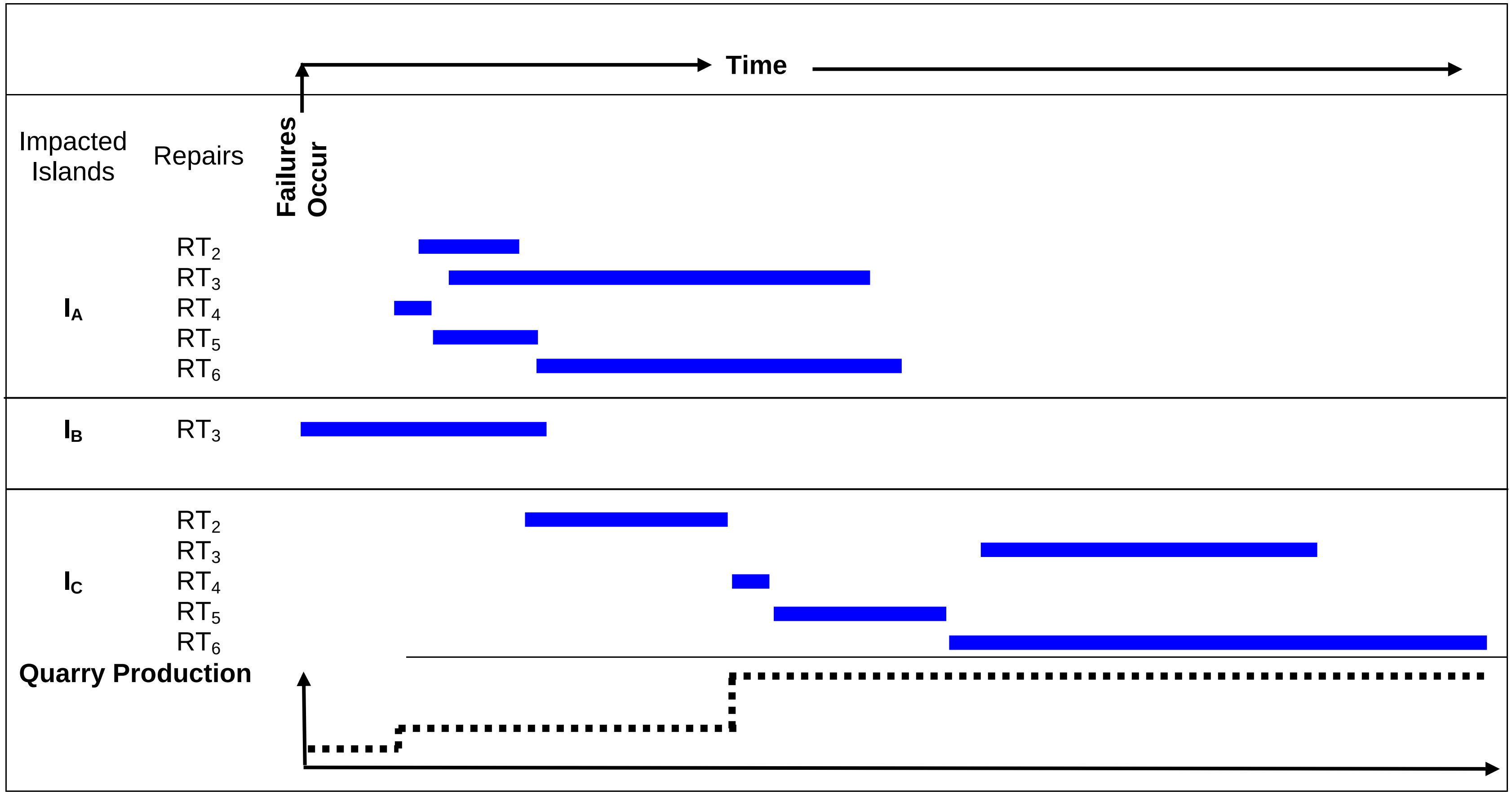

Figure 10-2 Schematic Illustration of the ER&R Model Timeline of Repairs for a Levee Failure Sequence

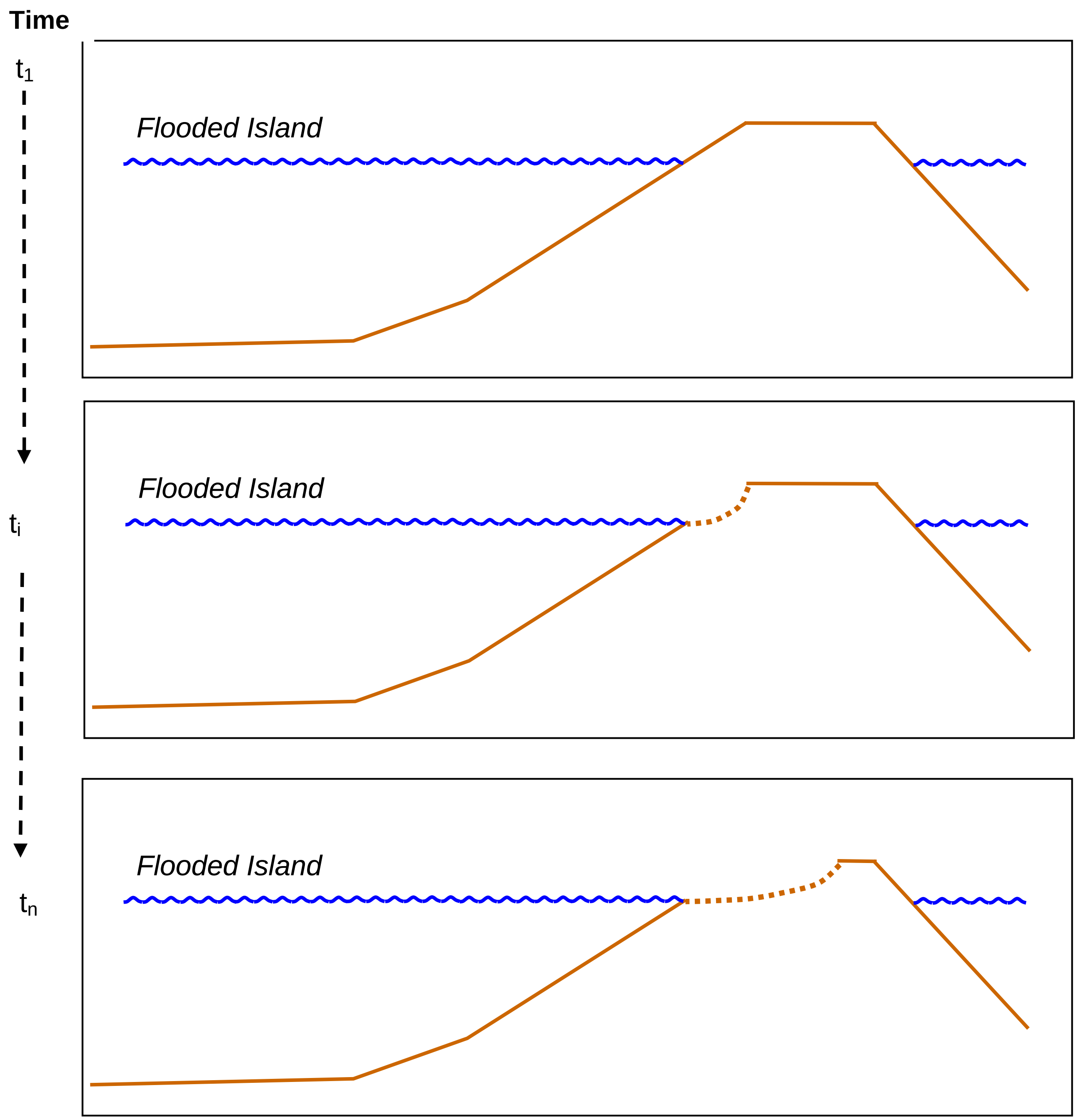

Figure 10-3 Schematic Illustration of the Levee Interior Erosion Model

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One or more Delta levee breaches that result in island flooding may impact Delta water quality (most obviously salinity) and water operations. A substantial amount of saline water may be drawn in from the Bay – depending on the initial salinity of the river/Delta/Bay system, river inflows at the time of the breach event, and the number, size, and locations of the breaches and flooded islands. Subsequently, salinity may be dispersed and degrade Delta water quality for a prolonged period due to the complex interrelationship between ongoing Delta inflows, tidal mixing, and the breach repair schedule. Other water quality measures, such as organic carbon, are also important. However, the essential first step in characterizing Delta water quality, in context of a levee breach event, is to characterize salinity.

Tracking of any contaminant in the Delta waterway system is dependent on first being able to accurately simulate the movement and mixing of Delta waters – that is, Delta hydrodynamics. Salinity is the obvious marker for tracking the movement and mixing of Delta waters. It is ubiquitous, easily measured, and exhibits strong variations due to the low salinity of fresh water inflow, the high salinity of Bay waters, and the strong tidal hydrodynamic movement and mixing. Unless salinity movement, mixing and resulting concentration gradients can be accurately represented, a model will not be able to track the movement, mixing, and concentration variations of any other contaminant. Modeling salinity is the essential first step and is the only water quality parameter used for the DRMS Phase 1 risk analysis.

A given levee breach scenario considered in the DRMS risk analysis is identified and specified by the modules discussed in previous sections – seismic or flood hazard, levee vulnerability, and emergency response. The Water Analysis Module (WAM) receives the specifics of the breach event as input and simulates direct, salinity-related consequences of the event. Specifically, WAM incorporates:

- Initial island flooding
- Upstream reservoir management response
- Delta water operations
- Salinity disruption of Delta irrigation
- Delta net water losses (or net consumptive water use)
- Hydrodynamics
- Delta water quality (initially represented by salinity)
- Water exports as impacted by salinity

The module is central to the risk analysis, as illustrated in Figure 11-1, receiving the description of each breach scenario (e.g., resulting from a seismic or other event) and the details of the levee repair process from the emergency response and repair part of the analysis. The model produces hydrodynamic, water quality (salinity), and water supply consequences for use in the economic and ecosystem modules. The water quality consequences of levee failures in the Delta are dependent not only on the initial state of the Delta at the time of failure, but also on the time series of tides, inflows, exports, other uses, and on the water management decisions that influence these factors. Thus, WAM is the model that tracks water management and the Delta's water quality response starting before the initial breach event and proceeding through the breach, emergency operations, repair, and recovery period. The model is a key link in facilitating assessment of ecosystem and economic consequences and associated risks.

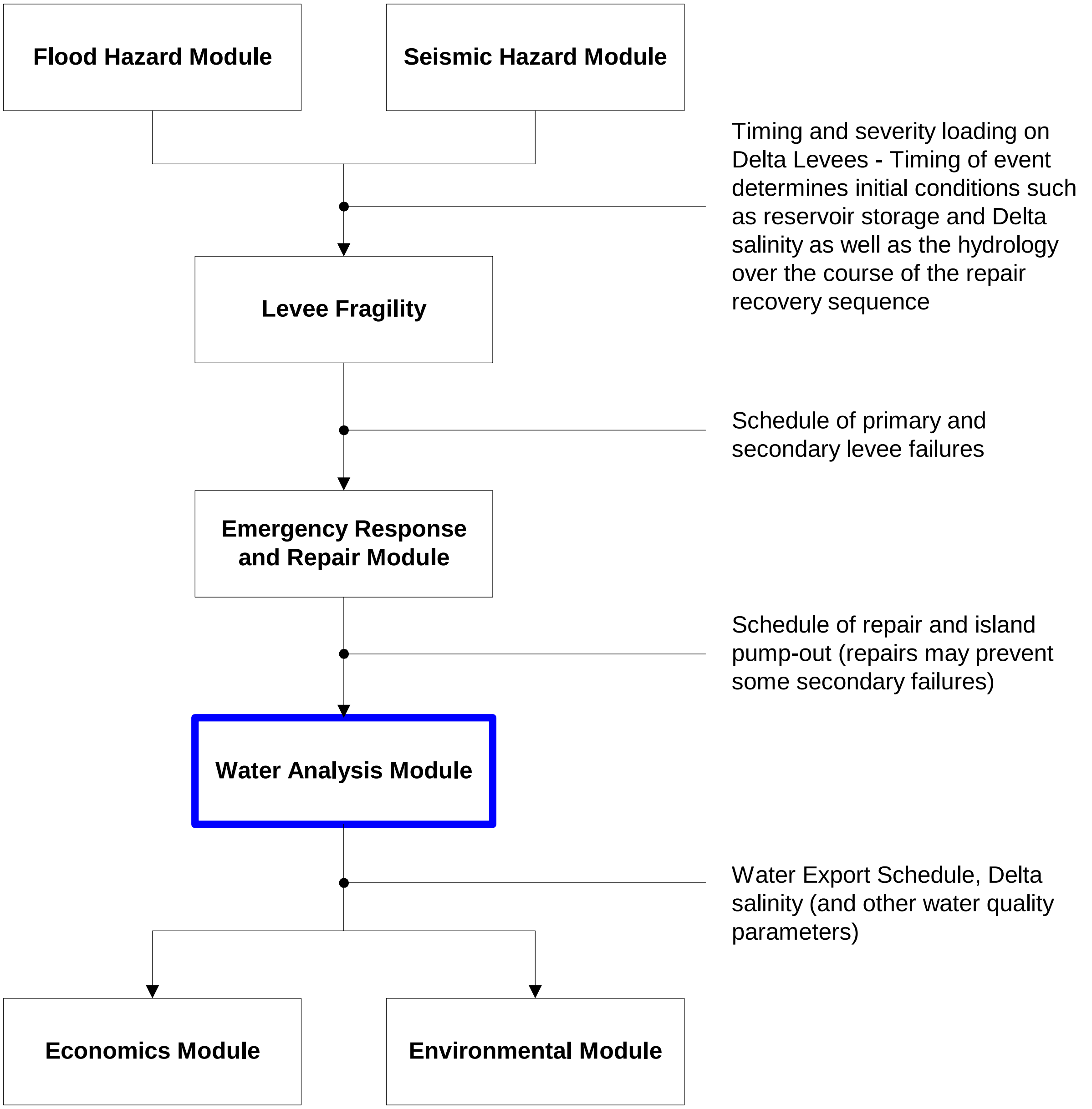


Figure 11-1 Position of the Water Analysis Module in the Risk Analysis Framework

The Water Analysis Module Technical Memorandum (TM) (URS/JBA 2007e) presents more detailed information on the WAM and its use to estimate salinity impacts. Note that available schedule and budget have not allowed incorporation of other water quality parameters into WAM. Additional parameters, such as organic carbon, can be incorporated during a subsequent model development phase. Since organic carbon is important to urban water agencies, a preliminary analysis of potential organic carbon increases caused by contact of waters with flooded island organic soils has been provided in Appendix I of the Water Analysis Module TM (URS/JBA 2007e). The results of the preliminary analysis indicate that increased organic carbon concentrations are potentially very significant, that organic carbon should be modeled in more detail, and that island dewatering should be managed to minimize organic carbon impacts. This effort would require extensions of both WAM and the Emergency Response and Repair Module.

11.1 OVERVIEW

11.1.1 Background

In the past, water management modeling (calculating quantities of Delta inflows and outflows) and Delta hydrodynamics/water quality modeling have usually been conducted separately. Few modeling efforts of either type have addressed levee breaches.

The models of either type that are most capable for this application tend to be elaborate and sophisticated. They would be impractical in the context of a risk analysis that is to examine many scenarios, primarily because they require large amounts of computation time.

The CalSim model (Draper et al. 2004) is the recognized state-of-the-art for simulating the translation of hydrologic inputs to the Delta tributaries into storage in upstream reservoirs, allocations for various uses, and inflows into the Delta. It is a monthly simulation model designed to use a defined development state (e.g., 2005) and to then simulate monthly water management for historical hydrologic inputs (1922 to 2003).

CalSim bases its management on the need to meet Delta water quality standards by including an Artificial Neural Network feature that is trained to estimate required Net Delta Outflow using a DWR Delta salinity model (DSM2) for the normal Delta configuration (no levee breaches). It has no present ability to represent Delta levee breaches. It is useful for DRMS as a base case, with no breaches (see URS/JBA 2007e, Appendix C).

Several hydrodynamic models of the Delta can be used to simulate its hydrodynamic interaction with fresh water inflows and San Francisco Bay's tidal action and salinity. Model outputs generally include time varying flows and salinity at selected stations in the Delta. The models include DSM2 (DWR 2008), which is a one-dimensional model (including tidal movements), the RMA Bay Delta model (see URS/JBA 2007e, Appendix D), which is a two-dimensional (depth averaged) model (including tides), and TRIM and UnTRIM (see URS/JBA 2007e, Appendix H), which are three-dimensional models (including tides).

Each of those models simulates Delta hydrodynamics on a short time interval (e.g., 7.5 minutes) and relatively fine spatial grid so that it captures tidal variations. This requires the models to use large amounts of computer time for any one scenario, especially if it requires several years of simulation.

The RMA Bay Delta Model has previously been used to represent Delta levee breach events (JBA 2005). However, as described in the Water Analysis Module TM (URS/JBA 2007e, Appendix D), even with this capability, the RMA Bay Delta Model is too computationally intensive and its best use is for calibrating a simpler, more-efficient model.

Similarly, the three-dimensional models are used for calibrating simpler models. A key simplification adopted in WAM is to use a tidally averaged model and include the effects of tidal mixing through the use of dispersion coefficients.

In the prior assessment of risks to water quality and water uses from Delta levee failures (JBA 2005), the RMA Bay Delta model was used, but only two scenarios were simulated – a 20–islands-flooded case and a 19-islands-flooded case (where Sherman Island was assumed to be hardened so it was no longer seismically vulnerable).

Only one earthquake and event initiation time was considered: July 1, 2002. In the present case, DRMS requires consideration of many other failure scenarios and different start times for each.

Also, historic Delta inflows were used in the previous study. This was a convenient assumption for a preliminary analysis, but it is recognized that an effort will be made to adjust upstream reservoir releases to flush salinity and reestablish fresh conditions for in-Delta water use and exports, providing sufficient stored water is available. This will require new simulation capabilities as well as decreased computation time.

11.1.2 Objectives

The following are the objectives established for the Water Analysis Module:

- WAM must provide simulation results (water storage and flows and Delta salinity throughout the event) for a wide variety of levee breach events – results that are adequate to characterize economic and environmental consequences, including salinity impacts on in-Delta irrigation and state and federal water exports.
- WAM must be practical (computationally efficient) for evaluating many (potentially thousands of) levee failure scenarios – that is, various combinations of flooded islands and various event initiation times associated with different seasons and hydrologic conditions.

11.1.3 Approach

Because a complex interrelationship exists between reservoir operations upstream of the Delta, hydrodynamics and water quality within the Delta, and the ability to use or export water from the Delta, these features of WAM within the risk analysis framework are combined into a single module. When an emergency occurs, decisions will be made to manage ongoing reservoir releases and Delta exports based on the water quality of the Delta, so it is not possible to set release or export strategies without considering the evolution of Delta water quality. In WAM, water quality conditions are initially represented by salinity; other measures of water quality can be added later, if desired.

The decision submodels incorporated into WAM calculate Delta water operations, upstream reservoir releases, and exports immediately after a breach event and throughout the repair/recovery period. The decision submodels are based, to the extent possible, on operating rules included in existing models of the California water system, water rights, water quality standards, contractual requirements, and operating guidelines.

CalSim is an example of an existing model that includes operations components. However, because it does not consider levee breach emergencies, different operating rules than those currently included in CalSim are required to manage water operations in response to such an emergency.

Considerable input was required from operators and policy makers responsible for managing the state and federal water systems to develop the decision submodels. The initial versions of the models reflect this input, but the amount of input was constrained by the limited schedule and budget. Additional input is needed and will be reflected in future versions of the models.

The overall WAM simulation of a levee breach scenario has been subdivided into three phases, as illustrated in Figure 11-2, to reflect the dramatically different hydrodynamic and water management situations that define each phase. The phases in WAM simulation can be described as follows:

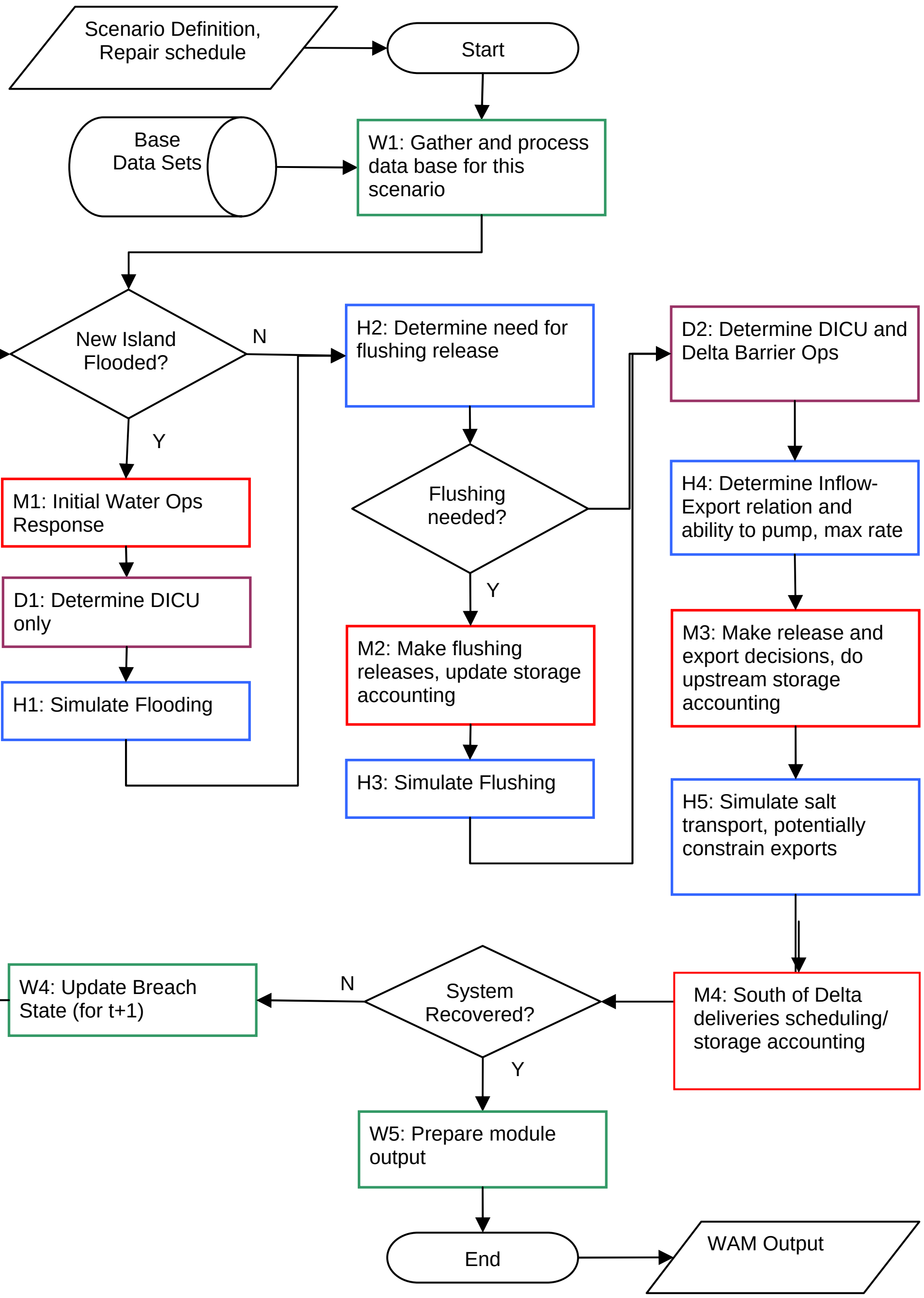


Figure 11-2 Schematic of the WAM Calculations

- **Island Flooding (on the left in Figure 11-2) –** The rush of water filling an island(s) immediately following a levee breach will often dominate Delta water flow or hydrodynamics (especially in the dry season or after multiple, approximately simultaneous levee breaches). Island flooding may take up to several days. The water needed to fill the islands comes initially from adjacent Delta channels, but the effect will be felt at an ever-expanding spatial scale. Ultimately, the total volume required to fill the islands and restore overall balance will come from river inflows and/or flow from Suisun Bay.

  The hydrodynamics submodel considers the initial flow and salinity conditions in the Delta (as obtained from CalSim results for the selected event initiation time); calculates the sources, amounts and distribution routes of the required inflows; and characterizes the resulting Delta salinity distribution at the time a stable flow situation reestablishes (post flooding). The "flooding" phase of WAM accomplishes this modeling task.

- **Flushing (in the middle in Figure 11-2) –** During the flushing period, WAM's focus is on the Delta fresh water inflows, tidal mixing, dispersion and dilution of salinity, and the gradual movement or reestablishment of a fresh water/saline water interface at a more normal downstream location. Upstream reservoir management and flushing releases are primary considerations, and the hydrodynamics and water quality submodel is focused on characterizing the distribution and timing of water quality improvements that result from flushing.

  Pumping for export during the flushing period could exacerbate the situation by drawing saline water into the Delta. Specifically, the south Delta can be very strongly impacted by salinity intrusion. Previous modeling (JBA 2005) suggests the south Delta may experience a degraded water quality condition and prolonged disruption. Under such conditions, adverse results would include prolonged noncompliance with water quality standards for environmental (in channel) conditions, local (Delta area) uses and exports.

- **Limited Pumping (on the right in Figure 11-2) –** When Delta water quality is sufficient to allow in-Delta use and export pumping, the WAM focus shifts to maintenance of the Delta's water quality and deciding how much upstream reservoir water can be used in support of export pumping. These decisions are not straightforward. Maintaining Delta water quality when several islands are still flooded requires more than the usual inflow of fresh water because of the extra volume of tidal inflow and outflow under breach conditions (due to flow into and out of flooded islands) and the resultant increased mixing. Additionally, the amount of water required, over and above the amount of pumping to prevent quality degradation (i.e., carriage water), will also increase. If poorly considered decisions are made, the upstream reservoir storage may be significantly depleted or opportunities for additional export could be missed.

  The WAM calculator simulates these upstream reservoir operation and pumping decisions until Delta levee repairs are completed and both pumping and reservoir storage return to normal. Obviously, these decisions and the resulting Delta water quality have impacts on in-Delta uses and the ecosystem as well as exports.

WAM simulates the water-quality consequences of the levee breach occurrence, repair and water management responses, Delta inflows, Delta hydrodynamics, and water quality through time – in some cases, through an extended period of time. To avoid iteration – a computationally intensive approach – WAM calculations for the current time step rely only on the calculation results from the previous time step. Internally, WAM includes several processes (such as island flooding and Delta flushing) that must be addressed on a daily basis. Thus, a daily interval is the basic time step used. However, the overall results of Delta water quality, changes in reservoir storage, exports, and other items used to assess consequences are reported monthly.

At the daily time step, the model includes tidal averaging simplifications as an approach to achieve computational efficiency. This approach is made possible by using dispersion coefficients to capture the impacts of tidal mixing, as required for accuracy. More spatially and temporally detailed three-dimensional models (TRIM and UnTRIM) and two-dimensional models (the RMA Bay-Delta Model) have been used to calibrate the dispersion coefficients for the simpler tidally averaged one-dimensional model that is central to WAM. Details of calibration and verification are provided in Appendices D and E of the Water Analysis Module TM (URS/JBA 2007e).

The following subsections provide additional summary information on each major submodel included in WAM; further detail is available in the Water Analysis Module TM and its appendices (URS/JBA 2007e). The order of the subsections has been chosen in order to describe the simpler things first, since they then become inputs to the more involved hydrodynamics calculations. Thus, we present the subsections in the following order:

- Delta Water Operations
- Net Delta Area Consumptive Use
- Upstream Reservoir Operations, Target Exports, and Deliveries
- Hydrodynamics and Water Quality.

11.2 DELTA WATER OPERATIONS

In the event of a Delta levee breach resulting in island flooding, Delta water operations may be substantially altered – gate positions may be changed (including the Delta Cross Channel gates and the South Delta barriers), export pump operations may be curtailed (e.g., emergency shutdowns), in-Delta diversions may cease (for Delta island irrigation) and, potentially, upstream reservoir releases may occur to counteract salinity intrusion during island flooding. The purpose of the Delta Water Operations Submodel is to represent these operations as they are expected to occur in a BAU response to a Delta levee breach incident. This effort is necessary because they will impact Delta hydrodynamics and salinity concentrations. Details are presented in Appendix B of the Water Analysis Module TM (URS/JBA 2007e).

The operations submodel is subdivided into three phases in coordination with the hydrodynamics and upstream reservoir management submodels. The phases for Delta Water Operation actions are: (1) immediate response (during flooding), (2) flushing, and (3) limited pumping.

The operations submodel reflects the standard project operating procedures that existed in 2005 together with additional details that could be inferred from discussions with operators. In general, operations are tightly controlled by the water quality standards established by the State Water Resources Control Board (SWRCB 2000) and set forth in their Water Rights Decision 1641. Under BAU, WAM assumes that the projects would not intentionally violate a requirement of D-1641, even if the "emergency" provided a common-sense rationale for doing so.

To the extent the projects can be operated with discretion, such actions often require consultation with federal and state fish and wildlife agencies under their respective Endangered Species Act provisions. These consultations require some time to formulate a request, discuss conditions and concerns, and agree on an action. Thus, the operations submodel assumes that any action requiring consultation will not be immediately available (within hours), but will require several days for formulation of a proposed action, discussion, agreement, and implementation. Consequently, such actions will typically occur during the flushing phase. Another assumption is that consultation will generally not allow compromises of intended protections for endangered species. During the limited pumping phase, normal D-1641 provisions are assumed to be in force.

In-Delta water use is assumed to be affected only by salinity conditions at the Delta island irrigation intakes. Delta water users are generally believed to have riparian or senior water rights and therefore would not be obliged to respond to requests to suspend withdrawals, though they may cooperate voluntarily. Their responses to emergency orders are not predictable – no plan exists to issue and enforce such orders, so compliance with such orders is not part of the BAU scenario for base-case analysis.

Since the analyses for future years are to be for BAU, 2005 Delta water operations approaches and rules will remain unchanged. The one potential exception (included in the 2030 California Water Plan) (DWR 2005d) is inclusion of the proposed operable south Delta barriers (DWR and USBR 2005). It is not clear that barrier operation in a levee breach emergency would be substantially different than that assumed for the 2005 case with temporary barriers. This will be addressed if a 2030 or 2050 analysis is performed.

11.3 NET DELTA AREA CONSUMPTIVE USE

Within WAM the net Delta area consumptive water use or Net Delta Area Losses submodel (referred to herein as NDAL) determines the return flow, return flow salinity and net channel withdrawals for each island and/or groupings of islands. Net consumptive use is total consumptive use minus precipitation. NDAL and net channel withdrawals are the same as net consumptive water use, because consumptive water is supplied by either precipitation or water from Delta channels. Details on the NDAL submodel are provided in Appendix A of the Water Analysis Module TM (URS/JBA 2007e). This section provides an overview.

To represent NDAL within WAM, the Delta is divided into spatial groups. Initially the Delta is divided into five groups representing each of the major Delta flow paths as defined by the hydrodynamics (HD) submodel. Each of the 142 subareas (defined by DWR for tabulating Delta net evapotranspiration) (DWR 1995) is assigned to a group and these groupings are used to report the NDAL output to the HD calculator. Each of the subareas is assigned to an evapotranspiration group, an evaporation group, and a precipitation group.

NDAL assesses in-Delta water demands based on normal irrigation net consumptive use, breach event details, islands flooded, channel salinity, and repair progress. If an island is flooded, irrigation demand ceases, as does seepage, and return flow. No evapotranspiration occurs, but evaporation occurs instead.

When an island is repaired, seepage and return flow are restarted. Irrigation can commence as well, if the island has been pumped out and adjacent channel salinity is of appropriate quality.

For an unbreached or a repaired island, NDAL checks channel salinity calculated by the HD submodel and determines whether water quality conditions are sufficient to provide irrigation water. If water quality is unsatisfactory, irrigation does not occur until water quality conditions become satisfactory.

The NDAL submodel includes the ability to read and incorporate climate changes in the form of Delta area precipitation changes, temperature increases, and carbon dioxide concentration increases. Precipitation increases result in a corresponding decrease in NDAL. The opposite is true for precipitation decreases. Temperature increases would increase evaporation and plant transpiration. Carbon dioxide increases, on the other hand, are believed to decrease water use for transpiration (JBA 2006a, 2006b) and will thus dampen the effect of future temperature increases. A summary of available information on future changes in Delta area precipitation, temperature, evapotranspiration, evaporation, and carbon dioxide is presented in Appendix G of the Water Analysis Module TM (URS/JBA 2007e).

11.4 UPSTREAM RESERVOIR OPERATIONS, TARGET EXPORTS, AND DELIVERIES

Depending on the severity of the levee breach scenario, the management of upstream and south of Delta reservoirs may be substantially altered. A small event, like Jones Tract, may require only slight modifications. But in a larger event, a prolonged period may occur with reduced or no pumping and an associated need to ration south-of-Delta supplies. Managed Delta inflows will also be needed to provide flushing and the additional Delta outflow to maintain water quality.

After adequate flushing is achieved, the quantity of inflow required (simply to maintain water quality) will include normal Delta outflow and an increased amount based on the larger tidal prism due to tidal flow into and out of unrepaired, flooded islands. Finally, when limited export pumping can be reestablished, additional Delta inflow will be needed to provide the water that is to be pumped plus both the normal and increased carriage water needed to maintain water quality.

Details on this submodel are presented in Appendix C of the Water Analysis Module TM (URS/JBA 2007e). This section presents an overview.

The reservoir management submodel makes emergency reservoir operating decisions related to the levee breaches in order to balance the amount of water released for Delta inflow (while the emergency and repairs progress) with the need to conserve water for other and future uses. For reservoirs south of Delta, this effort means balancing deliveries to respond to water users' needs with the need to conserve water in south-of-Delta reservoirs in case the disruptions last longer than expected or encounter dry or critical years. For reservoirs north of Delta, this effort means balancing releases to reestablish through-Delta conveyance with the need to conserve in upstream reservoirs, so that other needs can be served, drought protection is provided and, when export pumping is reestablished, water is available to pump.

The basic approach used north of Delta is to receive daily requests from the HD submodel indicating the amounts of Delta inflow needed to reestablish or maintain required water quality. Separately, the HD submodel indicates the extra amount required to facilitate any given amount of pumping. These requests are then considered by the reservoir management submodel in light of the time of year, stored water available, the quantity requested and the projected duration of the incident (with its anticipated future requirements for extra water). A set of decision rules is incorporated into the submodel to make reasonable releases while saving enough water in storage to get through the incident and be in a position to recover toward normal operations, even encountering dry years. These daily decisions are accumulated to report monthly amounts of releases, Delta exports, and end-of-month storage.

The approach is similar for south of Delta storage. Releases may be made for CVP and SWP contractors after considering and balancing available stored water, anticipated incident duration, normal allocations, anticipated limited pumping during the incident, and the intensity of needs from the earlier cuts that are part of the incident. These water contractor deliveries are apportioned in full conformance with existing contracts. Again, the decision rules are crafted to get through the incident without implementing even more drastic cuts (due to running out of water) and then being able to rebuild deliveries in a reasonable way when pumping from the Delta is reestablished.

WAM produces time-series output for Delta exports, south of Delta water deliveries, south and north of Delta storage, and north of Delta flow and delivery changes. The figures identified in the next three paragraphs show output from a sample WAM simulation – a preliminary version of a multi-island breach case beginning in August 1992. Note that the only purposes of this simulation and the results presented are to illustrate the way WAM may react to a breach scenario and to indicate the types of water flow and storage output information that will be generated.

The figures contain traces of Delta exports for a baseline (without disruption) and for a preliminary multi-island breach case. Figures 11-3 and 11-4 show Delta exports for each month for the CVP and SWP, respectively, for the WAM simulation. Both CVP and SWP exports are halted during the flooding and flushing period after the breach and resume after 7 months.

Figure 11-5 provides plots of total (SWP and CVP) south-of-Delta deliveries with and without the breach and total delivery reductions due to the disruption. WAM allocates water to each group of contractors of the SWP and CVP based on contract priority. The total reduction in delivery is about 2.8 million acre-feet.

Figure 11-6 shows plots of south-of-Delta storage. During this model simulation, south-of-Delta storage dropped by about 2 million acre-feet.

WAM is designed to provide these types of data for each levee breach scenario that is considered. Additional example plots and more detailed discussion of the reservoir management submodel are provided in the Water Analysis Module TM (URS/JBA 2007e).

Refinements of the upstream reservoir management submodels for future years will generally be avoided in the spirit of providing a BAU analysis. Operating rules will be altered as necessary in the CalSim runs (used as input) to develop reasonable base cases. The objective will be to ensure that reservoirs are not unrealistically drawn down in the “no breaches” case used as a baseline. Follow up refinements of WAM operating rules may be required to avoid similarly unrealistic drawdowns in levee breach events. Operating rules are discussed in more detail in Appendix C of the Water Analysis Module TM (URS/JBA 2007e).

The hydrologic input to WAM may change quite dramatically for future years. WAM is designed to use CalSim input and output as the basic source of hydrologic information. For present (2005) conditions, it uses the CalSim Common Assumptions 2005 LOD simulation. For future years, WAM will need to have available future year CalSim runs reflecting changes in level of development and climate change-induced modifications to the hydrologic regime. Although little information is available beyond 2030 regarding level of development, substantial work has been performed to assess the impacts of climate change on the input hydrology (rim flows) for CalSim and the resulting impacts on amounts of water available for water supply. This work is described and summarized in Appendix F of the Water Analysis Module TM (URS/JBA 2007e). Additional work is needed for other inputs, including precipitation, temperature, carbon dioxide, and the resultant evaporation and evapotranspiration (see the Water Analysis Module TM [URS/JBA 2007e], Appendix G).

11.5 HYDRODYNAMICS AND WATER QUALITY

The challenge of modeling the hydrodynamics and water quality has been somewhat different – it has not been to balance decisions, but to have a working interaction with the water management decisions to calculate the Delta salinity resulting from these decisions in the context of the specific levee breach scenario. Very sophisticated models are already available for doing this calculation – e.g., the Delta Simulation Model 2 (DSM2), or the RMA Bay-Delta Model. However, it takes hours to days of real time for these models to simulate a large-scale levee breach event, so it is not feasible to use them in a fully interactive mode or for each of several thousand scenarios.

A simplified hydrodynamics/water quality submodel has therefore been developed as part of the WAM. It is described in detail in Appendix D of the Water Analysis Module TM (URS/JBA 2007e) and its calibration is described in Appendix E of the Water Analysis Module TM (URS/JBA 2007e). The following summarizes the approach that has been implemented:

- Use existing physically based numerical models (RMA Bay Delta Model and TRIM/UnTRIM 3D models) to explicitly evaluate hydrodynamic, salinity, and other water quality impacts for a limited number of specific breach events, as well as to characterize the dynamics of the system.
- Analyze scenario simulations conducted using existing multidimensional models to estimate dispersion coefficients that quantify the strength of salt intrusion and mixing processes.
- Create a new tidally averaged flow and salinity transport model using a one-dimensional network approximation reaching from the central San Francisco Bay to the upstream limits of the Delta to rapidly evaluate salinity impacts of levee breach events and interact with the water management decision-making component of WAM.

The primary challenge in developing the simplified hydrodynamic/water quality model has been to represent enough of the physics to provide sufficient accuracy while maintaining the computational speed needed to simulate many thousands of levee breach events. The primary outputs of the WAM are monthly average quantities including export volumes and salinity, and in-Delta salinity at selected locations. Therefore, it is not necessary for the simplified model to explicitly represent the flow and transport on the tidal time scale or variations in flow velocity or salinity concentrations across a channel cross section.

The simplified model is therefore a one-dimensional, tidally averaged transport model. This type of model considers net flow (advection) and tidal mixing (tidal dispersion, turbulent diffusion, and vertical stratification and mixing) relations derived from full dynamic models of the system. The simplified model then interacts with the water management component of WAM during the course of simulation, both providing input to the water management decision-making component and receiving calculated inflows and exports. Figure 11-7 illustrates the basic conceptual structure of the simplified model.

Figures 11-8 and 11-9 provide samples of daily outputs from the HD model for an example of a multi-island levee breach event occurring in various years (assuming July 1 of each year) and in various months (for 1993). The figures indicate that the WAM HD submodel is capable of showing dramatic increases in salinity (at Jersey Point) as expected from an event of substantial magnitude. It also shows that the HD submodel will respond to the different Delta inflows and salinity conditions that prevail with different types of water years and different months during a year.

More details on the calibration and performance of the HD submodel are provided in Appendices D and E of the Water Analysis Module TM (URS/JBA 2007e). The WAM module, including both Delta HD simulation and reservoir/export operations, completes a 5-year simulation of multiple island breach events in about 90 seconds on personal computers.

Appendix E describes intensive calibration efforts for the normal (non-breach case for October 1991 through September 2003 using “dayflow” boundary conditions – all the inflows and outflows for the Delta and their associated salinities. Five additional in-Delta locations with important channel connections were also used in the calibration. The HD submodel calculations of salinity (EC) at the SWP and CVP export locations (for no breaches) are generally within about 15 percent of peak summer observations. Figure 11-10 provides an example (from the Water Analysis Module TM, Appendix E) of WAM-computed EC at the SWP intake as compared to “dayflow” data from the calibration period.

A large number of comparisons of calculated versus observed data for stations other than those used in the calibration are presented in Appendix E. Also, the 50-breach (20-island) simulation by the RMA Bay Delta model (JBA 2005) was used to calibrate dispersion between channels and flooded islands for breach cases. Data from the Jones Tract breach incident were used to perform a limited verification. As a DRMS risk assessment tool, WAM HD has met the requirements for computational speed, simulation capability and accuracy for present (2005) conditions.

The hydrodynamics and water quality model will reflect future changes in two substantial ways. First, the sea-level rise attributed to a future analysis year will be incorporated. This will change Delta hydrodynamics and may require recalibration of the dispersion coefficients used in the simplified hydrodynamics model. Second, when a levee breach with island flooding occurs, a larger volume will be flooded because of both the higher flood water level (higher sea level) and the lower island surfaces where subsidence has occurred.

11.6 WAM SUMMARY

Overall, WAM has achieved the two objectives set forth in Section 11.1.2. It efficiently calculates the water quantity and quality information needed to estimate the economic and environmental consequences of a wide variety of levee breach scenarios, each of which may occur during dramatically different seasonal and hydrologic conditions These capabilities are illustrated in Figures 11-11 and 11-12, which show WAM results for five seismic scenarios used in the Draft Phase 1 Report, issued in June 2007 (URS/JBA 2007b). Cases 2 through 6 are respectively:

- Case 2 – three flooded islands with no repairs needed for other, unflooded islands
- Case 3 – three flooded islands with substantial repairs needed for unflooded island causing delays in initiation of repairs for the flooded islands
- Case 4 – ten flooded islands, no others damaged
- Case 5 – twenty flooded islands, others damaged and repaired first
- Case 6 – thirty flooded islands, others damaged and repaired first.

Figure 11-11 shows the export deficit at the time pumping can be resumed as calculated by WAM for each scenario, assuming different event initiation times. Because of the need to limit the width of the figure, only 154 event initiation times are shown, covering the first of each month from January 1986 through October 1998. The calculations were actually performed for the first day of each month from January 1923 through October 1998 (910 event initiation times), as indicated by the exceedance probability plot shown in Figure 11-12. This demonstrates the abilities of WAM, both to address a wide variety of hydrologic conditions and to cover the spectrum of available hydrologic data with computational efficiency.

11.7 OTHER WATER QUALITY IMPACTS

In WAM, water quality conditions are represented by salinity, but other water quality measures can potentially be modeled in future versions. As with salinity, other water quality parameters have concentrations that are influenced by the volume of water required to fill the islands, tidal mixing, dispersion, dilution, fresh water inflows, flushing, water exports, and management decisions. These conditions are already modeled by WAM.

One of the potential water quality impacts for water exports is from increased treatment costs due to organic carbon released from flooded islands with predominately organic soil. Organic carbon can act as a disinfection byproduct precursor. Such byproducts include carcinogens. As part of the water treatment process, excess organic carbon can be removed prior to chemical disinfection and, thus, reduce the prospective creation of disinfection byproducts. However, this may require capital facilities that are not already in place when the emergency occurs, and a significant operating cost even when the facilities are online.

In contrast to salinity, sources for other potential water quality pollutants can include water inputs from the river/Delta/Bay system as well as benthic sediments, suspended sediments, island stockpiles, or accidental contaminant releases from the Delta islands. Chemical pollutants have the potential to impact in-Delta water use, ecosystems, and water exports. The location, quantities, and chemical composition of potential toxics located on Delta islands are not extensively inventoried.

The locations of some of the potential sources of toxics can be seen on Figures 11-13 and 11-14. Figure 11-13 shows toxic sources in the Delta complied from EPA Envirofacts database, from the Department of Toxic Substances Control EnviroStor database, and from narrative information included in the Land Use and Resource Management Plan for the Primary Zone of the Delta (Delta Protection Commission 2002). Envirofacts contains the toxic release inventory and a list of facilities that are hazardous waste generators, transporters, or NPDES permit holders. EnviroStor inventories cleanup sites including federal superfund sites, state response sites, and voluntary cleanup sites.

Figure 11-14 shows the location of all of the oil and gas wells and production fields in the Delta. Although safeguards and controls exist for toxic material storage containers and oil and gas extraction wells, these controls are not necessarily designed for an extended submergence after a period of stress. Additional information regarding potential water quality pollutants on Delta islands is provided in Section 12.

Potentially, future versions of the WAM can use transport modeling and particle tracking to model the dispersion of known sources of toxic chemicals.

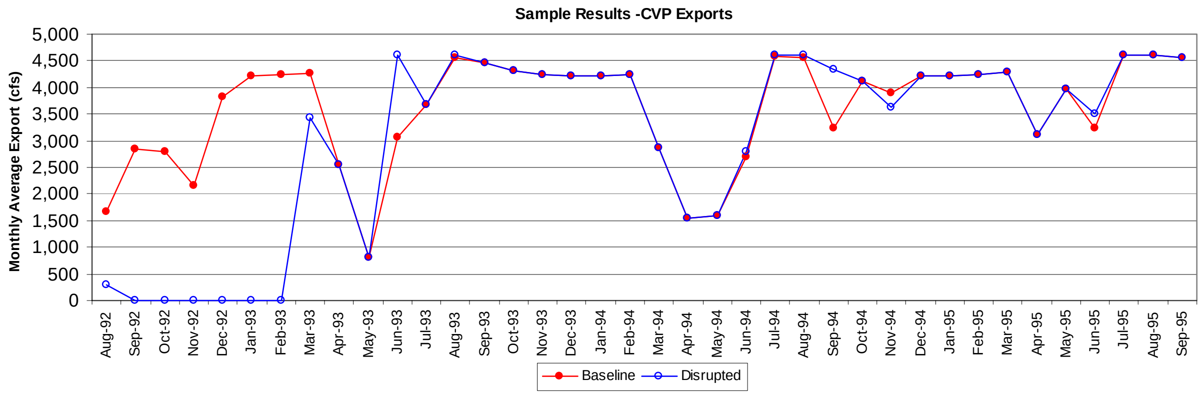


Figure 11-3 CVP Exports

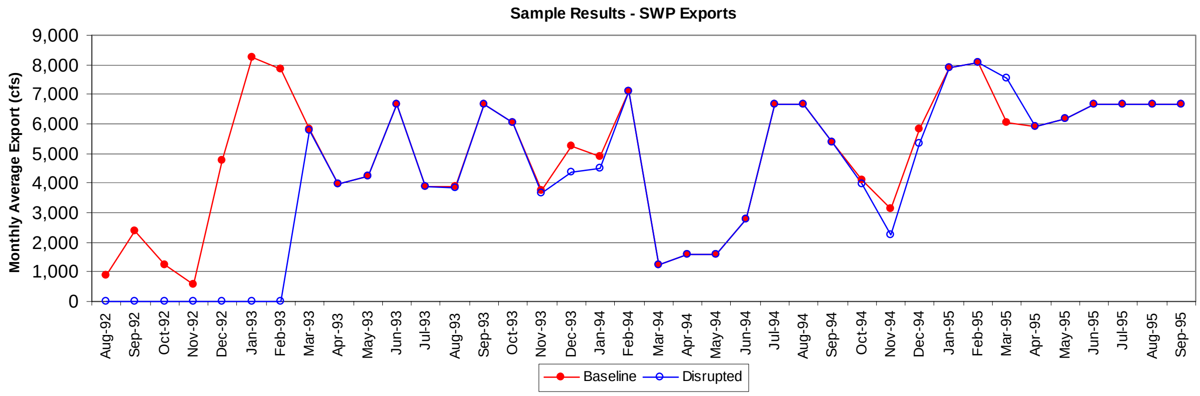


Figure 11-4 SWP Exports

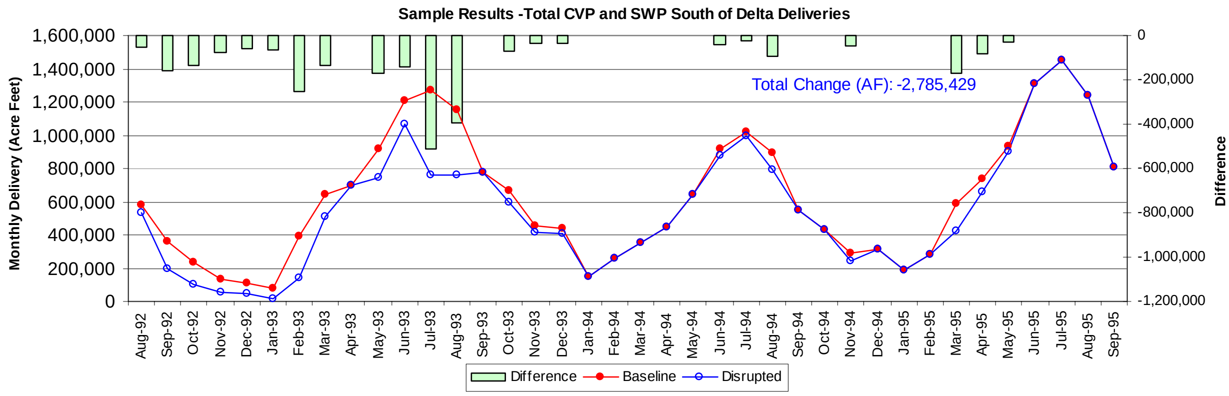


Figure 11-5 Total South of Delta Deliveries

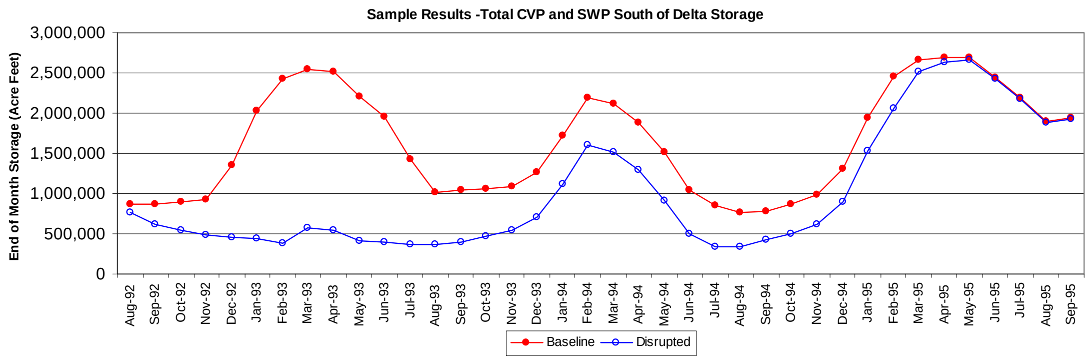


Figure 11-6 Total South of Delta Storage

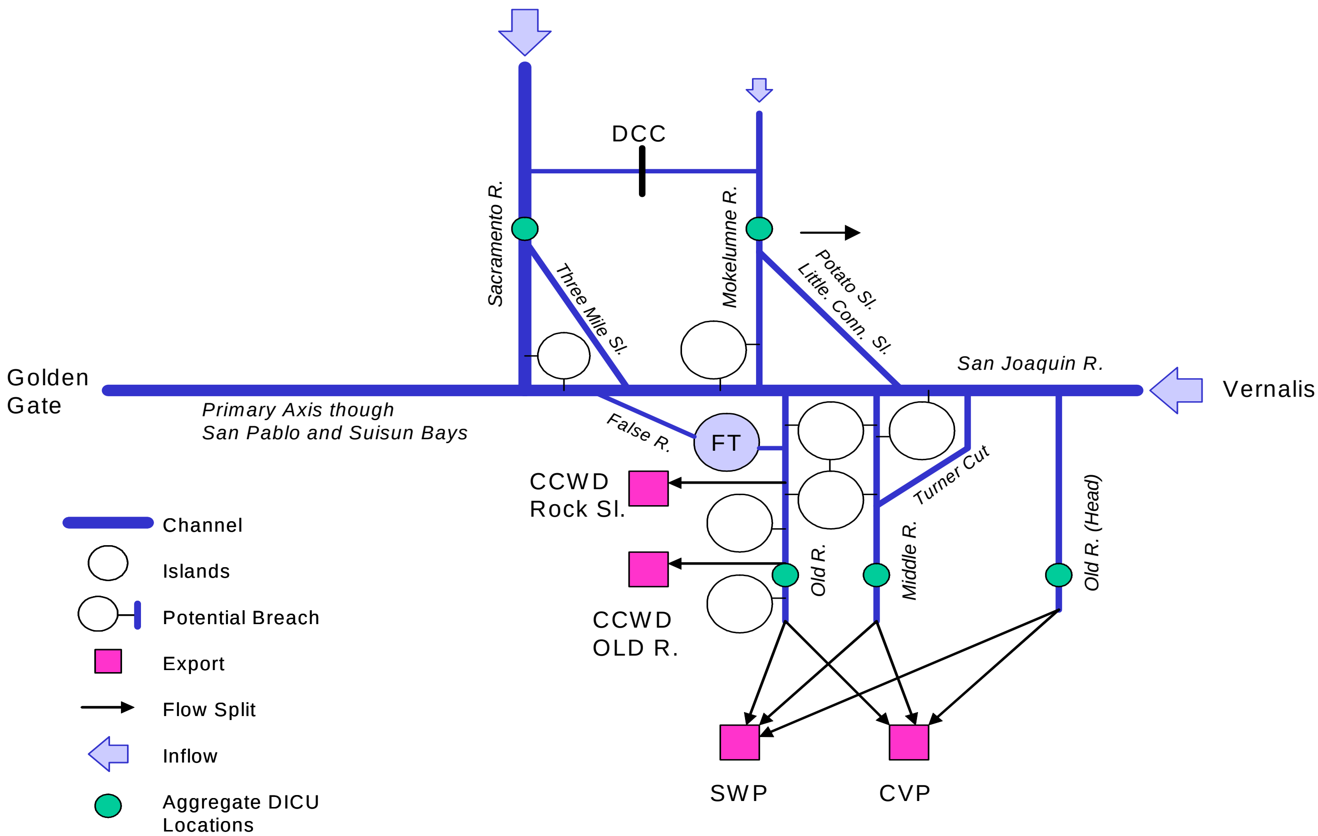


Figure 11-7 Simplified Hydrodynamic/Water Quality Submodel Schematic (showing example islands only)

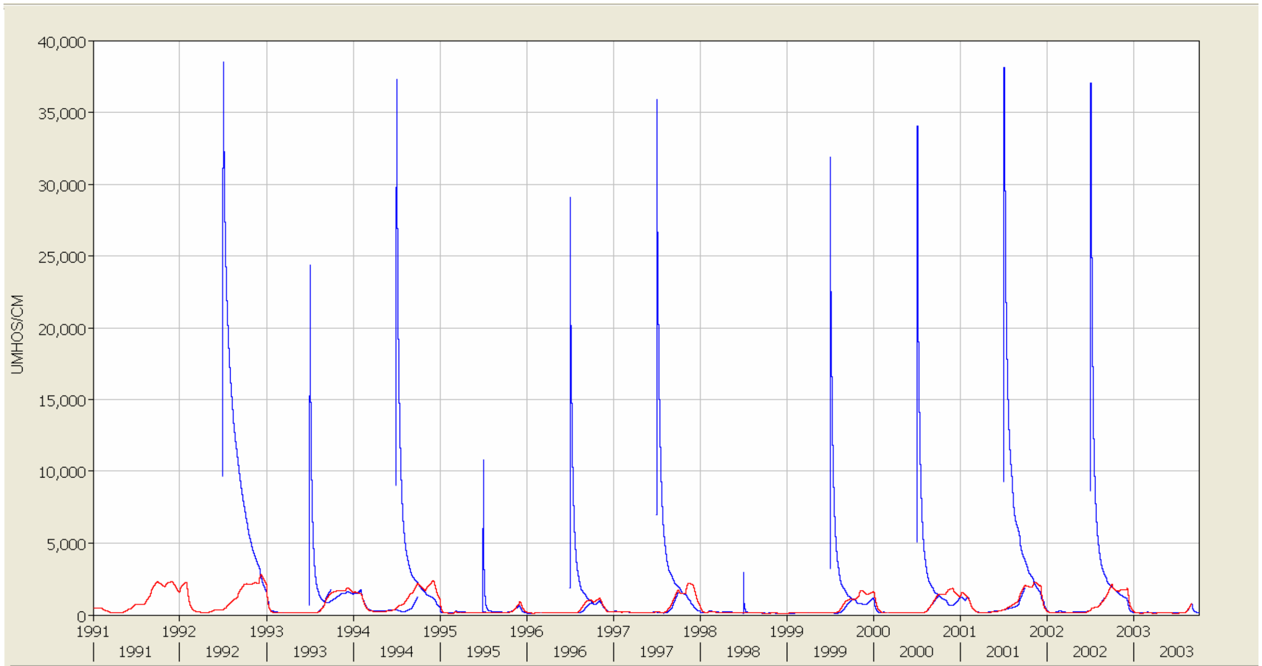


Figure 11-8 WAM HD Calculation of the Jersey Point Salinity Response to a Multi-Island Levee Breach Event Occurring on July 1 in Various Years

(Note: red line shows salinity without levee breaches; blue lines show salinity with levee breaches at alternative times.)

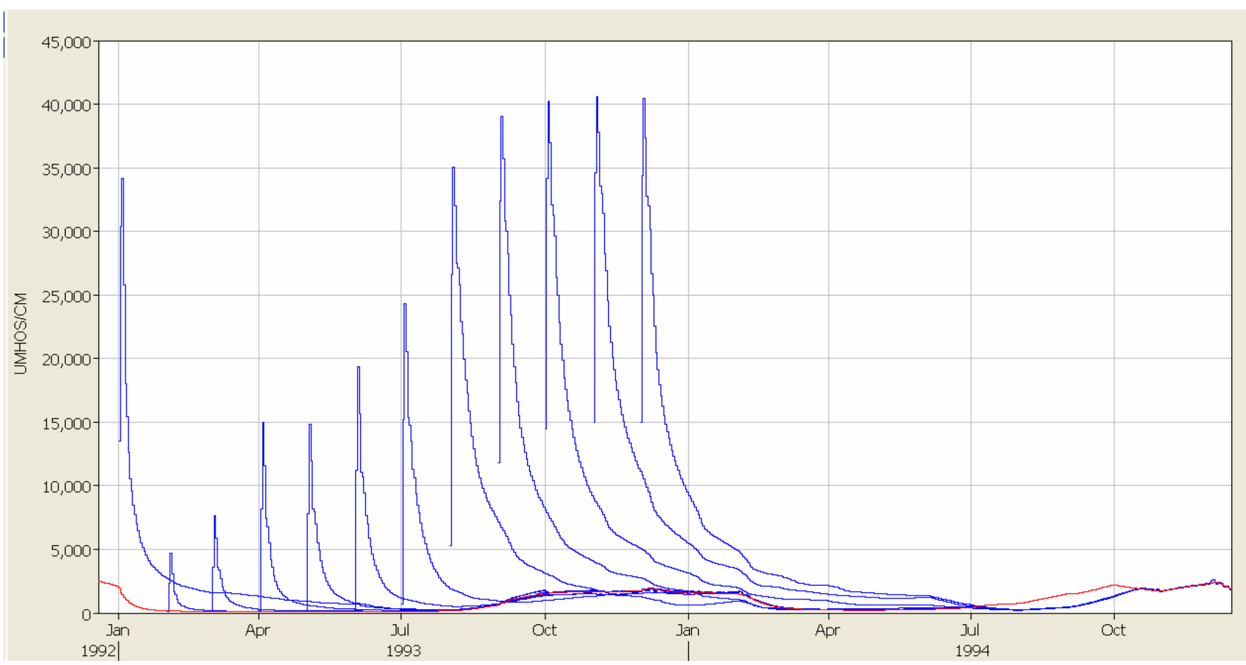


Figure 11-9 WAM HD Calculation of Jersey Point Salinity Response to a Multi-Island Levee Breach Event Occurring (Alternatively) on the First of Each Month During 1993

(Note: red line shows salinity without levee breaches; blue lines show salinity with levee breaches at alternative times.)

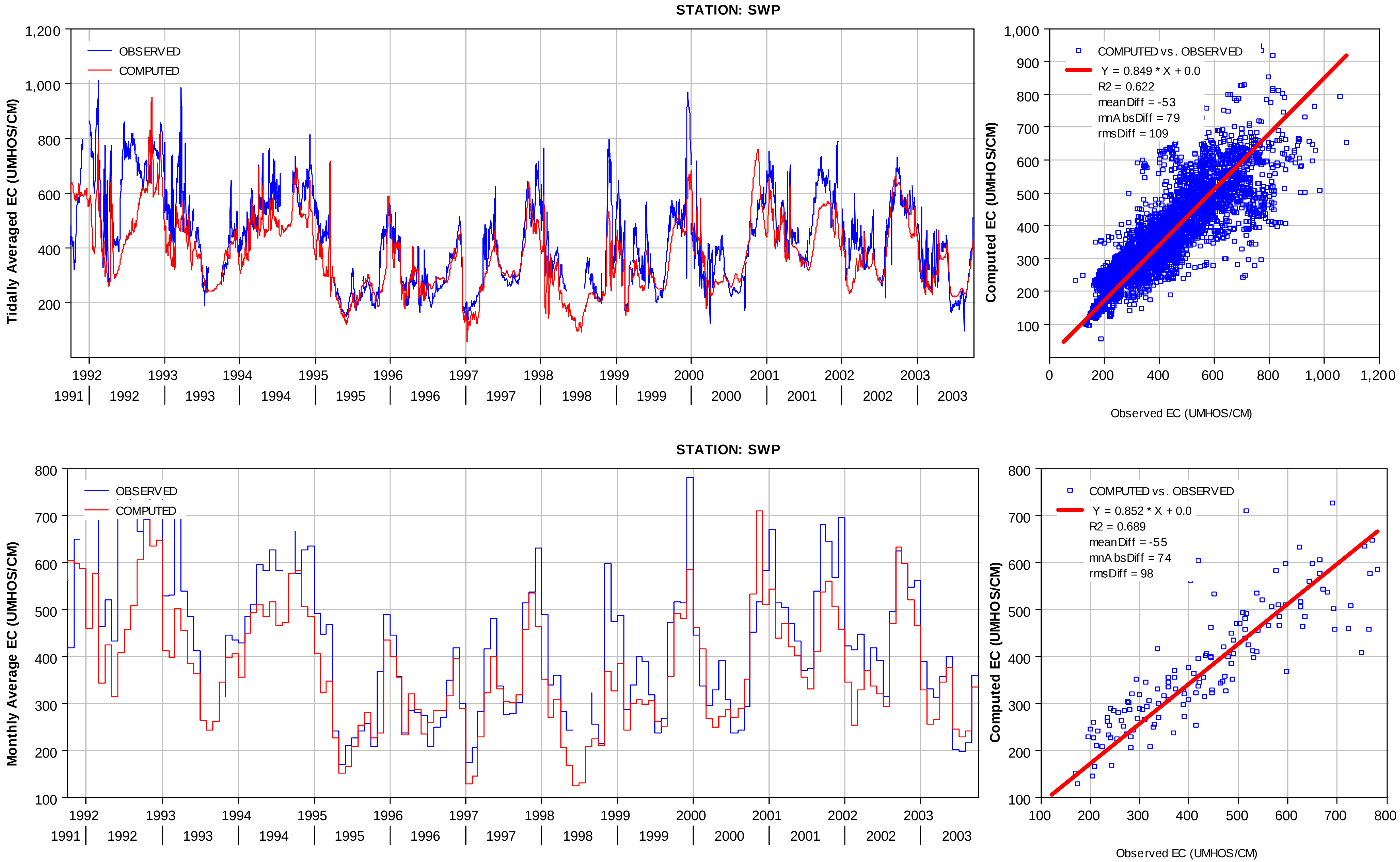


Figure 11-10 WAM-Calculated Tidally Averaged and Monthly Averaged Salinity (EC) at Station SWP Export – Calibration to Dayflow Boundary Conditions

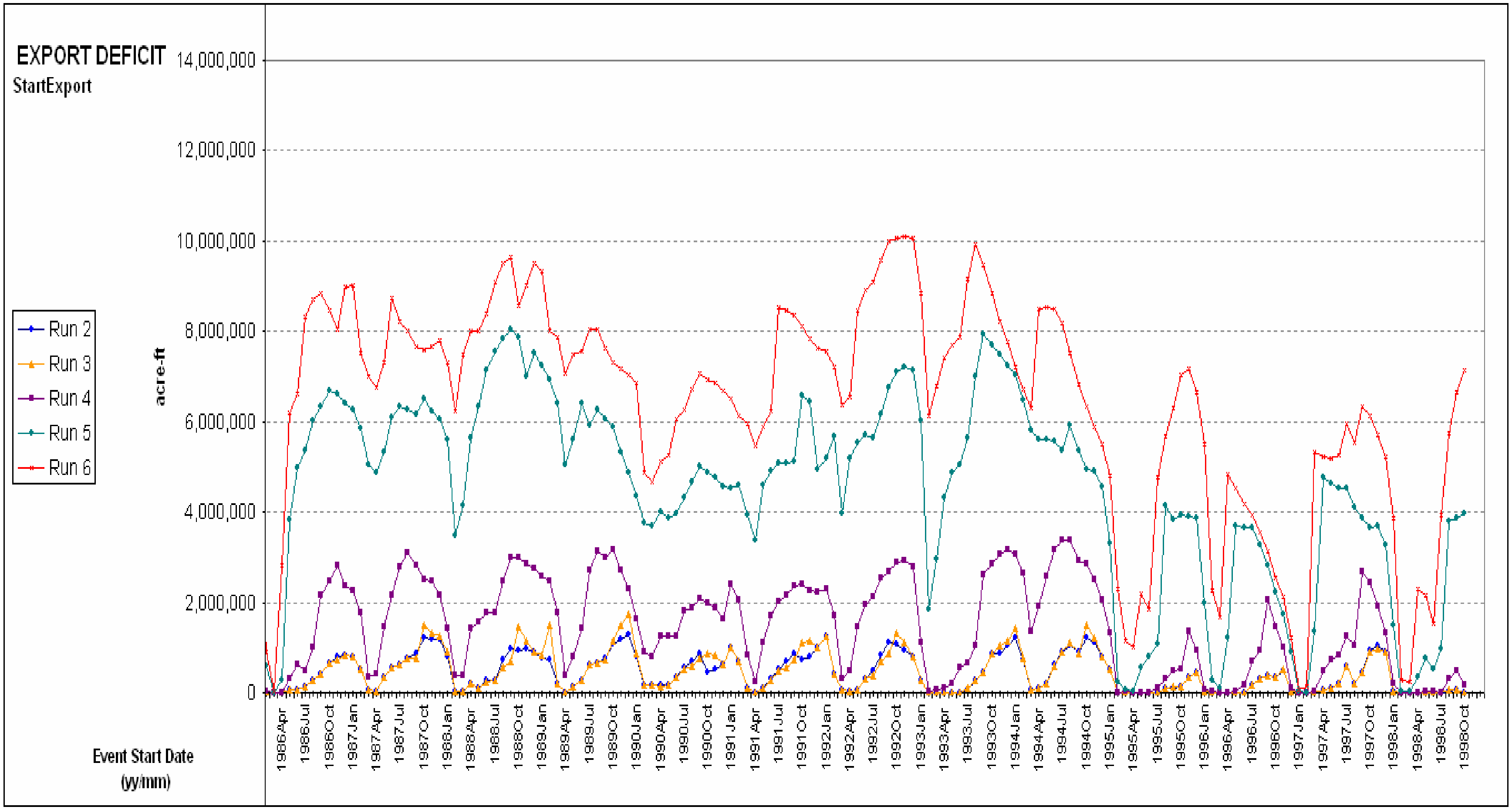


Figure 11-11 Export Deficit at Time Exports are Initially Resumed Based on Starting Breach Events on the First of Each Month from January 1986 through October 1998

Risk Analysis Event Seismic Sequences 2 through 6 as Defined in Phase 1 Draft Report (URS/JBA 2007b)

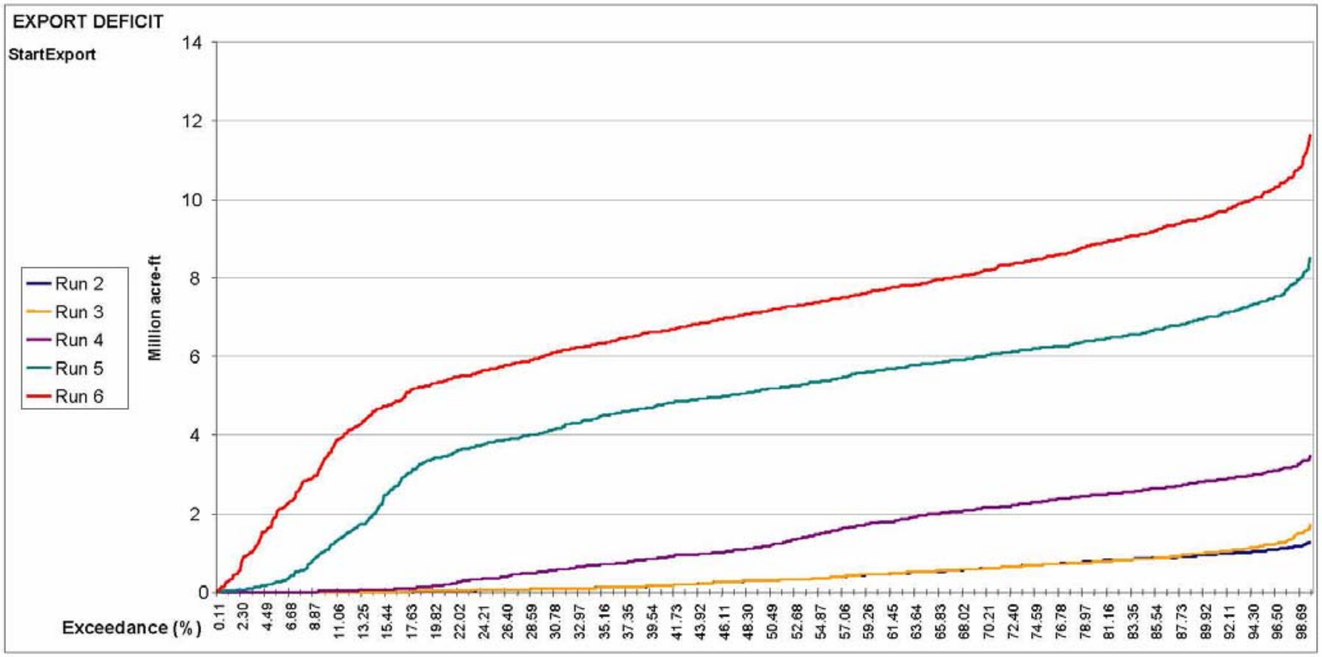


Figure 11-12 Exceedance Probability of Export Deficit at Time Exports are Initially Resumed Based on Starting Breach Events on the First of Each Month from January 1923 through October 1998

Risk Analysis Event Seismic Sequences 2 through 6 as Defined in Phase 1 Draft Report (URS/JBA 2007b)

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Toxics\DRMS_toxics_map.mxd Date: 3/6/2007 5:55:39 PM Name: akkeele0

Type of Toxic Area

- Chemical Storage
- Clean-up
- NPDES
- Small Generator
- Superfund
- Toxic Release
- Transporter

Wastewater and Biosolids Disposal

Dredge Materials Disposal

Analysis Zone

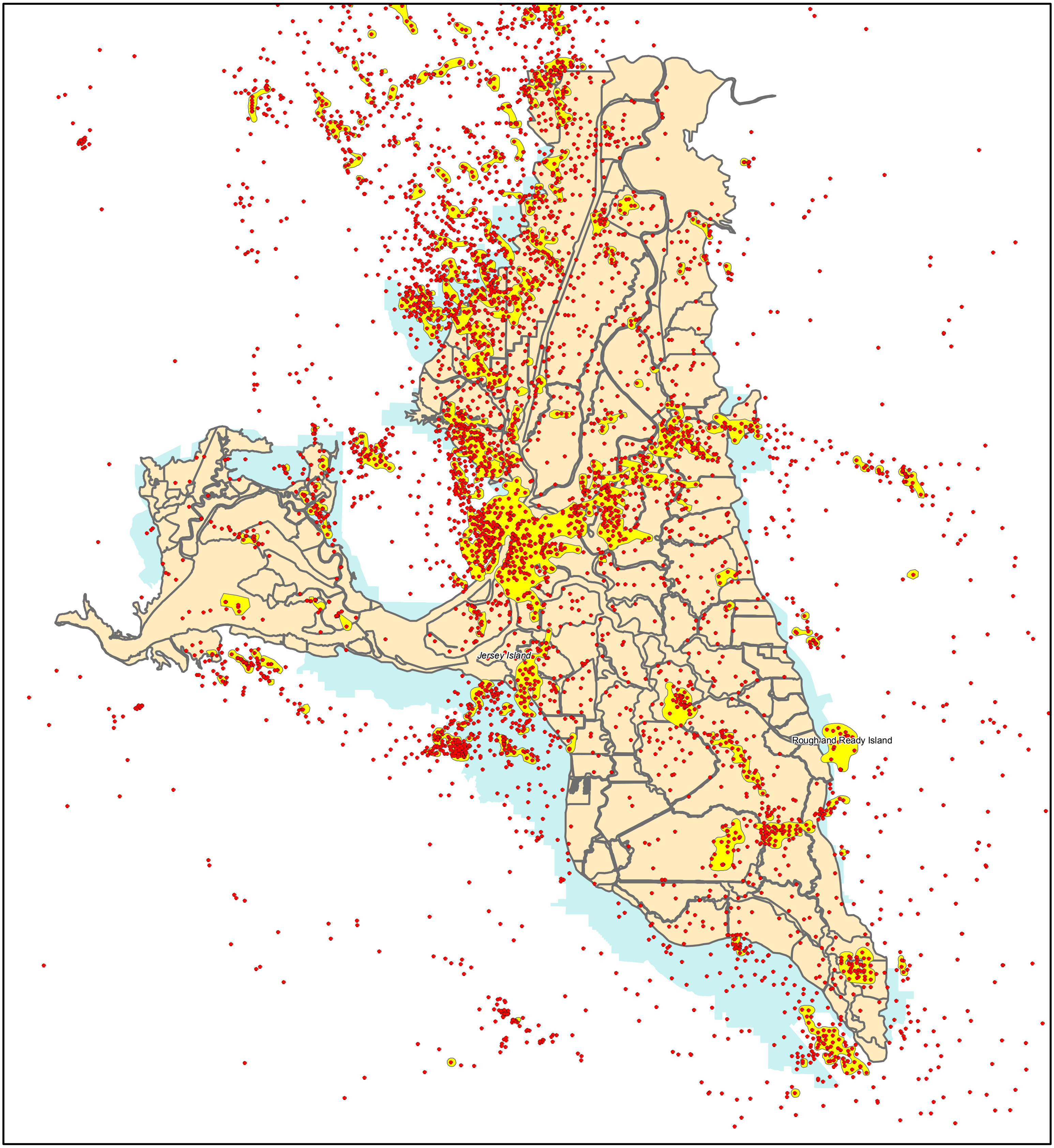
FEMA 100-year Floodplain

Legal Delta and Suisun Boundary

0 2 4 8 Miles

N

URS	DRMS / 26815621	Toxics Known in the Delta	Figure 11-13



Analysis Zone

FEMA 100-year Floodplain

Legal Delta and Suisun Boundary

Gas and Oil Production Fields

Gas and Oil Wells

0 2 4 8
Miles

N

URS	DRMS / 26815621	Gas and Oil Facilities in the Delta	Figure 11-14

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Toxics\DRMS_gas_oil_data.mxd Date: 3/6/2007 5:55:39 PM Name: akkeele0

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The consequences of Delta and Suisun Marsh levee failures are far reaching. Often, the direct consequences to life and property are the most obvious to the general public, since the flooding shows up on the front pages of newspapers and on the evening news. Other consequences, like the costs to repair the damaged levees and recover the flooded areas, are not immediately evident. Short-term and long-term changes to the ecosystem are even harder to quantify. Other economic costs to the immediate flooded area and to the state can be substantial. The saltwater intrusion that can accompany a levee failure in the Delta can shut down the in-Delta and export water supplies to urban and agricultural water users. Also, there are economic impacts caused by economic linkages beyond the direct costs.

This section provides an overview of the types of consequences addressed. The goal is to provide a broad understanding of each type of consequence and recognition of aspects that are quantitatively evaluated versus other (often very important) aspects that could not be quantified. The four broad types of consequences considered are:

- Impacts to Life Safety
- Changes in Water Quality
- Ecosystem Impacts
- Economic Consequences

More details on the ecosystem and economics consequence analyses are provided in, respectively, the Impact to Ecosystem Technical Memorandum (TM) (URS/JBA 2008e) and the Economic Consequences TM (URS/JBA 2008f).

12.1 IMPACTS TO LIFE SAFETY

12.1.1 Estimation of Loss of Life Caused By Levee Breaches

This section describes the estimation of the potential loss of life caused by the flooding that would result from a levee breach on an island. Historically, many California floods caused by levee breaches have resulted in substantial property damage and economic losses. Some have also caused fatalities. Some recent Northern California levee breach events that resulted in fatalities include the 1955 and 1997 floods. Thirty-eight fatalities were reported after the 1955 levee breaches and the resulting flood that occurred near Yuba City (Roos 2007). The 1997 levee breaches and resulting floods in the San Joaquin River basin caused three fatalities (SafeLevee Web Site). The 2004 levee breach on Jones Tract required evacuation of tens of people, but caused no fatalities (California Department of Water Resources [DWR] 2004).

The loss-of-life risk has increased over the years because of the rapid housing growth closer to areas behind levees that were built to protect farmland. Also, the past levee breaches in the Delta occurred under winter floods or normal (“sunny-day”) conditions. The levees have not been subjected to a significant seismic event. The loss-of-life risk from levee breaches caused by a seismic event is likely to be greater because such breaches could occur more rapidly, leaving less public warning time and making evacuation less likely.

A methodology was developed to estimate the probabilities of exceeding different numbers of fatalities on Delta islands for given initiating events. For a given initiating event, *levee failure* *sequences* were defined in terms of the number of breaches and their locations on each island, and the time of the event. In this report, the probabilities of different numbers of fatalities estimated in the methodology are conditional on the levee failure sequence. These conditional probabilities are used in the risk analysis quantification to estimate the frequency of occurrence of different numbers of fatalities.

Many of the current models/procedures for the estimation of loss of life from flooding have been derived based on empirical data from dam failures. Some of these models are briefly described below.

Graham (1999) describes a procedure to estimate loss of life from dam failures using three factors – flood severity level, warning time for people to evacuate before being impacted by flood waters, and the warning issuers' understanding of the flood severity. In his 1999 published paper, Graham recommended assigning fatality rates for different combinations of these three factors. This procedure has been enhanced since its original publication (Graham, personal communication, 2008). The enhanced procedure provides a method to estimate the percentage of people at risk that would be evacuated to safety. Fatality rates are then estimated that would be applied to the remaining population in the flood impact area.

Aboelata et al. (2003) describe a life-loss simulation model, LIFESim, which comprises four modules – flood routing, loss of shelter, warning and evacuation, and empirical fatality rates. The fatality rates are dependent on lethality zones that distinguish physical flood environments with significantly different destructive forces. The destructive forces are characterized by the interplay between available shelter and local flood depths, velocities, and presence of debris.

The LIFESIM model can be implemented in both deterministic and uncertainty modes. In the deterministic mode, best estimates of the input parameters are used to calculate the expected loss of life in different geographic areas impacted by a flood. In the uncertainty mode, probability distributions are assessed for the input parameters and the probability distribution of the number of fatalities is derived.

Johnstone et al. (2003) describe a Life Safety Model (LSM) developed by BC Hydro to assess the loss of life caused by an extreme flood event such as one caused by a dam failure. The key model inputs include representations of the natural environment (topography, water bodies), the socio-economic environment (people, buildings, vehicles, and roads), and the flood wave. The life safety simulator incorporates physical equations and logic to estimate the potential loss of life for different flood wave scenarios. The simulated output includes the estimated loss of life and dynamic computer-graphics visualizations of flood progression and resulting life safety impacts.

The Federal Emergency Management Agency has developed the HAZUS model (FEMA 2004) that uses a GIS-based system to estimate loss of life from flood events. Census data are used to estimate spatial distribution of population and facilities in the potential flood impact area.

For purposes of the DRMS study, it was necessary to estimate the loss of life that may result from one or more levee breaches on one or more islands during the same levee failure sequence. Also, the study was based on readily available GIS data on facilities and structures on different islands in the Delta. Data were not available on such factors as type of structures present in each island and number of floors in each structure. Because of these considerations, a relatively simple, high-level model was desired. The consulting team used the basic framework of the

LIFESim model to develop a model that would provide reasonable estimates of loss of life for the modeled levee failure sequences.

Section 12.1.1 describes the main elements of the loss-of-life model developed for the DRMS analysis. Results and discussion are presented in Section 12.1.7. Appendix 12A contains the results of the flood routing analysis. Appendix 12B contains the demographics data used in the analysis. Appendix 12C contains the detailed results of the estimated fatality risks for different islands. Appendix 12D includes an example to illustrate the calculation of probabilities of exceeding different number of fatalities for a given levee failure sequence.

A model was developed to estimate the loss of life on each Delta island for a set of levee failure sequences. Three types of initiating events were considered – flood, seismic, and normal ("sunny day"). These events have different effects on the breach development process and warning time and hence the events are analyzed separately. Two e*xposure* cases were considered – daytime breach and nighttime breach. These cases affect the amount of warning time available after a breach, and that variation can result in different numbers of lives lost. The three types of initiating events and two exposure cases define six different levee failure scenarios.

The main modules of the life-loss estimation model were:

- Flood routing module
- Population exposure module
- Warning and evacuation module
- Life-loss fraction module
- Life-loss calculation module

A brief description of each module follows.

12.1.2 Flood Routing Module

For each initiating event, a levee breach initiation and development process was defined. Flood routing analysis was performed to assess the velocity and depth of flooding and the inundation area at different times from the time of breach initiation.

Johnston et al. (2005) provide references for defining the thresholds of the product (flood depth, d × flood velocity, v) at which buildings would experience total and partial damage. Based on this information, thresholds of 7 and 3 square meters per second (m^2/s) were assumed for dv for total and partial building damage, respectively.

The threshold dv of 7 m^2/s was used to define the high flood severity zone within which all buildings would collapse and people in this zone would not be able to find shelter within any building. The threshold dv of 3 m^2/s was used to define the medium flood severity zone within which buildings would be damaged, but remain standing, and could provide shelter from a flood. The threshold dv of less than 3 m^2/s was used to define the low flood severity zone. The high, medium, and low flood severity zones defined for this analysis approximately correspond to the *chance*, *compromise*, and *safe* zones defined in the LIFESim model (Aboelata et al. 2003).

The flood routing analysis suggested that the initiating event and the size of the island would make a significant difference in the delineation of the flood severity zones. As noted previously, three initiating events were analyzed – flood, seismic, and sunny-day. For flood routing analysis, flood and sunny-day events were considered to be similar because the breaching process would be similar.

Two categories of islands were defined based on their sizes – large and small. A large island was defined as one with a major axis of more than 5,000 feet. The distance to the boundary of each flood severity zone and the time to reach that boundary were assessed separately for the different combinations of the initiating event and island size.

Table 12–1 summarizes the results for each combination of initiating event and island size. Details of the flood routing analysis are described in Appendix 12A.

12.1.3 Population Exposure Module

The continuous perimeter of the levee around an island was divided into eight sectors corresponding to four main geographic directions (N, S, E, and W) and four intermediate directions (NW, NE, SW, and SE)[1]. A breach on the arc of any given sector was assumed to occur at the mid-point of the arc. Given a breach on a particular arc sector, the inundation area within each flood severity zone was delineated.

Using GIS demographic data files, the population within each flood severity zone was estimated. Three separate population groups were considered – permanent (nighttime) population, daytime population, and highway users. The permanent population was estimated using the U.S. census data by census blocks. The population within each census block was assumed to be uniformly distributed. If the census block was mostly outside the flood zone for a particular sector on an island, aerial digital pictures of the island were reviewed and the population estimated for an adjacent comparable sector was assigned to the sector under consideration.

For nighttime exposure, it was assumed that the permanent population would be in houses/buildings. For daytime exposure, the daytime population was estimated based on the U.S. Census Bureau database on daytime population (U.S. Census 2008). This population includes the portion of the permanent population that works on the island and any transient population (e.g., workers) that visits the island during the daytime. If a highway was on the breached levee, the number of highway vehicles was estimated assuming an average spacing of 20 feet between vehicles and an average of two persons per vehicle.

Appendix 12B shows the estimated population in each group for each island (labeled “Analysis Zone”), initiating event, breach sector, and flood severity zone.

12.1.4 Warning and Evacuation Module

12.1.4.1 Flood Event

If the initiating event is a flood, systematic and frequent monitoring and surveillance of the levees are likely to be conducted as the floodwater rises. Both local agencies/owners of individual islands as well as state and federal agencies would be involved in such monitoring and surveillance. Also, a levee breach is likely to be preceded by such indicators as sand boils and

[1] These are the same sectors used in the emergency response and repair model.

water seepage, which are likely to provide an advance warning of an impending failure. Furthermore, a flood-initiated breach is likely to develop slowly, thus allowing more time to detect it.

Experience with the 2004 Jones Tract levee failure suggests that "Delta Levee Failure Incident" protocols would be established after a levee failure that specify coordination and mobilization of appropriate local, state, and federal agencies (DWR 2004). The protocols include communication procedures to enable rapid and effective warnings to all affected areas, including remote areas. Evacuation procedures and protocols are also a part of the emergency response planning.

Because of these factors, a levee breach during a flood event would likely be quickly detected and emergency response procedures would be promptly initiated. However, the breach detection time for a nighttime breach would likely be greater than for a daytime breach.

The experience with the 2004 Jones Tract breach provides a useful validation point. This breach occurred with no forewarning on a non-project levee outside the normal flood season. Even then, the breach was detected in minutes and evacuation began in less than 30 minutes (California Department of Transportation 2004). According to the U.S. census data, the estimated population on the island is around 40. There was no loss of life as a result of the flooding that occurred after this breach.

These considerations were used to estimate the warning issuance time; that is, the time after a breach initiation at which warnings would be issued to the population at risk. The warning time is primarily dependent on how quickly a levee breach would be detected. Once a levee breach is detected, emergency response planning procedures would be used to disseminate public warnings. For any initiating event, a daytime breach would likely be seen by people in the vicinity and calls to the emergency number would likely be made within minutes after the breach occurs. On the other hand, a nighttime breach under any initiating event may not be seen and would likely be detected only after some people are actually impacted by the resulting flood.

These considerations suggest that the warning time would be sensitive to the time category of breach, but would not depend on the initiating event. Accordingly, the warning issuance times were estimated to be 6 minutes and 30 minutes, respectively, for a daytime and nighttime breach.

Table 12–2 summarizes the warning issuance times for daytime and nighttime exposure. Note that, for a given exposure time, the warning issuance time is assessed to be the same for all initiating events.

Once a warning is issued, evacuation of people at risk would begin. The effectiveness of evacuation may be defined in terms of the percentage of the people in the risk area that would be evacuated safely. This effectiveness is influenced by several factors: the key factors being emergency response planning procedures that are in place and have been tested, availability of private vehicles to move out of the danger zone, the exposure time (daytime versus nighttime), and the *evacuation time window* (i.e., the time between the warning issued to a community at risk and the time at which flood waves arrive at a location). As noted above, emergency response planning procedures have been used in recent levee failures. Most people living in the Delta islands own cars that they can use for purposes of evacuation.

Using this information, the evacuation effectiveness was estimated as a function of the evacuation time window and breach exposure time scenario. Table 12–3 summarizes the evacuation effectiveness results. For a daytime breach, the evacuation effectiveness is assessed to be 0% when the evacuation time is 0 or less (i.e., the flood waves arrive before the resident receives any warning), 80% when the evacuation time is half an hour, 100% when the evacuation time window is greater than half an hour. This is consistent with the 2004 Jones Tract levee failure experience (California Department of Transportation 2004). For a nighttime breach, the evacuation effectiveness is assessed to be 0 percent when the evacuation time is 0 or less, 80 percent when the evacuation time is 1 hour, 100 percent when the evacuation time window is greater than 1 hour.

12.1.4.2 Seismic Event

An earthquake could cause a levee breach without much warning. Such a breach develops rapidly, reaching its full size in minutes. Also, multiple simultaneous breaches may occur on an island as a result of a single seismic event. There is no empirical data on seismically induced breaches in the Delta. As noted previously, the warning issuance time is sensitive to the exposure time (day or night), but is likely to be independent of the initiating event.

The warning issuance time for a seismically induced breach for a given exposure time (day or night) was assumed to be the same as those for a flood-induced breach. Table 12–2 shows these times for a seismic event.

Evacuation effectiveness would be affected because of damage to roads and bridges, and confusion and competing concerns after an earthquake. It was assumed that the evacuation of all people at risk would take longer for a seismic event than for a flood event. The estimated evacuation effectiveness for a seismic event is shown in Table 12–3.

12.1.4.3 "Sunny-Day" Failure Event

For a sunny-day event, the warning issuance time for a given exposure time (day or night) is likely to be the same as that for a flood event. On the other hand, the evacuation effectiveness is likely to be greater because only an isolated breach would occur rather than possible multiple breaches that would put a greater demand on available resources. Table 12–2 shows the assessed warning issuance time and Table 12–3 shows the assessed evacuation effectiveness for a sunny-day event. The Jones Tract breach of 2004 provides a reasonable validation for the assumed values of these parameters.

12.1.5 Life-Loss Fraction Module

Aboelata et al. (2003) developed empirical distributions of life-loss fractions for *chance*, *compromise*, and *safe* flood lethality zones. As noted previously, the lethality zones used in the LIFESim model approximately correspond to the high, medium, and low flood severity zones defined in the present analysis. The LIFESim empirical distributions were based on data from historical dam failures. The life loss in the low flood severity ("safe") zone was zero. Normal probability distributions were fitted to the empirical distributions for the high flood severity ("chance") and medium flood severity ("compromise") zones.

Figure 12–1 compares the two sets of distributions. The comparison shows that the normal distribution fits the empirical distributions reasonably well. For analytical convenience, the normal distributions were used in this analysis. Because the life-loss fractions must be between 0 and 1, the normal distributions were constrained to remain between these two end points.

Table 12–4 summarizes the statistical parameters of the normal distribution of the life-loss fraction for each flood severity zone.

12.1.6 Life-Loss Calculation Module

For each breach defined by a given levee failure sequence, the mean and variance of the number of fatalities in each flood severity zone were calculated using the following equations:

$$m(n_i) = m(f_i) \times N_i \quad (1)$$

$$s^2(n_i) = s^2(f_i) \times N_i^2 \quad (2)$$

in which
- n_i = number of fatalities in i^{th} zone
- $m(n_i)$ = mean number of fatalities in i^{th} zone
- f_i = fraction life-loss for i^{th} zone
- $m(f_i)$ = mean fraction life-loss for i^{th} zone
- N_i = post-evacuation population in i^{th} zone
- $s^2(n_i)$ = variance of n_i
- $s^2(f_i)$ = variance of f_i

The total number of fatalities, n, over all flood severity zones, on an island from a given breach is given by:

$$n = \sum_i n_i \quad (3)$$

The mean number of fatalities over all flood severity zones on an island from a given breach was calculated from the following equation:

$$m(n) = \sum_i m(n_i) \quad (4)$$

The numbers of fatalities in different flood severity zones on an island for a given breach are likely to be highly correlated, because the warning time and evacuation effectiveness would be affected by a common set of factors for all flood severity zones. The variance of the number of fatalities combined over all flood severity zones on an island from a given breach was calculated from the following equation in which a perfect correlation was assumed between the numbers of fatalities in different flood severity zones:

$$s^2(n) = \sum_i s^2(n_i) + 2\sum_{i=1}^{k-1}\sum_{j=i+1}^{k} s(n_i)\, s(n_j) \quad (5)$$

Using the mean and variance of the total number of fatalities, n, over all flood severity zones on an island from a given breach, one can calculate the (conditional) probability of exceeding different number of fatalities given a breach, using the properties of the normal distribution. The probability that n will exceed a specific value n_1 is given by:

$$P[n > n_1] = 1 - \Phi\left[\frac{n_1 - m(n)}{s(n)}\right] \quad (6)$$

in which $\Phi[\cdot]$ = standard normal cumulative probability function.

The probability of zero fatalities is calculated by subtracting from 1 the probability of 1 or more fatalities. The probability of the number of fatalities exceeding the total exposed population is set equal to 0.

Equations similar to (4) and (5) can be used to calculate the mean and variance of the number of fatalities combined over multiple breaches on an island and over all islands with levee breaches caused by the same levee failure sequence. To develop the specific equations for this calculation, indices *j* and *k* are added to *n* to refer to *k*th breach on *j*th island. Let n_{jk} denote the number of fatalities from the *k*th breach on *j*th island for a given levee failure sequence. The total number of fatalities summed over all breaches on the *j*th island for a given levee failure sequence, $n_{j.}$, was calculated from:

$$n_{j.} = \sum_{k} n_{jk} \tag{7}$$

The mean of $n_{j.}$ was calculated from the following equation:

$$m(n_{j.}) = \sum_{k} m(n_{jk}) \tag{8}$$

in which $m(n_{jk})$ is the mean number of fatalities from the *k*th breach on the *j*th island, as calculated from Equation (4).

In calculating the variance of $n_{j.}$, perfect correlation was assumed between the numbers of fatalities from different breaches on the same island and same initiating event. This is because the warning issuance time and evacuation effectiveness are likely to be the same for all breaches on a given island. With this assumption, the variance of $n_{j.}$ was calculated from:

$$s^2(n_{j.}) = \sum_{k} s^2(n_{jk}) + 2\sum_{k=1}^{p_{j-1}} \sum_{m=k+1}^{p_j} s(n_{jk})\, s(n_{jm}) \tag{9}$$

in which p_j is the number of breaches on the *j*th island.

The total number of fatalities summed over all islands impacted by the levee failure sequence, $n_{..}$, is obtained from:

$$n_{..} = \sum_{j} n_{j.} \tag{10}$$

The mean of $n_{..}$ was calculated from:

$$m(n_{..}) = \sum_{j} m(n_{j.}) \tag{11}$$

In calculating the variance of $n_{..}$, the number of fatalities from different islands were assumed to be uncorrelated. This is because the evacuation effectiveness for different islands is likely to be different given differences in such factors as the topography and spatial distribution of population. With this assumption, the variance of $n_{..}$ was calculated from:

$$s^2(n_{..}) = \sum_{j} s^2(n_{j.}) \tag{12}$$

Appendix 12D contains an example that illustrates the calculation of the mean and variance of the number of fatalities for a given levee failure sequence, and the probabilities of exceeding different numbers of fatalities.

12.1.7 Results and Discussion

12.1.7.1 Summary of Results

Appendix 12C contains detailed results of the life-loss analysis, including the mean and standard deviation of the number of fatalities from a breach in each sector in each island for each initiating event type. The probability of zero fatalities and probabilities of exceeding different numbers of fatalities are also shown in this appendix. A summary of the key results and main findings is presented in this section.

Figure 12–2 shows a graph of the number of islands with different expected number of fatalities given a breach. The breach is assumed to occur in the sector that has the maximum population exposure. Figure 12–3 shows a graph of the number of islands with different (conditional) probabilities of five or more fatalities given a breach. The results are shown separately for the different combinations of the initiating event and exposure time (day and night). Figures 12–4 and 12–5 show similar results for the (conditional) probability of 10 or more and 100 or more fatalities, respectively, given a breach. Table 12–5 lists the islands that have greater than 10 percent (conditional) probability of 10 or more and 100 or more fatalities given a breach under different combinations of the initiating event and the exposure time. Figures 12–6 through 12–11 display the islands identified in Table 12–5.

12.1.7.2 Sensitivity Analysis and Limitations

The effect of changing some key parameters for the estimated fatality risks was assessed. This assessment showed that the estimated fatality risks are sensitive to certain parameters. The uncertainty in the estimates of these parameters was also assessed qualitatively. Both the sensitivity of results to key parameters and potential uncertainty in the estimates of these parameters are discussed below.

12.1.7.3 Breach Detection and Warning Issuance

The quicker a breach is detected and warnings to the population at risk are issued, the longer the time available for people to evacuate. Issuing notice in advance of flooding will reduce the number of individuals that remain in the flood danger zone and hence will reduce the number of fatalities.

For this analysis, we assumed that a daytime breach would be detected quicker than a nighttime breach. Furthermore, a breach caused by a seismic event is likely to occur without much advance indication and the time to detect such a breach would be longer than a breach caused by a flood or sunny-day event.

Best estimates of the time when warnings would issue after a breach occurs were made based on the 2003 Jones Tract breach experience and case studies on dam failures reported in the literature (Graham 1999). The current communications technology, including emergency call system and wide usage of cellular phones, may facilitate the process of warning people of flood danger. Individuals who observed a breach or floodwaters rushing into an island would likely to call others downstream from them who could be exposed to the rushing flood waters. This could result in at least some at-risk residents receiving more timely warnings, thus allowing more people to evacuate and move to safe grounds.

12.1.8 Evacuation Effectiveness

Give a certain amount of time available for evacuation, the model assumes that some proportion of the population in the potential flood danger zone would be able to evacuate. Using census data about the demographics in the study area, best estimates of the evacuation effectiveness were made for different initiating events and exposure times. For example, for the flood-daytime scenario, it was assumed that if 30 minutes were available between receiving a warning about the imminent flood and the time the floodwaters would reach a particular area, 80 percent of the people in the area would be able to evacuate and move to safe places.

Breach Development Time

For a seismic event, the breach is assumed to develop rapidly over a span of some 15 minutes. The results of the flood routing model show that a rapidly developed breach would result in floodwater rushing out with higher velocity and reaching the boundary of the high flood severity zone quicker. This will reduce the time available to evacuate and increase the potential for a larger number of fatalities. If a longer breach development time (say 30 minutes) were to be assumed, the time for people to reach the boundary of the high flood severity zone would increase significantly, and would permit more people to evacuate.

12.1.8.1 Estimated Island Population Near the Levees

The available U.S. census database was used to estimate the population in each flood severity zone on each island for a given breach location. The population within each census block was assumed to be uniformly distributed. The actual population may be distributed in a non-uniform manner.

No small-scale digital data of population within each island were available. For some islands, the population on an island could be clustered close to the levee that protects the island from flooding. Such clustering will increase the population exposed to flood risk. Conversely, a significant portion of the population in an island, particularly a large island, could be in the center of the island, away from the flood impact zone. This would decrease the population exposed to the flood risk. Small-scale digital data on island population will be needed to resolve this uncertainty.

12.1.8.2 Main Findings

The main findings of the life-safety analysis are as follows:

- For the flood nighttime scenario, eight islands out of a total of 136 islands have a greater than 10 percent (conditional) probability of 100 or more fatalities given a breach. These islands contain significantly populated areas close to the levee perimeter around the island.

Similarly, for the seismic-nighttime scenario, two islands have greater than a 10 percent (conditional) probability of 100 or more fatalities given a breach.

- For floods, all islands within the 100-year flood plain are assumed to be at risk if a breach were to occur on the levees protecting these islands. For several islands within the 100-year floodplain, populations of several hundred are present within the high severity flood zone (i.e., within 1,000 feet from the levees). With the assumed warning times, about one-third of these people are likely to have insufficient time to evacuate before floodwaters reach their residences.
- For a seismic event, only those islands within the mean higher high water (MHHW) levels are assumed to be at risk. As a result, fewer islands are at risk of flooding from an earthquake-induced breach. On the other hand, such a breach is likely to occur suddenly and would cause floods with high velocity that move quickly across an island. As a result, people residing within the high flood severity zone (which was estimated to be up to 1,000 feet from the levees) would get little warning time about the impending flood. They would not be able to evacuate before the floodwaters arrived.
- Fatality risks are higher during a nighttime breach because it would take longer to detect such a breach and the warning issuance time is likely to be longer, which would reduce the time available to evacuate.
- Fatality risks from a breach during sunny-day conditions are relatively small. This is because only islands within the MHHW levels are assumed to be at risk and there is likely be sufficient warning time for people to evacuate. This result is consistent with the experience from the 2004 Jones Tract levee breach.
- The estimated fatality risks are sensitive to the data available to delineate the spatial distribution of the population within the high flood severity zones and to the key risk model parameters. Best estimates of the key parameters were made based on available data and professional judgment. The sensitivity of results to these parameters was discussed previously in this section. The uncertainty in the key model parameters and the sensitivity of results to the variations in these parameters suggest that the uncertainty factor in the estimated fatality risks could be on the order of 2 to 5. That is, the probability of exceeding a given number of fatalities could be higher or lower by a factor of 2 to 5.

12.2 CHANGES IN WATER QUALITY

12.2.1 Risk Modeling for Effects on Water Quality on Exports

12.2.1.1 Salinity

One or more Delta levee breaches that result in island flooding will impact Delta water quality (most obviously salinity) and water operations. A substantial amount of saline water may be drawn in from the Bay depending on the initial salinity of the river/Delta/Bay system, river inflows at the time of the breach event, and the number, size, and locations of the breaches and flooded islands. Subsequently, salinity may be dispersed and degrade Delta water quality for a prolonged period due to the complex inter-relationship between ongoing Delta inflows, tidal mixing, and the breach repair schedule.

The Water Analysis Module (WAM) simulates direct, water-quality-related consequences of levee breach events in relation to salinity. WAM incorporates initial island flooding, upstream reservoir management response, Delta water operations, water quality (salinity) disruption of Delta irrigation, Delta net losses (or net consumptive water use), hydrodynamics, water quality (initially represented by salinity), and water export (see Water Analysis Module TM [URS/JBA 2007e]). The module is central to the risk analysis, receiving the description of each breach scenario (e.g., resulting from a seismic or other event) and details of the levee repair process from the emergency response and repair part of the analysis. The model produces hydrodynamic, water quality, and water supply consequences for use in the economic and ecosystem modules. Water quality consequences of levee failures in the Delta are dependent, not only on the initial state of the Delta at the time of failure, but also on the time series of tides, inflows, exports, other uses, and on the water management decisions that influence these factors. Thus, WAM tracks water management and the Delta's water quality response starting before the initial breach event and proceeding through the breach, emergency operations, repair, and recovery period (see Section 11).

12.2.1.2 Organic Carbon

When subsided Delta islands flood due to a levee breach, significant amounts of organic carbon will be released from the high organic matter soils. Depending on the location of the flooded island, the timing of the pump out of the flood waters and the hydrodynamics and transport at the time of pump out, these elevated levels of organic carbon could adversely affect the drinking water supply derived from the Delta. Dissolved organic carbon reacts with disinfectants during the drinking water treatment process to produce disinfection byproducts (DBPs), which may be carcinogenic and mutagenic. This impact will be dependent on which islands flood, their proximity to drinking water intakes, and the hydrodynamic conditions governing transport.

A preliminary analysis of total organic carbon (TOC) increases was conducted for six specific Delta levee breach scenarios. These scenarios also include variations in water year type and seasonality. The mass of TOC produced from the flooded peat islands as well as the increases in TOC concentrations at Clifton Court Forebay were modeled for the time period when salinity was restored enough to allow water exports to resume. Drinking water can be reliably treated with enhanced coagulation in the 1 and 3 flooded islands scenarios evaluated, and in one of the 10 flooded islands scenarios. More substantial problems occur in the 20 and 30 flooded island scenarios. With sustained TOC concentrations greater than 6 mg/L, the Delta water may not be usable for municipal and industrial purposes; however, it may be suitable for agriculture. More details on TOC impacts on water treatment are provided in Appendix 12E. Decisions must then be made regarding water exports that impact potability in downstream reservoirs, storage, and drinking water treatment facilities.

More detailed modeling and an evaluation of dewatering locations and rates can be used to refine the predicted magnitude and duration of spikes. However additional treatment options would be needed to address periods when TOC concentrations are above 6 mg/L.

12.2.2 Qualitative

Levee failure and the resultant re-suspension of sediment and sediment associated pollutants, as well as damage to pipelines and hazardous material storage containers, is expected to adversely affect water quality and may result in stress or mortality to fish and other organisms. The severity of water quality degradation varies in response to a number of factors including the quantities of pollutants, the amount of dilution, and frequency of flushing flows.

Pollutants often have direct and negative effects to aquatic organisms. The severity of the effects is often dependent on the duration of exposure, the sensitivity of the species, and lifestage of the organism. Some pollutants can be taken up into tissues and bioconcentrate in specific organs and biomagnify in subsequent trophic levels. The following are a few examples of the effects of toxic substances on aquatic organisms.

- Excessive amount of suspended material in water reduces the amount of sunlight that reaches river and streambeds. Submerged aquatic plants can be affected by the lack of sufficient sunlight. Sedimentation can reduce the carrying capacity in streams, reduce the habitat size for fish, and can increase stress in adult fish. Clay and silt particles can harm fish by clogging gills or smothering larvae. Other pollutants like fertilizers, pesticides, and metals are often attached to the soil particles.
- Metals may adsorb strongly to clays, muds, humic, and organic materials, however they can also be very mobile in the environment. Depending upon the pH, hardness, salinity, oxidation state of the element, soil saturation, and other factors, metals are readily soluble (EPA 2008a).
    - Cadmium is cancer-causing and teratogenic and potentially mutation-causing with severe sublethal and lethal effects at low environmental concentrations. It accumulates in the livers and kidneys of fish.
    - Chromium has a wide range of adverse effects in aquatic organisms such as algae, benthic invertebrates, and embryos and fingerlings of freshwater fish and amphibians.
    - Copper toxicity to fish can occur through rapid binding of copper to the gill membrane, which cause damage and interferes with osmoregulatory processes.
    - Lead may cause muscular and neurological degeneration and destruction, growth inhibition, mortality, reproductive problems, and paralysis in fish. In invertebrates, lead can adversely affect reproduction. In algae, growth may be affected.
    - Selenium undergoes biomagnification as trophic levels increase. Aquatic organisms can experience loss of equilibrium and other neurological disorders, liver damage, reproductive failure, reduced growth, reduced movement rate, chromosomal aberrations, reduced hemoglobin and increased white blood cell count, and necrosis of the ovaries.
- Pesticides include insecticides, herbicides, and fungicides and are designed to prevent, deter, or exterminate pests. Each pesticide has certain risks for aquatic organisms because they are, by design, meant to disrupt biological processes. Organophosphates, such as chlorpyrifos and diazinon, can affect the nervous system. Organophosphates can impact the distribution and abundance of aquatic species. Organochlorines can bioaccumulate in fish tissue. Pyrethroids are synthetic versions of a naturally occurring pesticide in chrysanthemums, and some forms can be extremely toxic to the nervous systems of fish and invertebrates (DWR 2005a).

- Ammonia toxicity causes reduced growth, development, and reproductive rates. There can be injury to gill, liver, and kidney tissues. At moderate ammonia levels, fish can suffer a loss of equilibrium, become hyper-excited, which increases respiratory activity, oxygen uptake, and heart rate. High ammonia concentrations can lead to convulsions, coma, and death (USEPA 1999).
- Phosphorus compounds typically found in nature are not directly toxic to plants or aquatic species; however, surface waters with high phosphorus levels can exhibit eutrophication, increased growth of undesirable algae and aquatic weeds, and a decrease in dissolved oxygen.

12.2.2.1 Potential Contaminants on Delta Islands

Levee failure could inundate islands that have a variety of land uses such as irrigated and non-irrigated agriculture (cultivated croplands and pasture land with associated farm equipment, farm buildings, and isolated residential structures), small unincorporated communities, industrial areas, recreation areas, and wildlife areas or nature preserves. Larger communities and heavy industrial areas in the Delta are typically located above the 100-year flood plain, and are less likely to be inundated in the event of levee failure. Pollutants associated with areas of potential inundation may be mobilized directly by water or indirectly by soil erosion. These toxics can degrade water quality and can adversely impact the aquatic community as well as humans and wildlife that consume the affected species.

The mobility of these pollutants is influenced by the hydrodynamics of the breached island and by the specific chemical properties of each compound. A chemical constituent might be miscible with water or sorbed to soil particles or display a behavior in between. The toxics that could be associated with soil particles include legacy pollutants such as organochlorine pesticides (DDT, chlordane, dieldrin, etc.), PCBs, dioxins/furans and mercury; organophosphorus pesticides, such as chlorpyrifos and diazinon; pyrethoid insecticides; herbicides; and other organics. The soil may also have elevated concentrations of nutrients (nitrate, nitrite, ammonia, organic nitrogen, and phosphorus), salts, metals (cadmium, copper, lead, nickel, zinc, and selenium) and bacteria or pathogens which may have deleterious effects in the aquatic environment (Barrios 2000; Connor et al. 2004; Oros and Werner 2005). Other effects from Delta island inundation could include the decrease in dissolved oxygen levels, an increase in turbidity, and an increase in sediment accumulation.

Although the specific type and quantity of chemical pollutants located on the islands are unknown, there may be a correlation between pollutant type and land use. Typical agricultural residues would include organic carbon compounds, nutrients, pesticides, herbicides, trace elements, salts, and petroleum compounds. These residues can be on the soil, in farm equipment, or in storage containers. Urban and industrial areas could potentially contribute pesticides, oil, grease, petroleum, heavy metals (including cadmium, copper, lead, nickel, zinc, and mercury), polynuclear aromatic hydrocarbons, nutrients, and pathogens. Boat repair facilities may contribute paint, paint chips, and metals including copper, zinc, and tributyltin. If residential structures in either agricultural areas or small communities were inundated then additional pollutants could be released. Organic material, bacteria, and potential pathogens could be mobilized from sewage treatment systems, on-site septic systems, and leach fields (Delta Protection Commission 2002).

The increase in the concentration of many of these chemical constituents can have a deleterious effect on aquatic life. There is also a potential for additive and synergistic toxicity effects between pesticides or between pesticides and other water quality parameters (Lee and Jones-Lee 2005).

The Delta also contains extensive oil and gas wells and production fields (see Section 11.6). Although there are safeguards and controls on toxic material storage containers and oil and gas extraction wells, these controls are not necessarily designed for an extended submergence after a period of stress. One island in the 100 year flood plain, Rough and Ready Island, contains a federal superfund site; Rough and Ready Island was not one of the islands expected to breach.

As a consequence of the number of variables and unknowns affecting the exposure and fate of organisms from pollutants, and the high degree of uncertainty in the accuracy of predictions of environmental risk associated with contaminant exposure, the release of toxic substances is acknowledged as an environmental stressor, both incrementally and cumulatively, with levee failure but these effects have not been quantified as part of this analysis.

12.2.2.2 Methylation of Mercury

The soils in the Delta generally have elevated levels of mercury due to historic inputs from mercury and gold mining during the gold rush period. Methylmercury is the form of biologically active mercury that can bioaccumulate and biomagnify in the food chain. The flooding of subsided Delta Islands due to a levee breach will result in conditions conducive to methylation of mercury, at least during some of the flooding stages. Mercury methylation may occur when the soils are flooded and oxygen is consumed. The presence of high levels of dissolved organic carbon will facilitate the methylation process. Mercury methylation has been shown to occur when dry soils are initially flooded, the so called "reservoir effect." It is anticipated that initial wetting during flooding will produce methylmercury and further wetting and drying cycles will promote methylmercury production.

Of particular concern is the availability of methylmercury to phytoplankton during an algal bloom. This will provide a known pathway for bioaccumulation and biomagnifications of methylmercury up the food chain. A more detailed evaluation can be used to investigate potential ecosystem and human effects with respect to the pump out of water from the flooded island that may contains elevated methylmercury.

12.2.2.3 Nutrients

The flooding of islands will release substantial amounts of nutrients into the water column from the very fertile high organic matter soils. When the suspended sediments clear from the water column, light penetration in combination with the increased nutrients may promote algal blooms. A positive aspect of nutrients and organic carbon is the supply of potential food to the ecological food web. Nutrients and particulate organic carbon can provide a source of food and energy to the food web.

12.3 ECOSYSTEM IMPACTS

Ecosystem impacts are another type of consequence of levee failure that is recognized as extremely important, but is also very difficult to analyze quantitatively. Analysis of the impacts of levee breaches on species of fish ("Aquatics"), aquatic and terrestrial vascular plants ("Terrestrial Vegetation"), and birds and mammals ("Terrestrial Wildlife") began with creating conceptual models of the mechanisms through which impacts can occur. Species and groups were selected based on their status as endangered, threatened or species of concern, or because of their important contributions to biodiversity or ecosystem processes. The detailed body of information on key parameters and mechanisms of impact used in the risk analysis are described in the Impact to Ecosystem TM (URS/JBA 2008e). Some of these mechanisms were quantitatively modeled in the risk assessment, others were quantitatively described in the Impact to Ecosystem TM, and others could only be assessed qualitatively.

The risk assessment model for fish incorporates the spatial and temporal distribution of fish species and life history stages (see Figure 12–12 for fish sampling locations), direct mortality and changes in available habitat and its suitability due to levee breaches and the impact of water management operations. Impact models were developed to represent these mechanisms and to estimate the relative change in population and the likelihood of species survival. A similar model was created for terrestrial vegetation and for assessing the impact of levee breaches and repair work on sensitive species of vegetation on the channel side of levees. The risk assessment model of terrestrial vegetation presented in this report uses area of habitat flooded to quantify the primary impact of levee breaching on vegetation types, incorporating the spatial distribution and size of area of vegetation groups and the islands flooded (see Figure 12-13a for example of distribution of vegetation types in the northern Delta, Figure 12-13b for vegetation types in the southern Delta, and Figure 12-13c for vegetation types in Suisun Marsh). The risk assessment model for terrestrial wildlife assesses habitat lost to flooding by incorporating the home range of select sensitive species, the vegetation types utilized by sensitive species, the spatial distribution and area of those vegetation types, and the islands flooded.

It is important to recognize the limitations inherent in this characterization of ecosystem impacts. The results presented here primarily assess the number of individuals or areas of habitat impacted, which is similar to the coarse scale used to evaluate the impact of levee failure on life and safety through measuring the number of residents exposed to flooding. Therefore, these results provide a sense of the order of magnitude of the risk, primarily for the immediate impacts of levee breaches which last for a relatively short duration but cause widespread mortality during the time that they are in operation. Further consequences such as impacts of toxics released, impacts extending across food chains, long-term impacts of levee breach on organisms and the nonlinear impacts of multiple mechanisms of impacts on organisms, are examples of further impacts of levee breaches which are not quantitatively assessed here, but which may have far-reaching impacts on the ecosystem.

The Delta and Suisun Marsh provide habitat for a diverse assemblage of fish and macroinvertebrates, submerged and emergent aquatic vegetation, diverse plant communities, and a variety of birds, mammals, and insects. Levee failures within the Delta or Suisun Marsh have the potential to affect fish and wildlife species directly (e.g., mortality to individual fish entrained onto a flooded island, removal of vegetation during a levee break or as a result of levee reconstruction) or indirectly (e.g., changes in the amount or quality of habitat, water quality, or changes in upstream water releases and diversions from the Delta). Some effects may occur over a relatively short time frame of days to months (e.g., removal of plants by scour) while others may occur over longer time frames such as years to decades (high-salinity water alters the soil structure reducing the capacity of the soil to support upland vegetation). Changes in habitat conditions may be detrimental to some species or lifestages and beneficial to others; in particular young lifestages typically have more limited tolerance ranges than adults. Additionally, changes may have different effects depending on the geographic location and extent of the change, and the timing and duration of the occurrence. Existing data were used to create conceptual models (see Impact to Ecosystem TM [URS/JBA 2008e]) of the mechanisms by which levee failures could affect selected aquatic (see Figure 12–14 for aquatics conceptual model) and terrestrial species (see Figure 12–15 for vegetation conceptual model). The conceptual models were used to identify the key parameters and functional relationships. All of these parameters and relationships were considered when creating the risk assessment, even though not all parameters were explicitly modeled in the risk assessment presented here. Parameters were addressed in one of three ways: (1) they were utilized in the risk model, (2) they were discussed in the Impact to Ecosystem TM but not addressed but was recommended for refinement, or (3) they can only be assessed qualitatively.

The risk assessment models included the following key parameters and functional relationships:

- Parameters in risk model used to assess the impact of levee breaches on Aquatics
  - Breach duration
  - Number of breaches
  - Salinity or X_2 location
  - Coldwater pool and species tolerance
  - Entrainment onto Islands
  - Entrainment into SWP/CVP pumps
  - Species and lifestages location in space and time
- Parameters in risk model used to assess the impact of levee breaches on terrestrial vegetation
  - Location of breached islands
  - Spatial distribution of species
- Parameters in risk model used to assess the impact of levee breaches on terrestrial wildlife
  - Location of breached islands
  - Home range of species
  - Vegetation types utilized as habitat by species

Key parameters, functional relationships, and ecosystem impacts of levee breaches are summarized below. For more details on model development, input parameters, and the results of the analyses, see the Impact to Ecosystem TM (URS/JBA 2008e).

12.3.1 Aquatic Species

12.3.1.1 Foreword

The Impact to Ecosystem TM was revised after the CALFED Science Program Independent Review Panel (IRP) provided its review comments on August 23, 2007. The review comments were particularly critical of the aquatic impact model. Specifically, the comments indicated that the model lacked clarity and robustness. The review panel recommended that the Delta Risk Management Strategy (DRMS) ecosystem team uses a simpler approach and suggested the use of an expert elicitation process to develop the new aquatic impact model.

The new aquatic impact model presented in the Impact to Ecosystem TM (URS/JBA 2008e) was developed using input from the experts. However, the model application and execution has not been completed because the experts had limited availability during the time frame required to complete the work. The other two models used in the Impact to Ecosystem TM (the vegetation and terrestrial species impact models) were kept about the same. The overall TM was edited and updated in accordance with the IRP comments.

The experts convened for the elicitation process were:

- Dr. Wim Kimmerer (UCSF, Romberg Tiburon Center for Environmental Studies)
- Dr. William Bennett (UC Davis)
- Dr. Peter Moyle (UC Davis)
- Dr. Chuck Hanson (Hanson Environmental, Inc.)

The development of the aquatic impact model relied on input and recommendations from these experts. The approach was phased. The experts reviewed the general elements of potential impact mechanisms to assess their relevance to the particular application in DRMS (ecosystem impacts as a result of levee failures). Then, each relevant mechanism or its subset was developed separately and presented to the experts in a formal meeting-elicitation session for review and comments. Because of the limited availability of the experts to convene more frequently and the schedule constraint to complete the DRMS Phase 1 work, the aquatic model was not fully executed and implemented. Currently, the model has been developed and discussed with the experts and is presented in the Impact to Ecosystem TM (URS/JBA 2008e). The test runs and the production runs have not yet been performed.

12.3.1.2 Assessing Sources of Uncertainty and Limits of Knowledge

The purpose of the DRMS risk analysis is to estimate likelihood of adverse consequences that may occur as a result of levee failures. This analysis includes the effects of levee failures on the ecosystem. For each type of consequence that is evaluated, all sources of uncertainty (aleatory and epistemic) that affect the estimate of consequences, conditional on the occurrence of levee failures, can in principal be estimated.

Ecology is not a predictive science because ecological systems are unreplicated, complex, and stochastic (e.g., Mayr 1961; 1974). These “complex adaptive systems” (Brown 1995) respond to many, often subtle, and often non-linear forces and their structure and dynamics are not accurately characterized by a reductionist modeling approach (Brown 1995). Because of this complexity and because ecological outcomes are highly dependent on initial conditions (which often are not known or well understood), ecologists are ill-equipped to predict the outcomes of perturbations to ecosystems. As a result, comprehensive quantitative models that predict future population levels of any species after large-scale perturbations are generally unavailable. These limitations are particularly apparent because all but artificial, experimental “ecosystems” are open systems (they are nested entities with arbitrarily defined boundaries) where the composition of interacting entities changes continuously. For example, in the Delta aquatic ecosystem, species composition and the forces affecting species' interactions are constantly changing (e.g., Alpine and Cloern 1992; Matern et al. 2002). Indeed, the Delta aquatic ecosystem is in the midst of a rapid shift in biological diversity (commonly referred to as "pelagic organism decline"); the forces driving this shift are not well-understood (Sommer et al. 2007).

The DRMS ecosystem impact modeling methodology team was tasked with answering a very broad question: What will happen to the Delta after levee failure? Modern ecology cannot address such a broad question quantitatively because there are too many complex interactions, some dominated by non-linear dynamics and interactions that are not well understood even in "isolated" ecosystems (e.g., Werner 1992; Brown 1995). Instead, DRMS ecosystem impact modeling team identified different mechanisms that were expected to produce relatively large impacts to their focal ecosystems (aquatic or terrestrial) as a result of levee failure and island flooding. For each of these mechanisms, the team identified models to estimate the impact to the relevant ecosystems. These models provide "first-order" estimates of major impacts to selected focal organisms in the ecosystems of the Delta. They are based on relationships of focal species to physical characteristics of their environment. Possible biological interactions are innumerable, context-dependent, and poorly-understood; thus, modeling of these (potentially important) effects was severely limited.

The ability to estimate the environmental effects of levee failures is limited by our current state-of-knowledge of ecological processes in general, and the impact that significant stressing events such as levee failures may have in particular. Although substantial effort has been made to study and collect data on the species, habitats, and ecological processes in the Delta and Suisun Marsh, the state of knowledge on some subjects is quite limited. Our understanding of the critical attributes of species, habitats, and processes in the estuarine ecosystem is patchy. Although some species have been extensively studied, others have not and little significant or current information is available for them.

As described above, the Delta provides habitat to a diverse assemblage of resident and migratory estuarine organisms. A wide range of habitats, created by the interaction of physical forces (e.g., flow rates, tidal influence, water depth, salinity intrusion, temperature) with different primary producers (that influence both the local energy supply for other trophic levels and the physical structure of the habitat), and human activities (e.g., agriculture, suburban housing, managed diked-wetlands) leads to a geographically complex pattern of species assemblages. Furthermore, many species use the Delta and Suisun Marsh as a migration corridor, while other species are year-round residents that use different habitats throughout their life cycle. This physical, biological, geographical, and temporal complexity makes analysis of biological sampling data challenging. For example, even intensive sampling efforts may fail to capture important associations between species and habitats that happen seasonally or in a particular environment whose location changes seasonally or annually (e.g., based on freshwater outflow). Fortunately, several long-term and intensive fish and wildlife sampling programs such as those conducted by the California Department of Fish and Game (CDFG), U.S. Fish and Wildlife Service (USFWS), California Department of Water Resources (DWR), U.S. Geological Survey (USGS), University of California, Davis (UCD), and others have created data sets that are valuable for the study of biological trends and relationships within the Delta and Suisun Marsh.

In the Delta, key unknowns that contribute to our epistemic uncertainty for many of the species include (but are not limited to):

- Current or historical population abundance and relationships (e.g., linear, logarithmic) between population indices and actual population abundance
- Basic life history data (e.g., fecundity and mortality rates)
- Physical habitat tolerances and preferences (salinity, temperature, dissolved oxygen, turbidity, and pollutants)
- The strength, extent, and natural variability in biological interactions including predator-prey dynamics, diseases and their epidemiology, and competitive interactions
- Ecosystem carrying capacity, the trends in carrying capacity, and the drivers that produce those limits and trends

The risk analysis of environmental effects resulting from a wide range of potential levee failure events is characterized by a large amount of uncertainty. Uncertainty is associated with interpretation of existing data for a species, the range of individual responses and tolerances, variations in habitat preferences, and other factors related to developing a single response curve that is representative of the species. Other sources of uncertainty include lack of data regarding:

- The manner in which individual effects on species life stages compound or interact to produce overall changes in individuals
- The manner in which changes in individuals lead to changes in population levels of the species
- The manner in which changes in individual species lead to changes in ecosystem-level effects

In general, these and other knowledge gaps extend across species, habitats, and trophic guilds. Uncertainty regarding these factors is less for some species than for others. Further, factors such as population abundance and the strength of density-dependent limits on population growth can only rarely be determined precisely (May 1974).

In addition to the epistemic uncertainty surrounding predictions of ecosystem response to environmental perturbations, predictions of this sort in biological systems are also subject to significant aleatory uncertainty. Chance (aleatory) events play an important role in population dynamics, interactions among species, and other environmental processes. The forces that produce aleatory uncertainty become increasingly important as population abundance decreases ("Allee effects") (Stephens and Sutherland 1999) or the geographic extent of a critical habitat declines (e.g., Rosenfield 2002). Many of the species and habitats included in the environmental risk analysis component of the DRMS project are small, geographically limited, and endemic or extremely isolated. Thus, aleatory uncertainty is expected to have a relatively large impact on the predictions that will result from this analysis.

In contrast to the state of knowledge regarding the Delta's aquatic ecosystem, the relationships between the availability of terrestrial species habitats (i.e., extent, connectivity, patch sizes, and quality) and the distribution and abundance of wildlife in the Delta and Suisun Marsh are generally well understood. However, the data necessary to quantify these relationships is often lacking (e.g., the likely effects of a change in food availability on a species distribution, behavior, or abundance).

12.3.1.3 Risk Assessment Model

The aquatic species risk assessment model was developed in three separate components. Time considerations prevented completion and parameterization of these models. To the maximum extent possible, each model component was designed to make use of existing data sets.

The **first model** component estimates direct mortality to aquatic species arising from **entrainment** and elevated **suspended sediment** concentrations on flooding islands. This impact will be negative for any species considered but the magnitude of impact will vary depending on species-sensitivity to suspended sediment concentrations and the proportion of its population that exists in the Delta at the time of levee failure. This model uses data from aquatic community sampling programs in the Delta that to portray the spatial and temporal distribution of focal species (and how that distribution varies with hydrological conditions) and combines it with data on island volume and location to estimate potential entrainment on flooding. The time-course and magnitude of fish entrainment (measured as a proportion of a given species' population) can be integrated with estimates of the time-course and magnitude of suspended sediment concentrations to estimate the likely mortality (and uncertainty surrounding that estimate) for focal species. These results can then be evaluated by estimating the effect of entrainment mortality on the likelihood of population extirpation within a given time frame. A specific model for estimating these impacts is developed and described in the Impact to Ecosystem TM (URS/JBA 2008e, Sections 6.1.1 and 6.1.2).

The **second model** component estimates the mortality that would be *avoided* if levee failures lead to **cessation of export** pumping by the CVP and SWP pumps in the south Delta. This impact will be positive for any species considered but the magnitude of the impact depends on the species' susceptibility to entrainment and mortality at the south Delta pumps under business-as-usual operations. Different approaches to estimating the proportional impact of business-as-usual pumping practices are presented. Such impacts are particular to different species and life stages and change depending on season and hydrological conditions. The relative benefits of curtailed export pumping are evaluated by estimating the effect of averted mortality on the likelihood of population extirpation within a given time frame. This estimate is generated using the same approach as that used for estimating the negative impact of mortality due to entrainment on flooding islands, and is described in the Impact to Ecosystem Technical Memorandum, Sections 6.1.3 and 6.1.4.

The **third model** component assesses the potential for **creation of new habitat** that may be used by aquatic species. Flooded islands with acceptable physical conditions may represent a positive impact for focal aquatic species. But, they may represent a negative impact if "habitat" on flooded islands supports invasive predators or other species that alter the ecosystem in a way that impacts focal species negatively (e.g., invasive submerged aquatic vegetation, invasive clams). Physical habitat conditions on flooded islands can be assessed by the salinities expected on those islands (as predicted by hydrodynamic modeling performed elsewhere in the DRMS modeling context), island depth, water temperatures (predicted from current patterns), and turbidity (also predicted from current patterns). Furthermore, flooded islands that periodically experience extremely low dissolved oxygen concentrations (via eutrophication resulting from biological respiration) may represent "population sinks" for aquatic species that colonize them. Methods for estimating the likelihood of island eutrophication are developed in the Impact to Ecosystem TM (URS/JBA 2008e, Sections 6.1.5 through 6.1.7).

Each of these components addresses the central question: What is the impact of levee-failure (and subsequent flooding of islands) on the aquatic ecosystem? However, each model component operates on a different time scale and utilizes somewhat different data sources. For example, impacts estimated under the third model component (habitat creation) are not comparable to estimates of changes in extinction time resulting from the immediate impacts of island flooding. These models present somewhat independent efforts to characterize impacts to the aquatic ecosystem and it is not possible, scientifically advisable, or necessary to link them in a way that would produce a unified measure of impact.

These three model components are not expected to present a comprehensive view of the ecosystem response to levee-failure. Ecosystems are complex, adaptive systems; the dynamic response to perturbation reflects innumerable processes (many of which cannot currently be modeled), initial conditions (many of which are not known), and a various stochastic effects. Instead, these model components present estimates (to a first order) of major impacts that might be expected to result from levee-failure. They should provide insight into potential major effects of levee failure events (e.g., extinction or local extirpation of one or more species) and the impact of post-failure response strategies (e.g., island recovery priority and timing).

12.3.1.4 Further refinements

Mortality due to entrainment on flooding islands. Data on species-specific tolerances for suspended sediment concentrations are generally lacking. The best information is available for the family Salmonidae (including Chinook salmon and steelhead); however, even there, the available data presents a very large range of uncertainty. It may be possible to develop estimates of species-specific suspended sediment tolerances through an expert elicitation process; however, targeted research into the tolerances of the species in question would reduce this uncertainty substantially.

Averted entrainment-related mortality due to cessation of CVP/SWP export operations. Estimates of impact to aquatic species related to entrainment in CVP/SWP water export operations incorporate estimates of salvage and pre-entrainment loss at the pumping facilities as well as estimates of a species' total population size in the Delta. Both of these estimates can be improved. The Impact to Ecosystem TM (URS/JBA 2008e) provides several approaches for estimating these parameters, including some of the most recent approaches from experts in this ecosystem.

Not incorporated into this model component are estimates of the mortality to fish species from altered hydrodynamics in the Delta that result from export operations. These impacts, which may divert fish from their preferred habitats or migration paths into inhospitable environments in the inner Delta, may be significant (perhaps larger than the direct impact of entrainment at the pumping facilities), yet there is no estimate of their magnitude. Development of procedures for estimating indirect mortality due to export-related hydrodynamics would allow better estimation of the increase in population likely to result from temporary cessation of export pumping.

Creation of new habitat on flooding islands. Because this component projects impacts that may occur further in the future and those that result from potential biological interactions, the effect of this mechanism is highly uncertain. Still, improved projections of physical habitat conditions on these islands (e.g., temperature and salinity), combined with improved techniques for predicting colonization by invasive species would improve certainty of consequences from this mechanism.

12.3.2 Terrestrial Vegetation

12.3.2.1 Risk Assessment Model

Location of Species Types. Species of vegetation were grouped into 14 functional groups of wild vegetation called 'vegetation types." The location of vegetation types was determined from surveys conducted by DFG (see Figure 12–13a for example of vegetation type distribution in the northern Delta).

Flooding with Saline Water. The combination of salinity and flooding (i.e., flooding with high-salinity water), decreases growth and survival more than either type of stress alone (Figure 12–16) (Kozlowski 1997). Flooding cuts off oxygen supply to the submerged vegetation causing a cascade of responses, and flooding with saltwater causes additional osmotic shock and salt toxicity (Mitsch and Gosselink 1993). However, due to the paucity of information on plant response to flooding with saline water, responses of vegetation to flooding and salinity will be addressed separately (Figure 12-17).

Flooding (inundation). Flooding shuts off oxygen supply to submerged terrestrial plant parts. Respiration shifts from aerobic to anaerobic, impairing the energy status of cells, and reducing all metabolic activities. In particular, the low energy produced by anaerobic glycolysis in flooded upland plants causes a reduction in nutrient uptake. The toxic end-products of anaerobic glycolysis (fermentation) cause cytoplasmic acidosis and eventually death (Roberts 1988 in Mitsch and Gosselink 1993). Flooding also causes decreased water uptake, resulting in drought-like symptoms of closed stomata and wilting. Flooding not only cuts off the oxygen supply to submerged vegetative tissue, but cuts off oxygen supply to the soil, as well. These anaerobic soil conditions result in an accumulation of substances that have a toxic effect on roots, including by products of anaerobic bacteria, and soluble reducing minerals such as iron, manganese, and sulfur (Kozlowski 1997; Ernst 1990 in Mitsch and Gosselink 1993). Furthermore, infrequent flooding alters the soil structure and capacity of the soil to support plant growth of non-flood tolerant species (Mitsch and Gosselink 1993).

12.3.2.2 Further Refinements

Salinity. Plants adapt to salinity by physiologically tolerating high salt concentrations (e.g., through osmotic adjustment) or avoiding salt (salt extrusion, salt exclusion, or dilution) (Kozlowski 1997). Specialized tissues or organs are involved with avoiding salt, such as the inner cells of the cortex of roots of vascular plants and the passage cells of the steele, which are barriers to transport of salt into the plant. Some plants leak salts through secretory organs, such as salt glands, in which energy is used to selectively move ions from vascular tissue in the leaves (Mitsch and Gosselink 1993). The precise mechanisms through which salinity inhibits growth are complex (Kozlowski 1997). Plants which have adapted to high salinity conditions can often survive in low salinity environments, but due to the energy expended on adaptations for high salinity, are typically out-competed by non salt tolerant plants.

Flowering Time. Flowering time relative to breach events is pertinent for upland plant species but not for wetland or aquatic species. If flooding occurs during the flowering time of a species, then pollination, seed set and fruits may be impacted, reducing the number of seeds in the seed bank for re-colonization after removal of flood water. For many perennial species in the marsh, flowering is intermittent and sexual reproduction through seed production is only favored in times of lowered salinity. Annual reproduction of these plants from seeds is not essential for their long-term survival (SEW report).

Lifespans. Lifespans of plant species range from 1 year (annuals), biennials (2 years), and perennials (several to > 200years; USDA 2007). For annual species, reduction of reproductive potential can have a large impact on population size of the subsequent generation; for small populations of annuals increases in variability of population size increases probability of population extinction. Reduction of a reproductive potential for a single year for biennials and perennials will have little long-term impact on the population size, if the adults are able to survive flooded conditions and reproduce in the following years.

Sensitive Species and Loss of Habitat. Sensitive species include those listed as endangered, threatened or species of concern by federal and state entities. Many sensitive species live in the Delta, and the channel-side of the levee provides a refuge for many observed occurrences of sensitive species as well as fringing tidal wetlands. This habitat is lost in the breach cross section when levees breach. During breach repair operations the channel-side of the levee is also impacted by construction equipment approximately 1.5 times the breach width, to either side of the breach. From the Jones tract report, it does not appear that interstitial islands near the breach are lost by water flowing into the breach (pers. comm. S. Salah-Mars 2006); therefore, we assume that habitat on interstitial islands are not affected by proximal levee breaks. Habitat in levee breach scour hole is also lost.

12.3.2.3 Qualitative

Seed Banks. Seed persistence describes the duration that seeds remain viable as well as the speed at which seeds in the seed bank germinate. Seed persistence varies among species, from short seed persistence (e.g., *Avena fatua* seeds do not stay in the seed bank long because they germinate rapidly) to other plant species in which viable seeds can be stored for upwards of 20 years; the upper limit of seed viability is unknown. Viability of seeds is influenced by storage conditions (e.g., levels of moisture and salinity), but little is known about the impact of flooding on seed viability for the range of communities found in the Delta and Suisun Marsh. The ability of seedbanks to re-establish communities is impacted by soil characteristics, salinity, and hydrology (LePeyre 2005).

Vegetative Propagules. Vegetative (non-sexual) reproduction can include growing new plants from stolons, bulbs, cuttings (pieces of a plant), sprigs, rhizomes, or tubers. Some of these modes of vegetative reproduction allow for long distance dispersal of propagules (bulbs, cuttings, sprigs) and others short distance dispersal (daughter plants from stolons, rhizomes, tubers). The tolerance of vegetative structures to flooding and salinity varies. For some plants (e.g., *Egeria*) which can reproduce by cuttings, the scour associated with flooding creates vegetative propagules and spreads them with flood waters. Other vegetative structures, such as *Typha* rhizomes can also break-off and relocate during disturbances such as flood events. For many aquatic and marsh species, reproduction by vegetative propagules has a much larger contribution to population size than seeds; clonal marsh plants including tules or bulrushes (*Scirpus* spp.) have a low rate of establishment from seed, but populations are maintained and spread by clonal rhizomes (Adam 1990; Cook 1985).

Sedimentation. Sedimentation can affect post-inundation vegetation recovery by reducing light penetration and decreasing the amplitude of the daily temperature fluctuation (van der Valk 1986), affecting seed germination (Mitsch and Gosselink 1993) and photosynthetic depths. Increasing sediment to 2 cm significantly reduced taxa density and seedling emergence in tidal wetland vegetation (Peterson and Baldwin 2004). In freshwater to brackish wetlands (Canada) seedling emergence is significantly reduced at sedimentation coverage of as little as 1 cm, and larger seeds (e.g., *Hordeum* an upland grass tolerates 5cm sediment) can emerge from greater soil depth than small seeded vegetation (e.g., *Typha* spp. tolerates 1 cm sediment, but primarily spreads vegetatively) (Galinato and Van der Valk 1986).

Disturbance. Disturbance, including scour and sedimental burial accelerates change in community composition upon vegetation recovery (Howard and Mendelssohn 2000). Scour resulting from levee breach also abraids plants creating vegetative propagules from plants which can reproduce vegetatively via floodwaters. Some particularly difficult to eradicate aquatic invasive species (e.g., *Egeria densa,* which propagates solely by vegetative reproduction in North America) can propagate from small pieces of vegetation (e.g., 10 cm *Ludwigia* sp.).

Dampened Tidal Range. Water flowing into breached areas can dampen the tidal range in the entire Delta region, as much as 45% in scenarios where large numbers of islands are breached. The tidal range would be restored over the duration of the levee repair operations. Tidal range defines suitable habitat for mid, low, and high marsh communities, and may reduce the total area of marsh habitat in the many pockets of fringing tidal marsh vegetation on the channel-side of Delta levees and islands in channels.

12.3.3 Terrestrial Wildlife

12.3.3.1 Risk Assessment

Wildlife Habitat. Species home range and the vegetation types utilized as habitat were used to determine potential habitat for each species.

Direct Loss of Habitat as a Result of Flooding. Levee breaches on Delta islands could result in loss of agricultural habitats, marsh and riparian habitats associated with island drains and ditches, and herbaceous habitats located at elevations below the flood level. These effects would be temporary on islands that are drained and reclaimed to their former uses. Breaches of dikes in Suisun Marsh would also result in loss of these habitats as a result of the initial inundation after the breach and subsequent tidal inundation.

12.3.3.2 Further refinement

Direct Loss of Levee Habitat due to Failures. Levees support linear habitats that include riparian scrub and woodland (in locations where such vegetation is not periodically removed for levee maintenance), herbaceous vegetation, and emergent vegetation (that may be present along the interior and exterior toes of levees). Levee failures would result in the direct and immediate loss of these habitats at the point of failure. Additional loss could occur as a result of ongoing erosion of the levee breach.

Loss of Habitat as a Result of Changed Hydrology and Salinity. Vegetation type, quality and extent as well as the species associated with specific habitats could change due to altered salinity and hydrology if such changes are of sufficient magnitude to convert one habitat to another. Figure 12–17 shows the tolerance of pondweed to changing physical conditions of water depth, flood duration, and salinity. Prolonged conditions outside these tolerance range will result in species loss.

12.4 ECONOMIC CONSEQUENCES

12.4.1 Measuring Economic Consequences.

Of the four types of consequences, economics has the strongest tradition and discipline for quantitatively estimating the results of a dramatic event such as a major combination of Delta levee breaches. With this tradition and discipline come well-defined concepts and analytical procedures. For example, federal projects have very tight rules for conducting cost-benefit analyses while regional and state governments have precise concepts defining the adverse or beneficial impacts to their territories. These conflict with the straightforward interpretation that the public often wants to attach – the public and their political representatives are looking for a single all-encompassing measure (X million or billion dollars). Thus, in assessing economic consequences, substantial attention must be devoted to understanding what the resulting numbers mean. The idea of one all-encompassing, bottom-line number is elusive and likely unachievable.

To begin, economists attach different meanings to "cost" and "impact".

- Economic cost is the potential economic benefit of measures which eliminate flooding. This definition of cost has developed from the guidelines for analyses performed relative to federal flood control projects.
- Economic impacts are measures that people often ask to see – the values of output, employment, labor income and value added that are changed by the flooding event. (Value added is labor income plus property income plus certain business taxes.) However, even these measures can be elusive. For example, if Delta flooding were to prevent harvest of a local asparagus crop, that would have impact on local output, employment, labor income and value added. However, if this shortage of asparagus caused prices to rise and Imperial Valley farm income to increase substantially, the adverse impact might be counterbalanced by a benefit when considering the state as a whole.

In summary, the economic costs are the net costs to the state economy without any consideration of who within the state bears that cost. All economic costs are generally additive. Economic impacts include a variety of other economic measures. For this study, four measures of economic impacts were evaluated. These were value of lost output, lost jobs, lost labor income, and lost value added. These measures are not additive with each other, and they should not be added to economic costs. Value added is the sum of wages and salaries, proprietors' incomes, other property income, and indirect business taxes.

So, economic estimates relative to levee breach events are developed with very carefully defined points of view and precise meanings. It is easy to misinterpret the numbers or to believe they include consequences that they do not. In the levee failure case, there may be some winners as well as losers. For example, if a railroad fails as a result of a levee breach, the railroad will lose revenues, and truck drivers that transport the goods instead will gain income. The net costs to the state as a whole will be limited to the additional costs that result from the use of road transport rather than rail. It should be noted that economic impacts do not reflect potential legal costs to the state that might arise if the state were held liable for losses due to levee failure.

Finally, although the approaches for assessing economic consequences are relatively well developed, they do not cover all the effects that stem from a major incident. The stark contrast between numbers mentioned after hurricane Katrina for the actual consequences of the event compared with estimates that had been made in studies before the event is a reminder that economics is an imprecise forecasting science.

The following economic consequences analyses are reported:

- Economic costs
  - Repair and recovery costs
  - Direct flooding damage to infrastructure
  - In-Delta lost use economic costs
  - In-Delta and water export lost use economic costs
  - Other statewide economic costs
- Economic impacts

The following subsections provide more detailed summaries of the Ecosystem and Economic consequences analyses performed.

12.4.2 Economic Costs

12.4.2.1 Repair and Recovery Costs

The Emergency Response and Repair (ER&R) model estimates the time and material required, and the associated costs, to stabilize damaged levee sections, prevent further damage, close breaches, and dewater flooded islands after levee failure(s). The ER&R model must be applicable for the range of events/sequences that will be modeled in the DRMS study, while also considering the effect on emergency response capability resulting from flood fighting activities during the winter months.

Given a sequence that identifies a set of levee breaches and/or damage throughout the Delta, the ER&R model makes an assessment of the ability to respond. The assessment will address the following factors key to estimating the amount of time required for achieving a return to normal operations (i.e., normal water export):

- Prevention of continuing damage (remediation of damaged sections of levee, capping of breached levee ends, and interior levee protection)
- Breach closure
- Dewatering of flooded islands

The emergency response and repair module was developed as a simulation model, using the simulation software package Extend™, which is an industry-standard, general-purpose simulation tool that can be used to model a large variety of processes. Extend is a powerful object-oriented simulation tool that uses the MOD-L programming language. This tool has been employed on many projects that required probabilistic assessment to determine the risk/probability of outcomes.

The model employs Extend's capability of combining discrete event simulation with continuous simulation flow architecture. In the discrete event simulation items are generated, each item representing a specific repair that must be carried out for the particular sequence being analyzed. The number of items required for a particular sequence depends on the number of individual breaches and damaged sections on the affected islands plus all eight levee segments on flooded islands that are susceptible to interior slope erosion, and the repair work order that has been specified for that sequence. The flow architecture in Extend is used to model the production rates, which represent the combination of production capacity of the quarries and transportation capability.

The Emergency Response and Repair TM (URS/JBA 2008d) provides a detailed discussion of the ER&R model. The analysis considers gross quantities and costs of material required for repairing damage and closing breaches and does not differentiate between material types. The model allows prioritization of levee repairs. As an example of order of magnitude costs, a 3 island failure was evaluated with the model with repair and recovery costs of approximately $100 million.

12.4.2.2 Direct Flooding Damage to Infrastructure

The Impact to Infrastructure TM (URS/JBA 2007f) details the infrastructure analysis. A large amount of infrastructure is located within the Delta and Suisun Marsh. Some of the infrastructure that crosses the Delta to other parts of California provides vital resources such as water, gas, power, communications, shipping, and railroad freight transportation. Levee failure would cause direct physical damage to residential, commercial, recreational, and public assets. Chapter 5 includes more detailed description of the linear and point assets that could be flooded and lists infrastructure that is not included in the asset estimates. Also, although the Delta levees themselves are assets, they are not considered to be infrastructure assets in this section, but are included in the repair and recovery costs in Section 12.4.2.

Since any combination of islands and tracts could be inundated from levee failures, the DRMS evaluations required estimates of the net asset value for each island and tract. Since flooding of an island doesn't necessarily result in total loss of the assets, an estimate of the percent damage was also required.

The general approach to the work is divided into the following three main parts:

- Data Compilation/Asset Definition:
  - Gather Geographic Information System (GIS) data (quantity and type of assets) for each island including asset attributes.
  - Obtain unit cost data and repair times for the infrastructure assets.
  - Define analysis zones.

- Analysis/Evaluation:
  - Assess potential damage to infrastructure due to stressing events considering flooding depth.
  - Assess uncertainty in infrastructure repair cost estimates.
- Summary of Results/Technical Memorandum:
  - Summarize analysis results due to the stressing events.
  - Prepare a technical memorandum on damage assessment potential on Delta infrastructure.

The analysis was conducted for inundation from levee breaching from two different flood stage conditions. The first accounted for asset value and damage for areas that could be inundated when the tide was at Mean Higher High Water (MHHW). The second accounted for asset value and damage for areas that could be inundated during a 100-year flood event. The amount of infrastructure that could be damaged during the 100-year flood is significantly larger than the infrastructure that could be damaged at MHHW. The analysis for MHHW includes only the infrastructure that is below approximately the 5-foot contour. The flood stages for the 100-year flood exceed 20 feet in some areas near the fringes of the study area.

The damage analysis also includes infrastructure that could be in the direct line of scour at a levee breach. Past levee failures have shown scour holes on the islands where high velocity water passes through the levee breach. From these historical data, the scour holes were assumed to be 2,000 feet long (perpendicular to the island perimeter/levee). As such, the areas of islands that would be vulnerable to scour extend 2,000 feet inboard of and parallel to the island levees/perimeters.

Scour due to levee breaching is included in the inundation events (i.e., scour of levee is followed by inundation/flooding of an island). The potential scour zones for the Delta islands are shown on Figure 5-12 (see Section 5.5), together with the MHHW and 100-year flood plain limits. Assets that are within the scour zones are assumed to be destroyed. Therefore, the repair costs would equal the replacement costs within the scour zones. The repair costs due to scour damage are treated as incremental costs that are added to the cost of repair from inundation to obtain the total cost of repair.

The cost for repairs due to multiple island failures is likely to be more than for a few island failures due to many complexities such as material shortages and gaining access. For multiple island failures (up to 30), scaling factors are applied to the estimated costs. The assumed linear cost scaling factors (for both point and linear assets) that would be applied to more than five island failures follow:

- 1 to 5 island failures: 1.0
- 10 island failures: 1.2
- 20 island failures: 1.6
- 30 island failures: 2.0

The asset values and damage estimates are shown in the following three tables (at end of section): Table 12–6 for MHHW, Table 12–7 for the 100-year flood, and Table 12–8 for scour during the 100-year flood. Figure 12–18 shows a map of islands within the MHHW boundary; these islands were included in estimating economic consequences of failures under seismic and normal (“sunny-day”) events. Figure 12–18 also shows the islands within the 100-year flood boundary; these islands were included in estimating economic consequences of failures under flood events.

The costs for rebuilding are estimated at replacement cost, plus the scaling factors. This reflects the fact that rebuilding under conditions of widespread emergency causes materials and labor shortages that drive up the cost of reconstruction. This is developed to reflect the cost of rebuilding the asset stock that would be damaged. However, this is not an estimate of the economic value of the assets lost, or economic cost, required by the USACE in its cost-benefit analyses. To develop an estimate economic cost, two steps are required to adjust the replacement cost estimates presented in this report:

- The scaling factors used to estimate rebuilding costs under multi-island emergencies would need to be removed.
- An additional deflation factor would be used to reflect the fact that the existing asset stock is depreciated, and not worth as much as the new assets that would result from rebuilding.

These steps have not been taken in this report. The scaling factors used are known, but the appropriate deflation factors have not been estimated. When required for USACE cost-benefit analyses, the appropriate deflation factors should be estimated and used with the inflation factors and results presented here to develop the appropriate cost measure for cost-benefit analyses.

12.4.2.3 In-Delta Lost Use Economic Costs

The Economic Consequences TM (URS/JBA 2008f) details the economic analysis.

In-Delta costs and impacts include those associated with the following aspects of the Delta and Suisun Marsh:

- Lost use of structures used by residents, businesses and public services in the Delta (for example, loss of use of homes, lost use of business places and loss of government offices)
- In-Delta agricultural losses
- In-Delta recreation losses

The methodology for estimating these costs are shown in the following:

Residential Structures

The residential lost use analysis counts costs and impacts to people living in the areas at the time of the flood event. The economic methodology is based on FEMA (2005). The FEMA method for estimating displacement costs consists of a one time cost of $500 per household if flooded, plus $500 per month per household, plus a monthly cost based on local rental rates. The direct costs are based on information from National Flood Insurance Program claims. Local rental rates are from USDC (2003). The monthly rental cost is $747 per household. HAZUS residential structure data were used to estimate current occupied households.

Under the 2005 mean-higher-high-water (MHHW) flood condition the daily residential displacement cost for all analysis zones is $244,000. For the 100-year floodplain, daily costs for all zones would be $3.4 million. These costs do not include the one-time costs of $500 per household which would be spread over the entire duration of lost use. In 2005, these one-time costs total about $2.14 million under the MHHW flood condition and $33 million for the 100-year condition. In 2030, daily costs are about $380,000 per day under the MHHW flood condition and $8.5 million for the 100-year condition, and additional one-time costs are about $3.6 million under the MHHW condition and $91.3 million for the 100-year condition.

Tables in Appendix A of the Economic Consequences TM (URS/JBA 2008f) provide the estimates of the population and household data for named subregions in the study area. The lost use cost estimates are also provided by named subregions for years 2005 and 2030, for subregions in the 100-year flood plain and in under MHHW flooding.

Businesses

Flooded businesses incur costs and impacts beyond the costs of repair and replacement of facilities and inventory. The FEMA methodology (2005) allows for displacement costs analogous to those for residential costs; a one-time cost when flooded, plus monthly costs based in part on costs for rented space. The FEMA methodology includes lost business income, but lost income should be counted only to the extent that sales will not continue from the rented space. If a business is able to rent space, then some of the time of lost use does not result in lost sales. That is, either the business finds another space and keeps selling, or sales will cease. The economic cost analysis for lost sales assumes that sales stop for the duration of lost use and that businesses do not pay rental costs. The analysis also assumes that a share of the lost sales are captured by other California businesses. This share is determined by regional purchase coefficients (RPCs) from IMPLAN. A summary of impacts per day for all analysis zones is shown in Table 12–9.

Public Services

The FEMA method allows for value of loss of public services to be included. Costs are based on the annual operating budget or revenues, functional downtime, and a continuity premium. For ordinary public services, the value of public services is estimated simply as the cost to provide them. A day of functional downtime is one day with no service or 2 days with 50% service, and so on. The data on public offices in the study area included number of employees, but not costs, so data on budgets and employment by state and local government offices in the Sacramento area were collected and analyzed. It is assumed that the average cost of service per employee is $100,000, and the continuity premium of 10 times is applied for police and fire services. Given these assumptions, the costs of lost government services per day of lost use for all affected analysis zones under the 100-year condition is $13.72 million. Most of this cost, 88 percent, is associated with Zone 196, in Sacramento. This zone includes 394 government offices, most of them being state government.

In-Delta Agricultural Losses

DWR estimates there were 405,899 acres of harvested or grazed, irrigated crop acres in the Delta during the 1998–2004 period ((DWR 2006e). The annual value of Delta agricultural production over this period averaged $680 million in 2005 dollars, of which 87% was associated with crop production and 13% with animal husbandry.

A spatial representation of agricultural production within the 100-year flood plain of the Delta was developed from URS, UC Davis, and DWR data sources (DWR 2006e; URS 2006; UC

Davis 2006). For the analysis zones defined by URS, the dataset includes total agricultural and non-agricultural acres and inundation depths within the 100-year and mean-highest-high flood plains; scour acres; and estimated crop mix. The crop mix of each analysis zone was estimated using the UC Davis and DWR data sources. Crops were aggregated into eight crop groups: (1) alfalfa; (2) field crops; (3) grain; (4) rice; (5) tomato; (6) truck; (7) orchard; and (8) vineyards.

Agricultural losses from flooding of an analysis zone are the sum of (1) scour impacts, (2) permanent crop loss, (3) field cleanup and rehabilitation, and (4) annual production losses.

- Scour Impacts. Scouring was assumed to render land unusable for farming or other uses. Scour impacts were defined as the amount of agricultural acreage lost to scour multiplied by the average agricultural land value for the analysis zone.
- Permanent Crop Loss. Inundation periods lasting 14 or more days were assumed to kill permanent crops. The analysis assumed permanent crops would be reestablished, either on the same acreage or in some other area.
- Field Cleanup and Rehabilitation. An average cost of $235 per acre for clean-up and rehabilitation was assumed (USACE 2002).
- Annual Production Losses. Production losses were estimated for fall/winter and spring/summer flood events using planting/crop loss decision rules.

Loss of net farm income due to annual production losses is the difference between unrealized crop revenue and avoided variable production costs at the time of the flood event. These values were calculated using Delta crop revenue and cost estimates prepared by DWR and monthly distributions of crop production costs and revenues developed for the Sacramento and San Joaquin River Basins Comprehensive Study (DWR 2006e; USACE 2002).

Losses Due to Water Quality Degradation

Farm income losses may occur in Delta analysis zones unaffected by flooding when levee events increase salinity of Delta water used for crop irrigation. All crops do not respond to salinity in a similar manner; some crops produce acceptable yields at much greater soil salinity than others. The baseline assumption is that all crops are yielding at their full potential. Maas and Hoffman (1977) established relationships between yield and crop sensitivity to salinity.

The economics team estimated potential reductions in crop yield for each of eight crops and developed crop income loss tables (see the Economic Consequences TM [URS/JBA 2008f]).

In-Delta Recreation Losses

This section describes the models and data used to estimate losses in consumer surplus, business income, value added, and employment from reductions in delta boating, fishing, and hunting recreation caused by Delta levee failure. Models for boating and fishing recreation within Delta recreation zones defined by the Delta Protection Commission and for hunting, fishing, and wildlife viewing within Suisun Marsh are presented.

- **Delta Boating/Fishing Impacts.** Damage to Delta levees may require parts of the Delta to be shut down to boating/fishing recreation for public safety or to facilitate repairs. Flooding may also destroy recreation infrastructure in the Delta, such as marinas, boat launches, and fishing access points. The flooded island model calculates lost visitor-days, consumer surplus, and economic impacts as a function of the list of islands flooded by a levee event and the duration each island is out of service.

- **Suisun Marsh Hunting/Wildlife Viewing Impacts.** Flooding within Suisun Marsh impacts recreation primarily by disrupting or closing roads used by marsh visitors to get to its recreation sites. Fishing and boating in the Marsh could also be disrupted by levee breaks in that area. However, we do not have any information as to the size and importance of that activity independent of the activity in the Delta. The losses to Suisun Marsh boating and fishing activity is included in this analysis only to the extent that it is included in the DPR survey of Delta boating and fishing.

The Economics Consequences TM (URS/JBA 2008f) provides data on visitor-days by geographic and monthly distributions. Consumer surplus estimates developed by other studies are also reported. These estimates were used to develop the economic costs of lost recreation.

12.4.2.4 In-Delta Water Export Lost Use Economic Costs

Water export economic impacts include the potential cost for disruption of water supplies that transit the Delta, including water delivered by the State Water Project (SWP), Central Valley Project (CVP) and the conveyance facilities crossing the Delta (Mokelumne Aqueduct). These include consequences to agriculture and consequences to urban users. The Economic Consequences TM (URS/JBA 2008f) provides detailed information on the analysis and the results.

Water Supplies to Agriculture

In cases where SOD, CVP, and SWP deliveries are reduced, growers and districts will adjust operations to minimize income losses. In regions with developed groundwater pumping capacity, growers and districts will substitute groundwater subject to physical and economic limits. In some cases, groundwater substitution will eliminate the shortage. In other cases, the shortage will remain. In these cases, available water supply will be rationed. The rationing is assumed to allocate available water first to permanent crops, second to high value row crops, and third to forage and pasture.

Analysis was conducted for the San Felipe Unit of the CVP, Central Coast regions, South Coast regions, and the San Joaquin Valley. The SOD Farm Income Loss Model estimates the change in south of Delta farm income relative to a baseline condition given a temporary reduction in CVP and SWP project water deliveries. The model selects the response combination that maximizes farm income subject to water balance and groundwater pumping capacity constraints. Farm income loss is then calculated as the difference in farm income between the baseline condition and the shortage condition. The SOD Farm Income Loss Model was run over the range of possible starting shortage months, shortage durations, and project water shortage magnitudes to map the model solution spaces for each subregion. Shortage durations were expressed as the number of months that project deliveries to a subregion are below baseline as a result of the levee event.

Information on each agency served was collected and aggregated to CVPM regions, and all analyses were conducted at that level. This was done because there is a considerable body of existing analysis at this level that could be relied on for this study. Table 12–10 identifies the

CVPM regions and the irrigation districts that are included in each. Table 12–11 describes the water supply and crop revenue associated with each region.

Water Supply to Urban Users

The methodology used to estimate the effects of a disruption of Delta export water supplies to urban users required identification of agencies susceptible to the disruption, estimating the levels of shortage by agency, estimating the cost of shortage by agencies, and extrapolating the universe of urban agencies affected. Urban water agencies are required to file an Urban Water Management Plan (UWMP) with the California Department of Water Resources every five years, most recently in 2005. This is required to show the agency's expected demand for water, and supplies expected to meet those requirements over the next twenty to twenty five years. In addition, the agencies are required to show how they could respond to water supply shortages in the event of drought or other supply failure. For those urban agencies whose water supplies are at risk, the recent UWMPs were reviewed to determine how likely the agencies were to be affected by impaired Delta export pumping. A number of southern California agencies were found to use State Water Project (SWP) supplies to maintain extensive groundwater basins. These basins had largely recovered from overdraft conditions in the 1960s, and the agencies could be expected to be able to mine water from the basins over an extended SWP outage with very little effect. They are not expected to experience shortages or incur shortage costs. However, there will be costs associated with the reduction in Delta export deliveries. First, the agencies and society as a whole will SAVE the incremental cost of transportation of the water from the Delta – that is, there will be a savings because of the reduced water transport costs. These savings will be more than offset by the increase in pumping costs because the water levels in the aquifers will remain lower than they would otherwise be. This net cost was felt to be small enough compared to the modeling effort necessary to estimate it that it would be best ignored in order to have the time to complete other parts of the analysis. Because of this ability, the situations of these agencies were not explored further. It should be noted that these agencies could not maintain their water supplies during an indefinite closure of the Delta.

Then, a number of smaller agencies were removed from the list of agencies to be analyzed, because the net effect to the state of any shortages for those agencies would be expected to be small. The remaining larger agencies, or agencies expected to be particularly hard-hit were selected for further analysis and the effect on the smaller agencies estimated by extrapolation from the relative sizes of the populations served. Table 12–12 shows the population for each agency potentially affected by Delta levee failures.

The shortage cost by agency analyzed was estimated using the shortage loss function developed for use in DWR's LCPSIM model, as updated for use in the Common Assumptions process to evaluate reservoir storage, as discussed in the Economic Consequences TM (URS/JBA 2008f).

The data needed to develop these cost estimates were obtained from the agencies UWMPs, supplemented in some cases by an additional mail survey. The shortage costs estimated by agency and customer group were multiplied by the appropriate number of acre-feet and summed to get the total shortage cost for agencies analyzed. Key information from the UWMPs and description of the survey are summarized in Appendix E of the Economic Consequences TM (URS/JBA 2008f).

However, the LCPSIM equation has been fitted to estimates that reflect maximum shortages of 30 percent. At shortages of above 45 percent the LCPSIM assumption of protecting commercial and industrial users at the expense of residential users can no longer be maintained. To overcome this problem, it was assumed that if no water supply remained, the economic costs would be equal to the estimate of economic value added in that region under normal circumstances, and the estimates for losses between 45 percent and 100 percent were determined by interpolation. As discussed in the Economic Consequences TM (URS/JBA 2008f), this is likely to be an underestimate of costs to the state.

12.4.2.5 Other Statewide Economic Costs

This section addresses the potential costs from the loss of infrastructure in the Delta that serves a wider area than just the Delta. For example, electric utilities own local assets in the Delta (distribution lines) and also assets of statewide importance (transmission lines). The consequences of levee failure that results in changed operation of reservoirs include the loss of hydroelectric generation and recreation opportunities. The Economic Consequences TM (URS/JBA 2008f) includes the results of the analyses.

Mokelumne Aqueduct

The Mokelumne Aqueduct consists of three pipelines that carry water from the Calaveras watershed across the Delta to EBMUD. The loss of any of these pipelines reduces the ability of EBMUD to provide reliable water service to its consumers. In addition, if the aqueduct is in place it could be used to provide supplementary supplies to CCWD in the event that it was unable to obtain sufficient supplies from the Delta. The economic consequences resulting from failure of this asset is considered as part of the analysis of water supplies to urban users.

Deep Water Shipping Channels

The Ports of Sacramento and Stockton could be closed by a flood event. Additional costs are based on the cost of moving freight by rail instead of by ship. Data on recent tonnage is provided by the California Association of Port Agencies. Recent volume was 0.7 and 2.9 million metric tons in Sacramento and Stockton, respectively (CAPA 2005). The additional transport cost by rail per metric ton is $0.026 (AAR 2005) and it is assumed that freight would move by rail for 40 additional miles. The cost of outage per day is estimated to be $2,085 for Sacramento and $10,157 for Stockton.

Electric Transmission

The analysis of consequences arising from failure of electric transmission assets in the Delta concentrates on the loss of the major 500 kV lines. These lines import power from the Pacific Northwest during the summer months, allowing that more efficient generation to displace less efficient generation in California. As a result, the cost to the state of losing these lines is dependent on whether the lines are out of service over the summer months. An analysis by PG&E reported in the Economic Consequences TM (URS/JBA 2008f) estimated that an outage of these transmission lines would cost the state approximately $10.5 million per line per summer month. Costs were estimated to be negligible at other times of the year. These costs are not expected to change over time, because the differential between marginal summer generation in the Pacific Northwest and California is expected to be maintained for the foreseeable future.

There is a very low probability that failure of the transmission in the Delta could lead to massive transmission failures throughout the Western States, as the resulting instability in the electrical system causes areas to cut off electrical contact with each other to prevent damage to generators.

However, both PG&E and the Western Electricity Coordinating Council (which regulates electric transmission reliability) insist that they have instituted management procedures designed to prevent this occurrence.

Highways

Interstate 5, several important state highways and important county and local roads pass through some of the analysis zones. Flooded highways would require travelers to use alternate routes until floodwaters are removed and roads cleared of debris and repaired. Types of costs associated with this include increased travel time and expense for persons who must use another route, increased congestion on alternative routes, lost trips, and business costs associated with delays. Depending on the roads lost and the time taken for repair, this would likely be a major source of economic costs. Published estimates and results from two models were used to develop an estimated daily cost for combinations of road closures. Recommended daily costs for some likely combinations of closures are shown in Table 12–13.

Natural Gas Transmission and Storage

PG&E operates backbone natural gas transmission and storage within the Delta. The company's largest natural gas storage field is located on MacDonald Island. PG&E operates the storage field by adding gas to storage during summer when demands are lower, and withdrawing gas during peak winter days when demand is highest. This storage is integral to ensuring winter gas supplies to Northern California. On a peak winter day natural gas from this storage location can supply as much as 20 to 25 percent of supplies needed in Northern California. This storage is also used to mitigate variations in natural gas prices, by allowing PG&E to purchase gas when prices are relatively low, and reduce purchases when prices are high.

PG&E has developed redundant pipelines to protect the use of this resource under levee failure scenarios, and has designed the storage field to be operated under water. However, the storage area cannot be readily maintained under water, so with an extended flooding scenario the storage area could be required to close down as equipment required maintenance. Costs of this would be most significant over winter months, with the costs varying according to the severity of winter temperatures. In addition, although PG&E has constructed redundancy in its transmission lines, the multiple lines are located near each other because they travel from the same origin to the same destination, so it is possible that levee scour could destroy both the main and backup transmission line.

If both major transmission lines to the storage facility, or the facility itself were to fail over winter months there could be considerable economic costs that would vary according to the severity of winter temperatures. As reported in the Economic Consequences TM (URS/JBA 2008f), these costs could be as high as a billion dollars under extreme cold, but the expected value is $114.4 million per winter month disrupted.

Oil and Gas Wells

Natural gas production is an important economic activity within the Delta. Most natural gas production is not covered in the business sales analysis because most of the companies that own the gas wells are not located within the analysis zones. In a flood event, owners of the gas wells will shut them off if possible. Wells that cannot be shut off may be permanently lost. For this analysis, it is assumed that wells can be shut off before flooding, and that production can resume after a flooding event.

Economic costs of lost use of wells are estimated as the economic interest on natural gas that can not be produced because wells are shut down. For the 100-year condition this cost would be about $200,000 per day.

Petroleum Products Pipelines

Kinder Morgan Energy Partners (KMEP) owns and/or operates a number of "product" pipelines that cross the Delta. To date we have not identified the location of these pipelines, but we believe they include all or most of the following:

- KMEP Concord to Stockton and Bradshaw 10"/8" pipeline
- KMEP Concord to Sacramento and Rocklin 14" and 12" pipeline (connects to Reno and Chico pipeline systems, and serves the Naval Air Station at Fallon, NV)
- KMEP Concord to Fresno 12" pipeline
- KMEP Concord to Suisun 8" pipeline (serves Travis Air Force Base)
- Navy Concord to Ozol 8" pipeline.

These pipelines are estimated to provide approximately 50 percent of transportation fuels to Northern California, and are a major source of supply to northern Nevada. As can be seen from the list, failure of these pipelines will also be a national security concern because the pipelines provide aviation fuel to these military bases (Schremp 2006).

The pipelines are generally around 4 feet below the soil surface, and have remote electronic valves so they can be shut down fast in times of emergencies. They also have an operating practice of pumping out oil and filling with water if the pipeline site is flooded (Blurton 2006). This keeps the lines weighted to minimize spill in case of rupture. Flooding is not expected to cause failure of the lines, but any lines located in a scour zone should be expected to fail.

The California Energy Commission has developed contingency plans to respond to failure of these pipelines that could result from earthquake. These plans would likely also be activated as a result of pipeline failure due to levee break, and calls for tankers to ship fuel around the Delta to storage fuel depots in the east of the Delta. This would require an extensive fleet of tanker trucks, which may not be available. In addition, the loading docks at the East Bay refineries may have insufficient capacity to meet the state's fuel supply needs (Schremp 2006, 2007). To date we have not ascertained the location of these pipelines, so the economic cost of loss of the pipelines has not yet been estimated.

Railroads

Three major railroads cross the Delta. These railroads carry freight and passenger service. The railroads are described below.

The Union Pacific Railroad from Oakland to Sacramento. This railroad carries both freight and the Capital Corridors passenger service.

The Union Pacific Railroad from Fremont to Stockton. This railroad carries 11 trains per day. Six of these are passenger, and 5 are freight. The freight service ships automobiles from the Fremont NUMMI plant, other automobile, intermodal container freight, and other general freight (Schremp 2006, 2007).

The BNSF Railroad to Stockton. Because of the current law suit related to the flooding of Jones Tract, BNSF lawyers instructed their employees not to respond to questions related to the costs of interruption to railroad service across the Delta. The BNSF railroad to Stockton is a major freight line, so we have assumed that the revenues related to freight shipments on this line are the same as those estimated for the Union Pacific railroad from Oakland to Sacramento.

The economic losses associated with the loss of freight transportation is measured by the increased costs of using a less efficient alternative form of transportation. In this case, it has been assumed that the same freight would travel by truck across the Delta and be loaded on trains either in Stockton or Sacramento. As discussed in the section on petroleum products pipelines, it is not clear whether the necessary number of trucks could be found to meet these requirements.

It is assumed that rail transport would not be interrupted by inundation of an island that the railroad crosses, because these railroads are on embankments that are assumed to be above the water level. However, the railroads are subject to scour damage, and if the railroads are within the scour zone they are assumed to be disrupted. Based on comparisons between trucking and rail costs, the following cost estimates were used per month of disruption. A summary of the estimated losses are included in Table 12–14.

Wastewater Facilities

FEMA (2005) provides a simple method for calculating costs from loss of wastewater services. $33.50 per capita per day is assumed for complete loss of treatment and $8.50 per day for partial loss of treatment. Data requirements are the number of persons affected and days without service. A summary of the estimated losses are included in Table 12–15.

Changed Reservoir Operations

Levee failures in the Delta may cause a change in upstream reservoir operations, such as releasing water to repel saltwater. This can affect electrical generation/use and recreation.

- **Electricity Generation and Use.** When the operation of the water supply system is interrupted, hydroelectric generation will be changed. For the baseline analyses (with no disruption), the Water Analysis Module (WAM) could estimate hydroelectric generation and pumping loads for the export projects. For years with disruptions, the WAM could also estimate the hydroelectric generation and pumping loads for the North of Delta storage and for San Luis. The generation and pumping loads at south of Delta facilities other than San Luis could be estimated by extrapolation from the water deliveries south of Delta.

  The power used by agricultural agencies for additional groundwater pumping could be obtained from the San Joaquin agricultural model. Similarly, the power used for additional groundwater pumping, saved from additional treatment, and distribution could be estimated from the urban water supply model, with developed for the Common Assumptions process (CH2MHill 2006).

- **Recreation.** Re-operation may reduce the amount of water in storage, lower surface water elevations and impair opportunities for surface water recreation. The impact on recreation is estimated by losses in consumer surplus from reductions in reservoir recreation (see the Economic Consequences TM [URS/JBA 2008f]).

12.4.3 Economic Impacts

In addition to measuring economic costs in above sections, the analysis also estimates the economic impacts of the disruption. Economic impacts are measured by value of output, wages and salaries, employment, and value added. Value added consists of wages and salaries, proprietor's income, other property income, and certain business taxes.

The estimates are "total" in that they include reduced economic activity through backwards economic linkages. These linkages represent the purchases by affected businesses and households in the California economy. For example, if field crops are flooded, they will purchase less chemicals, labor and energy for crop production, and these businesses in turn reduce their purchases, and so on.

Economic impacts are counted only when value of output is lost. Value of output is lost in the analysis for one of three reasons: because of water shortage, because Delta recreation and other businesses lose sales, or because Delta agricultural production is lost. Economic impacts that might result from increased costs, from reconstruction activities, or from production delays (natural gas wells) are not counted. These economic impacts would often be positive.

Input-output (I-O) models estimate the effect of backwards trade linkages associated with a direct change in output. The direct loss of sales causes an equal reduction in purchases by these businesses, and the share of these purchases that are from California businesses represent an additional loss of California sales. This effect continues through additional backwards linkages. The total effect is limited by the share of purchases that are imports into California.

I-O uses information on sales and expenditures by industry, including the share of expenditures bought from in-state businesses, to estimate economic multipliers. The multipliers can be used to estimate the total economic impact per dollar of direct output reduction for any industry. For example, the ratio of the total loss of sales to the direct loss is the output multiplier.

IMPLAN is an I-O modeling package and database for 519 industries that can be used to develop an I-O model of any county-level or larger economy. For this analysis, 2004 data for every county in California were used to develop a state I-O database and model. The I-O model provides information on how direct sales losses caused by flooding affect the rest of the state economy through the backwards trade linkages.

IMPLAN provides data on employment, wage and salary income, other income, and value added, and multipliers for these measures can be used to estimate the total effect on these other economic measures. For this analysis, since the ESRI data provides employment in the Delta, the ESRI data are used to estimate that part of the direct employment effect, but IMPLAN multipliers are used to estimate the total employment effect.

Economic Impacts from Direct Effects in the Delta

The economic impacts from lost business sales were discussed above. In summary, business sales in the Delta are lost, but some of these sales are picked up by other businesses in-state. The net direct effect considers this substitution effect. The direct effect on output and employment is based on data in the ESRI database. The IMPLAN multipliers are used to calculate total effects on output, employment, labor income and total value added.

The analysis of output losses for in-Delta agriculture provides the basis for the impact analysis. Output losses occur because of flooding and because of water quality effects. Direct value of output losses are inputs to the I-O analysis. The analysis considers the share of agricultural purchases that would have occurred from businesses that are flooded. That is, output losses that occur because agricultural suppliers are flooded, or because farmers don't buy inputs from them, are not double counted.

There is no analysis included for natural gas. Little of the cost of natural gas production is for variable inputs, so the reduced gas production during a flood has a minimal effect on expenditures. Furthermore, it has been assumed that the gas production will resume and be recovered later. Therefore, and reduced spending during a flood will be offset by increased spending later.

The analysis of expenditure losses for in-Delta recreation provides the basis for the impact analysis. Direct value of expenditure reductions are inputs to the I-O analysis. The analysis considers the share of expenditure reductions that would have occurred from businesses that are flooded. That is, output losses that occur because marinas, resorts and hotels are flooded, or because recreationalists don't buy inputs from them, are not double counted.

Economic Impacts from Reduced Water Supply

As part of the analysis of water supply shortages to urban agencies, the level of shortage to urban industries is calculated for agencies in 5 Bay Area counties and 6 counties in Southern California. This was then converted to a percentage reduction in industrial output for each of these agencies, using the model described in the Economic Consequences TM (URS/JBA 2008f).

However, some agencies cross county lines, so where necessary, the populations in those agencies were apportioned between counties. The estimated population within each county that is served by one of the studied agencies was then compared with estimates developed by the Demographic Research Unit of the Department of Finance. The percentage of total county population served by agencies operating within those counties was calculated, and is provided in the Economic Consequences TM (URS/JBA 2008f). These percentages were used to develop a weighted average percentage reduction in county manufacturing output.

The percentage reductions were used in conjunction with the IMPLAN model to develop an estimate of the economic impacts resulting from the urban water supply shortages.

This approach has a number of limitations. First, it assumes that the major regions of economic impact to industry through changes in water supply are felt in the eleven counties that are analyzed. While these counties are the major industrial counties in the state, this will result in an underestimate of the total impacts because we have not included a number of counties with smaller industrial bases. Second, industrial output within a county is assumed spread between the agencies serving those counties according to the population served by each agency. This may be incorrect, because one agency may serve the suburbs of a county, while the other serves the industrial base, but this was the only way to recognize water supply differences within a county.

The economic impacts of losses to agricultural production were also analyzed using the changes in the value of agricultural production and the associated IMPLAN analyses, as described in the Economic Consequences TM (URS/JBA 2008f). These impacts were not identified by county, but were aggregated for the state as a whole.

Tables

Table 12–1 Results of Flood Routing Analysis

Initiating Event	Island Size	Flood Severity Zone	Distance to Boundary of Flood Severity Zone (ft)	Time for Flood to Reach Boundary of Severity Zone (hours)
Flood	Large	High	1,000	1.88
		Medium	1,900	2.12
		Low	>1,900	>2.12
	Small	High	1,000	3.08
		Medium	10,000	3.3
		Low	>10,000	>3.3
Seismic	Large	High	1,000	0.27
		Medium	1,650	0.43
		Low	>1,650	>0.43
	Small	High	1,000	0.29
		Medium	10,000	2
		Low	>10,000	>2
Normal ("Sunny Day")	Large	High	1,000	1.88
		Medium	1,900	2.12
		Low	>1,900	>2.12
	Small	High	1,000	3.08
		Medium	10,000	3.3
		Low	>10,000	>3.3

Table 12–2 Warning Issuance Times

Initiating Event	Exposure Time	Warning Issuance Time from Breach Initiation (hours)
Flood	Daytime	0.1
	Nighttime	0.5
Seismic	Daytime	0.1
	Nighttime	0.5
Normal ("Sunny Day")	Daytime	0.1
	Nighttime	0.5

Table 12–3 Evacuation Effectiveness

Initiating Event	Exposure Time	Evacuation Time Window (hours)	Evacuation Effectiveness
Flood	Daytime	0	0%
		0.5	80%
		>0.5	100%
	Nighttime	0	0%
		1	80%
		>1	100%
Seismic	Daytime	0	0%
		0.5	80%
		1	90%
		>1	100%
	Nighttime	0	0%
		1	80%
		2	90%
		>2	100%
Normal ("Sunny Day")	Daytime	0	0%
		0.5	90%
		>0.5	100%
	Nighttime	0	0%
		1	90%
		>1	100%

Table 12–4 Statistical Parameters of Life-Loss Fraction Distribution

Flood Severity Zone	Mean of Life Loss Fraction	Standard Deviation of Life Loss Fraction
High	0.925	0.111
Medium	0.121	0.178
Low	0	0

Table 12–5 Summary of Fatality Risks

Initiating Event	Exposure Time	Islands with ≥10% Probability of 10 or More Fatalities Given a Breach		Islands with ≥10% Probability of 100 or More Fatalities Given a Breach
Flood	Daytime	Boggs_Tract		(None)
		Lincoln_Village_Tract		
		Sacramento_Pocket_Area		
		Sargent_Barnhart_Tract 2		
		Shima_Tract		
		Smith_Tract		
		West Sacramento North		
		Zone 158		
		Zone 185		
Flood	Nighttime	57_124	Sacramento_Pocket_Area	Lincoln_Village_Tract
		Bethel_Island	Sargent_Barnhart_Tract 2	Sacramento_Pocket_Area
		Bishop_Tract	Sherman_Island	Sargent_Barnhart_Tract 2
		Boggs_Tract	Shima_Tract	Shima_Tract
		Elk_Grove 1	Smith_Tract	Smith_Tract
		Kassou_District	West Sacramento North	West Sacramento North
		Lincoln_Village_Tract	Zone 158	Zone 158
		Paradise Junction	Zone 185	Zone 185
		RD 17 (Mossdale)		
		Rio_Blanco_Tract		
Seismic	Daytime	57_124		(None)
		Sargent_Barnhart_Tract 2		
		Sargent_Barnhart_Tract 3		

Table 12–5 Summary of Fatality Risks

Initiating Event	Exposure Time	Islands with ≥10% Probability of 10 or More Fatalities Given a Breach		Islands with ≥10% Probability of 100 or More Fatalities Given a Breach
Seismic	Nighttime	57_124	Sherman_Island	57_124
		Bethel_Island	Shima_Tract	Sargent_Barnhart_Tract 2
		Bishop_Tract	Veale_Tract 1	
		Hotchkiss_Tract 1	Walnut_Grove	
		Libby_McNeil_Tract 1	Wright-Elmwood_Tract	
		Rio_Blanco_Tract	Zone 158	
		Sacramento_Pocket_Area		
		Sargent_Barnhart_Tract 2		
		Sargent_Barnhart_Tract 3		
Normal (“Sunny Day”)	Daytime	(None)		(None)
Normal (“Sunny Day”)	Nighttime	57_124		(None)
		Bethel_Island		
		Bishop_Tract		
		Rio_Blanco_Tract		
		Sacramento_Pocket_Area		
		Sargent_Barnhart_Tract 2		
		Sherman_Island		
		Zone 158		

Table 12–6 Estimate Summary of Asset Cost Damage by Island – Mean Higher High Water (MHHW)

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Bacon_Island	Bacon_Island	20,388	34,664	59
Bethel_Island	Bethel_Island	86,850	181,463	48
Bishop_Tract	Bishop_Tract	2,331	17,749	13
Bixler_Tract	Veale_Tract 1	91	434	21
Bouldin_Island	Bouldin_Island	8,667	21,511	40
Brack_Tract	Brack_Tract	2,275	12,429	18
Bradford_Island	Bradford_Island	8,150	19,003	43
Brannan-Andrus Island	Brannan-Andrus Island	90,424	176,691	51
Browns_Island	Browns_Island	0	0	0
Byron_Tract 1	Byron_Tract 1	17,153	116,612	15
Byron_Tract 2	Byron_Tract 2	1,953	19,612	10
Cache_Haas_Tract 1	Moore Tract 3	3,993	21,273	19
Cache_Haas_Tract 2	Moore Tract 1	913	3,747	24
Canal Ranch	Canal Ranch	1,958	8,294	24
Chipps_Island	Chipps_Island	0	0	0
Clifton Court Forebay Water	Clifton Court Forebay Water	254	3,804	7
Coney_Island	Coney_Island	7,280	14,614	50
Deadhorse Island	Deadhorse Island	86	910	9
Decker_Island	Decker_Island	0	1,536	0
Egbert_Tract	Zone 70	3,243	20,336	16
Elk_Grove 1	Zone 76	63	252	25
Empire_Tract	Empire_Tract	2,871	9,511	30
Fabian_Tract	Fabian_Tract	4,163	24,545	17
Fay Island	Fay Island	6	22	25
Glanville_Tract	Glanville_Tract	1,030	6,040	17
Grand Island	Grand Island	105,758	181,277	58
Hastings_Tract 1	Hastings_Tract 1	0	3	1
Hastings_Tract 2	Hastings_Tract 2	1,905	11,183	17
Holland_Land	Netherlands 5	5,624	22,496	25
Holland_Tract	Holland_Tract	4,845	14,669	33
Honker_Bay_Club	SM-201	37	2,022	2

Table 12–6 Estimate Summary of Asset Cost Damage by Island – Mean Higher High Water (MHHW)

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Hotchkiss_Tract 1	Hotchkiss_Tract 1	27,996	93,520	30
Hotchkiss_Tract 2	Hotchkiss_Tract 2	167	1,119	15
Jersey_Island	Jersey_Island	2,632	24,238	11
Jones_Tract-Upper_and_Lower	Jones_Tract	55,837	498,286	11
King_Island	King_Island	17,605	30,840	57
Libby_McNeil_Tract 1	Pierson District 3	3,444	13,712	25
Libby_McNeil_Tract 2	Pierson District 2	103	858	12
Liberte Island	Liberte Island	1,789	14,599	12
Lincoln_Village_Tract	Sargent_Barnhart_Tract 2	4,696	18,816	25
Lisbon_District	Netherlands 4	1,954	9,571	20
Little Holland Tract	Little Holland Tract	0	0	0
Little_Egbert_Tract	Zone 68	1,275	6,873	19
Lower_Roberts_Island	Roberts_Island 2	299	1,076	28
Mandeville_Island	Mandeville_Island	1,303	5,212	25
McCormack_Williamson_Tract	McCormack_Williamson_Tract	496	3,115	16
McDonald_Tract	McDonald_Tract	14,300	30,780	46
McMullin_Ranch-River_Junction Tract	Zone 161	1,902	7,607	25
Medford_Island	Medford_Island	3,347	7,594	44
Merritt Island	Merritt Island	4,103	15,938	26
Middle_Roberts_Island	Roberts_Island 1	31,348	516,500	6
Netherlands 2	Netherlands 3	23,536	97,516	24
New_Hope_Tract	New_Hope_Tract	8,231	32,642	25
Orwood_Tract	Palm-Orwood South	26,818	236,428	11
Palm_Tract	Palm-Orwood North	5,032	21,108	24
Peter Pocket	Peter Pocket	522	2,451	21
Pico_Naglee_Tract	Zone 126	4,124	20,867	20
Pierson_Tract	Pierson District 1	14,519	55,268	26
Pittsburg	Zone 209	2,381	20,385	12
Prospect_Island	Prospect_Island	368	1,552	24
Quimby_Island	Quimby_Island	84	1,084	8

Table 12–6 Estimate Summary of Asset Cost Damage by Island – Mean Higher High Water (MHHW)

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Rindge_Tract	Rindge_Tract	5,093	18,094	28
Rio_Blanco_Tract	Rio_Blanco_Tract	187	5,065	4
Roberts_Island	Roberts_Island 3	3,687	14,849	25
Rough_and_Ready_Island	Rough_and_Ready_Island	8,733	38,613	23
Ryer Island	Ryer Island	17,229	37,218	46
Sargent_Barnhart_Tract 2	Wright-Elmwood_Tract-Sargent Burnhart Tract	153,101	505,877	30
Sargent_Barnhart_Tract 3	Sargent_Barnhart_Tract 3	751	11,380	7
Schafter-Pintail Tract	SM-131	768	2,873	27
Sherman_Island	Sherman_Island	16,107	110,416	15
Shima_Tract	Shima_Tract	250	7,137	4
Shin_Kee_Tract	Shin_Kee_Tract	74	807	9
Simmons-Wheeler_Island	SM-203	35	168	21
SM-123	SM-123	346	3,522	10
SM-124	SM-124	4,253	210,359	2
SM-132	SM-132	65	175	37
SM-133	SM-133	0	0	0
SM-134	SM-134	0	0	0
SM-198	SM-198	357	2,924	12
SM-199	SM-199	283	1,111	25
SM-202	SM-202	37	177	21
SM-39	SM-39	364	2,011	18
SM-40	SM-40	389	1,556	25
SM-41	SM-41	11	3,595	0
SM-42	SM-42	250	1,754	14
SM-43	SM-43	49	168	29
SM-44	SM-44	532	3,023	18
SM-46	SM-46	117	471	25
SM-47	SM-47	0	0	0
SM-48	SM-48	2,380	25,425	9
SM-49	SM-49	537	2,902	19

Table 12–6 Estimate Summary of Asset Cost
Damage by Island – Mean Higher High Water (MHHW)

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
SM-51	SM-51	0	0	0
SM-52	SM-52	181	733	25
SM-53	SM-53	0	27	2
SM-54	SM-54	381	1,549	25
SM-55	SM-55	829	5,024	17
SM-56	SM-56	419	3,405	12
SM-57	SM-57	228	4,466	5
SM-58	SM-58	192	768	25
SM-59	SM-59	130	541	24
SM-60	SM-60	240	4,164	6
SM-84	SM-84	3,555	13,846	26
SM-85-Grizzly_Island	SM-85	2,587	16,371	16
Smith_Tract	Zone 157	20	158	13
Staten_Island	Staten_Island	3,363	20,191	17
Sutter Island	Sutter Island	6,578	22,725	29
Terminous_Tract 1	Terminous_Tract 1	131	2,099	6
Terminous_Tract 2	Terminous_Tract 2	27,276	51,464	53
Terminous_Tract 3	Terminous_Tract 3	173	643	27
Twitchell_Island	Twitchell_Island	6,101	12,106	50
Tyler_Island 2	Tyler_Island 2	13,785	91,184	15
Union_Island 1	Union_Island 1	17,286	110,289	16
Union_Island 4	Union_Island 5	2	8	25
Upper_Roberts_Island	Roberts_Island 4	108	2,024	5
Van_Sickle_Island	Van_Sickle_Island	15,139	100,540	15
Veale_Tract 1	Veale_Tract 2	3,040	13,650	22
Veale_Tract 2	Veale_Tract 3	407	3,674	11
Venice_Island	Venice_Island	3,352	13,288	25
Victoria_Island	Victoria_Island	11,505	45,322	25
Walnut_Grove	Tyler_Island 1	12,759	40,179	32
Water Zone 1	Water Zone 1	24,085	129,190	19
Water Zone 2	Water Zone 2	148,062	1,014,258	15

Table 12–6 Estimate Summary of Asset Cost Damage by Island – Mean Higher High Water (MHHW)

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Water Zone 3	Water Zone 3	5,816	120,130	5
Water Zone 4	Water Zone 4	11,816	102,417	12
Water Zone 5	Water Zone 5	1,579	19,251	8
Webb_Tract	Webb_Tract	114	359	32
Woodward_Island	Woodward_Island	10,280	124,673	8
Wright-Elmwood_Tract	Wright-Elmwood_Tract	890	15,967	6
Yolo_Bypass	Moore Tract 2	49	196	25
Zone 14	Zone 14	0	432	0
Zone 155	Zone 155	0	189	0
Zone 162	Zone 162	312	1,868	17
Zone 186	Zone 186	0	3,283	0
Zone 206	Zone 206	1,984	19,309	10
Zone 207	Zone 207	387	1,948	20
Zone 31	Zone 31	54	430	13
Zone 33	Zone 33	20	163	13
Zone 36	Zone 36	45	277	16
Zone 37	Zone 37	513	2,051	25
Zone 38	Zone 38	146	883	17
Zone 64	Zone 64	49	392	13
Zone 90	Zone 90	1	9	10
Total Replacement Cost	-	-	**5,886,042**	-

Table 12–7 Estimate Summary of Asset Cost Damage by Island – 100-Year Flood

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Bacon_Island	Bacon_Island	20,388	34,664	59
Bethel_Island	Bethel_Island	153,462	181,463	85
Bishop_Tract	Bishop_Tract	36,803	109,573	34
Bixler_Tract	Veale_Tract 1	253	784	32
Boggs_Tract	Zone 159	445,147	1,362,900	33
Bouldin_Island	Bouldin_Island	8,667	21,511	40
Brack_Tract	Brack_Tract	2,480	13,647	18
Bradford_Island	Bradford_Island	8,150	19,003	43
Brannan-Andrus Island	Brannan-Andrus Island	91,685	177,734	52
Browns_Island	Browns_Island	0	0	0
Byron_Tract 1	Byron_Tract 1	34,171	123,431	28
Byron_Tract 2	Byron_Tract 2	3,484	18,316	19
Byron_Tract 3	Byron_Tract 3	8,441	29,094	29
Cache_Haas_Tract 1	Moore Tract 3	12,942	64,279	20
Cache_Haas_Tract 2	Moore Tract 1	1,395	2,958	47
Canal Ranch	Canal Ranch	5,375	15,622	34
Chipps_Island	Chipps_Island	0	0	0
Clifton Court Forebay Water	Clifton Court Forebay Water	660	3,866	17
Coney_Island	Coney_Island	14,614	14,614	100
Deadhorse Island	Deadhorse Island	176	910	19
Decker_Island	Decker_Island	0	1,536	0
Discovery_Bay	Discovery_Bay	327,043	764,058	43
Egbert_Tract	Zone 70	6,549	32,639	20
Elk_Grove 1	Zone 76	367,526	908,302	40
Empire_Tract	Empire_Tract	2,871	9,511	30
Fabian_Tract	Fabian_Tract	10,832	33,364	32
Fay Island	Fay Island	6	22	25
Glanville_Tract	Glanville_Tract	12,962	49,828	26
Gliole_District	Netherlands 2	1,967	7,269	27
Grand Island	Grand Island	118,111	181,275	65
Hastings_Tract 2	Hastings_Tract 2	3,803	12,463	31

Table 12–7 Estimate Summary of Asset Cost Damage by Island – 100-Year Flood

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Holland_Land	Netherlands 5	1,019	3,541	29
Holland_Tract	Holland_Tract	5,345	14,669	36
Honker_Bay_Club	SM-201	66	2,020	3
Hotchkiss_Tract 1	Hotchkiss_Tract 1	34,377	94,633	36
Hotchkiss_Tract 2	Hotchkiss_Tract 2	219	1,326	17
Jersey_Island	Jersey_Island	2,632	24,238	11
Jones_Tract-Upper_and_Lower	Jones_Tract	65,972	497,784	13
Kasson_District	Zone 121	1,084	5,088	21
King_Island	King_Island	21,155	30,840	69
Libby_McNeil_Tract 1	Pierson District 3	4,928	13,712	36
Libby_McNeil_Tract 2	Pierson District 2	418	858	49
Liberte Island	Liberte Island	2,289	14,599	16
Lincoln_Village_Tract	Sargent_Barnhart_Tract 2	309,225	850,828	36
Lisbon_District	Netherlands 4	24,371	73,274	33
Little Holland Tract	Little Holland Tract	0	0	0
Little_Egbert_Tract	Zone 68	8,786	17,928	49
Lower_Roberts_Island	Roberts_Island 2	311	1,076	29
Mandeville_Island	Mandeville_Island	1,303	5,212	25
McCormack_Williamson_Tract	McCormack_Williamson_Tract	977	4,093	24
McDonald_Tract	McDonald_Tract	14,300	30,780	46
McMullin_Ranch-River_Junction Tract	Zone 161	9,677	37,101	26
Medford_Island	Medford_Island	3,347	7,594	44
Merritt Island	Merritt Island	18,854	33,623	56
Middle_Roberts_Island	Roberts_Island 1	60,002	538,471	11
Netherlands 1	Netherlands 1	1,286	3,700	35
Netherlands 2	Netherlands 3	85,355	163,107	52
New_Hope_Tract	New_Hope_Tract	23,540	73,570	32
Orwood_Tract	Palm-Orwood South	39,731	239,425	17
Palm_Tract	Palm-Orwood North	5,032	21,107	24
Paradise Junction	Paradise Junction	21,418	104,426	21
Pescadero	Pescadero	62,683	207,902	30

Table 12–7 Estimate Summary of Asset Cost Damage by Island – 100-Year Flood

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Peter Pocket	Peter Pocket	250	1,879	13
Pico_Naglee_Tract	Zone 126	84,143	242,833	35
Pierson_Tract	Pierson District 1	37,669	71,306	53
Pittsburg	Zone 209	10,043	50,510	20
Prospect_Island	Prospect_Island	742	1,552	48
Quimby_Island	Quimby_Island	209	584	36
RD 17 (Mossdale)	RD 17 Mossdale	209,898	682,140	31
Rindge_Tract	Rindge_Tract	5,093	18,094	28
Rio_Blanco_Tract	Rio_Blanco_Tract	1,102	9,988	11
Roberts_Island	Roberts_Island 3	0	100	0
Rough_and_Ready_Island	Rough_and_Ready_Island	14,103	66,049	21
Ryer Island	Ryer Island	22,394	55,877	40
Sacramento_Pocket_Area	Zone 196	7,467,904	18,758,793	40
Sargent_Barnhart_Tract 1	Sargent_Barnhart_Tract 1	6,819	42,063	16
Sargent_Barnhart_Tract 2	Wright-Elmwood_Tract-Sargent Burnhart Tract	431,024	1,364,049	32
Sargent_Barnhart_Tract 3	Sargent_Barnhart_Tract 3	6,260	15,247	41
Schafter-Pintail Tract	SM-131	808	2,873	28
Sherman_Island	Sherman_Island	16,407	110,416	15
Shima_Tract	Shima_Tract	281,340	670,166	42
Shin_Kee_Tract	Shin_Kee_Tract	1,101	12,324	9
Simmons-Wheeler_Island	SM-203	62	168	37
SM-123	SM-123	4,562	19,683	23
SM-124	SM-124	104,482	373,379	28
SM-132	SM-132	76	175	44
SM-133	SM-133	0	0	0
SM-134	SM-134	0	0	0
SM-198	SM-198	724	4,029	18
SM-199	SM-199	523	1,385	38
SM-202	SM-202	69	177	39
SM-39	SM-39	3,191	15,886	20
SM-40	SM-40	389	1,556	25

Table 12–7 Estimate Summary of Asset Cost Damage by Island – 100-Year Flood

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
SM-41	SM-41	424	3,813	11
SM-42	SM-42	250	1,753	14
SM-43	SM-43	62	168	37
SM-44	SM-44	1,029	5,019	21
SM-46	SM-46	118	471	25
SM-47	SM-47	0	0	0
SM-48	SM-48	6,190	32,145	19
SM-49	SM-49	7,315	32,384	23
SM-52	SM-52	1,104	4,288	26
SM-53	SM-53	8	41	19
SM-54	SM-54	17,220	82,090	21
SM-55	SM-55	895	5,024	18
SM-56	SM-56	535	3,403	16
SM-57	SM-57	2,548	13,558	19
SM-58	SM-58	192	768	25
SM-59	SM-59	432	1,694	25
SM-60	SM-60	2,251	13,559	17
SM-84	SM-84	3,900	13,846	28
SM-85-Grizzly_Island	SM-85	2,698	16,370	16
Smith_Tract	Zone 157	270,733	949,531	29
Stark_Tract	Union_Island 4	161	5,031	3
Staten_Island	Staten_Island	3,863	20,191	19
Stewart_Tract	Stewart_Tract	11,971	47,394	25
Sutter Island	Sutter Island	11,094	22,725	49
Terminous_Tract 1	Terminous_Tract 1	5,285	27,939	19
Terminous_Tract 2	Terminous_Tract 2	28,813	51,468	56
Terminous_Tract 3	Terminous_Tract 3	412	643	64
Twitchell_Island	Twitchell_Island	6,101	12,105	50
Tyler_Island 2	Tyler_Island 2	23,454	91,184	26
Union_Island 1	Union_Island 1	34,608	133,056	26
Union_Island 2	Union_Island 2	21	574	4

Table 12–7 Estimate Summary of Asset Cost Damage by Island – 100-Year Flood

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Union_Island 3	Union_Island 3	393	6,593	6
Union_Island 4	Union_Island 5	123	686	18
Upper_Roberts_Island	Roberts_Island 4	10,381	58,911	18
Van_Sickle_Island	Van_Sickle_Island	30,236	100,540	30
Veale_Tract 1	Veale_Tract 2	4,276	17,738	24
Veale_Tract 2	Veale_Tract 3	736	4,034	18
Venice_Island	Venice_Island	3,352	13,288	25
Victoria_Island	Victoria_Island	25,322	47,053	54
Walnut_Grove	Tyler_Island 1	32,648	40,179	81
Walthal_Tract	Walthal	14,716	39,782	37
Water Body	Water Body	0	0	25
Water Canal	Water Canal	0	224	0
Water Zone 1	Water Zone 1	160,560	381,711	42
Water Zone 2	Water Zone 2	386,013	1,256,735	31
Water Zone 3	Water Zone 3	45,669	140,438	33
Water Zone 4	Water Zone 4	31,788	136,104	23
Water Zone 5	Water Zone 5	31,336	93,185	34
Webb_Tract	Webb_Tract	114	359	32
West Sacramento North	West Sacramento North	1,587,014	2,229,847	71
West Sacramento South 1	West Sacramento South 1	436,240	507,228	86
West Sacramento South 2	West Sacramento South 2	254	1,547	16
Woodward_Island	Woodward_Island	10,280	124,671	8
Wright-Elmwood_Tract	Wright-Elmwood_Tract	1,408	15,967	9
Yolo_Bypass	Moore Tract 2	17,584	115,074	15
Zone 120	Zone 120	10,933	44,266	25
Zone 122	Zone 122	125	125	100
Zone 14	Zone 14	0	432	0
Zone 148	Zone 148	6,082	13,260	46
Zone 155	Zone 155	27	298	9
Zone 158 (Smith Tract_2)	Zone 158	56,925	266,201	21
Zone 160	Zone 160	3,489	11,128	31

Table 12–7 Estimate Summary of Asset Cost Damage by Island – 100-Year Flood

Island Name	Old Island Name	Repair Costs ($1,000)	Asset Value ($1,000)	% of total value damaged
Zone 162	Zone 162	1,183	3,516	34
Zone 171	Zone 171	5,640	28,837	20
Zone 185	Zone 185	130,838	523,318	25
Zone 186	Zone 186	0	3,283	0
Zone 197	Zone 197	13,737	30,316	45
Zone 206	Zone 206	70,134	200,463	35
Zone 207	Zone 207	1,712	7,360	23
Zone 214	Zone 214	0	269	0
Zone 216	Zone 216	204	467	44
Zone 31	Zone 31	140	430	33
Zone 33	Zone 33	53	163	33
Zone 36	Zone 36	1,286	6,953	18
Zone 37	Zone 37	213,933	1,027,059	21
Zone 38	Zone 38	8,498	70,178	12
Zone 64	Zone 64	1,546	6,834	23
Zone 65	Zone 65	87	350	25
Zone 69	Zone 69	212	847	25
Zone 74	Zone 74	7,387	44,631	17
Zone 75	Zone 75	6,987	20,654	34
Zone 77	Zone 77	1,955	9,643	20
Zone 78	Zone 78	6,974	25,063	28
Zone 79	Zone 79	1,937	8,974	22
Zone 80	Zone 80	2,180	10,803	20
Zone 81	Zone 81	1,855	9,156	20
Zone 82	Zone 82	548	7,124	8
Zone 90	Zone 90	6,814	58,199	12
Total Replacement Cost	**-**	**-**	**39,269,170**	-

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
Bacon_Island	Bacon_Island	0	0	8,458
Bethel_Island	Bethel_Island	0	0	16,193
Bishop_Tract	Bishop_Tract	37,819	864	15,080
Bixler_Tract	Veale_Tract 1	508	165	22
Boggs_Tract	Zone 159	269,101	10,208	18,623
Bouldin_Island	Bouldin_Island	0	0	11,310
Brack_Tract	Brack_Tract	0	0	2,653
Bradford_Island	Bradford_Island	0	0	7,030
Brannan-Andrus Island	Brannan-Andrus Island	3,000	16	51,066
Browns_Island	Browns_Island	0	0	0
Byron_Tract 1	Byron_Tract 1	1,500	25	6,293
Byron_Tract 2	Byron_Tract 2	4,960	236	11,069
Byron_Tract 3	Byron_Tract 3	20,192	4,490	531
Cache_Haas_Tract 1	Moore Tract 3	2,335	29	22,968
Cache_Haas_Tract 2	Moore Tract 1	0	0	1,462
Canal Ranch	Canal Ranch	2,796	55	1,235
Chipps_Island	Chipps_Island	0	0	0
Clifton Court Forebay Water	Clifton Court Forebay Water	23	1	3,183
Coney_Island	Coney_Island	0	0	0
Deadhorse Island	Deadhorse Island	0	0	734
Decker_Island	Decker_Island	0	0	1,528
Discovery_Bay	Discovery_Bay	417,511	18,566	16,190
Egbert_Tract	Zone 70	0	0	4,537
Elk_Grove 1	Zone 76	48,432	583	13,362
Empire_Tract	Empire_Tract	0	0	5,549
Fabian_Tract	Fabian_Tract	2,329	27	11,510
Fay Island	Fay Island	0	0	17
Glanville_Tract	Glanville_Tract	6,670	121	8,674
Gliole_District	Netherlands 2	0	0	5,302

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
Grand Island	Grand Island	3,250	22	41,647
Hastings_Tract 1	Hastings_Tract 1	2	0	0
Hastings_Tract 2	Hastings_Tract 2	0	0	3,378
Holland_Land	Netherlands 5	0	0	2,522
Holland_Tract	Holland_Tract	1,500	30	6,211
Honker_Bay_Club	SM-201	112	6	1,842
Hotchkiss_Tract 1	Hotchkiss_Tract 1	24,579	847	12,013
Hotchkiss_Tract 2	Hotchkiss_Tract 2	0	0	1,107
Jersey_Island	Jersey_Island	0	0	13,129
Jones_Tract-Upper_and_Lower	Jones_Tract	2,000	23	37,556
Kasson_District	Zone 121	800	37	2,595
King_Island	King_Island	3,000	73	5,077
Libby_McNeil_Tract 1	Pierson District 3	5,992	1,035	2,791
Libby_McNeil_Tract 2	Pierson District 2	389	61	52
Liberte Island	Liberte Island	1,500	21	5,773
Lincoln_Village_Tract	Sargent_Barnhart_Tract 2	414,014	17,758	19,497
Lisbon_District	Netherlands 4	32,579	561	9,905
Little Holland Tract	Little Holland Tract	0	0	0
Little_Egbert_Tract	Zone 68	1,500	29	5,101
Lower_Roberts_Island	Roberts_Island 2	67	15	698
Mandeville_Island	Mandeville_Island	0	0	3,909
McCormack_Williamson_Tract	McCormack_Williamson_Tract	0	0	3,116
McDonald_Tract	McDonald_Tract	0	0	9,512
McMullin_Ranch-River_Junction Tract	Zone 161	4,597	98	11,720
Medford_Island	Medford_Island	0	0	4,247
Merritt Island	Merritt Island	0	0	13,206
Middle_Roberts_Island	Roberts_Island 1	6,134	34	44,026
Netherlands 1	Netherlands 1	0	0	2,303

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
Netherlands 2	Netherlands 3	2,550	17	32,573
New_Hope_Tract	New_Hope_Tract	5,138	82	9,756
Orwood_Tract	Palm-Orwood South	0	0	9,535
Palm_Tract	Palm-Orwood North	0	0	10,899
Paradise Junction	Paradise Junction	18,518	583	7,001
Pescadero	Pescadero	8,662	168	14,918
Peter Pocket	Peter Pocket	231	9	1,101
Pico_Naglee_Tract	Zone 126	10,938	223	17,844
Pierson_Tract	Pierson District 1	3,944	51	16,463
Pittsburg	Zone 209	22,716	628	17,606
Prospect_Island	Prospect_Island	0	0	810
Quimby_Island	Quimby_Island	750	57	0
RD 17 (Mossdale)	RD 17 Mossdale	135,326	1,660	30,570
Rindge_Tract	Rindge_Tract	250	3	17,001
Rio_Blanco_Tract	Rio_Blanco_Tract	1,500	57	5,798
Roberts_Island	Roberts_Island 3	100	58	0
Rough_and_Ready_Island	Rough_and_Ready_Island	20,160	771	16,922
Ryer Island	Ryer Island	1,500	15	18,146
Sacramento_Pocket_Area	Zone 196	1,804,749	14,275	141,955
Sargent_Barnhart_Tract 1	Sargent_Barnhart_Tract 1	38,591	5,328	1,583
Sargent_Barnhart_Tract 2	Wright-Elmwood_Tract-Sargent Burnhart Tract	496,000	11,799	38,416
Sargent_Barnhart_Tract 3	Sargent_Barnhart_Tract 3	8,567	6,181	238
Schafter-Pintail Tract	SM-131	165	6	1,844
Sherman_Island	Sherman_Island	0	0	34,985
Shima_Tract	Shima_Tract	263,652	5,753	22,235
Shin_Kee_Tract	Shin_Kee_Tract	0	0	5,881
Simmons-Wheeler_Island	SM-203	89	2	0
SM-123	SM-123	7,100	166	6,559

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
SM-124	SM-124	119,205	2,100	29,235
SM-132	SM-132	99	8	0
SM-133	SM-133	0	0	0
SM-134	SM-134	0	0	0
SM-198	SM-198	442	7	2,780
SM-199	SM-199	259	161	598
SM-202	SM-202	100	6	0
SM-39	SM-39	5,457	269	7,237
SM-40	SM-40	0	0	1,167
SM-41	SM-41	29	16	3,360
SM-42	SM-42	750	366	753
SM-43	SM-43	106	8	0
SM-44	SM-44	919	101	3,071
SM-46	SM-46	2	0	351
SM-47	SM-47	0	0	0
SM-48	SM-48	12,602	286	6,463
SM-49	SM-49	11,406	315	9,533
SM-51	SM-51	0	0	0
SM-52	SM-52	1,859	95	1,318
SM-53	SM-53	24	6	8
SM-54	SM-54	39,184	809	18,732
SM-55	SM-55	188	5	3,894
SM-56	SM-56	364	6	2,345
SM-57	SM-57	5,252	141	6,041
SM-58	SM-58	0	0	576
SM-59	SM-59	115	4	1,128
SM-60	SM-60	4,903	210	601
SM-84	SM-84	830	9	6,107
SM-85-Grizzly_Island	SM-85	554	7	12,199

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
Smith_Tract	Zone 157	434,795	18,268	27,622
Stark_Tract	Union_Island 4	187	12	4,462
Staten_Island	Staten_Island	0	0	7,313
Stewart_Tract	Stewart_Tract	10,198	150	11,608
Sutter Island	Sutter Island	0	0	11,352
Terminous_Tract 1	Terminous_Tract 1	2,284	84	4,483
Terminous_Tract 2	Terminous_Tract 2	1,750	19	10,441
Terminous_Tract 3	Terminous_Tract 3	194	96	38
Twitchell_Island	Twitchell_Island	0	0	4,431
Tyler_Island 2	Tyler_Island 2	33,829	309	24,227
Union_Island 1	Union_Island 1	0	0	29,217
Union_Island 2	Union_Island 2	0	0	553
Union_Island 3	Union_Island 3	196	12	5,611
Union_Island 4	Union_Island 5	0	0	564
Upper_Roberts_Island	Roberts_Island 4	5,685	72	19,317
Van_Sickle_Island	Van_Sickle_Island	220	6	0
Veale_Tract 1	Veale_Tract 2	2,918	115	5,008
Veale_Tract 2	Veale_Tract 3	3,279	564	19
Venice_Island	Venice_Island	0	0	9,447
Victoria_Island	Victoria_Island	0	0	16,209
Walnut_Grove	Tyler_Island 1	3,076	294	4,389
Walthal_Tract	Walthal	11,721	N/A	6,296
Water Canal	Water Canal	0	N/A	0
Water Zone 1	Water Zone 1	1,195	N/A	9,804
Water Zone 2	Water Zone 2	4	N/A	2
Water Zone 3	Water Zone 3	0	N/A	0
Water Zone 4	Water Zone 4	0	N/A	8
Water Zone 5	Water Zone 5	0	N/A	0
Webb_Tract	Webb_Tract	0	0	245

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
West Sacramento North	West Sacramento North	150,479	2,261	70,257
West Sacramento South 1	West Sacramento South 1	4,306	66	20,831
West Sacramento South 2	West Sacramento South 2	0	0	1,293
Woodward_Island	Woodward_Island	0	0	5,863
Wright-Elmwood_Tract	Wright-Elmwood_Tract	0	0	9,394
Yolo_Bypass	Moore Tract 2	11,201	61	27,429
Zone 120	Zone 120	4,465	78	11,120
Zone 122	Zone 122	0	0	0
Zone 14	Zone 14	0	0	432
Zone 148	Zone 148	479	11	6,124
Zone 155	Zone 155	0	0	271
Zone 158 (Smith Tract_2)	Zone 158	190,639	19,807	17,347
Zone 160	Zone 160	6,245	1,243	1,395
Zone 162	Zone 162	1,205	81	1,127
Zone 171	Zone 171	4,892	89	9,440
Zone 185	Zone 185	374,932	28,635	16,055
Zone 186	Zone 186	0	0	3,283
Zone 197	Zone 197	0	0	16,250
Zone 206	Zone 206	78,778	1,705	19,695
Zone 207	Zone 207	0	0	5,649
Zone 214	Zone 214	0	0	269
Zone 216	Zone 216	263	72	0
Zone 31	Zone 31	290	118	0
Zone 33	Zone 33	110	62	0
Zone 36	Zone 36	3,832	661	1,812
Zone 37	Zone 37	88,122	7,355	6,371
Zone 38	Zone 38	35,273	5,416	26,591
Zone 64	Zone 64	4,035	3,517	1,252
Zone 65	Zone 65	0	0	262

Table 12–8 Estimate Summary of Asset Cost Damage by Island – Scour (100-Year Flood)

Island Name	Old Island Name	Differential Repair Costs for Point Assets - By Island ($1,000)	1,000ft Increment Cost for Point Assets - By Island ($1,000)	Differential Repair Costs for Linear Assets ($1,000)
Zone 69	Zone 69	0	0	635
Zone 74	Zone 74	1,032	29	8,704
Zone 75	Zone 75	5,016	133	4,204
Zone 77	Zone 77	3,392	441	4,381
Zone 78	Zone 78	5,327	147	4,164
Zone 79	Zone 79	1,693	68	3,233
Zone 80	Zone 80	1,659	57	4,779
Zone 81	Zone 81	2,080	49	2,384
Zone 82	Zone 82	0	0	4,494
Zone 90	Zone 90	17,092	500	34,293

Table 12–9 Summary of Business Sales and Cost Analysis 2005 and 2030

For All Analysis Zones

	MHHW Flood		100-Year Flood	
	2005	**2030**	**2005**	**2030**
Number of businesses	883	883	15,930	15,930
Economic costs				
Mil $ One-time cost if flooded	$0.88	$0.88	$15.93	$15.93
Mil $ Lost Profit per Day Lost Use	$0.60	$0.97	$8.27	$17.83
Mil $ Lost Profit per Day after RPCs [1.]	$0.05	$0.10	$1.22	$2.42
Economic Impact, Includes Backward Linkages (after RPCs)				
Mil $ Value of Output	$1.05	$1.85	$24.40	$48.48
Person-years Employment [2.]	10	13	222	326
Mil $ Labor income	$0.35	$0.64	$8.41	$17.89
Mil $ Value Added [3.]	$0.58	$1.04	$13.08	$27.07

[1] After accounting for lost sales that are captured by other California businesses

[2] One person year of employment is 365 persons unemployed per day

[3] Value added is labor income, proprietor's income, other property income and indirect business taxes

Note that the large number of businesses associated with the 100 year flood zone reflect the inclusion of south and west Sacramento and parts of Stockton in the larger area. The MHHW zone is, by contrast, largely confined to the primary Delta. The Economic Consequences Technical Memorandum (URS/JBA 2008f) provides these details by analysis zone.

Table 12–10 CVPM Areas Analyzed and Corresponding Irrigation Areas

CVPM Region	Irrigation Areas Included
R10	Delta Mendota Canal, CVP Users: Panoche Pacheco, Del Puerto, Hospital, sunflower, West Stanislaus, Mustang, Orestimba Patterson, Foothill, San Luis WD, Broadview, Eagle Field, Mercy Springs, Pool Exchange Contractors, Schedule 2 water, more.
R13	Merced ID CVP Users: Chowchilla, Madera, Gravelly Ford
R14	Westlands WD
R15	Tulare Lake Bed, CVP Users: Fresno Slough, James, Tranquility, Traction Ranch, Laguna Real, Dist. 1606
R16	Eastern Fresno C. CVP Users: Friant-Kern Canal, Fresno 10, Garfield, International
R17	Friant-Kern Canal, Hills Valley, Tri-Valley Orange Cove
R18	Friant-Kern Canal, County of Fresno, Lower Tule River ID, Pixley ID, Portion of Rag Gulch, Ducor, County of Tulare, most of Delano Earlimart, Exeter, Ivanhoe, Lewis Cr., Lindmore, Lindsay-Strathmore, Porterville, Sausalito, Stone Corral, Tea Pot Dome, Terra Bella, Tulare
R19	Kern Co. SWP Service Area
R20	Friant-Kern Canal, Shafter Wasco, S. San Joaquin
R21	Cross-Valley Canal, Friant-Kern Canal, Arvin Edison

Note:
For this analysis, Region 10 was separated into Exchange Contractors and others to appropriately reflect the greater reliability of water supplies to Exchange Contractors.

Table 12-11 Regional Water Supplies[1] (1,000 AF), Permanent Crops and Gross Crop Revenue[2]

Water Source	R10A	R10B	R13	R14	R15	R16	R17	R18	R19	R20	R21	TOTAL
CVP (Delta + Friant)	360	657	317	986	84	62	33	508	-	539	107	3,653
SWP	5	-	-	-	265	-	-	-	737	58	357	1,421
Local Surface & Gw	64	-	454	211	334	272	295	335	27	20	156	2,168
Total Supplies	429	657	771	1,197	683	334	328	843	764	617	619	7,241
% Of Acreage In Permanent Crops	17%	5%	46%	9%	17%	86%	38%	25%	70%	24%	33%	
Gross Crop Revenue ($million)	366	277	1,082	931	803	352	646	1,215	487	545	670	7,376

Notes:
R10A = Non Exchange Contractors
R10B = Exchange Contractors
[1] Regional Water Supplies are for year 2000, an average water year.
[2] Gross Crop Revenue in millions of $2002.

Table 12–12 Population With Urban Water Supplies Potentially Affected by Delta Levee Failures

		Population	
Supplier	**Agency**	**2005**	**2030**
SWP/CVP/SFPUC	Santa Clara Valley Water District[1]	1,750,000	2,267,100
CVP	Contra Costa Water District	507,800	649,300
CVP	City of Tracy	70,800	160,100
CVP	City of Avenal	16,200	23,500
CVP	City of Coalinga	17,100	24,800
CVP	City of Dos Palos	4,800	7,000
CVP	City of Huron	7,000	10,200
	Subtotal CVP[2]	**2,373,700**	**3,142,000**
SWP	Alameda County Water District	324,000	405,900
SWP	Alameda Zone 7	196,000	264,000
SWP	Kern County Water Agency	326,000	458,000
SWP	Antelope Valley- East Kern	313,500	650,400
SWP	Palmdale Water District	109,800	214,300
SWP	San Gabriel Valley MWD	217,000	239,800
SWP	Castaic Lake Water Agency	235,000	401,700
SWP	Desert Water Agency	68,000	100,000
SWP	Coachella Valley WD	314,300	490,600
SWP	Crestline-lake Arrowhead Water Agency	34,500	46,100
SWP	Mojave Water Agency	358,800	700,000
SWP	San Bernardino Valley MWD	661,700	1,097,700
SWP	MWD of Southern California	18,233,800	22,053,200
SWP	Central Coast Water Authority	409,000	618,200
SWP	Casitas Municipal Water District	66,200	78,800
	Subtotal SWP[2]	**23,617,600**	**30,085,800**
	Total Export Projects[3]	**24,241,300**	**30,960,700**
EBMUD	EBMUD	1,338,000	1,017,000
	Total Potentially Disrupted[3]	**25,579,300**	**31,977,700**

Notes:
[1] SFPUC does not serve SCVWD but supplies water to SCVWD retail customers
[2] Includes SCVWD
[3] SCVWD included only once
[4] Not including those in SCVWD service territory
Source: Urban Water Management Plans
For smaller CVP towns, San Joaquin Council of Governments
http://www.sjcog.org/sections/departments/planning/research/projections

Table 12–13 Recommended Daily Economic Costs for Combinations of Delta Road Closures

Highway Number and Status						Recommended Cost per Day, Million $
4	**12**	**160**	**205**	**J11**	**I-5**	
Closed	Open	Open	Open	Open	Open	$0.50
Open	Closed	Open	Open	Open	Open	$0.30
Open	Open	Closed	Open	Open	Open	$0.12
Open	Open	Open	Closed	Open	Open	$4.00
Open	Open	Open	Open	Closed	Open	$0.10
Open	Open	Open	Open	Open	Closed	$3.00
Closed	Closed	Open	Open	Open	Open	$0.96
Closed	Open	Closed	Open	Open	Open	$0.74
Closed	Open	Open	Closed	Open	Open	$5.40
Closed	Open	Open	Open	Closed	Open	$0.72
Closed	Open	Open	Open	Open	Closed	$4.20
Open	Closed	Closed	Open	Open	Open	$0.50
Open	Closed	Open	Closed	Open	Open	$5.16
Open	Closed	Open	Open	Closed	Open	$0.48
Open	Closed	Open	Open	Open	Closed	$3.96
Open	Open	Closed	Closed	Open	Open	$4.94
Open	Open	Closed	Open	Closed	Open	$0.26
Open	Open	Closed	Open	Open	Closed	$3.74
Closed	Closed	Closed	Open	Open	Open	$1.29

Source: Economic Consequences Technical Memorandum (URS/JBA 2008f).

Table 12–14 Economic Costs for Railroad Disruption

($million per month)

	2005	2030
Oakland to Sacramento lines	$23.5	$39.6
Fremont to Stockton	$6.1	$10.3

Source: Economic Consequences Technical Memorandum (URS/JBA 2008f).

Table 12–15 Summary of Economic Costs Associated with Lost Use of Wastewater Facilities

Facility	Analysis Zone	Cost/Day of Outage	When Cost Incurred
City of Stockton	Zone 159	$9,000,000 or less	Immediately when flooded
City of Stockton	Roberts Island	Discharge of secondary treated effluent to the Delta. No cost estimate available.	Immediately when flooded
Ironhouse	Jersey Island	$930,000	After 1 week in winter, 1 month in summer
City of Isleton	Brannan Andrus	$50,000	About ½ is a new subdivision
City of Sacramento	Zone 76, 196	$26,800,000 or less	Only if the existing ring levee fails (22 feet)

Source: Economic Consequences Technical Memorandum (URS/JBA 2008f).

Figures

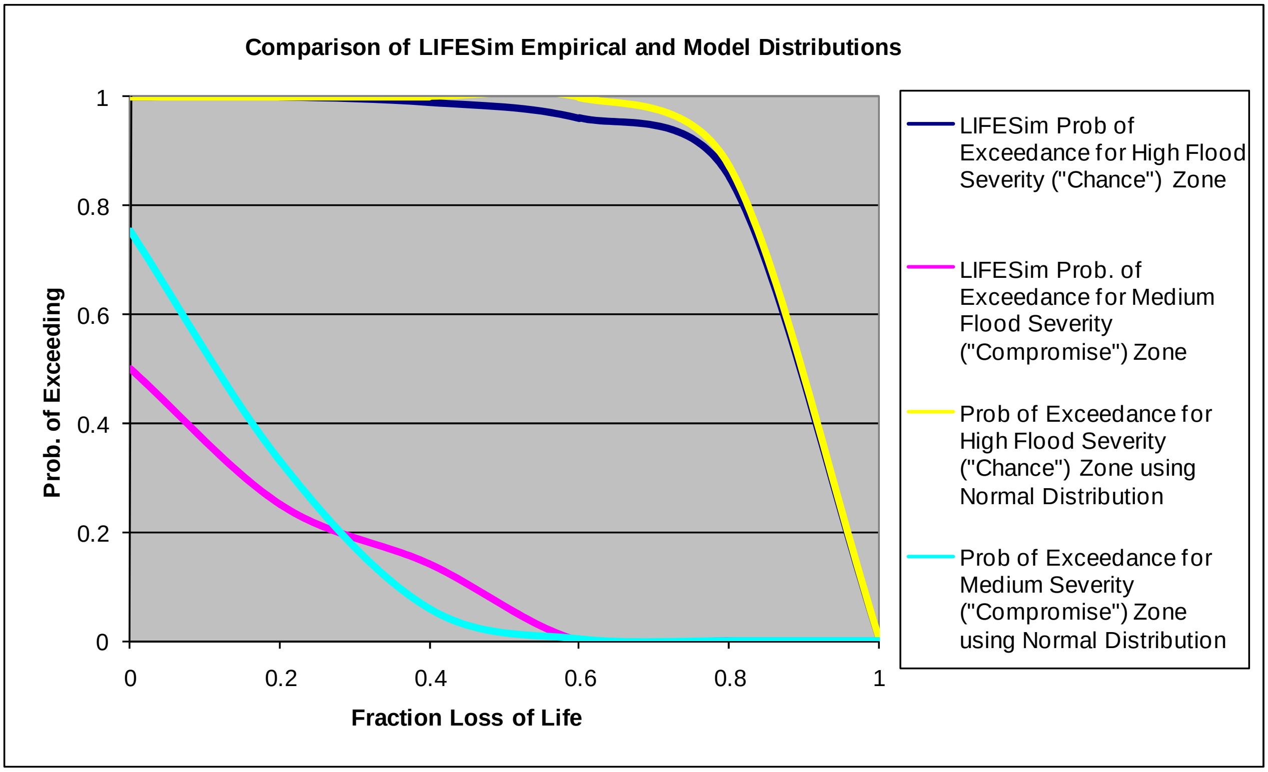


Figure 12–1 Model and empirical distributions of fraction life-loss

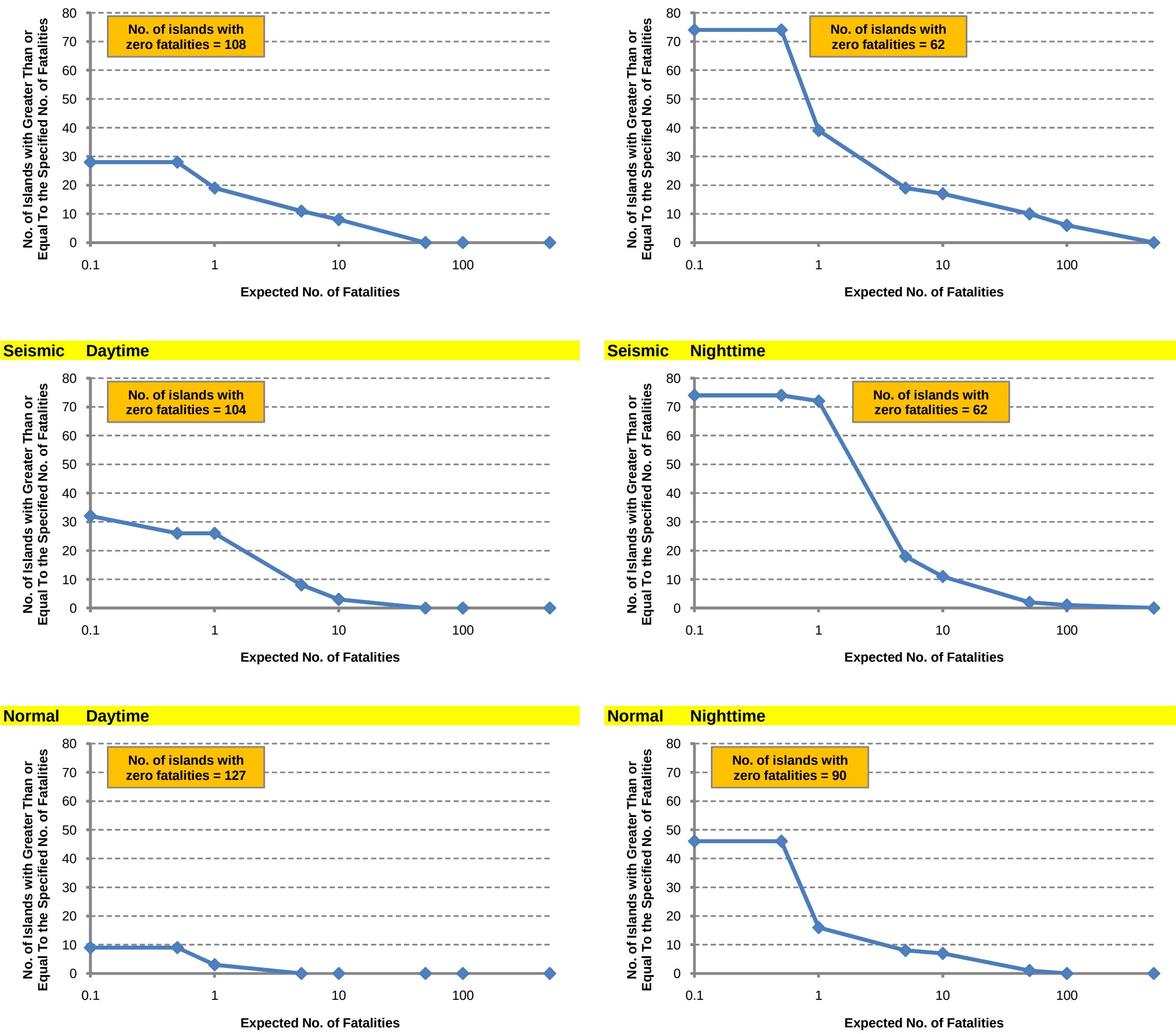


Figure 12–2 Number of islands with different expected number of fatalities given a breach

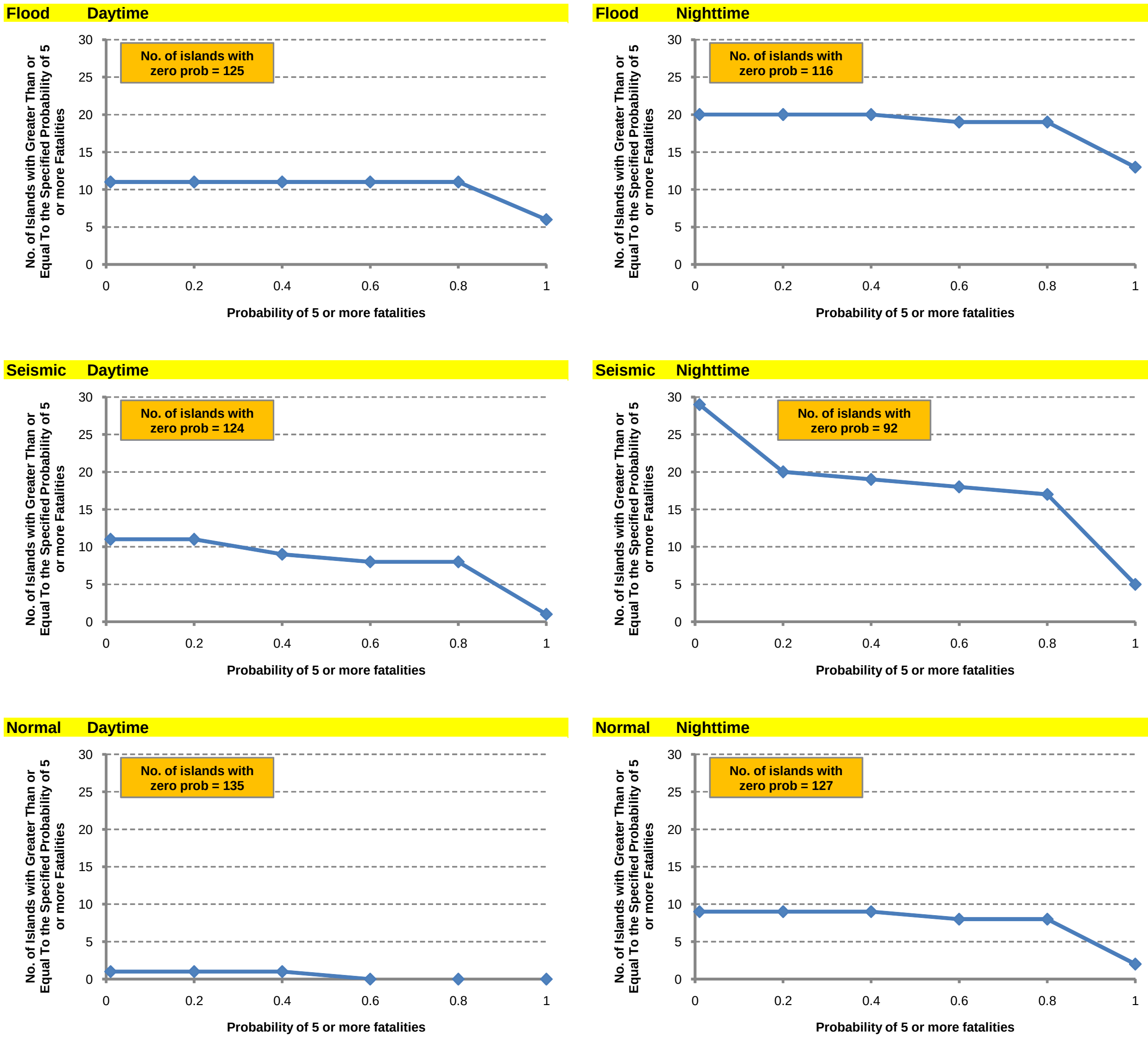


Figure 12–3 Number of islands with different (conditional) probabilities of 5 or more fatalities given a breach

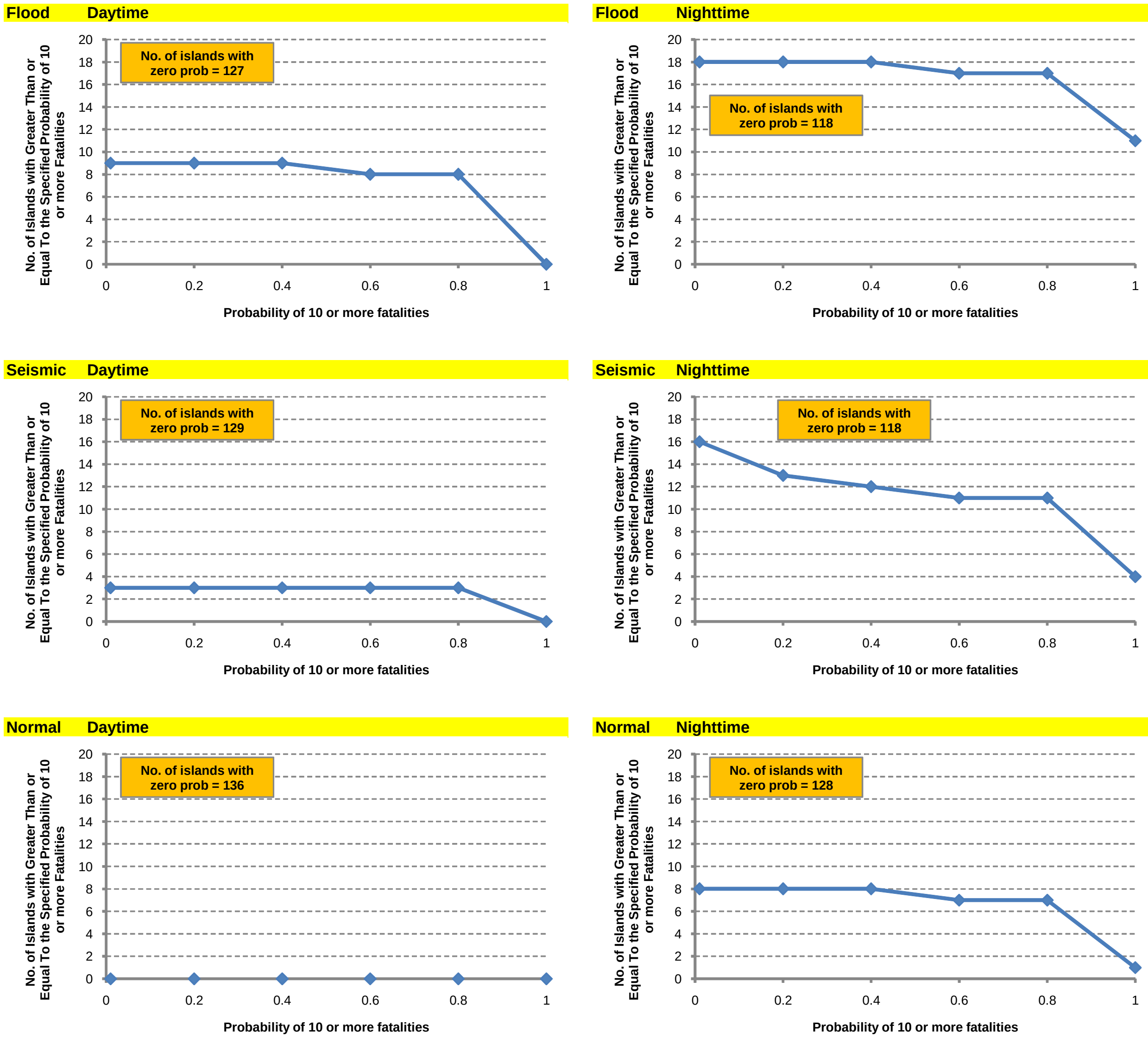


Figure 12–4 Number of islands with different (conditional) probabilities of 10 or more fatalities given a breach

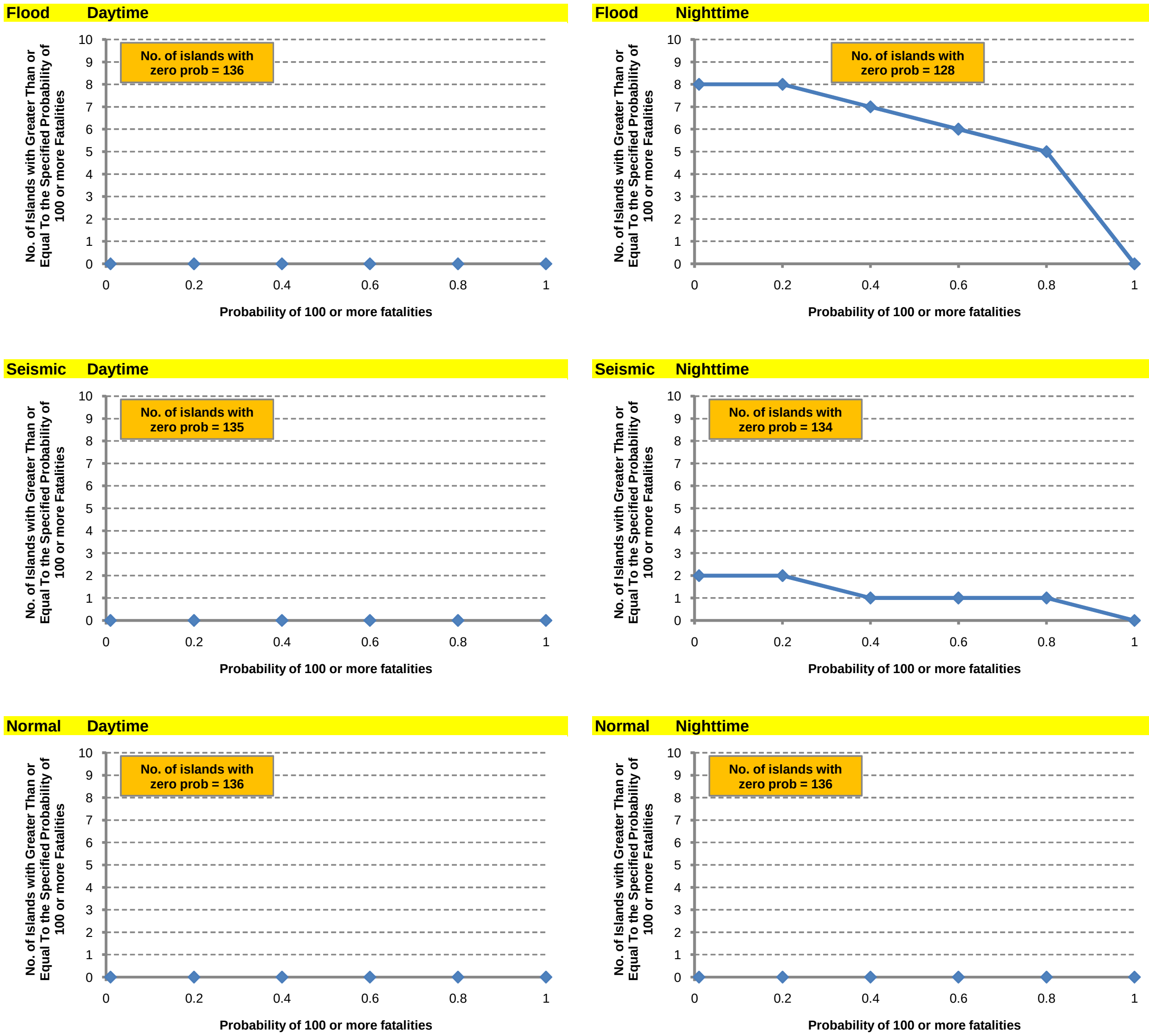
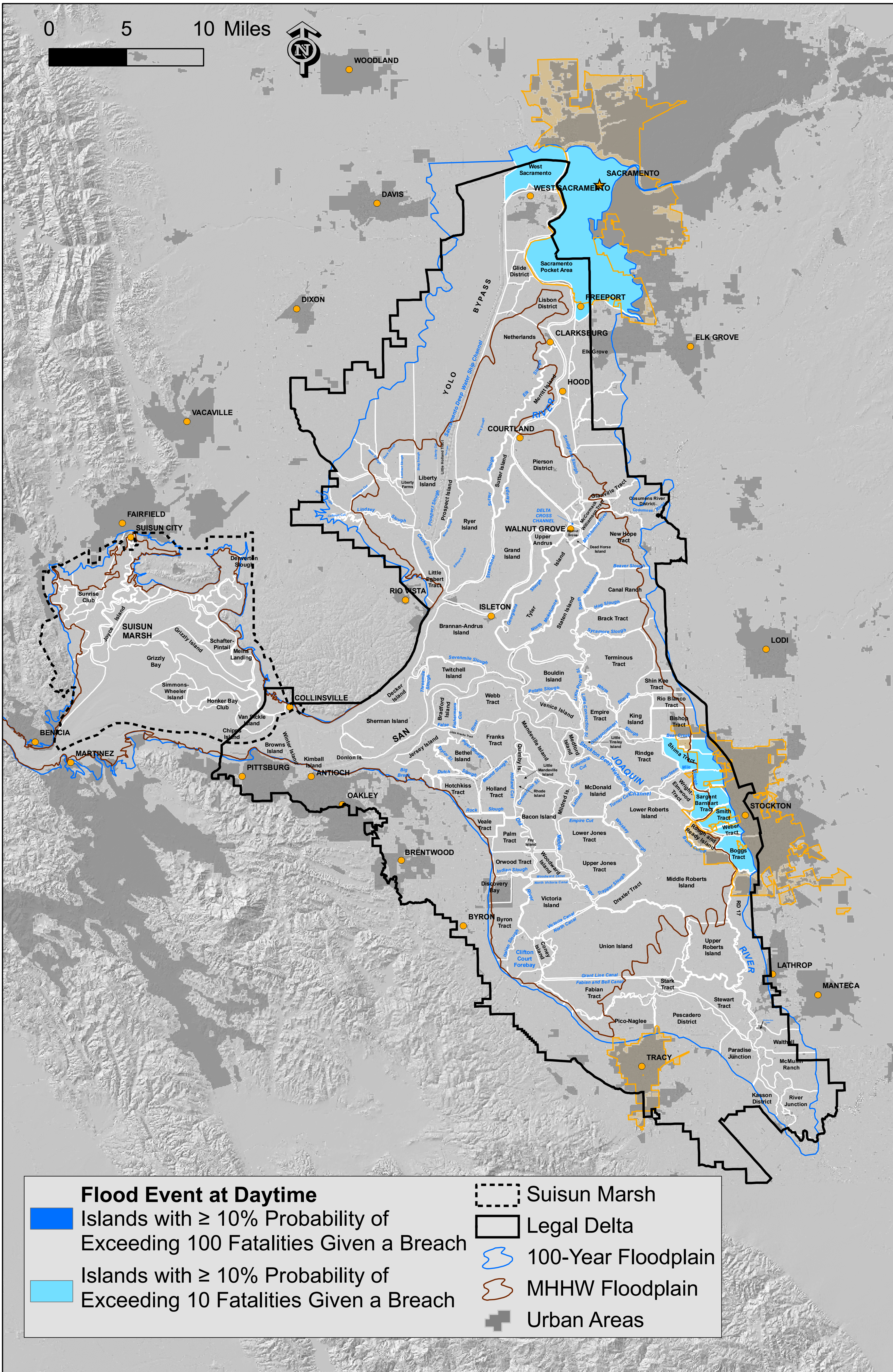


Figure 12–5 Number of islands with different (conditional) probabilities of 100 or more fatalities given a breach



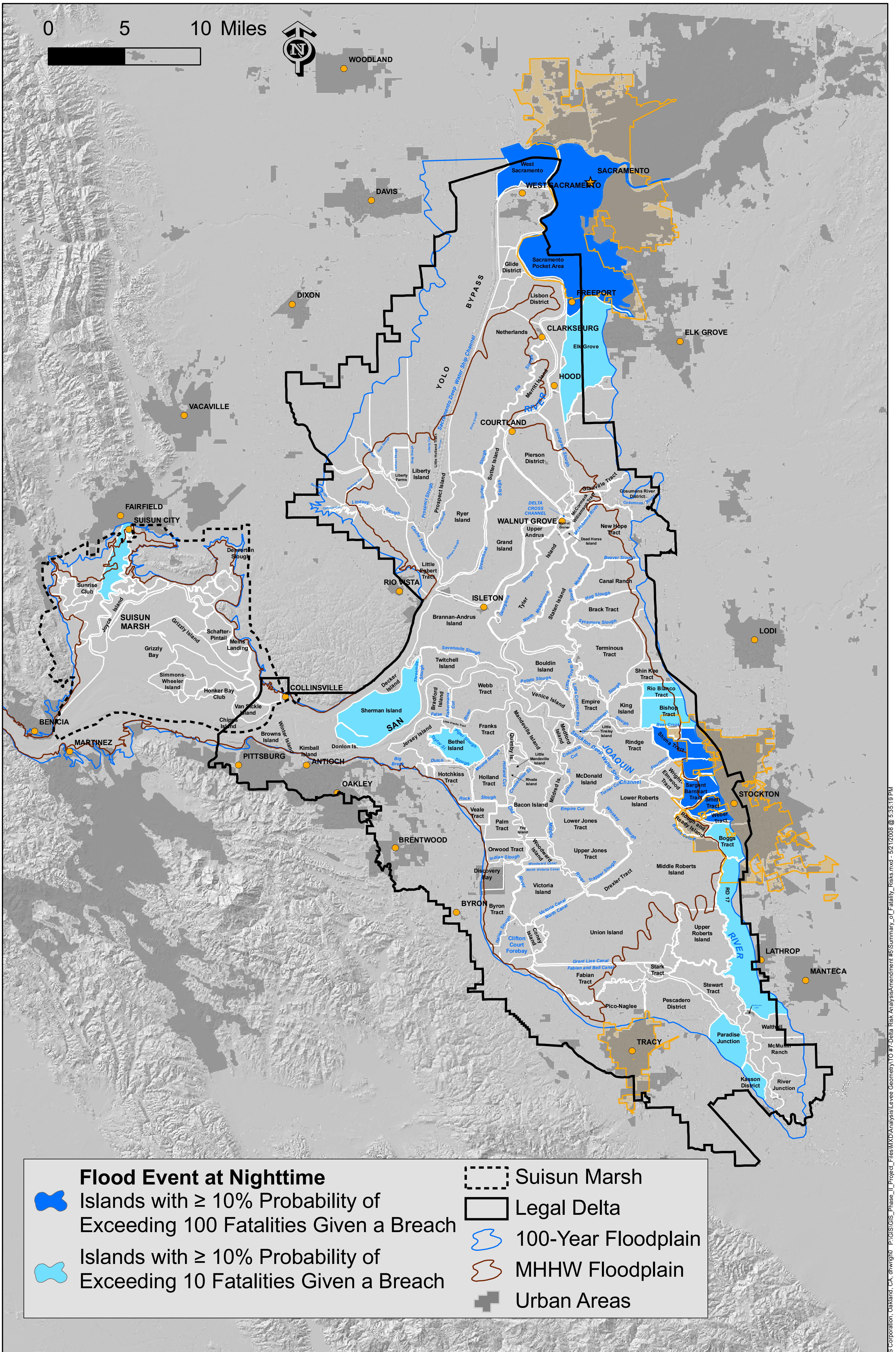
URS

Delta Risk Management Strategy (DRMS)
Phase 1

26815935

Fatality Risks for Flood Event at Daytime

Figure 12-6



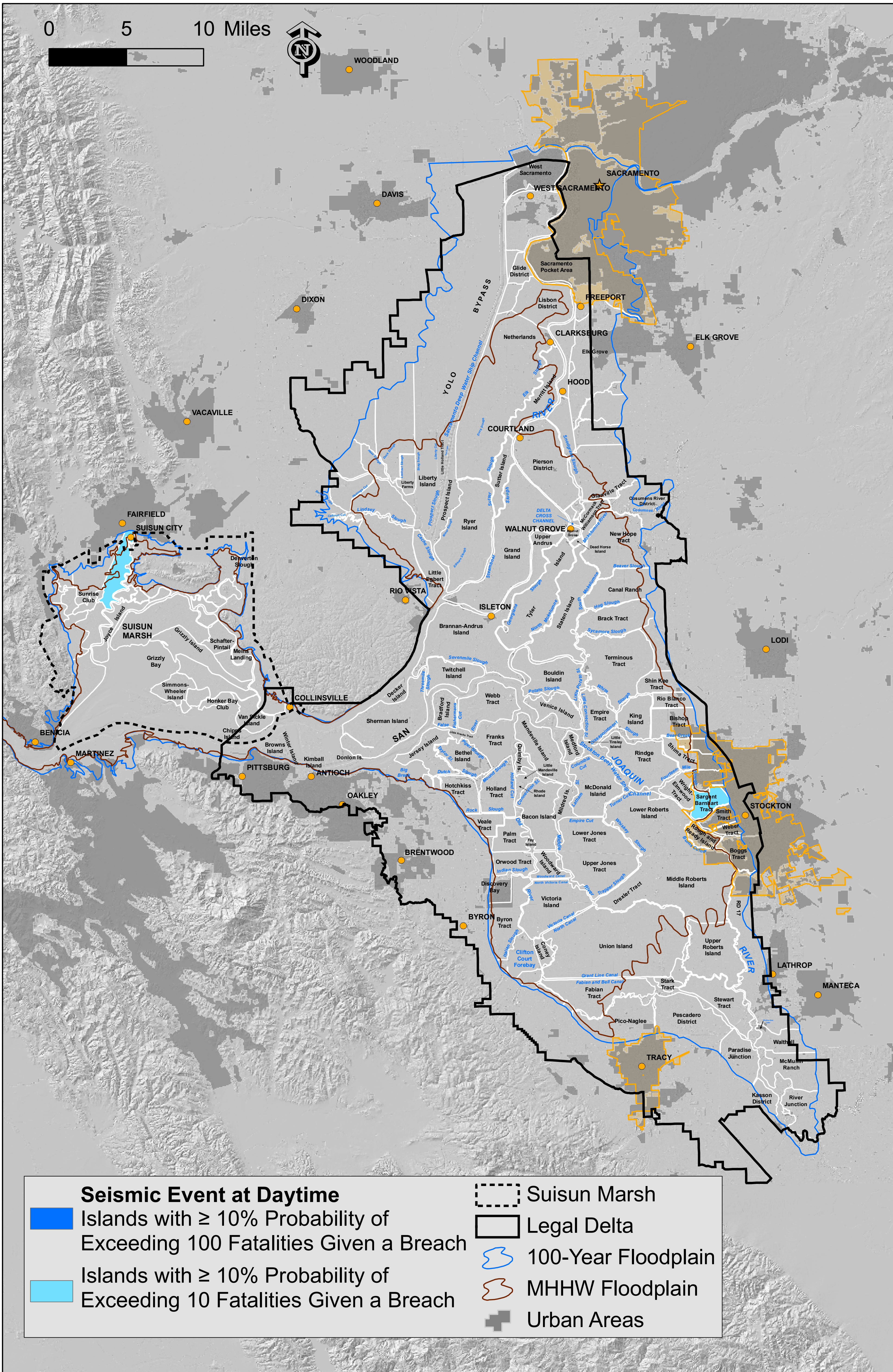
URS

Delta Risk Management Strategy (DRMS)
Phase 1

26815935

Fatality Risks for Flood Event at Nighttime

Figure 12-7



URS

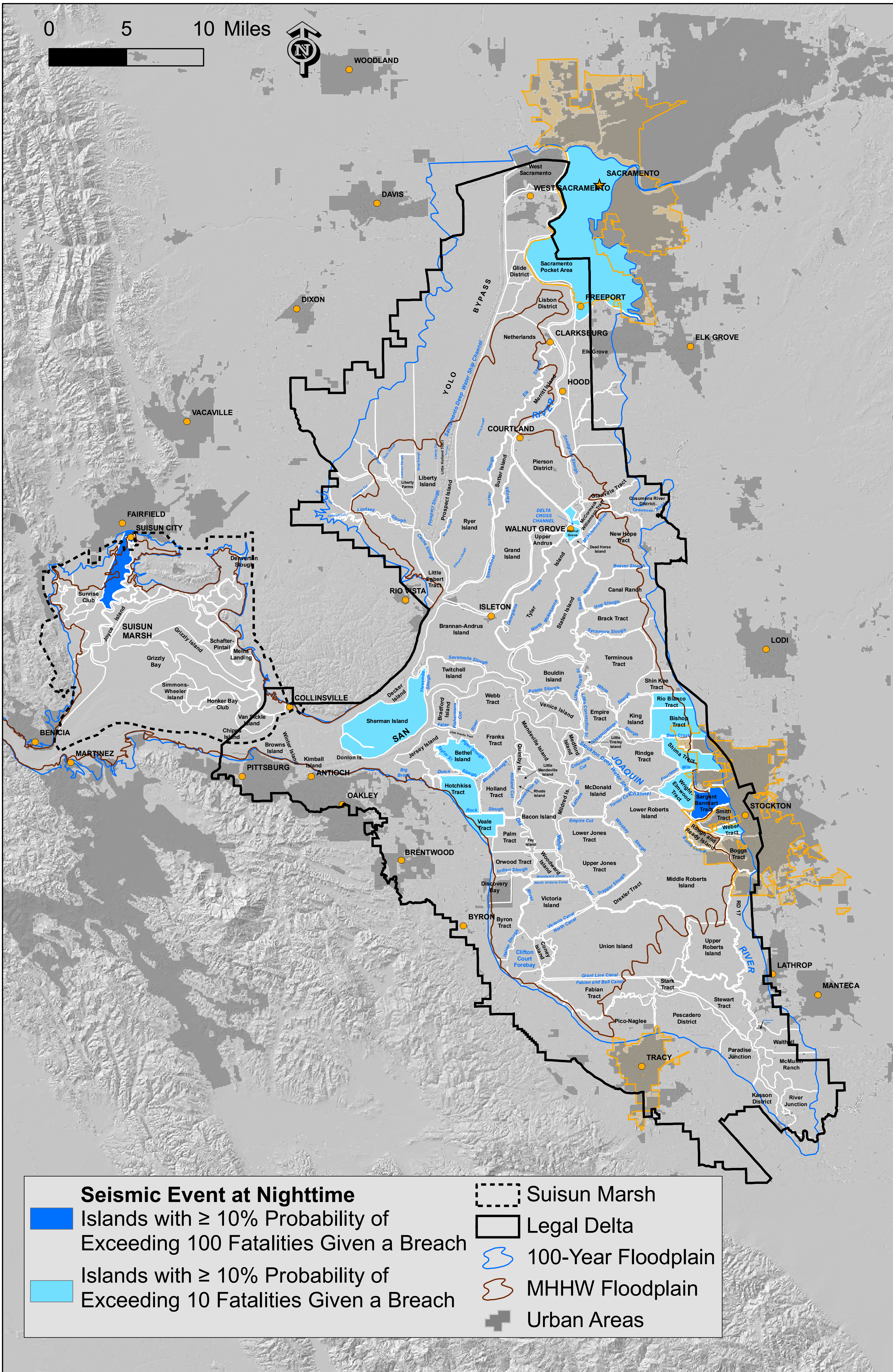
Delta Risk Management Strategy (DRMS)
Phase 1

26815935

Fatality Risks for
Seismic Event at Daytime

Figure
12-8

URS Corporation, Oakland, CA, dhwright0 P:\GIS\GIS_Phase_II_Project_Files\MXD\Analysis\Amendment #5\Summary_of_Fatality_Risks.mxd - 5/21/2008 @ 5:35:19 PM



URS

Delta Risk Management Strategy (DRMS)
Phase 1

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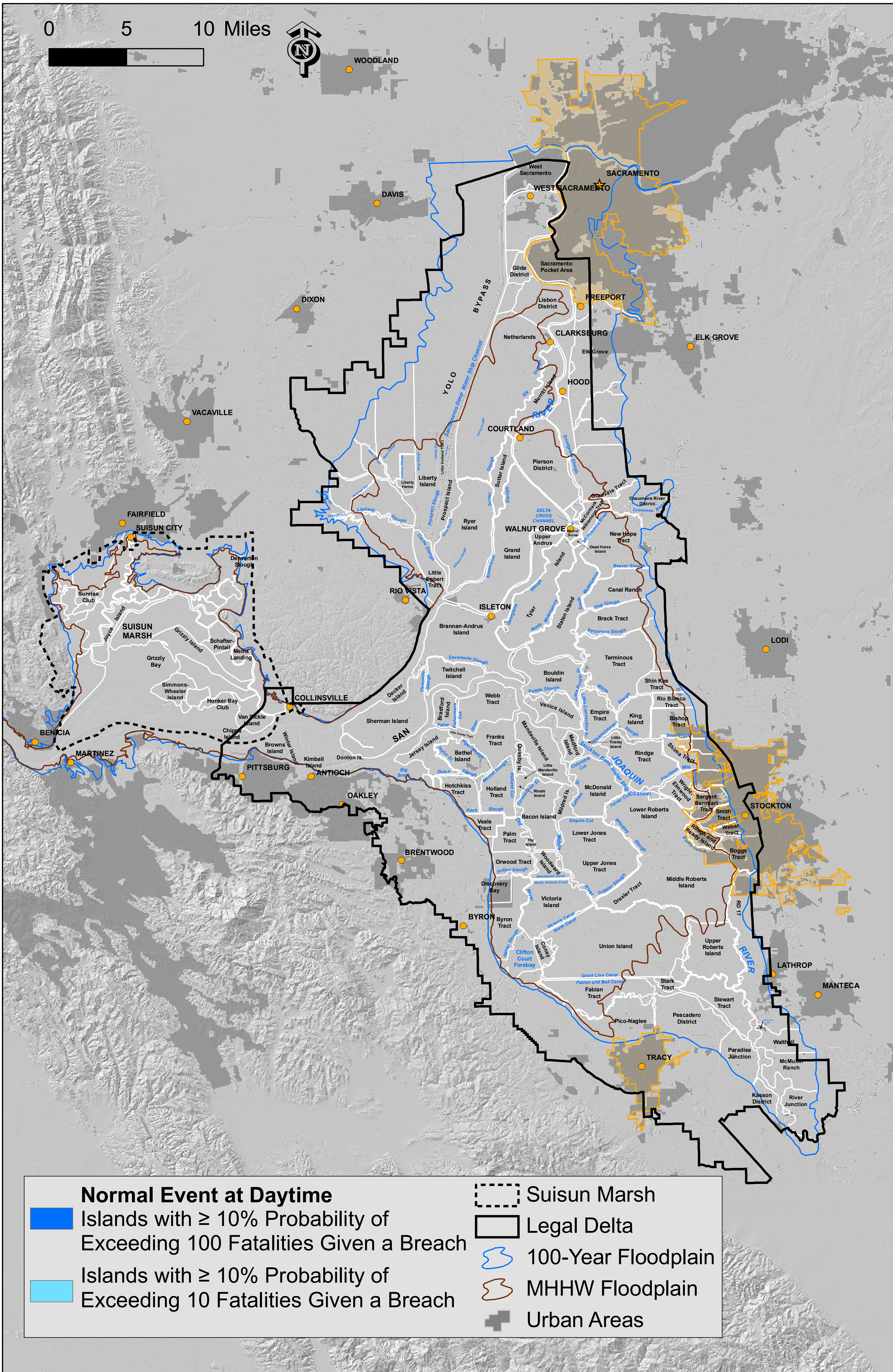
Fatality Risks for Seismic Event at Nighttime

Figure 12-9



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Phase 1

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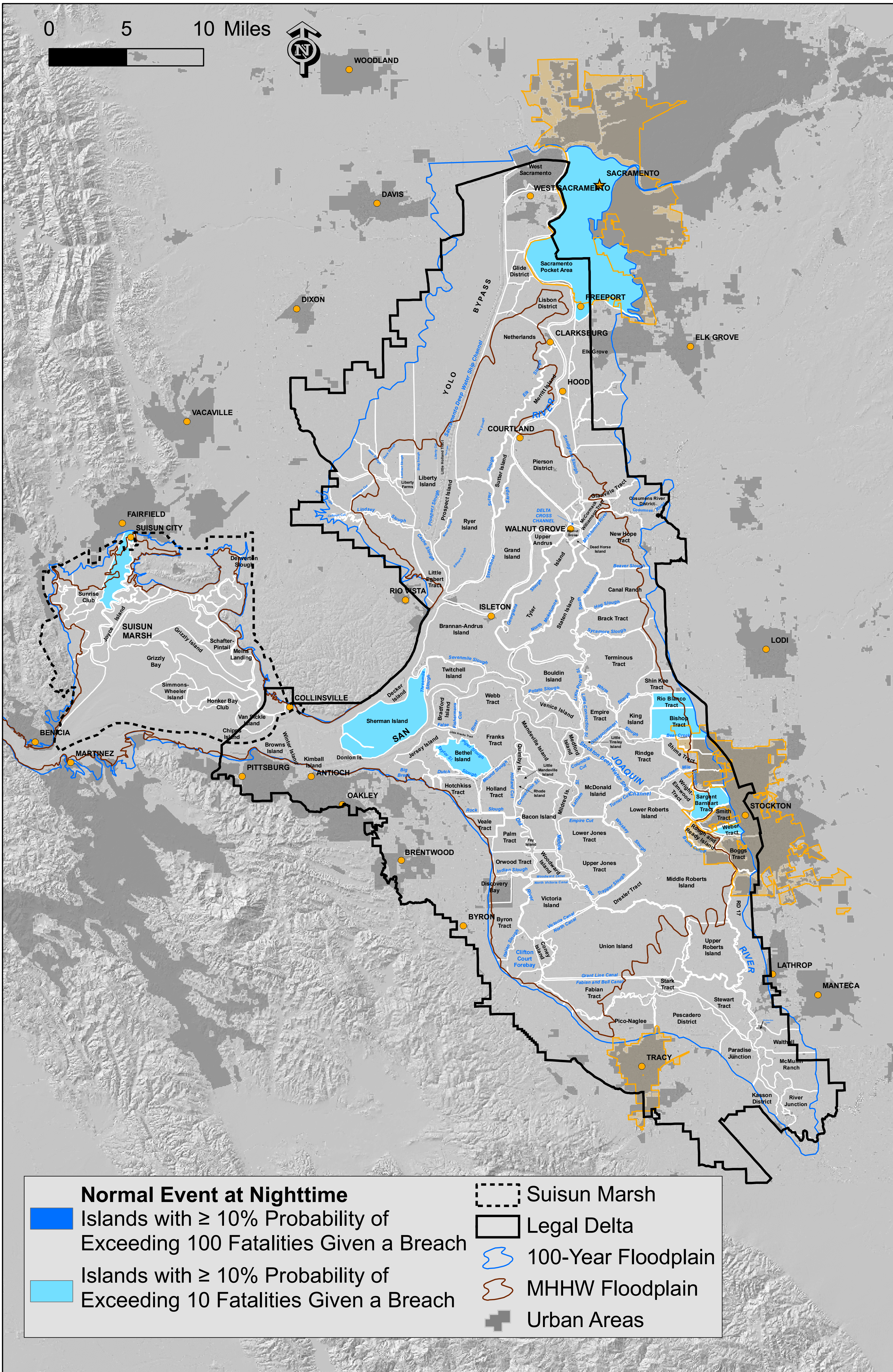
Fatality Risks for
Normal Event at Daytime

Figure
12-10



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Delta Risk Management Strategy (DRMS)
Phase 1

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Fatality Risks for Normal Event at Nighttime

Figure 12-11

URS Corporation, Oakland, CA, drwright0 P:\GIS\GIS_Phase_II_Project_Files\MXD\Analysis\Levee Geometry\TO #7-Delta Risk Analysis\Amendment #5\Summary_of_Fatality_Risks.mxd - 5/21/2008 @ 5:35:19 PM

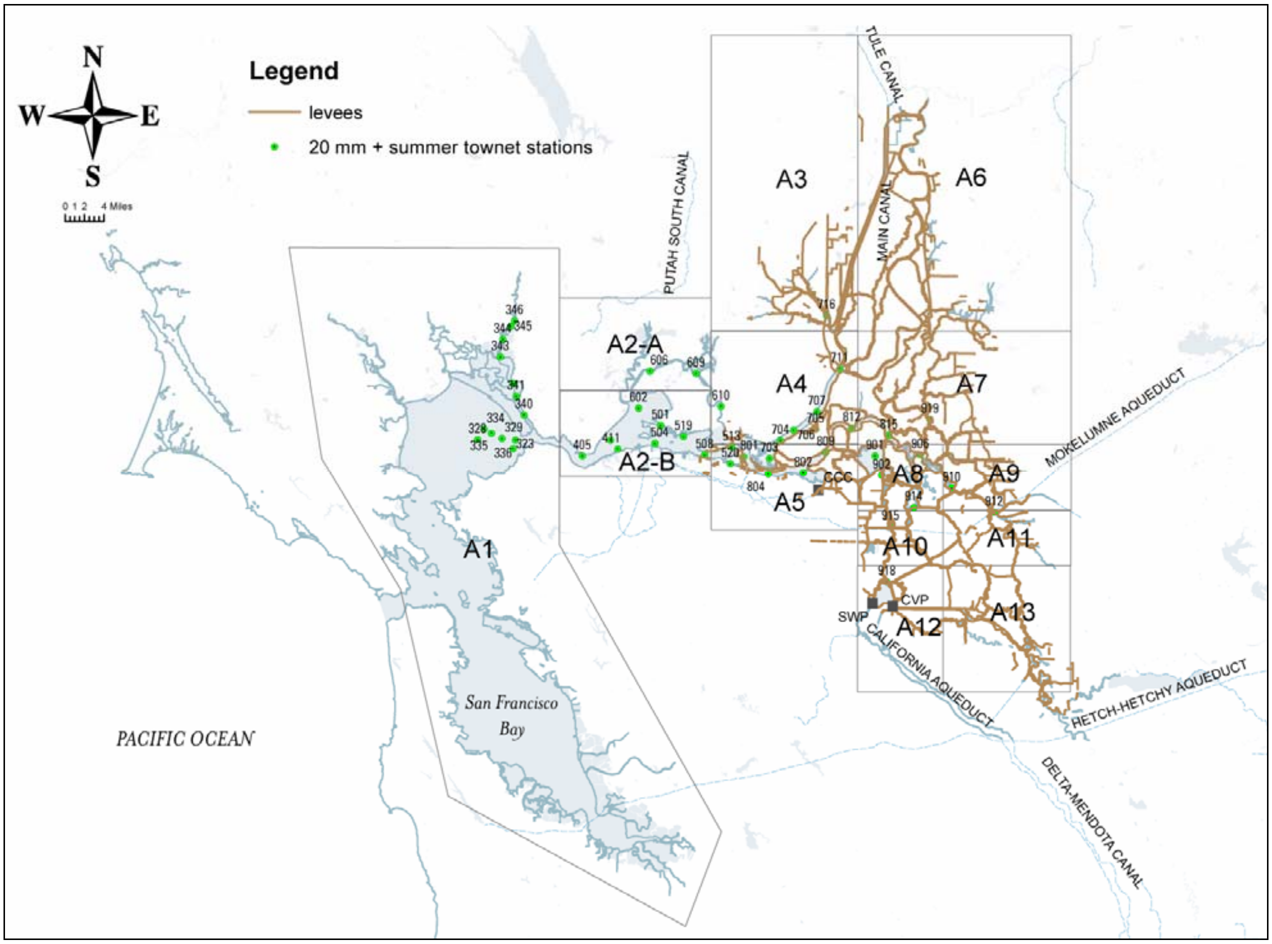
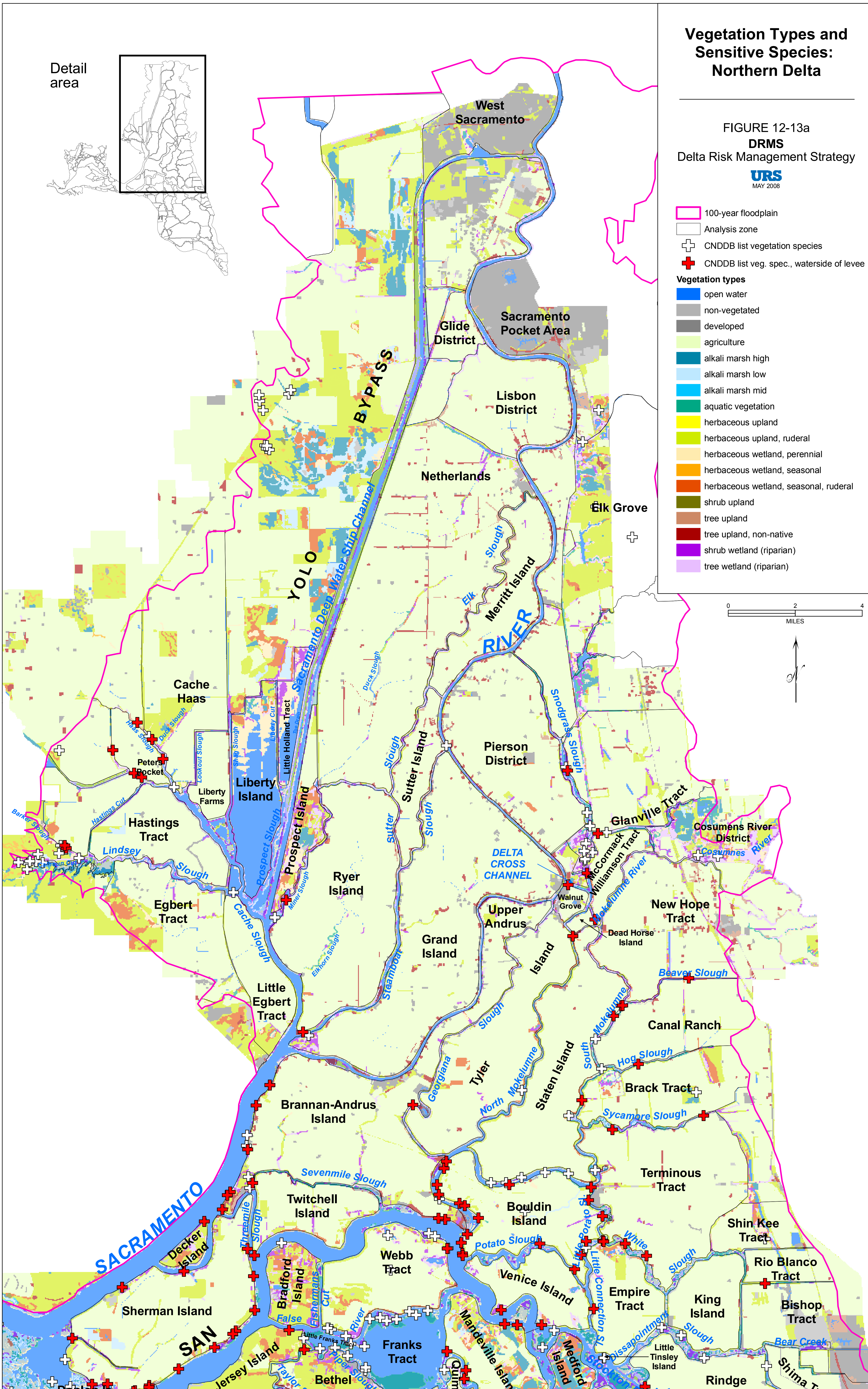


Figure 12–12 Division of the Delta developed for the DRMS fishery assessment and sites of relative CDFG fishery sampling sites (20 mm delta smelt survey)

Note: Source: CDFG 2006 data



Vegetation Types and Sensitive Species: Northern Delta

FIGURE 12-13a
DRMS
Delta Risk Management Strategy
URS
MAY 2008

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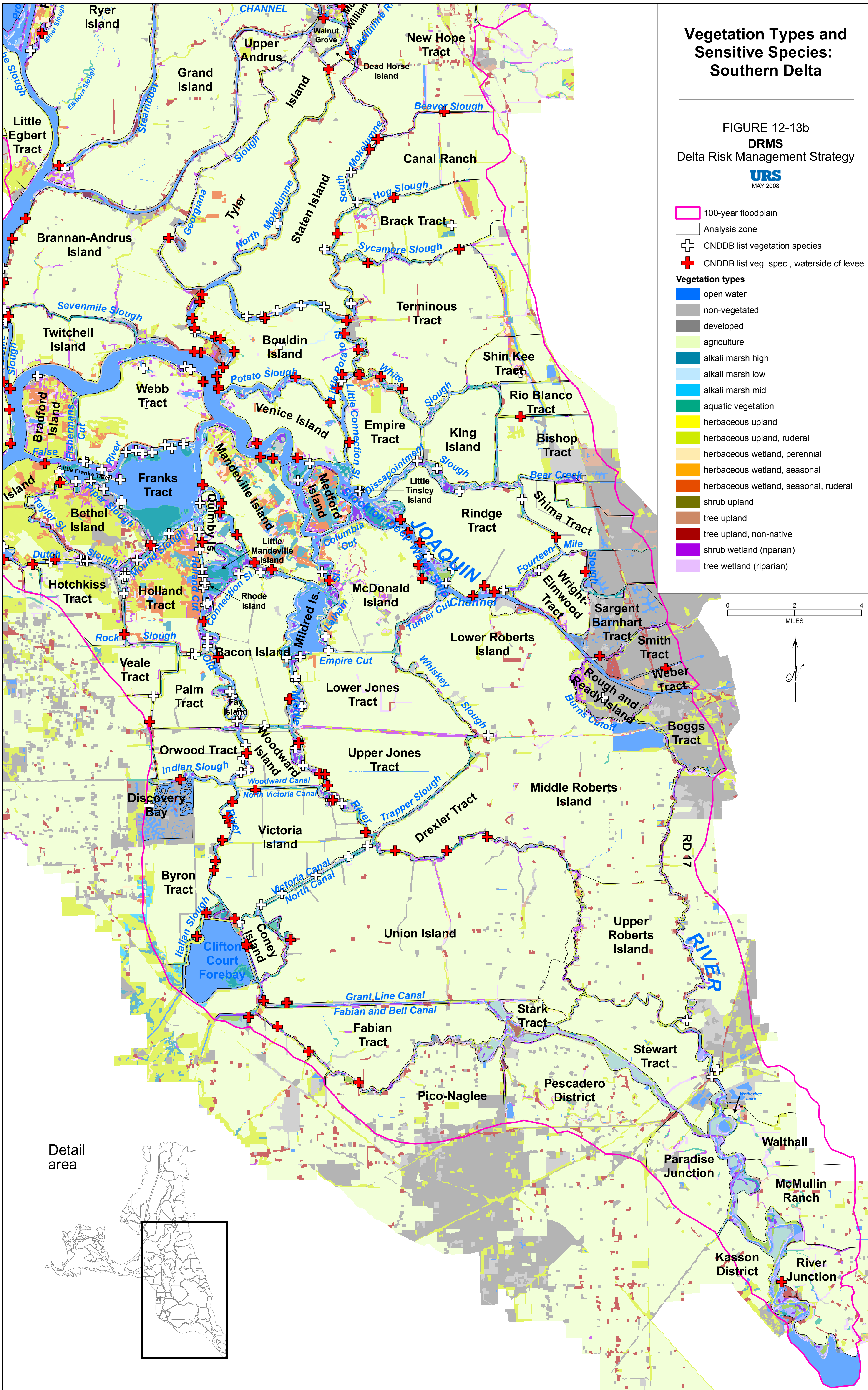
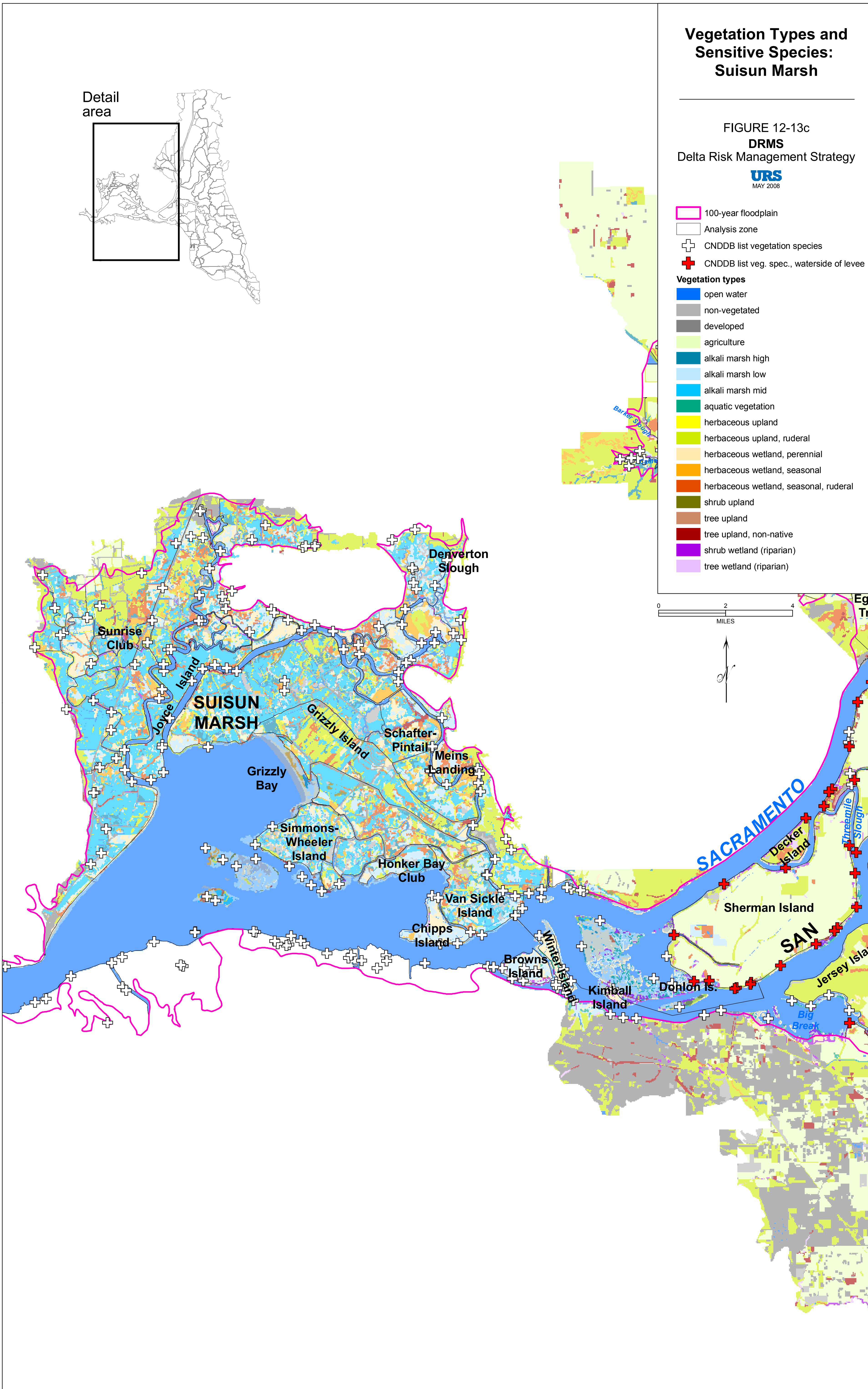


Vegetation Types and Sensitive Species: Southern Delta

FIGURE 12-13b


Vegetation Types and Sensitive Species: Suisun Marsh
FIGURE 12-13c
DRMS
Delta Risk Management Strategy
URS
MAY 2008
100-year floodplain
Analysis zone
CNDDB list vegetation species
CNDDB list veg. spec., waterside of levee
Vegetation types
open water
non-vegetated
developed
agriculture
alkali marsh high
alkali marsh low
alkali marsh mid
aquatic vegetation
herbaceous upland
herbaceous upland, ruderal
herbaceous wetland, perennial
herbaceous wetland, seasonal
herbaceous wetland, seasonal, ruderal
shrub upland
tree upland
tree upland, non-native
shrub wetland (riparian)
tree wetland (riparian)
0
2
4
MILES
N
Detail area
Denverton Slough
Sunrise Club
Joyce Island
SUISUN MARSH
Grizzly Island
Schafter-Pintail
Meins Landing
Grizzly Bay
Simmons-Wheeler Island
Honker Bay Club
Van Sickle Island
Chipps Island
Browns Island
Winter Island
Kimball Island
Dohlon Is.
SACRAMENTO
Decker Island
Threemile Slough
Sherman Island
SAN
Jersey Islan
Big Break
Barker Slough
Egb
Tra

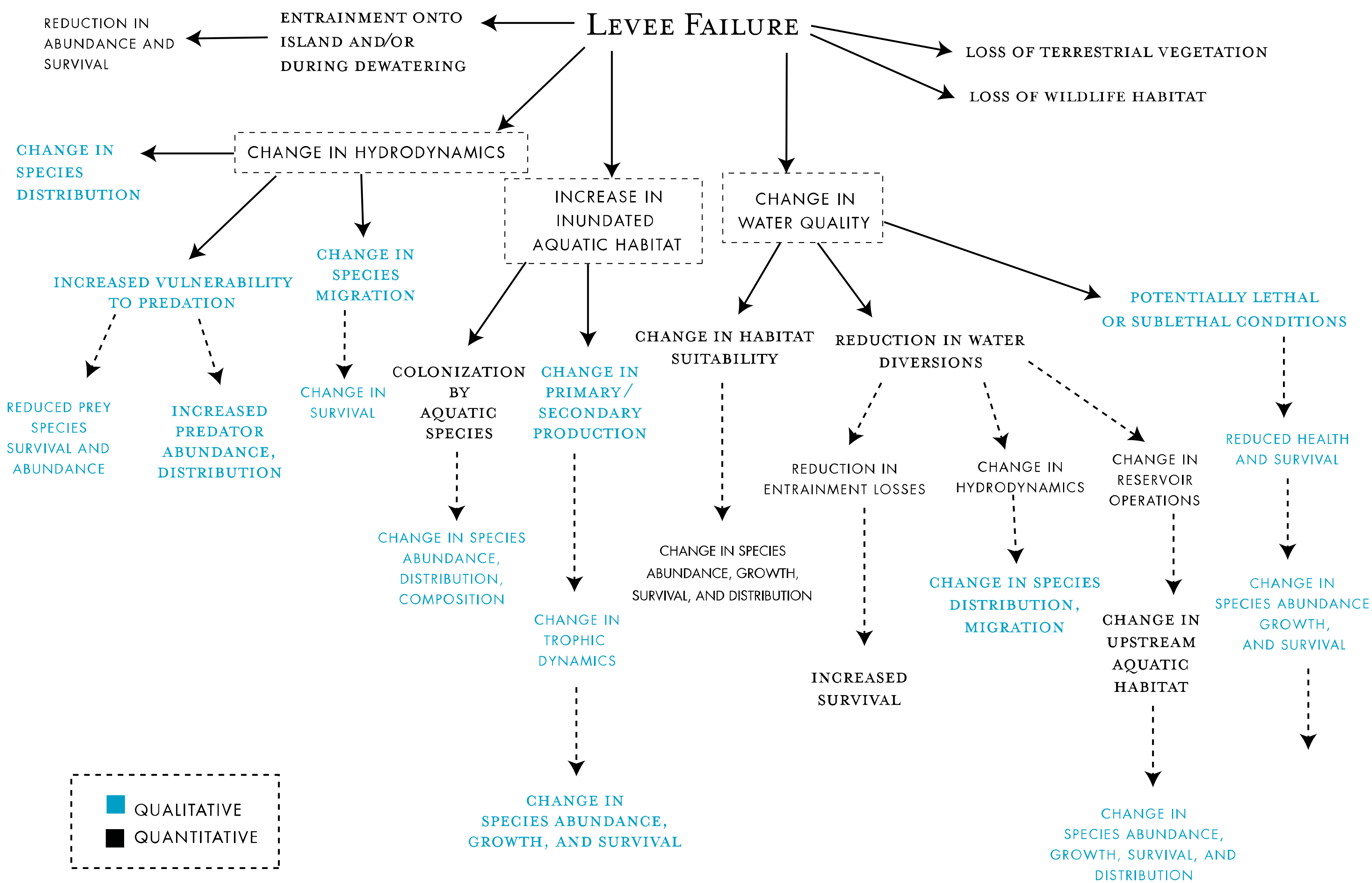


Figure 12–14 Conceptual model of aquatic ecosystem impact mechanisms

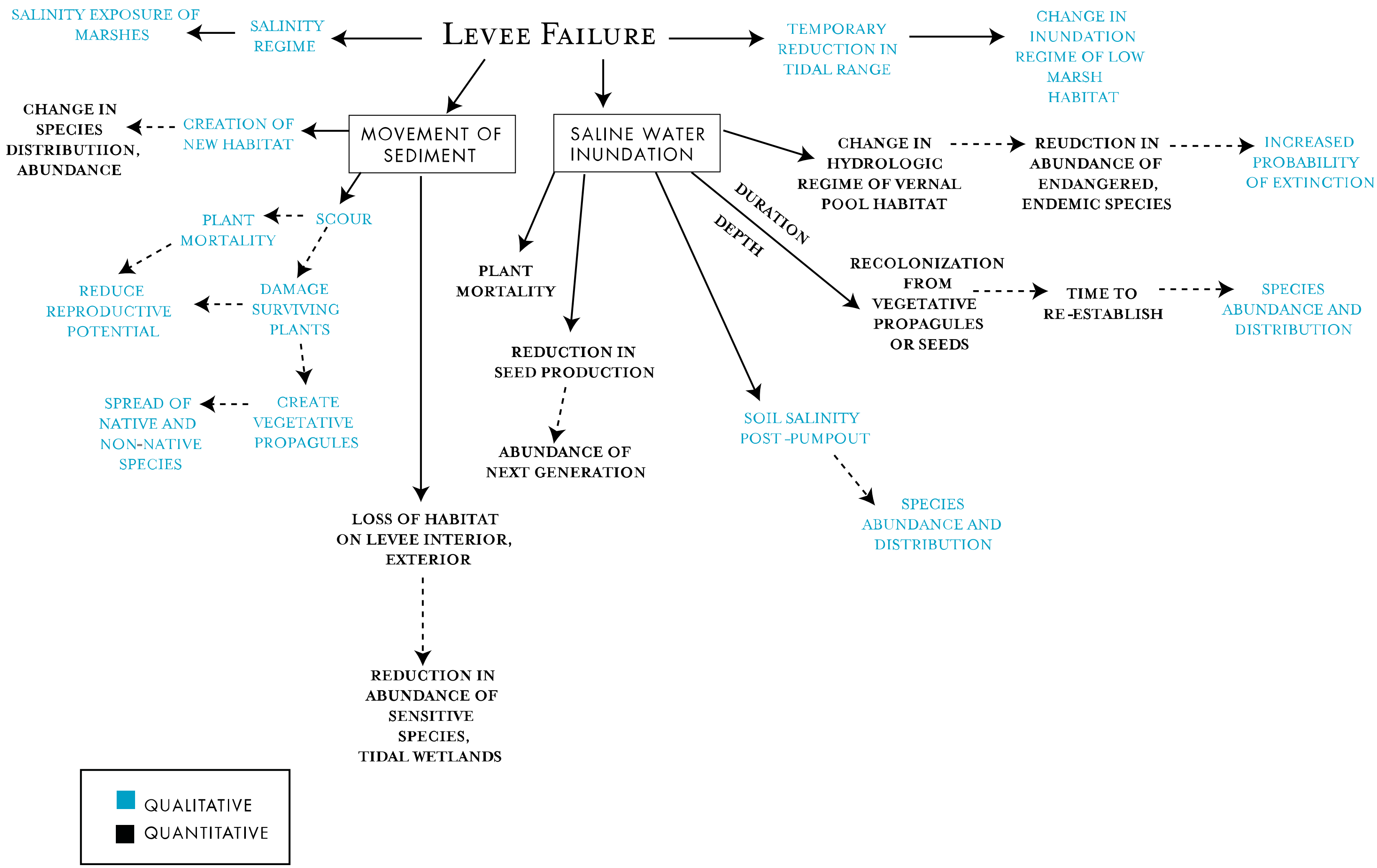
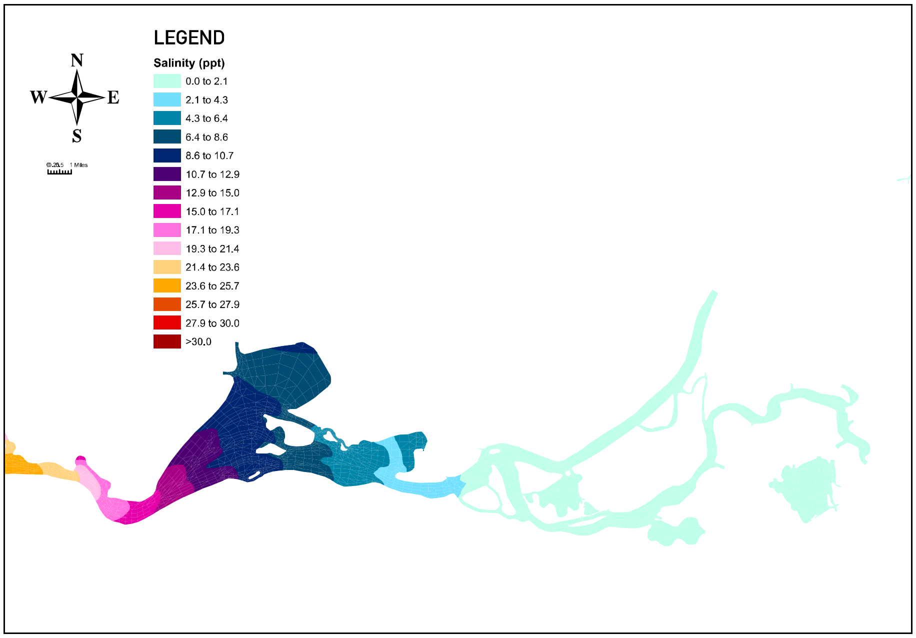
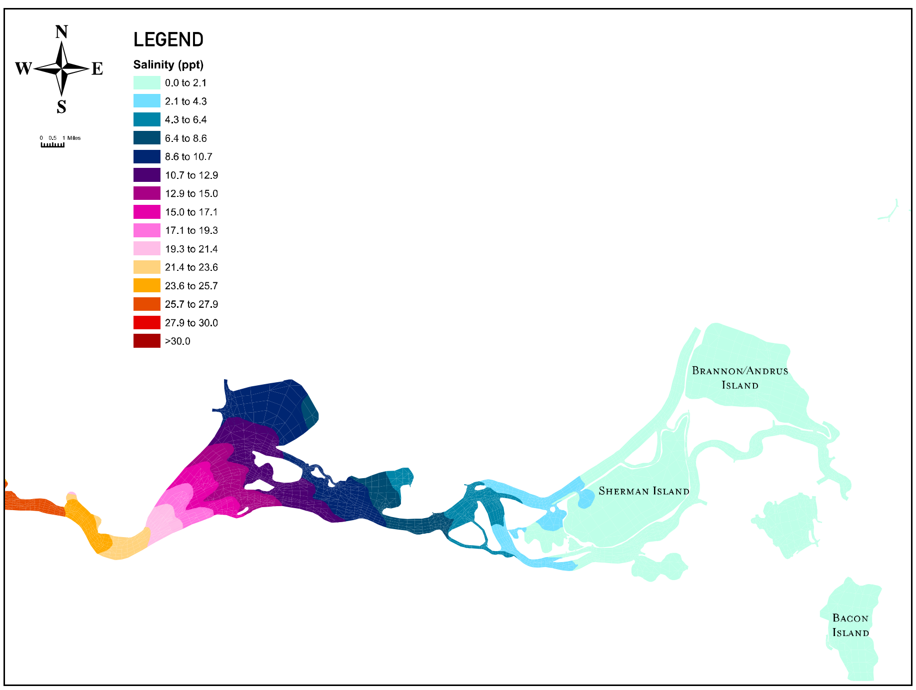


Figure 12–15 Conceptual model of impacts of levee breach on vegetation



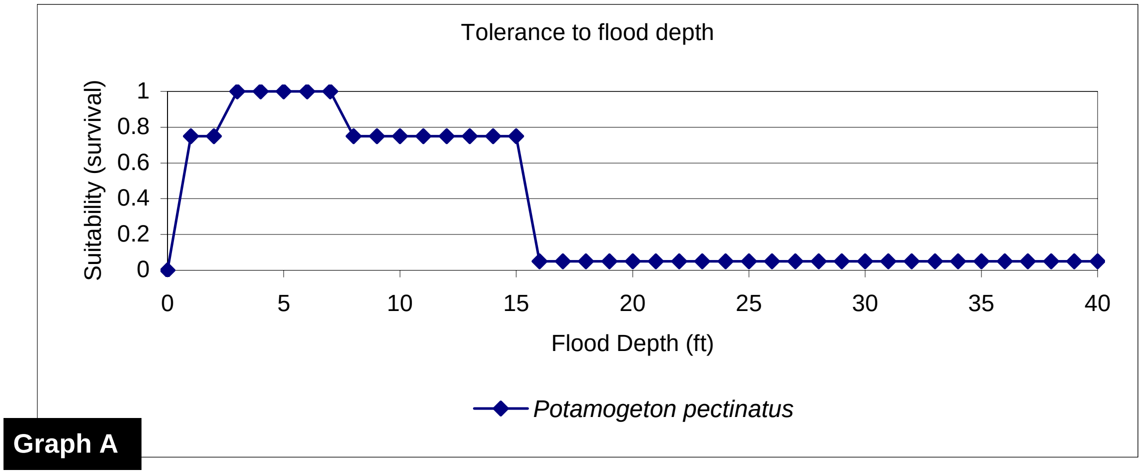
(A)

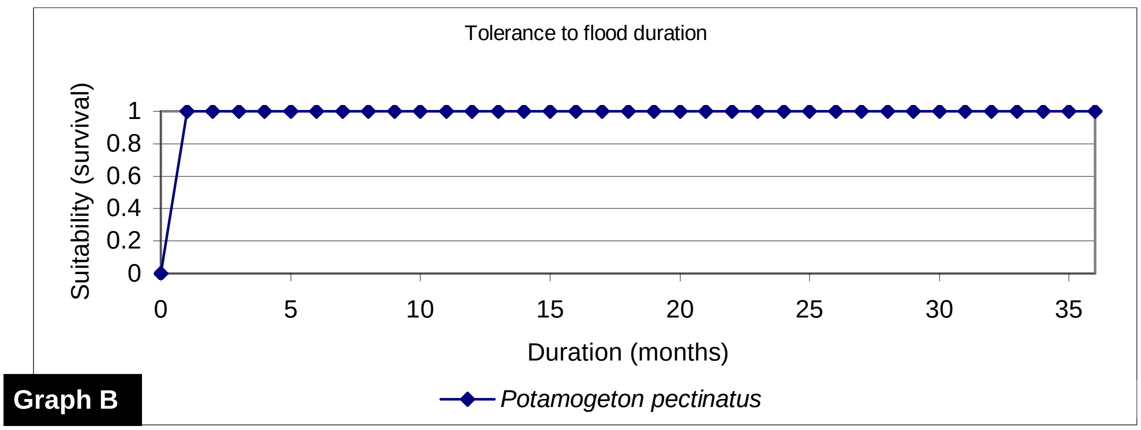


(B)

Figure 12–16 Example of salinity changes after levee-failure

Panel (A) represents baseline salinities on a hypothetical July 2 (based on 1992 hydrology). Panel (B) represents changes in salinity conditions two hours after the failure of three levees in the Delta (RMA 2006).





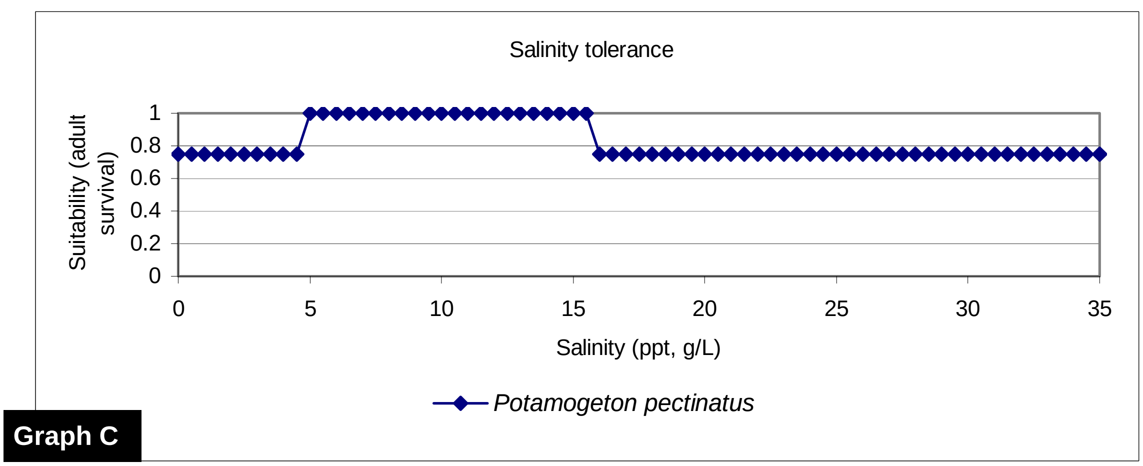
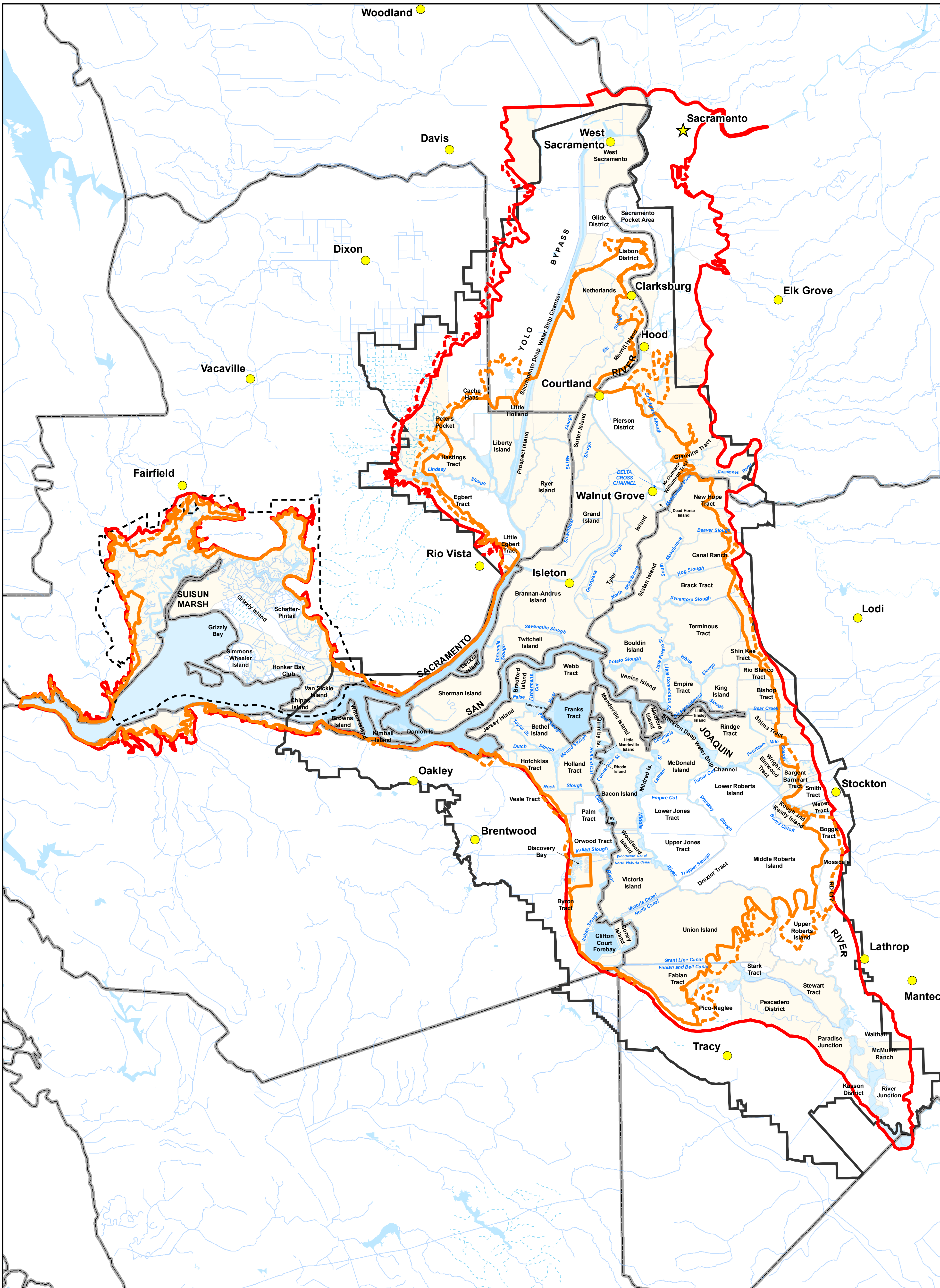


Figure 12–17 Tolerance of focal species (pondweed [*Potamogeton pectinatus*]) to flood depth, flood duration, and salinity



Legend

- MHHW Boundary (Current)
- MHHW (2050)
- 100-Year Floodplain (Current)
- 100-Year Floodplain (2050)
- CA Water
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; Reservoir
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS

DRMS

26815431

MHHW and 100-Year Flood Boundaries

Figure 12-18

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\Floodplains+1 ft and subsided surfaces\4-1 MHHW and 100-year flood boundaries.mxd Date: 2/28/2007 12:49:32 PM Name: dhwright0

Appendix 12-A

Flood Routing Analysis

APPENDIX A

INUNDATION ANALYSIS FOR LEVEE BREACH ON DELTA ISLANDS

A.1 PURPOSE AND SCOPE

The purpose of this study is to determine the depth and velocity of flow on a flooded Delta Island due to failure of a surrounding levee. This information is used in the calculations of probability of fatalities due to levee failure. Two failure modes were analyzed; a sudden failure due to a seismic event and a slower failure due to a flood event.

This report describes the breach modeling and flood wave routing analyses that were completed for preparation of the inundation map. It also describes the assumptions and limitations associated with the mapping results.

A.2 BREACH OUTFLOW HYDROGRAPH

Two methods are commonly used for estimating the outflow hydrograph from failure of an earthfill embankment. In one method, the outflow hydrograph is calculated from an assumed breach size, shape, and development time. The second method uses a physically based model to calculate the outflow hydrograph from embankment characteristics and sediment transport theory.

The first method was used in this study. The results of this analysis are meant to apply generally throughout the Delta and are not meant to represent the failure of a particular levee or island. The parameters that need to be specified include the time of breach formation, the final breach width, the angle or side slope of the breach, and the final breach elevation.

Two failure times were simulated. A 15-minute failure time was used to represent sudden failure due to an earthquake. A two-hour failure time was used to represent a failure due to a flood. For both cases the breach was assumed to be trapezoidal with side slopes of 1:1. The final breach bottom width was 400 feet wide with an invert at -10 feet (the same elevation as was assumed for the invert of the island).

The method used to calculate the outflow hydrograph from the breach is described in the FLDWAV Users Manual (Fread and Lewis, 1998). The major assumption is that flow through the breach can be simulated as broad-crested weir flow.

Data required to calculate the outflow hydrograph are shown in Table A-1.

Table A-1
Data and Values Used to Estimate Breach Parameters

Parameter	Unit	Symbol	Value	Comment
Height of Water over Breach	feet	h_d	20	Initial WSE minus bottom of breach elevation. Bottom of breach was assumed to be at bottom of the island.
Final Breach Width	feet	B_{avg}	400	Typical breach size from historic levee failures
Breach Formation Time	hours	τ	0.25, 2	0.25 hours was used to represent an earthquake, 2 hours was used to represent a flood.

A2.1 Dynamic Flood Routing

The outflow hydrograph from the breach was routed across the island using the FLDWAV model developed by the National Weather Service (NWS) (Fread and Lewis 1998). This model is the successor to the NWS DAMBRK model (NWS, 1988). The FLDWAV model uses an implicit finite-difference numerical scheme to solve the one-dimensional St. Venant equations. Input parameters needed by the FLDWAV model are discussed in the following paragraphs.

Channel Geometry

Two different sized island were analyzed, one 5,000 feet wide and one 10,000 feet wide. Cross-sections representing the island were assumed to be rectangular in shape. Since the flow through the breach can not immediately flow through the entire cross-section of the island (i.e., the breach is 400 feet wide, the island cross-section is 5,000 or 10,000 feet wide) the cross-sections were assumed to grow radially in size. That is, the length of the model cross-section was calculated as:

$$\text{Length} = \pi x \qquad \text{A-1}$$

Where Length is the length of the cross-section and x is the distance the cross-section is from the breach in the direction of flow. The length of the section grew at this rate until it equaled the width of the island (either 5,000 or 10,000 feet) and then remained constant.

Manning's Roughness

Mannings n roughness values were assumed to vary from 0.035 to 0.03 with the smaller values for deep water and the larger for shallow water.

Expansion and Contraction Coefficients

According to the FLDWAV user's manual (Fread and Lewis 1998), expansion coefficients should range from -0.05 to -0.75 and contraction coefficients from 0.10 to 0.40. Expansion coefficients varied from -0.75 at the breach decreasing to 0.00 at 200 feet from the breach. These were picked to help stabilize the model.

Downstream Boundary

Level pool routing was used as the downstream boundary. At the last cross-section in the model a depth-storage relationships was specified to represent the island filling with water as the flood wave reached the opposite end of the island. The results of the model near the breach are not sensitive to the downstream boundary.

Key Assumptions

- Channel geometry is assumed "fixed," meaning that changes in cross section due to erosion are not included in the model.
- Flow can be characterized by one-dimensional solutions to equations of fluid motion.
- Channel losses are negligible.

A.3 RESULTS

The FLDWAV model results are provided in Table A-2. For the loss of life calculations the maximum distances from the breach location were rounded to 1000 feet.

Table A-2 Results of Island Flooding Analysis using FLDWAV Model

Initiating Event	Island Size	Depth x Velocity = 7 m^2/sec Max. Distance from Breach Location (feet)	Depth x Velocity = 7 m^2/sec Time from Breach Initiation to Reach Max. Distance (hours)	Depth x Velocity =3 m^2/sec Max. Distance from Breach Location (feet)	Depth x Velocity =3 m^2/sec Time from Breach Initiation to Reach Max. Distance (hours)
Flood	Large (10,000 feet wide)	900	1.88	1900	2.12
	Small (5,000 feet wide)	1000	3.08	whole island	reaches 2 miles in 3.3 hrs, reaches 1 mile in 2.4 hrs,
Seismic	Large (10,000 feet wide)	890	0.27	1650	0.426
	Small (5,000 feet wide)	970	0.28	whole island	reaches 1 mile in 1.6 hrs, 2 miles in 2.87 hrs

Figures A-1 and A-2 summarize the results for the flood and seismic cases respectively.

The opinions presented in this report were developed with the standard of care commonly used as state-of-the practice in the profession. No other warranties are included, either expressed or implied, in this technical memorandum. URS is not responsible for any other use of the results and analysis presented herein.

Fread, D.L., and J.M. Lewis. 1998. NWS FLDWAV Model: Theoretical Description and User Documentation. Hydrologic Research Laboratory, Office of Hydrology. National Weather Service, National Oceanic and Atmospheric Administration, Silver Spring, MD. November 28.

NWS. 1988. DAMBRK: The NWS Dam Break Flood Forecasting Model. National Weather Service, Office of Hydrology. Davis, CA. September.

Figures

Figure A-1 Depth times Velocity
2 hour breach onto large and small islands
(breach starts at time 0.5 hours, lasts 2 hours and is 400 feet wide at completion large island is 10,000 ft wide, small island is 5,000 ft wide both islands are 3.8 miles long)

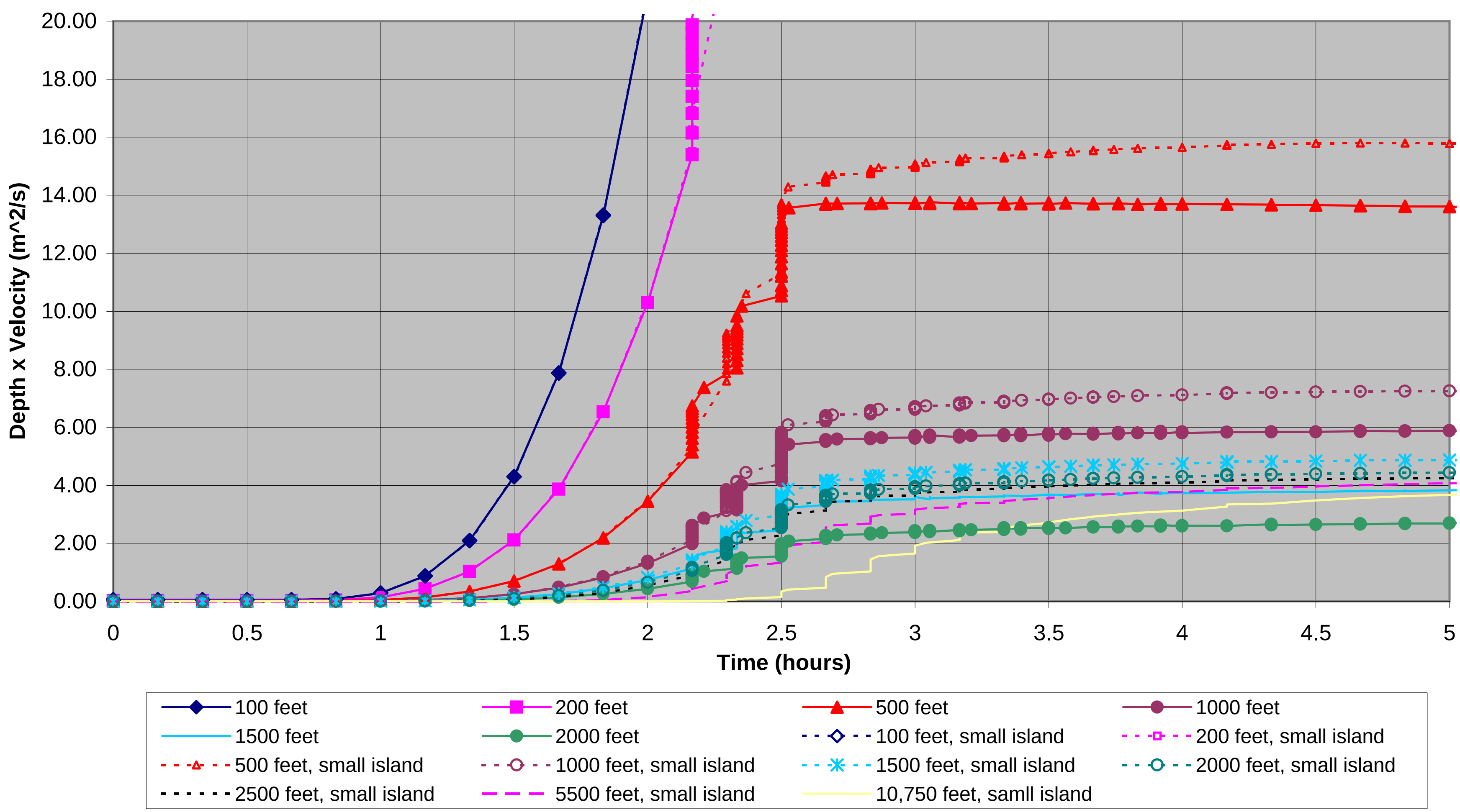
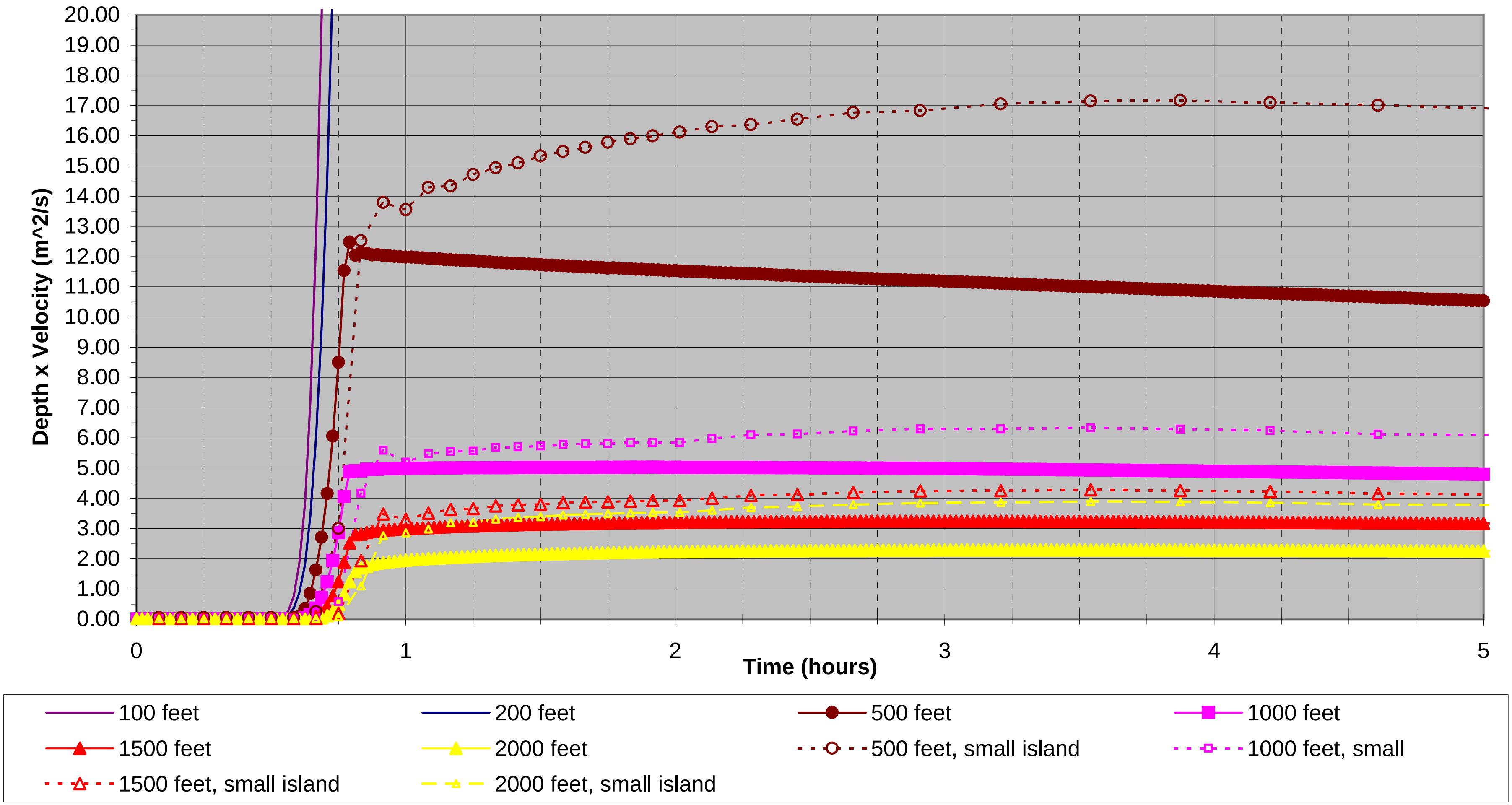


Figure A-2 Depth times Velocity
0.25 hour breach onto large and small islands
(breach starts at 0.5 hours, lasts 0.25 hours and is 400 feet wide at completion
large island is 10,000 ft wide, small island is 5,000 ft wide both islands are 3.8 miles long)



Appendix 12-B

Demographics Data User In Fatality Risk Analysis

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
1	Delta	4	Webb_Tract	Large	1	High	1	2	1	2	0
1	Delta	4	Webb_Tract	Large	2	High	1	2	1	2	0
1	Delta	4	Webb_Tract	Large	3	High	1	2	1	2	0
1	Delta	4	Webb_Tract	Large	4	High	1	1	1	1	0
1	Delta	4	Webb_Tract	Large	5	High	1	1	1	1	0
1	Delta	4	Webb_Tract	Large	6	High	1	2	1	2	0
1	Delta	4	Webb_Tract	Large	7	High	1	1	1	1	0
1	Delta	4	Webb_Tract	Large	8	High	1	2	1	2	0
1	Delta	4	Webb_Tract	Large	1	Medium	3	4	2	3	0
1	Delta	4	Webb_Tract	Large	2	Medium	3	5	2	3	0
1	Delta	4	Webb_Tract	Large	3	Medium	3	4	2	3	0
1	Delta	4	Webb_Tract	Large	4	Medium	3	4	2	3	0
1	Delta	4	Webb_Tract	Large	5	Medium	3	4	2	3	0
1	Delta	4	Webb_Tract	Large	6	Medium	3	4	2	3	0
1	Delta	4	Webb_Tract	Large	7	Medium	3	4	2	3	0
1	Delta	4	Webb_Tract	Large	8	Medium	3	4	2	3	0
2	Delta	5	Empire_Tract	Large	1	High	1	1	1	1	0
2	Delta	5	Empire_Tract	Large	2	High	1	1	1	1	0
2	Delta	5	Empire_Tract	Large	3	High	1	1	1	1	0
2	Delta	5	Empire_Tract	Large	4	High	1	1	1	1	0
2	Delta	5	Empire_Tract	Large	5	High	1	1	1	1	0
2	Delta	5	Empire_Tract	Large	6	High	1	2	1	2	0
2	Delta	5	Empire_Tract	Large	7	High	1	1	1	1	0
2	Delta	5	Empire_Tract	Large	8	High	1	2	1	2	0
2	Delta	5	Empire_Tract	Large	1	Medium	2	3	1	2	0
2	Delta	5	Empire_Tract	Large	2	Medium	2	4	1	2	0
2	Delta	5	Empire_Tract	Large	3	Medium	2	4	1	2	0
2	Delta	5	Empire_Tract	Large	4	Medium	2	4	2	3	0
2	Delta	5	Empire_Tract	Large	5	Medium	2	4	1	2	0
2	Delta	5	Empire_Tract	Large	6	Medium	3	4	2	3	0
2	Delta	5	Empire_Tract	Large	7	Medium	2	4	1	2	0
2	Delta	5	Empire_Tract	Large	8	Medium	3	4	2	3	0
3	Delta	6	Bradford_Island	Large	1	High	1	1	1	1	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
3	Delta	6	Bradford_Island	Large	2	High	1	2	1	2	0
3	Delta	6	Bradford_Island	Large	3	High	1	1	1	1	0
3	Delta	6	Bradford_Island	Large	4	High	1	1	1	1	0
3	Delta	6	Bradford_Island	Large	5	High	1	1	1	1	0
3	Delta	6	Bradford_Island	Large	6	High	1	1	1	1	0
3	Delta	6	Bradford_Island	Large	7	High	1	1	1	1	0
3	Delta	6	Bradford_Island	Large	8	High	1	2	1	2	0
3	Delta	6	Bradford_Island	Large	1	Medium	2	3	1	2	0
3	Delta	6	Bradford_Island	Large	2	Medium	2	3	2	2	0
3	Delta	6	Bradford_Island	Large	3	Medium	3	4	2	2	0
3	Delta	6	Bradford_Island	Large	4	Medium	3	4	2	2	0
3	Delta	6	Bradford_Island	Large	5	Medium	3	4	2	2	0
3	Delta	6	Bradford_Island	Large	6	Medium	2	4	2	2	0
3	Delta	6	Bradford_Island	Large	7	Medium	3	4	2	3	0
3	Delta	6	Bradford_Island	Large	8	Medium	2	4	2	2	0
4	Delta	7	King_Island	Large	1	High	1	2	1	2	0
4	Delta	7	King_Island	Large	2	High	1	1	1	1	0
4	Delta	7	King_Island	Large	3	High	1	1	1	1	0
4	Delta	7	King_Island	Large	4	High	1	1	1	1	0
4	Delta	7	King_Island	Large	5	High	1	1	1	1	0
4	Delta	7	King_Island	Large	6	High	1	1	1	1	0
4	Delta	7	King_Island	Large	7	High	1	1	1	1	0
4	Delta	7	King_Island	Large	8	High	1	1	1	1	0
4	Delta	7	King_Island	Large	1	Medium	2	4	2	3	0
4	Delta	7	King_Island	Large	2	Medium	2	3	1	2	0
4	Delta	7	King_Island	Large	3	Medium	2	4	2	2	0
4	Delta	7	King_Island	Large	4	Medium	2	4	2	3	0
4	Delta	7	King_Island	Large	5	Medium	2	4	1	2	0
4	Delta	7	King_Island	Large	6	Medium	3	5	2	3	0
4	Delta	7	King_Island	Large	7	Medium	2	4	2	2	0
4	Delta	7	King_Island	Large	8	Medium	2	4	1	2	0
5	Delta	9	Jersey_Island	Large	1	High	1	1	1	1	0
5	Delta	9	Jersey_Island	Large	2	High	1	2	1	2	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
5	Delta	9	Jersey_Island	Large	3	High	1	1	1	1	0
5	Delta	9	Jersey_Island	Large	4	High	1	1	1	1	0
5	Delta	9	Jersey_Island	Large	5	High	1	2	1	2	0
5	Delta	9	Jersey_Island	Large	6	High	1	1	1	1	0
5	Delta	9	Jersey_Island	Large	7	High	1	1	1	1	0
5	Delta	9	Jersey_Island	Large	8	High	1	2	1	2	0
5	Delta	9	Jersey_Island	Large	1	Medium	2	3	2	2	0
5	Delta	9	Jersey_Island	Large	2	Medium	2	4	2	2	0
5	Delta	9	Jersey_Island	Large	3	Medium	3	4	1	2	0
5	Delta	9	Jersey_Island	Large	4	Medium	3	4	2	2	0
5	Delta	9	Jersey_Island	Large	5	Medium	3	5	2	3	0
5	Delta	9	Jersey_Island	Large	6	Medium	3	4	2	3	0
5	Delta	9	Jersey_Island	Large	7	Medium	3	4	2	3	0
5	Delta	9	Jersey_Island	Large	8	Medium	3	4	2	3	0
6	Delta	10	Bethel_Island	Large	1	High	11	16	11	16	0
6	Delta	10	Bethel_Island	Large	2	High	22	32	22	32	0
6	Delta	10	Bethel_Island	Large	3	High	19	27	19	27	0
6	Delta	10	Bethel_Island	Large	4	High	14	20	14	20	0
6	Delta	10	Bethel_Island	Large	5	High	11	17	11	17	0
6	Delta	10	Bethel_Island	Large	6	High	10	15	10	15	0
6	Delta	10	Bethel_Island	Large	7	High	13	19	13	19	0
6	Delta	10	Bethel_Island	Large	8	High	13	19	13	19	0
6	Delta	10	Bethel_Island	Large	1	Medium	37	54	25	36	0
6	Delta	10	Bethel_Island	Large	2	Medium	63	90	42	60	0
6	Delta	10	Bethel_Island	Large	3	Medium	57	81	37	54	0
6	Delta	10	Bethel_Island	Large	4	Medium	35	51	23	34	0
6	Delta	10	Bethel_Island	Large	5	Medium	29	43	19	29	0
6	Delta	10	Bethel_Island	Large	6	Medium	25	36	16	24	0
6	Delta	10	Bethel_Island	Large	7	Medium	29	43	20	30	0
6	Delta	10	Bethel_Island	Large	8	Medium	34	51	23	35	0
7	Delta	11	Quimby_Island	Large	1	High	1	2	1	2	0
7	Delta	11	Quimby_Island	Large	2	High	1	1	1	1	0
7	Delta	11	Quimby_Island	Large	3	High	1	1	1	1	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
7	Delta	11	Quimby_Island	Large	4	High	1	1	1	1	0
7	Delta	11	Quimby_Island	Large	5	High	1	2	1	2	0
7	Delta	11	Quimby_Island	Large	6	High	1	1	1	1	0
7	Delta	11	Quimby_Island	Large	7	High	1	1	1	1	0
7	Delta	11	Quimby_Island	Large	8	High	1	1	1	1	0
7	Delta	11	Quimby_Island	Large	1	Medium	3	3	2	2	0
7	Delta	11	Quimby_Island	Large	2	Medium	2	3	1	2	0
7	Delta	11	Quimby_Island	Large	3	Medium	3	4	2	3	0
7	Delta	11	Quimby_Island	Large	4	Medium	2	3	2	2	0
7	Delta	11	Quimby_Island	Large	5	Medium	3	4	2	3	0
7	Delta	11	Quimby_Island	Large	6	Medium	3	4	2	2	0
7	Delta	11	Quimby_Island	Large	7	Medium	2	4	2	2	0
7	Delta	11	Quimby_Island	Large	8	Medium	2	3	1	2	0
8	Delta	12	McDonald_Tract	Large	1	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	2	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	3	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	4	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	5	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	6	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	7	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	8	High	1	1	1	1	0
8	Delta	12	McDonald_Tract	Large	1	Medium	3	2	2	1	0
8	Delta	12	McDonald_Tract	Large	2	Medium	3	2	2	1	0
8	Delta	12	McDonald_Tract	Large	3	Medium	2	1	1	1	0
8	Delta	12	McDonald_Tract	Large	4	Medium	2	1	1	1	0
8	Delta	12	McDonald_Tract	Large	5	Medium	2	2	2	1	0
8	Delta	12	McDonald_Tract	Large	6	Medium	3	2	2	1	0
8	Delta	12	McDonald_Tract	Large	7	Medium	2	2	1	1	0
8	Delta	12	McDonald_Tract	Large	8	Medium	2	2	2	1	0
9	Delta	13	Holland_Tract	Large	1	High	1	1	1	1	0
9	Delta	13	Holland_Tract	Large	2	High	1	1	1	1	0
9	Delta	13	Holland_Tract	Large	3	High	1	1	1	1	0
9	Delta	13	Holland_Tract	Large	4	High	1	2	1	2	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
9	Delta	13	Holland_Tract	Large	5	High	1	2	1	2	0
9	Delta	13	Holland_Tract	Large	6	High	1	2	1	2	0
9	Delta	13	Holland_Tract	Large	7	High	1	2	1	2	0
9	Delta	13	Holland_Tract	Large	8	High	1	1	1	1	0
9	Delta	13	Holland_Tract	Large	1	Medium	2	4	2	2	0
9	Delta	13	Holland_Tract	Large	2	Medium	3	4	2	2	0
9	Delta	13	Holland_Tract	Large	3	Medium	3	4	2	2	0
9	Delta	13	Holland_Tract	Large	4	Medium	3	4	2	3	0
9	Delta	13	Holland_Tract	Large	5	Medium	3	4	2	3	0
9	Delta	13	Holland_Tract	Large	6	Medium	3	4	2	3	0
9	Delta	13	Holland_Tract	Large	7	Medium	3	4	2	3	0
9	Delta	13	Holland_Tract	Large	8	Medium	3	4	2	2	0
10	Delta	14	Zone 14	Small	1	High	4	6	4	6	0
10	Delta	14	Zone 14	Small	2	High	5	6	5	6	0
10	Delta	14	Zone 14	Small	3	High	4	5	4	5	0
10	Delta	14	Zone 14	Small	4	High	3	5	3	5	0
10	Delta	14	Zone 14	Small	5	High	0	0	0	0	0
10	Delta	14	Zone 14	Small	6	High	0	0	0	0	0
10	Delta	14	Zone 14	Small	7	High	4	5	0	0	0
10	Delta	14	Zone 14	Small	8	High	4	5	4	5	0
10	Delta	14	Zone 14	Small	1	Medium	29	37	29	37	0
10	Delta	14	Zone 14	Small	2	Medium	29	37	29	37	0
10	Delta	14	Zone 14	Small	3	Medium	29	38	29	38	0
10	Delta	14	Zone 14	Small	4	Medium	30	39	30	39	0
10	Delta	14	Zone 14	Small	5	Medium	0	0	0	0	0
10	Delta	14	Zone 14	Small	6	Medium	0	0	0	0	0
10	Delta	14	Zone 14	Small	7	Medium	29	38	0	0	0
10	Delta	14	Zone 14	Small	8	Medium	29	38	29	38	0
11	Delta	15	Bacon_Island	Large	1	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	2	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	3	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	4	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	5	High	1	1	1	1	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
11	Delta	15	Bacon_Island	Large	6	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	7	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	8	High	1	1	1	1	0
11	Delta	15	Bacon_Island	Large	1	Medium	2	2	2	1	0
11	Delta	15	Bacon_Island	Large	2	Medium	2	2	2	1	0
11	Delta	15	Bacon_Island	Large	3	Medium	2	1	1	1	0
11	Delta	15	Bacon_Island	Large	4	Medium	2	2	1	1	0
11	Delta	15	Bacon_Island	Large	5	Medium	3	2	2	1	0
11	Delta	15	Bacon_Island	Large	6	Medium	2	2	2	1	0
11	Delta	15	Bacon_Island	Large	7	Medium	2	2	1	1	0
11	Delta	15	Bacon_Island	Large	8	Medium	2	1	1	1	0
12	Delta	16	Palm_Tract	Large	1	High	2	2	2	2	0
12	Delta	16	Palm_Tract	Large	2	High	3	2	3	2	0
12	Delta	16	Palm_Tract	Large	3	High	2	2	2	2	0
12	Delta	16	Palm_Tract	Large	4	High	3	3	3	3	0
12	Delta	16	Palm_Tract	Large	5	High	2	2	2	2	0
12	Delta	16	Palm_Tract	Large	6	High	2	2	2	2	0
12	Delta	16	Palm_Tract	Large	7	High	2	2	2	2	0
12	Delta	16	Palm_Tract	Large	8	High	2	2	2	2	0
12	Delta	16	Palm_Tract	Large	1	Medium	7	6	4	4	0
12	Delta	16	Palm_Tract	Large	2	Medium	7	6	5	4	0
12	Delta	16	Palm_Tract	Large	3	Medium	5	4	3	3	0
12	Delta	16	Palm_Tract	Large	4	Medium	8	7	6	5	0
12	Delta	16	Palm_Tract	Large	5	Medium	6	6	4	4	0
12	Delta	16	Palm_Tract	Large	6	Medium	6	6	4	4	0
12	Delta	16	Palm_Tract	Large	7	Medium	6	5	4	3	0
12	Delta	16	Palm_Tract	Large	8	Medium	6	6	4	4	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	1	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	2	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	3	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	4	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	5	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	6	High	1	1	1	1	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	7	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	8	High	1	1	1	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	1	Medium	2	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	2	Medium	2	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	3	Medium	3	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	4	Medium	2	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	5	Medium	3	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	6	Medium	3	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	7	Medium	3	2	2	1	0
13	Delta	17	Jones_Tract-Upper_and_Lower	Large	8	Medium	3	2	2	1	0
14	Delta	19	Woodward_Island	Large	1	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	2	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	3	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	4	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	5	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	6	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	7	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	8	High	1	1	1	1	0
14	Delta	19	Woodward_Island	Large	1	Medium	2	2	2	1	0
14	Delta	19	Woodward_Island	Large	2	Medium	2	1	1	1	0
14	Delta	19	Woodward_Island	Large	3	Medium	2	2	2	1	0
14	Delta	19	Woodward_Island	Large	4	Medium	2	2	2	1	0
14	Delta	19	Woodward_Island	Large	5	Medium	2	2	2	1	0
14	Delta	19	Woodward_Island	Large	6	Medium	3	2	2	1	0
14	Delta	19	Woodward_Island	Large	7	Medium	2	1	1	1	0
14	Delta	19	Woodward_Island	Large	8	Medium	3	2	2	1	0
15	Delta	20	Orwood_Tract	Large	1	High	2	2	2	2	0
15	Delta	20	Orwood_Tract	Large	2	High	3	2	3	2	0
15	Delta	20	Orwood_Tract	Large	3	High	2	2	2	2	0
15	Delta	20	Orwood_Tract	Large	4	High	2	2	2	2	0
15	Delta	20	Orwood_Tract	Large	5	High	2	2	2	2	0
15	Delta	20	Orwood_Tract	Large	6	High	2	2	2	2	0
15	Delta	20	Orwood_Tract	Large	7	High	2	2	2	2	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
15	Delta	20	Orwood_Tract	Large	8	High	2	2	2	2	0
15	Delta	20	Orwood_Tract	Large	1	Medium	6	6	4	4	0
15	Delta	20	Orwood_Tract	Large	2	Medium	7	6	5	4	0
15	Delta	20	Orwood_Tract	Large	3	Medium	7	6	4	4	0
15	Delta	20	Orwood_Tract	Large	4	Medium	3	3	2	2	0
15	Delta	20	Orwood_Tract	Large	5	Medium	3	3	2	2	0
15	Delta	20	Orwood_Tract	Large	6	Medium	3	3	2	2	0
15	Delta	20	Orwood_Tract	Large	7	Medium	6	6	4	4	0
15	Delta	20	Orwood_Tract	Large	8	Medium	6	6	4	4	0
16	Delta	21	Victoria_Island	Large	1	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	2	High	1	0	1	0	0
16	Delta	21	Victoria_Island	Large	3	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	4	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	5	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	6	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	7	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	8	High	1	1	1	1	0
16	Delta	21	Victoria_Island	Large	1	Medium	2	2	2	1	0
16	Delta	21	Victoria_Island	Large	2	Medium	2	1	1	1	0
16	Delta	21	Victoria_Island	Large	3	Medium	2	2	2	1	0
16	Delta	21	Victoria_Island	Large	4	Medium	2	2	2	1	0
16	Delta	21	Victoria_Island	Large	5	Medium	2	2	2	1	0
16	Delta	21	Victoria_Island	Large	6	Medium	3	2	2	1	0
16	Delta	21	Victoria_Island	Large	7	Medium	2	1	1	1	0
16	Delta	21	Victoria_Island	Large	8	Medium	3	2	2	1	0
17	Delta	32	Coney_Island	Large	1	High	2	2	2	2	0
17	Delta	32	Coney_Island	Large	2	High	2	2	2	2	0
17	Delta	32	Coney_Island	Large	3	High	2	1	2	1	0
17	Delta	32	Coney_Island	Large	4	High	1	1	1	1	0
17	Delta	32	Coney_Island	Large	5	High	1	1	1	1	0
17	Delta	32	Coney_Island	Large	6	High	2	2	2	2	0
17	Delta	32	Coney_Island	Large	7	High	2	2	2	2	0
17	Delta	32	Coney_Island	Large	8	High	3	2	3	2	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
17	Delta	32	Coney_Island	Large	1	Medium	5	5	4	3	0
17	Delta	32	Coney_Island	Large	2	Medium	6	5	4	3	0
17	Delta	32	Coney_Island	Large	3	Medium	4	4	3	3	0
17	Delta	32	Coney_Island	Large	4	Medium	4	4	3	2	0
17	Delta	32	Coney_Island	Large	5	Medium	5	4	3	3	0
17	Delta	32	Coney_Island	Large	6	Medium	6	6	4	4	0
17	Delta	32	Coney_Island	Large	7	Medium	6	6	4	4	0
17	Delta	32	Coney_Island	Large	8	Medium	6	5	4	4	0
18	Delta	62	Walnut_Grove	Small	1	High	11	12	11	12	0
18	Delta	62	Walnut_Grove	Small	2	High	10	11	10	11	0
18	Delta	62	Walnut_Grove	Small	3	High	11	11	11	11	0
18	Delta	62	Walnut_Grove	Small	4	High	10	11	10	11	0
18	Delta	62	Walnut_Grove	Small	5	High	10	11	10	11	0
18	Delta	62	Walnut_Grove	Small	6	High	12	12	12	12	0
18	Delta	62	Walnut_Grove	Small	7	High	10	10	10	10	0
18	Delta	62	Walnut_Grove	Small	8	High	11	11	11	11	0
18	Delta	62	Walnut_Grove	Small	1	Medium	128	135	128	135	0
18	Delta	62	Walnut_Grove	Small	2	Medium	129	136	129	136	0
18	Delta	62	Walnut_Grove	Small	3	Medium	128	135	128	135	0
18	Delta	62	Walnut_Grove	Small	4	Medium	129	135	129	135	0
18	Delta	62	Walnut_Grove	Small	5	Medium	129	135	129	135	0
18	Delta	62	Walnut_Grove	Small	6	Medium	127	134	127	134	0
18	Delta	62	Walnut_Grove	Small	7	Medium	129	136	129	136	0
18	Delta	62	Walnut_Grove	Small	8	Medium	128	135	128	135	0
19	Delta	63	Tyler_Island 2	Large	1	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	2	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	3	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	4	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	5	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	6	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	7	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	8	High	1	1	1	1	0
19	Delta	63	Tyler_Island 2	Large	1	Medium	4	3	2	2	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
19	Delta	63	Tyler_Island 2	Large	2	Medium	4	3	2	2	0
19	Delta	63	Tyler_Island 2	Large	3	Medium	3	3	2	2	0
19	Delta	63	Tyler_Island 2	Large	4	Medium	3	3	2	2	0
19	Delta	63	Tyler_Island 2	Large	5	Medium	3	2	2	2	0
19	Delta	63	Tyler_Island 2	Large	6	Medium	5	5	3	3	0
19	Delta	63	Tyler_Island 2	Large	7	Medium	3	3	2	2	0
19	Delta	63	Tyler_Island 2	Large	8	Medium	3	3	2	2	0
20	Delta	68	Little_Egbert_Tract	Large	1	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	2	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	3	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	4	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	5	High	0	0	0	0	0
20	Delta	68	Little_Egbert_Tract	Large	6	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	7	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	8	High	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	1	Medium	2	2	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	2	Medium	2	2	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	3	Medium	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	4	Medium	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	5	Medium	1	1	0	0	0
20	Delta	68	Little_Egbert_Tract	Large	6	Medium	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	7	Medium	1	1	1	1	0
20	Delta	68	Little_Egbert_Tract	Large	8	Medium	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	1	High	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	2	High	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	3	High	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	4	High	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	5	High	0	0	0	0	0
21	Delta	70	Egbert_Tract	Large	6	High	0	0	0	0	0
21	Delta	70	Egbert_Tract	Large	7	High	0	0	0	0	0
21	Delta	70	Egbert_Tract	Large	8	High	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	1	Medium	2	2	1	1	0
21	Delta	70	Egbert_Tract	Large	2	Medium	2	2	1	1	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
21	Delta	70	Egbert_Tract	Large	3	Medium	2	2	1	1	0
21	Delta	70	Egbert_Tract	Large	4	Medium	1	1	1	1	0
21	Delta	70	Egbert_Tract	Large	5	Medium	0	0	0	0	0
21	Delta	70	Egbert_Tract	Large	6	Medium	0	0	0	0	0
21	Delta	70	Egbert_Tract	Large	7	Medium	0	0	0	0	0
21	Delta	70	Egbert_Tract	Large	8	Medium	1	1	1	1	0
22	Delta	72	Peter Pocket	Large	1	High	1	1	0	0	0
22	Delta	72	Peter Pocket	Large	2	High	1	1	0	0	0
22	Delta	72	Peter Pocket	Large	3	High	1	1	1	1	0
22	Delta	72	Peter Pocket	Large	4	High	1	1	1	1	0
22	Delta	72	Peter Pocket	Large	5	High	1	1	1	1	0
22	Delta	72	Peter Pocket	Large	6	High	1	1	0	0	0
22	Delta	72	Peter Pocket	Large	7	High	1	1	0	0	0
22	Delta	72	Peter Pocket	Large	8	High	1	1	0	0	0
22	Delta	72	Peter Pocket	Large	1	Medium	3	3	0	0	0
22	Delta	72	Peter Pocket	Large	2	Medium	2	2	0	0	0
22	Delta	72	Peter Pocket	Large	3	Medium	2	2	2	2	0
22	Delta	72	Peter Pocket	Large	4	Medium	3	3	2	2	0
22	Delta	72	Peter Pocket	Large	5	Medium	2	2	2	2	0
22	Delta	72	Peter Pocket	Large	6	Medium	2	2	0	0	0
22	Delta	72	Peter Pocket	Large	7	Medium	2	2	0	0	0
22	Delta	72	Peter Pocket	Large	8	Medium	2	2	0	0	0
23	Delta	81	Zone 81	Large	1	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	2	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	3	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	4	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	5	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	6	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	7	High	1	1	0	0	0
23	Delta	81	Zone 81	Large	8	High	0	0	0	0	0
23	Delta	81	Zone 81	Large	1	Medium	2	2	0	0	0
23	Delta	81	Zone 81	Large	2	Medium	1	1	0	0	0
23	Delta	81	Zone 81	Large	3	Medium	1	1	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
23	Delta	81	Zone 81	Large	4	Medium	2	2	0	0	0
23	Delta	81	Zone 81	Large	5	Medium	1	1	0	0	0
23	Delta	81	Zone 81	Large	6	Medium	1	1	0	0	0
23	Delta	81	Zone 81	Large	7	Medium	2	2	0	0	0
23	Delta	81	Zone 81	Large	8	Medium	0	0	0	0	0
24	Delta	83	Hastings_Tract 2	Large	1	High	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	2	High	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	3	High	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	4	High	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	5	High	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	6	High	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	7	High	1	1	0	0	0
24	Delta	83	Hastings_Tract 2	Large	8	High	1	1	0	0	0
24	Delta	83	Hastings_Tract 2	Large	1	Medium	2	2	1	1	0
24	Delta	83	Hastings_Tract 2	Large	2	Medium	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	3	Medium	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	4	Medium	2	2	1	1	0
24	Delta	83	Hastings_Tract 2	Large	5	Medium	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	6	Medium	1	1	1	1	0
24	Delta	83	Hastings_Tract 2	Large	7	Medium	1	1	0	0	0
24	Delta	83	Hastings_Tract 2	Large	8	Medium	1	1	0	0	0
25	Delta	86	Terminous_Tract 1	Large	1	High	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	2	High	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	3	High	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	4	High	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	5	High	1	1	1	1	0
25	Delta	86	Terminous_Tract 1	Large	6	High	1	1	1	1	0
25	Delta	86	Terminous_Tract 1	Large	7	High	1	1	1	1	0
25	Delta	86	Terminous_Tract 1	Large	8	High	1	1	1	1	0
25	Delta	86	Terminous_Tract 1	Large	1	Medium	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	2	Medium	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	3	Medium	0	0	0	0	0
25	Delta	86	Terminous_Tract 1	Large	4	Medium	0	0	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
25	Delta	86	Terminous_Tract 1	Large	5	Medium	2	4	2	2	0
25	Delta	86	Terminous_Tract 1	Large	6	Medium	2	4	2	3	0
25	Delta	86	Terminous_Tract 1	Large	7	Medium	2	4	2	3	0
25	Delta	86	Terminous_Tract 1	Large	8	Medium	2	4	2	3	0
26	Delta	87	Terminous_Tract 2	Large	1	High	1	1	1	1	0
26	Delta	87	Terminous_Tract 2	Large	2	High	1	1	1	1	0
26	Delta	87	Terminous_Tract 2	Large	3	High	1	1	1	1	0
26	Delta	87	Terminous_Tract 2	Large	4	High	1	2	1	2	0
26	Delta	87	Terminous_Tract 2	Large	5	High	1	2	1	2	0
26	Delta	87	Terminous_Tract 2	Large	6	High	1	2	1	2	0
26	Delta	87	Terminous_Tract 2	Large	7	High	1	2	1	2	0
26	Delta	87	Terminous_Tract 2	Large	8	High	1	2	1	2	0
26	Delta	87	Terminous_Tract 2	Large	1	Medium	2	4	1	2	0
26	Delta	87	Terminous_Tract 2	Large	2	Medium	2	4	2	3	0
26	Delta	87	Terminous_Tract 2	Large	3	Medium	2	4	2	2	0
26	Delta	87	Terminous_Tract 2	Large	4	Medium	3	4	2	3	0
26	Delta	87	Terminous_Tract 2	Large	5	Medium	3	5	2	3	0
26	Delta	87	Terminous_Tract 2	Large	6	Medium	3	5	2	4	0
26	Delta	87	Terminous_Tract 2	Large	7	Medium	3	4	2	3	0
26	Delta	87	Terminous_Tract 2	Large	8	Medium	3	4	2	3	0
27	Delta	88	Cache_Haas_Tract 1	Large	1	High	0	0	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	2	High	1	1	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	3	High	1	1	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	4	High	1	1	1	1	0
27	Delta	88	Cache_Haas_Tract 1	Large	5	High	1	1	1	1	0
27	Delta	88	Cache_Haas_Tract 1	Large	6	High	1	1	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	7	High	1	1	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	8	High	0	0	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	1	Medium	0	0	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	2	Medium	2	2	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	3	Medium	2	2	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	4	Medium	2	3	2	2	0
27	Delta	88	Cache_Haas_Tract 1	Large	5	Medium	2	3	2	2	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
27	Delta	88	Cache_Haas_Tract 1	Large	6	Medium	2	3	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	7	Medium	2	2	0	0	0
27	Delta	88	Cache_Haas_Tract 1	Large	8	Medium	2	2	0	0	0
28	Delta	89	Cache_Haas_Tract 2	Large	1	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	2	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	3	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	4	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	5	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	6	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	7	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	8	High	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	1	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	2	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	3	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	4	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	5	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	6	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	7	Medium	1	1	1	1	0
28	Delta	89	Cache_Haas_Tract 2	Large	8	Medium	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	1	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	2	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	3	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	4	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	5	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	6	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	7	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	8	High	1	1	1	1	0
29	Delta	106	Lower_Roberts_Island	Small	1	Medium	4	3	4	3	0
29	Delta	106	Lower_Roberts_Island	Small	2	Medium	4	3	4	3	0
29	Delta	106	Lower_Roberts_Island	Small	3	Medium	4	3	4	3	0
29	Delta	106	Lower_Roberts_Island	Small	4	Medium	4	3	4	3	0
29	Delta	106	Lower_Roberts_Island	Small	5	Medium	4	3	4	3	0
29	Delta	106	Lower_Roberts_Island	Small	6	Medium	4	3	4	3	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
29	Delta	106	Lower_Roberts_Island	Small	7	Medium	4	3	4	3	0
29	Delta	106	Lower_Roberts_Island	Small	8	Medium	4	3	4	3	0
30	Delta	108	Hotchkiss_Tract 1	Large	1	High	1	1	1	1	0
30	Delta	108	Hotchkiss_Tract 1	Large	2	High	1	1	1	1	0
30	Delta	108	Hotchkiss_Tract 1	Large	3	High	1	1	1	1	0
30	Delta	108	Hotchkiss_Tract 1	Large	4	High	1	1	1	1	0
30	Delta	108	Hotchkiss_Tract 1	Large	5	High	1	1	0	0	0
30	Delta	108	Hotchkiss_Tract 1	Large	6	High	0	0	0	0	0
30	Delta	108	Hotchkiss_Tract 1	Large	7	High	0	0	0	0	0
30	Delta	108	Hotchkiss_Tract 1	Large	8	High	4	6	4	6	0
30	Delta	108	Hotchkiss_Tract 1	Large	1	Medium	2	4	2	2	0
30	Delta	108	Hotchkiss_Tract 1	Large	2	Medium	2	3	1	2	0
30	Delta	108	Hotchkiss_Tract 1	Large	3	Medium	2	3	2	2	0
30	Delta	108	Hotchkiss_Tract 1	Large	4	Medium	3	4	2	2	0
30	Delta	108	Hotchkiss_Tract 1	Large	5	Medium	2	3	0	0	0
30	Delta	108	Hotchkiss_Tract 1	Large	6	Medium	0	0	0	0	0
30	Delta	108	Hotchkiss_Tract 1	Large	7	Medium	0	0	0	0	0
30	Delta	108	Hotchkiss_Tract 1	Large	8	Medium	10	13	7	9	0
31	Delta	109	Hotchkiss_Tract 2	Small	1	High	4	5	4	5	0
31	Delta	109	Hotchkiss_Tract 2	Small	2	High	4	5	4	5	0
31	Delta	109	Hotchkiss_Tract 2	Small	3	High	5	6	5	6	0
31	Delta	109	Hotchkiss_Tract 2	Small	4	High	4	5	4	5	0
31	Delta	109	Hotchkiss_Tract 2	Small	5	High	0	0	0	0	0
31	Delta	109	Hotchkiss_Tract 2	Small	6	High	4	5	4	5	0
31	Delta	109	Hotchkiss_Tract 2	Small	7	High	5	6	5	6	0
31	Delta	109	Hotchkiss_Tract 2	Small	8	High	5	6	5	6	0
31	Delta	109	Hotchkiss_Tract 2	Small	1	Medium	26	34	26	34	0
31	Delta	109	Hotchkiss_Tract 2	Small	2	Medium	26	34	26	34	0
31	Delta	109	Hotchkiss_Tract 2	Small	3	Medium	25	33	25	33	0
31	Delta	109	Hotchkiss_Tract 2	Small	4	Medium	26	34	26	34	0
31	Delta	109	Hotchkiss_Tract 2	Small	5	Medium	0	0	0	0	0
31	Delta	109	Hotchkiss_Tract 2	Small	6	Medium	26	34	26	34	0
31	Delta	109	Hotchkiss_Tract 2	Small	7	Medium	25	33	25	33	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
31	Delta	109	Hotchkiss_Tract 2	Small	8	Medium	25	33	25	33	0
32	Delta	115	Upper_Roberts_Island	Large	1	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	2	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	3	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	4	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	5	High	0	0	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	6	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	7	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	8	High	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	1	Medium	2	2	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	2	Medium	2	2	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	3	Medium	2	2	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	4	Medium	3	2	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	5	Medium	1	1	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	6	Medium	3	2	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	7	Medium	2	2	0	0	0
32	Delta	115	Upper_Roberts_Island	Large	8	Medium	3	2	0	0	0
33	Delta	117	Union_Island 1	Large	1	High	1	1	1	1	0
33	Delta	117	Union_Island 1	Large	2	High	1	1	1	1	0
33	Delta	117	Union_Island 1	Large	3	High	1	1	0	0	0
33	Delta	117	Union_Island 1	Large	4	High	1	1	0	0	0
33	Delta	117	Union_Island 1	Large	5	High	1	1	1	1	0
33	Delta	117	Union_Island 1	Large	6	High	1	1	1	1	0
33	Delta	117	Union_Island 1	Large	7	High	1	1	1	1	0
33	Delta	117	Union_Island 1	Large	8	High	1	1	1	1	0
33	Delta	117	Union_Island 1	Large	1	Medium	2	2	2	1	0
33	Delta	117	Union_Island 1	Large	2	Medium	3	2	2	1	0
33	Delta	117	Union_Island 1	Large	3	Medium	3	2	0	0	0
33	Delta	117	Union_Island 1	Large	4	Medium	2	2	0	0	0
33	Delta	117	Union_Island 1	Large	5	Medium	2	2	2	1	0
33	Delta	117	Union_Island 1	Large	6	Medium	2	2	2	1	0
33	Delta	117	Union_Island 1	Large	7	Medium	2	2	1	1	0
33	Delta	117	Union_Island 1	Large	8	Medium	2	2	2	1	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
34	Delta	126	Pico_Naglee_Tract	Large	1	High	3	5	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	2	High	3	5	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	3	High	35	12	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	4	High	0	0	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	5	High	0	0	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	6	High	0	0	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	7	High	3	3	3	3	0
34	Delta	126	Pico_Naglee_Tract	Large	8	High	3	4	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	1	Medium	7	12	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	2	Medium	6	10	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	3	Medium	92	32	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	4	Medium	0	0	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	5	Medium	0	0	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	6	Medium	0	0	0	0	0
34	Delta	126	Pico_Naglee_Tract	Large	7	Medium	6	6	4	4	0
34	Delta	126	Pico_Naglee_Tract	Large	8	Medium	6	10	0	0	0
35	Delta	127	Byron_Tract 1	Large	1	High	3	2	3	2	0
35	Delta	127	Byron_Tract 1	Large	2	High	2	2	2	2	0
35	Delta	127	Byron_Tract 1	Large	3	High	1	1	1	1	0
35	Delta	127	Byron_Tract 1	Large	4	High	5	5	5	5	0
35	Delta	127	Byron_Tract 1	Large	5	High	5	5	5	5	0
35	Delta	127	Byron_Tract 1	Large	6	High	0	0	0	0	0
35	Delta	127	Byron_Tract 1	Large	7	High	0	0	0	0	0
35	Delta	127	Byron_Tract 1	Large	8	High	5	5	5	5	0
35	Delta	127	Byron_Tract 1	Large	1	Medium	7	6	4	4	0
35	Delta	127	Byron_Tract 1	Large	2	Medium	5	4	3	3	0
35	Delta	127	Byron_Tract 1	Large	3	Medium	10	10	6	6	0
35	Delta	127	Byron_Tract 1	Large	4	Medium	10	10	7	7	0
35	Delta	127	Byron_Tract 1	Large	5	Medium	10	10	7	7	0
35	Delta	127	Byron_Tract 1	Large	6	Medium	0	0	0	0	0
35	Delta	127	Byron_Tract 1	Large	7	Medium	0	0	0	0	0
35	Delta	127	Byron_Tract 1	Large	8	Medium	12	13	8	8	0
36	Delta	129	Veale_Tract 1	Large	1	High	2	2	2	2	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
36	Delta	129	Veale_Tract 1	Large	2	High	2	2	2	2	0
36	Delta	129	Veale_Tract 1	Large	3	High	2	2	2	2	0
36	Delta	129	Veale_Tract 1	Large	4	High	2	2	2	2	0
36	Delta	129	Veale_Tract 1	Large	5	High	2	2	2	2	0
36	Delta	129	Veale_Tract 1	Large	6	High	0	0	0	0	0
36	Delta	129	Veale_Tract 1	Large	7	High	0	0	0	0	0
36	Delta	129	Veale_Tract 1	Large	8	High	5	6	5	6	0
36	Delta	129	Veale_Tract 1	Large	1	Medium	7	7	5	4	0
36	Delta	129	Veale_Tract 1	Large	2	Medium	6	6	4	4	0
36	Delta	129	Veale_Tract 1	Large	3	Medium	6	6	4	4	0
36	Delta	129	Veale_Tract 1	Large	4	Medium	6	5	4	4	0
36	Delta	129	Veale_Tract 1	Large	5	Medium	6	6	4	4	0
36	Delta	129	Veale_Tract 1	Large	6	Medium	0	0	0	0	0
36	Delta	129	Veale_Tract 1	Large	7	Medium	0	0	0	0	0
36	Delta	129	Veale_Tract 1	Large	8	Medium	12	16	8	10	0
37	Delta	141	Merritt Island	Large	1	High	1	1	0	0	0
37	Delta	141	Merritt Island	Large	2	High	1	1	0	0	0
37	Delta	141	Merritt Island	Large	3	High	1	1	0	0	0
37	Delta	141	Merritt Island	Large	4	High	1	1	0	0	0
37	Delta	141	Merritt Island	Large	5	High	1	1	0	0	0
37	Delta	141	Merritt Island	Large	6	High	1	1	1	1	0
37	Delta	141	Merritt Island	Large	7	High	1	0	1	0	0
37	Delta	141	Merritt Island	Large	8	High	1	1	1	1	0
37	Delta	141	Merritt Island	Large	1	Medium	3	2	0	0	0
37	Delta	141	Merritt Island	Large	2	Medium	2	1	0	0	0
37	Delta	141	Merritt Island	Large	3	Medium	2	1	0	0	0
37	Delta	141	Merritt Island	Large	4	Medium	2	1	0	0	0
37	Delta	141	Merritt Island	Large	5	Medium	2	1	0	0	0
37	Delta	141	Merritt Island	Large	6	Medium	3	2	2	1	0
37	Delta	141	Merritt Island	Large	7	Medium	2	1	1	1	0
37	Delta	141	Merritt Island	Large	8	Medium	2	1	1	1	0
38	Delta	142	Netherlands 2	Large	1	High	1	2	0	0	0
38	Delta	142	Netherlands 2	Large	2	High	1	2	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
38	Delta	142	Netherlands 2	Large	3	High	1	1	1	1	0
38	Delta	142	Netherlands 2	Large	4	High	1	1	1	1	0
38	Delta	142	Netherlands 2	Large	5	High	1	1	1	1	0
38	Delta	142	Netherlands 2	Large	6	High	1	1	1	1	0
38	Delta	142	Netherlands 2	Large	7	High	1	1	1	1	0
38	Delta	142	Netherlands 2	Large	8	High	1	2	0	0	0
38	Delta	142	Netherlands 2	Large	1	Medium	3	4	0	0	0
38	Delta	142	Netherlands 2	Large	2	Medium	4	5	0	0	0
38	Delta	142	Netherlands 2	Large	3	Medium	3	2	2	1	0
38	Delta	142	Netherlands 2	Large	4	Medium	3	2	2	1	0
38	Delta	142	Netherlands 2	Large	5	Medium	2	2	1	1	0
38	Delta	142	Netherlands 2	Large	6	Medium	2	1	1	1	0
38	Delta	142	Netherlands 2	Large	7	Medium	2	1	1	1	0
38	Delta	142	Netherlands 2	Large	8	Medium	3	3	0	0	0
39	Delta	143	Rindge_Tract	Large	1	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	2	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	3	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	4	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	5	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	6	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	7	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	8	High	1	1	1	1	0
39	Delta	143	Rindge_Tract	Large	1	Medium	2	2	2	1	0
39	Delta	143	Rindge_Tract	Large	2	Medium	3	2	2	1	0
39	Delta	143	Rindge_Tract	Large	3	Medium	2	2	2	1	0
39	Delta	143	Rindge_Tract	Large	4	Medium	3	2	2	1	0
39	Delta	143	Rindge_Tract	Large	5	Medium	2	1	1	1	0
39	Delta	143	Rindge_Tract	Large	6	Medium	2	1	1	1	0
39	Delta	143	Rindge_Tract	Large	7	Medium	2	2	2	1	0
39	Delta	143	Rindge_Tract	Large	8	Medium	3	2	2	1	0
40	Delta	144	Mandeville_Island	Large	1	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	2	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	3	High	1	1	1	1	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
40	Delta	144	Mandeville_Island	Large	4	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	5	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	6	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	7	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	8	High	1	1	1	1	0
40	Delta	144	Mandeville_Island	Large	1	Medium	3	2	2	1	0
40	Delta	144	Mandeville_Island	Large	2	Medium	3	2	2	1	0
40	Delta	144	Mandeville_Island	Large	3	Medium	3	2	2	1	0
40	Delta	144	Mandeville_Island	Large	4	Medium	3	2	2	1	0
40	Delta	144	Mandeville_Island	Large	5	Medium	2	2	2	1	0
40	Delta	144	Mandeville_Island	Large	6	Medium	2	1	1	1	0
40	Delta	144	Mandeville_Island	Large	7	Medium	3	2	2	1	0
40	Delta	144	Mandeville_Island	Large	8	Medium	3	2	2	1	0
41	Delta	146	Sutter Island	Large	1	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	2	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	3	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	4	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	5	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	6	High	2	2	2	2	0
41	Delta	146	Sutter Island	Large	7	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	8	High	3	3	3	3	0
41	Delta	146	Sutter Island	Large	1	Medium	7	8	5	5	0
41	Delta	146	Sutter Island	Large	2	Medium	6	7	4	5	0
41	Delta	146	Sutter Island	Large	3	Medium	7	8	5	5	0
41	Delta	146	Sutter Island	Large	4	Medium	6	7	4	4	0
41	Delta	146	Sutter Island	Large	5	Medium	8	8	5	6	0
41	Delta	146	Sutter Island	Large	6	Medium	6	7	4	4	0
41	Delta	146	Sutter Island	Large	7	Medium	6	7	4	4	0
41	Delta	146	Sutter Island	Large	8	Medium	8	8	5	6	0
42	Delta	147	Grand Island	Large	1	High	3	4	3	4	0
42	Delta	147	Grand Island	Large	2	High	3	3	3	3	0
42	Delta	147	Grand Island	Large	3	High	3	3	3	3	0
42	Delta	147	Grand Island	Large	4	High	1	1	1	1	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
42	Delta	147	Grand Island	Large	5	High	1	1	1	1	0
42	Delta	147	Grand Island	Large	6	High	1	1	1	1	0
42	Delta	147	Grand Island	Large	7	High	2	2	2	2	0
42	Delta	147	Grand Island	Large	8	High	3	3	3	3	0
42	Delta	147	Grand Island	Large	1	Medium	9	10	6	7	0
42	Delta	147	Grand Island	Large	2	Medium	7	8	5	5	0
42	Delta	147	Grand Island	Large	3	Medium	7	7	4	5	0
42	Delta	147	Grand Island	Large	4	Medium	3	3	2	2	0
42	Delta	147	Grand Island	Large	5	Medium	3	3	2	2	0
42	Delta	147	Grand Island	Large	6	Medium	4	3	2	2	0
42	Delta	147	Grand Island	Large	7	Medium	5	5	3	4	0
42	Delta	147	Grand Island	Large	8	Medium	7	8	5	5	0
43	Delta	148	Zone 148	Large	1	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	2	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	3	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	4	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	5	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	6	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	7	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	8	High	1	1	0	0	0
43	Delta	148	Zone 148	Large	1	Medium	3	3	0	0	0
43	Delta	148	Zone 148	Large	2	Medium	2	2	0	0	0
43	Delta	148	Zone 148	Large	3	Medium	2	2	0	0	0
43	Delta	148	Zone 148	Large	4	Medium	2	2	0	0	0
43	Delta	148	Zone 148	Large	5	Medium	2	2	0	0	0
43	Delta	148	Zone 148	Large	6	Medium	3	2	0	0	0
43	Delta	148	Zone 148	Large	7	Medium	2	2	0	0	0
43	Delta	148	Zone 148	Large	8	Medium	2	2	0	0	0
44	Delta	149	Pierson_Tract	Large	1	High	3	3	0	0	0
44	Delta	149	Pierson_Tract	Large	2	High	3	3	0	0	0
44	Delta	149	Pierson_Tract	Large	3	High	3	3	3	3	0
44	Delta	149	Pierson_Tract	Large	4	High	3	3	3	3	0
44	Delta	149	Pierson_Tract	Large	5	High	3	3	3	3	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
44	Delta	149	Pierson_Tract	Large	6	High	3	3	3	3	0
44	Delta	149	Pierson_Tract	Large	7	High	3	3	3	3	0
44	Delta	149	Pierson_Tract	Large	8	High	3	3	3	3	0
44	Delta	149	Pierson_Tract	Large	1	Medium	6	6	0	0	0
44	Delta	149	Pierson_Tract	Large	2	Medium	7	6	0	0	0
44	Delta	149	Pierson_Tract	Large	3	Medium	7	7	5	4	0
44	Delta	149	Pierson_Tract	Large	4	Medium	7	7	5	5	0
44	Delta	149	Pierson_Tract	Large	5	Medium	7	7	5	4	0
44	Delta	149	Pierson_Tract	Large	6	Medium	7	7	5	4	0
44	Delta	149	Pierson_Tract	Large	7	Medium	7	7	5	5	0
44	Delta	149	Pierson_Tract	Large	8	Medium	7	6	4	4	0
45	Delta	150	Venice_Island	Large	1	High	1	1	1	1	0
45	Delta	150	Venice_Island	Large	2	High	1	1	1	1	0
45	Delta	150	Venice_Island	Large	3	High	1	2	1	2	0
45	Delta	150	Venice_Island	Large	4	High	1	2	1	2	0
45	Delta	150	Venice_Island	Large	5	High	1	1	1	1	0
45	Delta	150	Venice_Island	Large	6	High	1	1	1	1	0
45	Delta	150	Venice_Island	Large	7	High	1	1	1	1	0
45	Delta	150	Venice_Island	Large	8	High	1	2	1	2	0
45	Delta	150	Venice_Island	Large	1	Medium	2	3	1	2	0
45	Delta	150	Venice_Island	Large	2	Medium	2	4	2	3	0
45	Delta	150	Venice_Island	Large	3	Medium	2	4	1	2	0
45	Delta	150	Venice_Island	Large	4	Medium	2	4	2	3	0
45	Delta	150	Venice_Island	Large	5	Medium	2	4	2	3	0
45	Delta	150	Venice_Island	Large	6	Medium	2	4	1	2	0
45	Delta	150	Venice_Island	Large	7	Medium	2	4	1	2	0
45	Delta	150	Venice_Island	Large	8	Medium	2	3	1	2	0
46	Delta	152	Medford_Island	Large	1	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	2	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	3	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	4	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	5	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	6	High	1	1	1	1	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
46	Delta	152	Medford_Island	Large	7	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	8	High	1	1	1	1	0
46	Delta	152	Medford_Island	Large	1	Medium	2	1	1	1	0
46	Delta	152	Medford_Island	Large	2	Medium	2	2	2	1	0
46	Delta	152	Medford_Island	Large	3	Medium	2	1	1	1	0
46	Delta	152	Medford_Island	Large	4	Medium	2	1	1	1	0
46	Delta	152	Medford_Island	Large	5	Medium	2	1	1	1	0
46	Delta	152	Medford_Island	Large	6	Medium	3	2	2	1	0
46	Delta	152	Medford_Island	Large	7	Medium	2	2	2	1	0
46	Delta	152	Medford_Island	Large	8	Medium	2	2	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	1	High	1	1	0	0	0
47	Delta	153	Rough_and_Ready_Island	Large	2	High	1	1	0	0	0
47	Delta	153	Rough_and_Ready_Island	Large	3	High	1	1	0	0	0
47	Delta	153	Rough_and_Ready_Island	Large	4	High	1	1	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	5	High	1	1	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	6	High	1	1	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	7	High	1	1	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	8	High	1	1	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	1	Medium	2	2	0	0	0
47	Delta	153	Rough_and_Ready_Island	Large	2	Medium	2	2	0	0	0
47	Delta	153	Rough_and_Ready_Island	Large	3	Medium	2	2	0	0	0
47	Delta	153	Rough_and_Ready_Island	Large	4	Medium	2	1	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	5	Medium	3	2	2	1	0
47	Delta	153	Rough_and_Ready_Island	Large	6	Medium	2	2	1	1	0
47	Delta	153	Rough_and_Ready_Island	Large	7	Medium	2	2	2	1	0
47	Delta	153	Rough_and_Ready_Island	Large	8	Medium	3	2	2	1	0
48	Delta	154	Middle_Roberts_Island	Large	1	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	2	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	3	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	4	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	5	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	6	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	7	High	1	1	1	1	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
48	Delta	154	Middle_Roberts_Island	Large	8	High	1	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	1	Medium	3	2	2	1	0
48	Delta	154	Middle_Roberts_Island	Large	2	Medium	2	1	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	3	Medium	3	2	2	1	0
48	Delta	154	Middle_Roberts_Island	Large	4	Medium	3	2	2	1	0
48	Delta	154	Middle_Roberts_Island	Large	5	Medium	2	2	2	1	0
48	Delta	154	Middle_Roberts_Island	Large	6	Medium	2	2	2	1	0
48	Delta	154	Middle_Roberts_Island	Large	7	Medium	2	2	1	1	0
48	Delta	154	Middle_Roberts_Island	Large	8	Medium	4	3	3	2	0
49	Delta	157	Smith_Tract	Large	1	High	236	329	0	0	0
49	Delta	157	Smith_Tract	Large	2	High	0	0	0	0	0
49	Delta	157	Smith_Tract	Large	3	High	0	0	0	0	0
49	Delta	157	Smith_Tract	Large	4	High	216	395	0	0	0
49	Delta	157	Smith_Tract	Large	5	High	326	429	0	0	0
49	Delta	157	Smith_Tract	Large	6	High	48	69	0	0	0
49	Delta	157	Smith_Tract	Large	7	High	59	87	0	0	0
49	Delta	157	Smith_Tract	Large	8	High	218	271	0	0	0
49	Delta	157	Smith_Tract	Large	1	Medium	590	764	0	0	0
49	Delta	157	Smith_Tract	Large	2	Medium	0	0	0	0	0
49	Delta	157	Smith_Tract	Large	3	Medium	0	0	0	0	0
49	Delta	157	Smith_Tract	Large	4	Medium	827	1176	0	0	0
49	Delta	157	Smith_Tract	Large	5	Medium	611	810	0	0	0
49	Delta	157	Smith_Tract	Large	6	Medium	129	189	0	0	0
49	Delta	157	Smith_Tract	Large	7	Medium	264	402	0	0	0
49	Delta	157	Smith_Tract	Large	8	Medium	581	679	0	0	0
50	Delta	159	Boggs_Tract	Large	1	High	64	23	0	0	0
50	Delta	159	Boggs_Tract	Large	2	High	0	0	0	0	0
50	Delta	159	Boggs_Tract	Large	3	High	0	0	0	0	0
50	Delta	159	Boggs_Tract	Large	4	High	216	262	0	0	0
50	Delta	159	Boggs_Tract	Large	5	High	145	210	0	0	0
50	Delta	159	Boggs_Tract	Large	6	High	236	251	0	0	0
50	Delta	159	Boggs_Tract	Large	7	High	72	25	0	0	0
50	Delta	159	Boggs_Tract	Large	8	High	65	24	0	0	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
50	Delta	159	Boggs_Tract	Large	1	Medium	133	48	0	0	0
50	Delta	159	Boggs_Tract	Large	2	Medium	0	0	0	0	0
50	Delta	159	Boggs_Tract	Large	3	Medium	0	0	0	0	0
50	Delta	159	Boggs_Tract	Large	4	Medium	541	631	0	0	0
50	Delta	159	Boggs_Tract	Large	5	Medium	321	464	0	0	0
50	Delta	159	Boggs_Tract	Large	6	Medium	502	428	0	0	0
50	Delta	159	Boggs_Tract	Large	7	Medium	250	75	0	0	0
50	Delta	159	Boggs_Tract	Large	8	Medium	165	60	0	0	0
51	Delta	162	Zone 162	Large	1	High	2	2	2	2	0
51	Delta	162	Zone 162	Large	2	High	3	3	3	3	0
51	Delta	162	Zone 162	Large	3	High	2	2	2	2	0
51	Delta	162	Zone 162	Large	4	High	0	0	0	0	0
51	Delta	162	Zone 162	Large	5	High	0	0	0	0	0
51	Delta	162	Zone 162	Large	6	High	0	0	0	0	0
51	Delta	162	Zone 162	Large	7	High	0	0	0	0	0
51	Delta	162	Zone 162	Large	8	High	3	3	3	3	0
51	Delta	162	Zone 162	Large	1	Medium	6	6	4	4	0
51	Delta	162	Zone 162	Large	2	Medium	7	7	5	5	0
51	Delta	162	Zone 162	Large	3	Medium	6	6	4	4	0
51	Delta	162	Zone 162	Large	4	Medium	0	0	0	0	0
51	Delta	162	Zone 162	Large	5	Medium	0	0	0	0	0
51	Delta	162	Zone 162	Large	6	Medium	0	0	0	0	0
51	Delta	162	Zone 162	Large	7	Medium	0	0	0	0	0
51	Delta	162	Zone 162	Large	8	Medium	6	6	4	4	0
52	Delta	163	Fabian_Tract	Large	1	High	1	1	1	1	0
52	Delta	163	Fabian_Tract	Large	2	High	1	1	1	1	0
52	Delta	163	Fabian_Tract	Large	3	High	4	2	0	0	0
52	Delta	163	Fabian_Tract	Large	4	High	1	1	0	0	0
52	Delta	163	Fabian_Tract	Large	5	High	1	1	1	1	0
52	Delta	163	Fabian_Tract	Large	6	High	1	1	1	1	0
52	Delta	163	Fabian_Tract	Large	7	High	1	1	1	1	0
52	Delta	163	Fabian_Tract	Large	8	High	1	1	1	1	0
52	Delta	163	Fabian_Tract	Large	1	Medium	2	2	2	1	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
52	Delta	163	Fabian_Tract	Large	2	Medium	2	2	2	1	0
52	Delta	163	Fabian_Tract	Large	3	Medium	6	3	0	0	0
52	Delta	163	Fabian_Tract	Large	4	Medium	2	2	0	0	0
52	Delta	163	Fabian_Tract	Large	5	Medium	3	2	2	1	0
52	Delta	163	Fabian_Tract	Large	6	Medium	3	2	2	1	0
52	Delta	163	Fabian_Tract	Large	7	Medium	2	2	1	1	0
52	Delta	163	Fabian_Tract	Large	8	Medium	2	2	2	1	0
53	Delta	168	Libby_McNeil_Tract 1	Small	1	High	11	11	11	11	0
53	Delta	168	Libby_McNeil_Tract 1	Small	2	High	8	8	8	8	0
53	Delta	168	Libby_McNeil_Tract 1	Small	3	High	10	11	10	11	0
53	Delta	168	Libby_McNeil_Tract 1	Small	4	High	9	9	9	9	0
53	Delta	168	Libby_McNeil_Tract 1	Small	5	High	17	17	17	17	0
53	Delta	168	Libby_McNeil_Tract 1	Small	6	High	10	11	10	11	0
53	Delta	168	Libby_McNeil_Tract 1	Small	7	High	11	11	11	11	0
53	Delta	168	Libby_McNeil_Tract 1	Small	8	High	10	11	10	11	0
53	Delta	168	Libby_McNeil_Tract 1	Small	1	Medium	104	109	104	109	0
53	Delta	168	Libby_McNeil_Tract 1	Small	2	Medium	107	113	107	113	0
53	Delta	168	Libby_McNeil_Tract 1	Small	3	Medium	104	110	104	110	0
53	Delta	168	Libby_McNeil_Tract 1	Small	4	Medium	106	111	106	111	0
53	Delta	168	Libby_McNeil_Tract 1	Small	5	Medium	98	103	98	103	0
53	Delta	168	Libby_McNeil_Tract 1	Small	6	Medium	104	110	104	110	0
53	Delta	168	Libby_McNeil_Tract 1	Small	7	Medium	104	110	104	110	0
53	Delta	168	Libby_McNeil_Tract 1	Small	8	Medium	105	110	105	110	0
54	Delta	169	McCormack_Williamson_Tract	Large	1	High	1	1	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	2	High	1	1	0	0	0
54	Delta	169	McCormack_Williamson_Tract	Large	3	High	1	1	0	0	0
54	Delta	169	McCormack_Williamson_Tract	Large	4	High	1	1	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	5	High	1	1	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	6	High	1	1	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	7	High	1	1	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	8	High	1	1	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	1	Medium	2	2	2	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	2	Medium	3	2	0	0	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
54	Delta	169	McCormack_Williamson_Tract	Large	3	Medium	2	2	0	0	0
54	Delta	169	McCormack_Williamson_Tract	Large	4	Medium	2	2	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	5	Medium	2	2	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	6	Medium	2	2	2	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	7	Medium	2	2	1	1	0
54	Delta	169	McCormack_Williamson_Tract	Large	8	Medium	2	2	2	1	0
55	Delta	170	Glanville_Tract	Large	1	High	1	1	0	0	0
55	Delta	170	Glanville_Tract	Large	2	High	0	0	0	0	0
55	Delta	170	Glanville_Tract	Large	3	High	0	0	0	0	0
55	Delta	170	Glanville_Tract	Large	4	High	3	3	0	0	0
55	Delta	170	Glanville_Tract	Large	5	High	1	1	0	0	0
55	Delta	170	Glanville_Tract	Large	6	High	1	1	1	1	0
55	Delta	170	Glanville_Tract	Large	7	High	1	1	1	1	0
55	Delta	170	Glanville_Tract	Large	8	High	1	1	0	0	0
55	Delta	170	Glanville_Tract	Large	1	Medium	2	2	0	0	0
55	Delta	170	Glanville_Tract	Large	2	Medium	0	0	0	0	0
55	Delta	170	Glanville_Tract	Large	3	Medium	0	0	0	0	0
55	Delta	170	Glanville_Tract	Large	4	Medium	10	8	0	0	0
55	Delta	170	Glanville_Tract	Large	5	Medium	2	2	0	0	0
55	Delta	170	Glanville_Tract	Large	6	Medium	3	2	2	2	0
55	Delta	170	Glanville_Tract	Large	7	Medium	2	2	1	1	0
55	Delta	170	Glanville_Tract	Large	8	Medium	2	2	0	0	0
56	Delta	172	New_Hope_Tract	Large	1	High	1	1	0	0	0
56	Delta	172	New_Hope_Tract	Large	2	High	7	9	0	0	0
56	Delta	172	New_Hope_Tract	Large	3	High	0	0	0	0	0
56	Delta	172	New_Hope_Tract	Large	4	High	2	2	0	0	0
56	Delta	172	New_Hope_Tract	Large	5	High	1	1	1	1	0
56	Delta	172	New_Hope_Tract	Large	6	High	1	1	1	1	0
56	Delta	172	New_Hope_Tract	Large	7	High	1	1	1	1	0
56	Delta	172	New_Hope_Tract	Large	8	High	1	2	1	2	0
56	Delta	172	New_Hope_Tract	Large	1	Medium	2	4	0	0	0
56	Delta	172	New_Hope_Tract	Large	2	Medium	19	23	0	0	0
56	Delta	172	New_Hope_Tract	Large	3	Medium	0	0	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
56	Delta	172	New_Hope_Tract	Large	4	Medium	8	10	0	0	0
56	Delta	172	New_Hope_Tract	Large	5	Medium	2	3	1	2	0
56	Delta	172	New_Hope_Tract	Large	6	Medium	2	4	1	2	0
56	Delta	172	New_Hope_Tract	Large	7	Medium	2	4	2	3	0
56	Delta	172	New_Hope_Tract	Large	8	Medium	3	5	2	3	0
57	Delta	173	Deadhorse Island	Small	1	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	2	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	3	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	4	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	5	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	6	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	7	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	8	High	1	1	1	1	0
57	Delta	173	Deadhorse Island	Small	1	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	2	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	3	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	4	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	5	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	6	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	7	Medium	4	4	4	4	0
57	Delta	173	Deadhorse Island	Small	8	Medium	4	4	4	4	0
58	Delta	174	Staten_Island	Large	1	High	1	1	1	1	0
58	Delta	174	Staten_Island	Large	2	High	1	2	1	2	0
58	Delta	174	Staten_Island	Large	3	High	1	1	1	1	0
58	Delta	174	Staten_Island	Large	4	High	1	1	1	1	0
58	Delta	174	Staten_Island	Large	5	High	1	1	1	1	0
58	Delta	174	Staten_Island	Large	6	High	1	2	1	2	0
58	Delta	174	Staten_Island	Large	7	High	1	1	1	1	0
58	Delta	174	Staten_Island	Large	8	High	1	1	1	1	0
58	Delta	174	Staten_Island	Large	1	Medium	3	4	2	3	0
58	Delta	174	Staten_Island	Large	2	Medium	3	4	2	3	0
58	Delta	174	Staten_Island	Large	3	Medium	2	4	1	2	0
58	Delta	174	Staten_Island	Large	4	Medium	1	2	1	2	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
58	Delta	174	Staten_Island	Large	5	Medium	2	4	2	3	0
58	Delta	174	Staten_Island	Large	6	Medium	3	5	2	3	0
58	Delta	174	Staten_Island	Large	7	Medium	2	4	1	2	0
58	Delta	174	Staten_Island	Large	8	Medium	3	4	2	3	0
59	Delta	175	Canal Ranch	Large	1	High	1	1	1	1	0
59	Delta	175	Canal Ranch	Large	2	High	1	1	0	0	0
59	Delta	175	Canal Ranch	Large	3	High	0	0	0	0	0
59	Delta	175	Canal Ranch	Large	4	High	1	1	1	1	0
59	Delta	175	Canal Ranch	Large	5	High	1	1	1	1	0
59	Delta	175	Canal Ranch	Large	6	High	1	2	1	2	0
59	Delta	175	Canal Ranch	Large	7	High	1	1	1	1	0
59	Delta	175	Canal Ranch	Large	8	High	1	1	1	1	0
59	Delta	175	Canal Ranch	Large	1	Medium	2	4	2	3	0
59	Delta	175	Canal Ranch	Large	2	Medium	3	5	0	0	0
59	Delta	175	Canal Ranch	Large	3	Medium	0	0	0	0	0
59	Delta	175	Canal Ranch	Large	4	Medium	2	4	2	3	0
59	Delta	175	Canal Ranch	Large	5	Medium	2	4	2	2	0
59	Delta	175	Canal Ranch	Large	6	Medium	2	4	1	2	0
59	Delta	175	Canal Ranch	Large	7	Medium	3	4	2	3	0
59	Delta	175	Canal Ranch	Large	8	Medium	2	4	2	3	0
60	Delta	176	Brack_Tract	Large	1	High	1	2	1	2	0
60	Delta	176	Brack_Tract	Large	2	High	1	1	1	1	0
60	Delta	176	Brack_Tract	Large	3	High	1	2	0	0	0
60	Delta	176	Brack_Tract	Large	4	High	1	1	1	1	0
60	Delta	176	Brack_Tract	Large	5	High	1	1	1	1	0
60	Delta	176	Brack_Tract	Large	6	High	1	2	1	2	0
60	Delta	176	Brack_Tract	Large	7	High	1	2	1	2	0
60	Delta	176	Brack_Tract	Large	8	High	1	1	1	1	0
60	Delta	176	Brack_Tract	Large	1	Medium	3	4	2	3	0
60	Delta	176	Brack_Tract	Large	2	Medium	2	4	1	2	0
60	Delta	176	Brack_Tract	Large	3	Medium	2	4	0	0	0
60	Delta	176	Brack_Tract	Large	4	Medium	2	4	2	3	0
60	Delta	176	Brack_Tract	Large	5	Medium	2	4	1	2	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
60	Delta	176	Brack_Tract	Large	6	Medium	2	4	2	3	0
60	Delta	176	Brack_Tract	Large	7	Medium	2	4	2	2	0
60	Delta	176	Brack_Tract	Large	8	Medium	2	3	1	2	0
61	Delta	177	Bouldin_Island	Large	1	High	1	2	1	2	0
61	Delta	177	Bouldin_Island	Large	2	High	1	1	1	1	0
61	Delta	177	Bouldin_Island	Large	3	High	1	2	1	2	0
61	Delta	177	Bouldin_Island	Large	4	High	1	1	1	1	0
61	Delta	177	Bouldin_Island	Large	5	High	1	2	1	2	0
61	Delta	177	Bouldin_Island	Large	6	High	1	1	1	1	0
61	Delta	177	Bouldin_Island	Large	7	High	1	2	1	2	0
61	Delta	177	Bouldin_Island	Large	8	High	1	2	1	2	0
61	Delta	177	Bouldin_Island	Large	1	Medium	2	4	2	3	0
61	Delta	177	Bouldin_Island	Large	2	Medium	2	3	1	2	0
61	Delta	177	Bouldin_Island	Large	3	Medium	2	4	2	3	0
61	Delta	177	Bouldin_Island	Large	4	Medium	2	3	1	2	0
61	Delta	177	Bouldin_Island	Large	5	Medium	2	4	2	3	0
61	Delta	177	Bouldin_Island	Large	6	Medium	3	4	2	3	0
61	Delta	177	Bouldin_Island	Large	7	Medium	3	4	2	3	0
61	Delta	177	Bouldin_Island	Large	8	Medium	2	4	2	3	0
62	Delta	178	Brannan-Andrus Island	Large	1	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	2	High	1	1	1	1	0
62	Delta	178	Brannan-Andrus Island	Large	3	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	4	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	5	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	6	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	7	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	8	High	1	2	1	2	0
62	Delta	178	Brannan-Andrus Island	Large	1	Medium	3	5	2	3	0
62	Delta	178	Brannan-Andrus Island	Large	2	Medium	3	3	2	2	0
62	Delta	178	Brannan-Andrus Island	Large	3	Medium	4	6	3	4	0
62	Delta	178	Brannan-Andrus Island	Large	4	Medium	3	5	2	3	0
62	Delta	178	Brannan-Andrus Island	Large	5	Medium	3	5	2	3	0
62	Delta	178	Brannan-Andrus Island	Large	6	Medium	3	5	2	3	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
62	Delta	178	Brannan-Andrus Island	Large	7	Medium	3	4	2	3	0
62	Delta	178	Brannan-Andrus Island	Large	8	Medium	2	4	2	3	0
63	Delta	179	Twitchell_Island	Large	1	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	2	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	3	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	4	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	5	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	6	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	7	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	8	High	1	2	1	2	0
63	Delta	179	Twitchell_Island	Large	1	Medium	3	5	2	3	0
63	Delta	179	Twitchell_Island	Large	2	Medium	3	5	2	3	0
63	Delta	179	Twitchell_Island	Large	3	Medium	3	5	2	3	0
63	Delta	179	Twitchell_Island	Large	4	Medium	2	4	2	3	0
63	Delta	179	Twitchell_Island	Large	5	Medium	3	5	2	3	0
63	Delta	179	Twitchell_Island	Large	6	Medium	3	5	2	3	0
63	Delta	179	Twitchell_Island	Large	7	Medium	3	5	2	3	0
63	Delta	179	Twitchell_Island	Large	8	Medium	3	5	2	3	0
64	Delta	181	Sherman_Island	Large	1	High	1	2	1	2	0
64	Delta	181	Sherman_Island	Large	2	High	1	2	1	2	40
64	Delta	181	Sherman_Island	Large	3	High	1	2	1	2	0
64	Delta	181	Sherman_Island	Large	4	High	1	2	1	2	0
64	Delta	181	Sherman_Island	Large	5	High	1	2	1	2	0
64	Delta	181	Sherman_Island	Large	6	High	2	3	2	3	0
64	Delta	181	Sherman_Island	Large	7	High	1	2	1	2	0
64	Delta	181	Sherman_Island	Large	8	High	1	2	1	2	0
64	Delta	181	Sherman_Island	Large	1	Medium	3	5	2	3	0
64	Delta	181	Sherman_Island	Large	2	Medium	3	5	2	3	0
64	Delta	181	Sherman_Island	Large	3	Medium	3	4	2	3	0
64	Delta	181	Sherman_Island	Large	4	Medium	3	4	2	3	0
64	Delta	181	Sherman_Island	Large	5	Medium	3	5	2	3	0
64	Delta	181	Sherman_Island	Large	6	Medium	5	9	4	6	0
64	Delta	181	Sherman_Island	Large	7	Medium	3	5	2	3	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
64	Delta	181	Sherman_Island	Large	8	Medium	3	5	2	3	0
65	Delta	182	Shin_Kee_Tract	Large	1	High	1	2	1	2	0
65	Delta	182	Shin_Kee_Tract	Large	2	High	1	1	0	0	0
65	Delta	182	Shin_Kee_Tract	Large	3	High	0	0	0	0	0
65	Delta	182	Shin_Kee_Tract	Large	4	High	1	1	1	1	0
65	Delta	182	Shin_Kee_Tract	Large	5	High	1	1	1	1	0
65	Delta	182	Shin_Kee_Tract	Large	6	High	1	2	1	2	0
65	Delta	182	Shin_Kee_Tract	Large	7	High	1	1	1	1	0
65	Delta	182	Shin_Kee_Tract	Large	8	High	1	1	1	1	0
65	Delta	182	Shin_Kee_Tract	Large	1	Medium	2	4	2	3	0
65	Delta	182	Shin_Kee_Tract	Large	2	Medium	1	2	0	0	0
65	Delta	182	Shin_Kee_Tract	Large	3	Medium	0	0	0	0	0
65	Delta	182	Shin_Kee_Tract	Large	4	Medium	2	4	1	2	0
65	Delta	182	Shin_Kee_Tract	Large	5	Medium	2	4	2	2	0
65	Delta	182	Shin_Kee_Tract	Large	6	Medium	3	4	2	3	0
65	Delta	182	Shin_Kee_Tract	Large	7	Medium	2	3	1	2	0
65	Delta	182	Shin_Kee_Tract	Large	8	Medium	2	4	2	2	0
66	Delta	183	Rio_Blanco_Tract	Large	1	High	1	1	1	1	0
66	Delta	183	Rio_Blanco_Tract	Large	2	High	1	1	0	0	40
66	Delta	183	Rio_Blanco_Tract	Large	3	High	0	0	0	0	0
66	Delta	183	Rio_Blanco_Tract	Large	4	High	1	1	1	1	0
66	Delta	183	Rio_Blanco_Tract	Large	5	High	1	1	1	1	0
66	Delta	183	Rio_Blanco_Tract	Large	6	High	1	1	1	1	0
66	Delta	183	Rio_Blanco_Tract	Large	7	High	1	1	1	1	0
66	Delta	183	Rio_Blanco_Tract	Large	8	High	1	1	1	1	0
66	Delta	183	Rio_Blanco_Tract	Large	1	Medium	2	4	1	2	0
66	Delta	183	Rio_Blanco_Tract	Large	2	Medium	2	4	0	0	0
66	Delta	183	Rio_Blanco_Tract	Large	3	Medium	0	0	0	0	0
66	Delta	183	Rio_Blanco_Tract	Large	4	Medium	2	4	2	2	0
66	Delta	183	Rio_Blanco_Tract	Large	5	Medium	2	4	2	2	0
66	Delta	183	Rio_Blanco_Tract	Large	6	Medium	2	4	2	2	0
66	Delta	183	Rio_Blanco_Tract	Large	7	Medium	2	4	2	3	0
66	Delta	183	Rio_Blanco_Tract	Large	8	Medium	2	4	2	2	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
67	Delta	184	Bishop_Tract	Large	1	High	1	1	1	1	0
67	Delta	184	Bishop_Tract	Large	2	High	1	1	0	0	0
67	Delta	184	Bishop_Tract	Large	3	High	0	0	0	0	0
67	Delta	184	Bishop_Tract	Large	4	High	10	16	0	0	40
67	Delta	184	Bishop_Tract	Large	5	High	17	26	17	26	0
67	Delta	184	Bishop_Tract	Large	6	High	19	30	19	30	0
67	Delta	184	Bishop_Tract	Large	7	High	9	15	9	15	0
67	Delta	184	Bishop_Tract	Large	8	High	1	1	1	1	0
67	Delta	184	Bishop_Tract	Large	1	Medium	2	4	2	2	0
67	Delta	184	Bishop_Tract	Large	2	Medium	2	3	0	0	0
67	Delta	184	Bishop_Tract	Large	3	Medium	0	0	0	0	0
67	Delta	184	Bishop_Tract	Large	4	Medium	32	51	0	0	0
67	Delta	184	Bishop_Tract	Large	5	Medium	42	68	28	45	0
67	Delta	184	Bishop_Tract	Large	6	Medium	50	81	33	53	0
67	Delta	184	Bishop_Tract	Large	7	Medium	23	37	15	24	0
67	Delta	184	Bishop_Tract	Large	8	Medium	2	4	2	2	0
68	Delta	186	Zone 186	Small	1	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	2	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	3	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	4	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	5	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	6	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	7	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	8	High	0	0	0	0	0
68	Delta	186	Zone 186	Small	1	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	2	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	3	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	4	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	5	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	6	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	7	Medium	0	0	0	0	0
68	Delta	186	Zone 186	Small	8	Medium	0	0	0	0	0
69	Delta	187	Shima_Tract	Large	1	High	10	17	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
69	Delta	187	Shima_Tract	Large	2	High	201	346	0	0	0
69	Delta	187	Shima_Tract	Large	3	High	0	0	0	0	0
69	Delta	187	Shima_Tract	Large	4	High	387	567	0	0	0
69	Delta	187	Shima_Tract	Large	5	High	9	16	9	16	0
69	Delta	187	Shima_Tract	Large	6	High	8	15	8	15	0
69	Delta	187	Shima_Tract	Large	7	High	9	16	9	16	0
69	Delta	187	Shima_Tract	Large	8	High	9	16	9	16	0
69	Delta	187	Shima_Tract	Large	1	Medium	25	44	0	0	0
69	Delta	187	Shima_Tract	Large	2	Medium	380	609	0	0	0
69	Delta	187	Shima_Tract	Large	3	Medium	0	0	0	0	0
69	Delta	187	Shima_Tract	Large	4	Medium	747	1123	0	0	0
69	Delta	187	Shima_Tract	Large	5	Medium	26	45	17	29	0
69	Delta	187	Shima_Tract	Large	6	Medium	21	36	13	23	0
69	Delta	187	Shima_Tract	Large	7	Medium	24	42	16	28	0
69	Delta	187	Shima_Tract	Large	8	Medium	27	47	17	30	0
70	Delta	188	Lincoln_Village_Tract	Large	1	High	141	171	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	2	High	175	181	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	3	High	0	0	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	4	High	174	316	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	5	High	91	270	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	6	High	109	175	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	7	High	143	249	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	8	High	181	314	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	1	Medium	729	793	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	2	Medium	395	408	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	3	Medium	0	0	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	4	Medium	523	900	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	5	Medium	309	653	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	6	Medium	241	386	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	7	Medium	376	646	0	0	0
70	Delta	188	Lincoln_Village_Tract	Large	8	Medium	649	908	0	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	1	High	67	10	67	10	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	2	High	0	0	0	0	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
71	Delta	189	Sargent_Barnhart_Tract 3	Small	3	High	0	0	0	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	4	High	77	0	77	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	5	High	88	0	88	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	6	High	63	0	63	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	7	High	86	0	86	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	8	High	93	0	93	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	1	Medium	46	0	46	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	2	Medium	0	0	0	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	3	Medium	22	0	0	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	4	Medium	35	0	35	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	5	Medium	25	0	25	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	6	Medium	49	0	49	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	7	Medium	26	0	26	0	0
71	Delta	189	Sargent_Barnhart_Tract 3	Small	8	Medium	19	0	19	0	0
72	Delta	190	Wright-Elmwood_Tract	Large	1	High	1	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	2	High	6	9	6	9	0
72	Delta	190	Wright-Elmwood_Tract	Large	3	High	2	2	2	2	0
72	Delta	190	Wright-Elmwood_Tract	Large	4	High	1	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	5	High	1	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	6	High	1	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	7	High	1	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	8	High	1	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	1	Medium	2	1	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	2	Medium	4	5	3	4	0
72	Delta	190	Wright-Elmwood_Tract	Large	3	Medium	2	2	2	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	4	Medium	2	2	2	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	5	Medium	2	2	1	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	6	Medium	3	2	2	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	7	Medium	2	2	2	1	0
72	Delta	190	Wright-Elmwood_Tract	Large	8	Medium	2	2	2	1	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	1	High	171	185	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	2	High	0	0	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	3	High	267	280	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
73	Delta	191	Sargent_Barnhart_Tract 2	Large	4	High	116	137	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	5	High	104	123	104	123	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	6	High	94	111	94	111	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	7	High	170	163	170	163	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	8	High	192	183	192	183	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	1	Medium	551	642	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	2	Medium	0	0	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	3	Medium	766	621	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	4	Medium	389	493	0	0	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	5	Medium	277	326	179	211	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	6	Medium	230	266	153	177	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	7	Medium	448	428	295	282	0
73	Delta	191	Sargent_Barnhart_Tract 2	Large	8	Medium	506	484	344	329	0
74	Delta	210	Ryer Island	Large	1	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	2	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	3	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	4	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	5	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	6	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	7	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	8	High	1	1	1	1	0
74	Delta	210	Ryer Island	Large	1	Medium	2	2	1	1	0
74	Delta	210	Ryer Island	Large	2	Medium	1	1	1	1	0
74	Delta	210	Ryer Island	Large	3	Medium	2	2	1	1	0
74	Delta	210	Ryer Island	Large	4	Medium	2	2	1	1	0
74	Delta	210	Ryer Island	Large	5	Medium	2	2	1	1	0
74	Delta	210	Ryer Island	Large	6	Medium	1	1	1	1	0
74	Delta	210	Ryer Island	Large	7	Medium	2	2	1	1	0
74	Delta	210	Ryer Island	Large	8	Medium	2	2	1	1	0
75	Delta	211	Prospect_Island	Large	1	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	2	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	3	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	4	High	0	0	0	0	0

Appendix 12B
Demographics Data Used in Fatality Risk Analysis

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
75	Delta	211	Prospect_Island	Large	5	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	6	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	7	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	8	High	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	1	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	2	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	3	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	4	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	5	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	6	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	7	Medium	0	0	0	0	0
75	Delta	211	Prospect_Island	Large	8	Medium	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	1	High	2	2	2	2	0
76	Delta	212	Clifton Court Forebay Water	Large	2	High	2	2	2	2	0
76	Delta	212	Clifton Court Forebay Water	Large	3	High	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	4	High	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	5	High	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	6	High	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	7	High	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	8	High	2	2	2	2	0
76	Delta	212	Clifton Court Forebay Water	Large	1	Medium	7	6	4	4	0
76	Delta	212	Clifton Court Forebay Water	Large	2	Medium	5	5	4	3	0
76	Delta	212	Clifton Court Forebay Water	Large	3	Medium	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	4	Medium	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	5	Medium	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	6	Medium	0	0	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	7	Medium	1	1	0	0	0
76	Delta	212	Clifton Court Forebay Water	Large	8	Medium	5	5	4	3	0
77	Delta	216	Zone 216	Small	1	High	2	2	2	2	0
77	Delta	216	Zone 216	Small	2	High	3	3	0	0	0
77	Delta	216	Zone 216	Small	3	High	2	2	2	2	0
77	Delta	216	Zone 216	Small	4	High	2	2	0	0	0
77	Delta	216	Zone 216	Small	5	High	0	0	0	0	0

Order	Region	Analysis Zone Number	Analysis Zone	Island Size	Breach Sector	Flood Severity Zone	Flood Daytime Population	Flood Nighttime Population	Seismic or Normal Daytime Population	Seismic or Normal Nighttime Population	Highway User
77	Delta	216	Zone 216	Small	6	High	0	0	0	0	0
77	Delta	216	Zone 216	Small	7	High	0	0	0	0	0
77	Delta	216	Zone 216	Small	8	High	3	3	0	0	0
77	Delta	216	Zone 216	Small	1	Medium	8	8	8	8	0
77	Delta	216	Zone 216	Small	2	Medium	7	7	0	0	0
77	Delta	216	Zone 216	Small	3	Medium	8	8	8	8	0
77	Delta	216	Zone 216	Small	4	Medium	8	8	0	0	0
77	Delta	216	Zone 216	Small	5	Medium	0	0	0	0	0
77	Delta	216	Zone 216	Small	6	Medium	0	0	0	0	0
77	Delta	216	Zone 216	Small	7	Medium	8	8	0	0	0
77	Delta	216	Zone 216	Small	8	Medium	8	8	0	0	0
78	Delta	412	Clifton Court Forebay	Large	1	High	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	2	High	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	3	High	2	2	2	2	0
78	Delta	412	Clifton Court Forebay	Large	4	High	1	1	1	1	0
78	Delta	412	Clifton Court Forebay	Large	5	High	2	2	2	2	0
78	Delta	412	Clifton Court Forebay	Large	6	High	1	1	0	0	0
78	Delta	412	Clifton Court Forebay	Large	7	High	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	8	High	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	1	Medium	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	2	Medium	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	3	Medium	5	5	4	3	0
78	Delta	412	Clifton Court Forebay	Large	4	Medium	6	5	4	4	0
78	Delta	412	Clifton Court Forebay	Large	5	Medium	6	5	4	3	0
78	Delta	412	Clifton Court Forebay	Large	6	Medium	4	3	0	0	0
78	Delta	412	Clifton Court Forebay	Large	7	Medium	0	0	0	0	0
78	Delta	412	Clifton Court Forebay	Large	8	Medium	0	0	0	0	0

Appendix 12-C

Fatality Risks By Island And Breach Sector

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	Probability of Number of Fatalities Equal to or Greater than Given Number: 0	1	2	5	10	20	50	100	200	500	1000
1	Delta	4	Webb_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Daytime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
7	Delta	11	Quimby_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
14	Delta	19	Woodward_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
21	Delta	70	Egbert_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
27	Delta	88	Cache_Haas_Tract 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	3	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
41	Delta	146	Sutter Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	1	12.025	1.443	0.00E+00	1.00E+00	1.00E+00	1.00E+00	9.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	4	10.175	1.221	0.00E+00	1.00E+00	1.00E+00	1.00E+00	7.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	5	15.725	1.887	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	6	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	7	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Daytime	8	11.1	1.332	0.00E+00	1.00E+00	1.00E+00	1.00E+00	8.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	1	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	4	10.175	1.221	0.00E+00	1.00E+00	1.00E+00	1.00E+00	7.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	5	7.4	0.888	3.89E-15	1.00E+00	1.00E+00	9.99E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	6	12.025	1.443	0.00E+00	1.00E+00	1.00E+00	1.00E+00	9.60E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	7	3.7	0.444	2.86E-13	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Daytime	8	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
54	Delta	169	McCormack_Williamson_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
61	Delta	177	Bouldin_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	2	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	2	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	4	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
68	Delta	186	Zone 186	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	2	10.175	1.221	0.00E+00	1.00E+00	1.00E+00	1.00E+00	7.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	4	19.425	2.331	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.87E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	1	7.4	0.888	3.89E-15	1.00E+00	1.00E+00	9.99E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	2	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	4	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	5	4.625	0.555	5.33E-14	1.00E+00	1.00E+00	5.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	6	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	7	7.4	0.888	3.89E-15	1.00E+00	1.00E+00	9.99E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Daytime	8	9.25	1.11	0.00E+00	1.00E+00	1.00E+00	1.00E+00	4.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	1	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	4	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	5	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	6	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	7	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Daytime	8	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	1	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	3	12.95	1.554	0.00E+00	1.00E+00	1.00E+00	1.00E+00	9.87E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	4	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	5	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	6	4.625	0.555	5.33E-14	1.00E+00	1.00E+00	5.89E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	7	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Daytime	8	9.25	1.11	0.00E+00	1.00E+00	1.00E+00	1.00E+00	4.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
75	Delta	211	Prospect_Island	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Daytime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Delta	4	Webb_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
2	Delta	5	Empire_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Delta	6	Bradford_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
3	Delta	6	Bradford_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Delta	7	King_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Delta	9	Jersey_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	1	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	2	11.1	1.332	0.00E+00	1.00E+00	1.00E+00	1.00E+00	8.85E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	3	9.25	1.11	0.00E+00	1.00E+00	1.00E+00	1.00E+00	4.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	4	6.475	0.777	7.33E-15	1.00E+00	1.00E+00	9.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	5	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	6	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	7	6.475	0.777	7.33E-15	1.00E+00	1.00E+00	9.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
6	Delta	10	Bethel_Island	Flood	Nighttime	8	6.475	0.777	7.33E-15	1.00E+00	1.00E+00	9.94E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
7	Delta	11	Quimby_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Delta	12	McDonald_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	Delta	13	Holland_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
10	Delta	14	Zone 14	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
10	Delta	14	Zone 14	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
11	Delta	15	Bacon_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Delta	16	Palm_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	Delta	17	Jones_Tract-Upper_and_Lower	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	Delta	19	Woodward_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Delta	20	Orwood_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	Delta	21	Victoria_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
17	Delta	32	Coney_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	Delta	32	Coney_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	1	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	2	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	3	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	4	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	5	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	6	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	7	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	Delta	62	Walnut_Grove	Flood	Nighttime	8	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Delta	63	Tyler_Island 2	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	Delta	68	Little_Egbert_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	Delta	70	Egbert_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
22	Delta	72	Peter Pocket	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
23	Delta	81	Zone 81	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	Delta	83	Hastings_Tract 2	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	Delta	86	Terminous_Tract 1	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	Delta	87	Terminous_Tract 2	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
27	Delta	88	Cache_Haas_Tract 1	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	Delta	89	Cache_Haas_Tract 2	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	Delta	106	Lower_Roberts_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
30	Delta	108	Hotchkiss_Tract 1	Flood	Nighttime	8	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
31	Delta	109	Hotchkiss_Tract 2	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	Delta	115	Upper_Roberts_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	Delta	117	Union_Island 1	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	1	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	2	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	3	3.7	0.444	2.86E-13	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	Delta	126	Pico_Naglee_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	4	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	5	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
35	Delta	127	Byron_Tract 1	Flood	Nighttime	8	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
36	Delta	129	Veale_Tract 1	Flood	Nighttime	8	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
37	Delta	141	Merritt Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	Delta	141	Merritt Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
38	Delta	142	Netherlands 2	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	Delta	143	Rindge_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	Delta	144	Mandeville_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	Delta	146	Sutter Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	Delta	147	Grand Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	Delta	148	Zone 148	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
44	Delta	149	Pierson_Tract	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
44	Delta	149	Pierson_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	Delta	150	Venice_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	Delta	152	Medford_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	Delta	153	Rough_and_Ready_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
48	Delta	154	Middle_Roberts_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	1	113.775	13.653	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.52E-01	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	4	135.975	16.317	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.87E-01	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	5	148	17.76	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.97E-01	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	6	24.05	2.886	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	7	29.6	3.552	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.98E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
49	Delta	157	Smith_Tract	Flood	Nighttime	8	93.425	11.211	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.94E-01	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	1	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	4	90.65	10.878	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	5	72.15	8.658	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.96E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	6	86.025	10.323	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	7	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
50	Delta	159	Boggs_Tract	Flood	Nighttime	8	8.325	0.999	2.33E-15	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
51	Delta	162	Zone 162	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
51	Delta	162	Zone 162	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
52	Delta	163	Fabian_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	1	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	2	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	3	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	4	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	5	3.7	0.444	2.86E-13	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	6	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	7	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
53	Delta	168	Libby_McNeil_Tract 1	Flood	Nighttime	8	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
54	Delta	169	McCormack_Williamson_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
55	Delta	170	Glanville_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	2	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
56	Delta	172	New_Hope_Tract	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
57	Delta	173	Deadhorse Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
57	Delta	173	Deadhorse Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
58	Delta	174	Staten_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
59	Delta	175	Canal Ranch	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
60	Delta	176	Brack_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
61	Delta	177	Bouldin_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
62	Delta	178	Brannan-Andrus Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
63	Delta	179	Twitchell_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	2	14.8	1.776	0.00E+00	1.00E+00	1.00E+00	1.00E+00	9.99E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	4	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
64	Delta	181	Sherman_Island	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	7	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
64	Delta	181	Sherman_Island	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	6	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
65	Delta	182	Shin_Kee_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	2	13.875	1.665	0.00E+00	1.00E+00	1.00E+00	1.00E+00	9.96E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
66	Delta	183	Rio_Blanco_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	4	19.425	2.331	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.87E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	5	9.25	1.11	0.00E+00	1.00E+00	1.00E+00	1.00E+00	4.11E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	6	10.175	1.221	0.00E+00	1.00E+00	1.00E+00	1.00E+00	7.10E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	7	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
67	Delta	184	Bishop_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
68	Delta	186	Zone 186	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	1	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	2	119.325	14.319	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.17E-01	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	4	195.175	23.421	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	4.27E-01	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	5	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	6	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	7	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
69	Delta	187	Shima_Tract	Flood	Nighttime	8	5.55	0.666	1.70E-14	1.00E+00	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	1	59.2	7.104	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.14E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	2	61.975	7.437	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.53E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	4	109.15	13.098	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.69E-01	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	5	93.425	11.211	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	2.94E-01	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	6	60.125	7.215	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.30E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	7	86.025	10.323	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
70	Delta	188	Lincoln_Village_Tract	Flood	Nighttime	8	108.225	12.987	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	7.49E-01	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	1	1.85	0.222	5.97E-10	1.00E+00	9.43E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
71	Delta	189	Sargent_Barnhart_Tract 3	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	2	2.775	0.333	4.19E-12	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
72	Delta	190	Wright-Elmwood_Tract	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	1	63.825	7.659	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.69E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	3	96.2	11.544	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	3.87E-01	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	4	47.175	5.661	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	3.41E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	5	42.55	5.106	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	6	37.925	4.551	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	7	56.425	6.771	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	8.47E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
73	Delta	191	Sargent_Barnhart_Tract 2	Flood	Nighttime	8	62.9	7.548	0.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	9.62E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
74	Delta	210	Ryer Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
75	Delta	211	Prospect_Island	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	1	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	Delta	212	Clifton Court Forebay Water	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	2	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	3	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	5	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
77	Delta	216	Zone 216	Flood	Nighttime	8	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	1	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12C
Fatality Risks by Island and Breach Sector

Order	Region	Analysis Zone Number	Analysis Zone	Initiating Event	Exposure Time	Breach Sector	Breach Mean (Life Loss)	Breach Std Dev (Life Loss)	0	1	2	5	10	20	50	100	200	500	1000
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	2	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	3	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	4	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	5	0.925	0.111	6.44E-05	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	6	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	7	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	Delta	412	Clifton Court Forebay	Flood	Nighttime	8	0	0	1.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Appendix 12-D

Example Calculation Of Probabilities
Of Exceeding Different Number Of Fatalities For A Given Levee Failure Sequence

Island #1: Bethel Island; breaches at N, E, and SW sectors

Island #2: Bradford Island; breaches at S and W sectors

Initiating Event: Seismic

Exposure Time: Nighttime

For Bethel Island - N sector, GIS search for population within the high and medium severity zones shows 16 and 36 people, respectively. The warning issuance time is 0.5 hour. The times to reach the boundary of high and medium severity zones are 0.27 and 0.43 hour, respectively. Therefore, 100% of the population in each zone is at risk. For the high severity zone, the mean and standard deviation of fraction life loss are 0.925 and 0.111, respectively. For the medium severity zone, the mean and standard deviation of fraction life loss are 0.121 and 0.178, respectively.

Mean number of fatalities in the high severity zone

$= 0.925 \times 16$

$= 14.8$ … Equation (1)

Variance of number of fatalities in the high severity zone

$= 0.111^2 \times 16^2$

$= 3.2$ … Equation (2)

Mean number of fatalities in the medium severity zone

$= 0.121 \times 36$

$= 4.4$ … Equation (1)

Variance of number of fatalities in the medium severity zone

$= 0.178^2 \times 36^2$

$= 41.1$ … Equation (2)

Therefore,

Mean number of fatalities for both severity zones

$= 14.8 + 4.4$

$= 19.2$ … Equation (4)

Variance of number of fatalities for both severity zones

$= 3.2 + 41.1 + 2 \times \sqrt{3.2} \times \sqrt{41.1}$

$= 67.0$ … Equation (5)

Similar calculations are performed for other islands/sectors and the results are shown as follows:

Island	Sector	Mean Number of Fatalities	Variance of Number of Fatalities	Standard Deviation of Number of Fatalities
Bethel Island	N	19.2	67.0	8.2
Bethel Island	E	31.5	159.0	12.6
Bethel Island	SW	16.8	35.2	5.9
Bradford Island	S	1.17	0.22	0.47
Bradford Island	W	1.29	0.42	0.65

<u>Bethel Island:</u>

Mean number of fatalities for all breaches

$= 19.2 + 31.5 + 16.8$

$= 67.5$ … Equation (8)

Variance of number of fatalities for all breaches

$= 8.2^2 + 12.6^2 + 5.9^2 + 2 \times (8.2\times12.6 + 8.2\times5.9 + 12.6\times5.9)$

$= 712.9$ … Equation (9)

<u>Bradford Island:</u>

Mean number of fatalities for all breaches

$= 1.17 + 1.29$

$= 2.46$ … Equation (8)

Variance of number of fatalities for all breaches

$= 0.47^2 + 0.65^2 + 2 \times (0.47 \times 0.65)$

$= 1.25$ … Equation (9)

<u>Combined fatality risk over both islands:</u>

Mean number of fatalities for both islands

$= 67.5 + 2.46$

$= 69.96$ … Equation (11)

Variance of number of fatalities for both islands

$= 712.9 + 1.25$

$= 714.15$ … Equation (12)

Assuming normal distribution (using Equation (6)):

Probability of greater than or equal to 10 fatalities,

$$P[n \geq 10] = 1 - \Phi\left[\frac{10 - 69.96}{\sqrt{714.15}}\right] = 0.99$$

Probability of greater than or equal to 100 fatalities,

$$P[n \geq 100] = 1 - \Phi\left[\frac{100 - 69.96}{\sqrt{714.15}}\right] = 0.13$$

Appendix 12-E
Total Organic Carbon

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Tables

Figures

WAM Acronyms and Abbreviations

BAU	Business as Usual
CalSim	California Water System Simulation Model (DWR & USBR)
cfs	cubic feet per second
CO_2	Carbon Dioxide
CVP	Federal Central Valley Project
DRMS	Delta Risk Management Strategy
DWR	California Department of Water Resources
dss	Data storage system
EC	Electrical Conductivity
HD	The WAM Hydrodynamic / Water Quality Submodel
ITF	Initial Technical Framework
JBA	Jack R. Benjamin & Associates
mg/L	milligrams per liter
MWH	Megawatt Hours
NDAL	Net Delta Area Losses (or Net Delta Consumptive Water Use)
RMA	Resource Management Associates, the DRMS hydrodynamics consultant
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	Thousand Acre-Feet
TM	Technical Memorandum
TOC	Total organic carbon
µmhos/cm	micro mhos per centimeter – Electrical Conductivity, a measure of salinity
URS	URS Corporation
USBR	United States Bureau of Reclamation
WAM	Water Analysis Module or Model
WY	Water Year

Executive Summary

A preliminary analysis of total organic carbon (TOC) increases was conducted for six specific Delta levee breach scenarios. These scenarios also include variations in water year type and seasonality. The mass of TOC produced from the flooded peat islands as well as the increases in TOC concentrations at Clifton Court Forebay were modeled for the period when salinity was restored enough to allow water exports to resume. Particle tracking hydrodynamic modeling was not used in the analysis.

Two critical drinking water quality thresholds were determined for TOC: the point at which additional treatment costs would be incurred, and the point at which current operations for organic carbon treatment (enhanced coagulation) was no longer effective.

The island inundation scenarios evaluated range from one breach on one island to forty-six breaches among thirty islands. The schedule to reclaim the islands ranges from 1.6 to 6.6 years. Enhanced coagulation is needed for 100 to 560 days with an estimated cost that ranged from $12 to $68 million. Water exports are interrupted due to salinity intrusion for 1 to 23 months. Additional decisions regarding water exports and interruptions due to TOC range from 0 to 30 months.

Drinking water can be reliably treated with enhanced coagulation in the 1 and 3 flooded islands scenarios evaluated, and in one of the 10 flooded islands scenarios. More substantial problems occur in the 20 and 30 flooded island scenarios. With sustained TOC concentrations greater than 6 milligrams per liter (mg/L), the Delta water may not be usable for municipal and industrial purposes however it may be suitable for agriculture. Decisions must then be made regarding water exports that impact potability in downstream reservoirs, storage, and drinking water treatment facilities.

More detailed modeling and an evaluation of dewatering locations and rates can be used to refine the predicted magnitude and duration of spikes. However additional treatment options would be needed to address periods when TOC concentrations are above 6 mg/L.

E.1 Introduction

Water exported from the Sacramento-San Joaquin river delta (Delta) is an important drinking water source for more then 20 million people in California. Dissolved organic carbon (DOC) is a disinfection byproduct precursor for chlorinated drinking water. It is estimated that 20 to 50 percent of Delta water trihalomethane precursors originate from drainage water from Delta islands peat soil (Fujii et al. 1998).

The high organic matter content of peat is associated with high DOC concentrations in the soil pore water. DOC production within peat soil and sediment is a result of microbial activities that break down complex organic compounds in decaying plant matter to simpler compounds. These low molecular weight compounds then undergo a series of condensation reactions to recombine into higher molecular weight compounds such as fulvic acids and humic substances which make up DOC (Thibodeaux and Aguilar 2005). When inundated, the DOC will move from the bed layer into the overlaying water.

The organic matter fraction of peat soils in the central Delta is particularly high. Jersey Island, Orwood Tract, Sherman Island, and Twitchell Island have soil organic matter fractions that range from 18 to 37 percent (Aguilar and Thibodeaux 2005). Muck, which primarily consists of decomposed peat, is the predominant soil type in the central Delta (Delta Protection Commission 2005).

Delta water exporters are concerned about the potential impact of organic carbon on drinking water intakes due to flooded peat islands.

E.2 Purpose

The purpose of this memorandum is to address the concerns raised by drinking water exporters regarding total organic carbon increases and the resulting water quality treatment cost increases that would occur from Delta island flooding in the event of multiple island/multiple levee breaches.

E.3 Approach

The Department of Water Resources (DWR) conducted measurements and modeling of organic carbon releases as part of the 2004 Jones Tract levee failure and response. We have adapted the organic carbon model created by the DWR to predict the mass of organic carbon produced and released for the six levee failure cases described in the Phase 1 DRMS report. This includes both a quick release fraction and sustained production due to microbial mediated production.

The Jones Tract report also presents a fingerprint for DOC at Clifton Court Forebay during dewatering at Upper and Lower Jones Tract. This fingerprint was based on output from the DWR Delta Simulation Model (DSM2). The mass of DOC in the fingerprint that is attributed to Jones Tract was calculated and compared to the mass of DOC released during dewatering. This comparison was used to create a global scaling factor that accounts for the difference between the amount of organic carbon produced and the amount of organic carbon that reaches Clifton Court Forebay. Scaling factors were then assigned to each of the islands based upon this factor as well as island location/net flow direction during exports.

The water treatments costs associated with organic carbon removal, as provided by Delta exporters, was then used to develop an order of magnitude cost estimate for the increase in water treatment costs due to the increases in organic carbon at the southern Delta drinking water intakes for each of the six cases.

E.4 Organic Carbon Models

E.4.1 Island Production

Several factors can influence the release of organic carbon from island peat soil due to island inundation. The quick release fraction of DOC comes from a finite amount of readily available material. This fraction becomes suspended on the time scale of hours to days. When a Delta levee is breached, the water that fills the island is turbulent and has high velocity flows. Particle suspension occurs during filling. Shear forces may release colloids that were previously attached to soil surfaces. The inundation also gives rise to flows within the pore spaces of the soil. This may cause colloids to become detached from soil particles within the bed and will also cause unassociated organic carbon material to enter the overlaying water.

Another portion of the DOC is generated by microbial processes in the peat sediment and is produced nearly continuously and is subsequently released from the bed. This long-term fraction can be generated on the time scale of years to decades. The release rate is dependent on the organic fraction in the soil and on temperature/seasonal variations. As time increases the percent organic carbon in the bed soil slowly decreases, as does the release rate (Aguilar and Thibodeaux 2005). The DOC is transported from sediment pore water to the overlying water through molecular diffusion or advection.

The conversion between DOC and TOC is necessary for calculations. Operationally DOC is defined as non-settleable organic matter in the <0.45 μm size range (Aguilar and Thibodeaux 2005). TOC includes both particulate organic carbon and DOC. In the flooded peat soils at Jones Tract, DOC comprised an average of 85 percent of the TOC (DuVall et al. 2005); this conversion factor was assumed for all Delta islands.

Quick Release

DuVall et al. (2005) estimated the initial release DOC concentration at Jones Tract by multivariate regression analysis. Upper Jones had a quick release concentration (as determined by wet oxidation analysis) of 2.22 mg/L, and Lower Jones had a quick release concentration of 5.78 mg/L. Assuming that Jones Tract had an average depth of 3.7 meters, the initial release is 8.2 g/m^2 of DOC for Upper Jones and 21.4 g/m^2 of DOC for Lower Jones.

Thibodeaux and Aguilar (2005) developed a model that predicts both the quick release fraction and the bacterial mediated long-term release fraction for DOC. For a hypothetical enclosed reservoir, with a depth of 3 meters, a peat bed consisting of 15% organic carbon, and inundation flows which disturb 10 cm of soil and release the associated pore water DOC content, the initial average DOC concentration in the reservoir is 3.53 mg/L with a reported range of uncertainty between 2.65 and 4.39 mg/L. This is equivalent to an initial release of 10.6 g/m^2 of DOC, with a range of 8 to 13.2 g/m^2 of DOC.

It is interesting to note some of the experimental differences behind these quick release estimates. The Jones Tract estimates represent actual field data from a dynamic system. Upper Jones was an open system that was in contact with fresher river water through the unrepaired levee for three weeks. During this time there was potential DOC loss into the channels and dilution by the channel water at the sampling location. Lower Jones was connected to Upper Jones via a passage under a railroad trestle, opposite to and nearly five miles away from the levee breach. Any DOC loss or dilution was by water from Upper Jones and not directly by channel water. The quick release estimate for Lower Jones would be less confounded by freshwater dilution and DOC lost from the system.

The Thibodeaux and Aguilar model was calibrated by laboratory scale experimentation. They simulated the organic carbon flux from bed sediment pore water for three peat soils with different percent organic matter. As part of the experimental design, soil samples were homogenized and sieved prior to subsampling, and water was placed on sediment so as to avoid particle suspension in the jar reactors. The sample preparation for the experiment potentially contributed to an increase in the amount of readily available organic carbon in the pore water; the experimental design potentially decreased the amount of organic carbon flux due to colloid detachment from suspended sediments. The Thibodeaux and Aguilar model quick release estimate does not fully account for field conditions which occur during Delta island inundation.

The quick release estimate for Lower Jones derived from the multivariate regression analysis was chosen to determine the quick release fraction for the six levee failure cases. Section 4.3 contains the quick release organic carbon production (by mass in kg) for each of the islands in each three DRMS scenarios.

Bacterial Mediated Long-term Production

DuVall et al. (2005) developed a monthly average organic carbon flux rate in their seasonal flux model. This rate varies between 0 and 0.5 g/m^2-d of TOC depending on time of year. A monthly flux rate from this model and a monthly time step was used to determine the organic carbon areal flux for each of the islands in the DRMS scenarios. The monthly flux rates used in the calculations for the DRMS scenarios are as follows.

Table 1 Seasonal Flux Rates (Year One), DWR Seasonal Flux Model

Month	Flux rate for TOC (g/m^2-d)	Month	Flux rate for TOC (g/m^2-d)
January	0	July	0.5
February	0.04	August	0.47
March	0.13	September	0.38
April	0.25	October	0.25
May	0.38	November	0.13
June	0.47	December	0.04

Experimental data and other model values have similar flux rates as the seasonal flux model. The time dependent portion of the by multivariate regression analysis for DOC at Jones Tract is 0.118 mg/L-d (DuVall et al. 2005), which is calculated from field scale data acquired from Jones Tract. Assuming that Jones Tract had an average depth of 3.7 meters, the equivalent long-term release flux rate is 0.44 g/m^2-d of DOC or 0.51 g/m^2-d of TOC, when DOC is assumed to account for 85% of the TOC. A multi-year mesocosm experiment, performed by the DWR, had tanks with flooded peat soil that yielded a TOC flux rate of 0.41 to 0.45 g/m^2-d in warmer months and 0.12 to 0.15 g/m^2-d in cooler months (DuVall et al. 2005). The model developed and presented by Thibodeaux and Aguilar (2005) predicts the microbial produced DOC concentration from a hypothetical reservoir, which has a depth of 3 meters and a peat bed consisting of 15% organic carbon, to be 0.241 mg/L-d. This is equivalent to an areal flux rate of 0.72 g/m^2-d of DOC or 0.85 g/m^2-d of TOC.

The carbon flux model developed by the DWR in DuVall et al. 2005 was chosen for the long-term release of organic carbon. This model is consistent with field scale measurements and accounts for season variation, but does not account for variation in peat bed percent organic carbon.

E.4.2 Scaling Factors

Scaling factors were applied to each of the Delta islands to account for the difference between the amount of organic carbon that was produced on each island and the amount of organic carbon from that island that is expected to reach south Delta drinking water intakes. These scaling factors are based upon the assumed net flow direction during exports and a global scaling factor that accounts for additional loss.

Island Location / Distance from Southern Delta Pumps

Yield factors were applied to each island based on net flow direction during water exports and the distance from southern Delta drinking water intakes. Each island is assigned a zero percent, fifty percent, or one hundred percent yield factor. Figure 1 shows the location of central Delta islands and the assigned yield factors.

It is assumed that all of the organic carbon that is produced on Sherman Island would be swept into the bay and away from the southern Delta drinking water intakes by the Sacramento River. Jersey Island, Bradford Island, Twitchell Island, Brannon-Andrus Island, and Grand Island were assigned a 50 percent scaling factor to account for the influence of both water exports and the Sacramento River on net flow direction. Bethel Island, Webb Tract, Staten Island, Bouldin Island, Venice Island, Empire Tract, Medford Island, Mandeville Island, Quimby Island, Holland Island, Hotchkiss Tract, Veale Tract, Palm Tract, Bacon Island, McDonald Tract, Rindge Tract, Upper and Lower Jones Tract, Woodward Island, Orwood Tract, Victoria Island, Byron Tract, Middle Roberts Island, Union Island, and Fabian Tract are assumed to be close enough to Clifton Court Forebay to have pumping activities dominate the net flow direction of the surrounding channels.

0%

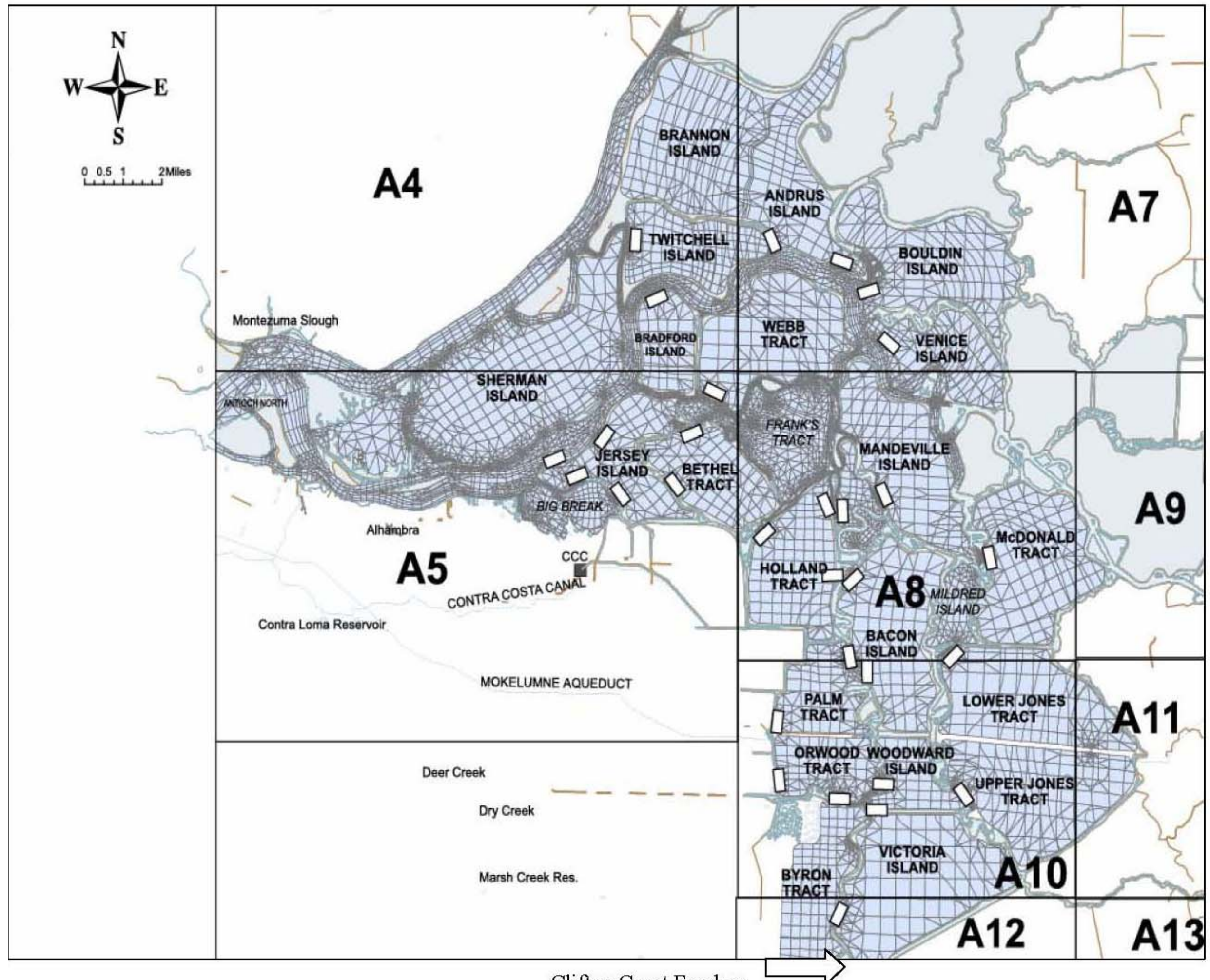
Sherman

50%

Brannon-Andrus Island
Twitchell Island
Bradford Island
Jersey Island

100%

Webb Tract
Bethel Island
Holland Tract
Quimby Island
Mandeville Island
McDonald Tract
Venice Island
Bouldin Island
Bacon Island
Palm Tract
Upper and Lower Jones Tract
Orwood Tract
Woodward Island
Byron Tract
Victoria Island



Clifton Court Forebay

Figure 1 Yield factors for Central Delta islands due to net flow direction during exports/distance from Clifton Court Forebay.

Island Production vs. Intake Water

A global scaling factor of 50 percent was applied at each island regardless of location to account for the difference between the amount of organic carbon produced at Jones Tract and the amount of Jones Tract organic carbon found at the Banks Pumping Plant drinking water intakes.

DuVall et al. (2005) presents the DSM2 modeled fingerprint for DOC at Clifton Court Forebay, developed by the Bay Delta Office, during dewatering at Jones Tract. In this model, the sources that contribute DOC include the Sacramento River, the San Joaquin River, the east side tributaries, the Delta, and Jones Tract. Jones Tract contributed approximately 1.5 mg/L of DOC to Clifton Court Forebay in the last two months of the island pump-out. During this time the water intake volume ranged from 2,968 to 14,237 acre-feet per day (USBR 2005).

The DSM2 fingerprint indicates approximately a week delay between completion of the island pumping at Lower Jones Tract and the last of the Jones tract DOC to arrive at Clifton Court Forebay. This indicates a travel time on the order of days to weeks for organic carbon from Jones Tract pump-out water to travel to Clifton Court Forebay.

From 10/25/04 to 12/20/04, Jones Tract contributed approximately 1.7 million kilograms of organic carbon to its adjacent channel through water pump-out in the final stage of repairs. This estimate is based upon information provided in DuVall et al. (2005), which includes the DOC linear regression equations, the average Jones Tract island depth that was used in DSM2 model, and the area of Upper and Lower Jones.

Approximately 0.9 million kilograms of organic carbon originating from Jones Tract arrived at the drinking water intakes at Clifton Court Forebay from 10/31/04 to 12/26/04. This estimate was calculated using information contained in the DSM2 fingerprint and from published intake volumes at Clifton Court Forebay.

The 50 percent scaling factor accounts for the difference between these calculations. The loss could be due to uptake, settling and burial, other water exports, tidal outflow to the Bay, and unknown processes.

E.4.3 Assumptions

The assumptions used in the models, the scaling factors, and in the calculations that predict the amount of TOC that potentially impacts drinking water treatments costs are discussed below.

Information from the Jones Tract levee failure and response was generalized to create the organic carbon quick release and long term flux calculations. There is an implicit assumption that the general flooded island scenario will have conditions similar to Jones Tract. In the flooded peat soils at Jones Tract, DOC contributed an average of 85 percent of the TOC; this conversion factor was assumed for all Delta islands. The quick release production seen at Upper Jones (21.4 g/m^2 of DOC) was the assumed areal production for all islands; this is potentially a lower end estimate because it does not account for possible dilution at Upper Jones. The long term TOC flux rates from the DWR seasonal flux model was the assumed production rate for all islands. These flux rates were calibrated with Jones Tract data but not experimentally derived.

Organic carbon production and transport can vary by island. The organic carbon flux rate would be influenced by the percent organic matter content in peat soil, which varies among islands and decays over time. Management decisions such as above Delta releases, i.e. reservoir releases north of the Delta, would influence the transport of organic carbon to southern Delta intakes. Additional factors that may be important include hydraulic exchange, organic carbon content of the channel water, and dispersion of organic carbon prior to levee repair.

Hydrodynamic modeling was not used for the transport of organic carbon from the islands to the Banks pumping plant. Instead, scaling factors were used based on general categorizations, which might not reflect actual flow dynamics.

The contribution of island TOC mass to southern Delta intakes was calculated after exports had resumed. These calculations account for the amount of mass predicted in the pump-out water and dewatering schedule and duration. Half of the island produced TOC was assumed to be transported from the island into the adjacent channels through open levees. This was modeled to occur until the breach repair was complete. For islands that had unrepaired levees during water exports, the TOC released from the open island contributed to the TOC loading at Clifton Court Forebay. The amount of TOC in the pump-out water was assumed to equal half of the initial “quick release” and long term TOC flux produced by that island prior to the completion of levee repair and all of the long term production thereafter.

The increase in TOC concentration at the southern Delta intakes due to flooded islands and dewatering repairs was also calculated. To model these increases the organic carbon contribution from Jones Tract was scaled. Jones Tract pump-out water was estimated to contribute 1.8 mg/L and approximately 15,000 kg/d of TOC to Clifton Court Forebay. (An increase of 1.5 mg/L of DOC was associated with Jones Tract pump-out water as seen in the DSM2 fingerprint for Clifton Court Forebay from 10/31/04 to 12/20/04, and it is assumed that DOC contributed an average of 85 percent of the TOC.)

There are several assumptions implicit in the scaling of Jones Tract organic carbon concentrations and the distribution of organic carbon loads over the pump-out stage. Assumptions include the following.

- The TOC released while the water exports are interrupted does not contribute to the organic carbon loading at Clifton Court Forebay after the exports have resumed. This assumes that the processes that pushed back the salinity also pushed back the organic carbon. (For example, this could occur when the Delta is flushed prior to resuming exports.)
- There are similar amounts of dispersion and dilution of organic carbon in the modeled breach scenarios as seen by Jones 2004. This implies a similar amount of above Delta releases during the pump-out phase.
- The mass of organic carbon produced prior to the start of dewatering is evenly distributed over the pump-out duration. This would imply a constant pump-out rate.
- Organic carbon impacts from multiple islands are additive.

E.5 Results

The CALFED Water Quality Program Record of Decision water quality goal for Clifton Court Forebay and other southern and central Delta drinking water intakes is 3.0 mg/L TOC (Brown and Caldwell 2005). Background concentrations of TOC and DOC in the Delta are typically between 3-4 mg/L, but are often higher during winter storm events (DWR 2007).

The Metropolitan Water District of Southern California provided a cost associated with the treatment of Delta water for organic carbon concentrations up to 6 mg/L of TOC. (Delta water is treated by Metropolitan to ensure a total organic carbon concentration of less then 4 mg/L.) A cost increase of $18 per acre-foot is associated with enhanced coagulation (operations and maintenance costs, not capital investments). At a high enough concentration over a prolonged period of time, additional capital investment would be required to reliably treat the water. For example, a combined background and additional island TOC concentration that is greater than 6 mg/L for a duration greater than 1 month would not be reliably treated by enhanced coagulation.

If elevated TOC concentrations are sustained (greater the 6 mg/L for more than one month), the Delta water could be considered non-potable. (Short duration spikes of TOC are diluted during transport and storage of the State Water Project water.) Water exports could then be used for agricultural use but not for urban drinking water use, resulting in loss of drinking water supply during portions of the island dewatering.

The additional TOC concentrations due to the flooded peat islands were estimated at Clifton Court Forebay and modeled for Cases 1 through 6. Cases 1 through 6 are described in the Delta Risk Management Strategy (DRMS) Phase 1 draft Risk Analysis Report (URS/JBA 2007). Input was acquired from the Emergency Response and Repair model and the Water Analysis Module. Water export interruption durations were determined based on salinity.

Cases 2A, 3A, 4A, 5A, and 6A represent a late spring event with a levee failure date of June 1, 1927. Cases 2B, 3B, 4B, 5B, and 6B represent a summer event with a levee failure date of August 1, 1972. Cases 2C, 3C, 4C, 5C, and 6C represent an early fall event with a levee failure date of October 1, 1930. Case 1 had an indeterminate start date; it was modeled with a June 1, 1927 levee failure date.

Two critical thresholds are determined for the model -- the level for which water treatment for TOC is necessary and the level for which water treatment by enhanced coagulation is no longer effective for TOC. In the model, the background TOC concentration for the Delta was assumed to be 3 mg/L. (A variable background concentration was not modeled.) Therefore an addition of 1 mg/L TOC would increase water treatment costs and a sustained increase of more then 3 mg/L TOC would not be able to be reliably treated by enhanced coagulation.

Cases 1 through 6 had minor to severe impacts due to increases in TOC concentrations at Clifton Court Forebay. Figures 2-17 illustrates the additional TOC concentrations expected at Clifton Court Forebay in Cases 1 through 6.

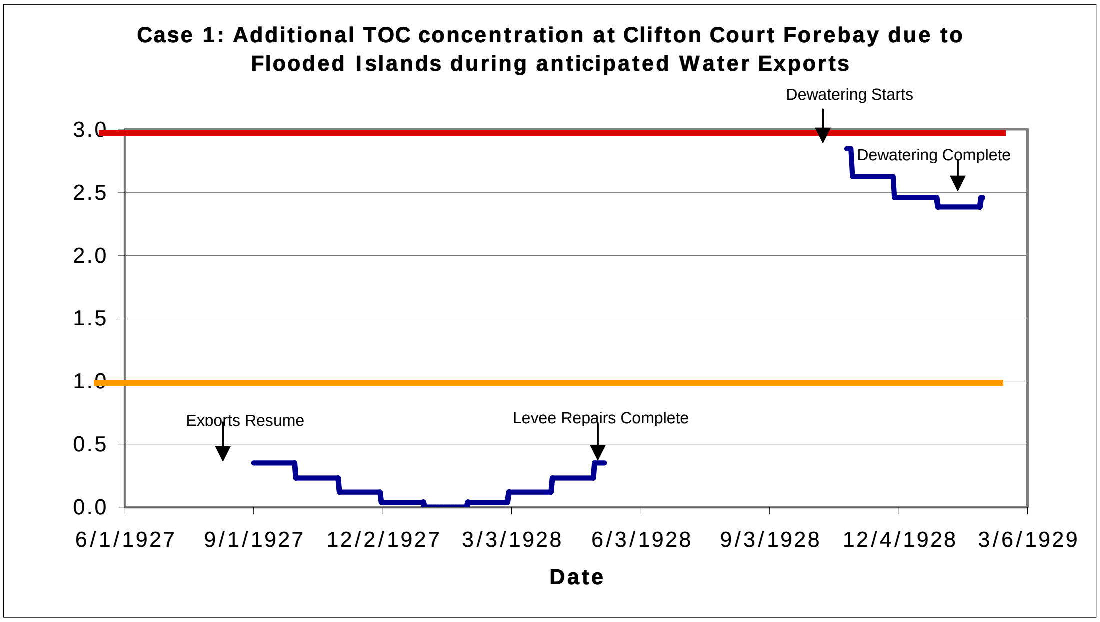


Figure 2 Case 1: One levee breach on Brannan-Andrus Island

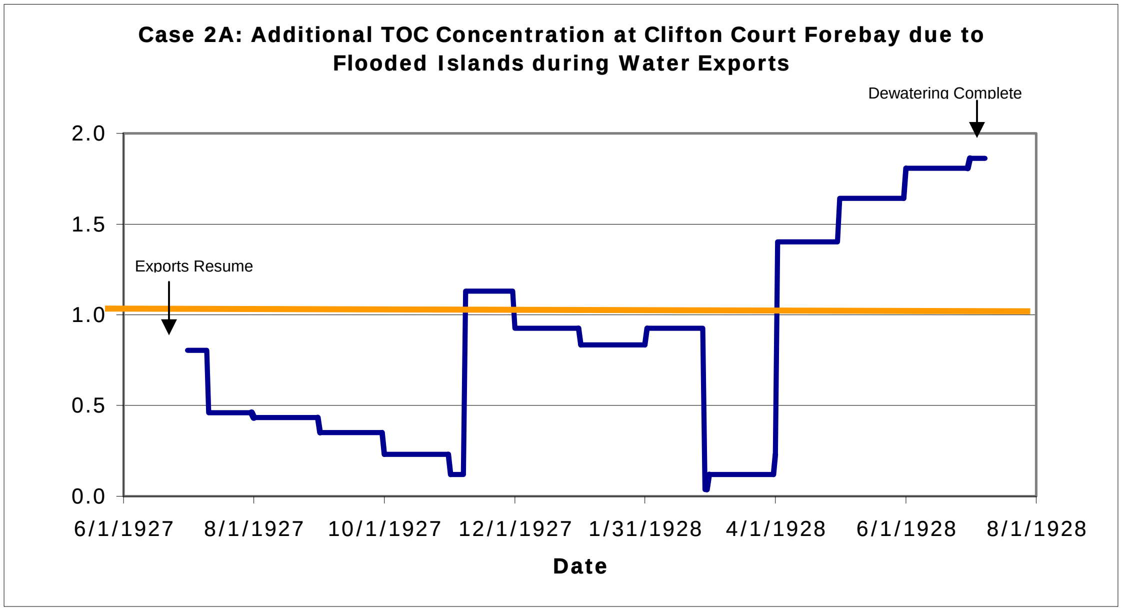


Figure 3 Case 2A: Three islands with one breach each (late spring event)

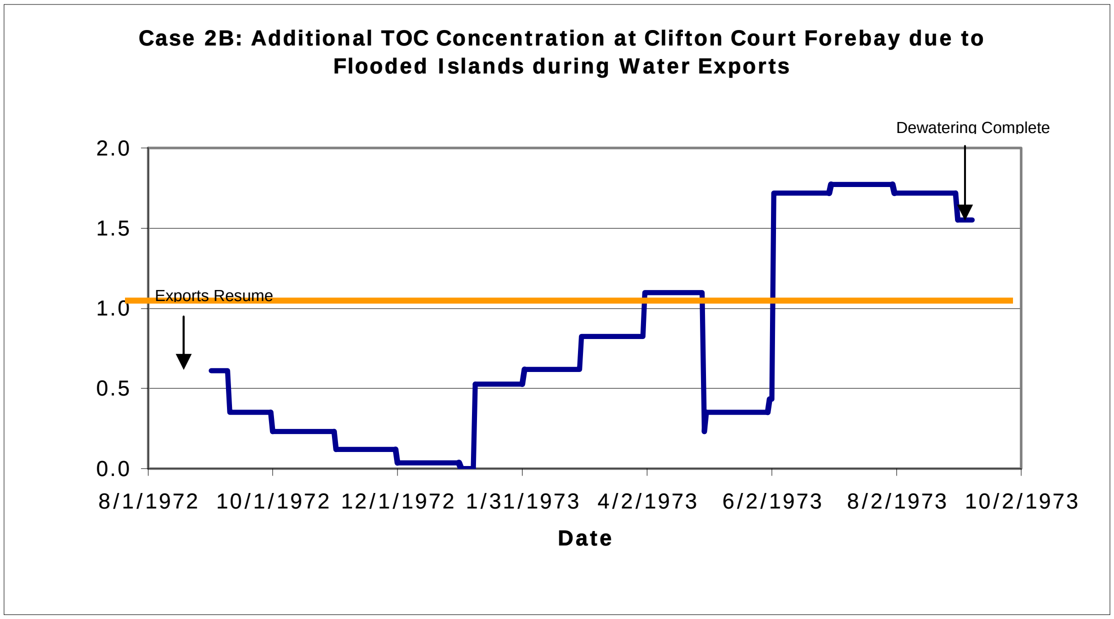


Figure 4 Case 2B: Three islands with one breach each (summer event)

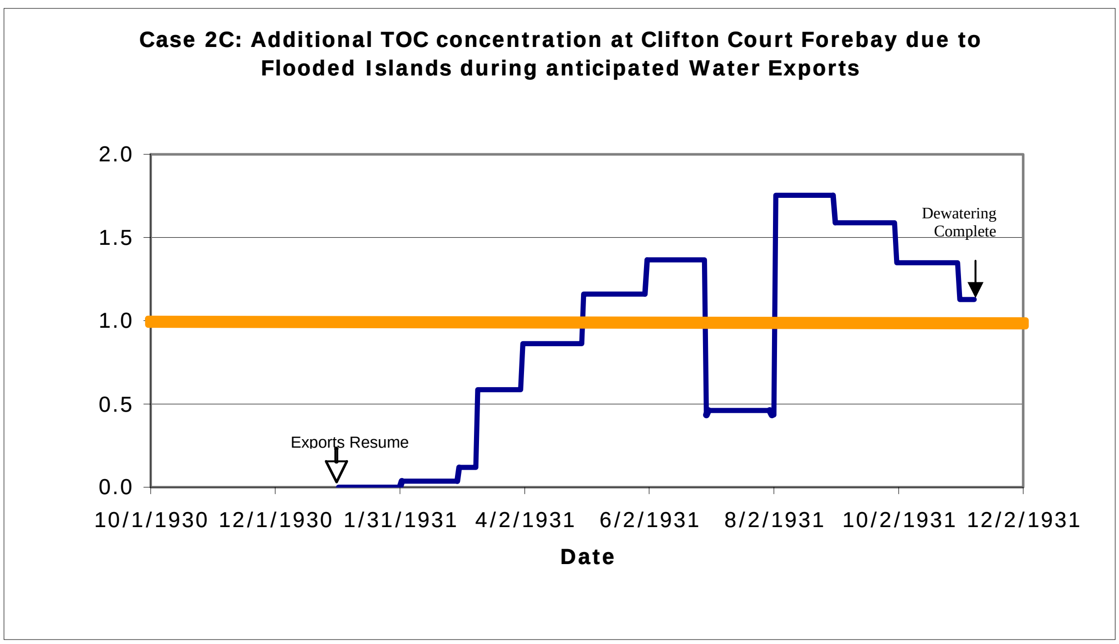


Figure 5 Case 2C: Three islands with one breach each (early fall event)

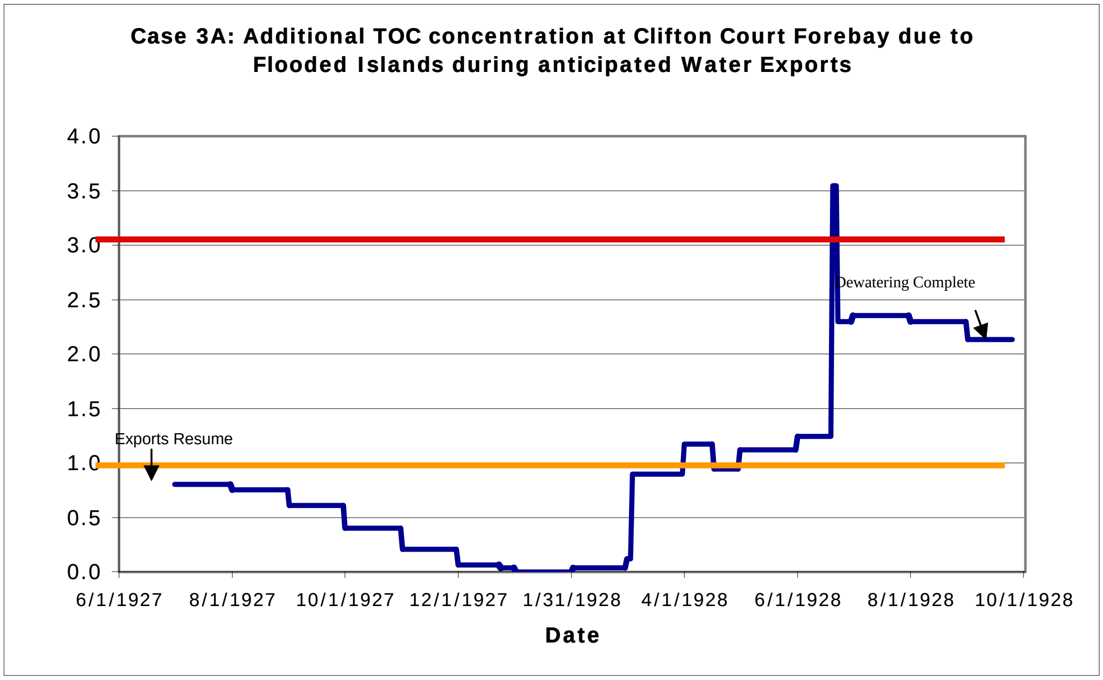


Figure 6 Case 3A: Three islands with one breach each, additional islands damaged but not flooded (late spring event)

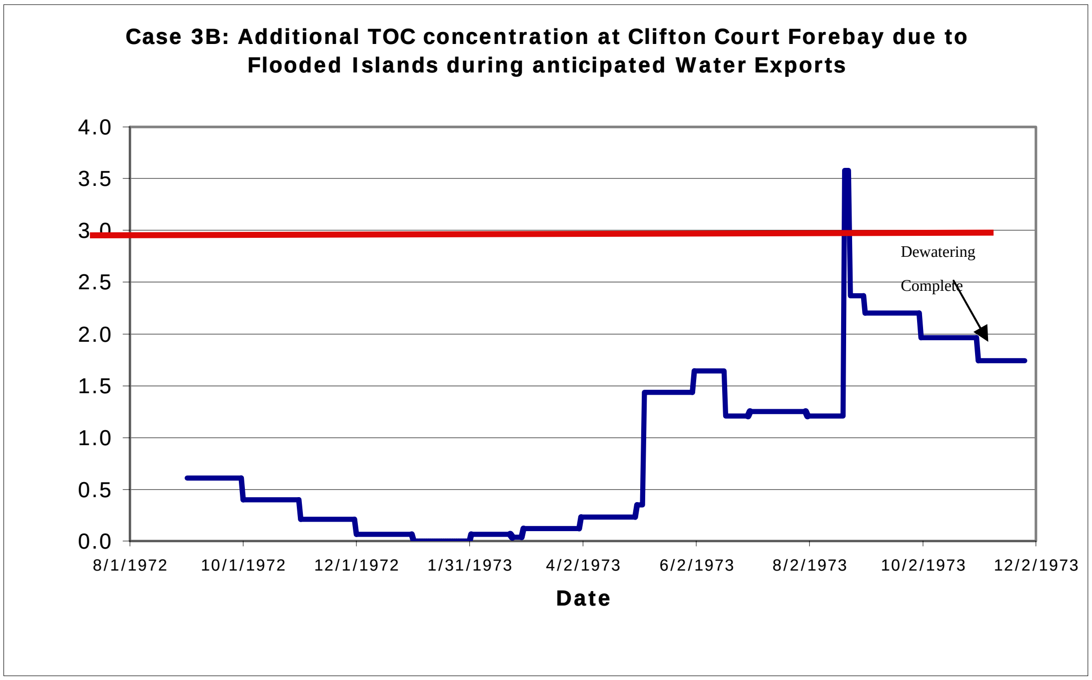


Figure 7 Case 3B: Three islands with one breach each, additional islands damaged but not flooded (summer event)

Dewatering
Complete

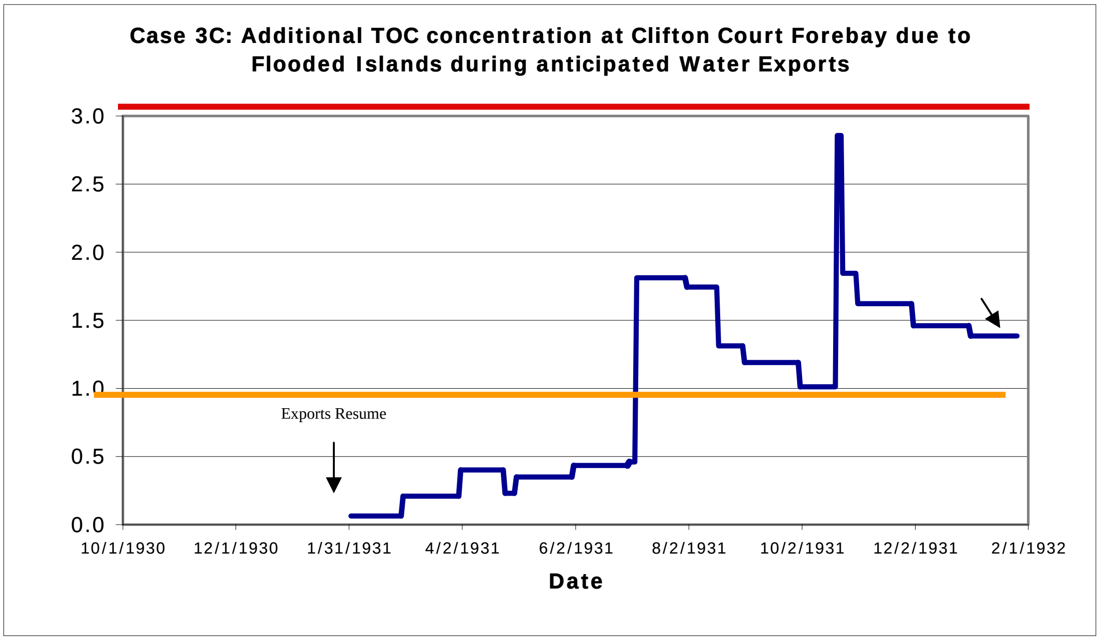
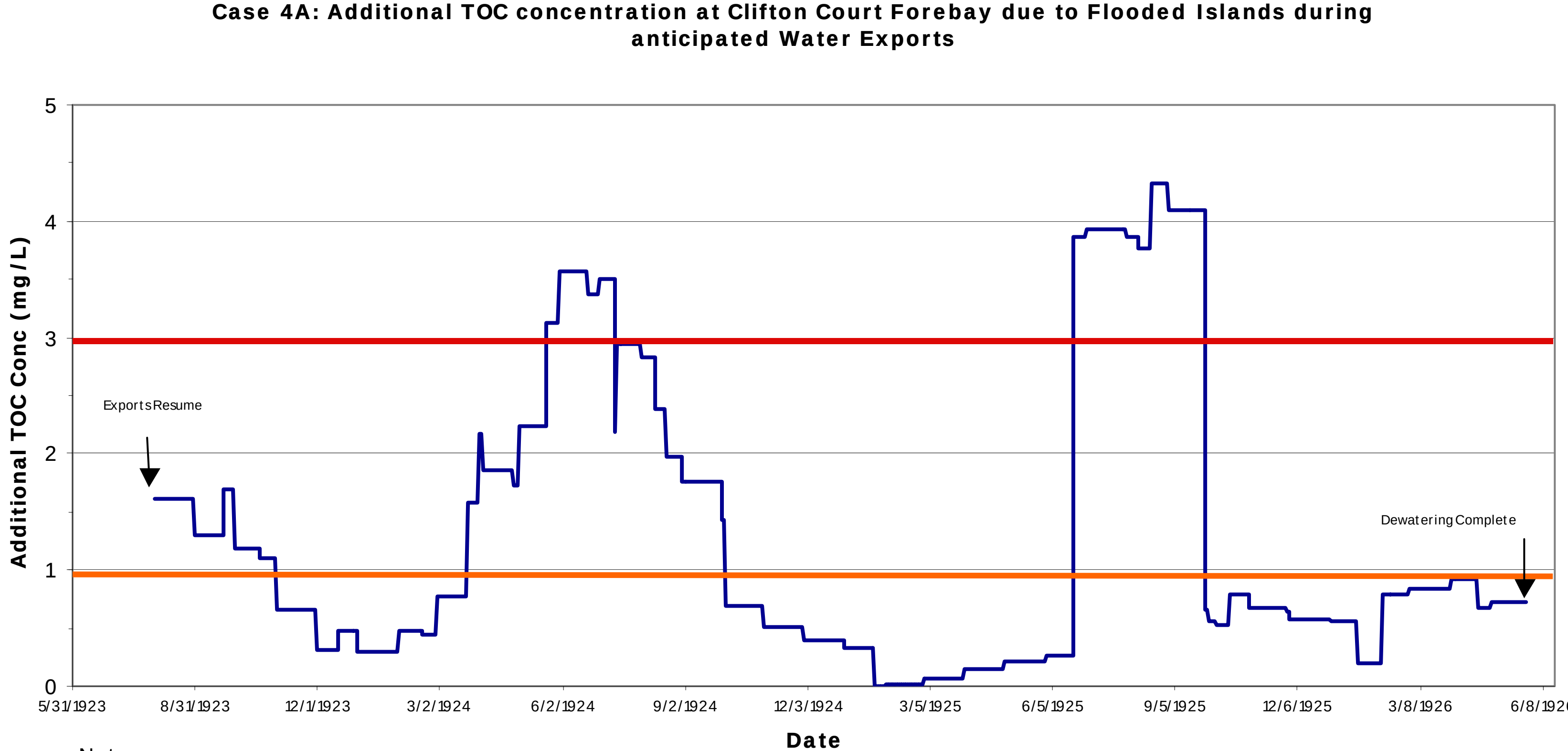
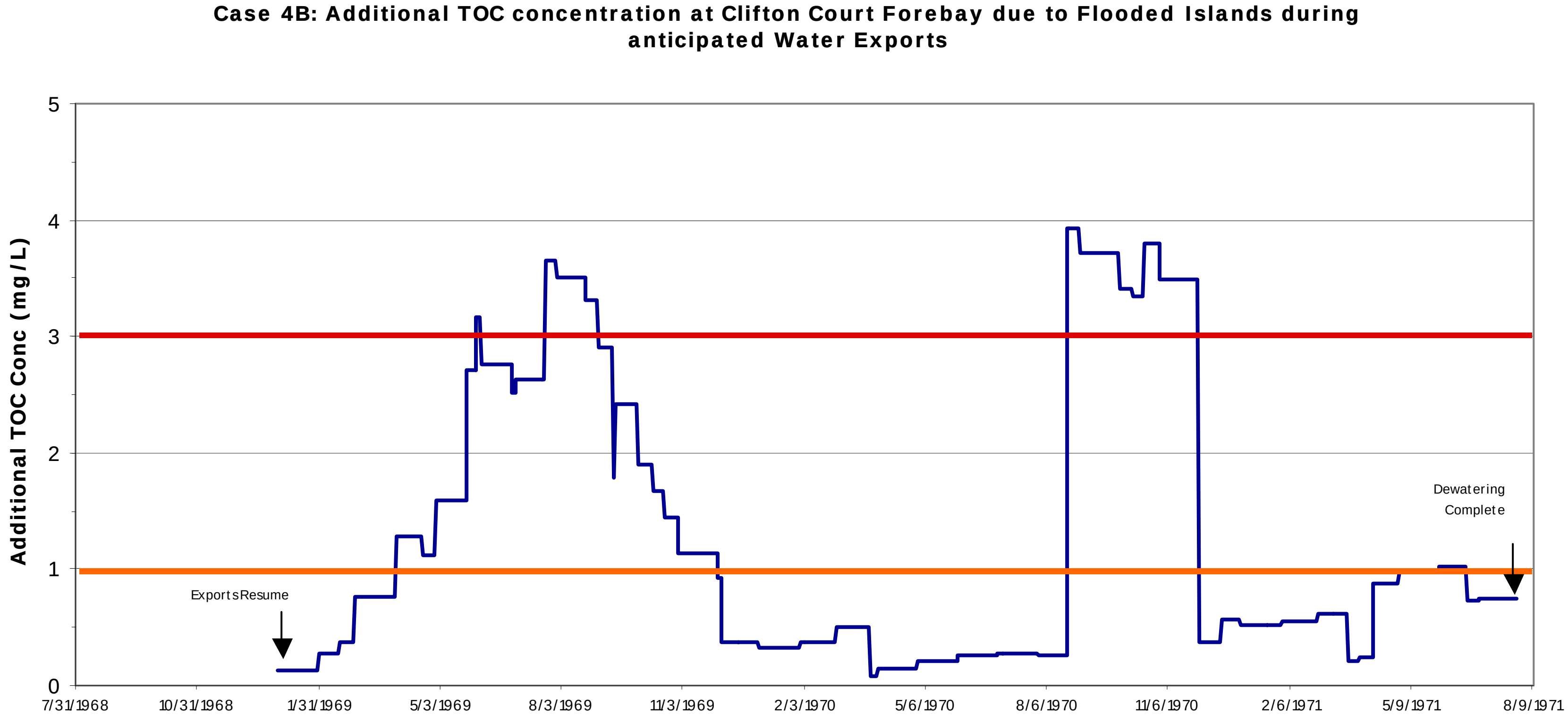


Figure 8 Case 3C: Three islands with one breach each, additional islands damaged but not flooded (early fall event)



Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

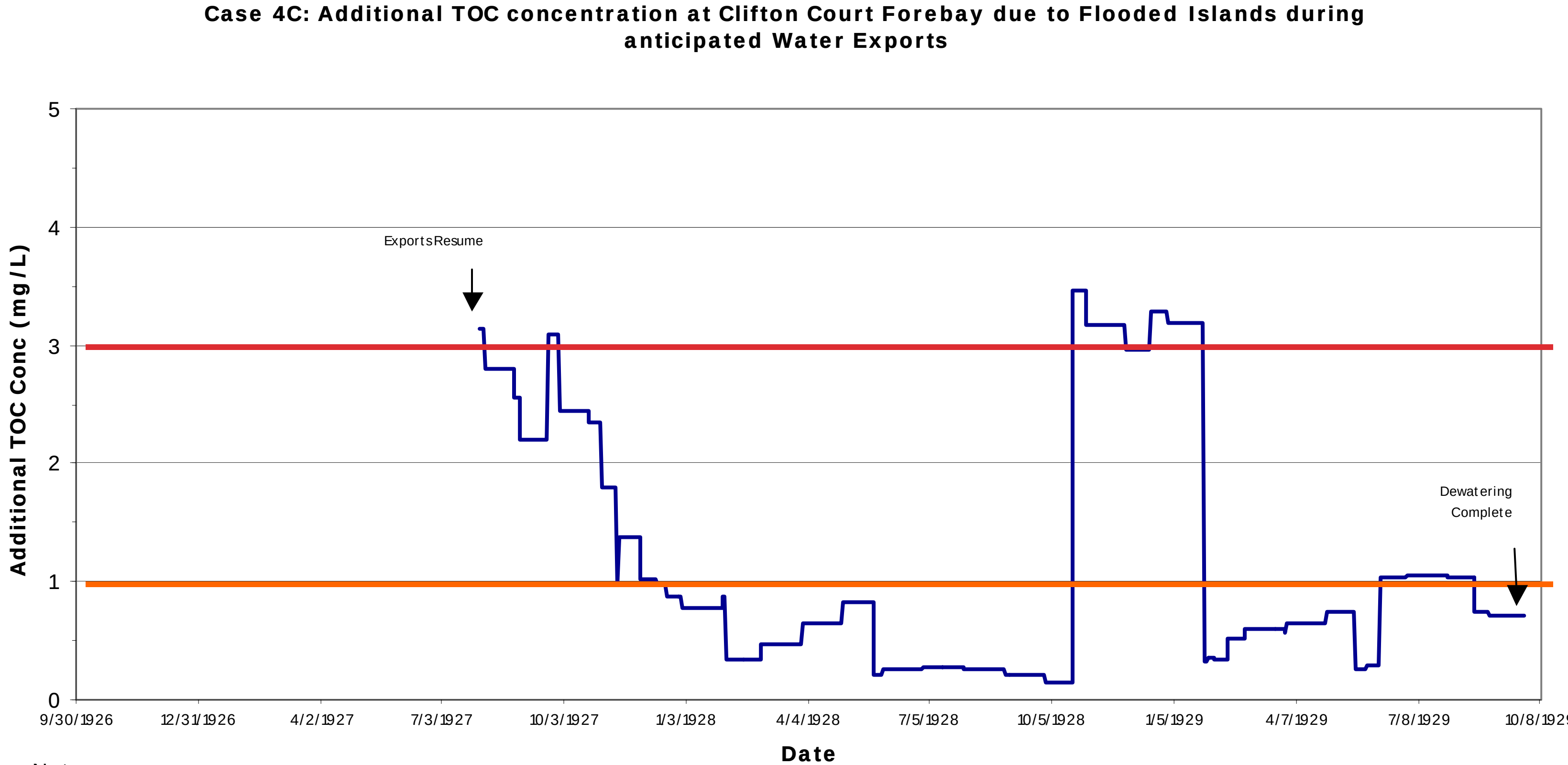
Figure 9 Case 4A: Eleven levee breaches among ten Delta islands (late spring event)



Notes:

Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

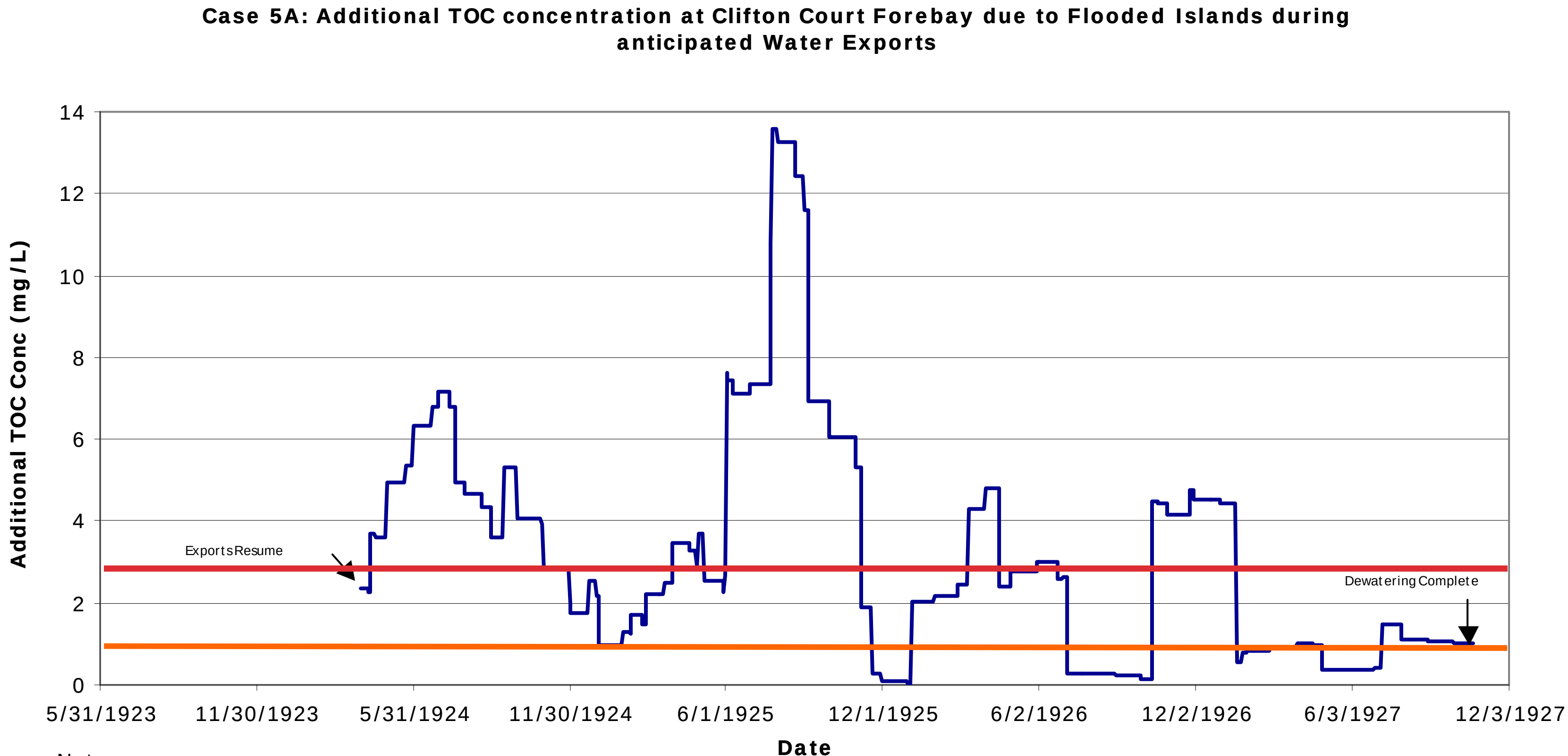
Figure 10 Case 4B: Eleven levee breaches among ten Delta islands (summer event)



Notes:

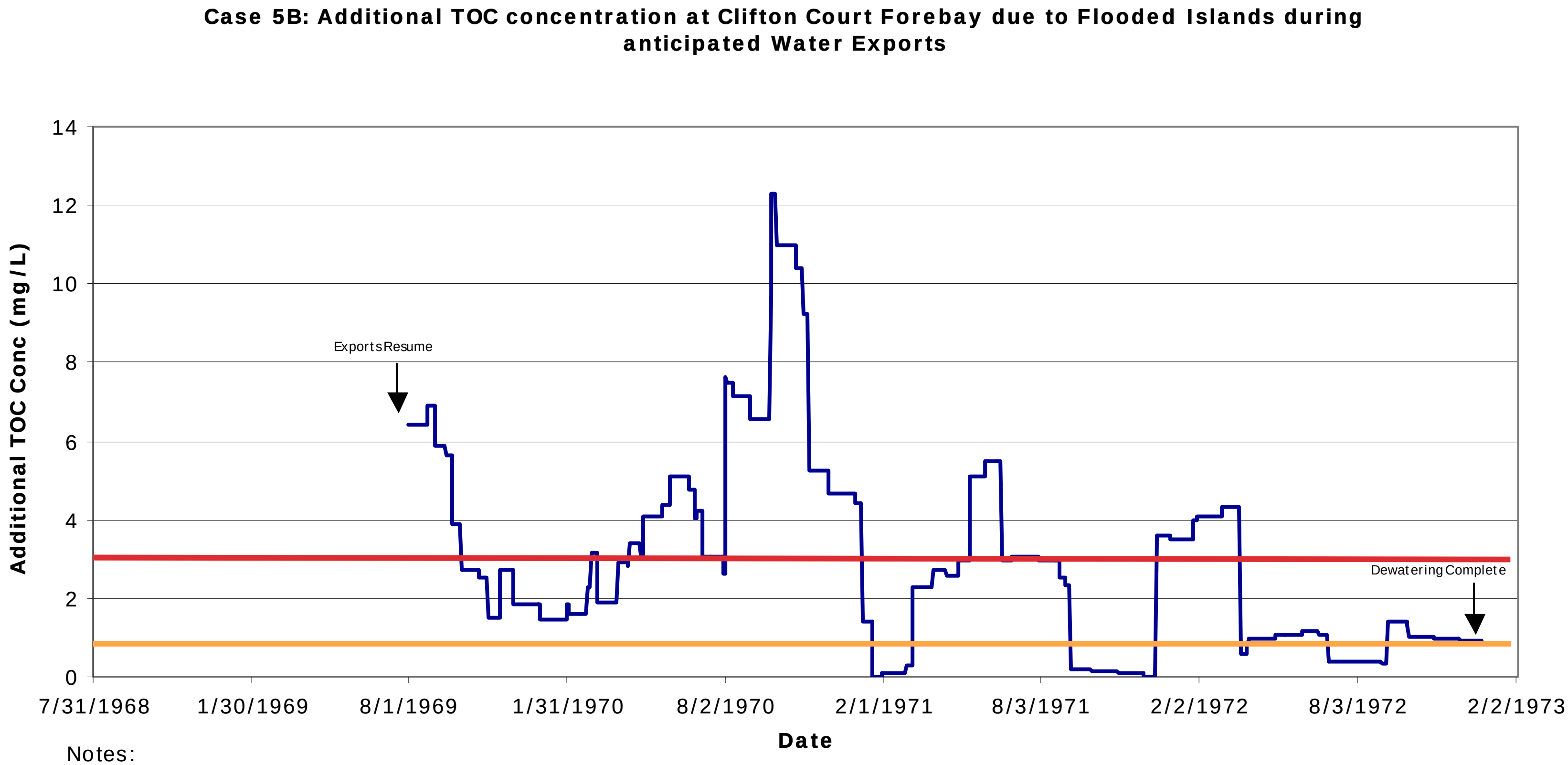
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 11 Case 4C: Eleven levee breaches among ten Delta islands (early fall event)



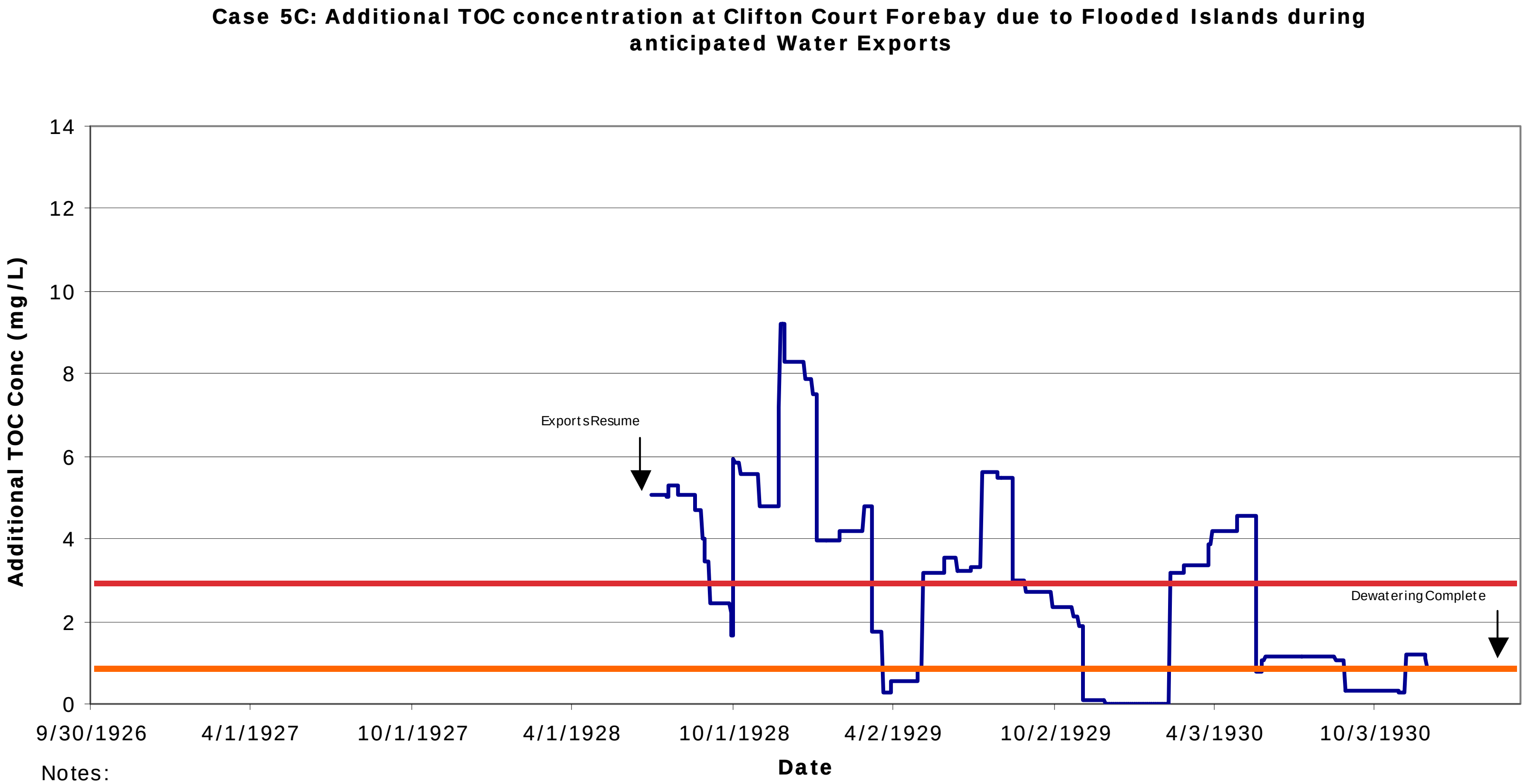
Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 12 Case 5A: Thirty-six levee breaches among twenty Delta Islands (late spring event)



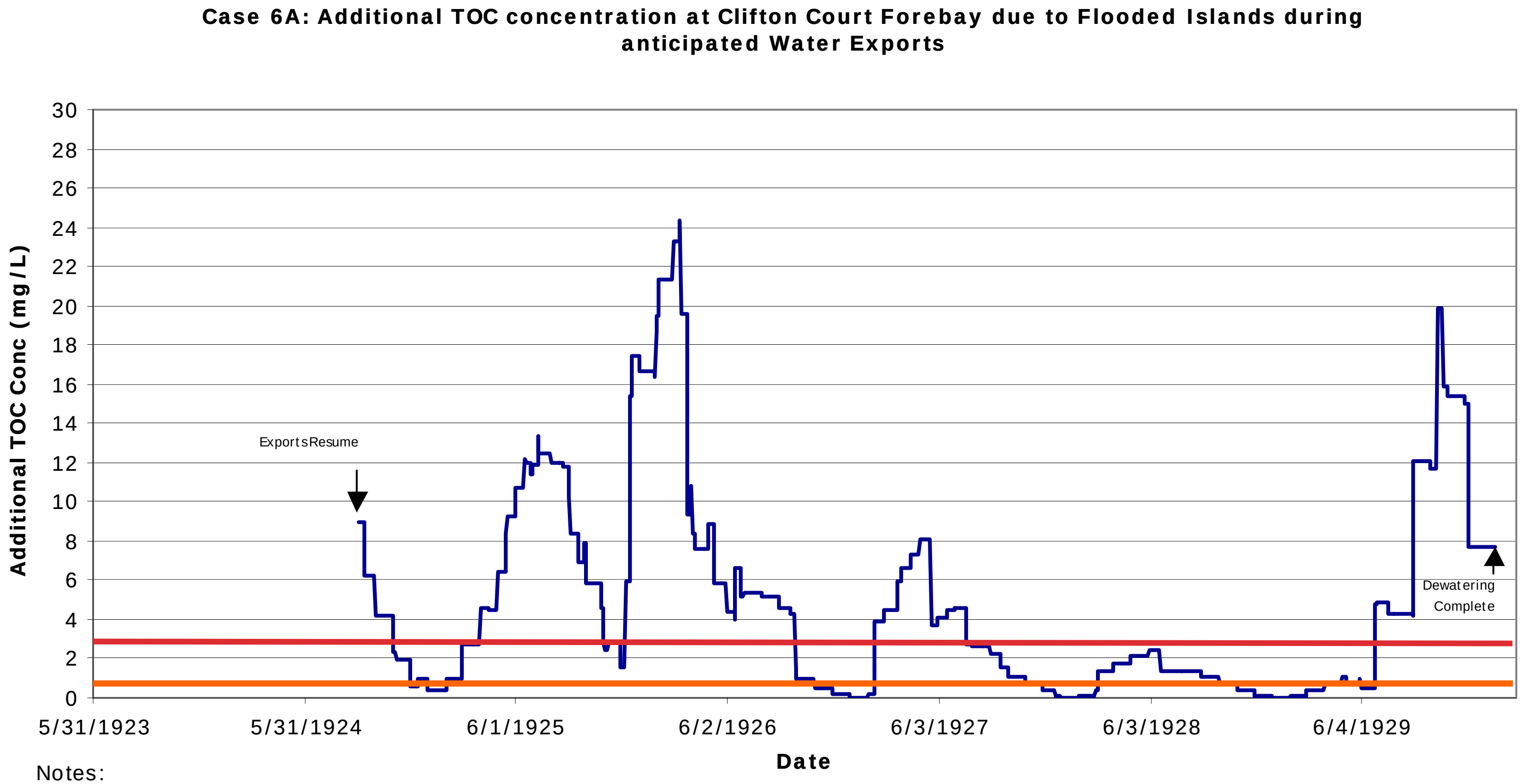
Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 13 Case 5B: Thirty-six levee breaches among twenty Delta islands (summer event)



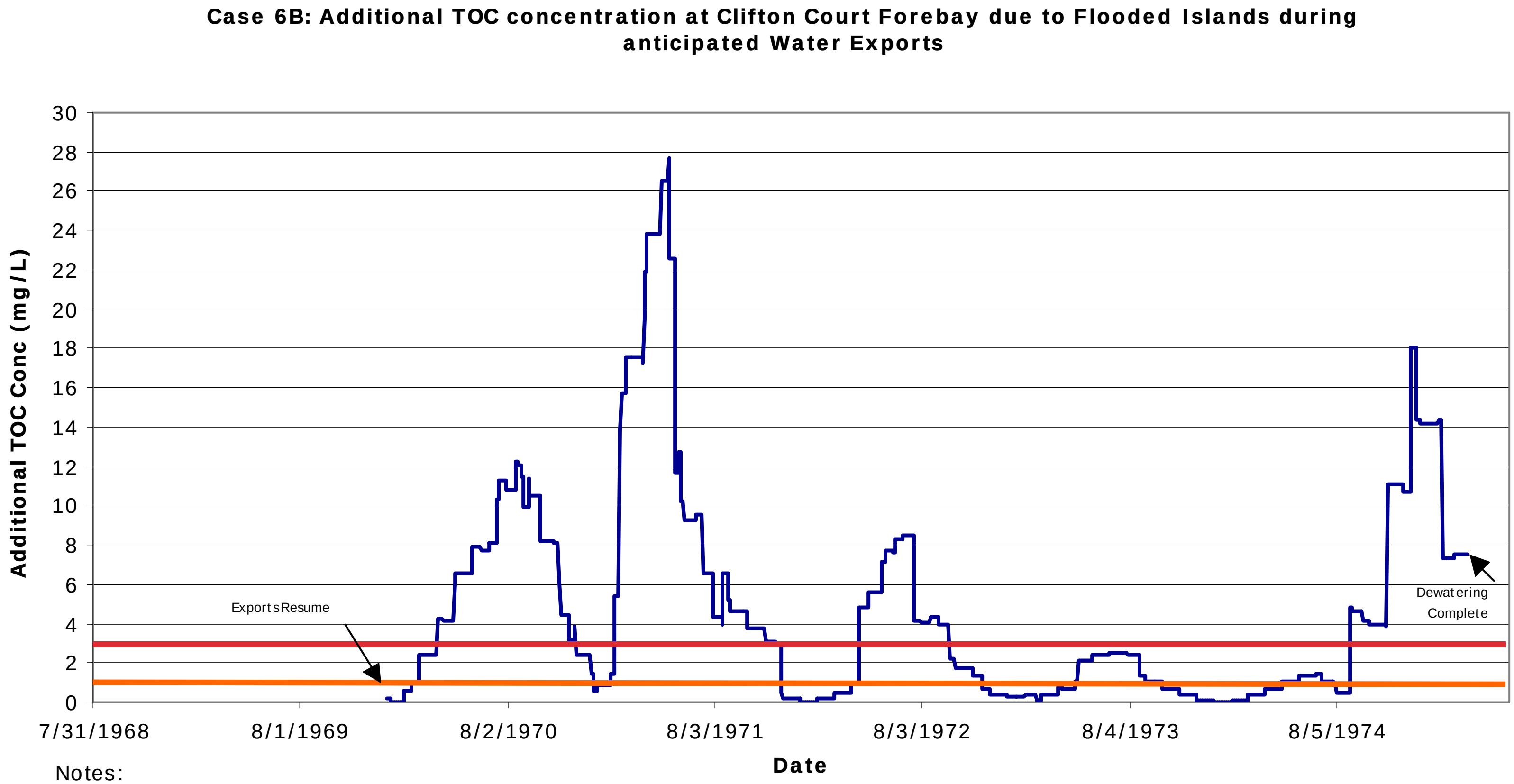
Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 14 Case 5C: Thirty-six levee breaches among twenty Delta islands (early fall event)



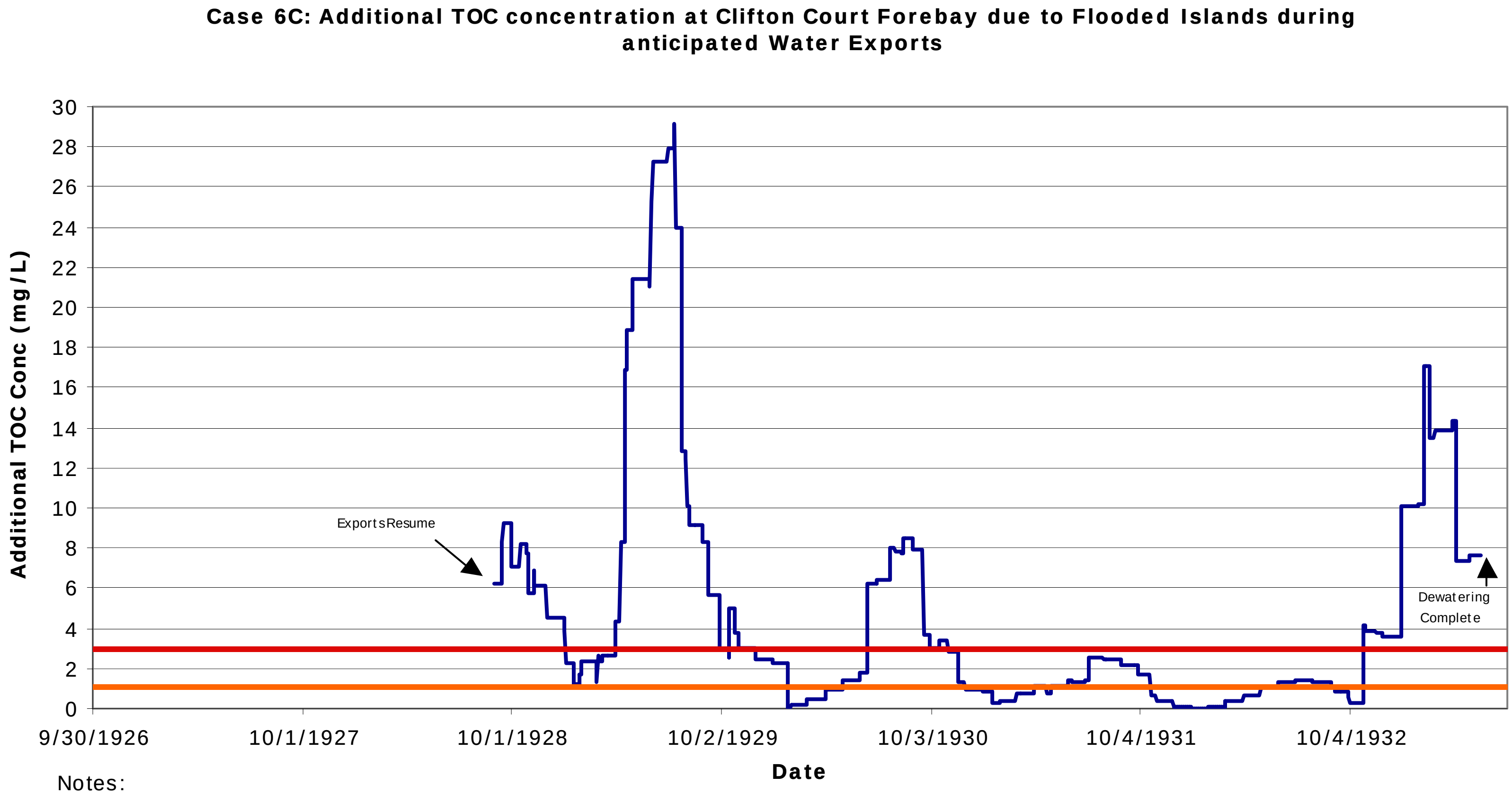
Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 15 Case 6A: Forty-six levee breaches among thirty Delta islands (late spring event)



Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 16 Case 6B: Forty-six levee breaches among thirty Delta islands (summer event)



Notes:
Assumed background TOC concentration for Delta water is 3 mg/L. Higher background concentrations may occur during winter storm events. Treatment costs are associated with a TOC increase of 1 mg/L (orange line). Treatment goal is less then 4 mg/L TOC from all sources. Exports are potentially curtailed when additional TOC is greater then 3 mg/L (red line). Treatment by enhanced coagulation is effective up to a combined background and additional TOC concentration of 6 mg/L.

Figure 17 Case 6C: Forty-six levee breaches among thirty Delta islands (early fall event)

E.6 Costs

The water treatment costs for excess organic carbon were provided by the Metropolitan Water District of Southern California. For a TOC concentration of 6 mg/L, the cost for enhanced coagulation is $18 per acre-foot. This cost is for enhanced coagulation operations and maintenance only, since Metropolitan has already made these capital investments. Enhanced coagulation operation and maintenance costs include chemical costs (coagulant and polymer) and solid handling.

A TOC concentration of 6 mg/L is considered very high and is at the upper end of the range of TOC concentrations that Metropolitan has historically observed in treatment plant influent. This cost was derived from actual treatment operations at Metropolitan's Mills treatment plant in Riverside, which treats 100% State Water Project water. If organic carbon concentrations were to occur above 6 mg/L for a sustained period of time (more than a month), additional capital investment would be required to reliably treat the water. Sustained TOC concentrations are less likely to be diluted during transport.

Table 2 shows the water treatment costs associated with Delta water that has an additional 1-3 mg/L TOC at Clifton Court Forebay. The number of days associated with the possibility of additional export interruptions is also included. Water treatment costs were not estimated for additional TOC concentrations greater then 3 mg/L. Additional water treatment costs may occur if water is exported during this time. Costs associated with additional export interruptions were not quantified.

Table 2 Estimated Costs Associated with Case 1 Through 6

Case	Possible Export Interruption (days)	Increases treatment due to TOC loading		
		Additional treatment needed (days)	Estimated Volume (acre-feet)	Estimated Treatment Cost
1	0	100	660,000	$12,000,000
2A	0	120	820,000	$15,000,000
2B	0	130	860,000	$15,000,000
2C	0	160	1,100,000	$19,000,000
3A	3	160	1,100,000	$20,000,000
3B	3	200	1,400,000	$25,000,000
3C	0	210	1,400,000	$25,000,000
4A	150	230	1,600,000	$28,000,000
4B	140	220	1,500,000	$27,000,000
4C	90	210	1,400,000	$25,000,000
5A	550	400	2,700,000	$49,000,000
5B	500	430	2,900,000	$53,000,000
5C	430	240	1,600,000	$29,000,000

Table 2 Estimated Costs Associated with Case 1 Through 6

Case	Possible Export Interruption (days)	Increases treatment due to TOC loading		
		Additional treatment needed (days)	Estimated Volume (acre-feet)	Estimated Treatment Cost
6A	940	450	3,000,000	$54,000,000
6B	900	380	2,600,000	$47,000,000
6C	700	560	3,800,000	$68,000,000

Notes:

Cost is $18/acre-foot for enhanced coagulation operations and maintenance only.

Assumes that 50% of the combined SWP (Banks Pumping Plant) and CVP exports would be treated with enhanced coagulation when the additional island derived TOC is greater then 1 mg/L and less then 3 mg/L at Clifton Court Forebay.

Assumes an average annual intake of 4,927 TAF from Clifton Court Forebay (DWR 2005).

E.7 Conclusions

A simplified model was used to estimate the amount of organic carbon production for each island in the six cases described in the DRMS Phase 1 report. Scaling factors were then applied to estimate the amount of total organic carbon (TOC) that originated from the islands and was transported to southern Delta water export facilities. The increases in water treatment costs associated with enhanced coagulation were calculated to provide an order of magnitude cost estimate for water treatment due to organic carbon increases at drinking water intakes. Additional costs would be incurred to treat the sustained increases predicted by the model in Cases 4, 5, and 6. These additional costs could include additional capital improvements by drinking water treatment facilities or the costs related to additional water export interruptions.

Repair schedules could be modified to reduce the predicted magnitude and duration of TOC concentrations. The following factors contributed to a greater organic carbon impact at Banks Pumping Plant.

- Longer duration between levee repair and island pump-out.
- Several islands pumped during the same time period.
- Accelerated island pump-out rates.
- Larger island size.
- Closer distance between the flooded island and Clifton Court Forebay (with a net flow direction to the pumps).

Hydrodynamic modeling was not used for the transport of organic carbon from the islands to the Banks pumping plant. Particle tracking would decrease the amount of uncertainty associated with the dispersion and dilution of TOC.

E.8 References

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13.1 INTRODUCTION

This section presents the results of the risk analysis associated with levee failures in the Delta and Suisun Marsh study area. The analyses are based on failures caused by various hazards identified by the Delta Risk Management Strategy (DRMS) under two conditions. The first condition addresses the present-day risk for the 2005 base year assuming business as usual (BAU), and the second condition addresses the future risks for 2050, 2100, and 2200. BAU is defined in the preamble to this report. The probabilities of the initiating events are combined with the probabilities of system failures (levee failures and island flooding), which in turn are combined with the simulated outcomes of hydrodynamics and salt intrusion, the economic costs and impacts, the ecological impacts, and the probability of loss of life to estimate the probable consequences. The detailed methodology used to estimate the risks is described in Section 4. The development of the conditional probabilities of outcome for the topics described below is discussed in each topic's respective section in this report and in more detail in the supporting technical memoranda referenced herein.

This section also provides a brief discussion of where the uncertainties associated with these topics are represented probabilistically and where they are represented by a range of outcomes when a formal uncertainty model was not available. The representation of the topics is summarized below.

- Seismic hazard characterization uses a probabilistic model for the present and future risks.
- Flood hazard characterization uses a probabilistic model for the present and future risks.
- Climate change characterization uses a range of values for the future risks.
- Subsidence uses a range of values for the future risks.
- Wind/wave hazard characterization uses a probabilistic model for the present risks.
- Levee response to seismic hazard uses a probabilistic model for the present and future risks.
- Levee response to flood hazard uses a probabilistic model for the present and future risks.
- Emergency response and repair uses simulation of all probable hazards and levee responses and estimates the cost of repair and repair duration for each sequence.
- The hydrodynamic/salinity intrusion/water management/export impacts use simulation of all probable hazards, levee failures, and emergency responses and estimate for each sequence of levee failures the loss of freshwater that otherwise would have been exported for the State Water Project and the Central Valley Project.
- Loss of life uses full probabilistic models for hazards, levee failures, island inundation, and loss of life for the seismic and flood hazards and daytime and nighttime events.
- Economic costs and impacts use simulation of all hazards, levee failures, emergency responses, and loss of freshwater for export and estimate for each sequence of levee failures the economic costs (direct) and economic impacts (indirect).
- Ecological impacts use simulation of all hazards, selected levee failures, emergency responses, and saltwater intrusion and estimate for each sequence of levee failures the

ecological impacts. The aquatic model was developed probabilistically but was not run at this time for the reasons discussed in Section 12.

In this section we occasionally report the probability of various outcomes for selected exposure periods (25 years, 50 years, etc.) in addition to annual probabilities. It should be noted that those probabilities reported for the various exposure periods represent today's risk and assume that no changes in the hazards, the state of the Delta, or the consequences are taking place during those exposure periods. This way of reporting is an alternate way to present the results for those more familiar with probability of failure and consequences in terms of exposure period. However, the exposure period results should not be interpreted as the projected future risks during those exposure periods. The time-dependent results are presented in Section 14. The risk results presented in this section are factored by the percent increases presented in Section 14 to estimate the future risks.

Previous sections of this report describe the various modules supporting the risk assessment, the characterization of their physical processes, the approach used to develop conditional probability models, and their typical output that becomes input into the risk model. Section 4 describes the risk analysis approach used to integrate the various module outputs in the risk model. This section presents the results of the system response (levee failures) to the various hazards and the consequences of such failures as summarized below. The future risks (i.e., effects of climate change, subsidence, etc., and their consequences) are presented in Section 14.

- Hazards: seismic, flood, wind-wave, and high-tide sunny-day occurrences
- System responses:
  - Levee vulnerability and probable failure modes under the above hazards
  - Emergency response and repair: particularly the order and rate of progress for repairs, including rate of erosion of flooded islands, and costs of repair
  - Salinity impacts: the intrusion of Bay salty water in response to the levee breaches and progress in returning to normal conditions over the repair period
- Consequences: public safety, environmental, and economic impacts

This section presents the results of the analyses of risks associated with the various hazards: (1) the potential for island flooding, both combined and individually, and (2) the consequences of that flooding. In so doing, the section begins with flooding potential tied to risks from:

- Sunny-day failures
- Seismic events
- Floods
- The combined risk of inundation from all hazards

After the likelihood of flooding is presented, the results of analyses of consequences of island flooding from various hazards are discussed, for each type of hazard event (sunny-day, seismic, and flood events) and for all hazards combined, as shown below.

- Economic consequences
- Ecosystem consequences

- Public health and safety consequences

It should be noted again that in this section the results are presented as annual frequencies and probabilities for the base year or, alternatively, for various exposure periods. The results presented in this section do not include the changing risks in future years. The increases to the risks for future years are presented in Section 14.

13.2 PROBABILITY OF ISLAND FLOODING

The probability of island inundation (resulting from levee breach) is presented individually for each causative event: sunny-day event, seismic event, and hydrologic (flood) event. Within each, two perspectives are adopted. The first considers possible outcomes from single events, including the prospect of multiple failures from the event, and the second considers potential flooding on an island-by-island basis, not considering what may be occurring on other islands.

13.2.1 Sunny-Day Risk

As described in Section 9, the risk of sunny-day failures, usually associated with high tides, is developed principally from historical observations. By definition, sunny-day failures occur only in the late spring, summer, and early fall (i.e., during the low-flow season) and are likely to occur during higher tides. The expected frequencies of island failures during sunny-day conditions are summarized in Table 13-1. The results were compiled for the islands and tracts within the mean higher high water (MHHW) boundary shown in Figure 13-1. About 911 miles of Delta levees and about 75 miles of exterior levees in Suisun Marsh lie within the MHHW boundary. The expected annual frequencies of historical breaches are about 1.06×10^{-4} /year/levee mile or 0.0969 failures/year for the Delta and 4.76×10^{-4} /year/levee mile or 0.036 failures/year for Suisun Marsh. These rates are applied uniformly to all levees within the MHHW boundary in the respective areas.

The historical record for Suisun Marsh is limited and incomplete. The only available information on sunny-day failures for Suisun Marsh consists of two data points that only go back to 1999. Prior information is not available.

Assuming no changes to the Delta and its drivers of change, it is expected that about 4.8 sunny-day breaches will occur on average in the Delta during a 50-year exposure period or 9.7 breaches during a 100-year exposure period. It is estimated that about 1.8 sunny-day breaches will occur on average in Suisun Marsh during a 50-year exposure period or 3.6 breaches during a 100-year exposure period. These estimates will change with the future years' risk, as discussed in Section 14.

Sunny-day failures are assumed to occur one island at a time. Historically, no simultaneous sunny-day failures have been observed. Consequently, for the 2005 base case conditions, the frequency of two or more sunny-day failures occurring during the same sunny-day, high-tide event is assumed to be insignificant. Further, it is assumed that the likelihood of increased seepage on adjacent islands that leads to a levee breach that results in additional island flooding is small (based on the occurrence of such events in the historical records). This assessment is consistent with the 2004 Jones Tract sunny-day failure that showed no adverse conditions that could have led to the failure of another island. However, increased seepage flows were observed on adjacent islands after the Jones Tract Failure (i.e., Woodward Tract [DWR 2004]).

13.2.2 Seismic Risk

When an earthquake occurs, all Delta and Suisun levees may be subject to dynamic loading and potential failure within several minutes—essentially simultaneously. If an earthquake is strong enough to cause the failure of one island, it is likely that other islands with the same or higher vulnerability would also fail. Thus, a strong earthquake affecting the study area could cause levee failures on several islands, and there is a real prospect of multiple islands flooding at the same time. For the seismic analysis, the highest, most likely water level that would exist both during and after an earthquake is the mean higher high water, as discussed in Section 7. Therefore, the islands included in the seismic analysis are those within the boundary of the MHHW, as shown in Figure 13-1. Figure 13-2 shows the annual frequency of exceeding a number of simultaneously flooded islands as a result of a seismic event in or in the vicinity of the Delta and Suisun Marsh. The figure shows the mean frequency of exceedance and the estimate of uncertainty calculated from the uncertainty in the ground motion hazard and the levee fragility uncertainties (which were discussed in more detail in Section 6 and in the Seismology Technical Memorandum (TM) [URS/JBA 2007a] and the Levee Vulnerability TM [URS/JBA 2008c]). Some key statistics from the figure are shown in Table 13-2.

If we take the specific case of 30 or more simultaneous island failures from Table 13-2, that outcome has about a 38 percent probability of being exceeded in an exposure period of 25 years.

Figure 13-3 shows the contribution of different seismic sources to the frequency distribution on flooded islands.

The 2005 base case results can be used to estimate the probability of island flooding events in 2005 caused by a seismic event. These estimates assume existing (2005) conditions prevail; they do not consider the increasing hazard potential or the changes in levee vulnerability that may exist in the future. Figure 13-4 shows the probability of exceeding a number of simultaneous island failures due to seismic events for 25-, 50-, and 100-year exposure periods.

Each island was also analyzed individually to estimate its annual frequency of failure caused by seismic events. This analysis answers the question, “How likely is it that a given island will flood as a result of an earthquake?” It does not consider whether other islands are or are not flooded at the same time.

Table 13-3 presents the estimated annual frequency of failure for each island in the study area. The islands were grouped into five seismic risk categories for different ranges of frequency of failure. The ranges include less than 0.01/year, 0.01 to 0.03/year, 0.03 to 0.05/year, 0.05 to 0.07/year, and greater than 0.07/year. The results indicate that the island levees are highly vulnerable to seismic shaking. The study area has been grouped into three regions: Delta, Suisun Marsh, and Cache Slough. Of the 70 Delta islands/tracts analyzed (within the MHHW boundary), 11 have frequency of failure per year of less than 0.01, 39 islands have a frequency of failure per year of 0.01 to 0.03, and the remaining 20 islands have a frequency of failure per year of between 0.03 and 0.05. All islands/tracts analyzed in the Suisun Marsh area have a frequency of failure per year of 0.01 to 0.05. All islands/tracts within the Cache Slough region have a frequency of failure per year of less than 0.02. Figure 13-5 illustrates the number of islands within each range of mean failure rates.

Table 13-4 summarizes the contributions of all seismic sources to island failures. Figure 13-6 presents the percent contribution from the major seismic sources to the island failures by region, as explained by the examples discussed in the bullets below. Figure 13-7 presents a color-coded map showing the range of the annual failure frequency of individual islands caused by seismic events. The contributions from the different seismic sources for the three identified study regions are summarized as follows:

- **Delta**: Hayward fault: 16 percent; Calaveras fault: 10.5 percent; Southern Midland fault: 9.5 percent; San Andreas fault: 9.5 percent; Mt. Diablo blind thrust fault: 5.5 percent; CRSB fault zone: 5 percent; Northern Midland fault: 5 percent; Creek-Berryessa fault: 5 percent; and the remaining sources: 34 percent.
- **Suisun Marsh**: Concord-Greenville fault: 14.5 percent; Hayward fault: 14.5 percent; Calaveras fault: 5.5 percent; San Andreas fault: 4 percent; and the remaining sources: 61.5 percent. (Many other local faults contribute equally to the hazard in Suisun Marsh.)
- **Cache Slough**: Northern Midland fault: 17 percent; Hayward fault: 14 percent; CRSB fault zone: 9 percent; Southern Midland fault: 8 percent; Hunting Creek-Berryessa fault: 7.5 percent; San Andreas fault: 6 percent; and the remaining sources 38.5 percent.

A few faults contribute relatively equally to the seismic hazard in the Delta region. The Hayward fault is the highest contributor to the hazard in the Delta. The Hayward and Concord faults are the highest contributors to the hazard in Suisun Marsh, and the Hayward and Northern Midland faults are the highest contributors to the hazard in the Cache Slough area.

Unlike for sunny-day and hydrologic (flood) events, the predicted failure frequencies for seismic events cannot be compared directly to historical failure frequencies for several reasons. First, seismic events are infrequent and hence do not provide a sufficient number of data points to calculate reliable statistics on the average failure frequency. This point is particularly relevant for the Delta levees, which have only existed in their current configurations for about 50 years.

Second, the recurrence process of seismic events (seismicity) is dependent on past history. For example, the probability of an earthquake may increase after a “seismic gap”; that is, an extended period with no major earthquake (see Figure 13-8 for the period between 1906 and 1989 [USGS 2002]).

Because the Delta region has not experienced a major earthquake over the past 100 years, the probability of a major earthquake is higher now. The DRMS seismic hazard analysis incorporates time-dependent seismicity models. The recorded earthquake ground motions in the Delta region (expressed as peak ground acceleration [PGA]) since the levees have been in their current configurations have been less than 0.1g (more accurately, around 0.05g). However, the faults in this region are capable of generating earthquakes that could result in ground motions (PGAs) in excess of 0.3g. The fact that no ground motion greater than 0.1g has been experienced in the Delta region in the past 100 years does not mean that such an event could not occur in the future. In fact, if a time-dependent seismicity model were assumed to apply, the probability of such an event would be higher now than before.

For example, between 1838 and 1906 (68 years), three major earthquakes occurred in the Bay Area region of magnitude greater than 6.5 and more than a dozen of magnitude between 6.0 and 6.5. The period from 1906 to today (102 years) has been relatively quiet (as far as earthquakes with magnitudes higher than 6.5) except for the 1989 Loma Prieta earthquake. One can reasonably expect that the cycle of higher seismic activities could return, particularly considering the more recent seismic activities beginning in 1969 (see Figure 13-8) and considering the strain accumulation in the tectonic plates since 1906. If we return to the pre-1906 period, it is conceivable that two to three major earthquakes could occur in the region, as indicated in Figure 13-8.

Comparison with Other Seismic Risk Studies and Case Histories

In the absence of historical events in the study area to compare with the results of this work, we compared the results of this work to relevant studies that others have done in the study area. Also, we compared the results of this work to available case histories outside the study area.

The CALFED study (CALFED 2000b) proved to be the most relevant past study for purposes of this comparison, because that study also analyzed the behavior of the Delta levees under seismic loading. Differences between the studies were established before the comparison was made. This allows the differences and similarities to be put in context.

- The CALFED study analyzed the frequency of levee failures, whereas the DRMS study analyzed the frequency of island failures (taking into account the possibility of multiple levee failures on any given island).
- The DRMS study used the most recent updates for both the seismic sources and the new attenuation relationships, as discussed in the Seismology TM (URS/JBA 2007a). Figure 6-21 in Section 6 presents a comparison of ground motions (PGAs for a 100-year return period) at six sites in the Delta and Suisun Marsh from the DWR 1992, CALFED 2000b, and DRMS studies. That comparison has shown that generally the ground motions are similar.
- The DRMS study used more than 2,000 boring logs, a number of cone penetration soundings, and downhole geophysical surveys to characterize the Delta and Suisun Marsh levee and foundation conditions. Because of the extensive data characterization, the geographic discretization of the project area extended down to multiple levee classes within each reach and multiple reaches within each island. The discretization was small enough to be able to represent the variation of levee fragilities within each island. The CALFED study relied on a coarser mesh of four sectors representing the Delta, which was appropriate for the scope and schedule allocated for that study.

The differences in the modeling details and the presentations of the results (levee breaches versus island failures) make it difficult to draw a one-to-one comparison of the results between the two studies.

Comparison of the study results with two case histories of known levee failures during past earthquakes were presented in Section 6. These two case histories included the 1995 Kobe, Japan, **M** 6.9 earthquake and the 1989 Loma Prieta **M** 6.7 earthquake. The Kobe earthquake represented the high ground motion benchmark, with a PGA at the levee site in Japan in excess of 0.5g. The Loma Prieta earthquake was more of a moderate ground motion benchmark, with an estimated PGA of 0.28g to 0.33g at the levee failure site along the Pajaro River in Watsonville, California. The observed deformations from these two cases were found to be consistent with the model results of this study, as discussed in Section 6.2.6.7.

The Delta has experienced low ground motions (PGAs of less than 0.1g) during small and recent earthquakes. No levee damage was reported during those small events. For the same ground motions, the response functions developed for the Delta in this study predict insignificant to no damage to the levees for the same events (see Section 6.2.6.7).

In summary, the calculated ground motions in DRMS are generally similar to those calculated in the CALFED 2000b study and the DWR 1992 study. Furthermore, the observed levee failures in the reported case histories are similar to the calculated deformations in this study for low, moderate, and high ground motions.

After completion of the levee response model to earthquake shaking, and the comparison with other studies and case histories, an analysis scenario was performed that considered an earthquake on the Hayward fault. The results of a simulated earthquake of **M** 7.2 on the Hayward fault are presented in Figure 13-9. The estimated mean number of island failures is about 50. The probability of 10 to 15 island failures is very high. Figure 13-9 presents estimates of the number of flooded islands resulting from a large earthquake on the Hayward fault. It should be recognized that many islands, though not flooded, will likely be damaged during a Hayward fault event and would need repair. The cost and duration of repairs are addressed in the consequences part in Section 13.3 for all outcomes from all events.

13.2.3 Hydrologic (Flood) Risk

Hydrologic events (floods) are major occurrences that can result in several islands flooding as a result of a single event. The expected number of simultaneous island failures under a large hydrologic event would be smaller than under a large earthquake event. However, hydrologic events (floods) are more frequent than earthquake events and would cumulatively cause more island failures over a long period. Figure 13-10 presents the frequencies of exceeding a number of simultaneous island failures due to a flood event. Figure 13-10 presents both the median frequency of exceedance and the uncertainties calculated from hazard and fragility functions (discussed in Section 7). Key statistics from Figure 13-10 are summarized in Table 13-5.

A comparison of flood events to seismic events indicates that 30 or more islands have about a 21 percent probability of being flooded under a single hydrologic event (Table 13-5), whereas the same number of islands would have about 38 percent probability of being flooded under a seismic event in 25 years (Table 13-2). However, the probability of a smaller number of simultaneous island failures occurring during hydrologic (flood) events is larger than for seismic events.

The 2005 base case results can be used to estimate the probability of island flooding events in 2005 as a result of hydrologic events. These estimates assume that existing (2005) conditions prevail; they do not consider the increasing hazard potential or the changes in levee vulnerability that may exist in the future. The changing risk picture over time is discussed in Section 14. Figure 13-11 shows the probability of exceeding a number of simultaneous island failures due to hydrological events for 25-, 50-, and 100-year exposure periods. For simplicity, no uncertainty bounds are shown; they would be similar to the ones shown in Figure 13-10.

Each island was also analyzed individually to estimate its annual frequencies of failure as a result of flood events. For islands for which sufficient historical flooding data were available, the model-estimated failure frequency was compared to the observed failure frequency. Table 13-6 presents the results of individual islands' annual frequency of failure and the probability of at least one failure in 25-, 50-, and 100-year exposure periods.

The islands were then grouped into five flood risk categories for different ranges of annual frequency of failure. The ranges were as follows: less than 0.01/year, 0.01 to 0.03/year, 0.03 to 0.05/year, 0.05 to 0.07/year, and greater than 0.07/year, as shown in Figure 13-12. Figure 13-12 also shows the number of islands within each annual failure frequency range.

In a manner similar to that used in the seismic case, the study area has been grouped into three regions: the Delta, Suisun Marsh, and the Cache Slough area. The results from the flood risk analysis are considered separately to assess the performance of levees during and after flooding in these regions. The number of islands evaluated for the flood risk are those islands and tracts within the boundary of the 100-year flood zone, as shown in Figure 13-1. The number of islands analyzed for the seismic risk and the flood risk are consequently different.

Of the 93 Delta islands and tracts analyzed (number of islands within the 100-year flood zone), 46 islands have a frequency of failure per year of less than 0.01, 33 islands have a frequency of failure per year of between 0.01 and 0.03, 11 islands have a frequency of failure per year of between 0.03 and 0.05, and 4 islands have a frequency of failure per year of between 0.05 and 0.07. The islands/tracts in Suisun Marsh have a frequency of failure per year of greater than 0.07. The levee crest elevations in the Suisun Marsh area are generally lower than in the rest of the Delta and therefore prone to more frequent overtopping at low-return-period water stages. In a few locations, the Suisun Marsh levees have been lowered to allow tidal exchange. It should also be noted that the consequences of failures in Suisun Marsh are not as significant as those for the Delta. The islands/tracts in the Cache Slough area have a frequency of failure per year of less than 0.03. Figure 13-13a shows a color-coded map of the range of the annual failure frequency of individual islands caused by hydrologic (flood) events. Figure 13-13b shows a comparable map of historical flood failures in the Delta since 1900. It should be noted that no complete data set exists for Suisun Marsh.

13.2.4 Combined Risk of Island Inundation

Figure 13-14 shows the comparison of the mean frequency distributions on the number of flooded islands caused by the three initiating events (sunny-day, seismic, and flood events). Only the seismic and flood distributions show up on the figure. As indicated above, the annual frequency of multiple sunny-day failures is insignificant. As a result, normal sunny-day failures appear as a point in the figure. Key values from Figure 13-14 are summarized in Table 13-7 for the annual frequency of exceedance and three exposure periods (25, 50, and 100 years). It is worth noting from Figure 13-14 that the flood events produce higher frequency of failure up to 10 flooded islands, whereas the seismic events produce higher frequency of failures for more than 10 flooded islands. For example, the frequency of exceeding 3 flooded island is about 22% for flood events and 8% for seismic events (2.75 times higher). Whereas the frequency of exceeding 50 flooded islands is about 0.1% for flood events and 0.8% for seismic events (8 times higher).

Figure 13-15 presents the probability of exceeding various numbers of islands flooding due to any causes (sunny-day events, earthquakes, or floods). The figure presents probability of exceedance for the same three exposure periods (i.e., 25, 50, and 100 years).

The consulting team also combined the contributions of all hazards to calculate the overall risk of individual island flooding. Table 13-8 shows the aggregated risk for each island from all hazards combined. Figure 13-16 depicts the risk by island in the same five color-coded ranges used in the previous cases.

13.3 CONSEQUENCES

Any Delta levee failure has consequences—for public safety, the state economy, and the ecosystem. Potential consequences are discussed in detail in Section 12. Each island has its own assets and resources, as summarized in Section 12 and in the Impact to Infrastructure TM (URS/JBA 2007f). However, a single stressing event that could cause the simultaneous failure of levees on multiple islands and subsequent flooding of these islands may have much larger consequences than those associated with the failure and flooding of the individual islands involved. This section considers the range of potential consequences and, especially, the escalation of consequences in multi-island failure events.

13.3.1 Seismic Consequences

To estimate the consequences that would result from levee failures initiated by a seismic event, Monte Carlo simulations were performed to generate sequences of levee failure events. The simulations were conducted for the range of earthquake magnitudes and earthquake ground motions that could occur and the performance of Delta levees. For each sequence of levee failures and combinations of island flooding, the consequences in terms of loss of life due to flooding, the economic consequences, and ecological impacts were evaluated. All uncertainties associated with each variable in the sequences of levee failures were formally carried through the simulation, including the consequences when a probabilistic model was used (i.e., life losses).

Each sequence of levee failures defines the state of each levee and island in the Delta given the occurrence of an earthquake (see the discussion in Section 4). The first step in the consequence analysis is the assessment of the cost and timing of emergency levee repairs. Given the timing of the repairs, the hydrodynamic response of the Delta is evaluated to assess the extent of the salinity intrusion that occurs and the impact of the salinity on water quality. Because an earthquake can occur at any time of year or during any particular year (and thus at random during a hydrologic cycle), the hydrodynamic analysis also considers this randomness in the evaluation of hydrodynamic response of the Delta. Using the historical hydrologic record as a dataset, earthquake occurrence times (in terms of months of the year and hydrologic year) are simulated to generate random event start times. For sequence and random start time, the hydrodynamic performance of the Delta is evaluated.

The result of this series of hydrodynamic calculations is a distribution of water export deficits and durations of export disruptions. The distribution of deficits was used to select a series of sequences that served as input to the economic consequences analysis. The sequences that were selected correspond to the 0.05, 0.50, and 0.95 probability levels of the south-of-Delta deficit distribution. For purposes of evaluating the number of fatalities that could occur on flooded islands, the complete set of simulated sequences was used.

13.3.1.1 Emergency Levee Response and Repair

For the levee failure sequences that are evaluated, the cost and timing of emergency levee repairs were evaluated. The range (mean plus and minus one standard deviation) of the costs of levee repairs and the timing of dewatering for various numbers of flooded islands are shown in Table 13-9. These results are based on the repair of seismically initiated levee breaches, the repair of non-breach damage on both flooded and non-flooded islands, and the repair of interior levee slope erosion damage on flooded islands.

For a 20-island breach event, the total cost of levee repair and dewatering would be about $1.8 billion on average, with a range of $1.4 to $2.3 billion. Repair would require 25 months on average, with a range of 20 to 30 months from the date of the earthquake. Dewatering of all the islands would occur about 29 months after the earthquake on average, with a range of 25 to 34 months. Repairs for 30 flooded islands could approximately double these cost and duration numbers.

13.3.1.2 Export Disruption

When levee failures occur during the late spring, summer, or early fall, saline water from Suisun Bay will be drawn into the Delta and onto flooded islands. Water might not be of adequate quality for use by the state and federal water projects, the Contra Costa Water District, or in-Delta users. Pumping may be disrupted for a relatively short period or for longer durations, depending on the levee failure sequence (the number and location of the islands that are flooded).

Figure 13-17 illustrates the variation in the duration of no water exports for levee sequences involving 3 and 20 flooded islands. The graphs in the figure show the cumulative distribution functions that quantify the variability in the duration of no water exports due to the variability in the combination of islands that are flooded (given that 3 or 20 islands are flooded, respectively) and the variation in the month of occurrence and in the hydrologic conditions that exist at the time of the earthquake. Figures 13-17a and 13-17c show the results when a single hydrologic start time is considered (month of the year and hydrologic condition). This so-called Normal hydrology was selected from the distribution of hydrodynamic calculations for a 30-breach case in which over 900 start times were considered (these start times are derived from the 55-year hydrologic record for California). The Normal hydrology corresponds to the median of the distribution of hydrologic start times. The results in Figures 13-17a and 13-17c suggest a considerable amount of variability due to the mix of islands that are flooded in a sequence. As expected, the duration of no exports is greater in the 20-island case than in sequences involving only 3 islands.

The cumulative distribution functions for the “Varied” hydrology case consider the same combination of flooded island sequences for each case (the 3- and 20-island cases in Figures 13-17b and 13-17d), with the addition of the variability due to hydrologic start times. In these cases, 3 hydrologic conditions were considered corresponding to the 0.05, 0.50 and the 0.95 probability levels of the distribution of 900 hydrologic start times (as described above). A comparison of the results for the Normal and the Varied hydrologic cases show the increased variability in the duration of no exports when the variation in hydrologic conditions is considered.

Figure 13-18 shows a similar set of results for the same simulations when the size of the south-of-Delta delivery deficits is considered. The disruptions shown in Figures 13-17 and 13-18 consider only salinity intrusion sufficient to make Delta waters unusable for both urban and agricultural contractors.

After pumping resumes, water may need additional treatment to satisfy drinking water standards. The primary contaminant of concern is organic carbon, which may react with disinfectants to produce byproducts that are carcinogenic. Preliminary analyses performed as part of the DRMS project indicate that some water may not be treatable by municipal agencies for many months, thereby extending the period that Delta supplies may be unavailable to urban users. Costs of additional treatment, when feasible, could be as much as $70 million (see Section 12.2). As such, careful management of island dewatering would be needed to avoid high concentrations of organic carbon. More detailed water quality modeling is needed to better analyze these treatability issues.

13.3.1.3 Economic Consequences of Earthquakes

As described in Section 12, economic consequences were quantified in terms of *economic costs* and *economic impacts*. The economic costs are the net costs to the state economy without consideration of who bears the cost. All economic costs are generally additive. Economic impacts include a variety of other economic measures. For this study, four measures of economic impacts were evaluated: the value of lost output, lost jobs, lost labor income, and lost value added. Value added is the sum of wages and salaries, proprietors' incomes, other property income, and indirect business taxes. These measures are not additive with each other, and they should not be added to economic costs.

Seismic Economic Case Study Results

The analysis for seismic events evaluated the economic consequences for a range of levee failure sequences that were simulated. As discussed previously with respect to the hydrodynamic response of the Delta to seismic sequences, the outcome of a sequence in terms of the economic consequences depends strongly on the nature of the levee failure sequence (the number and the specific islands that have flooded), the time of year that the earthquake occurs, and the hydrology at the time of the event.

Economic costs are summarized in terms of two broad categories: in-Delta costs and state-wide costs, as shown in Table 13-10a. The main elements of in-Delta costs are emergency response and repair costs, infrastructure repair costs, lost use of structures and services, agricultural losses, and lost recreation. About 30–40 percent of in-Delta costs are attributed to the cost of levee emergency response and repair, 40–50 percent of these costs are due to damage to infrastructure, including residences, businesses, etc., and 10–15 percent of these costs are from lost recreation. The distribution of in-Delta costs varies considerably, depending on the islands that are flooded and the number of islands involved in a sequence.

The main elements of state-wide costs are agricultural losses, urban user losses due to water supply disruption, and the lost use of major infrastructure (e.g., state highways that cross the Delta). Because the In-Delta cost and Statewide cost are not perfectly correlated, the percentiles of the two costs cannot be theoretically added to obtain the corresponding percentile of the total cost. However, the two costs are highly correlated and hence the sum of the percentiles of two costs is a reasonable approximation of the same percentile of the total cost. For simplicity, the percentiles of the total cost in Table 13-10a were calculated by adding the corresponding percentiles of the In-Delta and Statewide costs.

The economic impacts are mostly controlled by the value of lost output, followed by lost value added, and then lost labor income, as shown in Table 13-10b for a range of sequences of flooded islands. The lost jobs are also shown in the same table.

For sequences that involve water supply disruption, the variation in the total state-wide costs can be as much as 100 percent for sequences involving the same number of flooded islands. For a given number of flooded islands, this variability is about 70 percent from urban user loss due to water supply disruption and about 30 percent from lost use of major infrastructure.

Seismic Economic Risk Results

The economic costs and impacts were evaluated and combined with the frequency of occurrence of each sequence. The results are shown in Figures 13-19a and 13-19b in terms of the annual frequency of exceeding various economic costs and impacts and their uncertainties due to seismic events, respectively.

13.3.1.4 Ecological Consequences from Earthquakes

The conceptual model developed for the effects of levee failures on sensitive aquatic species, vegetation, and terrestrial wildlife provides a framework for a qualitative risk assessment, incorporating both the beneficial and the adverse effects associated with levee failures. The impacts to aquatic species, vegetation, and terrestrial wildlife are presented in Tables 13-11 through 13-25. The ecological impacts of five different seismic levee-failure scenarios were assessed. The scenarios involved levee failures on as few as 2 islands and as many as 30 islands. Each scenario was analyzed for three different water years: a spring wet year (represented by 1927 conditions), a summer average water year (represented by 1930), and a fall dry water year (represented by 1972).

Aquatic Species

As indicated in Section 12 and in the Impact to Ecosystem TM (URS/JBA 2008e), the aquatic model was developed through formal expert elicitation, as recommended by the DRMS Independent Review Panel (IRP). The work developed so far has focused on evaluation of potential short-term impact mechanisms, including levee-failure-induced fish entrainment, increased turbidity during breach events, saltwater effects, pump-out of flooded islands, export interruptions during levee failure events, and the potential for new habitat development in the flooded islands. The model was also constructed to accommodate uncertainties and provide probabilities and estimates of uncertainties on losses of different species and life stages as well as the probable extinction of species.

Because of limited time and the limited availability of experts, the model was not fully developed. The model was not fully executed for the production runs, and therefore the consequences on the aquatic species are not available at this stage.

Vegetation

The impacts to vegetation types and terrestrial species are shown as a percentage of vegetation or habitat area impacted. As discussed here, vegetation types do not include agricultural land, but agricultural land is incorporated into impacts on terrestrial species.

In all seismic levee-failure scenarios, the extent of impacts to habitat increased with area flooded, but the magnitude of the impacts depended on the vegetation type. For example, losses of up to 39 percent were forecasted for herbaceous wetland seasonal ruderal habitat, 29 percent for non-native trees, and 24 percent for shrub wetland in the Delta and Suisun Marsh. Of critical vegetation types that harbor native vegetation and rare species of vegetation, native herbaceous upland (which constitutes a small total area of the Delta [less than 500 acres]) was not affected by flooding in any of the cases. Less than 12 percent of critical intertidal and aquatic habitat was affected in any scenario; however, shrub wetland lost 24 percent of its total habitat in the Delta and Suisun Marsh in the worst case. Overall, these results, though not incorporating the impacts of levee breaches on sensitive species, suggest that primary impacts of flooding are on non-native species of vegetation. However, a considerable amount of critical habitat including alkali high marsh, shrub wetland, and riparian trees are reduced by 10 to 24 percent.

For breach scenarios involving less than 10 breaches, very small percentages (0 to 8 percent, average 1 percent) of the total area of the vegetation types in the Delta and Suisun Marsh are impacted, with the greatest impact on non-native upland trees (7 percent). In the 10-breach scenario, impacts to more than 10 percent of the total area are seen in herbaceous ruderal upland (17 percent) and herbaceous wetland seasonal ruderal (23 percent), shrub wetland (10 percent), and non-native upland trees (14 percent).

In the 20-breach scenario, greater losses in area are seen for each vegetation type affected in the 10-breach scenario (herbaceous ruderal upland (23 percent of the total area), herbaceous wetland seasonal ruderal (33 percent), shrub wetland (18 percent), non-native upland trees (15 percent), riparian trees (12 percent), with an additional loss of less than 10 percent for riparian trees. In the 30-breach scenario, alkali marsh lost about 11 percent of its total area, herbaceous ruderal upland about 30 percent, herbaceous wetland seasonal ruderal about 39 percent, shrub wetland about 24 percent, and non-native upland trees about 29 percent, with the exception of riparian trees about 17 percent.

In the 20-breach scenario, greater losses in area are seen for each vegetation type affected in the 10-breach scenario (herbaceous ruderal upland [23 percent]), herbaceous wetland seasonal ruderal [33 percent], shrub wetland [18 percent], non-native upland trees [15 percent], riparian trees [12 percent], with the additional loss of less than 10 percent of riparian trees). In the 30-breach scenario, alkali marsh lost about 11 percent of its total area, with the following distribution by subcategory of species: herbaceous ruderal upland (30 percent) and herbaceous wetland seasonal ruderal (39 percent), shrub wetland (24 percent), and non-native upland trees (29 percent), with the exception of riparian trees (17 percent).

Terrestrial Wildlife

The breaching of Delta levees resulted in no impacts to several terrestrial wildlife species of concern whose habitats are restricted to Suisun Marsh (including the federally endangered saltmarsh harvest mouse, saltmarsh common yellowthroat, California clapper rail, and Suisun ornate shrew). In contrast, large numbers of the levee breaches modeled would affect 32 percent of available habitat for sandhill cranes and 42 percent of available habitat for waterfowl. These estimates could over- or underestimate the impacts on these birds, because it was assumed that all agricultural land was habitat and that the loss of agricultural land resulted in a proportional loss of habitat. In actual fact, these birds use only a fraction of agricultural land (grains, pasture alfalfa, corn, and rice).[1] Nevertheless, the results suggest that large-scale levee breaches may cause substantial losses of available habitat, and depending on whether food is limited or plentiful in the available habitat, these habitat losses could cause food shortages and displace birds.

13.3.1.5 Public Health and Safety Consequences From Earthquakes

The primary public safety concern is the potential for loss of life on islands that are flooded as a result of a seismic event. The analysis and procedure used to calculate probable life losses is described in Section 12 of this report. Under seismic conditions, a full simulation was conducted for each fault, each magnitude, all combinations of multiple numbers of flooded islands, and for each island's conditional probability of loss of life. All uncertainties associated with each variable in the sequence were formally carried through the simulation. Figure 13-20 shows the mean frequencies of exceeding different numbers of fatalities due to seismic events. For example, the mean frequency of 10 or more fatalities is about 0.01 and the mean frequency of 100 or more fatalities is 0.002.

13.3.2 Flood Consequences

As in the case for seismic events, sequences of flood-initiated levee failures and island flooding sequences were simulated for the range of floods modeled in the risk analysis. The range of flood events varies from 289,000 cubic feet per second (cfs) total Delta inflow to nearly 2 million cfs. These potential inflows are higher than those that have been experienced to date. Based on preliminary flood vulnerability results, inflows larger than the 100-year flood can be expected to cause a significant number of failures and consequent island flooding.

For each simulated sequence, the emergency response and repair analysis was carried out and the economic consequences were evaluated. No non-breach damage to levees was assumed and only one breach was modeled per island.

13.3.2.1 Emergency Levee Response and Repair

The cost and duration of emergency levee repairs as a result of flood-initiated levee failures are shown in Table 13-26. The cost of repairs is less than that required for seismically initiated levee failures (for the same number of flooded islands) because of the more extensive damage caused by earthquakes. Emergency repairs are estimated to cost about $580 million to restore 10 simultaneously flooded islands, with a range of between $490 and $680 million. Also, it will take about 2 years to repair 10 flooded islands, and about 6 years to repair 30 flooded islands (see Section 10 and the Emergency Response and Repair TM [URS/JBA 2008d] for a discussion of the emergency response model and the assumptions used in the analysis).

[1] A crop map was not available for this analysis.

During flood events, high Delta inflows of freshwater will prevent the inflow of salty water into the Delta as islands flood. As a result, little to no impact to water export will occur as a result of levee failures that are initiated by hydrologic events (see the discussion in Section 4).

13.3.2.2 Economic Consequences of Floods

Flood Economic Case Study Results

The economic costs and impacts associated with levee failures that occur as a result of a flood event are different in a number of respects from those associated with seismically initiated levee failure sequences. These differences include the following:

- Seismic events cause non-breach damage on both flooded and non-flooded islands, whereas non-flooded islands are not damaged as a result of a hydrologic event.
- In the seismic analysis, the consulting team considered 76 analysis zones (islands and tracts) located within the MHHW boundary, excluding Suisun Marsh. In the flood analysis, 93 analysis zones (islands and tracts) were considered within the 100-year flood boundary. The 100-year flood boundary is larger than the MHHW boundary.
- The Delta islands that are vulnerable to hydrologic events differ in a number of respects from the islands that are vulnerable to seismic events. For one thing, the islands included in the flood analysis but not in the seismic analysis have (quite obviously) a different vulnerability to these hazards. Also, for islands that are considered in both analyses, on an island-by-island basis levees have different degrees of vulnerability to the different hazards. As a result, the levee failure sequences that can occur during hydrologic events may be different than the sequences that occur during seismic events.
- The distribution of peak flood elevations will be different than the distribution of earthquake ground motions for a given event. For instance, the majority of the inflow to the Delta occurs in the Sacramento-Yolo system. As a result, the islands in this part of the Delta will see higher peak flood elevations during a given flood event than other parts of the Delta. In the case of seismic events, strong earthquake ground motions may be experienced over all or large parts of the Delta. As a result, the differences in the spatial patterns of these hazards result in the flooding of different combinations of islands for the two types of hazards.
- A number of islands that are included in the hydrologic risk analysis and not in the seismic analysis are areas that have (relatively) high populations and infrastructure (residences, businesses, etc.).
- As discussed in Section 4, flood-related failures are unlikely to have water export impacts. As a result, the statewide impacts are not as great as those for seismic-related failures, all other factors being equal.
- When a seismic event occurs, 1 to 3 breaches may occur on an island that floods. In the case of a hydrologic event, only one breach occurs per flooded island.

When a seismic event occurs, the results of the seismic analysis indicate that non-breach damage can involve many tens of thousands of feet of levee. This damage involves additional repair costs. This damage also has additional downstream impacts on the amount of erosion damage that occurs on island levee interiors as they await repair and protection and on the period of disruption to island businesses and residents awaiting island repair and dewatering.

Tables 13-27a and 13-27b summarize the range of economic costs and economic impacts, respectively, for sequences of flood-initiated levee failures. Again, economic costs are summarized in terms of two broad categories: in-Delta costs and state-wide costs. As noted previously, for simplicity, the percentiles of the total cost in Table 13-27a were calculated by adding the corresponding percentiles of the In-Delta and Statewide costs. For a small number of flooded islands, the in-Delta costs dominate the total costs; however, for the larger number of flooded islands, the state-wide costs are approximately double those of the in-Delta costs. The main elements of in-Delta costs are the emergency response and repair costs, the infrastructure repair costs, the costs due to loss of use of structures and services, the costs of agricultural losses; and the costs of lost recreation. About 15 to 20 percent of in-Delta costs are from the emergency response and repair and the infrastructure repair, and 60 to 70 percent of the costs are from loss of use of structures and services. Other significant in-Delta costs are caused by loss of recreation and agricultural damage, corresponding to about 10 to 25 percent. The main state-wide infrastructure disruption is to the disruption of Delta area highways.

Flood Economic Risk Results

The economic costs and impacts were evaluated and combined with the frequency of occurrence of each sequence. The results are shown in Figures 13-21a and 13-21b as the probability of exceeding various economic costs and impacts, respectively, and their uncertainties due to flood events.

Although the total economic cost of a given number of flooded islands is similar for seismic and flood events, the frequency of a large number of islands flooding is much higher for seismic events. The overall risk for each hazard is calculated by combining the frequencies and consequences of different numbers of flooded islands. This risk is expressed in terms of the frequency of exceeding different amounts of the total economic cost. The results are shown in Figures 13-19b and 13-21b, respectively for seismic and flood hazards. As seen in these figures, the risk is much higher for seismic events than flood events. For example, the annual frequency of exceeding a total cost of $ 40 billion is about 1 % for seismic events and 0.3% for flood events.

The overall economic impacts of a given number of flooded islands are higher for flood events than seismic events. The two main contributors to the economic impacts are the loss of structures/services and water export disruption.

The impacts of loss of structures and services are higher for floods because all analysis zones within the 100-year flood boundary are considered. In contrast, only the analysis zones within the MHHW boundary are considered for the seismic events. Some of the zones with high population and infrastructure, such as the Sacramento Pocket Area, are outside the MHHW, but within the 100-year flood boundary.

On the other hand, the impacts of water export disruption are incurred only for seismic events and are negligible for flood events. However, the economic impacts of water export disruption depend on many factors, including the types of past, current, and future of hydrological years and the season. These impacts are relatively low for a large proportion of the sequences of flooded islands, for example, sequences in the north of the Delta will have minimal impacts on water exports. The average value of lost output for a sequence of 30 flooded islands is about $ 1 billion. In contrast, the average value of lost out due to loss of structures/services for the same sequence is about $6 billion for flood events and about $2 billion for seismic events. The net effect of water export disruption and loss of structures/services on the value of lost output is an increase of $3 billion for flood events.

13.3.2.3 Ecological Consequences of Floods

Aquatic Species

See Section 13.3.1.4 for discussion of the aquatic species impact model.

Vegetation

In the flood scenarios, the breached islands are primarily in the northern Delta, in contrast with seismic levee-breach scenarios, in which the breached islands are primarily in the western, central, and southern Delta. This shift in geography results in vastly different impacts associated with flood-induced breach scenarios relative to seismic-induced breach scenarios. The primary difference lies in the greater loss of all tree vegetation for the flood scenarios evaluated. For example, for the 20- and 30-breach scenarios, the damage by vegetation type is respectively as follows: native trees (34 percent, 45 percent), non-native trees (22 percent, 35 percent), and tree wetlands (19 percent, 21 percent). Flood scenarios also result in extremely large losses of total critical native tree habitat, which, in contrast, is diminished by less than 10 percent of its total area in a seismic failure. Herbaceous upland, which composes the largest percentage of impacted areas in the seismic scenarios with large numbers of breaches, lost only 9 percent and 13 percent of total area in 20- and 30-breach scenarios, respectively. Smaller percentage losses in total habitat (less than 10 percent) in the Delta and Suisun Marsh are seen for all other vegetation types, which lose large areas (more than 10 percent) in seismic events.

Terrestrial Wildlife

In contrast with vegetation, little difference occurred in the impacts associated with the seismic- and flood-induced levee-breach scenarios. Neither flood nor seismic breach scenarios in Suisun Marsh impact the several terrestrial wildlife species of concern whose habitats are restricted to Suisun Marsh. These species include the federally endangered saltmarsh harvest mouse, saltmarsh common yellowthroat, California clapper rail, and Suisun ornate shrew.

As in the seismic levee breaches, the impacts of flood levee breaches include large losses of total habitat for sandhill cranes (for the 20-breach scenario, 34 percent; for the 30-breach scenario, 57 percent) and waterfowl (for the 20-breach scenario, 22 percent; for the 30-breach scenario, 36 percent). However, a flood-induced 30-island flood scenario almost doubles the loss of sandhill crane foraging habitat (57 percent) compared with a seismically induced 30-island flooding scenario (32 percent).

13.3.2.4 Public Health and Safety Consequences from Floods

Similar simulations to those of the seismic events were conducted for the flood events (Sec.13.3.1.5). Detailed discussion of the methodology and the calculations of the conditional probabilities of loss of life under flood conditions is presented in Section 12. The primary public safety concern is the potential loss of life associated with hydrologic events that cause levee failures and island flooding. Figure 13-22 shows the mean frequencies of exceeding different numbers of fatalities as a result of hydrologic events. For example, the mean frequency of 10 or more fatalities is about 0.12, and the mean frequency of 100 or more fatalities is about 0.01.

13.3.3 Sunny-Day Failure Consequences

Sunny-day failures are assumed to occur one island at a time. Consequences are expected to be similar to the single-island consequences of floods or earthquakes. Because sunny-day failures are defined to occur in the late spring, summer, or early fall (i.e., during the low-flow season), some possibility of salinity intrusion and Delta salinity/water export impacts were thought possible. However, as discussed in Section 4, both historical experience and hydrodynamic sensitivity calculations indicate that single-island failures will not have any impact or will have minimal impact (water export disruptions of 3 months or less; see the discussion in Section 4). For instance, a single-island failure for Brannon-Andrus was considered for all months in the CalSim trace (984 months as different event start times) and no significant impact on water exports was found. The maximum disruption was less than 3 months, with negligible economic impacts.

13.4 2005 BASE CASE RESULTS SUMMARY

The 2005 base case shows considerable potential for the Delta and Suisun Marsh areas to face a high risk of multiple-island failures from both seismic and flood events. The population at risk and the economic and ecological consequences of a major event can be severe in some cases. Aside from the number of islands that flood in a sequence, the economic consequences of a sequence will depend on three primary factors: which islands have flooded, the month in which the initiating event occurs, and where that month is in the hydrologic cycle.

Our overall findings and observations are summarized in Section 15.

Table 13-1 Delta and Suisun Marsh Annual Frequency of Sunny-Day Failures

URS_ID	URS Name	Levee Length (Miles)	Annual Mean No. of Failures
4	Webb Tract	12.9	1.18E-03
5	Empire Tract	10.5	9.56E-04
6	Bradford Island	7.4	6.77E-04
7	King Island	9.1	8.28E-04
9	Jersey Island	15.5	1.41E-03
10	Bethel Island	11.5	1.05E-03
11	Quimby Island	7.0	6.40E-04
12	McDonald Tract	13.7	1.25E-03
13	Holland Tract	11.0	1.00E-03
14	Dutch Slough West	1.8	1.68E-04
15	Bacon Island	14.3	1.31E-03
16	Palm Tract	7.9	7.19E-04
17	Jones Tract-Upper and Lower	18.7	1.70E-03
19	Woodward Island	8.9	8.14E-04
20	Orwood Tract	8.6	7.83E-04
21	Victoria Island	15.0	1.37E-03
32	Coney Island	5.5	4.99E-04
62	Walnut Grove	2.9	2.63E-04
63	Tyler Island	22.9	2.09E-03
75	N. of Glanville Tract	6.2	5.63E-04
77	Elk Grove SE (Zones not in MHHW)	1.4	1.31E-04
78	Elk Grove Sth	6.1	5.54E-04
86	Terminous East	1.3	1.23E-04
87	Terminous	19.2	1.75E-03
108	Hotchkiss Tract	6.7	6.08E-04
109	Dutch Slough East	2.0	1.86E-04
112	Union Island East	3.4	3.08E-04
113	Union Island South East	4.3	3.97E-04
114	Stark Tract	5.1	4.66E-04
115	Upper Roberts Island	17.8	1.62E-03
117	Union Island	25.3	2.31E-03
118	Pescadero	9.0	8.24E-04
119	Paradise Junction	7.0	6.40E-04
120	McMullin Ranch	10.2	9.33E-04
121	Kasson District	3.8	3.49E-04
126	Pico Naglee Tract	10.1	9.18E-04
127	Byron Tract	9.8	8.94E-04
129	Veale Tract 1	5.4	4.91E-04
135	West Sacto 1	10.8	9.88E-04
141	Merritt Island	17.7	1.62E-03
143	Rindge Tract	15.8	1.44E-03
144	Mandeville Island	14.3	1.31E-03
146	Sutter Island	12.4	1.13E-03
147	Grand Island	28.3	2.58E-03
148	Elk Grove SW	7.4	6.78E-04
149	Pierson Tract	15.9	1.45E-03
150	Venice Island	12.4	1.13E-03
152	Medford Island	5.9	5.37E-04
153	Rough and Ready Island	6.8	6.21E-04
157	Smith Tract	5.8	5.28E-04
158	Weber Tract	3.8	3.45E-04
159	Boggs Tract	6.1	5.56E-04
162	Fabian Tract2	3.1	2.84E-04
163	Fabian Tract	18.8	1.71E-03
165	Walthal Tract	6.2	5.70E-04
166	RD 17 (Mossdale)	15.8	1.44E-03
168	Libby McNeil Tract 1_2	3.7	3.39E-04
169	McCormack Williamson Tract	8.7	7.96E-04
170	Glanville Tract	11.5	1.05E-03
171	Cosumnes River Area	6.8	6.17E-04
172	New Hope Tract	13.6	1.24E-03
173	Deadhorse Island	2.6	2.36E-04
174	Staten Island	25.3	2.31E-03
175	Canal Ranch	10.6	9.66E-04
176	Brack Tract	10.8	9.87E-04
177	Bouldin Island	17.9	1.63E-03

Table 13-1 Delta and Suisun Marsh Annual Frequency of Sunny-Day Failures

URS_ID	URS Name	Levee Length (Miles)	Annual Mean No. of Failures
179	Twitchell Island	11.9	1.08E-03
182	Shin Kee Tract	6.5	5.97E-04
183	Rio Blanco Tract	5.8	5.31E-04
185	Atlas Tract East	1.6	1.47E-04
187	Shima Tract	7.0	6.42E-04
190	Wright-Elmwood Tract	7.1	6.44E-04
191	Sargent Barnhart Tract	7.9	7.19E-04
196	Sacramento Pocket Area	15.7	1.44E-03
197	Elk Grove West	7.4	6.76E-04
210	Ryer Island	20.2	1.85E-03
212	Clifton Crt FW	7.8	7.15E-04
216	Fabian Tract South West 1	2.0	1.80E-04
1000	Netherlands	41.8	3.81E-03
1002	Drexler Tract	9.2	8.38E-04
1003	Roberts Island	29.6	2.70E-03
1004	West Sacto 2	12.6	1.15E-03
1005	Elk Grove	17.4	1.59E-03
1006	Upper Andrus Island	11.2	1.02E-03
1007	Lower Andrus Island	29.9	2.72E-03
1008	Stewart Tract	12.2	1.11E-03
1009	Mossdale R.D. No. 2107	5.7	5.16E-04
1010	Clifton Crt FS	5.2	4.70E-04
1012	Atlas Tract	3.0	2.72E-04
1013	Bishop Tract	8.7	7.90E-04
1014	McMullin Rch2 River Junction Tr	9.3	8.46E-04
1015	Sherman Island	19.4	1.77E-03
1016	Smith Tract - Lincoln Village Tr	5.6	5.07E-04
68	Little Egbert Tract	10.3	9.44E-04
70	Egbert Tract Includes 69	5.4	4.89E-04
72	Peter Pocket	7.5	6.88E-04
79	Peter's Pocket West	3.8	3.49E-04
80	Cache Haas Tract 1 East	2.1	1.88E-04
88	Cache Haas Tr1	8.9	8.16E-04
89	Cache Haas Tr2	7.2	6.57E-04
1001	Hastings Tract 81_82	17.1	1.56E-03
39	SM-39	4.3	7.21E-04
40	SM-40	5.7	9.49E-04
41	SM-41	2.6	4.37E-04
42	SM-42	1.5	2.41E-04
43	SM-43	4.7	7.78E-04
44	SM-44	6.1	1.01E-03
45	SM-45	3.0	4.97E-04
46	SM-46	4.1	6.73E-04
47	SM-47	4.5	7.53E-04
48	SM-48	12.1	2.00E-03
49	SM-49	8.0	1.33E-03
50	SM-1/2_50_58	20.2	3.35E-03
51	SM-51	5.2	8.60E-04
54	SM 54a	7.6	1.26E-03
55	SM-55_56_84_85_131_132	31.6	5.25E-03
59	SM-59a	6.2	1.02E-03
60	SM-60	14.1	2.33E-03
123	SM-123	8.3	1.37E-03
124	SM-57_124	9.9	1.64E-03
133	SM-133_134	8.9	1.48E-03
198	SM-198	9.5	1.57E-03
201	Honker Bay Club_Van Sickle Island	15.0	2.49E-03
202	SM-202	4.7	7.85E-04
203	Simmons-Wheeler Island_SM-204	9.9	1.63E-03
54b	SM 54b	5.3	8.79E-04
59b	SM-59b	4.2	6.91E-04

Notes: The expected annual frequencies of historical sunny-day breaches are about 1.06×10^{-4} failures/year/levee mile or 0.0969 failures/year in the Delta, and 4.76×10^{-4} failures/year/levee mile or 0.036 failures/year in Suisun Marsh.

Table 13-2 Annual Frequencies of Exceeding *N* Simultaneous Island Failures as a Result of Earthquake Event

Number of Islands (N)	Annual Frequency of Exceedance	Probability of Exceedance in 25 Years [a]	Probability of Exceedance in 50 Years [a]	Probability of Exceedance in 100 Years [a]
1	0.107	0.931	0.995	1.000
3	0.082	0.872	0.984	1.000
10	0.051	0.723	0.923	0.994
20	0.032	0.546	0.794	0.958
30	0.019	0.383	0.620	0.855

[a] Assumes no changes in risk in future years. The effects of the changing risks in future years are discussed in Section 14.

Table 13-3 Delta and Suisun Marsh Individual Island Rates of Seismic Failures

URS_ID	URS Name	Annual Mean No. of Failures	Probability of Failure in 25 years	Probability of Failure in 50 years	Probability of Failure in 100 years
127	Byron Tract	4.41E-02	67%	89%	99%
1006	Upper Andrus Island	4.26E-02	66%	88%	99%
1007	Brannan-Andrus Island	4.26E-02	66%	88%	99%
63	Tyler Island	4.20E-02	65%	88%	99%
1002	Drexler Tract	4.20E-02	65%	88%	98%
1003	Roberts Island	4.20E-02	65%	88%	98%
21	Victoria Island	4.18E-02	65%	88%	98%
10	Bethel Island	3.73E-02	61%	85%	98%
9	Jersey Island	3.73E-02	61%	85%	98%
1015	Sherman Island	3.67E-02	60%	84%	97%
19	Woodward Island	3.45E-02	58%	82%	97%
174	Staten Island	3.39E-02	57%	82%	97%
179	Twitchell Island	3.37E-02	57%	81%	97%
13	Holland Tract	3.37E-02	57%	81%	97%
4	Webb Tract	3.36E-02	57%	81%	97%
6	Bradford Island	3.36E-02	57%	81%	97%
12	McDonald Tract	3.34E-02	57%	81%	96%
143	Rindge Tract	3.23E-02	55%	80%	96%
16	Palm Tract	3.11E-02	54%	79%	96%
150	Venice Island	3.01E-02	53%	78%	95%
212	Clifton Court Forebay Water	2.96E-02	52%	77%	95%
172	New Hope Tract	2.93E-02	52%	77%	95%
144	Mandeville Island	2.90E-02	52%	77%	94%
147	Grand Island	2.86E-02	51%	76%	94%
108	Hotchkiss Tract	2.85E-02	51%	76%	94%
152	Medford Island	2.80E-02	50%	75%	94%
175	Canal Ranch	2.76E-02	50%	75%	94%
117	Union Island	2.70E-02	49%	74%	93%
17	Jones Tract-Upper and Lower	2.65E-02	48%	73%	93%
5	Empire Tract	2.62E-02	48%	73%	93%
11	Quimby Island	2.47E-02	46%	71%	92%
177	Bouldin Island	2.42E-02	45%	70%	91%
169	McCormack Williamson Tract	2.39E-02	45%	70%	91%
163	Fabian Tract	2.34E-02	44%	69%	90%
190	Wright-Elmwood Tract	2.26E-02	43%	68%	90%
109	Dutch Slough East	2.23E-02	43%	67%	89%
15	Bacon Island	2.19E-02	42%	67%	89%
87	Terminous Tract	2.17E-02	42%	66%	89%
210	Ryer Island	2.02E-02	40%	64%	87%
191	Sargent Barnhart Tract	1.99E-02	39%	63%	86%
176	Brack Tract	1.88E-02	37%	61%	85%
162	Fabian Tract South West 2	1.80E-02	36%	59%	83%
149	Pierson Tract	1.78E-02	36%	59%	83%
1010	Clifton Court Forebay South	1.77E-02	36%	59%	83%
14	Dutch Slough West	1.63E-02	33%	56%	80%
20	Orwood Tract	1.57E-02	33%	54%	79%
7	King Island	1.56E-02	32%	54%	79%
1000	Netherlands	1.50E-02	31%	53%	78%
146	Sutter Island	1.47E-02	31%	52%	77%
170	Glanville Tract	1.47E-02	31%	52%	77%
1013	Bishop Tract	1.43E-02	30%	51%	76%
129	Veale Tract 1	1.42E-02	30%	51%	76%
32	Coney Island	1.39E-02	29%	50%	75%
167	Libby McNeil Tract 2	1.29E-02	28%	48%	73%
168	Libby McNeil Tract 1	1.29E-02	28%	48%	73%
141	Merritt Island	1.27E-02	27%	47%	72%
153	Rough and Ready Island	1.26E-02	27%	47%	72%
216	Fabian Tract South West 1	1.13E-02	25%	43%	68%
148	Elk Grove South West	1.02E-02	23%	40%	64%
187	Shima Tract	9.80E-03	22%	39%	62%
183	Rio Blanco Tract	9.20E-03	21%	37%	60%
62	Walnut Grove	9.05E-03	20%	36%	60%
182	Shin Kee Tract	8.78E-03	20%	36%	58%
159	Boggs Tract	7.80E-03	18%	32%	54%
86	Terminous Tract East	7.63E-03	17%	32%	53%
1012	Atlas Tract	5.70E-03	13%	25%	43%
173	Deadhorse Island	5.55E-03	13%	24%	43%

Table 13-3 Delta and Suisun Marsh Individual Island Rates of Seismic Failures

URS_ID	URS Name	Annual Mean No. of Failures	Probability of Failure in 25 years	Probability of Failure in 50 years	Probability of Failure in 100 years
115	Upper Roberts Island	3.30E-03	8%	15%	28%
126	Pico Naglee Tract	3.17E-03	8%	15%	27%
1016	Smith Tract - Lincoln Village Tract	2.24E-03	5%	11%	20%
68	Little Egbert Tract	1.94E-02	38%	62%	86%
89	Cache Haas Tract 2	1.46E-02	31%	52%	77%
88	Cache Haas Tract 1	1.17E-02	25%	44%	69%
70	Egbert Tract	2.77E-03	7%	13%	24%
1001	Hastings Tract	2.59E-03	6%	12%	23%
72	Peter Pocket	2.46E-03	6%	12%	22%
203	Simmons-Wheeler Island	5.61E-02	75%	94%	100%
204	SM-204	5.61E-02	75%	94%	100%
202	SM-202	5.51E-02	75%	94%	100%
131	Schafter-Pintail Tract	5.43E-02	74%	93%	100%
132	SM-132	5.43E-02	74%	93%	100%
55	SM-55	5.43E-02	74%	93%	100%
56	SM-56	5.43E-02	74%	93%	100%
84	SM-84	5.43E-02	74%	93%	100%
85	SM-85-Grizzly Island	5.43E-02	74%	93%	100%
133	SM-133	3.42E-02	57%	82%	97%
134	SM-134	3.42E-02	57%	82%	97%
54	SM-54	2.80E-02	50%	75%	94%
49	SM-49	2.72E-02	49%	74%	93%
44	SM-44	2.67E-02	49%	74%	93%
47	SM-47	2.67E-02	49%	74%	93%
40	SM-40	2.67E-02	49%	74%	93%
48	SM-48	2.65E-02	48%	73%	93%
50	SM-50	2.63E-02	48%	73%	93%
39	SM-39	2.62E-02	48%	73%	93%
41	SM-41	2.58E-02	48%	73%	92%
46	SM-46	2.58E-02	48%	73%	92%
1	SM-1	2.40E-02	45%	70%	91%
2	SM-2	2.40E-02	45%	70%	91%
58	SM-58	2.40E-02	45%	70%	91%
200	Van Sickle Island	2.36E-02	45%	69%	91%
201	Honker Bay Club	2.36E-02	45%	69%	91%
60	SM-60	2.32E-02	44%	69%	90%
198	SM-198	2.27E-02	43%	68%	90%
57	SM-57	2.27E-02	43%	68%	90%
43	SM-43	2.13E-02	41%	66%	88%
59	SM-59	2.08E-02	41%	65%	88%
45	SM-45	1.99E-02	39%	63%	86%
123	SM-123	1.88E-02	38%	61%	85%
124	SM-124	1.85E-02	37%	60%	84%
51	SM-51	1.65E-02	34%	56%	81%
42	SM-42	1.20E-02	26%	45%	70%
	TOTAL DELTA	**1.60E+00**	**100.00%**	**100.00%**	**100.00%**
	TOTAL CACHE SLOUGH AREA	**5.36E-02**	**73.78%**	**93.13%**	**99.53%**
	TOTAL SUISUN MARSH	**1.14E+00**	**100.00%**	**100.00%**	**100.00%**

Table 13-4 Delta and Suisun Marsh Individual Island Rates of Seismic Failures: Seismic Source Contribution

		Fraction Contribution of Seismic Sources										
URS_ID	URS Name	San Andreas	Hayward	Calaveras	Concord	Mt. Diablo	Pittsburg-Kirby Hills	CRSB	Southern Midland	Hunting Creek - Berryesa	Northern Midland	Other
127	Byron Tract	8%	17%	16%	3%	6%	2%	3%	7%	3%	2%	32%
1006	Upper Andrus Island	8%	16%	9%	4%	4%	4%	7%	8%	6%	7%	27%
1007	Brannan-Andrus Island	8%	16%	9%	4%	4%	4%	7%	8%	6%	7%	27%
63	Tyler Island	8%	16%	9%	4%	4%	4%	7%	8%	6%	7%	27%
1002	Drexler Tract	11%	16%	11%	2%	6%	2%	4%	10%	4%	3%	28%
1003	Roberts Island	11%	16%	11%	2%	6%	2%	4%	10%	4%	3%	28%
21	Victoria Island	8%	17%	15%	3%	6%	2%	3%	7%	3%	3%	32%
10	Bethel Island	8%	17%	11%	4%	5%	3%	5%	9%	4%	4%	29%
9	Jersey Island	9%	17%	10%	4%	6%	4%	4%	12%	4%	4%	28%
1015	Sherman Island	8%	17%	9%	5%	5%	4%	6%	9%	5%	5%	28%
19	Woodward Island	9%	17%	14%	3%	6%	3%	4%	8%	4%	3%	31%
174	Staten Island	9%	16%	9%	4%	4%	3%	8%	8%	6%	7%	26%
179	Twitchell Island	8%	17%	9%	4%	5%	4%	6%	9%	5%	5%	27%
13	Holland Tract	9%	17%	11%	4%	6%	3%	4%	10%	4%	4%	29%
4	Webb Tract	9%	16%	9%	4%	5%	4%	5%	11%	5%	5%	27%
6	Bradford Island	8%	17%	10%	4%	5%	4%	5%	10%	5%	5%	27%
12	McDonald Tract	9%	16%	12%	3%	6%	3%	5%	8%	4%	4%	29%
143	Rindge Tract	9%	16%	12%	3%	5%	3%	5%	8%	5%	4%	29%
16	Palm Tract	9%	17%	12%	3%	6%	3%	4%	10%	4%	3%	30%
150	Venice Island	9%	16%	10%	4%	5%	3%	5%	9%	5%	5%	27%
212	Clifton Court Forebay Water	9%	17%	15%	3%	7%	2%	2%	8%	3%	2%	33%
172	New Hope Tract	9%	16%	8%	4%	4%	3%	8%	8%	7%	8%	25%
144	Mandeville Island	9%	16%	11%	4%	6%	3%	5%	10%	5%	4%	28%
147	Grand Island	8%	16%	7%	4%	4%	4%	8%	9%	7%	9%	24%
108	Hotchkiss Tract	9%	17%	11%	4%	6%	3%	4%	11%	4%	3%	28%
152	Medford Island	9%	16%	11%	3%	6%	3%	5%	10%	5%	4%	28%
175	Canal Ranch	9%	16%	9%	3%	4%	3%	8%	8%	6%	7%	25%
117	Union Island	10%	16%	16%	3%	7%	2%	2%	7%	3%	2%	33%
17	Jones Tract-Upper and Lower	10%	16%	13%	3%	6%	2%	3%	9%	4%	3%	30%
5	Empire Tract	9%	16%	10%	3%	5%	3%	5%	10%	5%	5%	27%
11	Quimby Island	9%	16%	11%	3%	6%	3%	4%	11%	4%	4%	28%
177	Bouldin Island	9%	16%	9%	4%	5%	4%	6%	11%	5%	6%	26%
169	McCormack Williamson Tract	9%	16%	8%	3%	4%	3%	9%	8%	7%	9%	24%
163	Fabian Tract	10%	16%	16%	2%	7%	2%	2%	7%	2%	2%	34%
190	Wright-Elmwood Tract	10%	16%	12%	3%	6%	3%	4%	9%	4%	4%	29%
109	Dutch Slough East	9%	17%	10%	4%	6%	4%	4%	12%	4%	3%	28%
15	Bacon Island	9%	16%	11%	3%	6%	3%	4%	12%	4%	3%	29%
87	Terminous Tract	10%	16%	9%	3%	5%	3%	6%	10%	6%	6%	26%
210	Ryer Island	8%	15%	6%	4%	4%	4%	9%	9%	7%	10%	23%
191	Sargent Barnhart Tract	11%	16%	13%	3%	6%	2%	4%	8%	4%	4%	30%
176	Brack Tract	10%	16%	8%	3%	5%	3%	7%	10%	6%	7%	25%
162	Fabian Tract South West 2	10%	16%	15%	2%	7%	2%	2%	7%	2%	1%	35%
149	Pierson Tract	8%	15%	6%	4%	4%	4%	10%	8%	8%	12%	22%
1010	Clifton Court Forebay South	10%	16%	15%	2%	8%	2%	2%	8%	2%	1%	34%
14	Dutch Slough West	9%	16%	10%	4%	6%	4%	3%	14%	4%	3%	27%
20	Orwood Tract	10%	16%	11%	3%	7%	3%	3%	13%	3%	2%	29%
7	King Island	11%	16%	10%	3%	6%	3%	5%	11%	5%	5%	27%
1000	Netherlands	8%	15%	6%	4%	3%	4%	11%	7%	9%	13%	20%
146	Sutter Island	8%	15%	6%	4%	4%	4%	10%	9%	8%	12%	22%
170	Glanville Tract	10%	15%	6%	3%	4%	3%	9%	9%	8%	11%	21%
1013	Bishop Tract	11%	16%	10%	3%	6%	3%	5%	10%	5%	5%	27%
129	Veale Tract 1	9%	15%	10%	3%	7%	3%	3%	16%	3%	2%	28%
32	Coney Island	10%	16%	13%	2%	8%	2%	2%	10%	2%	1%	33%
167	Libby McNeil Tract 2	9%	15%	7%	3%	4%	4%	9%	10%	8%	10%	22%
168	Libby McNeil Tract 1	9%	15%	7%	3%	4%	4%	9%	10%	8%	10%	22%
141	Merritt Island	9%	15%	5%	3%	3%	4%	12%	7%	10%	13%	20%
153	Rough and Ready Island	12%	16%	12%	2%	7%	2%	3%	9%	4%	3%	30%
216	Fabian Tract South West 1	10%	15%	15%	2%	8%	1%	2%	8%	2%	1%	37%
148	Elk Grove South West	10%	15%	5%	3%	3%	3%	10%	8%	9%	13%	19%
187	Shima Tract	11%	16%	11%	3%	6%	3%	4%	10%	5%	4%	28%
183	Rio Blanco Tract	12%	16%	9%	2%	6%	3%	5%	11%	5%	5%	26%
62	Walnut Grove	10%	15%	6%	3%	4%	3%	8%	11%	8%	10%	21%
182	Shin Kee Tract	12%	16%	9%	2%	5%	3%	5%	12%	6%	5%	25%
159	Boggs Tract	12%	16%	12%	2%	7%	2%	3%	9%	4%	3%	30%
86	Terminous Tract East	11%	16%	8%	2%	5%	3%	6%	12%	6%	7%	24%
1012	Atlas Tract	12%	16%	10%	2%	6%	2%	4%	11%	5%	4%	27%
173	Deadhorse Island	10%	15%	7%	3%	4%	3%	8%	11%	7%	9%	22%
115	Upper Roberts Island	12%	15%	13%	1%	8%	1%	2%	9%	2%	1%	36%

Table 13-4 Delta and Suisun Marsh Individual Island Rates of Seismic Failures: Seismic Source Contribution

URS_ID	URS Name	Fraction Contribution of Seismic Sources										
		San Andreas	Hayward	Calaveras	Concord	Mt. Diablo	Pittsburg-Kirby Hills	CRSB	Southern Midland	Hunting Creek - Berryesa	Northern Midland	Other
126	Pico Naglee Tract	11%	14%	13%	1%	8%	1%	1%	8%	2%	1%	40%
1016	Smith Tract - Lincoln Village Tract	7%	15%	13%	3%	6%	3%	5%	10%	4%	5%	30%
68	Little Egbert Tract	9%	16%	6%	4%	4%	5%	8%	11%	7%	9%	23%
89	Cache Haas Tract 2	8%	15%	5%	4%	3%	5%	10%	7%	8%	14%	21%
88	Cache Haas Tract 1	8%	14%	5%	4%	3%	5%	11%	7%	8%	16%	20%
70	Egbert Tract	4%	14%	6%	6%	3%	5%	8%	10%	6%	14%	23%
1001	Hastings Tract	4%	13%	5%	5%	3%	5%	9%	7%	7%	22%	20%
72	Peter Pocket	4%	13%	5%	5%	3%	4%	9%	7%	7%	24%	20%
203	Simmons-Wheeler Island	4%	15%	6%	12%	3%	2%	4%	3%	4%	3%	44%
204	SM-204	4%	15%	6%	12%	3%	2%	4%	3%	4%	3%	44%
202	SM-202	4%	15%	7%	12%	3%	3%	4%	3%	4%	3%	44%
131	Schafter-Pintail Tract	4%	15%	6%	12%	3%	3%	5%	3%	4%	3%	44%
132	SM-132	4%	15%	6%	12%	3%	3%	5%	3%	4%	3%	44%
55	SM-55	4%	15%	6%	12%	3%	3%	5%	3%	4%	3%	44%
56	SM-56	4%	15%	6%	12%	3%	3%	5%	3%	4%	3%	44%
84	SM-84	4%	15%	6%	12%	3%	3%	5%	3%	4%	3%	44%
85	SM-85-Grizzly Island	4%	15%	6%	12%	3%	3%	5%	3%	4%	3%	44%
133	SM-133	4%	14%	5%	13%	2%	4%	5%	3%	5%	4%	41%
134	SM-134	4%	14%	5%	13%	2%	4%	5%	3%	5%	4%	41%
54	SM-54	4%	15%	5%	17%	2%	2%	4%	2%	3%	2%	45%
49	SM-49	4%	15%	4%	18%	2%	2%	4%	2%	4%	2%	44%
44	SM-44	4%	15%	4%	18%	2%	2%	5%	2%	4%	2%	43%
47	SM-47	4%	15%	4%	17%	2%	2%	4%	2%	4%	2%	44%
40	SM-40	4%	15%	4%	18%	2%	2%	5%	2%	4%	2%	43%
48	SM-48	4%	15%	5%	16%	2%	2%	4%	2%	4%	2%	44%
50	SM-50	4%	15%	5%	16%	2%	2%	4%	2%	4%	2%	44%
39	SM-39	4%	15%	4%	18%	2%	2%	5%	2%	4%	2%	43%
41	SM-41	4%	16%	5%	14%	2%	2%	5%	2%	5%	3%	42%
46	SM-46	4%	15%	4%	17%	2%	2%	5%	2%	4%	2%	43%
1	SM-1	4%	14%	5%	15%	2%	3%	5%	2%	4%	3%	43%
2	SM-2	4%	14%	5%	15%	2%	3%	5%	2%	4%	3%	43%
58	SM-58	4%	14%	5%	15%	2%	3%	5%	2%	4%	3%	43%
200	Van Sickle Island	4%	14%	7%	12%	3%	4%	4%	3%	3%	3%	44%
201	Honker Bay Club	4%	14%	7%	12%	3%	4%	4%	3%	3%	3%	44%
60	SM-60	4%	14%	5%	14%	2%	3%	5%	2%	5%	3%	42%
198	SM-198	4%	14%	7%	11%	3%	4%	4%	3%	3%	3%	44%
57	SM-57	4%	14%	4%	15%	2%	3%	6%	2%	5%	3%	41%
43	SM-43	4%	14%	5%	12%	3%	4%	5%	3%	5%	4%	41%
59	SM-59	4%	14%	5%	13%	2%	4%	6%	3%	5%	4%	40%
45	SM-45	4%	14%	4%	18%	2%	2%	5%	2%	4%	2%	43%
123	SM-123	4%	14%	4%	17%	2%	2%	5%	2%	4%	3%	43%
124	SM-124	4%	14%	4%	16%	2%	2%	5%	2%	4%	3%	43%
51	SM-51	4%	14%	5%	13%	2%	4%	5%	3%	4%	3%	41%
42	SM-42	4%	13%	4%	16%	2%	3%	6%	2%	5%	3%	41%
	TOTAL DELTA	**9%**	**16%**	**10%**	**3%**	**6%**	**3%**	**5%**	**9%**	**5%**	**5%**	**28%**
	TOTAL CACHE SLOUGH AREA	**6%**	**14%**	**5%**	**5%**	**3%**	**5%**	**9%**	**8%**	**7%**	**17%**	**21%**
	TOTAL SUISUN MARSH	**4%**	**14%**	**5%**	**14%**	**2%**	**3%**	**5%**	**2%**	**4%**	**3%**	**43%**

Table 13-5 Annual Frequencies of Exceeding *N* Simultaneous Island Failures as a Result of Flood Event

Number of Islands (N)	Annual Frequency of Exceedance	Probability of Exceedance in 25 Years[1]	Probability of Exceedance in 50 Years[1]	Probability of Exceedance in 100 Years[1]
1	0.205	0.994	1.000	1.000
3	0.138	0.968	0.999	1.000
10	0.051	0.719	0.921	0.994
20	0.023	0.441	0.688	0.903
30	0.010	0.213	0.381	0.617

[1] Assumes no changes in risk in future years. The effects of the changing risks in future years are discussed in Section 14.

Table 13-6 Delta and Suisun Marsh Individual Island Rates of Flood Failures

URS_ID	URS Name	Annual Mean No. of Failures	Probability of Failure in 25 years	Probability of Failure in 50 years	Probability of Failure in 100 years
172	New Hope Tract	6.80E-02	82%	97%	100%
166	RD 17 (Mossdale)	5.79E-02	76%	94%	100%
1015	Sherman Island	5.79E-02	76%	94%	100%
191	Sargent Barnhart Tract	5.44E-02	74%	93%	100%
150	Venice Island	4.31E-02	66%	88%	99%
63	Tyler Island	4.19E-02	65%	88%	98%
176	Brack Tract	4.13E-02	64%	87%	98%
182	Shin Kee Tract	3.89E-02	62%	86%	98%
1016	Smith Tract - Lincoln Village Tract	3.89E-02	62%	86%	98%
165	Walthal Tract	3.43E-02	58%	82%	97%
174	Staten Island	3.39E-02	57%	82%	97%
10	Bethel Island	3.23E-02	55%	80%	96%
9	Jersey Island	3.23E-02	55%	80%	96%
20	Orwood Tract	3.23E-02	55%	80%	96%
17	Jones Tract-Upper and Lower	3.23E-02	55%	80%	96%
118	Pescadero	2.93E-02	52%	77%	95%
119	Paradise Junction	2.93E-02	52%	77%	95%
157	Smith Tract	2.93E-02	52%	77%	95%
15	Bacon Island	2.93E-02	52%	77%	95%
12	McDonald Tract	2.86E-02	51%	76%	94%
144	Mandeville Island	2.80E-02	50%	75%	94%
152	Medford Island	2.57E-02	47%	72%	92%
1000	Netherlands	2.57E-02	47%	72%	92%
5	Empire Tract	2.40E-02	45%	70%	91%
87	Terminous Tract	2.40E-02	45%	70%	91%
179	Twitchell Island	2.23E-02	43%	67%	89%
177	Bouldin Island	2.23E-02	43%	67%	89%
153	Rough and Ready Island	2.18E-02	42%	66%	89%
158	Weber Tract	1.63E-02	33%	56%	80%
1006	Upper Andrus Island	1.56E-02	32%	54%	79%
1007	Brannan-Andrus Island	1.56E-02	32%	54%	79%
21	Victoria Island	1.56E-02	32%	54%	79%
1008	Stewart Tract	1.52E-02	32%	53%	78%
1009	Mossdale R.D. No. 2107	1.52E-02	32%	53%	78%
4	Webb Tract	1.47E-02	31%	52%	77%
143	Rindge Tract	1.38E-02	29%	50%	75%
187	Shima Tract	1.38E-02	29%	50%	75%
7	King Island	1.38E-02	29%	50%	75%
19	Woodward Island	1.38E-02	29%	50%	75%
1002	Drexler Tract	1.32E-02	28%	48%	73%
1003	Roberts Island	1.32E-02	28%	48%	73%
115	Upper Roberts Island	1.32E-02	28%	48%	73%
169	McCormack Williamson Tract	1.31E-02	28%	48%	73%
210	Ryer Island	1.30E-02	28%	48%	73%
6	Bradford Island	1.08E-02	24%	42%	66%
86	Terminous Tract East	1.06E-02	23%	41%	65%
159	Boggs Tract	1.04E-02	23%	41%	65%
171	Cosumnes River Area	1.00E-02	22%	39%	63%
32	Coney Island	9.63E-03	21%	38%	62%
13	Holland Tract	9.07E-03	20%	36%	60%
141	Merritt Island	8.98E-03	20%	36%	59%
120	McMullin Ranch	8.90E-03	20%	36%	59%
147	Grand Island	7.39E-03	17%	31%	52%
14	Dutch Slough West	7.12E-03	16%	30%	51%
77	Elk Grove South East	6.46E-03	15%	28%	48%
175	Canal Ranch	6.46E-03	15%	28%	48%
170	Glanville Tract	6.46E-03	15%	28%	48%
173	Deadhorse Island	6.46E-03	15%	28%	48%
108	Hotchkiss Tract	6.31E-03	15%	27%	47%
183	Rio Blanco Tract	6.19E-03	14%	27%	46%
190	Wright-Elmwood Tract	6.19E-03	14%	27%	46%
196	Sacramento Pocket Area	5.90E-03	14%	26%	45%
1004	West Sacramento 2	5.90E-03	14%	26%	45%
135	West Sacramento 1	5.90E-03	14%	26%	45%
1013	Bishop Tract	5.50E-03	13%	24%	42%
11	Quimby Island	4.43E-03	10%	20%	36%
1010	Clifton Court Forebay South	3.80E-03	9%	17%	32%
16	Palm Tract	3.49E-03	8%	16%	29%
1014	McMullin Ranch-River Junction Tract	2.90E-03	7%	13%	25%
109	Dutch Slough East	2.90E-03	7%	13%	25%
75	N. of Glanville Tract	2.31E-03	6%	11%	21%
149	Pierson Tract	2.31E-03	6%	11%	21%

Table 13-6 Delta and Suisun Marsh Individual Island Rates of Flood Failures

URS_ID	URS Name	Annual Mean No. of Failures	Probability of Failure in 25 years	Probability of Failure in 50 years	Probability of Failure in 100 years
148	Elk Grove South West	2.31E-03	6%	11%	21%
167	Libby McNeil Tract 2	2.25E-03	5%	11%	20%
168	Libby McNeil Tract 1	2.25E-03	5%	11%	20%
62	Walnut Grove	1.84E-03	4%	9%	17%
1005	Elk Grove	1.76E-03	4%	8%	16%
197	Elk Grove West	1.76E-03	4%	8%	16%
78	Elk Grove South	1.76E-03	4%	8%	16%
121	Kasson District	1.73E-03	4%	8%	16%
129	Veale Tract 1	1.72E-03	4%	8%	16%
126	Pico Naglee Tract	1.71E-03	4%	8%	16%
113	Union Island South East	1.62E-03	4%	8%	15%
127	Byron Tract	1.04E-03	3%	5%	10%
117	Union Island	7.87E-04	2%	4%	8%
185	Atlas Tract East	5.53E-04	1%	3%	5%
1012	Atlas Tract	4.58E-04	1%	2%	4%
112	Union Island East	7.01E-05	0%	0%	1%
163	Fabian Tract	6.87E-05	0%	0%	1%
162	Fabian Tract South West 2	6.14E-05	0%	0%	1%
216	Fabian Tract South West 1	4.08E-05	0%	0%	0%
114	Stark Tract	1.74E-05	0%	0%	0%
146	Sutter Island	1.69E-05	0%	0%	0%
68	Little Egbert Tract	2.82E-02	51%	76%	94%
89	Cache Haas Tract 2	2.82E-02	51%	76%	94%
88	Cache Haas Tract 1	2.82E-02	51%	76%	94%
79	Peter's Pocket West	2.82E-02	51%	76%	94%
72	Peter Pocket	2.82E-02	51%	76%	94%
80	Cache Haas Tract 1 East	2.64E-02	48%	73%	93%
69	Egbert Tract East	2.63E-02	48%	73%	93%
82	Hastings Tract South West	2.63E-02	48%	73%	93%
1001	Hastings Tract	2.63E-02	48%	73%	93%
70	Egbert Tract	2.09E-02	41%	65%	88%
41	SM-41	4.75E-01	100%	100%	100%
1	SM-1	4.66E-01	100%	100%	100%
123	SM-123	4.66E-01	100%	100%	100%
124	SM-124	4.66E-01	100%	100%	100%
2	SM-2	4.66E-01	100%	100%	100%
42	SM-42	4.66E-01	100%	100%	100%
57	SM-57	4.66E-01	100%	100%	100%
58	SM-58	4.66E-01	100%	100%	100%
60	SM-60	4.66E-01	100%	100%	100%
39	SM-39	4.48E-01	100%	100%	100%
131	Schafter-Pintail Tract	4.07E-01	100%	100%	100%
132	SM-132	4.07E-01	100%	100%	100%
55	SM-55	4.07E-01	100%	100%	100%
56	SM-56	4.07E-01	100%	100%	100%
84	SM-84	4.07E-01	100%	100%	100%
85	SM-85-Grizzly Island	4.07E-01	100%	100%	100%
40	SM-40	3.54E-01	100%	100%	100%
46	SM-46	2.89E-01	100%	100%	100%
202	SM-202	2.60E-01	100%	100%	100%
48	SM-48	8.13E-02	87%	98%	100%
200	Van Sickle Island	8.00E-02	86%	98%	100%
201	Honker Bay Club	8.00E-02	86%	98%	100%
204	SM-204	8.00E-02	86%	98%	100%
49	SM-49	6.20E-02	79%	96%	100%
44	SM-44	5.51E-02	75%	94%	100%
203	Simmons-Wheeler Island	5.00E-02	71%	92%	99%
54	SM-54	4.00E-02	63%	86%	98%
45	SM-45	3.97E-02	63%	86%	98%
50	SM-50	3.76E-02	61%	85%	98%
47	SM-47	3.34E-02	57%	81%	96%
59	SM-59	3.14E-02	54%	79%	96%
133	SM-133	1.13E-02	25%	43%	68%
134	SM-134	1.13E-02	25%	43%	68%
51	SM-51	9.26E-03	21%	37%	60%
43	SM-43	9.13E-03	20%	37%	60%
198	SM-198	5.53E-03	13%	24%	42%
	TOTAL DELTA	**1.41E+00**	**100.00%**	**100.00%**	**100.00%**
	TOTAL CACHE SLOUGH AREA	**2.67E-01**	**99.87%**	**100.00%**	**100.00%**
	TOTAL SUISUN MARSH	**8.71E+00**	**100.00%**	**100.00%**	**100.00%**

Table 13-7 Annual Frequencies of Exceeding *N* Simultaneous Island Failures as a Result of All Hazards

Number of Islands	Annual Frequency of Exceedance	Probability of Exceedance in 25 Years[1]	Probability of Exceedance in 50 Years[1]	Probability of Exceedance in 100 Years[1]
1	0.420	1.000	1.000	1.000
3	0.220	0.996	1.000	1.000
10	0.102	0.922	0.994	1.000
20	0.055	0.746	0.936	0.996
30	0.029	0.515	0.764	0.945

[1] Assumes no changes in risk in future years. The effects of the changing risks in future years are discussed in Section 14.

Table 13-8 Delta and Suisun Marsh Individual Island Composite Rates of Failures

URS_ID	URS Name	Annual Mean No. of Failures	Probability of Failure in 25 years	Probability of Failure in 50 years	Probability of Failure in 100 years
172	New Hope Tract	9.73E-02	91%	99%	100%
1015	Sherman Island	9.46E-02	91%	99%	100%
63	Tyler Island	8.39E-02	88%	98%	100%
191	Sargent Barnhart Tract	7.43E-02	84%	98%	100%
150	Venice Island	7.31E-02	84%	97%	100%
10	Bethel Island	6.96E-02	82%	97%	100%
9	Jersey Island	6.96E-02	82%	97%	100%
174	Staten Island	6.78E-02	82%	97%	100%
12	McDonald Tract	6.20E-02	79%	95%	100%
176	Brack Tract	6.01E-02	78%	95%	100%
17	Jones Tract-Upper and Lower	5.88E-02	77%	95%	100%
1006	Upper Andrus Island	5.82E-02	77%	95%	100%
1007	Brannan-Andrus Island	5.82E-02	77%	95%	100%
166	RD 17 (Mossdale)	5.79E-02	76%	94%	100%
21	Victoria Island	5.73E-02	76%	94%	100%
144	Mandeville Island	5.69E-02	76%	94%	100%
179	Twitchell Island	5.60E-02	75%	94%	100%
1002	Drexler Tract	5.52E-02	75%	94%	100%
1003	Roberts Island	5.52E-02	75%	94%	100%
152	Medford Island	5.37E-02	74%	93%	100%
15	Bacon Island	5.12E-02	72%	92%	99%
5	Empire Tract	5.02E-02	71%	92%	99%
4	Webb Tract	4.83E-02	70%	91%	99%
19	Woodward Island	4.83E-02	70%	91%	99%
20	Orwood Tract	4.81E-02	70%	91%	99%
182	Shin Kee Tract	4.77E-02	70%	91%	99%
177	Bouldin Island	4.65E-02	69%	90%	99%
143	Rindge Tract	4.61E-02	68%	90%	99%
87	Terminous Tract	4.57E-02	68%	90%	99%
127	Byron Tract	4.51E-02	68%	90%	99%
6	Bradford Island	4.45E-02	67%	89%	99%
13	Holland Tract	4.28E-02	66%	88%	99%
1016	Smith Tract - Lincoln Village Tract	4.11E-02	64%	87%	98%
1000	Netherlands	4.07E-02	64%	87%	98%
157	Smith Tract	3.91E-02	62%	86%	98%
169	McCormack Williamson Tract	3.70E-02	60%	84%	98%
147	Grand Island	3.59E-02	59%	83%	97%
108	Hotchkiss Tract	3.48E-02	58%	82%	97%
16	Palm Tract	3.46E-02	58%	82%	97%
153	Rough and Ready Island	3.44E-02	58%	82%	97%
165	Walthal Tract	3.43E-02	58%	82%	97%
175	Canal Ranch	3.41E-02	57%	82%	97%
210	Ryer Island	3.32E-02	56%	81%	96%
7	King Island	2.94E-02	52%	77%	95%
118	Pescadero	2.93E-02	52%	77%	95%
119	Paradise Junction	2.93E-02	52%	77%	95%
11	Quimby Island	2.91E-02	52%	77%	95%
190	Wright-Elmwood Tract	2.88E-02	51%	76%	94%
117	Union Island	2.78E-02	50%	75%	94%
109	Dutch Slough East	2.52E-02	47%	72%	92%
187	Shima Tract	2.36E-02	45%	69%	91%
32	Coney Island	2.36E-02	45%	69%	91%
163	Fabian Tract	2.35E-02	44%	69%	90%
14	Dutch Slough West	2.34E-02	44%	69%	90%
141	Merritt Island	2.17E-02	42%	66%	89%
1010	Clifton Court Forebay South	2.15E-02	42%	66%	88%
170	Glanville Tract	2.11E-02	41%	65%	88%
149	Pierson Tract	2.01E-02	39%	63%	87%
1013	Bishop Tract	1.98E-02	39%	63%	86%
86	Terminous Tract East	1.83E-02	37%	60%	84%
159	Boggs Tract	1.82E-02	37%	60%	84%
162	Fabian Tract South West 2	1.81E-02	36%	59%	84%
115	Upper Roberts Island	1.65E-02	34%	56%	81%
158	Weber Tract	1.63E-02	33%	56%	80%
129	Veale Tract 1	1.59E-02	33%	55%	80%
183	Rio Blanco Tract	1.54E-02	32%	54%	79%
167	Libby McNeil Tract 2	1.52E-02	32%	53%	78%
168	Libby McNeil Tract 1	1.52E-02	32%	53%	78%
1008	Stewart Tract	1.52E-02	32%	53%	78%
1009	Mossdale R.D. No. 2107	1.52E-02	32%	53%	78%
146	Sutter Island	1.47E-02	31%	52%	77%
148	Elk Grove South West	1.25E-02	27%	47%	71%

Table 13-8 Delta and Suisun Marsh Individual Island Composite Rates of Failures

URS_ID	URS Name	Annual Mean No. of Failures	Probability of Failure in 25 years	Probability of Failure in 50 years	Probability of Failure in 100 years
173	Deadhorse Island	1.20E-02	26%	45%	70%
216	Fabian Tract South West 1	1.13E-02	25%	43%	68%
62	Walnut Grove	1.09E-02	24%	42%	66%
171	Cosumnes River Area	1.00E-02	22%	39%	63%
120	McMullin Ranch	8.90E-03	20%	36%	59%
77	Elk Grove South East	6.46E-03	15%	28%	48%
1012	Atlas Tract	6.16E-03	14%	27%	46%
196	Sacramento Pocket Area	5.90E-03	14%	26%	45%
1004	West Sacramento 2	5.90E-03	14%	26%	45%
135	West Sacramento 1	5.90E-03	14%	26%	45%
126	Pico Naglee Tract	4.88E-03	11%	22%	39%
1014	McMullin Ranch-River Junction Tract	2.90E-03	7%	13%	25%
75	N. of Glanville Tract	2.31E-03	6%	11%	21%
1005	Elk Grove	1.76E-03	4%	8%	16%
197	Elk Grove West	1.76E-03	4%	8%	16%
78	Elk Grove South	1.76E-03	4%	8%	16%
121	Kasson District	1.73E-03	4%	8%	16%
113	Union Island South East	1.62E-03	4%	8%	15%
185	Atlas Tract East	5.53E-04	1%	3%	5%
112	Union Island East	7.01E-05	0%	0%	1%
114	Stark Tract	1.74E-05	0%	0%	0%
68	Little Egbert Tract	4.76E-02	70%	91%	99%
89	Cache Haas Tract 2	4.28E-02	66%	88%	99%
88	Cache Haas Tract 1	3.99E-02	63%	86%	98%
72	Peter Pocket	3.06E-02	54%	78%	95%
1001	Hastings Tract	2.89E-02	51%	76%	94%
79	Peter's Pocket West	2.82E-02	51%	76%	94%
80	Cache Haas Tract 1 East	2.64E-02	48%	73%	93%
69	Egbert Tract East	2.63E-02	48%	73%	93%
82	Hastings Tract South West	2.63E-02	48%	73%	93%
70	Egbert Tract	2.37E-02	45%	69%	91%
41	SM-41	5.01E-01	100%	100%	100%
1	SM-1	4.90E-01	100%	100%	100%
2	SM-2	4.90E-01	100%	100%	100%
58	SM-58	4.90E-01	100%	100%	100%
60	SM-60	4.89E-01	100%	100%	100%
57	SM-57	4.89E-01	100%	100%	100%
123	SM-123	4.85E-01	100%	100%	100%
124	SM-124	4.85E-01	100%	100%	100%
42	SM-42	4.78E-01	100%	100%	100%
39	SM-39	4.74E-01	100%	100%	100%
131	Schafter-Pintail Tract	4.61E-01	100%	100%	100%
132	SM-132	4.61E-01	100%	100%	100%
55	SM-55	4.61E-01	100%	100%	100%
56	SM-56	4.61E-01	100%	100%	100%
84	SM-84	4.61E-01	100%	100%	100%
85	SM-85-Grizzly Island	4.61E-01	100%	100%	100%
40	SM-40	3.80E-01	100%	100%	100%
202	SM-202	3.15E-01	100%	100%	100%
46	SM-46	3.15E-01	100%	100%	100%
204	SM-204	1.36E-01	97%	100%	100%
48	SM-48	1.08E-01	93%	100%	100%
203	Simmons-Wheeler Island	1.06E-01	93%	100%	100%
200	Van Sickle Island	1.04E-01	92%	99%	100%
201	Honker Bay Club	1.04E-01	92%	99%	100%
49	SM-49	8.92E-02	89%	99%	100%
44	SM-44	8.18E-02	87%	98%	100%
54	SM-54	6.80E-02	82%	97%	100%
50	SM-50	6.39E-02	80%	96%	100%
47	SM-47	6.01E-02	78%	95%	100%
45	SM-45	5.96E-02	77%	95%	100%
59	SM-59	5.23E-02	73%	93%	99%
133	SM-133	4.55E-02	68%	90%	99%
134	SM-134	4.55E-02	68%	90%	99%
43	SM-43	3.04E-02	53%	78%	95%
198	SM-198	2.83E-02	51%	76%	94%
51	SM-51	2.58E-02	48%	72%	92%
	TOTAL DELTA	**2.99E+00**	**100.00%**	**100.00%**	**100.00%**
	TOTAL CACHE SLOUGH AREA	**3.21E-01**	**99.97%**	**100.00%**	**100.00%**
	TOTAL SUISUN MARSH	**9.85E+00**	**100.00%**	**100.00%**	**100.00%**

Table 13-9 Duration and Cost of Repair and Dewatering for Seismic Cases

No. of Flooded Islands	Estimated Range of Cost of Repair and Dewatering ($M)	Estimated Range of Breach Repair Time (days)	Estimated Range of Time to Dewater (days)
1	43–240	27–106	136–276
3	204–490	120–330	270–466
10	620–1260	290–586	460–700
20	1,400–2,300	620–880	750–1,020
30	3,000–4,200	1,120–1,520	1,240–1,660

[a] The range is provided for plus and minus one standard deviation from the mean values.

Table 13-10a Summary of Economic Costs of Flooded Islands due to Seismic Events									
	In-Delta Costs ($ Million)			Statewide Cost ($ Million)			Total Cost ($ Million)		
Number of Flooded Islands	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)
1	134	199	296	8	19	47	142	219	343
3	436	647	961	63	154	376	499	801	1,337
5	775	1,150	1,706	200	489	1,196	974	1,638	2,902
10	1,741	2,584	3,835	1,061	2,596	6,354	2,802	5,180	10,189
15	2,900	4,304	6,387	3,026	7,406	18,127	5,926	11,710	24,513
20	4,060	6,024	8,939	4,991	12,216	29,899	9,050	18,240	38,839
30	7,187	10,665	15,826	6,032	14,763	36,135	13,219	25,428	51,961
50	11,247	16,689	24,766	11,022	26,979	66,034	22,269	43,668	90,800

Table 13-10b Summary of Economic Impacts of Flooded Islands due to Seismic Events

Number of Flooded Islands	Value of Lost Output ($ Million)			Lost Employment (# of Lost Jobs)			Lost Labor Income ($ Million)			Lost Value Added ($ Million)		
	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)
1	27	52	100	162	281	488	7	12	20	11	20	39
3	106	204	392	737	1,276	2,212	28	49	86	46	87	165
5	201	385	740	1,488	2,578	4,468	54	96	169	91	172	325
10	475	912	1,751	3,863	6,694	11,600	135	238	420	226	429	811
15	786	1,510	2,899	6,750	11,697	20,271	229	405	715	387	732	1,386
20	1,124	2,158	4,144	10,030	17,381	30,119	335	591	1,043	566	1,071	2,026
30	1,860	3,572	6,859	17,526	30,371	52,630	570	1,007	1,777	966	1,829	3,461
50	3,510	6,739	12,940	35,404	61,352	106,318	1,115	1,969	3,476	1,897	3,590	6,794

Table 13-11. Ecosystem Consequences Case 2 Spring Wet Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	0.1	0.96	0	0.3	0	3.16	0.21	0	1.47	3.51	2.93	2.23	7.64	1.44
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.03	0	7.59	0	0	0	6.53							

Table 13-12. Ecosystem Consequences Case 2 Summer Average Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	0.1	0.96	0	0.3	0	3.16	0.21	0	1.47	3.51	2.93	2.23	7.64	1.44
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.03	0	7.59	0	0	0	6.53							

Table 13-13. Ecosystem Consequences Case 2 Fall Dry Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	0.1	0.96	0	0.3	0	3.16	0.21	0	1.47	3.51	2.93	2.23	7.64	1.44
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.03	0	7.59	0	0	0	6.53							

Table 13-14. Ecosystem Consequences Case 3 Spring Wet Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	0.1	0.96	0	0.3	0	3.16	0.21	0	1.47	3.51	2.93	2.23	7.64	1.44
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.03	0	7.59	0	0	0	6.53							

Table 13-15. Ecosystem Consequences Case 3 Summer Average Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	0.1	0.96	0	0.3	0	3.16	0.21	0	1.47	3.51	2.93	2.23	7.64	1.44
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.03	0	7.59	0	0	0	6.53							

Table 13-16. Ecosystem Consequences Case 3 Fall Dry Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	0.1	0.96	0	0.3	0	3.16	0.21	0	1.47	3.51	2.93	2.23	7.64	1.44
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.03	0	7.59	0	0	0	6.53							

Table 13-17. Ecosystem Consequences Case 4 Spring Wet Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	1.21	1.07	0	0.98	0	16.57	1.4	0.35	23.39	3.87	10.42	2.34	13.72	7.04
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.4	0	9.38	0	0	0	9.37							

Table 13-18. Ecosystem Consequences Case 4 Summer Average Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	1.21	1.07	0	0.98	0	16.57	1.4	0.35	23.39	3.87	10.42	2.34	13.72	7.04
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.4	0	9.38	0	0	0	9.37							

Table 13-19. Ecosystem Consequences Case 4 Fall Dry Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	1.21	1.07	0	0.98	0	16.57	1.4	0.35	23.39	3.87	10.42	2.34	13.72	7.04
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	0.4	0	9.38	0	0	0	9.37							

Table 13-20. Ecosystem Consequences Case 5 Spring Wet Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	7.91	1.75	0.43	5.11	0	23.46	3.79	0.35	33.02	8.27	18.06	2.59	15.25	12.23
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	2.88	0	16.56	0	0	0	20.3							

Table 13-21. Ecosystem Consequences Case 5 Summer Average Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	7.91	1.75	0.43	5.11	0	23.46	3.79	0.35	33.02	8.27	18.06	2.59	15.25	12.23
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	2.88	0	16.56	0	0	0	20.3							

Table 13-22. Ecosystem Consequences Case 5 Fall Dry Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	7.91	1.75	0.43	5.11	0	23.46	3.79	0.35	33.02	8.27	18.06	2.59	15.25	12.23
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	2.88	0	16.56	0	0	0	20.3							

Table 13-23. Ecosystem Consequences Case 6 Spring Wet Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	11.08	1.95	0.59	6.25	0	29.57	4.94	0.35	39.49	8.36	23.55	7.44	29.19	16.75
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	4.03	0	32.35	0	0	0	42.52							

Table 13-24. Ecosystem Consequences Case 6 Summer Average Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	11.08	1.95	0.59	6.25	0	29.57	4.94	0.35	39.49	8.36	23.55	7.44	29.19	16.75
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	4.03	0	32.35	0	0	0	42.52							

Table 13-25. Ecosystem Consequences Case 6 Fall Dry Seismic Scenario

Vegetation	Vegetation types	Alkali high marsh	Alkali low marsh	Alkali middle marsh	Aquatic vegetation	Herbaceous upland, native	Herbaceous upland ruderal	Herbaceous wetland perennial	Herbaceous wetland seasonal	Herbaceous wetland ruderal	Shrub upland	Shrub wetland	Tree upland, native	Tree upland, non-native	Tree wetland
	Acres	7748.3	16355.7	16179.7	4368.6	498.4	57760.5	16832.4	3171.4	9947.6	464.9	6410.7	2005.7	4125.6	6687.2
	Percent	11.08	1.95	0.59	6.25	0	29.57	4.94	0.35	39.49	8.36	23.55	7.44	29.19	16.75
Wildlife	Wildlife species	Black Rail	Clapper Rail	Crane	Yellow throat	Harvest Mouse	Ornate Shrew	Water fowl							
	Acres	23679.3	14646.5	174383.1	26300.3	11681.8	11681.8	418890.0							
	Percent	4.03	0	32.35	0	0	0	42.52							

Table 13-26 Estimated Duration and Cost of Repair and Dewatering for Flood Cases

No. of Flooded Islands	Range of Cost of Repair & Dewatering ($M)	Range of Breach Repair Time (days)	Range of Time to Dewater (days)
1	30–110	33–120	47–170
3	140–260	190–370	240–450
10	490–680	550–1,020	590–1,060
20	990–1,200	920–1,100	930–1,110
30	1,500–1,800	1,400–1,600	1,380–1,580

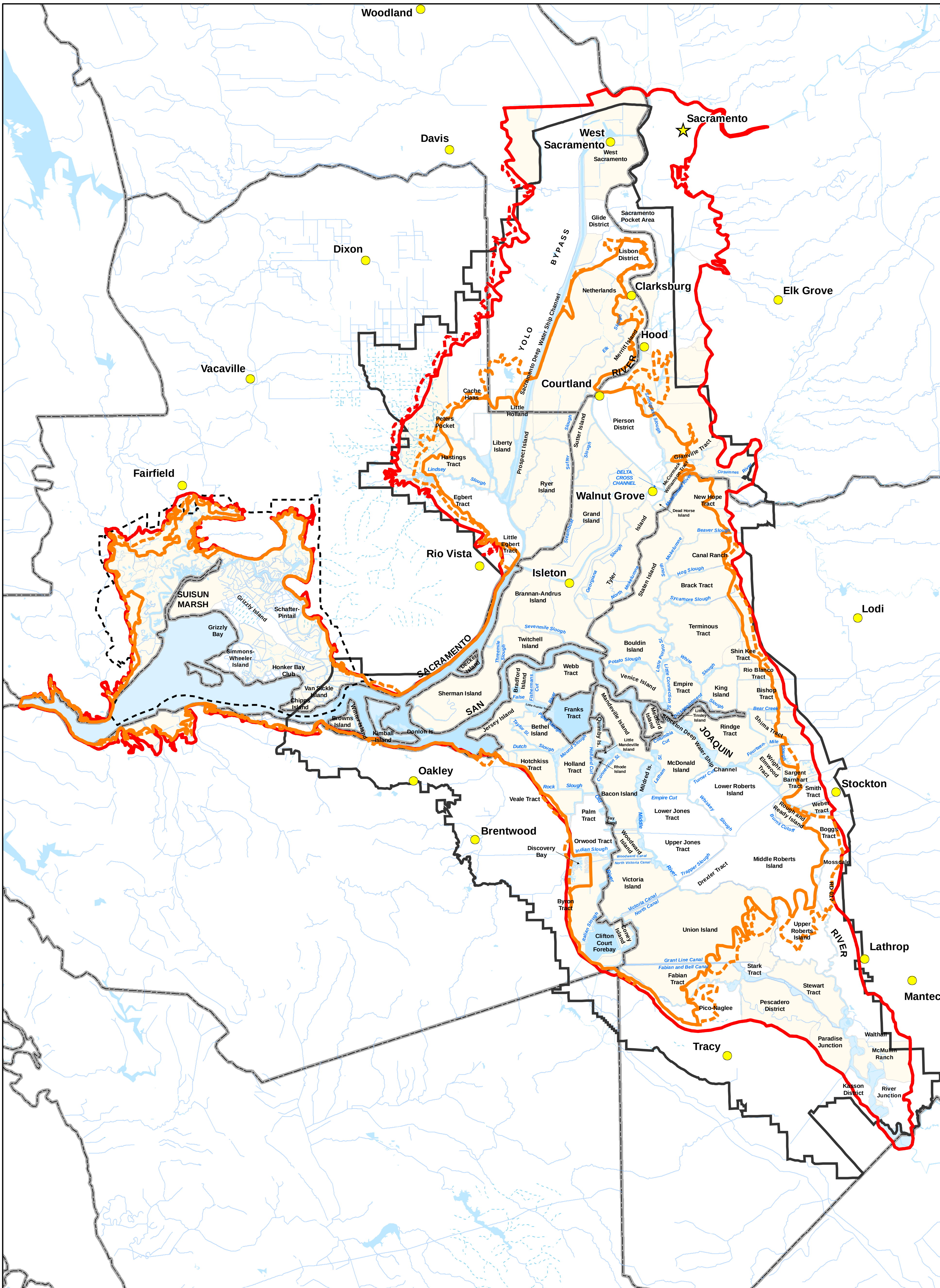
[a] The range is provided for plus and minus one standard deviation from the mean values.

Table 13-27a Summary of Economic Costs of Flooded Islands due to Hydrological Events

Number of Flooded Islands	In-Delta Costs ($ Million)			Statewide Cost ($ Million)			Total Cost ($ Million)		
	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)
1	86	128	190	5	12	29	91	140	219
3	337	500	742	60	146	358	397	647	1,100
5	636	943	1,399	192	470	1,150	828	1,413	2,550
10	1,502	2,229	3,308	935	2,289	5,603	2,438	4,519	8,911
15	2,527	3,749	5,563	2,746	6,722	16,452	5,273	10,471	22,015
20	3,551	5,269	7,819	4,557	11,154	27,301	8,108	16,423	35,120
30	5,873	8,715	12,933	5,458	13,360	32,700	11,331	22,075	45,632

Table 13-27b Summary of Economic Impacts of Flooded Islands due to Hydrological Events

Number of Flooded Islands	Value of Lost Output ($ Million)			Lost Employment (# of Lost Jobs)			Lost Labor Income ($ Million)			Lost Value Added ($ Million)		
	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)	Lower Estimate (16% Confidence)	Median (50% Confidence)	Upper Estimate (84% Confidence)
1	8	16	33	44	93	198	2	4	7	3	7	13
3	66	131	262	394	837	1,775	16	32	67	28	57	115
5	173	345	689	1,094	2,321	4,922	44	90	186	76	155	315
10	640	1,279	2,556	4,366	9,260	19,644	176	363	749	298	605	1,232
15	1,507	3,012	6,018	10,893	23,108	49,017	442	912	1,880	731	1,487	3,026
20	2,374	4,744	9,481	17,421	36,955	78,391	708	1,461	3,012	1,164	2,368	4,820
30	5,111	10,214	20,410	39,144	83,035	176,138	1,599	3,297	6,799	2,584	5,259	10,703



Legend

- MHHW Boundary (Current)
- MHHW (2050)
- 100-Year Floodplain (Current)
- 100-Year Floodplain (2050)
- CA Water
- Intermittent canal, ditch, aqueduct, stream, river, or wash
- Perennial canal, ditch, or aqueduct; stream, river; Reservoir
- CA Counties
- Legal Delta
- Suisun Marsh

0 5 10 Miles

URS	DRMS	MHHW and 100-Year Flood Boundaries	Figure 13-1
	26815431		

URS Corporation P:\GIS\GIS_Project_Files\MXD\Current Working Documents\Infrastructure\Floodplains+1 ft and subsided surface\4-1 MHHW and 100-year flood boundaries.mxd Date: 2/28/2007 12:49:32 PM Name: dhwrigh0

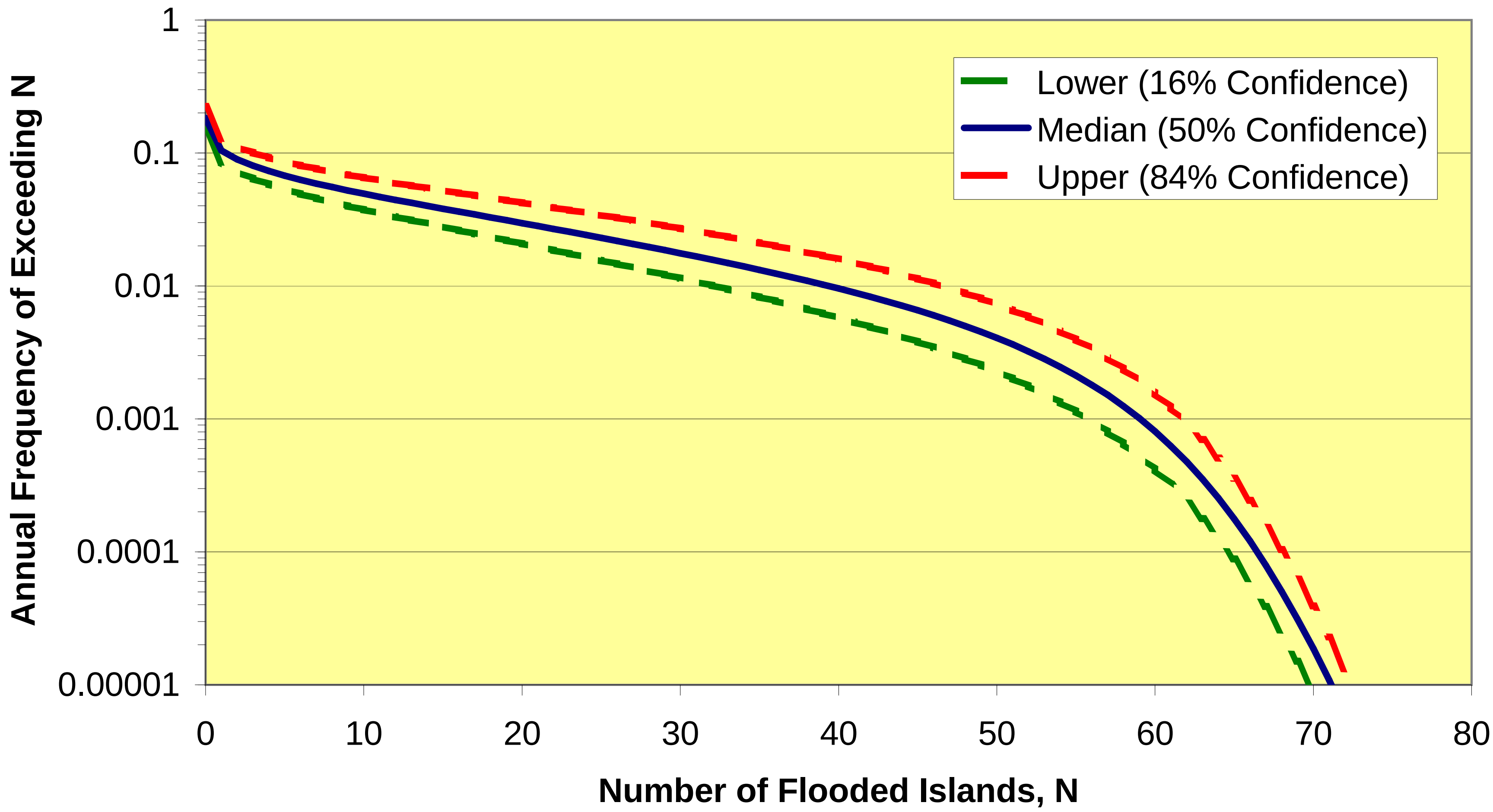


Figure 13-2 Annual Frequency of Exceeding N Flooded Islands due to a Seismic Event

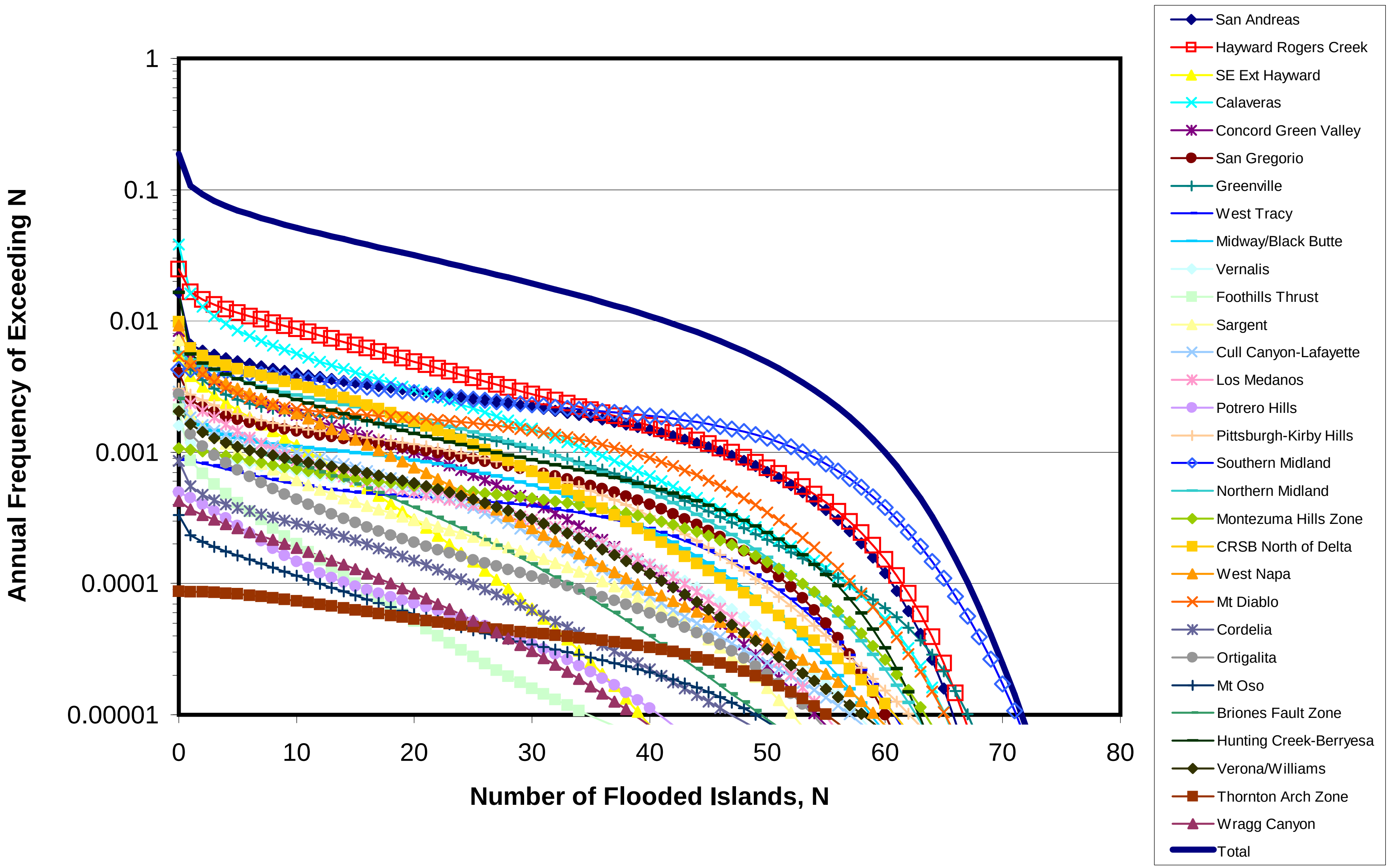


Figure 13-3 Deaggregation of the Mean Frequency Distribution on the Number of Flooded Islands in Delta by Seismic Source

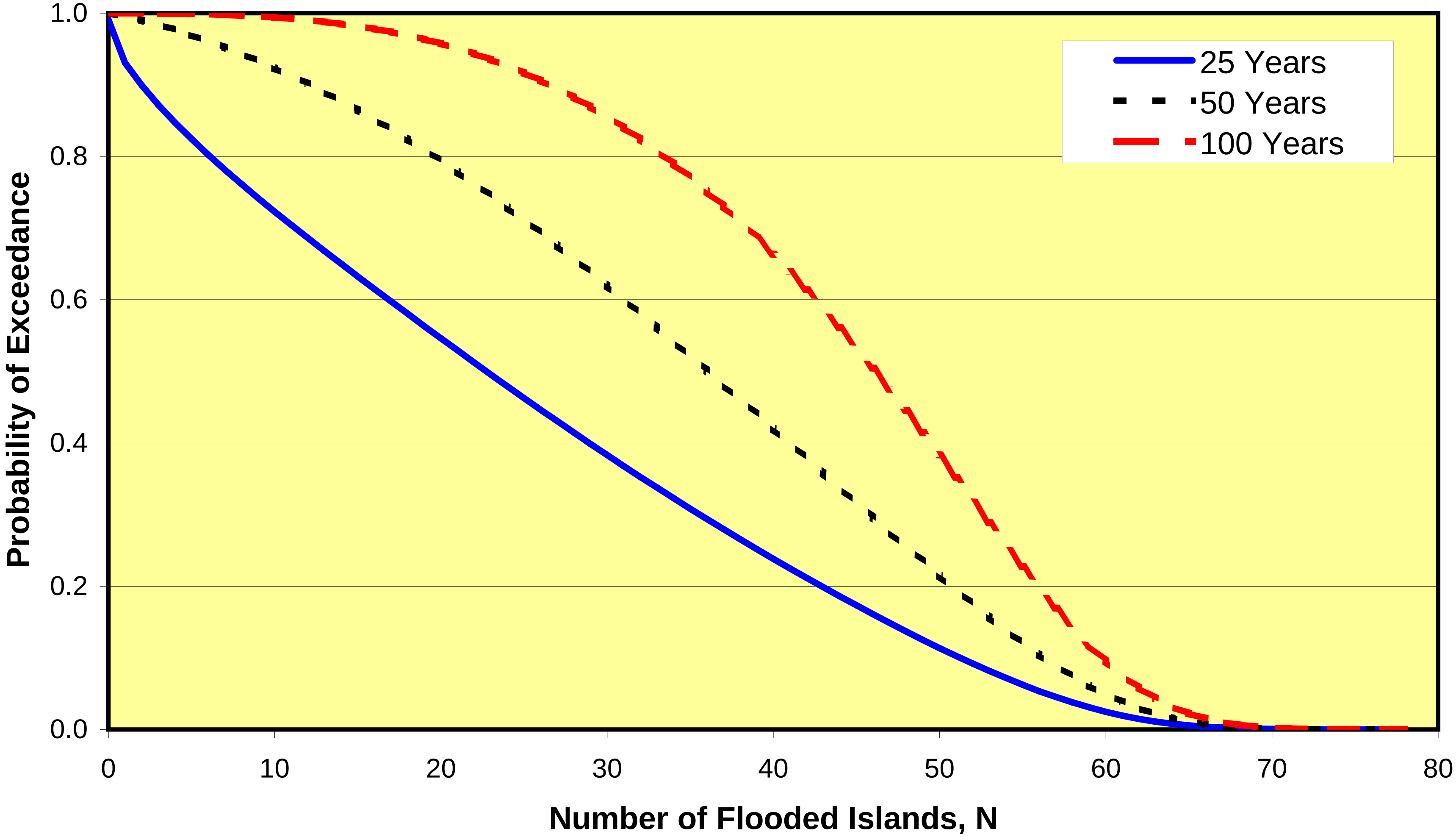


Figure 13-4 Probability of Exceeding a Number of Simultaneous Island Failures Due to Seismic Events for Exposure Periods of 25, 50 and 100 Years

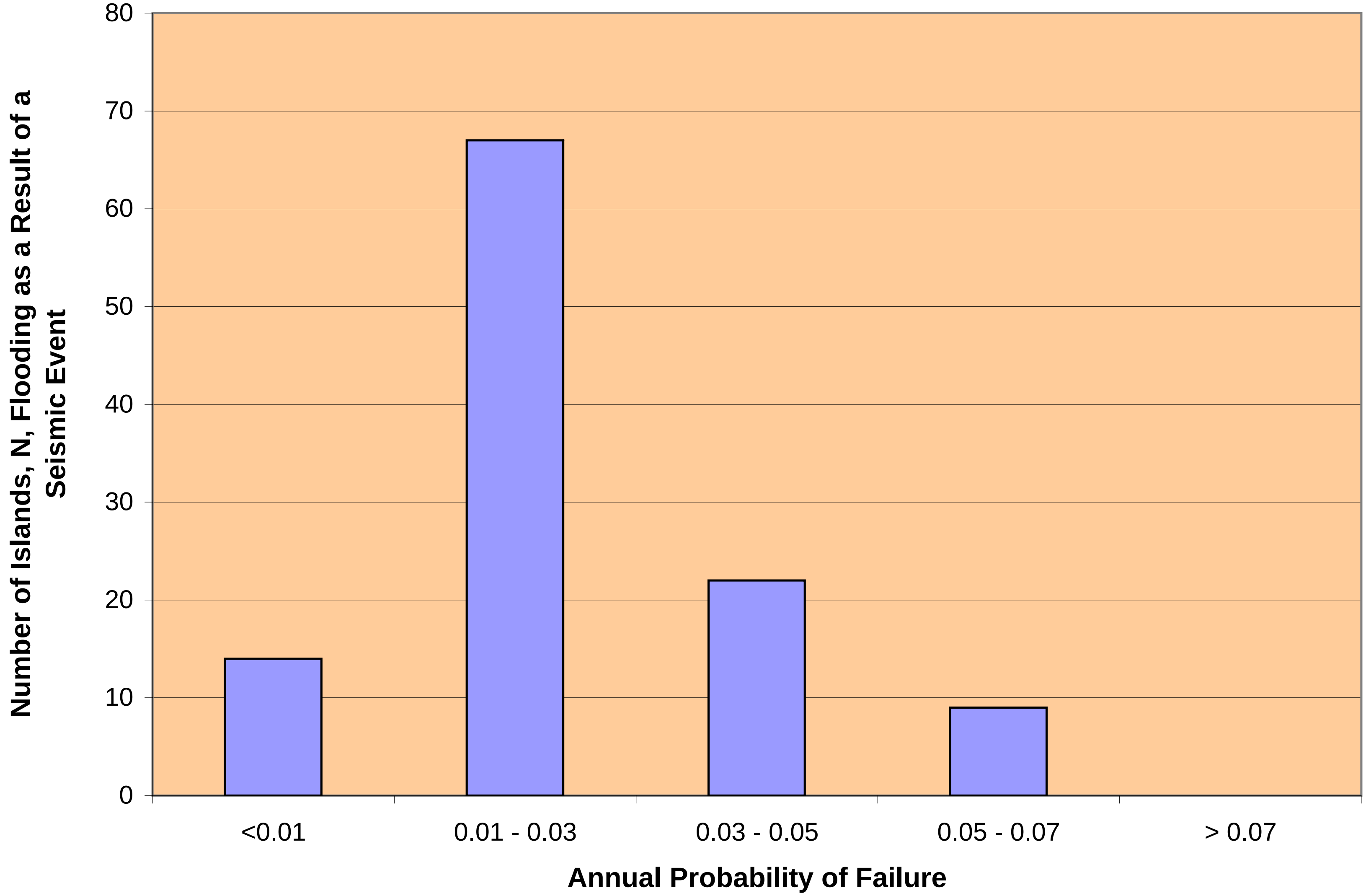


Figure 13-5 Number of Islands in Various Seismic Failure Rate Categories

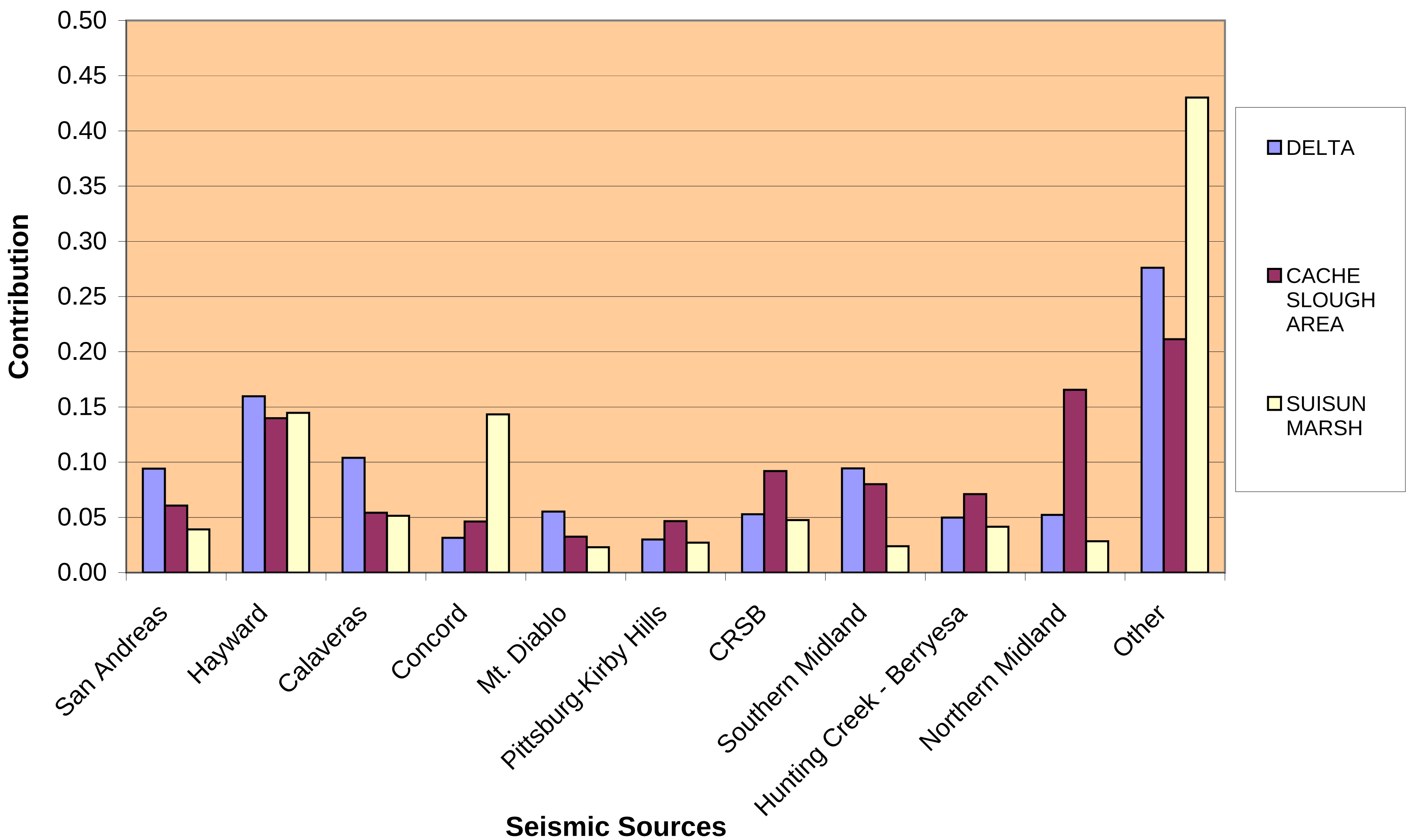
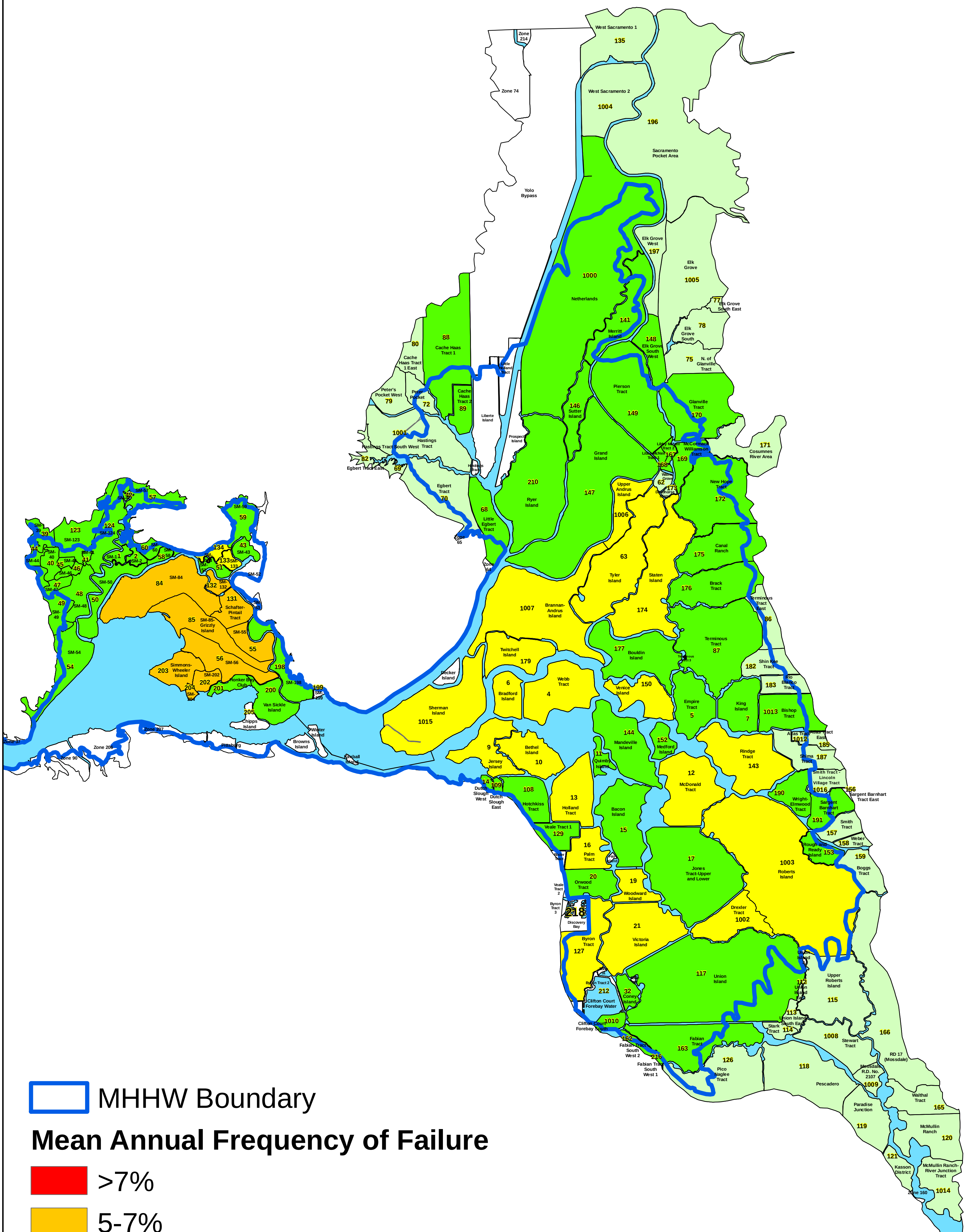


Figure 13-6 Seismic Source Contributions to Individual Island Failures



MHHW Boundary

Mean Annual Frequency of Failure

- >7%
- 5-7%
- 3-5%
- 1-3%
- <1%*

*<1% is either smaller than 1% or outside the MHHW boundary.

0 5 10 Miles

URS	DRMS	Mean Annual Frequency of Failure for Individual Islands Under Seismic Events	Figure 13-7
	26815431		

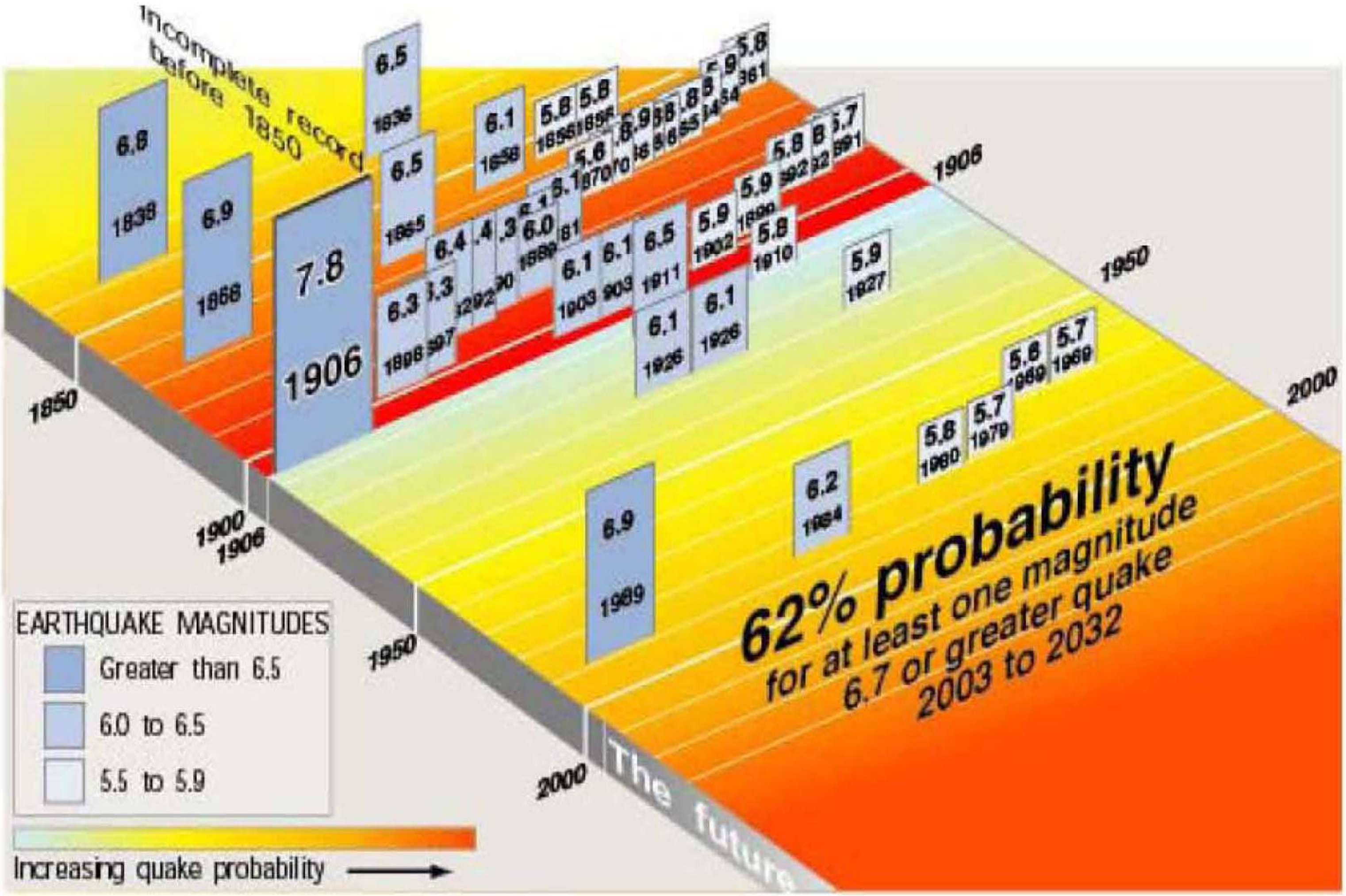


Figure 13-8 Historical Seismicity in the Bay Area Region (USGS 2002)

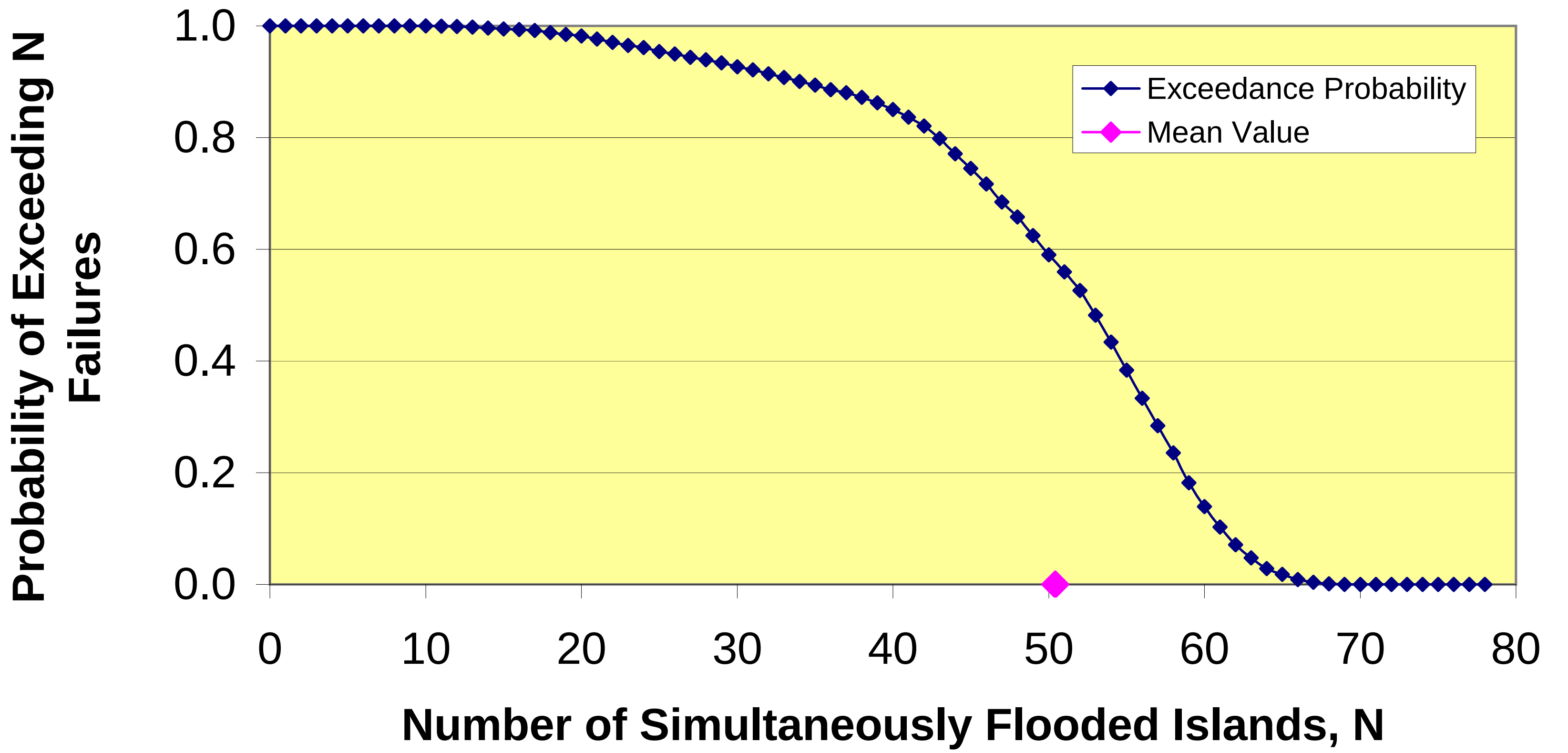


Figure 13-9 Probability of exceeding N Flooded Island Under a M 7.2 Hayward Earthquake Scenario

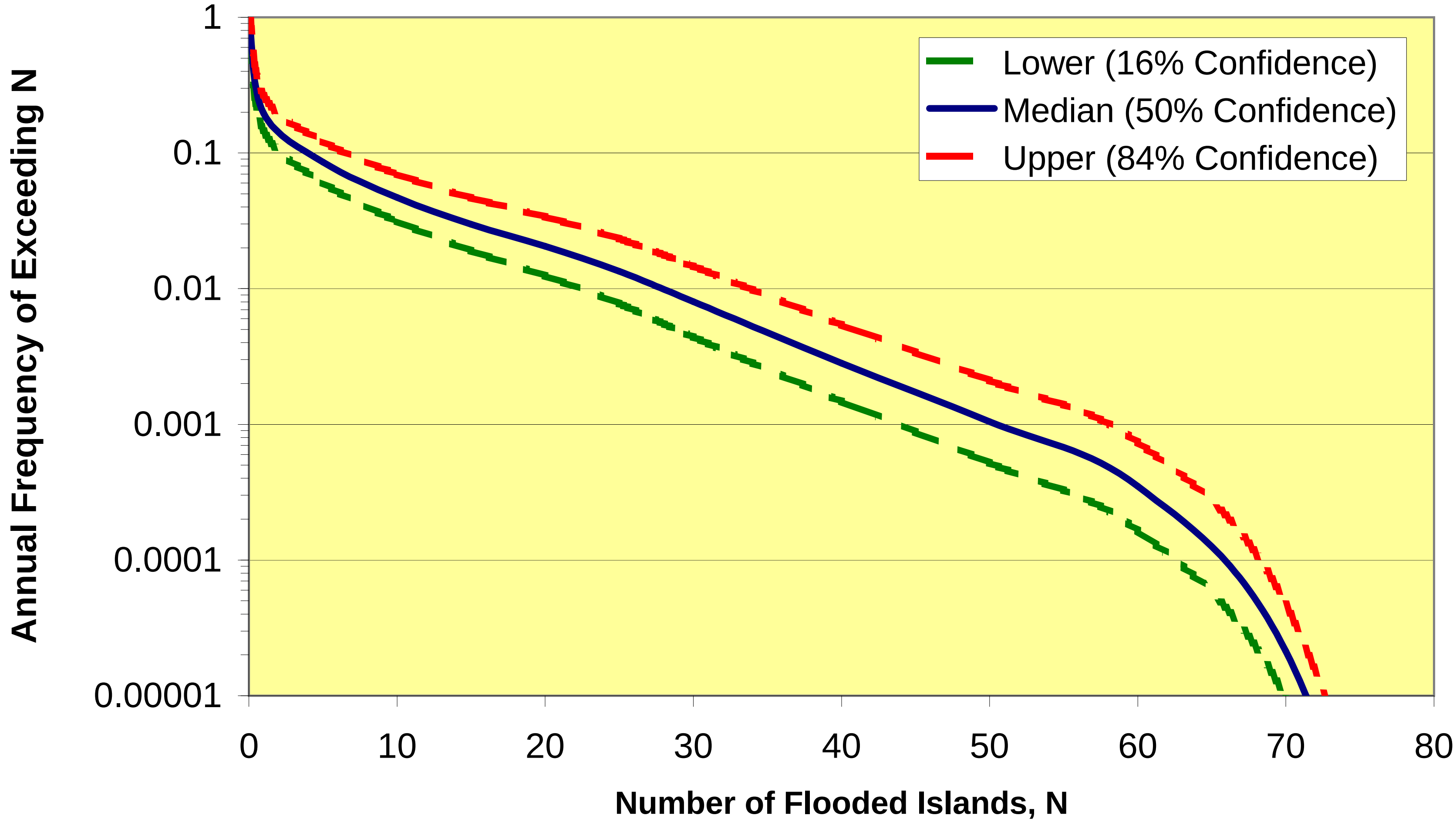


Figure 13-10 Annual Frequency of Exceeding N Flooded Islands Due to Hydrologic Events (Flood)

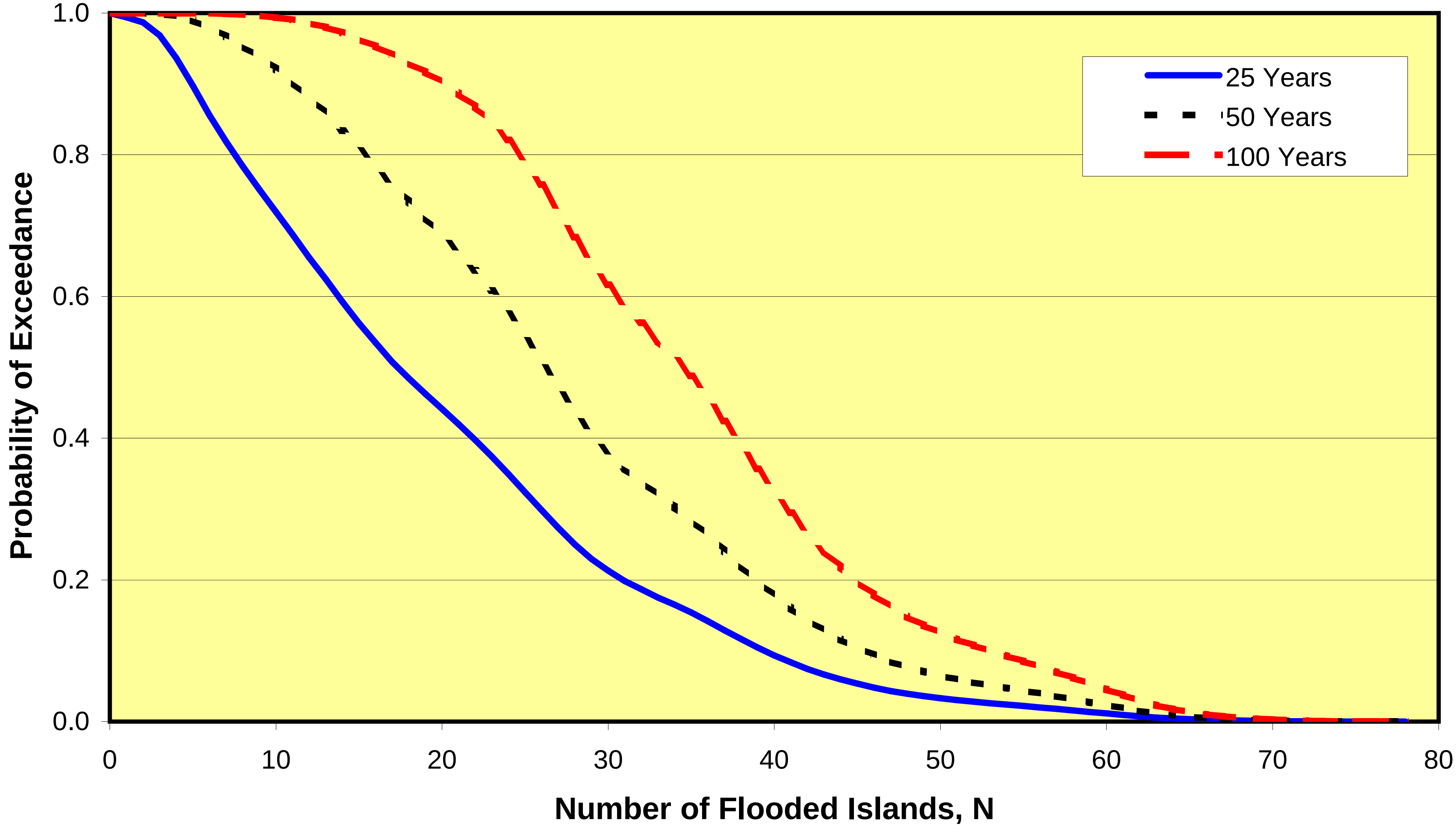


Figure 13-11 Probability of Exceeding a Number of Simultaneous Island Failures Due to Hydrologic Events for Exposure Periods of 25, 50 and 100 Years

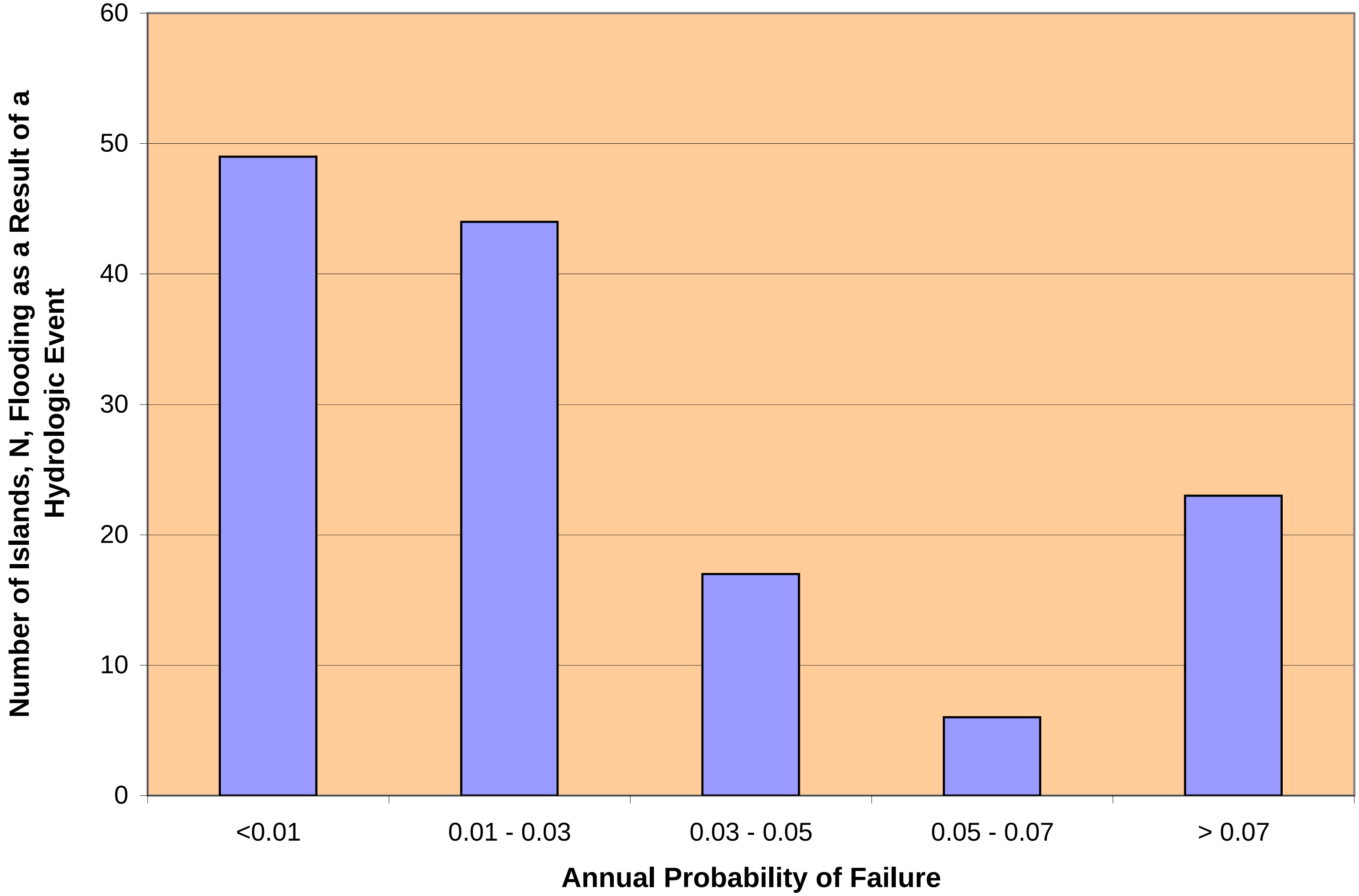
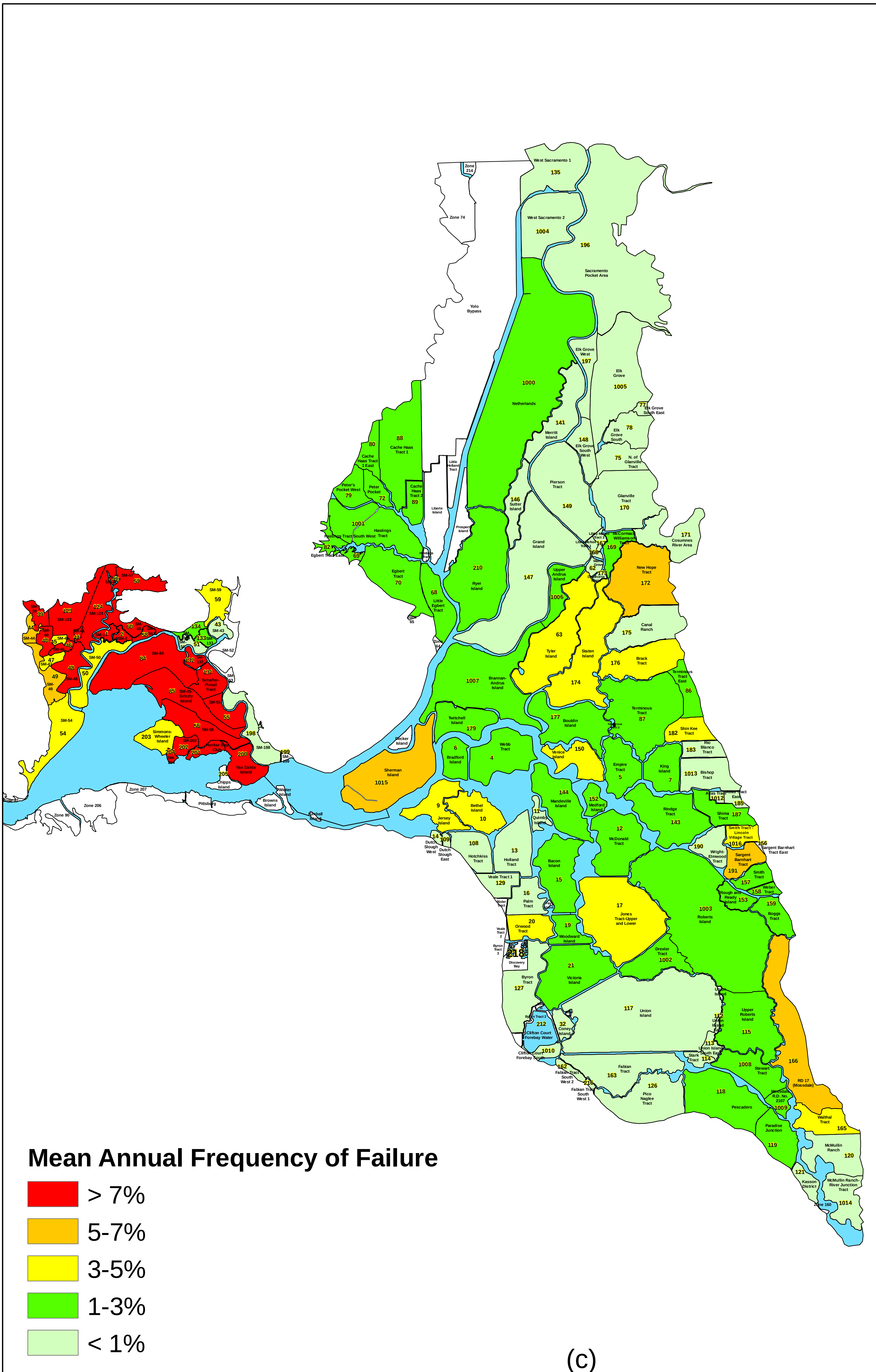


Figure 13-12: Number of Islands in Various Flood Failure Rate Categories



0 5 10 Miles

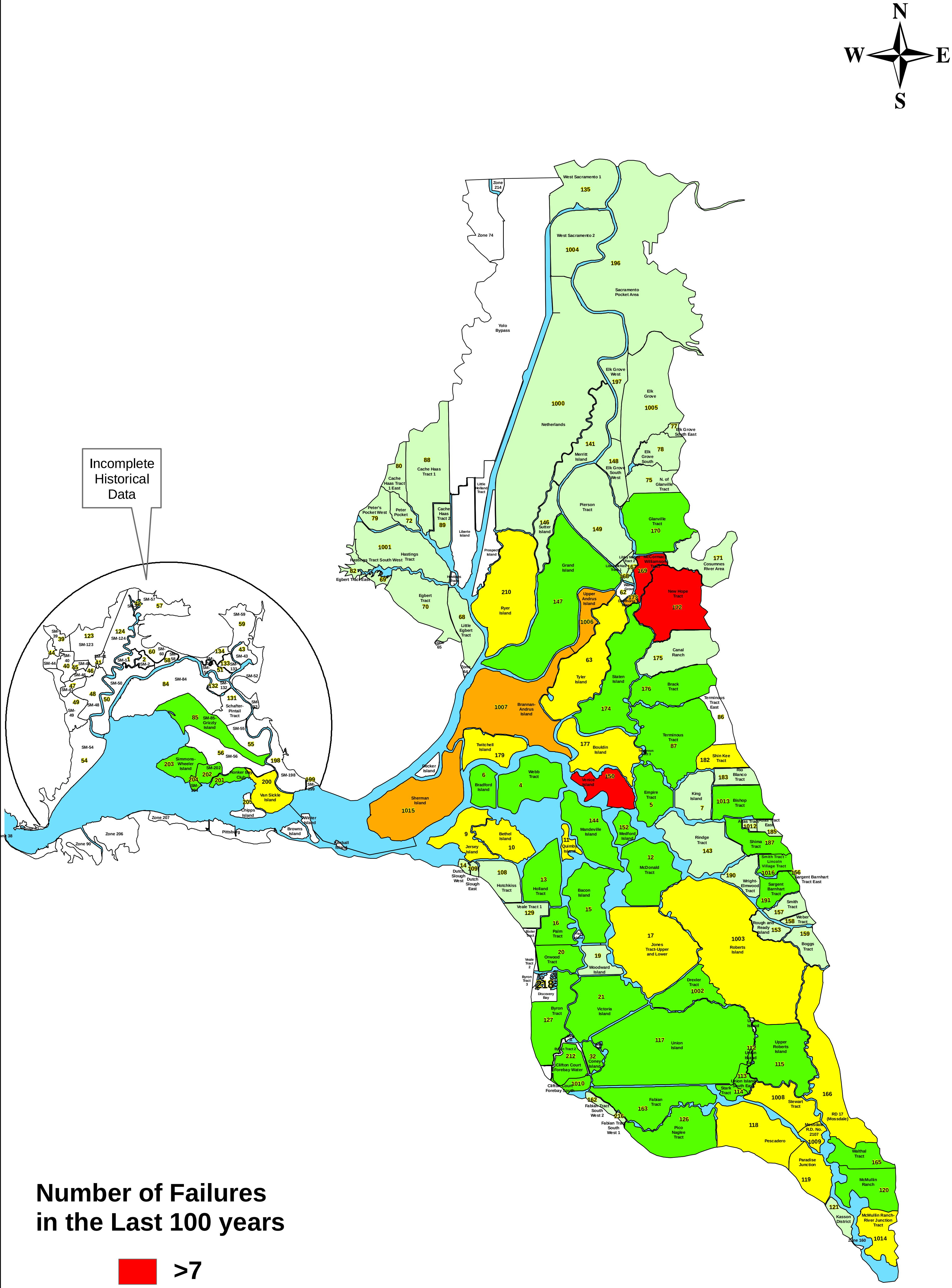
URS

DRMS

26815431

Mean Annual Frequency of Failure for Individual Islands Under Flooding Events

Figure 13-13a



Number of Failures in the Last 100 years

	Number of Failures
Red	>7
Orange	5-7
Yellow	3-5
Green	1-3
Light green	<1

0 2.5 5 10 Miles

URS

DRMS

26815935

Historical Number of Failures in the Last 100 years for Individual Islands Under Flooding Events

Figure 13-13b

URS Corporation, Oakland, CA, dhwrigh0 P:\GIS\GIS_Phase_II_Project_Files\MXD\Current Working Documents\Risk\Flooding\Historical Inundation Failure Map.mxd - 6/25/2007 @ 4:59:11 PM

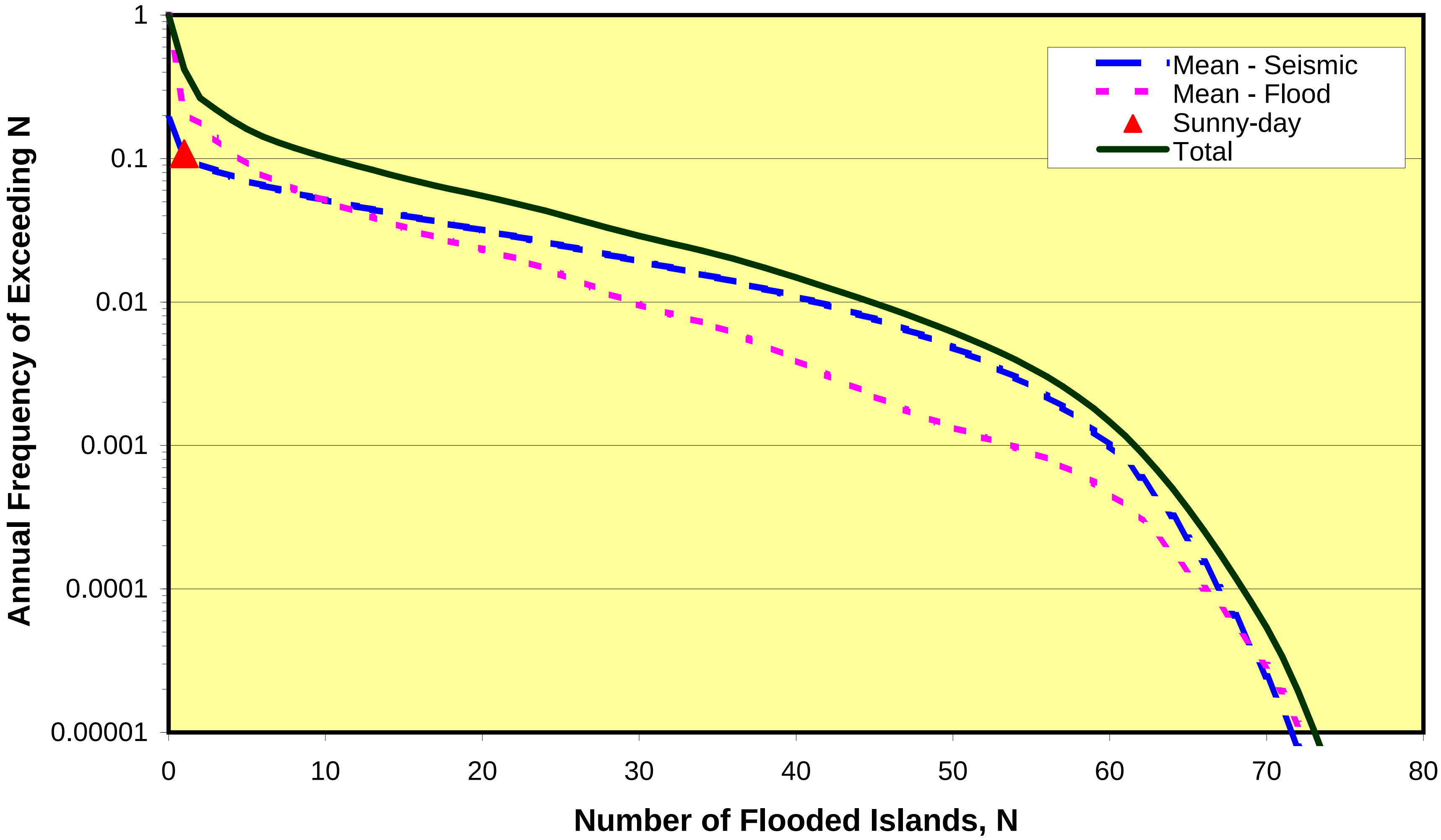


Figure 13-14 Mean Annual Frequency of Exceeding a Number of Flooded Islands Due to Seismic, Flood and Sunny-day Events

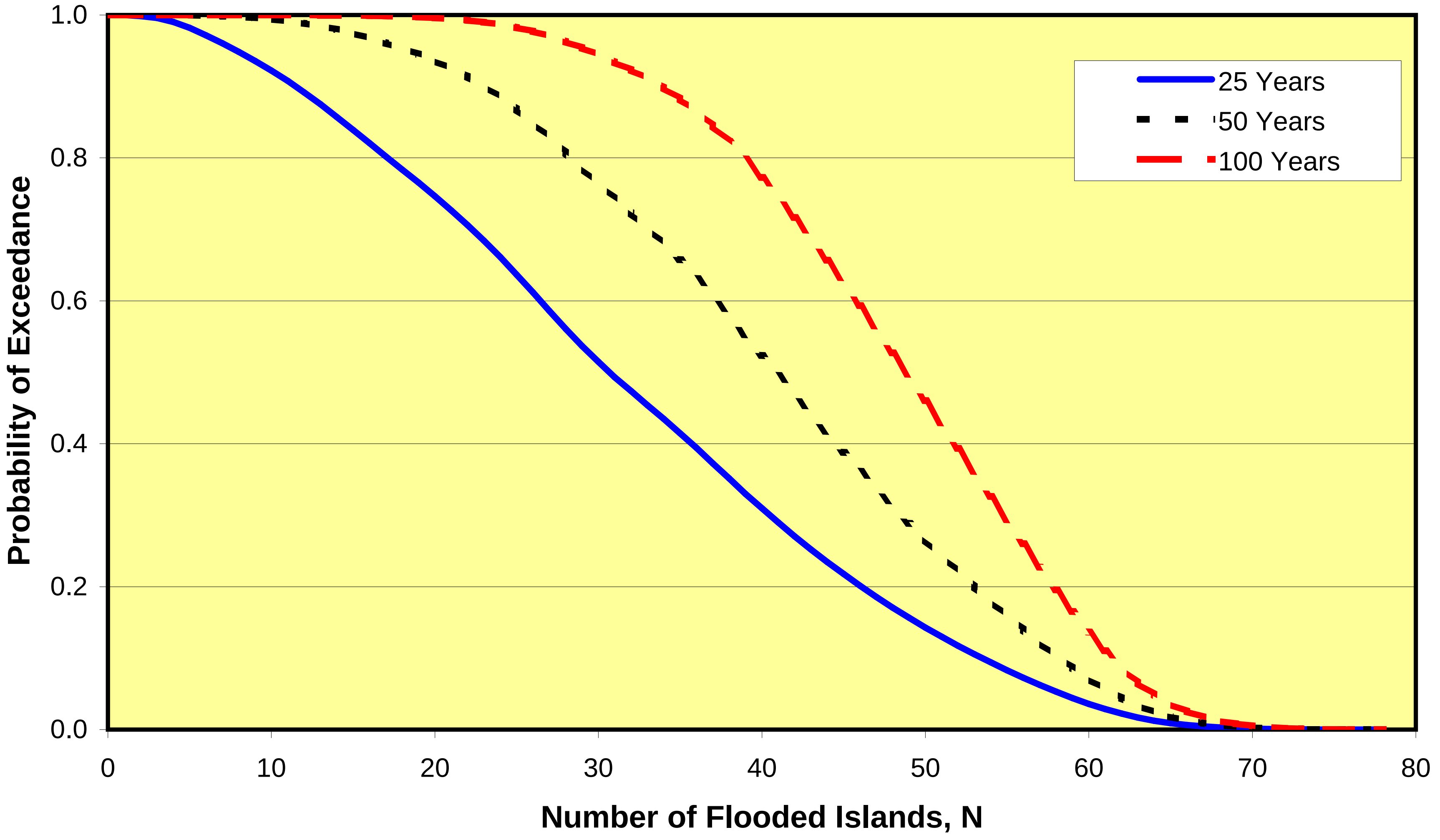
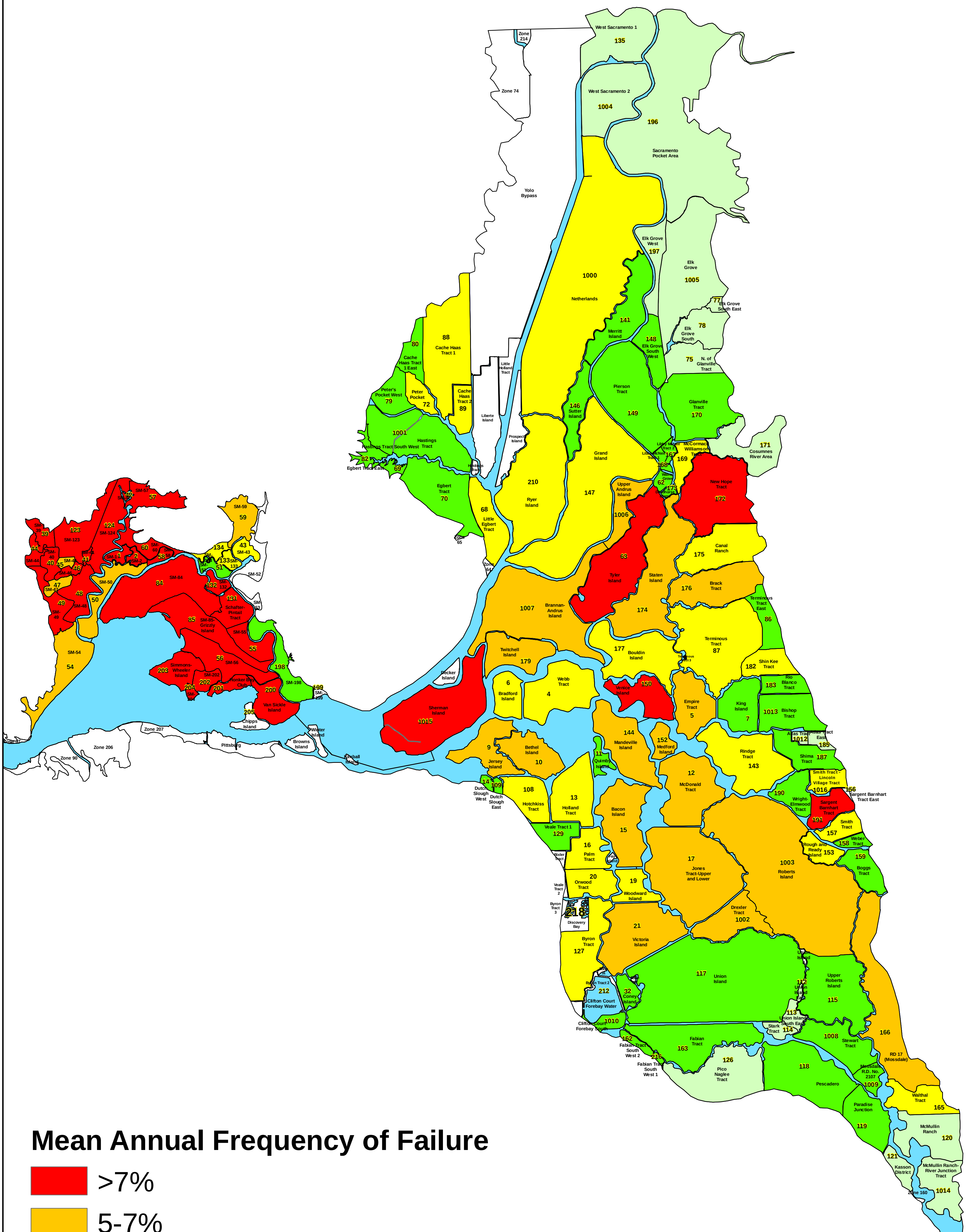


Figure 13-15 Probability of Exceeding a Number of Simultaneous Island Failures Due to All Hazards for Exposure Periods of 25, 50 and 100 Years



Mean Annual Frequency of Failure

- >7%
- 5-7%
- 3-5%
- 1-3%
- <1%

0 5 10 Miles

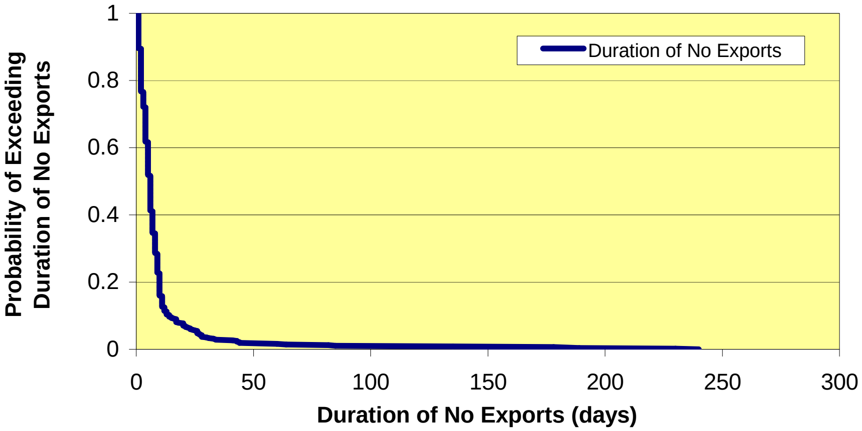
URS

DRMS

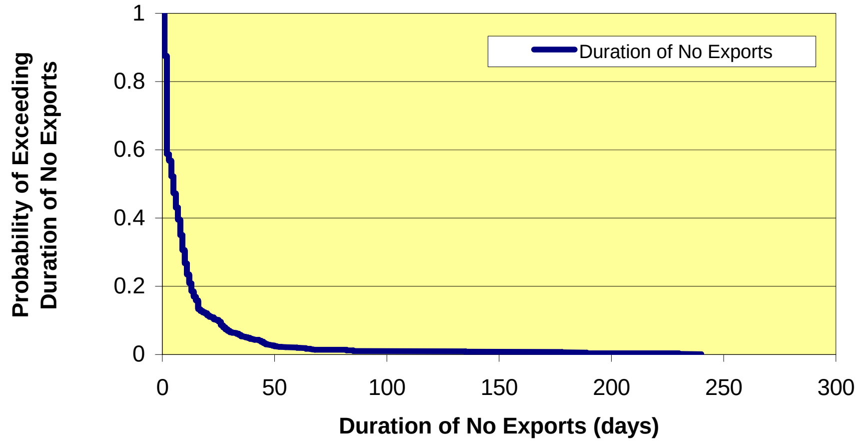
26815431

Mean Annual Frequency of Failure for Individual Islands Under Combined Flooding and Seismic Risk

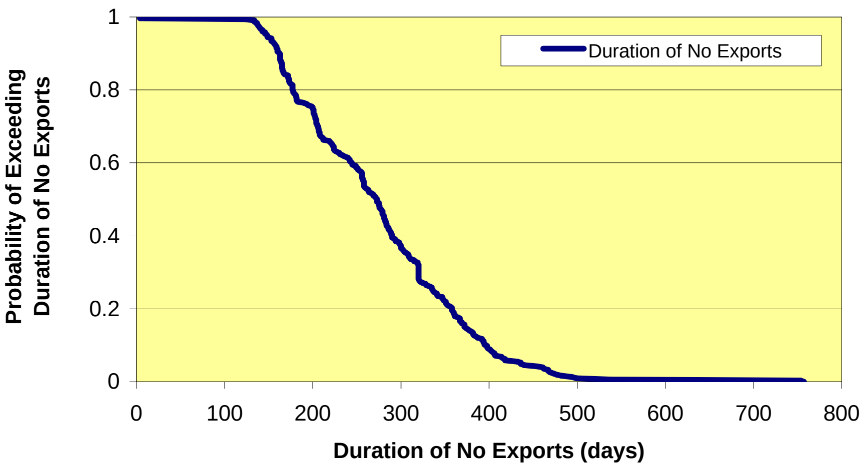
Figure 13-16



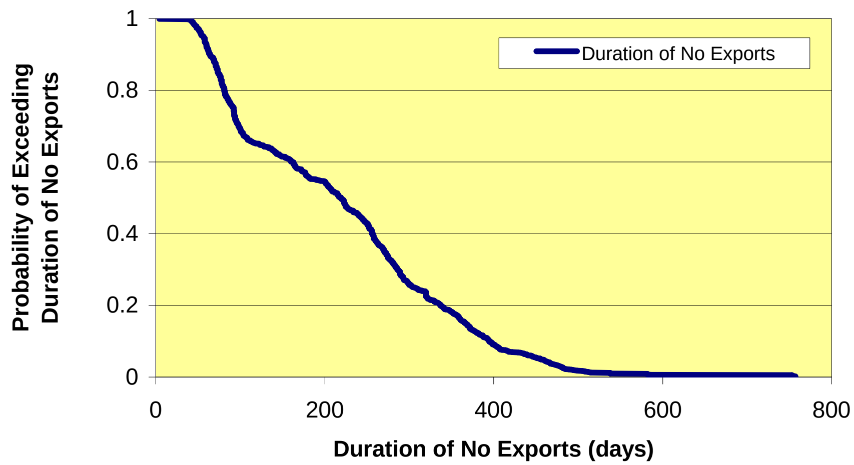
a. Three Flooded Islands; "Normal" Hydrology



b. Three Flooded Islands; "Varied" Hydrology



c. Twenty Flooded Islands; "Normal" Hydrology



d. Twenty Flooded Islands; "Varied" Hydrology

Figure 13-17 Durations of No Exports for Simulated Three-Island and Twenty-Island Sequences
(see text for definitions of "Normal" and "Varied" hydrology)

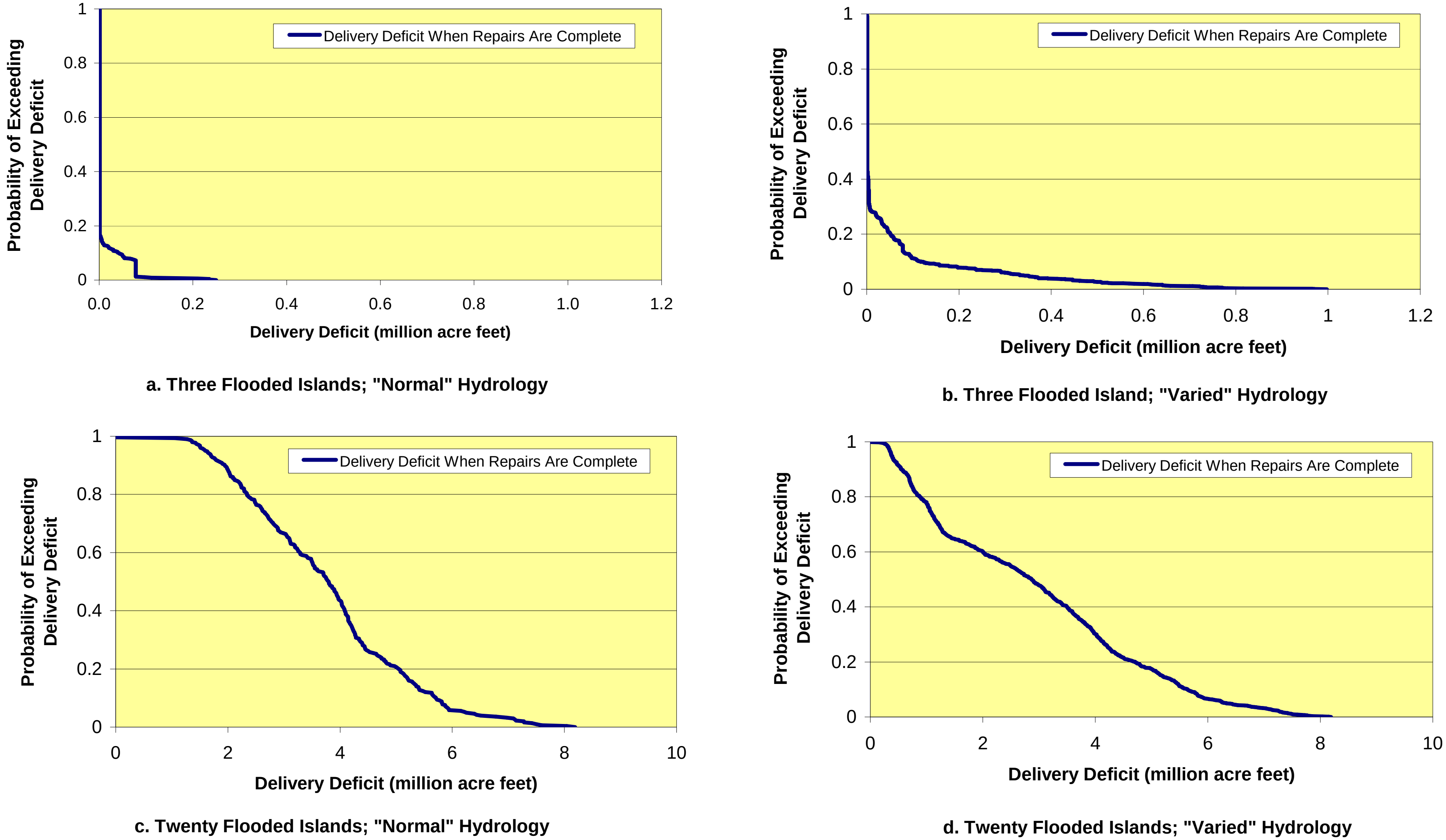


Figure 13-18 South of Delta Delivery Deficits at Completion of Repairs for Simulated Three-Island and Twenty-Island Sequences

(see text for definitions of "Normal" and "Varied" hydrology)

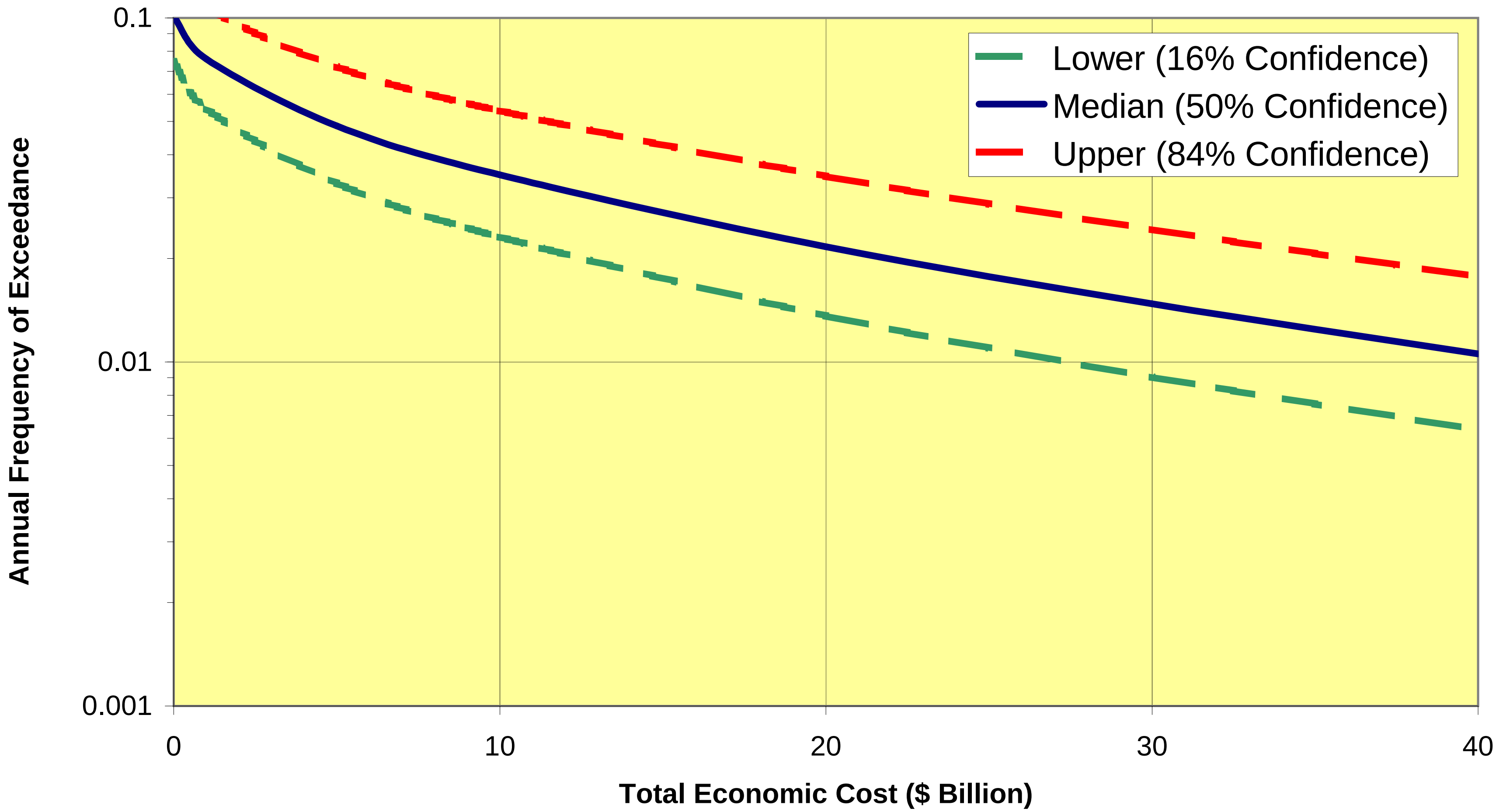


Figure 13-19a Annual Frequency of Exceeding Total Economic Cost due to Seismic Events

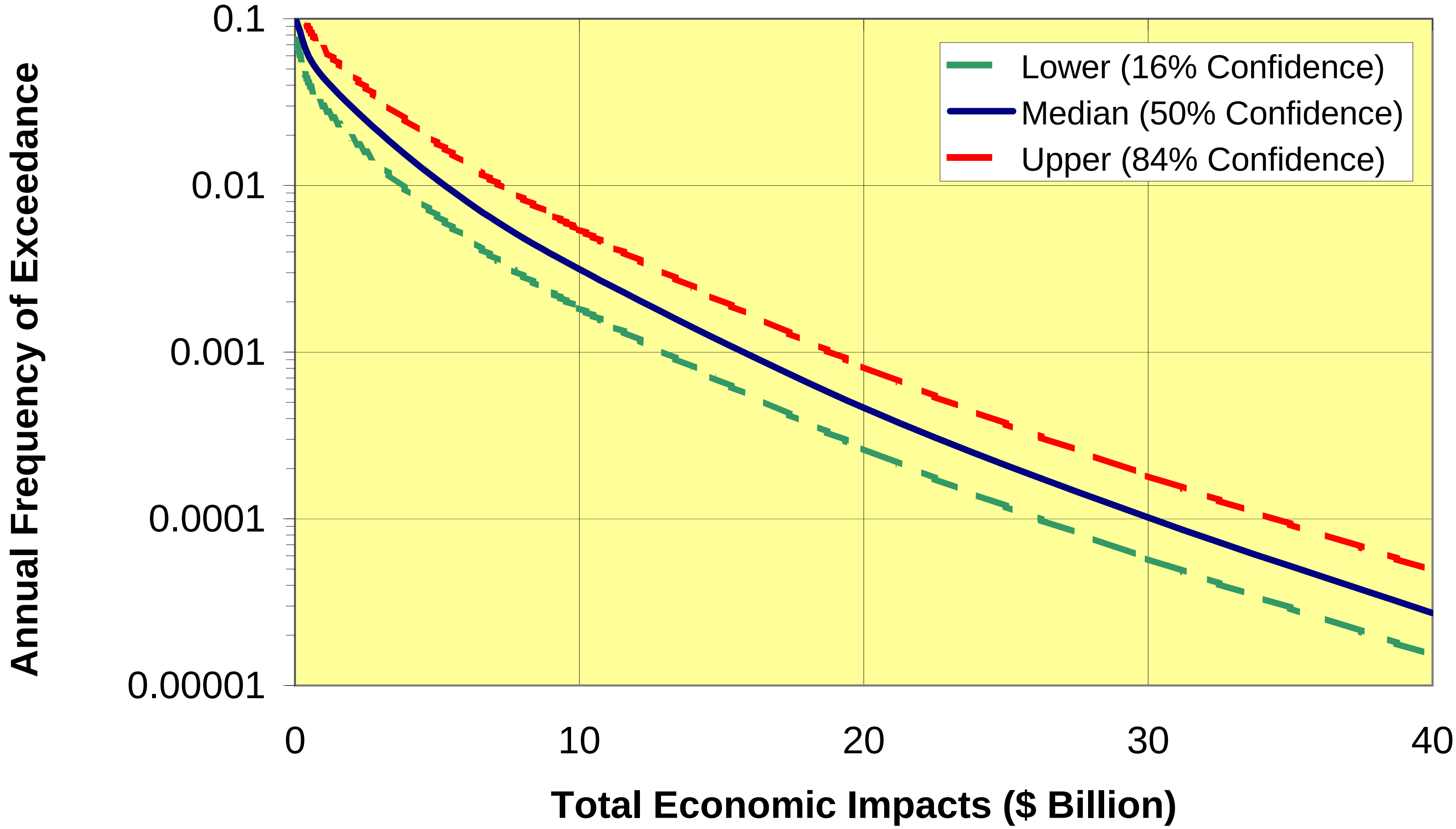


Figure 13-19b Annual Frequency of Exceeding Total Economic Impacts Due to Seismic Events

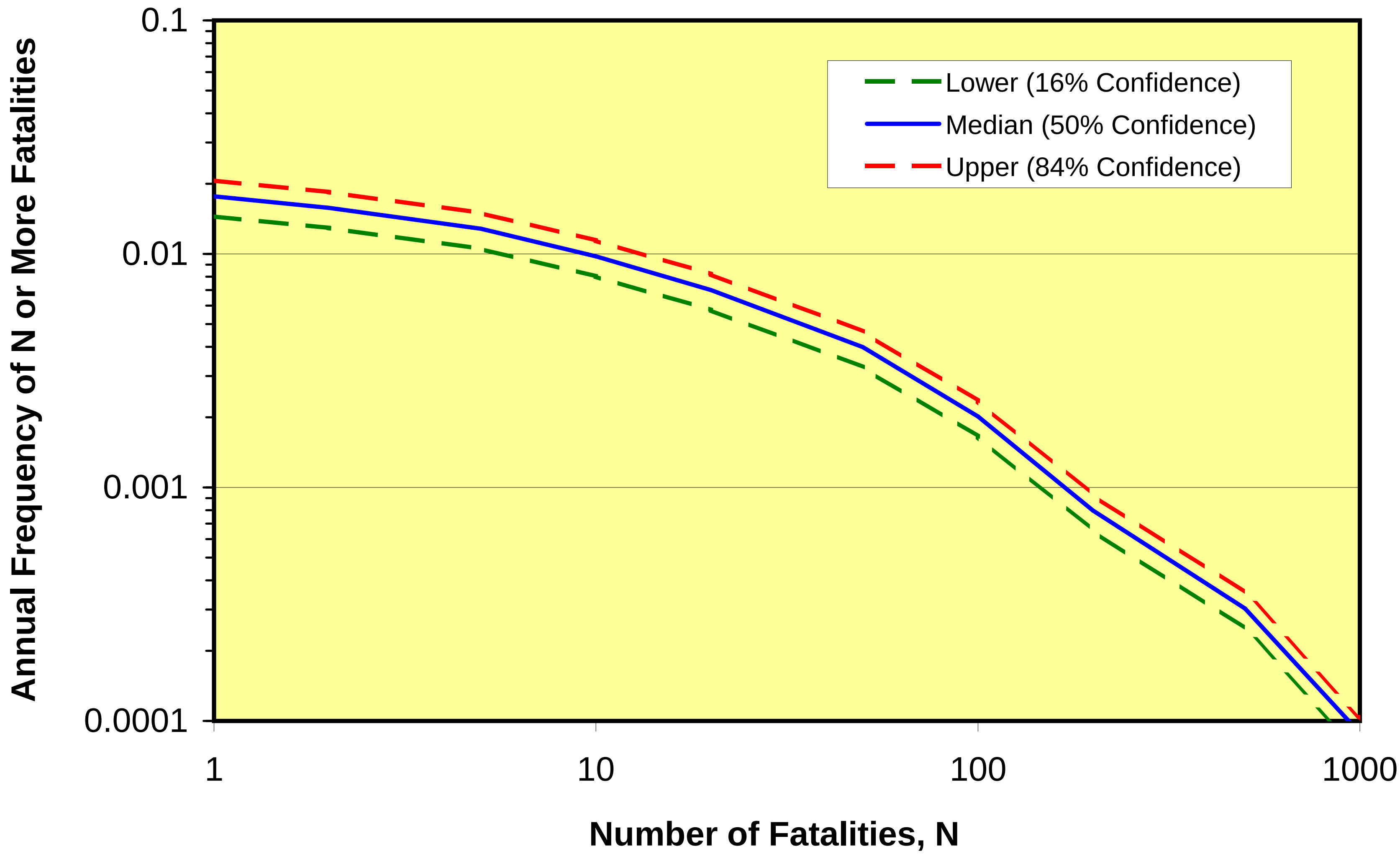


Figure 13-20 Expected Life Loss due to Earthqakes

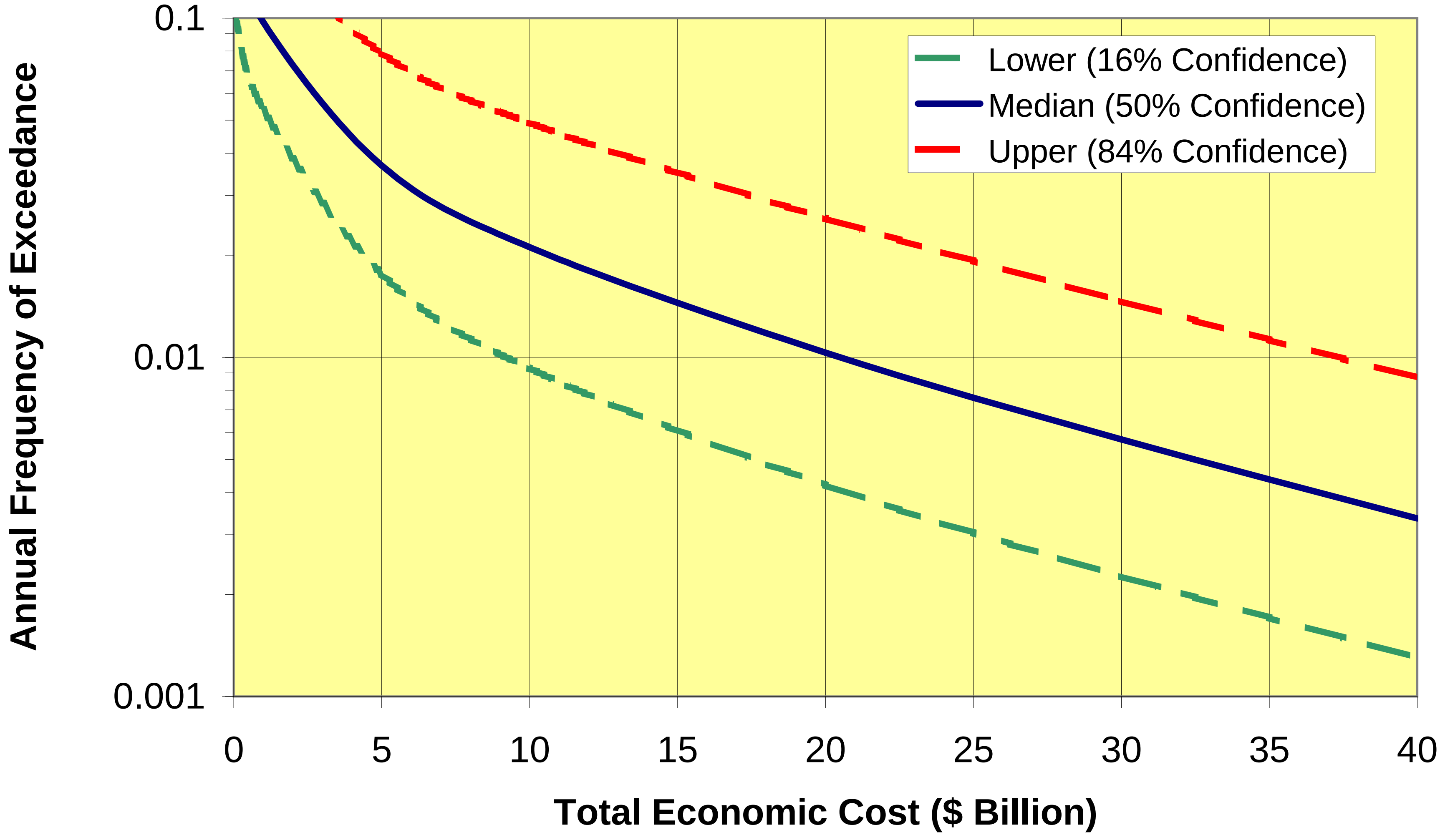


Figure 13-21a Annual Frequency of Exceeding Total Economic Cost due to Hydrological (Flood) Events

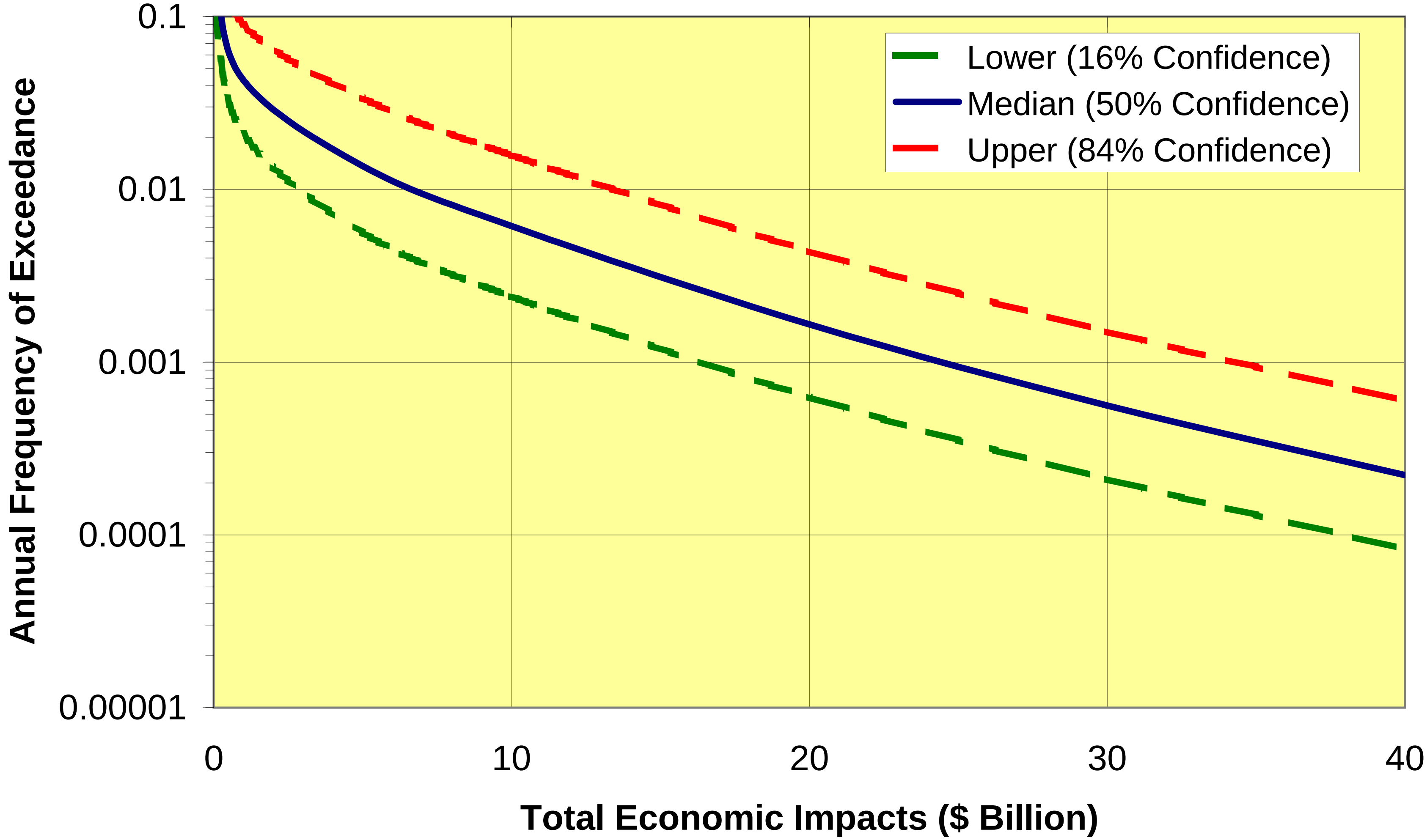


Figure 13-21b Annual Frequency of Exceeding Total Economic Impacts due to Hydrological (Flood) Events

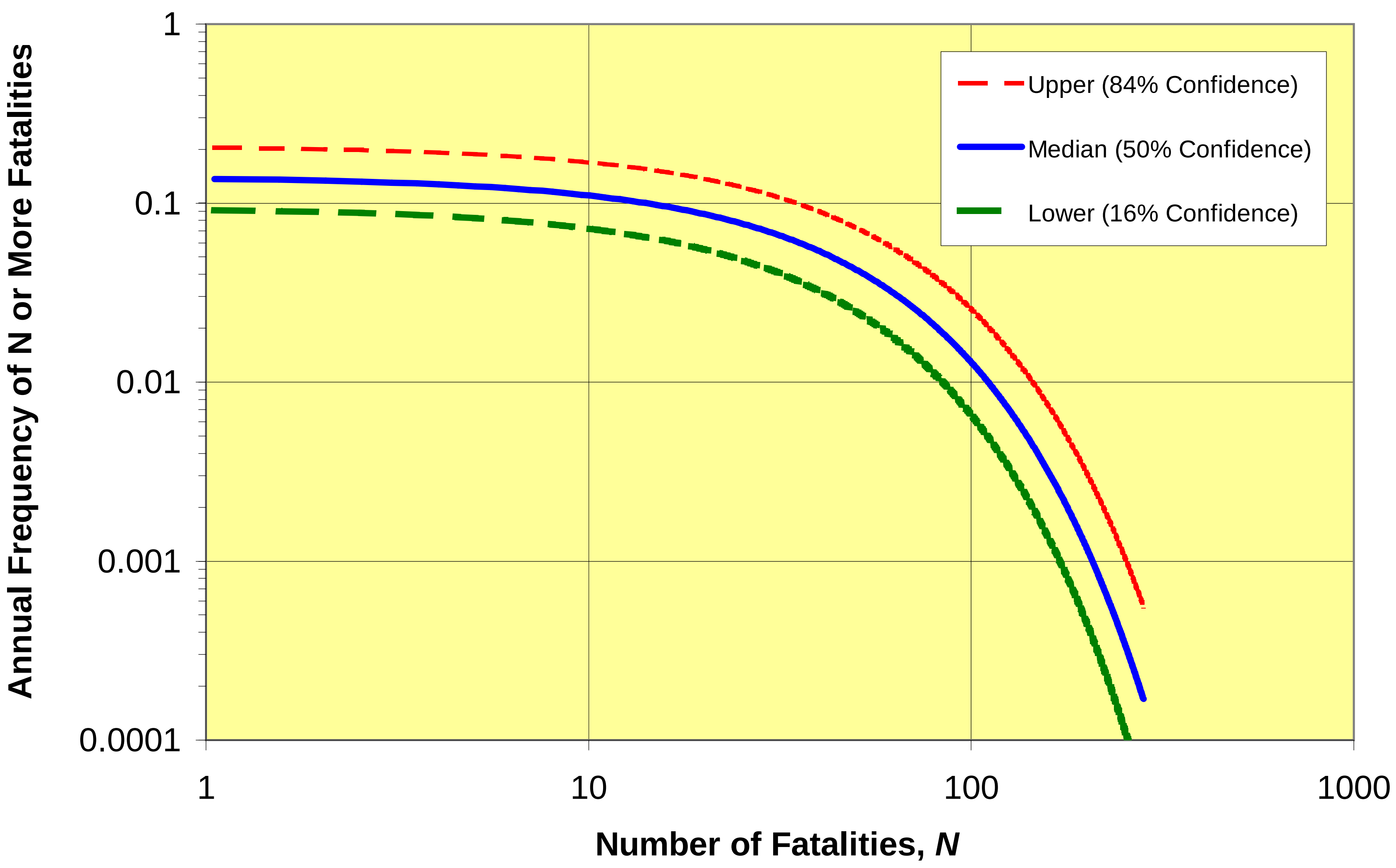


Figure 13-22 Expected Life Loss due to Hydrological (Flood) Events

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14.1 INTRODUCTION AND APPROACH

The previous section presented risk analysis results associated with Delta levee failures for 2005 base conditions. The purpose of this section is to evaluate how these risks evolve and compound into the future. The evaluation of risks for the future has various dimensions:

- The changing landscape of the Delta due to climate change and subsidence.
- The changing probabilities of natural hazards such as earthquakes and floods.
- Other evolving exogenous factors such as state and regional population, local land use, economic activity, and ecosystem affected by levee failures.

A separate, yet constant factor that contributes to future risk is time. As we look ahead over the next 50, 100, or 200 years, in addition to the ongoing sea-level rise and subsidence, the probability of an event (an earthquake or major flood) occurring in the Delta increases. At the same time, the probability of adverse consequences also increases as the economy and the population continue to grow.

In reference to the 2005 base case risk analysis of the Delta and the State due to levee failures, the analysis of risks for the future years considers the “Business As Usual” (BAU) assumption–the continuation of present (2005) management policies and practices. As discussed in Section 4, a full range of reliable information is not always available or adequate to conduct a detailed, quantitative analysis of future risks. The rationale behind using BAU as a point of reference is described in Section 14.1.3.1.

14.1.1 2005 Base Case Levee Failure Risks

Previous sections of this report have focused on assessing Delta levee failure risks for 2005 base-year conditions. Figure 14-1 presents the influence diagram that illustrates the relationship between events that occur in the Delta and the impacts to the state and the Delta. A risk model was developed to evaluate these interactions and to estimate risk. A given earthquake may or may not occur, and if it were to occur, it may occur at any time during the year. The year may be relatively wet or dry. And a given flood may or may not occur, and if it were to occur, it might occur at any time during the flood season.

The risk model also recognizes uncertainty in the relationships between the various elements (topical areas) in the diagram. When a reliable probabilistic model was available, the DRMS consulting team used it to estimate the outcome of that element of work and its formal representation of the uncertainty. When probabilistic models did not exist, the consulting team used known factors for the key elements (sea-level rise, subsidence) to develop ranges around mean values.

Section 13 provides the quantitative results of these 2005 base case risk analyses and also presents uncertainty bands. The results consider the full range of variability of 2005 events that may have occurred – that is, all potential earthquakes, floods, hydrologic conditions, and event time dependency.

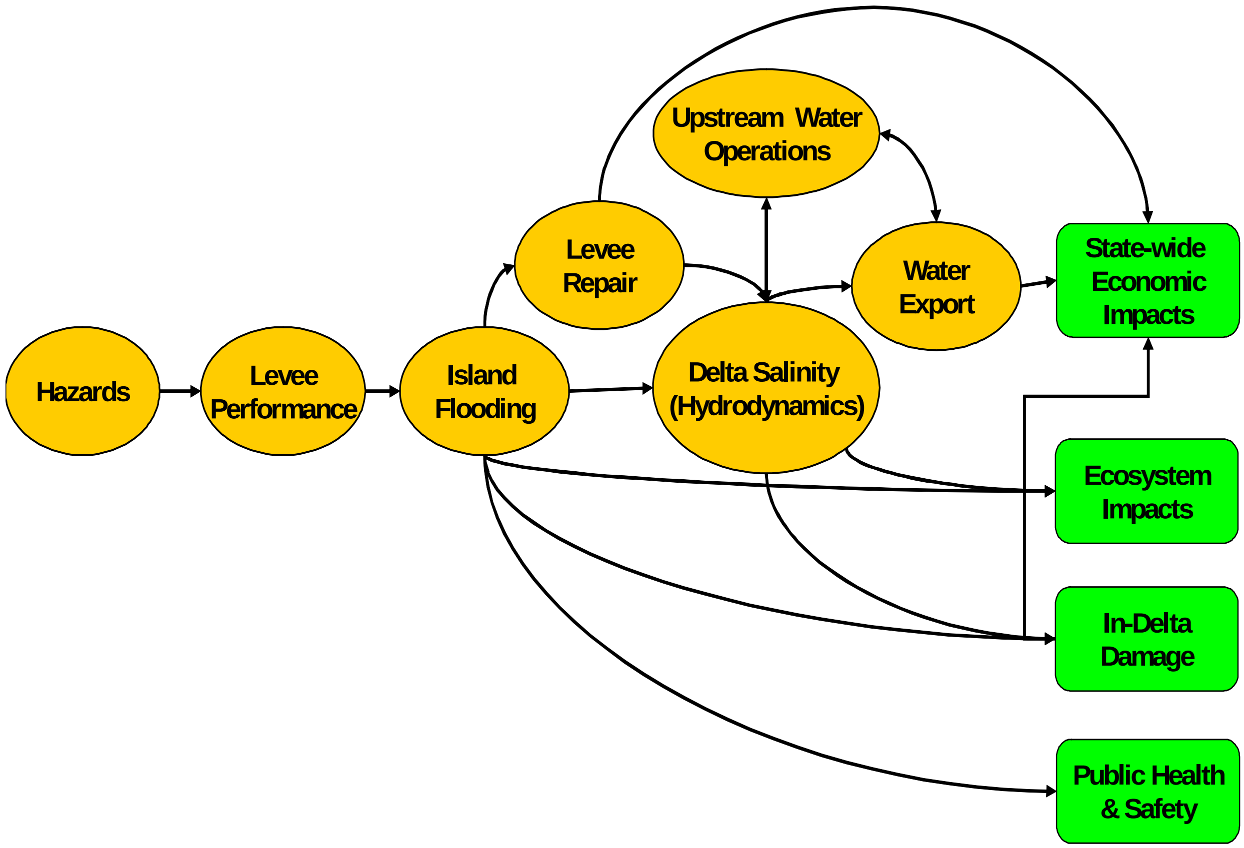


Figure 14-1 2005 Base Case Risk Model Overview: Chain of Causation

14.1.2 Information to Evaluate Risks In Future Years

To evaluate future risks, information was gathered on the drivers of change – factors that change the Delta landscape, the capabilities and condition of levees, the growth of the state economy and population, infrastructure and environmental changes in the Delta. The amount of information across the range of topical areas varies considerably, particularly looking out 200 years. The search for information focused on existing data, models, or modeling results that either assess conditions in future years or provide a model or basis for projecting to future years. Table 14-1 summarizes the state of information available to estimate risks in future years (details of this information are discussed subsequently). The availability of information is projected on a time scale in Figure 14-2.

Table 14-1 Summary of Information Available to Estimate Future Risks

Topical Area	Available Future Info	Information Reliability
Climate Change	Projections to 2100	Wide uncertainty bands
Subsidence	Projections to 2200	Moderately wide uncertainty
Geomorphology	No future information	N/A
Seismic Hazard	Projections to 2200	Minor uncertainty bands
Flood Hazard	Projections to 2100 from Climate Change	Wide uncertainty bands
Wind and Wave	No useful projections	N/A
Levee Vulnerability	Projections to 2200	Minor uncertainty
Emergency Response & Repair	No useful information	Uncertainty on key topics
Water Management	Projections to 2100 from Climate Change	Moderate uncertainty bands
Hydrodynamics	Use Subsidence and Sea Level Projections	Moderate additional uncertainty
Infrastructure	Projections to 2100	Large uncertainty
Economic Impacts	Projections to 2030	Moderate uncertainty
Ecological Impacts	No useful information	N/A

A review of Table 14-1 and Figure 14-2 indicates that beyond 2030, the availability of information to estimate risks begin to fall off. For instance state estimates of economic activity have not been made beyond 2030. There is very little information on changes to the ecosystem (although there are some probabilistic projections for extinction of aquatic species). Additional information limitations occur after 2050; official state or regional population projections are not available after this date.

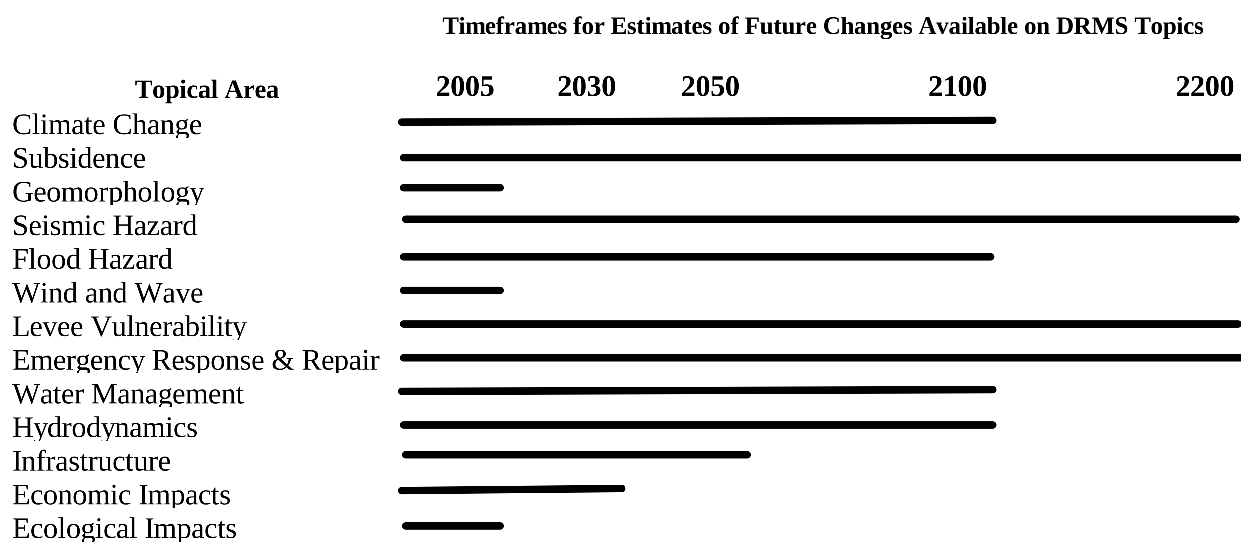


Figure 14-2 Availability of Information in Various Topical Areas versus Future Years

14.1.3 Approach for Considering Risk in Future Years

The methodology for assessing Delta risks as they evolve 200 years into the future is not simple, and often requires making broad assumptions. The assumptions are mostly driven by the trend; less so by their absolute future values. The uncertainties are mostly driven by the lack of available, reliable information in key topical areas. To overcome the inherent difficulty, a two-part evaluation is reported. In the first part, a conceptual model is developed to obtain a sense of how the drivers of change are progressing and how they will alter risks in future years. The second part is the development of the quantitative evaluation.

A consideration of future risks begins from the same starting point as for the 2005 model, as displayed in Figure 14-1.

14.1.3.1 Business as Usual

As with the base case analysis, future risks are evaluated based on BAU – which assumes that existing (2005) management practices are continued (see Section 3.4). BAU assumes that major rehabilitation projects and/or changes in policies and practices do not occur. Therefore, the BAU assumption supports the objectives of the Delta risk analysis and risk management strategies in that it allows an assessment of whether current practices and policies are sustainable in the future. These baseline results can then be used later, in Phase 2 of the DRMS project, to assess the risk reduction benefits of various project alternatives and changes in policy or management practices.

14.1.3.2 Drivers of Change in the Delta

The "Status and Trends" document (URS Corporation 2007) prepared for Delta Vision identifies the following "drivers of future change" for the Delta:

- Subsidence
- Global Climate Change – Sea-Level Rise
- Regional Climate Change – More Winter Floods
- Seismic Activity
- Introduced Species
- Population Growth and Urbanization

These broadly stated drivers of change can be expanded and characterized in a bit more detail as summarized in Table 14-2. The additional detail is designed to facilitate assessment of future risks due to levee failures.

Table 14-2 Drivers of Change Relative to Delta Levee Risks

Driver	Availability	Summary
Sea Level	Projections to 2100	All increase, high uncertainty
Tidal Amplitude	Limited past trend	May increase but unreliable
Storm Surge Frequency	No connection established	May increase but unreliable
El Nino Southern Oscillation (ENSO) Frequency	No connection established	No direction established; nothing useable
Inflow Flood Frequency	Projections (CC) to 2100	All increase, high uncertainty
Wind/Wave Event Frequency	No reliable information	Nothing useable
Seismic Frequency	Projections to 2200	All increase, relatively reliable
Subsidence	Projections to 2200	All increase, modest uncertainty
Seasonal Runoff	Projections (CC) to 2100	Less spring/summer, uncertain
Water Supply Yield	Projections (CC) to 2100	Generally less, uncertain
Water Supply Demand	No reliable projections	Nothing useable
Delta Area Population	Limited projections 2050	All increase, high uncertainty
Delta Land Use/Infrastructure	Limited projections	All increase, high uncertainty
Delta Area Economic Activity	Limited projections 2030	All increase, high uncertainty
Regional and State Population	Limited projections 2050	All increase, high uncertainty
State Economic Activity	Limited projections 2030	All increase, high uncertainty
Introduced or Lost (extinct) Species	No projections, some probability of extinction	Highly uncertain

14.1.3.3 Conceptual Model of Changing Delta Levee Risks

The drivers of change influence or alter the inputs to or interactions within the basic risk model illustrated in Figure 14-1. The basic risk model is enhanced at a conceptual level in order to evaluate the drivers of change in the Delta and capture a sense of the direction and importance of their influence in future risks from levee failures. The conceptual model puts the drivers of change into context. It identifies the mechanisms by which they influence other parts or intermediate variables within the risk model and thus progress through the model to alter future risks. The conceptual model also establishes the framework for a more-detailed, quantitative evaluation.

14.1.3.4 Quantitative Analysis

The quantitative analysis will use available, reliable quantitative information and established relationships to implement the model of future risk to the extent that is practical.

14.2 DEVELOPING AND APPLYING THE CONCEPTUAL MODEL

Figure 14-3 illustrates the expanded risk model needed to incorporate the drivers of future change and their influences on future risk. The following subsections address the inputs, interactions and outputs of the underlying model at a conceptual level. Topics include the directions of expected future changes, their relative importance, and the degree of certainty (or uncertainty) associated with each variable or interaction. Some drivers of change are discussed but, because of uncertainty on their magnitudes or importance, they are not shown in Figure 14-3 and will not be addressed in additional discussion of the conceptual model. Additional detail, to the extent it is available, is provided in Subsection 14.3.2.

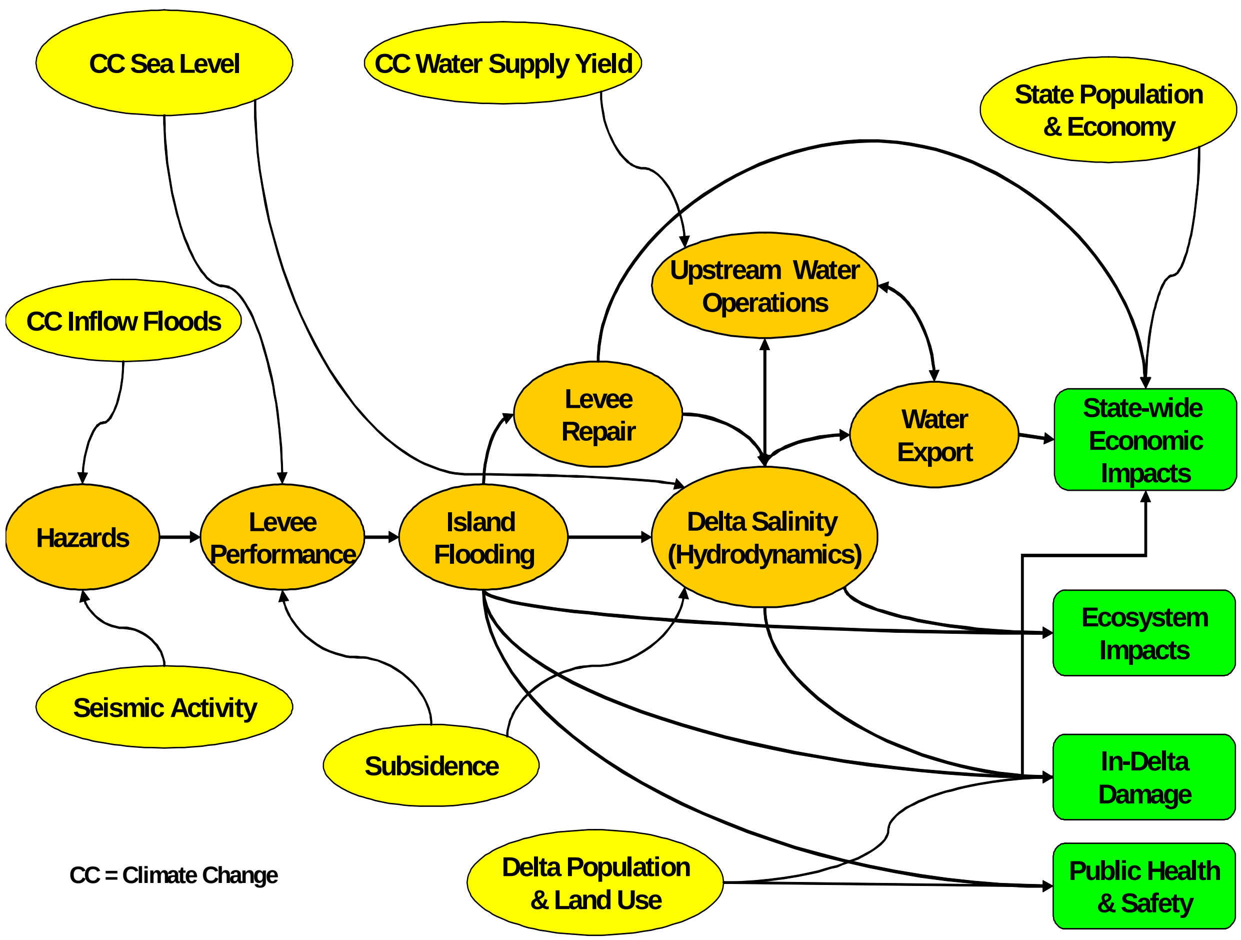


Figure 14-3 Risk Model Overview with Principal Drivers of Future Change: Simplified Chain of Causation

14.2.1 Exogenous Drivers – Magnitudes and Directions of Change for Model Inputs

The following paragraphs summarize the drivers of change and their directions and magnitudes of future evolution, to the extent information is available.

Changes in Sea Level. Rising mean sea level is expected as a result of global warming, (see Climate Change Technical Memorandum [TM] [URS/JBA 2008b]). Higher sea levels produce higher hydrostatic loads against a levee as well as increased internal seepage gradients. The amounts of sea-level rise recommended in the Climate Change TM (URS/JBA 2008b) for use in modeling future risks are:

- For 2050: between 4 and 16 inches
- For 2100: between 8 inches and 4.6 feet

In line with the BAU definition, the DRMS consulting team assumed that levees will be raised to keep up with sea-level rise.

Changes in Tidal Amplitude. Observations of modest increases in tidal amplitudes (range) specific to San Francisco Bay have been noted from existing records during the last century, coincident with increasing mean sea level (see Flick et al. 2003; URS/JBA 2007e, Appendix H3). The future change in tidal amplitude is uncertain. Based on the available data, one would expect continuing increases, if there is any future change. A simulation performed to test the effects of tidal amplitude changes on salinity intrusion (see the Water Analysis Module [WAM] TM, Appendix H3 [URS/JBA 2007e]), showed that tidal amplitude increases are likely to cause increased salinity and increased risk consequences. However, because of its uncertainty and limited evidence regarding direction and magnitude, it is not further addressed in the conceptual model.

Changes in Storm Surge Frequency. Storm intensities or frequencies are expected to change as a result of regional climate change. There are expectations of more frequent, intense precipitation events (storms) with future climate change (IPCC FAR 2007, WG1, p750). It also appears these events will be accompanied by more intense low-pressure systems resulting in increases in sea-level surge. The United Nations Intergovernmental Panel on Climate Change's (IPCC's) recent report indicates increased frequency of more severe strong cyclones in mid latitudes and a decrease in the central pressure of such storms (IPCC 2007 FAR WG1, p.789). Such conditions would be expected to cause more frequent occurrence of sea-level storm surges. This is potentially important to water levels relative to Delta levees, especially in combination with sea-level rise and potentially increasing tidal amplitude. However, the available science does not yet offer complete set of modeling tools that could be used in this analysis, and hence this driver was not further considered.

Changes in El Nino Southern Oscillation. There has been some suspicion that there will be increased effective sea level in the Delta due to increased storms and surges as El Nino Southern Oscillation (ENSO) events increase. However, according to the IPCC (2007, WG1, p751), "there is no consistent indication at this time of discernible changes in projected ENSO amplitude or frequency in the 21st century." This is similar to the finding by van Oldenborgh, et al (2005). Accordingly, ENSO changes are not incorporated in the conceptual model.

Changes in Inflow Flood Frequency. Flood frequencies (high Delta inflows) are expected to increase due to the regional impacts of global warming. This will result in more winter precipitation as rain rather than snow, and in more frequent high intensity precipitations. Expected changes in runoff patterns due to a warming climate are described in the Climate Change TM (URS/JBA 2008b). Although the total amount of yearly precipitation may not change substantially, increases in winter precipitation as rainfall rather than snow and increasing frequencies of large storm events are predicted.

The climate change team was able to provide four different scenario/simulations of daily, unimpaired runoff at key sites tributary to the Delta. These data were analyzed by the DRMS flood hazard team to quantify the trends in the frequency of major storms. Although the results vary among the four simulations (see the Flood Hazard TM [URS/JBA 2008a]), each simulation indicates increasing frequencies of the seven-day Delta inflow that represents the year 2000 1 percent annual frequency (i.e., 100-year) flood event, referred to here as the Standard Inflow Flood. The ranges of frequency increases are indicated below:

- For 2050: Frequency increases of standard inflow flood are between 40% and 500%
- For 2100: Frequency increases of standard inflow flood are between 130% and 1,140%

Changes in the Frequency of Wind/Wave Events. A regional alteration in temperatures and weather pattern frequencies or intensities may lead to increased or decreased frequencies of wind-wave events of given magnitude, direction or duration. However, simulated wind velocities for future climate and weather conditions in the Delta are unreliable at this time. Even state-of-the-art nested models are probably incapable of making trustworthy projections of wind speed responses on the small spatial scales of interest (see the Climate Change TM [URS/JBA 2008b]). Thus, although the possibility of future changes in the frequencies of particular intensities, directions, and durations of wind-wave events are recognized, no probabilistic quantitative assessment tool for future wind models is available. This driver is not addressed in the conceptual model.

Changes in the Frequency of Seismic Activity. The time-dependent hazard curves developed as part of the probabilistic seismic hazard analysis (see the Seismology TM [URS/JBA 2007a]) were used to estimate the increasing probability of ground motions for the future years: 2050, 2100, and 2200. The peak ground acceleration (PGA) was used as a gauge for estimated percent increase in future earthquake hazards. The expected increases in frequency of a 0.20g Peak Ground Acceleration (PGA) event are given below as percentages of the 2005 (base year) frequency:

- For 2050: Frequency increases by 10%
- For 2100: Frequency increases by 20%
- For 2200: Frequency increases by 40%

The assessment of the future seismic hazard is based on the assumption that a major seismic event does not occur on one of the major Bay Area faults between now and the future evaluation years (2050, 2100, and 2200). As a result, tectonic strains are not released. Instead, they keep building up, thus increasing the probability of occurrence of future earthquakes.

Progression of Subsidence. The ground surface elevations in areas of the Delta-Suisun that have organic (peat) soils are expected to continue subsiding if current management practices are not altered. The DRMS analysis of subsidence has provided an analysis of the rates and amounts of subsidence both historically and projected into the future (see the Subsidence TM [URS/JBA 2007d]).

Subsidence rates are expected to decrease as the organic content percentage of the soil decreases and ultimately cease when the organic-rich layer is depleted. The duration of subsidence is dependant on the presence and thickness of the peat and organic deposits which are highly variable across the Delta (see the Subsidence TM [USR/JBA 2007d]). These effects largely counterbalance each other and the nominal subsidence for typical central Delta histosol is expected to be relatively constant at about 2.2 cm (0.9 inch) per year, until the organic content is largely depleted. An uncertainty band on this subsidence rate of +40% and –30% is stated. Subsidence rates in Suisun Marsh are expected to be much lower, because of a different management of the Suisun Mash.

An example of the result is given in the subsidence map for 2100 in Figure 14-4. The Subsidence TM (USR/JBA 2007d) has similar maps for 2050 and 2200. The medium expectation for future subsidence for the Delta and Suisun area with highly organic soils in terms of decreases in surface elevation and cumulative area-wide increases in accommodation space relative to 2005 sea level are:

- For 2050: Up to 3 feet of subsidence and about a 25% increase of accommodation space
- For 2100: Up to 8 feet of subsidence and about a 50% increase of accommodation space
- For 2200: Up to 17 feet of subsidence (accommodation space not estimated)

Note that these estimates of accommodation space increases are based only on progression of subsidence. Additional accommodation space increases will result due to any increases in mean sea level.

Changes in Seasonal Runoff and Water Supply Yield. With warming temperatures, more precipitation in the Sierra Nevada mountains will fall as rain and less as snow, snow pack will not be as large and will melt earlier and, thus, less spring and early summer runoff will be captured for water supply. This will decrease water supply yields that are tributary to the Delta. The DRMS analysis includes a review of recent studies regarding the changing seasonal pattern of runoff, including analyses of climate change model simulations for inflows to Shasta and Oroville, the primary reservoirs for the Central Valley Project and State Water Project, respectively. The details of these reviews and analyses and their implications for future water supply availability are presented in the Water Analysis Module TM (URS/JBA 2007e, Appendix F). Figure 14-5 illustrates the decrease in snow pack, its earlier melting and resultant decrease of spring and summer runoff (into the state's water supply reservoirs) for Oroville. There is a major shift of the monthly fractions of annual runoff from late spring and summer months to winter months. This will decrease the yield of the present water supply system. Available estimates of decreased median South of Delta yields are:

- For 2050: Median yields for the CVP will decrease between 4% and 16% from 2005 and, for the SWP, decreases will be between 4% and 11% from 2005
- For 2100: Median yields for the CVP will decrease between 7% and 34% from 2005 and, for the SWP, decreases will be between 4% and 27% from 2005

Variations among the climate simulations indicate uncertainty, with at least one simulation indicating no or only slight decreases in yield and others indicating more decreases. There is substantial uncertainty in these estimates due to variations among climate simulation models and to approximations in subsequent analyses.

Changes in Water Supply Demand. Increased temperatures may lead to increased water demand, especially in terms of evaporation and transpiration (see the Water Analysis Module TM [URS/JBA 2007e, Appendix G]). This is potentially important, especially for agricultural and landscape water use upstream of the Delta, in the Delta, and in the service areas south of the Delta. There is, however, a counterbalancing mechanism in operation; increased atmospheric CO_2 is believed to decrease the amount of water needed for evapo-transpiration (DWR 2006). Although, the amount of water consumed is likely to increase just due to evaporation increases, the overall magnitude of increase may not be substantial. At present, this driver is considered uncertain, although water demand is likely to increase to some extent and thereby increase future consequences of Delta levee breaches.

Changes in Delta Area Population, Land Use, and Economic Activity. The forecasts for Delta area population and land use under current policies foresee infill in the present Primary Zone communities and intensive development in the Secondary Zone in the Delta (URS 2007; URS/JBA 2007f [Impact to Infrastructure TM]; URS/JBA 2008f [Economic Consequences TM]). Thus, the people, material assets, and economic activity located in the Delta and Suisun area are expected to increase. This will lead to increased consequences to in-Delta life safety and assets in the event of levee failures.

Population – Data and projections of Delta area population are difficult to obtain because they are typically developed for cities and counties, while the Delta comprises fractions of the cities and counties. However, available data reported in the "Status and Trends" report (URS Corporation 2007) indicate that population on Delta/Suisun islands is expected to increase from 26,000 to 67,000 from 2000 to 2030, which is about a 160% increase.

The population of the legal Delta in 2000 was about 470,000. "Status and Trends" indicates an increase in Delta-Suisun population of 600,000 by 2050, pointing to a 2050 total population of 1,070,000. Full development of the Secondary Zone is estimated to lead to a Delta-Suisun population of well over a million people. These areas are now experiencing high rates of growth. These estimates of future population are very uncertain and they will be quite variable geographically during any particular period. For example, housing units on Stewart Tract, Bishop Tract, Shima Tract, and Sargent Barnhart Tract are expected to increase from 1,700 to 14,200 units between 2000 and 2030, an increase of over 800%.

Infrastructure and Public and Private Property – The DRMS infrastructure analysis provides an assessment of assets subject to flooding from levee failures keyed to both Mean Higher High Water (MHHW) and the 100-year floodplain. That assessment is summarized below.

- For 2050 conditions, the MHHW and 100-year flood asset values subject to flooding are expected to increase by about 20% to 25%.
- For 2100 conditions, in addition to continuation of normal asset growth, both the MHHW and 100-year flood exposures are expected to cover increased areas because of sea-level rise and the increasing magnitude of the 100-year flood. Some of the additional areas that will be exposed to flooding are now highly developed urban areas or are in the path of urban development.

There is no indication these development trends will slow under BAU policies.

Business and Recreation Activities – Business activity is usually reported in terms of the value of output, employment and labor income. Projections for these measures were developed to 2030 by Woods and Poole (2006), (see the Economic Consequences TM [URS/JBA 2008f]). Those projections for 2030 that address Delta area counties and combined statistical areas are:

- Regional product: 100 to 160% increases over year 2000 values
- Earnings: 90 to 150% increases over year 2000 values
- Employment: 50 to 80% increases over year 2000 values

Agriculture, natural gas production and recreation are important economic activities in the primary Delta. Natural gas and agricultural production values will probably not increase significantly in the future. Recreation-related expenditures in the Delta were recently estimated to be over $500 million annually (see the Economic Consequences TM [URS/JBA 2008f]). These recreation expenditures will probably increase in the future with population increases in the Delta and the larger Bay Area region. Economic activity tied to residential development will increase dramatically by 2030 on some Delta islands near Stockton and can be expected to continue increasing thereafter. There is no useful projection for economic activity beyond 2030; however, business activity is expected to continue growing with population.

Changes in Regional and State Population and Economic Activity. Available forecasts (see the Economic Consequences TM [URS/JBA 2008f]) indicate continuing population and economic growth for the Delta and Bay regions and for the state as a whole. This will result in an increased dependence on infrastructure that traverses the Delta and especially on the water supplies that are conveyed through the Delta (see URS 2007; DWR 2005c; URS/JBA 2008f [Economic Consequences TM]).

***Population* –** The California Department of Finance (DOF 2007a) provides state population projections to 2050. They estimate 59.5 million people will reside in California by that date, a 61% increase over the 2005 base year. Although official projections are not available beyond 2050, the “Status and Trends” report indicates the possibility of 90 million people by 2100, a 143% increase.

Economic Activity –The historical data available from DOF (2007b) indicate that economic activity is closely tied to population growth. As with population, official projections are not available for the long term. The state DOF provides forecasts through 2010 (DOF 2007c). The projections to 2030 by Woods & Poole (2006) are:

- State product: 94% increase over year 2000
- Earnings: 87% increase over year 2000
- Employment: 47% increase over year 2000

Introduced or Lost (Extinct) Species. Changes in the species present in the Delta and in their relative populations certainly must be expected over the next several decades, given the threats of extinction for existing Delta species and the record of exotic species introductions over the past several decades (URS 2007; URS/JBA 2008e [Impact to Ecosystem TM]). Not enough information is available to forecast long-term changes to the diverse and dynamic Delta ecosystem 50, 100, or 200 years from now.

Translating such changes into an assessment of whether risks to the ecosystem from a given levee breach incident will increase or decrease in the future is similarly daunting. Present trends, including endangered and listed species and the introductions of exotic species, make it difficult to argue that BAU will result in a more robust and healthy ecosystem. Some assessments of impacts to habitat and species from levee failures indicate adverse outcomes (Impact to Ecosystem TM [URS/JBA 2008e]). A simple probabilistic model that represents the primary and short term impacts and probable extinction of aquatic species was developed and is presented in the Impact to Ecosystem TM (URS/JBA 2008e). The testing and execution of the model have not been completed due to schedule constraints.

For purposes of the analysis in this section, we assume (optimistically) that the future ecosystem (without levee breaches) is similar to today's ecosystem. Obviously, there is massive uncertainty in this "forecast." However, this assumption will allow us to focus on how other future changes might result in greater or lesser risks to the ecosystem.

14.2.2 Uncertainty and Further Analysis

The foregoing discussion of drivers of change for Delta levee risk can be summarized in a further development of Table 14-2, as shown in Table 14-3. For 2050 and 2100, the relative magnitudes of driver of changes are shown, based on a medium estimate. Two major points may be recognized from Table 14-3:

Table 14-3 Directions and Apparent Magnitudes of Drivers of Change Under BAU

Driver	Increase or Decrease Risk?	Large or Small Relative Increase?
Sea Level	Increase	Moderate to Large
Tidal Amplitude	Not Clear; Maybe Increase	? Unknown; Small/Moderate
Storm Surge Frequency	Not Clear, Maybe Increase	? Unknown; Maybe Moderate
El Nino Southern Oscillation (ENSO) Frequency	Not Clear	? Unknown
Inflow Flood Frequency	Increase	May be Large to Very Large
Wind/Wave Event Frequency	Not Clear, Maybe Increase	? Unknown
Seismic Frequency	Increase	Moderate
Subsidence	Increase	Moderate to Large
Seasonal Runoff	Increase	Moderate
Water Supply Yield	Increase	Moderate
Water Supply Demand	Not Clear	? Unknown
Delta Area Population	Increase	Large
Delta Land Use/Infrastructure	Increase	Moderate to Large
Delta Area Economic Activity	Increase	Moderate to Large
Regional and State Population	Increase	Large
State Economic Activity	Increase	Large
Introduced or Lost (extinct) Species	Not Clear	? Unknown

- For the six items that have uncertain impact as drivers (indicated by ?'s), part of the uncertainty is due to lack of an obvious major impact. Although these items could ultimately prove to be significant, better understanding must be achieved before they will deserve emphasis as important drivers of change in an analysis of future Delta levee risks. Thus, they were not included in Figure 14-3 for use in the conceptual model.

- For the 11 other items, there is a clearer impact of anticipated change and the magnitudes of some of them demand careful attention. In particular, the potential magnitude of sea-level rise , the increased frequency of major inflow floods, the Delta region's changing population and land uses, and the state's growing population and economy may substantially increase the consequences felt from Delta levee breaches in future years. Furthermore, the importance of these factors seems to increase more dramatically as the time horizon is lengthened, although it is recognized that these drivers are very difficult to project.

The "conceptual model" of changing levee risks in future years will then focus on the items indicated above and in Figure 14-3. The other six "unknown" items are not being dismissed, but are not included in this future risk estimation at this time.

The following sections will work through a sequential analysis of the impacts of these drivers within the Delta levees conceptual model to gain insights on the overall magnitude of prospective changes in Delta levee failure consequences – i.e., changes in risk.

14.2.3 Effects of Exogenous Drivers within the Risk Model

To consider the changing risks in the Delta and Suisun Marsh, there are factors that have large-scale temporal and/or spatial variability that may influence future risks. In this discussion, 2005 is used as the base year. This analysis estimates how risks may change relative to 2005 in future target years of 2050, 2100, and 2200.

Risks factors can change dramatically with location within the Delta and Suisun Marsh. Rather than estimating future risk at many different locations, this section discusses an evaluation of risks for the region as a whole. Therefore, the Delta and Suisun Marsh are considered as one area in the estimates, recognizing that changes for specific areas may be somewhat different from the regional scale assessment presented.

As discussed in the DRMS technical memoranda, considerable uncertainty exists in projections of future conditions in the Delta and Suisun Marsh (subsidence, sea level) and the potential increase in future hazards and their frequency of occurrence. For purposes of this conceptual discussion of future risks, the evaluation relies only on the direction and apparent importance of the expected change. More detailed information on the respective topics, including ranges of estimates and uncertainties, are provided in Subsection 14.3.2 and in the TM for each topical area.

14.2.3.1 Sunny-Day, High-Tide Events

Considering the conceptual model representation in Figure 14-3 and describing the evolution of model intermediate variables that are implied for sunny-day, high-tide events, the following points are noted:

- Increased sea level will increase the hydrostatic load on the levee, the seepage gradient within the levee, the possibility of overtopping the levee and, thus, the frequency of sunny-day, high-tide failures.

- Increased subsidence will also increase the hydrostatic loading and seepage gradients for at least some sections of levees and will increase levee vulnerability to sunny-day, failure in those cases.
- More levee failures will require more repair effort (cost).
- Increased sea level and the progression of subsidence together will create more accommodation space that has to be filled with water when a breach occurs. This will mean additional salinity intrusion (when significant intrusion occurs) and increased pump-out costs. Salinity intrusion into the Delta is not presently a major impact of a sunny-day breach that floods a single island. With increased accommodation space, however, this impact will definitely increase and could become problematic. In any case, additional water for flushing will be required.
- Disruptions for both in-Delta water users and exports, to the extent that they occur will be lengthened and more severe.

In summary, no relationship within the conceptual model suggests an improved outcome for an intermediate variable that is important to risk. All the intermediate variables will escalate in the direction of increasing risk under the changes expected for future sunny-day events.

14.2.3.2 Seismic Events

Considering the conceptual model representation in Figure 14-3 and describing the evolution of model intermediate variables that are implied for seismic events, the following points are noted:

- Future increases in the frequency of seismic events (increasing probability of occurrence) for given earthquake magnitudes on a given fault will translate into comparable increases in frequencies of seismic levee failures.
- Increased sea level will increase the hydrostatic load on the levee, the seepage gradient within the levee, and the conditional probability of a seismic failure.
- Increased subsidence will also increase the hydrostatic loading and seepage gradients for at least some sections of levees (if the subsidence is within the “zone of influence” for the levee) and will increase levee vulnerability to seismic failure in those cases.
- Thus, a given seismic event will occur more frequently and result in an increased number of levee failures and will likely flood additional islands.
- More levee failures and flooded islands will require longer repair periods and more repair effort (cost).
- Increased sea level and the progression of subsidence together with more islands flooded will create more accommodation space to be filled with water. This will mean additional salinity intrusion into the Delta and will require additional time and water for flushing
- Disruptions for both in-Delta water users and exports will be lengthened and more severe.

In summary, no relationship within the conceptual model suggests an improved outcome for an intermediate variable that is important to risk. All the intermediate variables will escalate in the direction of increasing risk under the changes expected for future seismic events.

14.2.3.3 Flood Events

Considering the conceptual model representation in Figure 14-3 and describing the evolution of model intermediate variables that are implied for flood inflow events, the following points are noted:

- Future increases in flood frequencies for given inflow magnitudes will translate into comparable increases in frequencies of flood-caused levee failures.
- Increased sea level will increase the hydrostatic load on the levee, the seepage gradient within the levee, the possibility of overtopping the levee and, thus, the conditional probability of a flood failure.
- Increased subsidence will also increase the hydrostatic loading and seepage gradients for at least some sections of levees and will increase levee vulnerability to flood failure in those cases.
- Thus, a given flood inflow will occur more frequently and result in an increased number of levee failures and will likely flood additional islands.
- More levee failures and flooded islands will require longer repair periods and more repair effort (cost).
- Increased sea level and the progression of subsidence together with more islands flooded will create more accommodation space that needs to be filled with water. This will mean additional pump-out costs. Salinity intrusion into the Delta is not expected to be an immediate occurrence during inflow flood events. However, if the repair period is prolonged into the dry season for very large events, salinity could develop as a problem due to intrusion with tidal exchange. If so, it will require additional water for flushing.

In summary, no relationship within the conceptual model suggests an improved outcome for an intermediate variable that is important to risk. All the intermediate variables will escalate in the direction of increasing risk under the changes expected for future flood events.

14.2.4 Changes to Model Outputs – Risk Consequences

The combined effects of the changes for future years from the factors discussed in the foregoing sections are presented below, focusing on the key risk model outputs indicated in Figure 14-3 (the consequences of Delta levee breach events). The following points are noted:

- Public Health and Safety – The risk consequences for public health and safety (endangerment of peoples lives) must be expected to increase in future years because there will be more frequent events involving the flooding of more islands and, with increases in Delta population and urbanization, more people will be exposed.
- In-Delta Damage – The consequential damages to in-Delta infrastructure, property and economic activity and the cost of levee repairs are expected to increase in future years as a result of the increasing likelihood of the hazards and the decreasing reliability of the levees, as discussed above**.** More frequent flooding involving more islands and more salinity intrusion for longer durations can only mean that damage levels escalate. In addition, more

people and higher levels of land use and economic activity will be exposed. This will further escalate in-Delta damages.

- State-wide Economic Impacts – The consequences to California's economy will certainly increase in future years. The above-described in-Delta damage escalation will be part of the increasing impact to the state. However, with less water supply yield and more frequent Delta levee breach events involving more islands and more salinity intrusion, the disruption of Delta water exports will be more severe.

  Even if target amounts of water export remain unchanged, more people and higher values of economic activity will be exposed to disruptions of their water supply. Thus, the consequences to the California economy will be driven higher by multiple forces.

- Ecosystem Impacts – More frequent levee breach events involving more islands with more salinity intrusion for longer duration will, in the short term, increase the adverse impacts (entrainment, turbidity, loss of water quality, pump out, loss of habitat, increase predation, etc.) as well as offer opportunities (new habitat, temporary interruption of water export, etc.). A few species may see beneficial impacts (see the Impact to Ecosystem TM [URS/JBA 2008e]). However, an increased threat to sensitive species must be expected.

14.2.5 Results of Conceptual Model Analysis

14.2.5.1 Annual Risks Increase in Future Years

As discussed in Subsection 14.1.2, the input information regarding the future becomes less available and less reliable as one looks further ahead. Economic projections are available only to 2030, and population projections are not available beyond 2050. Climate change inputs have broad uncertainty bands for 2050, much broader uncertainty bands for 2100, and no information beyond 2100. However uncertain they are, all risk variables point to increasing future risks, and no evidence has been found that indicates any exogenous driver or risk model relationship will reverse direction. Therefore, risk consequences in future years are expected to continue escalating through 2050, 2100, and into the years beyond.

Useful data are generally not available for addressing the conditions in 2200 and the effects on risks from Delta levee failures in that time frame. The two exceptions are subsidence and seismic hazard. Under the concept of BAU, both subsidence and seismic hazard will continue to increase. An altered rate of subsidence requires changes in land use or management practices, and an alteration in the rate of increase of seismic hazard requires that a major stress-relieving earthquake occur during the intervening period. Other factors are not so easy to predict. However, in light of the discussion and assessments above, there is no reason to expect that risks in 2200 will remain the same or decrease relative to risks for 2100. Thus, the risks from Delta levee failures are expected to continue to increase between 2100 and 2200 under the BAU assumption.

No significant risk factor has been identified that decreases the likelihood of Delta levee failures or decreases associated consequences. In contrast, all significant risk factors are increasing as one looks forward to 2050 and 2100 – some are increasing modestly, while others are expected to increase significantly (e.g., Delta and state-wide population and economic activity). The overall likelihood of a major event is increasing and the magnitudes of consequences from a given event are also rising.

14.2.5.2 Implications of Exposure Period

Although the trends in factors that influence the estimate of future risks combine to indicate steadily increasing annual risks from Delta levee failures, there is another important dimension in considering future risk. That dimension is the exposure period to an already high-risk situation.

In performing a risk analysis, engineers usually work with annual frequency of events. The important concept about such events is they have the same likelihood of occurrence every year.

The risk of adverse events increases as longer periods of exposure are considered. Figure 14-6 indicates how the likelihood of an occurrence increases as the length of the exposure period grows. In 30 years of exposure, a 1 percent annual event has a 26% chance of being equaled or exceeded. In 50 years, the chance is 39.5% and in 100 years, the chance is 63.4%. Figure 14-6 also illustrates the increasing probability of failure for other annual frequencies.

In the Delta, the likelihood of severe levee breach incidents is more likely than an annual frequency of 0.01. The figures in the previous chapter show annual frequencies of failure ranging from 0.005 to 0.07 for the Delta. However, the frequency of failure is much higher in the Suisun Marsh. These frequencies are also illustrated on Figure 14-6. It is just a matter of time (exposure period) until a severe event occurs.

14.2.5.3 Summary Perspective on Future Risk

The annual risks from Delta levee failures are already high and are increasing. Each initiating cause (seismic, flood and high-tide/sunny-day) is expected to result in an increased likelihood of island flooding and increases in expected consequences. When combined, these initiating causes must be expected to yield escalating risk consequences as each future year is considered in turn. These increases depend, of course, on how future conditions such as climate change, subsidence, and Delta-area population growth and land use materialize.

Although the increase in yearly risk is important, one must remember to consider exposure periods. With only the present risks from Delta levee failures (and assuming no future increases in annual risks), the people of California face a 50/50 chance of a major-impact incident within the next few decades. This risk from exposure period deserves special consideration by decision makers.

Thus, the principal findings so far regarding future risk are the following:

- No factor (under a BAU scenario) was found that is expected to significantly decrease risks of or from Delta levee failures in the future. All factors considered point to increasing risks. And the increasing risk is compounded because the factors are all working together to increase the probability of future adverse consequences from levee failures in the Delta.
- When an exposure period of several years is considered (e.g., 25 years or, especially for periods of 50, 100 or 200 years, as set forth for the scope for this project), the likelihood of a major adverse event becomes very high, almost unavoidable. .

14.3 QUANTITATIVE ANALYSIS

14.3.1 Organizing a Quantitative Analysis of Future Risks Including Uncertainty

Conducting a properly organized and quantitatively meaningful analysis of future risks, including characterization of uncertainties, is a challenging undertaking. It is challenging in terms of the complexity of the analysis required and it is extremely demanding in terms of the information needed as inputs. The following subsections address organizational concepts, information limitations, and the approach to be taken.

14.3.1.1 Organizing the Analysis – The Logic Tree

Figure 14-7 presents a logic tree, the tool used to organize analysis of future Delta levee risks including uncertainty. It is built based on several columns each identifying key variables (exogenous drivers of change or intermediate relationships) that can take on different values in the analysis. Branching is used in proceeding from left to right through the tree to indicate that each value in the next column defines a different state of the system – a unique scenario that may prevail. When considering all the branching, the logic tree has potential to grow very large. The tree in Figure 14-7 is relatively simple, mainly because we do not have alternate values for several of the variables that are important to the analysis, for example estimates of Delta area and State population and economic activity. Thus, Figure 14-7 has only 216 branches rather than a much larger number.

When a column takes on several values, the consideration of each is the vehicle for including uncertainty in the analysis. For example, in the Subsidence TM (URS/JBA 2007d), uncertainty was assessed as “-30% to +40%” relative to the best estimate of subsidence. Thus, the subsidence column has three unique entries indicating the best estimate of subsidence, a higher value and a lower value. Ideally, each of the values in a column has a probability weight that indicates its likelihood of that value being true. The weights of the values in the column sum to one, so it is clear that only one of the alternatives can prevail and one of them must prevail. By this branching to alternate values and including each (with its weight) in the risk analysis, uncertainty is recognized and quantitatively assessed. Unfortunately, alternate subsidence values do not have associated weights, a situation that is a common shortcoming in such analyses.

Such a tree would be fully developed (including a column for each significant factor) for each future year being addressed. Thus, we would create trees for 2050, 2100, and (perhaps) 2200.

Figure 14-7 illustrates the logic tree applicable for performing an analysis of levee risks for 2050. Although it may seem quite elaborate and complex (it would certainly be busy if all 216 branches were explicitly shown), it already includes many simplifications dictated by information limitations as described in the next subsection.

14.3.1.2 Information Limitations

The specific information limitations for a 2050 analysis that are reflected by the logic tree presented in Figure 14-7 are:

- Sea-level rise estimates should be associated with each climate change scenario/model, since sea-level rise will not occur independently of the scenario and model.

- The IPCC scenarios considered only two of the six IPCC marker scenarios. A more comprehensive analysis of future risk and uncertainty would include more scenarios.
- The general circulation models addressed are limited to two of the 15 to 23 models that are generally reported and discussed.
- The estimates of water supply yield are based on preliminary analyses, again with few scenarios and models.
- The calculated changes in flood frequency are similarly limited and preliminary. The frequency changes are large and merit further study.
- The ER&R model does not reflect any future change that may deviate from the 2005 situation for availability of rock to be used for levee repairs. The epistemic uncertainty incorporated into the model should also be characterized but is not.
- The WAM model has not been assessed to characterize epistemic uncertainty although calibration and limited verification indicate it provides satisfactory representation of salinity. This modeling uncertainty should be included in the uncertainty analysis.
- Although an estimate of 2050 Delta-Suisun population has been found, the uncertainty band for this estimate should be substantial. No uncertainty characterization was found.
- Economic activity specific to the Delta-Suisun area is not projected for future years.
- The state population projection for 2050 has no associated uncertainty band.
- State economic activity is not projected beyond 2030 and no uncertainty characterization is provided for the 2030 projection that is available.
- The models for estimation of economic consequences also have substantial epistemic uncertainty that has not been estimated.
- It is particularly important to note that the information limitations are more severe on the right side of the logic tree – involving the social topics that may have very large changes.
- To perform a formal risk analysis, it is necessary to have a probability weighting at each branching point. For example, we need to assign a probability to each of the four estimates of future sea level (and the four probabilities must sum to 1.0). Those probability weights are not available. And the IPCC, for example, insists on not assigning them to their SRES scenarios. Without those probabilities an overall quantitative assessment of risk cannot be performed.

A similar logic tree can be developed for 2100, but with even more information limitations. Rather than burden the reader with another diagram, a summary of the information that is available for use in a 2100 evaluation will be provided in table format.

14.3.1.3 Approach

Given the information limitations described above, it does not make sense to perform 216 analyses (one for each branch in Figure 14-7) for 2050 and a similar number for 2200. In addition to being unwieldy, these analyses might give a false sense of accuracy or precision and the impression of far less uncertainty than a more comprehensive analysis would make apparent.

Instead, quantitative assessments will be performed for high, medium, and low examples of the branches to the extent that available data and relationships allow.

14.3.2 Exogenous Driver Inputs Available

The following paragraphs present the quantitative information available for input.

Changes in Sea Level. Rising mean sea level is expected everywhere as a result of global warming. The San Francisco Bay area is no exception, as is recognized by DRMS background work on Climate Change (see Climate Change TM [URS/JBA 2008b]). It is obvious that higher sea levels mean higher risks of levee failure, given BAU (assuming the levees are raised to keep up with sea-level rise, but strengthening the levee beyond current condition is not included). The amounts of sea-level rise recommended for analysis by the DRMS climate change team are set forth in Table 14-4. They constitute a significant percentage of the 1.5 feet of freeboard required over the 100-year flood elevation as a PL 84-99 design standard. Note that the range of estimates presented indicates considerable uncertainty regarding what will actually occur as the future presents itself.

Table 14-4 Estimates of Future Delta–Suisun Marsh Sea-level Rise

	Centimeters (cm)	Inches (in)	Feet (ft)
Estimates for 2050			
Low	11	4.3	0.36
Med Low	20	7.9	0.66
Med High	30	11.8	0.98
High	41	16.1	1.34
Estimates for 2100			
Low	20	7.9	0.66
Med Low	50	19.7	1.64
Med High	90	35.5	2.96
High	140	55.1	4.59

Changes in Seasonal Runoff and Water Supply Yield. With warming temperatures, more Sierra precipitation will fall as rain and less as snow, and the snow pack will not be as large and will melt earlier. Thus, less spring and early summer runoff will be available for capture for water supply. This change will decrease water supply yields that are tributary to the Delta. The DRMS analysis includes a review of recent studies regarding the changing seasonal pattern of runoff, including analyses of climate change model simulations for inflows to Shasta and Oroville, the primary reservoirs for the Central Valley Project and State Water Project, respectively. The details of these reviews and analyses and their implications for future water supply availability are presented in the Water Analysis Module TM (URS/JBA 2007e, Appendix F). The decrease in snow pack accumulation, the earlier melting of the smaller snow pack and the resultant decrease of spring and summer runoff (into the state's water supply reservoirs) is illustrated in Figure 14-5 for Oroville. There is a major shift of the monthly fractions of annual runoff from late spring and summer months to winter months. This will decrease the yield of the present water supply system. Table 14-5 summarizes the available results for the various climate change scenarios/models being considered for 2050 (DWR 2006, pp 4-17 through 4-21) and

2085 as an estimate of 2100 (Vicuna 2006). Variations among the simulations indicate uncertainty, with at least one simulation indicating no or only slight decreases in yield and others indicating more.

There is substantial uncertainty in these estimates due to variations among climate simulations and also due to approximations in subsequent analyses. More detailed analysis is possible to markedly reduce analysis approximations. Different climate scenarios would still provide varying results representing substantial remaining uncertainty. There are other scenarios that are worthy of consideration (see Vicuna 2006).

Table 14-5 Estimates of Change in Future Water Supply Median Yield (from previous studies)

Year/Scenario/Model	CVP	SWP
Base Year (1976 based on 1961-1990)	base	base
Estimates for 2050		
SRES-a2, GFDL (based on 2035-2064)	-15%	-11%
SRES-a2, NCAR/PCM (based on 2035-2064)	-7%	-10%
SRES-b1, GFDL (based on 2035-2064)	-11%	-11%
SRES-b1, NCAR/PCM (based on 2035-2064)	No Change	-1%
Estimates for 2100		
SRES-a2, GFDL (based on 2070-2099)	-31%	-27%
SRES-a2, NCAR/PCM (based on 2070-2099)	-14%	-7%
SRES-b1, GFDL (based on 2070-2099)	-20%	-19%
SRES-b1, NCAR/PCM (based on 2070-2099)	-8%	-4%

Progression of Subsidence. The ground surface elevations in the areas of the Delta and Suisun Marsh that have organic (peat) soils are expected to continue subsiding if current management practices are not altered. The DRMS analysis of subsidence has provided an analysis of the rates and amounts of subsidence both historically and projected into the future (see Subsidence TM [URS/JBA 2007d]). Subsidence rates are expected to decrease as the percentage organic content of the soil decreases (due to previous oxidation) and to increase with increasing future ambient temperatures. These effects largely counterbalance each other and the nominal subsidence for typical central Delta histosol is expected to be relatively constant at about 2.2 cm (0.9 inch) per year, until the organic content is largely depleted. An uncertainty band on this subsidence rate of +40% and –30% is stated. Subsidence rates in Suisun Marsh are expected to be much lower because land management practices. An example of the result is given in the subsidence map for 2100 in Figure 14-4. The Subsidence TM (URS/JBA 2007d) has similar maps for 2050 and 2200. Table 14-6 summarizes the medium expectation for future subsidence for the Delta and Suisun area with highly organic soils in terms of decreases in surface elevation and cumulative area-wide increases in accommodation space relative to 2005 sea level:

Table 14-6 Estimate of Future Subsidence Relative to 2005 for Delta and Suisun Marsh

Year	Expected Subsidence (ft)[c]	Accommodation Space Relative to 2005 Sea Level	
		(maf)[b]	(% Increase)
2005[a]	Base case	1.97	base
2050	Up to 3+ feet	2.47	25%
2100	Up to 8+ feet	3.01	53%
2200	Up to 17+ feet	Not estimated	Not estimated

[a] 2005 values are interpolated using 1998 values from the Subsidence TM (URS/JBA 2007d).
[b] maf = million acre feet
[c] Values shown above, apply only to areas with that thickness of peat/organic deposits or thicker. Other areas with less peat available will be limited by their peat thickness.

Note that these estimates of accommodation space are based only on progression of subsidence. Additional accommodation space increases will also result due to increases in mean sea level.

Changes in the Frequency of Seismic Activity. The time-dependent hazard curves developed as part of the probabilistic seismic hazard analysis (see the Seismic Hazard TM [URS/JBA 2007a]) were used to estimate the likelihood of peak ground accelerations (PGA) for the future analysis years: 2050, 2100, and 2200. Table 14-7 presents the expected frequency of a 0.20g Peak Ground Acceleration (PGA) event in 2005 and future years, and also shows the percentage frequency increase over 2005 (base year).

Table 14-7 Estimated Mean Annual Frequencies of 0.20g PGA Events at Sherman Island

Year	Frequency	% Increase Over 2005
2005	$1.7x10^{-2}$	base
2050	$1.9x10^{-2}$	10%
2100	$2.0x10^{-2}$	20%
2200	$2.4x10^{-2}$	40%

The assessment of the future seismic hazard is based on the assumption that a major seismic event does not occur on one of the major Bay Area faults between now and the future evaluation years (2050, 2100, and 2200). As a result, tectonic strains are not released. Instead, they keep building, thus increasing the expected frequency of earthquakes or the magnitude of resultant ground motions when the earthquake finally occurs.

Changes in Inflow Flood Frequency. Flood frequencies (high Delta inflows) are expected to increase due to the regional impacts of global warming, occurrence of more winter precipitation as rain rather than snow, and more frequent occurrence of high intensity precipitation events. Expected changes in runoff patterns due to a warming climate are described in Climate Change TM (URS/JBA 2008b). Although the total amount of yearly precipitation may not change substantially, increases in winter precipitation as rainfall rather than snow and increasing frequencies of large storm events are predicted. The climate change team was able to provide four different scenario/simulations of daily, unimpaired runoff at key sites tributary to the Delta. These data were analyzed by the DRMS flood hazard team to quantify the trends in the frequency of major storms. Although the results vary among the four simulations (see the Flood Hazard TM [URS/JBA 2008a]), each indicates increasing frequencies of the seven-day Delta inflow representing the year-2000 one percent annual frequency (i.e., 100-year) flood event as indicated in Table 14-8. The results indicate occurrence of present day 100-year floods 1.35 to 6.0 times as often in 2050 and 2.3 to 12.4 times as often in 2100, substantially increasing Delta levee risks.

Table 14-8 Median Probability of Exceedance of Year 2000 1 Percent Annual Frequency Delta Inflow Floods

Scenario[a]	Year 2000	Year 2025	Year 2050	Year2075	Year 2100
SRES-b1, GFDL	0.01	0.010	0.017	0.020	0.023
SRES-b1, NCAR	0.01	0.018	0.060	0.092	0.124
SRES-a2, GFDL	0.01	0.014	0.027	0.030	0.034
SRES-a2, NCAR	0.01	0.010	0.014	0.031	0.048

[a] See the Flood Hazard TM (URS/JBA 2008a) for a description of the scenarios.

Changes in Delta Area Population, Land Use, and Economic Activity. The forecasts for Delta area population and land use under current policies foresee infill in present Primary Zone communities and intensive development in the Secondary Zone of the Delta (URS 2007; URS/JBA 2007f [Impact to Infrastructure TM]; URS/JBA 2008f [Economic Consequences TM]). Thus, the people, material assets, and economic activity located in the Delta and Suisun Marsh that will be exposed to future levee failures and flooding are expected to increase. This increased exposure in the event of levee failure contributes to increased risk.

Population – Data and projections of Delta area population are difficult to obtain because they are typically developed for smaller or larger geographic areas. However, available data reported in the DRMS “Status and Trends” report (URS Corporation 2007) indicate that the population on Delta and Suisun Marsh islands is expected to increase from 26,000 to 67,000 from 2000 to 2030 -- that is to about 260%. In other words, there will be 2.6 times as many people living on Delta and Suisun Marsh islands in 2030. Similarly, the six-county area that encompasses the Delta and Suisun Marsh is projected to have 2.3 times as many people in 2050 as were resident in 2000. The population of the legal Delta in 2000 was about 470,000. The “Status and Trends” report provides an estimated population increase for Delta-Suisun of 600,000 people by 2050. Thus, it is estimated that full development of the Secondary Zone could lead to a population of over a million people. Given the above, Table 14-9 provides estimates of Delta population for the specific years of interest compared with the 2000:

Table 14-9 Population Forecasts for the Delta and Suisun Marsh

	Delta–Suisun Marsh Islands	Legal Delta
2000	26,000	470,000
2030	67,000	Not Available
2050	Not Available	1,070,000
2100	Not Available	Not Available

These estimates of future population are very uncertain but no quantitative characterization of the uncertainty is available. For the secondary Delta zone, where areas are also protected from large floods by Delta levees, there may be a population increase of more than 120% by 2050. But a small change in expected subdivision development could mean many more or many less new people. For example, housing units on Stewart Tract, Bishop Tract, Shima Tract and Sargent Barnhart Tract are expected to increase from 1,700 to 14,200 units between 2000 and 2030, a localized increase of over 800%. State and local agencies do not have population projections beyond 2050. However, under BAU policies, there is no indication that the population growth rates given for Delta islands and the surrounding Secondary Zone will decrease substantially until all the available land is developed. In absence of changed development policies a continuing increase beyond the 2050 populations appears to be a reasonable working assumption in looking toward 2100.

***Infrastructure and Public and Private Property* –** The analysis in the Impact to Infrastructure TM (URS/JBA 2007f) provides an assessment of assets subject to flooding from levee failures keyed to both Mean Higher High Water (MHHW) and the 100-year flood plain. Their assessment is summarized below.

For 2050 conditions, the MHHW and 100-year flood asset values subject to flooding are expected to increase by about 20% to 25%.

For 2100 conditions, in addition to continuation of normal asset growth, both the MHHW and 100-year flood exposures are expected to cover increased areas because of sea-level rise and the increasing magnitude of the 100-year flood. Some of the additional areas that will be exposed to flooding are now highly developed urban areas or are in the path of urban development. There is no indication these development trends will change under BAU policies.

***Business Activity* –** Business activity is usually counted by value of output, employment and labor income. Table 14-10 shows year 2000 and 2030 business activity for the State and for selected Delta region economies. In general, the Delta region is expected to grow faster than the State. Between 2000 and 2030 gross regional product and earnings are expected to double and employment is expected to increase 50 to 80 percent. There is no useful projection for economic activity after 2030; however, business activity is expected to continue growing with population.

Table 14-10 Economic Indicators for California and Delta Regions, 2000 and 2030

	Regional Product Billions 2005 $			Earnings Billions 2005 $			Employment (Thousands)		
Region	**2000**	**2030**	**% Inc**	**2000**	**2030**	**% Inc**	**2000**	**2030**	**% Inc**
California	$1,443	$2,804	94	$977	$1,831	87	19,626	28,924	47
Combined Statistical Areas									
Sac-Arden	$73	$191	161	$49	$125	152	1,141	2,081	82
Stockton	$15	$29	101	$10	$19	95	259	388	49
Vallejo-Fairfield	$10	$22	130	$6	$14	124	160	273	70
Counties									
Contra Costa Co	$37	$81	122	$25	$53	114	478	769	61
Sacramento Co	$50	$130	161	$34	$85	152	729	1,318	81
San Joaquin Co	$15	$29	101	$10	$19	95	259	388	49
Solano Co	$10	$22	130	$6	$14	124	160	273	70
Yolo Co	$7	$15	130	$4	$10	123	108	177	64

Woods and Poole 2006

Business sales by Delta Island and Suisun Marsh businesses that are located below the MHHW were about $3 billion in 2000. Agriculture, natural gas production and recreation are important economic activities in the primary Delta. DWR estimates the annual value of Delta agricultural production over the 1998 to 2004 period averaged $680 million in 2005 dollars. Average annual value of natural gas production in 2004 and 2005 was over $300 million. Natural gas and agricultural production values will probably not increase significantly in the future. Recreation-related expenditures in the Delta were recently estimated to be over $500 million annually. These recreation expenditures will probably increase in the future with population in the Delta and the larger Bay Area region. Economic activity tied to residential development will increase dramatically by 2030 on some Delta islands near Stockton and can be expected to continue increasing thereafter.

Changes in Regional and State Population and Economic Activity. Available forecasts indicate continuing population and economic growth for the Delta and Bay regions and for the state as a whole. This will result in an increased dependence on infrastructure that traverses the Delta and especially on the water supplies that are conveyed through the Delta (URS 2007; DWR 2005c; URS/JBA 2008f [Economic Consequences TM]).

Population – The California Department of Finance (DOF 2007) provides state population projections to 2050. They estimate 59.5 million people will reside in California by that date, a 61% increase over the 2005 base year. Official DOF projections are not available beyond 2050. Table 14-11 summarizes available projections, including one provided in "Status and Trends" for 2100. The uncertainties in future state population are quite large, but not quantified.

Table 14-11 Estimated Future California Population

Year	Population (million)	Percent Increase Over 2005	Source
2005	37.0	base	DOF 2007
2050	59.5	61%	DOF
2100	90	143%	URS 2007

Economic Activity – Economic activity is closely tied to population growth. Historical data are available from DOF (2007a). As with population, official projections are not available for the long term. The state DOF provides forecasts through 2010 (DOF 2007c). Table 14-10 presents available projections to 2030 by Woods & Poole (2006). They show an expected 94% increase in gross state product from 2000 associated with an expected population increase of 41%.

Based on the above input information that is available, the scenarios to be analyzed quantitatively are defined in Tables 14-12 for 2050 and 14-13 for 2100. If no quantitative input information is available for the particular year of interest, the analysis will use the next earlier estimate that is available.

Table 14-12 Risk Analysis Scenario for 2050

Variable	Low Risk Scenario	Medium Risk Scenario	High Risk Scenario
Sea-level rise	11 cm (4.3 inches)	20 cm (7.9 inches)	41 cm (16.1 inches)
Accommodation Space Due to Sea-level rise[a]	0.09 MAF (+4.7%)	0.17 MAF (8.7%)	0.35 MAF (+17.7%)
Water Supply Yield	-1%	-10%	-13%
Subsidence (Accommo-dation Space)	0.35 MAF (+13%) 2.1 ft	0.5 MAF (+19%) 3 ft	0.7 MAF (+27%) 4.2 ft
Seismic Frequency	+10%	+10%	+10%
Flood Frequency	+35%	+194%	+500%
In-Delta Population	+128%	+128%	+128%
In-Delta Economics	Unknown	Unknown	Unknown
State Population	61% Increase	61% Increase	61% Increase
State Economy[b]	94% Increase	94% Increase	94% Increase

[a] The part of the Delta–Suisun Marsh area that is below sea level is about 260,000 acres.
[b] Woods and Poole estimate for 2030.

Table 14-13 Risk Analysis Scenario for 2100

Variable	Low Risk Scenario	Medium Risk Scenario	High Risk Scenario
Sea-level rise	20 cm (7.9 inches)	90 cm (35.5 inches)	140 cm (55.1 inches)
Accommodation Space Due to Sea-level rise[a]	0.17 MAF (+8.7%)	0.77 MAF (39%)	1.19 MAF (+61%)
Water Supply Yield	-6%	-15%	-29%
Subsidence (Accom-modation Space)	0.73 MAF (+35%) 5.6 ft	1.04 MAF (+51%) 8 ft	1.46 MAF (+71%) 11.2 ft
Seismic Frequency	+20%	+20%	+20%
Flood Frequency	+130%	+458%	+1,140%
In-Delta Population	Unknown	Unknown	Unknown
In-Delta Economics	Unknown	Unknown	Unknown
State Population	143% Increase	143% Increase	143% Increase
State Economy[b]	Unknown	Unknown	Unknown

[a] The part of the Delta–Suisun Marsh area that is below sea level is about 260,000 acres.
[b] Woods and Poole estimate for 2030.

14.3.3 Details on Changing Risk Factors as They Progress Through the Risk Model and Become Consequences

An assessment is presented below of future year risks based on the quantitative input information in the above tables. The assessment generally follows the conceptual model presented in Figure 14-3 and the branches visible in the logic tree of Figure 14-7. Sunny-day/high-tide events, seismic events and floods are addressed separately and the risk results are then combined.

14.3.3.1 Sunny-Day Risk Assessment

Sunny-Day Failure Frequency. Sea-level rise will directly influence the stage versus frequency curve for every Delta location under tidal influence and, thus, the frequency of sunny-day, high-tide failures. A given Delta levee has a fragility (conditional probability of failure) that is related to its hydraulic head. Table 14-14 calculates the increased probability of failure (higher gradients) as a result of sea-level rise. The increased probability of failure relates to the exit gradient. The higher the gradient, the higher the probability of failure (see Section 7.0).

Table 14-14 Effects of Sea-level Rise on Sunny-Day Failures

Year/Scenario	Sea-level rise (feet)	Increase in Probability of Failure (%)
2050 Low Risk	0.36	2.3
2050 Medium Risk	0.66	4.2
2050 High Risk	1.34	8.5
2100 Low Risk	0.66	4.2
2100 Medium Risk	2.96	18.7
2100 High Risk	4.59	29.0

Accordingly, Table 14-15 indicates the subsidence induced hydraulic head increases and their effect on sunny-day, high-tide fragilities. The increased head from subsidence will occur only in areas with highly organic soil that happen to be within the “zone of influence” for the levee. This will increase the vulnerability of these levees to failures caused by under-seepage and through-seepage.

Table 14-15 Effects of Subsidence on Sunny-Day Failures

Year/Scenario	Subsidence (feet)	Increase in Probability of Failure (%)
2050 Low Risk	2.1	13
2050 Medium Risk	3.0	19
2050 High Risk	4.2	27
2100 Low Risk	5.6	35
2100 Medium Risk	8.0	51
2100 High Risk	11.2	71

Expected Increases in Sunny-Day Failures. Since the above drivers directly affect the hydraulic head, they are additive to the overall increase in levee fragility and hence to the probability of failure, as shown in Table 14-16.

Table 14-16 Percent Increased Frequency of Sunny-Day, High-Tide Breaches Under BAU

Year	Low Risk Scenario	Medium Risk Scenario	High Risk Scenario
2050	16%	23%	35%
2100	40%	61%	100%

14.3.3.2 Seismic Risk Assessment

Seismic Hazard. Per Tables 14-12 and 14-13, the frequencies of seismic events will increase relative to 2005 – by 10% in 2050 and 20% in 2100.

Seismic Fragility. Sea-level rise and increased subsidence will combine to increase the effective hydraulic head on levees by about 4 feet (+/-) in 2050 and nearly 10 feet (+/-) in 2100 compared with 2005 conditions and hence reduce the stability of the levee by the amounts shown in Table 14-16.

Frequency of Seismic Flooding. The resulting increase in probability of island flooding from higher frequency seismic events is compounded by the increase in of the conditional probability of failure (levee fragility) producing the results shown in the Table 14-17.

Table 14-17 Percent Increased Frequency of Seismic Breach Events Under BAU

Year	Low Risk Scenario	Medium Risk Scenario	High Risk Scenario
2050	28%	35%	49%
2100	68%	93%	140%

14.3.3.3 Flood Risk Assessment

Flood Hazard. Per Tables 14-12 and 14-13, inflow flood frequencies equal to or exceeding the 2005 100-year flood (i.e., present frequency of 0.01/year) are expected to increase dramatically – from a 40% minimum increase (2050, low value) to 1,140% maximum increase (2100, high value). Other severe inflow flood frequencies are also expected to increase in similar ways but with somewhat different numbers. The key need for assessing the implications of these frequency changes is to have revised normal stage versus frequency curves at various points in the Delta that reflect future tides, sea-level rise, and today's floods. The present day 0.01 frequency/year flood (the Standard Flood) occurs on the historical stage frequency curve – likely somewhere between the 0.01 and 0.02 frequency points because the curve may reflect extreme tides. Table 14-18 presents the percentage increase in frequency of inflow events, namely the 2005 1% flood (i.e., the Standard Flood used as representative for increased future flood frequency).

Flood Fragility. For levees that would not overtop, the conditional probability of levee failure is a function of remaining freeboard, but also considering hydraulic head and its influence on under-seepage and through-seepage. The hydraulic head will increase in the future due to sea-level rise and the progression of subsidence as shown in Table 14-16. Obviously, levees will overtop more frequently if not raised to keep up with increases in sea level.

Frequency of Inflow Flood Breaches. The resulting frequency of island flooding from high inflow events is expected to increase according to the Table 14-18, which combines the alterations to the flood frequency curves and the altered fragility curves due to subsidence and sea-level rise. Note that these frequency increases do not include overtopping. Raising levees to keep up with sea-level rise is assumed.

Table 14-18 Percent Increased Frequency of High Inflow Breach Events Under BAU

Year	Low Risk Scenario	Medium Risk Scenario	High Risk Scenario
2050	241%	261%	297%
2100	681%	798%	1016%

The number of digits do not represent accuracy in the results; they are simply the outcome of the calculations.

14.3.3.4 Emergency Response and Repair

Major changes in Delta levee damage response and repair technology are not expected. Availability of marine resources for levee repair is unpredictable, but is assumed not to change markedly. Availability of repair material in future years could be a major concern, since reliance is currently placed on obtaining rock from the San Rafael Quarry. Its unique advantage is its marine loading facilities. If this quarry were to close, exhaust its reserves or be unavailable for other reasons, the ability to repair Delta levees may be compromised and prolonged. These potential impacts have not been quantified.

14.3.3.5 Salinity Response

Hydrodynamics and salinity in the Delta are expected to change in future years both during normal operations (without levee breaches) and when levee breaches occur. In normal BAU operations (without levee breaches), sea-level rise will increase the driving forces (gravitational mixing and dispersion) for intrusion of saline water into the Delta (see the Water Analysis Module TM, Appendix H3 [URS/JBA 2007e]). Figure 14-8 provides an indication of the present-day salinity and the additional salinity intrusion that can be expected from 90 cm of sea-level rise (slightly less than 3 feet), assuming that today's normal summer flows are maintained. (Note that 1 psu is the same as 1 part per thousand.) This intrusion of salinity will require an increase in Net Delta Outflow (NDO) to repulse salinity and meet BAU water quality standards.

The increase in the NDO has been estimated at about 7% of the present typical summer season outflow in 2050 (for 1 foot of sea-level rise) and 20% of typical summer outflow in 2100 (with 2.5 feet of sea-level rise). This increase in outflow will combine with the reduced availability of upstream reservoir inflow to decrease reservoir storage and the yields of the SWP and the CVP. In addition, the decrease in reservoir storage reduces the water that will be available when a levee breach occurs.

When a levee breach occurs, the volume of water that floods the island(s) will increase over conditions today because of subsidence and higher sea level. Table 14-19 details the increased volumes under various future year scenarios. This increased flooding volume will be saline water intruding from the Bay, except in major floods. In addition, the increased dispersive forces mentioned above will be active. Salinity will intrude farther into the Delta. More water and more time will be required to complete repairs, repulse the salt, and reestablish Delta water quality, but less water will be available for this purpose. Thus, recovery times will increase.

Table 14-19 Increased Island Flooding Volumes Due to Subsidence and Sea-Level Rise

Year/Scenario	Increased Volume Due to Subsidence (%)	Increased Volume Due to Sea Level (%)	Increased Volume Total (%)
2050 Low Risk	17	4.7	22
2050 Medium Risk	25	8.7	34
2050 High Risk	35	17.7	53
2100 Low Risk	36	8.7	45
2100 Medium Risk	53	39	92
2100 High Risk	71	61	132

With higher sea level, more Delta outflow will be needed to repulse the salinity and maintain Delta water quality (see the Water Analysis Module TM [URS/JBA 2007e, Appendix H3]). This will compound the reductions in water supply yield due to climate change. For smaller events (three flooded islands or fewer) until 2050, the modest Delta recovery times calculated for 2005 will remain modest, although they will increase. For somewhat larger events in 2050, Delta recovery times of several months will increase noticeably. For larger events (20 or 30 flooded islands), changes in Delta recovery times will be more strongly impacted by less water availability upstream in normal and dry years. Management and recovery from levee breach events that are now calculated to require several years may simply have to wait for one or more wet years to renew fresh water conditions in the Delta. In 2100, the same pattern of change will occur with larger impacts on the time required for Delta recovery. Estimates of recovery period increases are provided below in Table 14-20. They are quite sensitive to the amount of sea-level rise.

Table 14-20 Salinity Impacts

Year/Scenario	Extra NDO (%)	Less Water Supply (%)	Increased Flood Volume (%)	Recovery Time Increase (%)
2050 Low Risk	0	-1 - 0 = -1	22	5
2050 Medium Risk	1	-10 - 1 = -11	34	15
2050 High Risk	9	-13 - 5 = -18	53	25
2100 Low Risk	1	-6 - 1 = - 7	45	20
2100 Medium Risk	22	-15 - 15 = -30	92	60
2100 High Risk	33	-29 - 20 = -49	132	100

NDO = Net Delta Outflow

14.3.3.6 Potential Loss of Life

The number of people exposed to injury or loss of life due to island flooding is taken as the population of the Delta and Suisun Marsh. Increases in future years are calculated based on the increased population and the increased frequency of flooding. The only future population estimate available is for a 128% increase by 2050.

14.3.3.7 Economic Losses

For large events, the economic cost and impacts to the state dominate the measure of economic losses. Thus the percentage increase in economic losses will be based on the increase in state population and the increase in recovery time required relative to salinity. The state population is expected to have increased by 61% in 2050 and 143% in 2100%.

14.3.4 Combined Risk Consequences in Future Years

The combined effect of the changes for future years of the factors discussed in the foregoing sections is presented below, by addressing sunny-day, high-tide events, seismically initiated events, and floods. The relative importance of risk factors to future changes for each of these types of failure events is illustrated in the tables identified below, and in Figures 14-9 and 14-10.

Sunny-Day High-Tide Failures. The effects of sea-level rise and subsidence will increase the vulnerability of the levees and their probability of failure. The combined effects of higher probability of levee failure and the increased consequences are shown in Table 14-21. Based on 2005 conditions, single levee breaches such as these were found to not have significant impacts beyond on-island flooding and repair costs. The largest island, if flooded, had a salinity recovery period of less than 90 days in the worst case. In the future, if such breaches occur one island at a time and are quickly repaired, the extended impacts are unlikely to increase in a substantial way. However, if sea-level rise causes such events to occur on two to four islands at a time, and causes additional salinity intrusion as well, impacts will escalate as indicated in Table 14-21.

Table 14-21 Expected Increase in Sunny-Day Risk in Future Years Over 2005

Risk Factor	*2050*			*2100*		
	Low	*Medium*	*High*	*Low*	*Medium*	*High*
Frequency of Island Flooding[a]	16%	23%	35%	40%	61%	100%
Potential Loss of Life	164%	180%	207%	N/A	N/A	N/A
Expected Economic Losses	136%	174%	227%	226%	400%	676%

Seismic Levee Breach Events. For the future years 2050 and 2100, the seismic risk factors are expected to increase approximately as indicated in Table 14-22. The risk of island flooding (hazard and levee fragility) increases modestly. The more significant increases are expected to be from impacts on in-Delta resources (population, property, ecosystem) and the statewide impact of salinity intrusion on the statewide population and economy, as indicated in Table 14-22.

Table 14-22 Expected Increase in Seismic Risk in Future Years Over 2005

	2050			*2100*		
Risk Factor	***Low***	***Medium***	***High***	***Low***	***Medium***	***High***
Seismic Hazard	10%	10%	10%	20%	20%	20%
Frequency of Island Flooding[a]	28%	35%	49%	68%	93%	140%
Potential Loss of Life	229%	249%	283%	N/A	N/A	N/A
Expected Economic Losses	160%	202%	260%	291%	500%	831%

[a]Increased frequency in island flooding reflects increased hazard and fragility.

Flood-Induced Levee Breach Events. The climate change shift to more frequent major floods will substantially increase future flood risk. The fresh water inflow from the floods will generally prevent immediate salinity intrusion, but long levee repair periods may present problems in subsequent periods of low flow. However, export disruptions have been capped in Table 14-23. Large in-Delta impacts from additional flooding are expected, due especially to increased population and development and increased pressure on the ecosystem. The primary driver of escalating impacts is the increased frequency of flooding. Economic loss escalations have been estimated based on Delta population growth (therefore, life loss and economic impacts are the same).

Table 14-23 Expected Increase in Flood Risk in Future Years Over 2005

	2050			*2100*		
Risk Factor	***Low***	***Medium***	***High***	***Low***	***Medium***	***High***
Flood Hazard	35%	194%	500%	130%	458%	1140%
Frequency of Island Flooding[a]	241%	261%	297%	681%	798%	1016%
Potential Loss of Life	676%	723%	803%	N/A	N/A	N/A
Expected Economic Losses	676%	723%	803%	NA	NA	NA

[a]Increased frequency in island flooding reflects increased hazard and fragility.

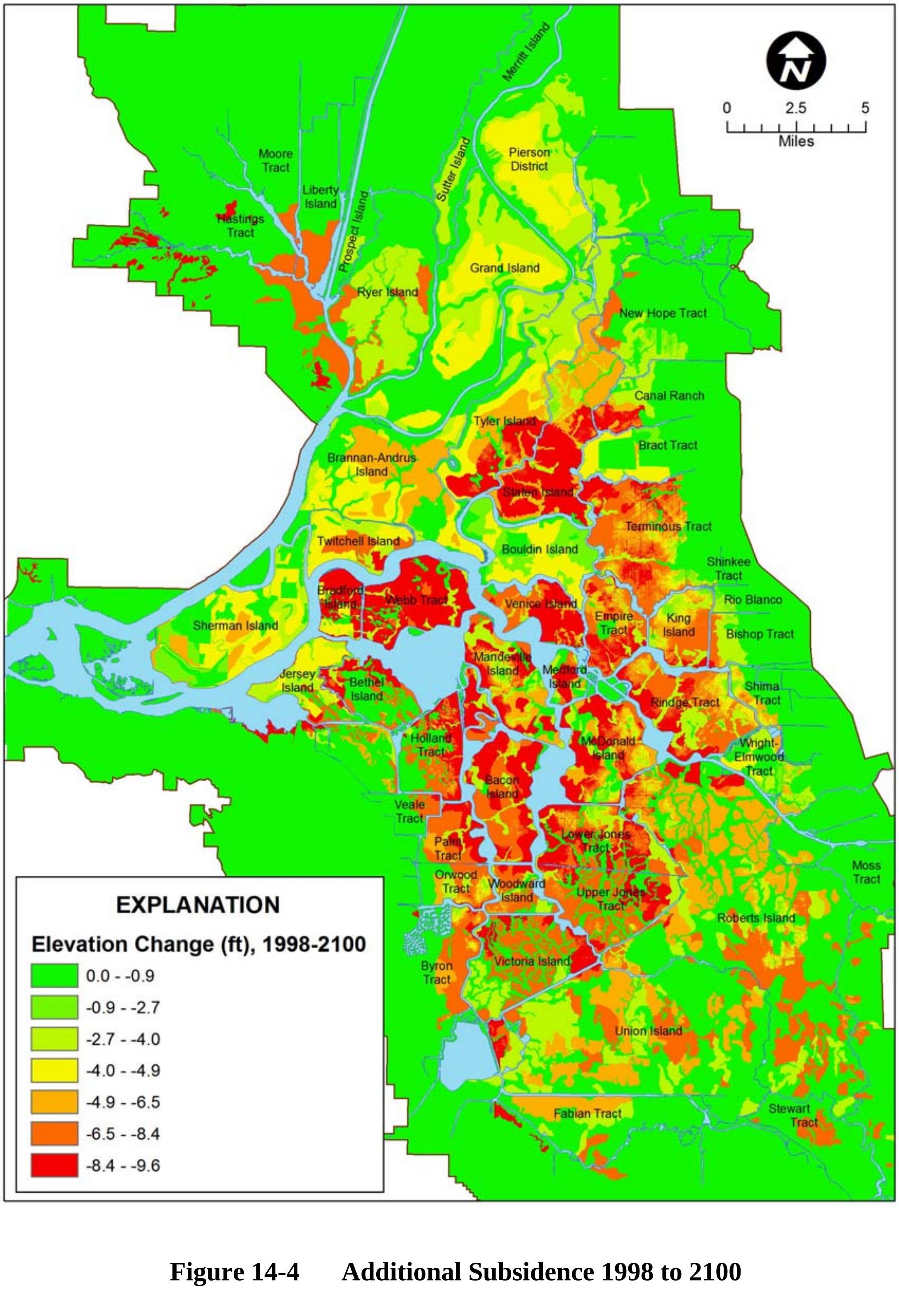


Figure 14-4 Additional Subsidence 1998 to 2100

Figure 14-5 Oroville Changes in Monthly Runoff Pattern (One of Four Simulations; SRESa2, gfdl).

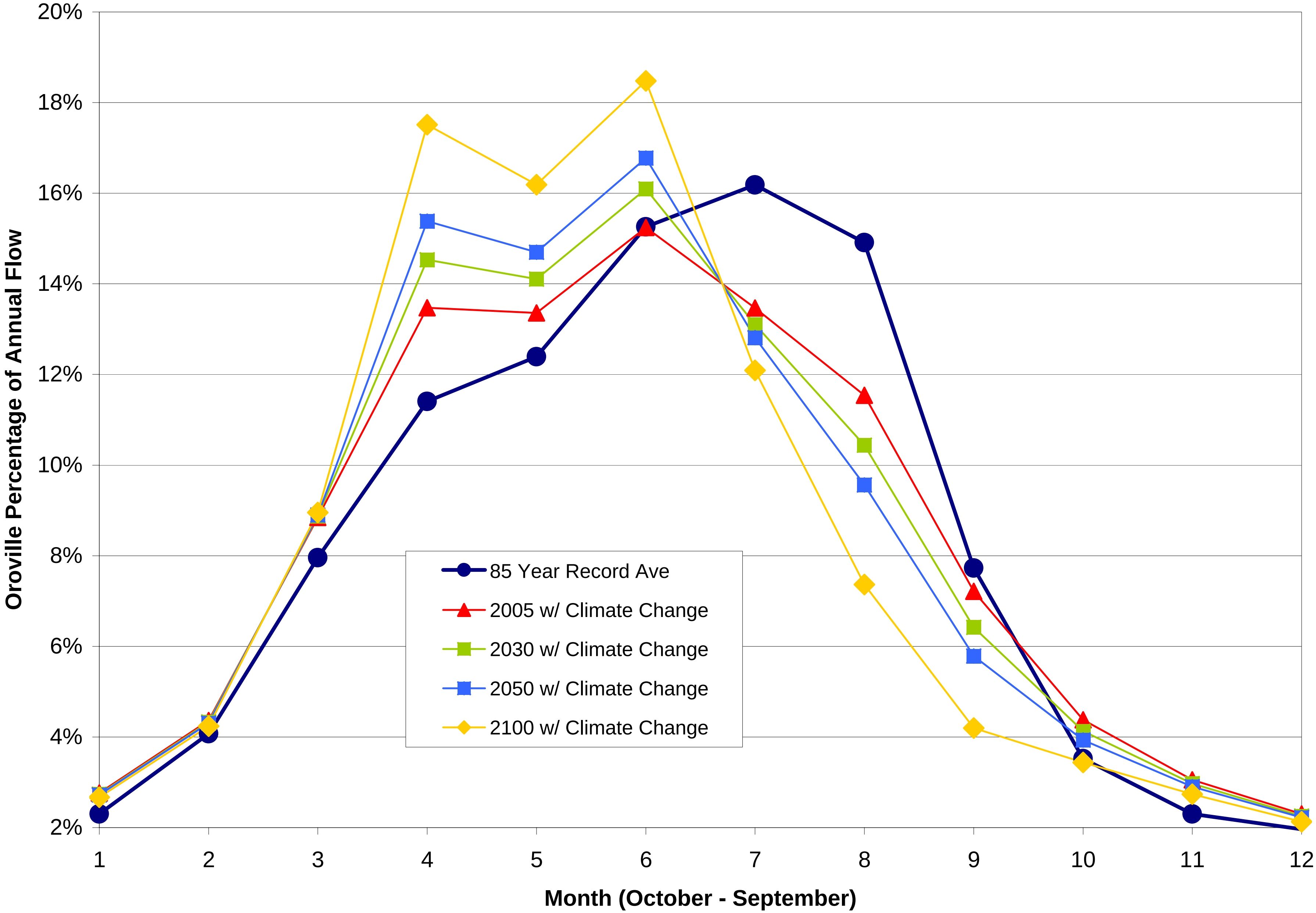
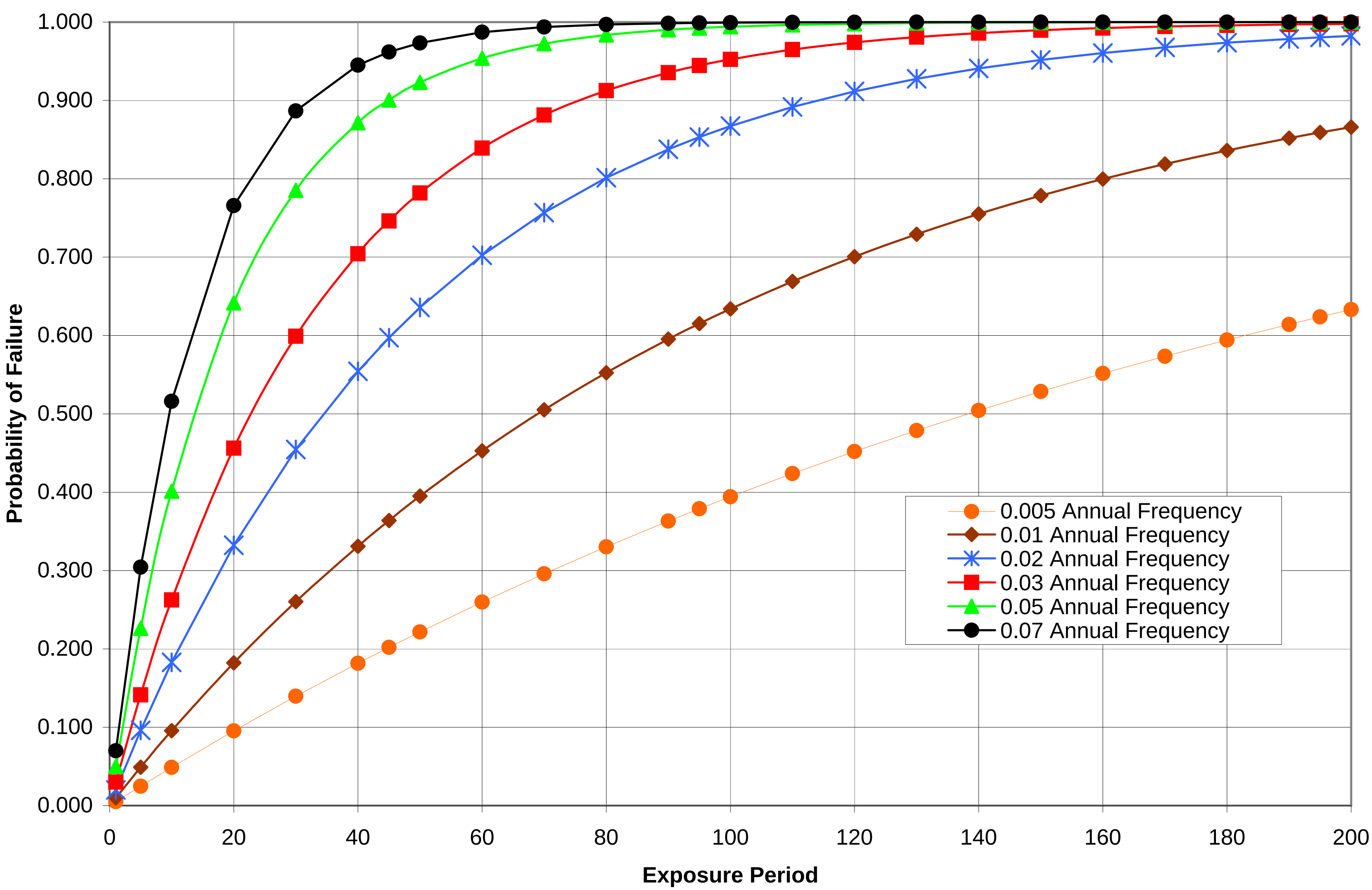


Figure 14-6 Failure Probability Versus Exposure Period



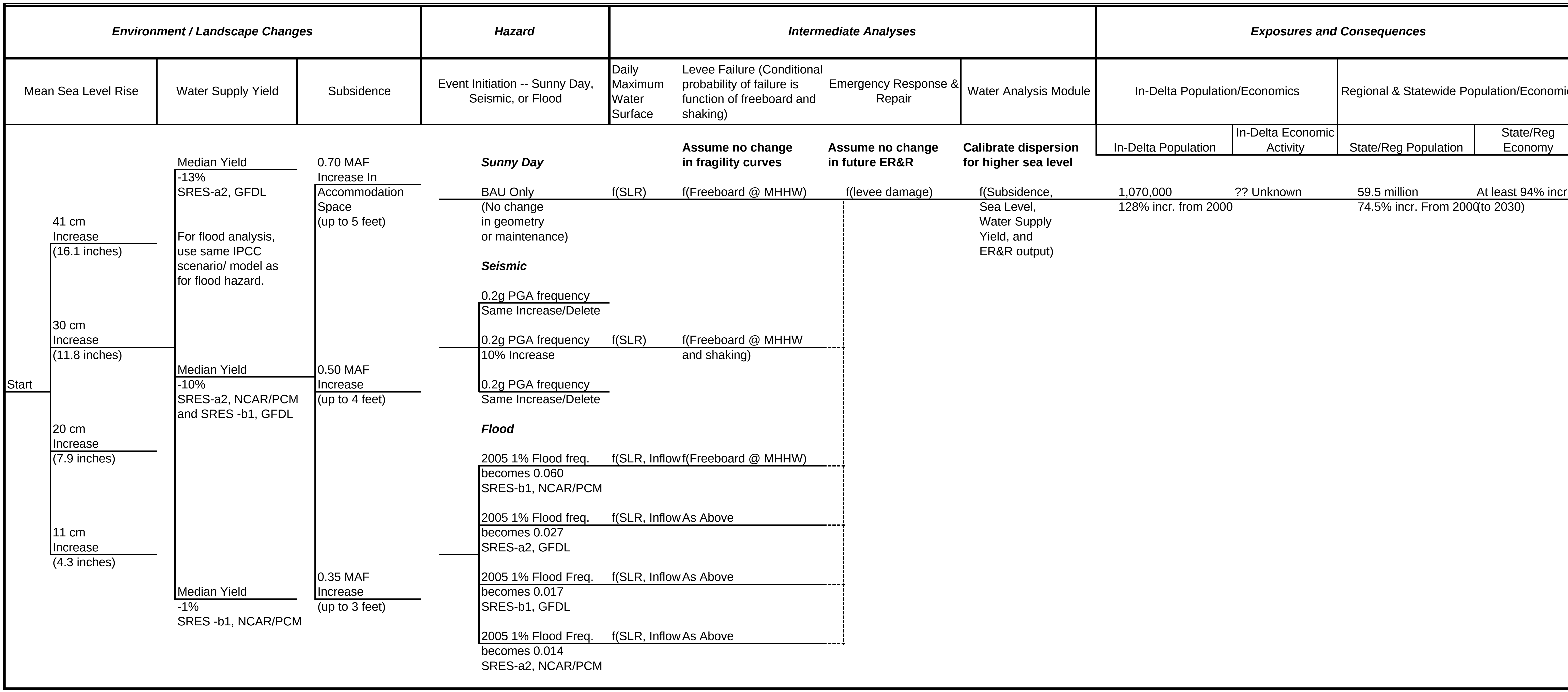


Figure 14-7 Logic Tree for Future Year Risk Analysis -- 2050

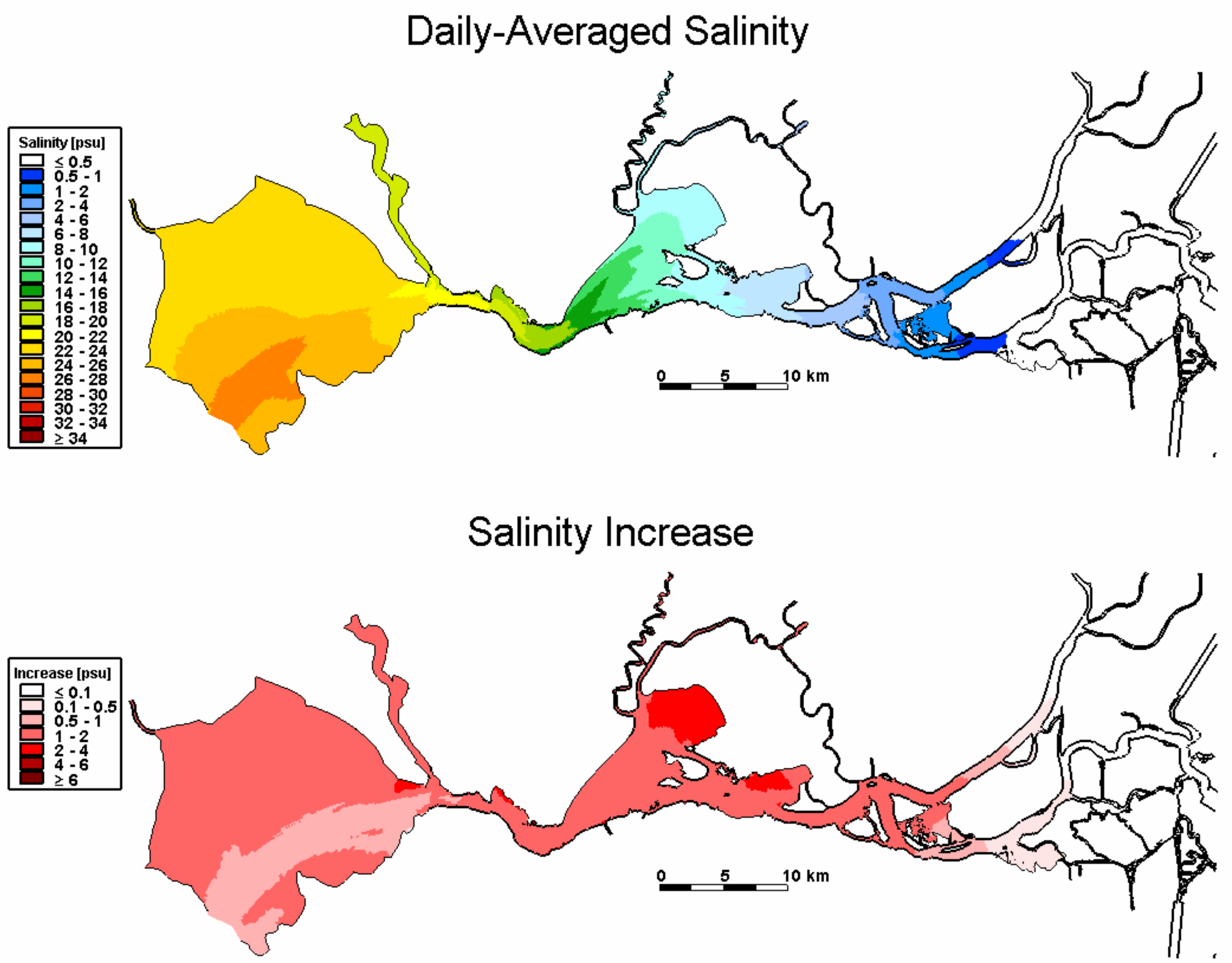


Figure 14-8 Depth-averaged and tidally averaged salinity at tidally averaged steady-state conditions for the 90 cm MSL rise and increase in salinity relative to the baseline scenario

Figure 14-9 Risk Factor Ratios for 2050

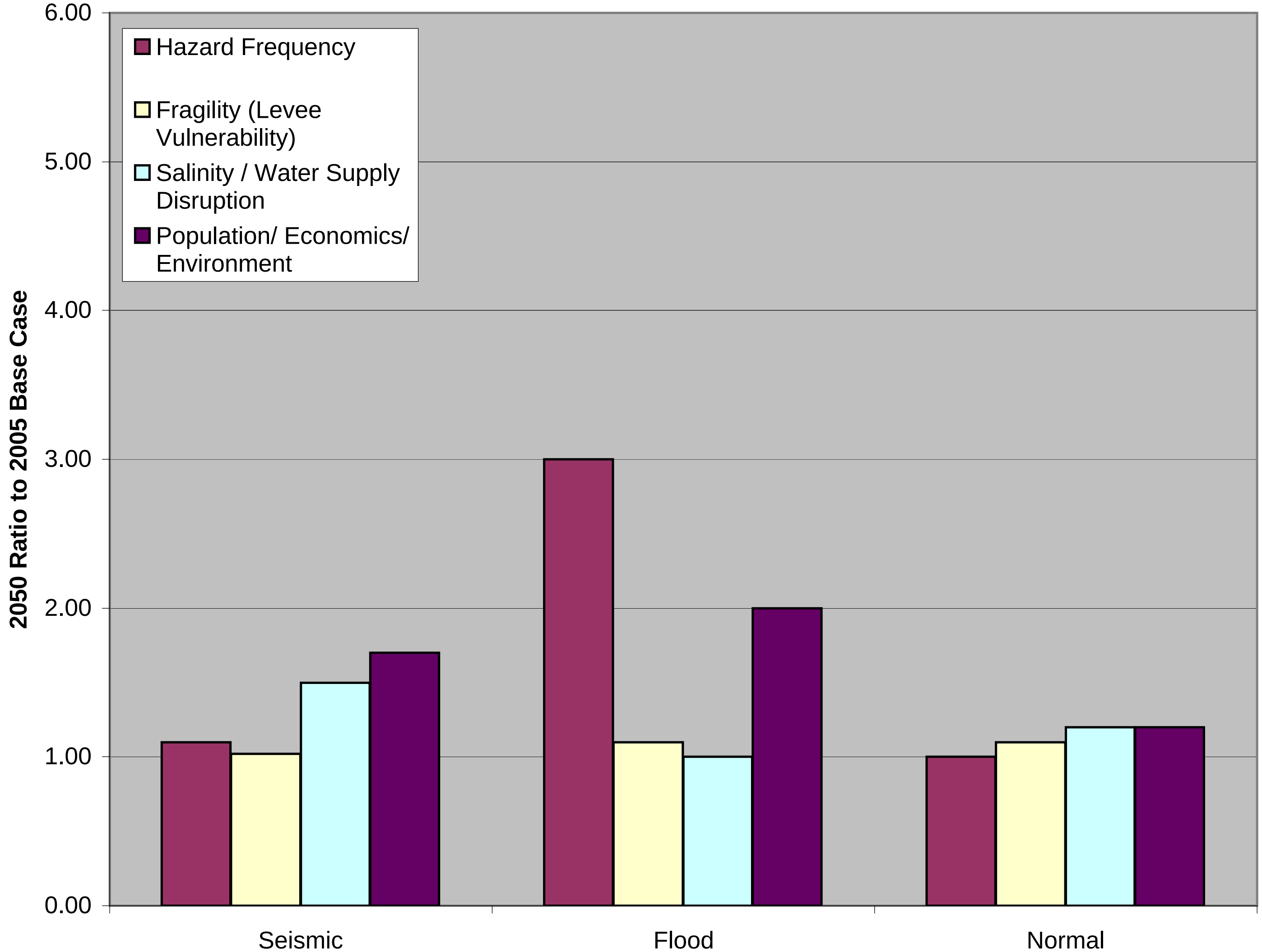
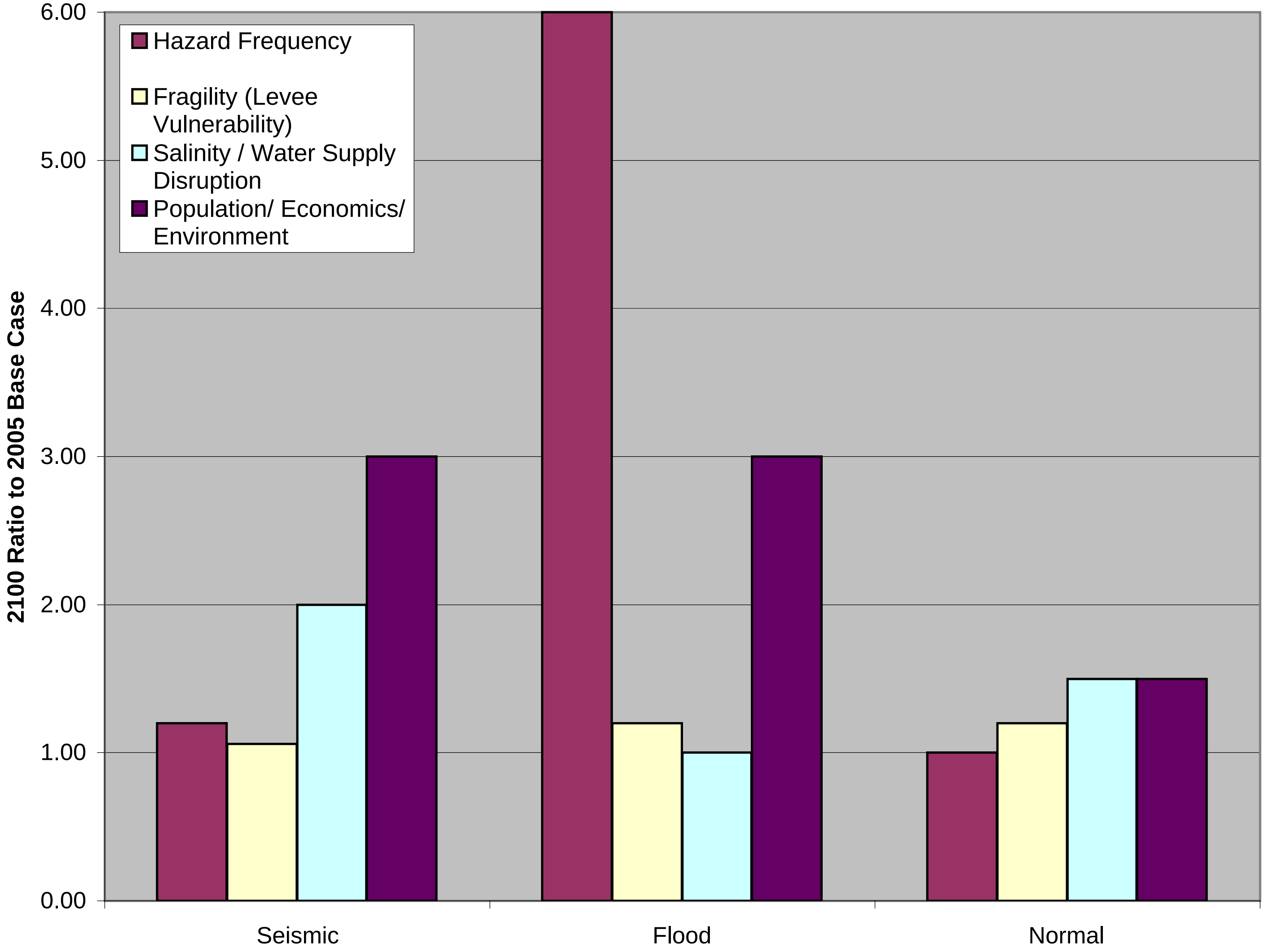


Figure 14-10 Risk Factor Ratios for 2100



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The risk analysis was carried out, for the most part, using existing information (data and analyses). The project schedule and scope do not afford the opportunity to conduct field investigations, laboratory tests, or research. As the analysis progressed, the Delta Risk Management Strategy (DRMS) consulting team noted several data gaps that contribute to the limitations and the uncertainties of the analysis results. Consideration should be given to filling these data gaps prior to any post-DRMS evaluations or designs of Delta improvement projects. The identified gaps are as follows:

- DRMS addressed the risk of levee failures (under various hazards and stressors) and estimated the consequential impacts on life safety, the ecosystem, water exports, water quality, land use, economics, etc. DRMS does not address other stressors and their impacts on the various resources and assets in the Delta and Suisun Marsh. For example, the impact of nonnative invasive species on native species and habitat, and the impact of changes to water quality (pollutants) on the native species are not addressed. On the other hand, the impact of levee failure on the habitat, water quality, and their effects on the Delta ecosystem and water exports are addressed.
- To have a common basis for risk comparison, a business-as-usual (BAU) scenario was assumed for the current and the future Delta and Suisun Marsh. Earlier sections of the report describe the meaning and definition of BAU, the continuation of existing (2005-era) policies and management practices. This assumption offers a common basis for comparison of the present and future risks of the Delta, and allows the answer to the question of whether the current Delta status and practices are sustainable in the future. We understand that the continuation of the BAU is not likely, and changes towards a more sustainable Delta would likely occur as a result of this and other relevant studies.
- The risk model used in this study relies on input from the hazard models (seismic, flood, climate change, subsidence, and wind/wave), levee system response model, and the consequences models. The hazards, the levee response, and the life safety models have been represented probabilistically. The model development of the aquatic species impact is built on a probabilistic framework although the parameters have not been set and results have not been produced yet. The climate change model is based on ranges of possible outcomes as opposed to a full probabilistic representation. The economic model is based on best estimate values and use neither ranges nor a probabilistic representation.
- The engineering analyses conducted for this risk evaluation project were developed at a regional level using broad interpolation and smoothing of the engineering and scientific properties and parameters that are naturally highly variable across a large area such as the Delta and Suisun Marsh. These analyses were conducted at a planning level, using a coarse geographic grid, hence carrying less site-specific and locally detailed information typically required for specific engineering and design projects.
- Topographic and bathymetric base maps are essential for the development of the levee vulnerability assessment. These data are of first order importance to the entire risk analysis. The data used for the draft DRMS project (URS/JBA 2007b) relied on surveys compiled from various topographic data sets prepared at different times, with different reference datum, and by different methods and entities. However, since then, a new LiDAR survey was completed for the entire Delta and Suisun Marsh in late 2007, and the work (URS/JBA 2008h) was updated making use of this new survey.

- It is assumed that scour depth is a direct function of peat thickness (see Section 7.5 for discussion of this issue). The validity of this assumption should be further investigated to determine whether other parameters, such as island area or volume, are better predictors of scour depth.
- Breach depth is important in estimating the quantity of rock for breach closure and repair times. It is also important for estimating the volume of suspended sediments in a flooded island.
- Net Delta consumptive uses are a major source of water demand in the Delta, especially in low-flow years. Existing estimates are useful, but data and modeling limitations may contribute significant errors to the water balance in dry and critical years. Better estimates of the timing and distribution of Delta consumptive use is important for calibration of Delta models and simulation of levee breach consequences.
- The sequence and types of repairs of flooded islands have a strong effect on the time necessary to flush the Delta of intruded salinity and return to a stable salinity regime that supports normal in-Delta water use, ecosystem functions, and water exports. There are many permutations and sequences of emergency repair work for each set of levee failure outcomes. There are many sets of levee failure simulated outcomes. There are multiple permutations of repair types for each sequence of island repair, e.g., capping the breach first and coming back later to close and dewater, capping and closing the breach immediately, repairing damaged but not flooded islands first, protecting the inner slopes of the flooded islands from erosion, etc.

  The study did not exhaustively analyze this particular topic as it is outside the scope of this work and would deserve a specific research and study because of the extensive nature of its scope. The repair sequencing used in the study was based on professional judgment using one repair sequence with each simulated levee failure realization, rather than multiple repair sequences for each simulated levee failure outcome.
- Although CalSim is a powerful and useful tool, it is a limitation on how water issues can be analyzed. Two major limitations result from use of the historical hydrologic sequence to drive CalSim. The historical series is likely to trend through time, since it is now recognized that global warming and climate change have been with us for at least 30 to 40 years. Also, the historical record includes less than half of the 125 potential 3-year sequences of water year types.
- The impacts of levee breaches on Delta salinity may be more strongly influenced by the wetness or dryness of the winters after a breach event than by hydrologic conditions in the event year or in the year preceding the event. Under BAU conditions, a winter with significant San Joaquin River flows may be required to flush the southern Delta if salinity significantly intrudes the area.
- Future water demands have not been characterized in detail, but seem certain to increase. Population and demands upstream of the Delta seem likely to increase, leaving less inflow available for managing the Delta during either normal times or during levee breach incidents. Although the demands for Delta exports are limited by contract amounts and other factors, population growth will likely cause available export water to be used more intensively for

higher value uses. The effect of climate change is less certain; some indication exists that increased water demand due to increased temperatures may be counter balanced by less vegetative water requirements caused by increased atmospheric carbon dioxide.

- One of the most important outstanding questions is about the impact of unrepaired flooded islands with active tidal prism on Net Delta Outflow (carriage water) requirements. This study has not had enough time to provide conclusive quantification of flooded islands on carriage water requirements. Numerical experiments using particle tracking and salt transport simulation under a variety of flow and breach conditions provide insight, but no evident trend. The changes in tidal mixing vary by island and breach location resulting in both increases and decreases in salinity across the Delta.

  Besides changing the tidal dynamics, flooded islands act as capacitors that buffer seasonal salinity variation. In general, breached islands tend to increase mixing near the breach locations and reduce mixing away from the flooded island. Additional tidal mixing caused by flooded islands located near Sherman Island appears to be particularly effective in mixing salt into the Delta, and, therefore, is likely to have a large effect on carriage water requirements.

- Improved net (tidally averaged) flow observations (specifically at the key flow split locations of Three Mile Slough on the Sacramento and False rivers, Turner Cut, Old River near Franks Tract, and Old River at Head on the San Joaquin River) with uncertainty estimates throughout the Delta will support calibration of all Delta models as well as allowing better setting of parameters of the net flows for the WAM-HD.

- It is important to recognize the limitations inherent in the characterization of ecosystem impacts. The results presented here primarily assess the number of individuals or area of habitat impacted, which is similar to the coarse scale used to evaluate the impact of levee failure on life and safety by measuring the number of residents exposed to flooding. Therefore, these results provide a sense of the order of magnitude of the risk, primarily for the immediate impacts of levee breaches, which last for a relatively short duration but cause widespread mortality during the time they are in operation.

- The aquatic species impact model was developed solely using expert elicitation. The model was developed and presented in the Impact to Ecosystem Technical Memorandum. However, the aquatic species impact results have not been completed yet because of the project schedule limitation and the lack of availability of the experts used in the elicitation process.

- For many of the species and impact mechanisms, data were not available to support predictive response relationships to a levee failure event. Therefore, a number of assumptions were made that contribute to a high degree of uncertainty in the ecosystem risk analysis. The risk assessment model identifies assumptions and required data and provides a framework with which to incorporate new data and to evaluate the effects of alternative assumptions on the levee failure impacts on ecosystems.

- Consequences such as impacts of toxins released, water quality impacts, impacts extending across food chains, long-term levee breach impacts on organisms, and the nonlinear impacts of multiple mechanisms on organisms are examples of further effects of levee breaches that are not quantitatively assessed here but which may have far-reaching impacts on the ecosystem.

- The region queried for the purposes of measuring regional plant impacts was defined as those 12 counties that include and border the Delta and the San Francisco Bay. The results of the California Natural Diversity Database query overlaid with flooding patterns indicate that levee breaches and subsequent repair activities can greatly reduce the population size of sensitive plant species, thereby increasing the probability of species extinction. However, exhaustive surveys of rare plant locations and species-specific responses to low population size would be required to fully quantify the impact of levee breaches on species extinction.
- The DRMS Risk Analysis considered damage to infrastructure assets that could result from levee breaching and island flooding. Infrastructure assets that would not be damaged by levee failure (e.g., pumping plants and power plants) are beyond the scope of the DRMS Risk Analysis. Because some asset types lack attribute information, it was not always possible to estimate asset costs from the GIS data. In these cases, definition of quantitative attributes is insufficient to evaluate reliable replacement and repair costs, and assumptions had to be made so that damage loss could be estimated. Also, some assets were not available in the GIS database.

  Further characterization of the Delta infrastructure assets would reduce the uncertainty in the damage estimates. Because of the lack of information on repair times (due to the absence of historical experience), especially for multi-island failures, judgment and experience were used to estimate repair times.

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Appendix A

Independent Review Panel Comments on June 26, 2007, Draft of the Risk Analysis Report and the Responses of the Consulting Team (Dated November 2, 2007)

Note: This appendix provides the August 23, 2007, comments of the Independent Review Panel (IRP) on the June 26, 2007, draft of the Risk Analysis Report and the responses of the consulting team (dated November 2, 2007).

Throughout this appendix, the IRP comments are shown in regular type. The comments of the URS/JBA consulting team are provided after each comment in blue italic type.

Delta Risk Management Strategy (DRMS) Phase 1

Responses to IRP Comments on Risk Analysis Report

Prepared by:
URS Corporation/Jack R. Benjamin & Associates, Inc.

Prepared for:
California Department of Water Resources (DWR)

November 2, 2007

Review of the Delta Risk Management Strategy Report, Phase 1

URS Corporation/Jack R. Benjamin & Associates, Inc., June 26, 2007

CALFED Science Program Independent Review Panel

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August 23, 2007

Review Summary

The *Delta Risk Management Strategy study* (DRMS), which comprises two phases, will underpin policy decisions regarding future infrastructure investments and water resource management in the San Joaquin-Sacramento Delta region for decades to come. *Phase I* results must establish a robust scientific and engineering foundation. This is essential for completing *Phase II*, the identification, and prioritization of strategies for reducing risk in the Delta. In short, *Phase I* is a vital first step in assuring the future sustainability and productivity of the Delta region.

The Independent Review Panel (Panel) found many technical problems in each section of the *Phase I Report*. Several of these emerged as major concerns because they may greatly influence the results and conclusions presented in the report. The major concerns which the Panels terms Tier 1, were: (1) lack of documentation and transparency of analyses, (2) limited actual analyses carried through to the end, (3) limited treatment of uncertainty, (4) lack of integration of single component analyses to produce the final results, and (5) lack of a clear, robust methodology for assessing impacts on aquatic resources. Other important technical concerns (Tier 2) were related to specific analyses in each section. The Panel believes the impact of these issues on the final analyses may be moderate to minor in nature.

For many components of the report, the general approach of the DRMS analysis is well done and consistent with standard practice. However, for other components, the science must be strengthened and most importantly, the implementation (coupling of the components and their models) must be fully transparent, which can only result from improved documentation and completeness to the analyses. As written, many of the analyses are generally incomplete and therefore inadequate to serve as a foundation from which to make reasonable policy decisions about future resource allocations concerning strategies for the Delta region. In other words, the Panel believes strongly that the inadequacies in some of the analyses may lead policymakers and others to erroneous conclusions and inappropriate decisions.

Tier 1 Issues

Lack of Transparency of Analyses

The report is poorly written, lacks transparent documentation of methods, including assumptions (and departures from assumptions), is unbalanced in terms of treatment of hazards and lacks consistency in how the risk analyses are performed. Probability, frequency, rate, likelihood, and even risk are used interchangeably and not consistently or clearly defined. It was difficult for the Panel, who are well versed in these topics and models, to piece together exactly what was done. One very important aspect of good scientific and engineering practice is clear and understandable documentation of assumptions, methods, results, interpretations, and conclusions. Indeed, the report is inconsistent to the point that what was described as having been done in the beginning sections does not match what was done in later sections. A few of the sections are better documented, especially when coupled with their associated technical memoranda (e.g., seismic and flooding), but most, including the critical sections that integrate the various analyses, suffer greatly from inadequate documentation. There is little comparison of results to previous analyses, and some spot-checking by the members of the Panel suggested that aspects of some of these new results are significantly different from the results of similar previous analyses. In fact, the entire project seems not to have followed standard review practices. As it is written, this draft report fails the adequate documentation standard, which necessarily means it fails the test of providing adequate information for public decision-making.

This comment is primarily a documentation/editorial issue and will be addressed in the next revision of the report. The discussion of the development of the analyses (assumptions, methods, results, and interpretation of results and how they fit with the overall risk model) will be expanded. The Phase 1 Risk Analysis Report (and if needed, the TMs) will be reviewed and the text expanded to provide a complete description of the methods used and the evaluations performed. We will also provide a clear and consistent definition of the terminology we use in the reports.

A comment is made with regard to comparisons (spot-checking) of previous studies. We are not clear which other previous studies the comment is referring to. There are a few limited examples where we will add a discussion that compares elements of the DRMS risk analysis to other studies and highlight the reasons for any differences between our results and the results of the other studies. Examples of the previous studies that we will reference include the CALFED 2000 levee seismic vulnerability study, the Department of Water Resources 1992 summary of previous studies (this report contains a complete summary of relevant previous studies), the Jack R. Benjamin & Associates (JBA) 2004 risk analysis (which actually made use of the CALFED (2000) work), the USGS national hazard maps, and other applicable references to other topics presented in the report.

While we will modify the document as stated above, in our response to detailed comments on individual sections, there are a number of comments which suggest this work has already *been done or that parts of it have been done and were on the shelf and ready to be adopted in the DRMS analysis.*

A study with a scope similar to DRMS has not been done for the Delta and Suisun Marsh.

The work done by others referenced in the detailed comments such as Torres, et al. (2000) and Mount and Twiss (2005) for example, are studies that could not be used in DRMS. These studies were out of date when DRMS was started (Torres, et al., 2000) or broad overviews of risks facing the Delta (Mount and Twiss, 2005, which cites the JBA 2004 risk analysis) and thus of no specific value to the assessments. We note that neither Professor Ray Seed, Dr. Les Harder, Mr. Gilbert Cosio or Professor Robert Twiss all active participants in DRMS (at least as members of the Steering Committee and as experts (with the exception of Professor Twiss) involved in the levee vulnerability analysis and the Torres, et al. study) suggested at any stage of the project that these studies should be used in any way, let alone be adopted. Thus we disagree with the characterization that is made in a number places in the review that work was available that could have been adopted by DRMS but was not.

Limited Actual Analyses Carried Through to the End

Beyond the poor documentation issues, the fundamental technical problem with the report is that many of the critical analyses are simply incomplete. That is, what is promised in early sections of the report (complete probabilistic assessment of risk) is not delivered. The probabilities and consequences are not integrated over the full range of possibilities, from high-frequency, small consequence events to low-frequency, large consequence events. Human health risks, in terms of probabilities and consequences, are not provided. Only 18 earthquake scenarios are assessed for economic and ecosystem consequences, and even fewer flooding scenarios are assessed and they all correspond to low-frequency, large magnitude events. There is little if any attempt to evaluate the sensitivity of the results to input parameters and to assumptions in the modeling. This product at present is a major departure from the plan, from what was described at public presentations by the DRMS team, and even from what is described in the report itself.

Furthermore, there is an apparently unbalanced treatment of seismic versus hydrologic events in the risk analysis. For hydrologic events, consequences are only assessed for two scenarios of flooding. Consequences for the most frequent types of hydrologic failures historically, where fewer than ten islands are flooded, are completely neglected. Consequences due to water-supply disruption in the case of flooding from hydrologic events, even though it has occurred historically in a high-tide event, are neglected. Conversely for seismic events, consequences are assessed for eighteen cases of flooding, ranging from single to multiple-island failures. In addition, the estimated frequency for flooding from seismic events is much larger than what is supported based on available information. The return period for an earthquake causing at least one levee failure is estimated to be about ten years, while a single event of this type has not occurred in over 100 years of history. Even considering only the past 20 years of history in which the configuration of the levees has been more similar to that at present, the analysis predicts that there would have been two failures on average and only a 16-percent chance of observing what has actually been observed: no failures. This unbalanced treatment of risks provides a potentially biased result, especially when comparing between seismic and flooding effects in evaluating mitigation measures. It is a serious flaw in the analyses presented in the draft report, which would be best solved by completing the analyses the project team was initially going to undertake, which means simulating many additional and more representative scenarios or fully enumerating all the scenarios. It is critical to recognize that electing to limit the full range of scenarios considered is a subjective decision, and without clear documentation as to why the decision was made, damages the concept of applying a quantitative tool as a way of being more objective.

Again, we believe that when we provide proper documentation of how the analyses are carried out in the Risk Analysis Report, we will address these concerns. However, it would be helpful to get a more specific description as to what is meant by, "[T]he probability … [is] not integrated over the full range of possibilities."

As far as the specific areas raised by the IRP, we have provided some preliminary answers below. First, as a general response to this comment, we will add the necessary documentation of the analyses for the various topics, the treatment of uncertainty, and the limitations and the assumptions applied. We will also provide the justifications for the limitations and assumptions and their practical reasons. In places where we applied simplifications, we will fully explain and justify them (see some preliminary responses in item 3 below). In other places, we will conduct additional analyses as requested. For example, we will show the high-frequency, low-consequence hydrologic events. However, these events will not change the frequency of failures for the other analysis cases (moderate- to low-frequency flood events). The disruption of water supplies due to flood-induced single-island failure was found to be insignificant and will not lead to significant degradation of water quality and hence to interruptions of water export. Furthermore, we will also add probable life loss to our estimate of the population at risk.

As for the estimated probability of levee failure due to seismic events, we maintain our conclusions on the expected future probabilities of earthquake occurrences, the results of the probabilistic seismic hazard analysis (PSHA), and their impacts on the levees. We note that the PSHA is based on the USGS seismic source models for the major Bay Area faults, and the analysis was reviewed by both the USGS and the California Geologic Survey (CGS). Because many updates have been made to the seismic hazard models in recent years, we believe that the previous studies are no longer applicable. Specifically, the 2002 National Hazard Map ground motions, HAZUS model, and CALFED 2000 study (work done in 1999) do not include the recent updates of the seismic sources, the new attenuation relationships, the time dependency, or more recent site-specific data. We discuss these key points further below.

Limited Treatment of Uncertainty

The IRP found that the method proposed to treat uncertainty described in the assessment was not actually represented in the reported results. That is, the authors included uncertainty, which is admirable, but only in the originating analyses of seismic and flooding events. They then report this originating uncertainty as the *total* uncertainty, which implies much more confidence in results than is actually justified. For example, consider the climate change projections. In the *Climate Change Technical Memorandum*, the uncertainties in sea-level rise and temperature for the year 2100 are captured through a recommended set of ranges or probabilistic curves that should be used in the simulations. However, in the actual report these are simplified to single values for years 2050, and 2100. This creates a false and potentially dangerous sense of inevitability and certainty. It implies that this is what "will" happen in the future, when in fact what happens could be far worse or better based on the uncertainty.

Scientific and socio-economic uncertainty must be presented clearly and propagated through all analyses. The analyses performed actually show the sensitivity of results to uncertainty for a few selected parameters. Since this is not the uncertainty one would realistically expect in the entire analysis, the assumption that only a few parameters really influence uncertainty must be documented and empirically supported. Without a true uncertainty analyses or documentation of why only a few uncertainties actually matter, it is impossible for the Panel to be confident that the results are a reasonable presentation of the risks and uncertainties embedded in the system. At a minimum, the report text should reflect what has actually been done (as seen in the reported results), should clearly document and support procedures and critical assumptions, and should include simple numerical examples displaying the linkages throughout the empirical sections of the report showing how uncertainty is propagated.

The treatment of uncertainties is not highlighted in the documentation equally among the various topics covered. We will expand our presentation of this topic and be clear as to where uncertainties have/have not been addressed.

As we discussed at our meeting with the IRP in March, there are areas of the analysis where the evaluation of uncertainties (aleatory and epistemic) could not be evaluated due to the level of work that would be required to make a credible assessment. The reasons for this vary from one topic to the other. On this point, we note that during the meeting with the IRP, one of the panel members indicated that in his view the epistemic uncertainties in an ecosystem analysis are so great that assessing them and displaying them are counterproductive to decision making.

In the areas where the uncertainty evaluation could not be carried out (i.e., economics, hydrodynamic and water management, ecosystem impacts, and climate change), we attempted to mention it in the report. As we revise the document we will insure that this is done and discuss the simplifications. Where ranges in outcome are applicable we will use them.

The discussion of the uncertainty with regard to estimates of risk in future years is quite problematic and we internally debated it a great deal. In our response to comments in Section 14 we provide the rational for the approach we did take. This said, we disagree that "a false and potentially dangerous sense of inevitability and certainty" is presented. We are quite clear as to what we did (taking medium estimates of parameters). Further, we found no evidence that any of the key factors which influence risk will lead to a reduction in risk in future years under the business-as-usual approach we were directed to take.

In conclusion, we plan to add a more substantive discussion of the treatment of uncertainty where it has been evaluated and propagated in the analysis, and where it has not been addressed, we will explain why.

Lack of Integration of Analyses

The Panel was unable to fully understand how the multiple models used to assess the risks were linked together and how robust the results are to assumptions made in linking them. In analyses that use multiple, linked models, the details of how information and computer files are transferred and maintained to ensure all analyses use consistent information is a major bookkeeping challenge. As such, it is important that the discussion is transparent in terms of how the pieces (models, assumptions, etc.) fit together, and how robust the subsequently estimated frequencies and consequences are. Documentation of the QA/QC procedures used with the modeling process should comprise a separate technical memorandum. More information should specifically be included with the consequences modeling, especially with the consequences to human health and safety and fisheries resources.

As we discuss later in our responses we will be expanding the presentation of the risk analysis methodology and the quantitative methods that were used in the analysis. As reflected by the specific wording of the IRP comment, this is less about a "lack of integration of analyses" and more about completing and documenting the analyses and providing QA/QC for the integration. Our action plan is to provide a more detailed description of the integration of the various parts of the risk model and documentation on the QA/QC process that was followed.

Lack of Robust Methodology for Assessing Impacts on Aquatic Resources

The Panel is concerned about the treatment of ecosystem consequences in the analysis. There is, again, a major disconnect between the introductory methodology description, both in the beginning of the report and the beginning of the ecosystem consequences section, and what ultimately seems to have been done. As currently structured, the ecosystem analysis is incomplete, difficult to interpret and potentially understates the ecosystem effects of the various hazards confronting the Delta. While the Panel was of the opinion that the simplified approach used for terrestrial taxa was reasonable, the simplified approach used for the fish was inadequate. A new "risk index" was introduced for assessing the risks to key fish species. No justification or rationale is provided for, what appears to be, a new method. The reader has no idea how the weights were determined, how the computed risk index behaves, and what levels of the index should flag concern. The Panel had no idea how to interpret the changes in the risk index under the few earthquake and flooding scenarios that were performed and the authors also seemed to have little idea on how to interpret their own risk index. While the Panel appreciates the complexity of performing such an analysis and the unsuccessful attempt to develop a quantitative metric, alternative approaches are available to provide information on this important category of effects. For example, the authors may wish to assemble an expert panel to evaluate a small set of scenarios, which encompass a wide range of outcomes. Something better than the risk index needs to be developed, evaluated, and implemented to understand potential ecosystem consequences.

We agree that the methodology for assessing quantitative aquatic impacts can be improved. At this time we are working on a new approach that will focus on assessing the increase in the probability of extinction of selected aquatic species. The goal of this effort is develop a quantitative (or quantitative/qualitative hybrid) model that provides a best estimate of the immediate impact (and the range or uncertainty around that estimate) for any levee breach scenario for each fish species that we will be evaluating in the Delta estuary.

As we are going through this effort it is not clear that we will be able to develop a quantitative estimate of the epistemic uncertainty in the model results. While we believe it is preferred that such an estimate be made, it is not clear the experts and the science will be able support such an effort at this time and/or within the time frame of this work. Thus, our goal is focused on developing a simple model with a range about a best estimate.

Specifically, we plan to simplify and quantity the impacts in a simple, expert- elicitation-based approach. The main elements of the revised model are based on a simple cause and effect evaluation. The model will focus primarily on the impacts to the aquatic species from levee failures and entrainment. The failure mechanisms, timing of breach formation, turbidity, entrainment (percent of population entrained based on toe-net survey and density of population by region), island closing and pump-out models have been already developed by the DRMS technical team members. These will be defined and quantified in a manner suggested by the experts assembled to help with the development of the model. The quantification of impact (percent mortality and increase in the probability of extinction) will be developed based on input from the experts.

Currently the experts assembled for this effort include Professors Wim Kimmerer, Peter Moyle and Bill Bennett and Dr. Chuck Hanson. We are adding possibly two more experts on fishery from the DWR as suggested by the three experts.

Concluding Tier 1 Comments

Until the major issues presented above are substantively addressed and the analyses are completed as originally proposed, the results of the DRMS *Phase I Report* are of limited utility. The Panel seriously questions the usefulness of any Phase 2 analyses that relies on results reported in a Phase 1 draft report that is not significantly revised to address the Panel's Tier 1 comments. The Panel is also emphatic that simple responses to their major comments that do not involve changes to the analysis methods would be considered an inadequate response by the Panel. We understand the time pressures that have been placed on the DRMS analysis, but the results are too important and potentially too useful to be rushed to the point that the results are not trusted or that the generated results are unjustified. In reviewing the DRMS project team responses to previous comments on the *Phase I Report* and technical memoranda, there seemed to be an inconsistency in the way in which review comments were handled. Some comments appeared to be simply dismissed, despite raising valid concerns, while others received more thoughtful responses. In scanning the review comments, there seems to be a predisposition toward constraining the scope of the report to an inappropriate degree. The Panel raises this final issue so that authors of the draft report can address our major comments with thoughtfulness, and make the needed changes in the analysis to make the DRMS as useful as possible.

We appreciate the comments provided by the panel and believe they will be helpful in achieving an improved product. We are in the process of revising the Phase 1 analysis report and improving elements of the risk analysis. We believe these changes will satisfy the panel's concerns.

Summary Report (June 26th Version)

General Comments:

The following comments pertain to the "Summary" section that the Independent Review Panel (Panel or IRP) reviewed prior to the August 2-3 meeting. Some of these comments may no longer apply if the summary has been rewritten, but the general concerns raised here, and in the IRP's summary review of the entire document, should be addressed in any revision of this chapter.

As with most complex assessments done in support of public policy decisions, this report starts with an introduction followed by a lengthier "Summary" section (42 pages) describing procedures and results from the overall Phase 1 effort. Collectively, this "Summary" section is arguably the most important part of the entire *Phase 1 Report*, given that policy makers, stakeholders, and the public are unlikely to read the entire report. It is critical that this section represent clearly and concisely the nature of the problem (i.e., the charge as contained in AB 1200); the methods used to assess the charge; including assumptions, strengths, and weakness of the methods; the results of that assessment; and some cautionary overview of how these findings should, or should not be used in the public policy arena.

Given the objective and scope of work that we were charged with for this report, it would be difficult to fully meet the intent of the comment by describing the methods, assumptions, and other such aspects in any detail.

While the panel has sympathy for the authors of this report in terms of the complexity of their charge and the timelines under which they operated, we are disappointed with the original "Summary" section for several reasons. First, we find the quality of exposition uneven (we judge it to be among the most poorly written of the entire set of chapters). Second, and more important, we find the description of procedures to be confusing and misleading regarding what was actually performed in developing the findings. Third, we believe the authors are overstating the nature of their findings, giving greater weight to earthquake damages (and implicitly less weight to other hazards, such as low damage, high frequency events). The discussion in the current "Summary" section concerning the definition and treatment of risk and uncertainty in the assessment also implies a greater degree of precision than actually exists in the results. This combination of lack of balance in the hazard analysis and false precision in reporting the results is worrisome because it may encourage inappropriate use of the findings, particularly with respect to allocation of future resources to address Delta problems and by focusing attention on the risks to each island. Fourth, the overall risk framework used in the report and described in both this "Summary" section, and later individual sections differ from standard risk assessments that are familiar in the economics literature (e.g., the authors chose to combine risk and consequences, whereas their charge clearly distinguishes between them – see AB 1200). This is not necessarily a problem but it does call into question whether the economic losses are reported correctly (e.g., as Expected Monetary Values, EMV's). Finally, the treatment of uncertainty in the assessment is confusing and unbalanced.

We appreciate the comments offered in this paragraph. In response to the points raised we offer the following:

With respect to the first and second concerns, we will be revising this document in light of the comments provided to improve the presentation. In addition, we will discuss with DWR and the Steering Committee to get additional guidance as to who the audience is that should be targeted and what approach should be taken to address that audience.

We do not agree with the third concern, regarding overstating the findings, for reasons stated in the response to the Tier 1 and 2 comments. We note that in past risk studies for critical facilities, such as nuclear power plants in the eastern U.S. (which have been performed since the 1980s), there was a similar reaction to the level of the seismic risk that was being estimated, even for plants located in quiet zones (outside New York City, Philadelphia, Chicago, etc.). Seismic risk is unique, due to the nature of the hazard that earthquakes pose. It is often not well understood. At this point, over 20 years later, seismic risk in the central and eastern U.S. is better understood and it remains a dominant contributor to risk. In addition, seismic risk analysis and the results it generates is an integral part of current engineering and regulatory practice.

With respect to the fourth concern we are a bit puzzled by the comments made here. The risk analysis methods that have been used to evaluate the Delta levee system are consistent with current practice. The statement, "standard risk assessments that are familiar in the economics literature (e.g., the authors chose to combine risk and consequences, whereas their charge clearly distinguishes between them – see AB 1200)" we do not understand, particularly the note in parenthesis. Consequences are part of the risk as indicated in the definition we provide and in the equation presented in Section 4. Lastly, we do not compute EMV's as a measure of risk.

The writing was extremely uneven, with too much detail in some places, not nearly enough in others. It was very difficult to pull out the main messages of the report: What were the big results? Why are they important? The "Summary" section needs to present the big picture, not just smaller details, and at a level that can be read by anyone with more than an eighth grade education. The authors should be aiming for an Intergovernmental Panel on Climate Change (IPCC) like "Summary for Policymakers" product. Use of summary tables would help, as would a good edit of the bullet points as the language used was very repetitious and made no effort to distinguish between more important vs. less important results. The whole thing is in desperate need of a good edit to get rid of grammatical typos and repetitive sentence structures.

We appreciate these comments and will work to present a clear message in our revised report.

There appears to be conflicting guidance in this paragraph. It states, "The Summary section needs to present the big picture, not just smaller details, and at a level that can be read by anyone with more than an eighth grade education." Should smaller details be *presented as part of the big picture presentation? This would seem to contradict the point being made here of trying to address those with an eighth grade education or higher.*

Furthermore, we were very confused between the overview and the actual summary (beginning on page 9). They contain much of the same information, word-for-word! What is the point?

The point made here is well taken. We were asked by the Steering Committee to produce a summary of the summary report. The expectation was the summary would be the 'short' document that saw the widest distribution. In producing the summary, some of the text in the summary report was used.

Specific Comments:

Regarding sea level rise (SLR), absolutely no explanation why this report considers a wider range of future SLR than the IPCC. The summary must be a stand-alone document and in its present state, it is not.

This comment presents a difficult charge. If the comment means a full scientific discussion should be provided, we disagree. Further, we were offered guidance by DWR and our Steering Committee that presentations of this nature are not appropriate for this document. If on the other hand the comment means a simple sentence or two should be provided with a reference to the Climate Change TM, this could be done.

"More winter flooding" is not the right title for the next paragraph.

We will consider alternative titles when we revise this report.

Probabilities of different events (hole-in-one, cancer, etc.) are cute but don't really have a place in a serious scientific report. These are not the funny pages of the Sunday newspaper. Not to mention deceptive – many more people have hit a hole-in-one than one in 5000 – that's per shot, not per lifetime.

In the discussions with the Steering Committee and DWR we were not given the direction to write a scientific report. Rather, we were asked to tell a story (a very non-scientific notion) about the Delta and the risks. Further, it was suggested that a technical writer, experienced in matters related to California water, CALFED, etc. be charged with writing this document for the masses. This is what was done. As a result the summary report was not written with the notion of preparing a scientific document.

The table that is referred to is an attempt to provide probabilities for events which are familiar to most people.

We will take this comment into consideration as we revise the report.

All references to "delta" should be capitalized.

We will make this correction.

Page ii: The box with a definition of risk is helpful (encourage even more sidebars in explaining key concepts and definitions) but it seems to be combining standard notions of risk with the consequences. This requires presenting results in terms of expected monetary values (EMVs), which we do not think is actually done. Also, the text in the adjacent paragraph claims that this framework is *unique*, in that it includes dimensions of the problem previously not treated. Is this really true? Since there was no original or new research performed in this study, it seems that what the study has done is bring together secondary information (including from other studies). The failure to cite important previous studies, such as Torres et al. (2000) on earthquake risks, along with a general lack of citations overall, is unacceptable.

The definition of risk provided in the box is a standard, common definition. It entails two elements – chance and a negative consequence. The idea of representing risk as an expected value is neither required nor, for purposes of this analysis, preferred. An expected value representation of risk is but one metric. It is our objectives in the DRMS analysis to estimate the entire distribution of a particular consequence (economic cost). This way one knows the full range of possibilities and their frequency. From this information an expected value could be computed. Alternatively an expected value can be computed without deriving the full distribution first. A more complete analysis derives the full distribution first.

The comment is correct; we do not calculate the expected monetary values in Phase 1. As we state in Section 4 of the Phase 1 report, we do not estimate (measure) risk in this way. In the Phase 2 analysis we do use the results of Phase 1 in this manner.

The results of this study are unique. No prior study, including the Torres, et al. (2000) work, estimates the frequency of islands flooding due to seismic or other events. No other study has attempted to quantify the impact of levee failures on water exports, or the economic impact or costs of these disruptions; to develop a systematic tool to quantify the cost and duration of levee breach and damage repairs, etc.

Page ii: We do not agree with the statement "While estimating the likelihood of stressing events can generally be done using current technologies, estimating the consequences of these stressing events at future times is somewhat more difficult." Why is it any easier to estimate the likelihood of an event than the consequences of the event? This perspective biases this study because a disproportionate effort was devoted to assessing likelihoods versus consequences.

We do not find this sentence in our version of the Summary Report.

The statement referred to is admittedly a bit vague. By the same token it is quite general, and not a very strong statement at that. We will attempt in our revision of the document to improve the presentation of the message we are trying to get across.

We were trying to make a simple point. The best way to state this is by example. For 2100 we have estimates of the frequency of earthquake ground motions and sea level rise. However there is no information we are aware that predicts the population of the state, the state of the ecosystem, etc. in the year 2100. As such, with no data, we consider it more difficult to estimate consequences when there are no available estimates of our exposure (i.e., population size, etc.).

Page iii. First bullet: Do you really have the precision in your analysis to make this sort of assessment of differing probabilities on such fine scale, given that it appears that inventories of levee integrity are lacking? Also, the paragraph on seismic risk is confusing. For example, what does the second sentence mean, "it is expected [...] could happen […] in next 25 years"

We do have information on the correlation of earthquake ground motions over relatively short distances (see Bazzuro and Baker, 2006). There is considerable uncertainty in the estimate of earthquake ground motions, which we model in the analysis. Note, the ground motion modeling is one area were we have a tremendous amount of data and modeling experience. Thus, the models are empirical. This said, there still remains a considerable amount of aleatory and epistemic uncertainty in the estimate of ground motions.

Page iv: Comparing the forecast risk of a flood event with the historical record is useful. We suggest that the authors add information on the historical frequency of the forecast risk to the discussion of other events, such as "sunny day."

We will consider this suggestion in our revision of this report.

Page v. First bullet: Explain why the frequency is expected to increase by 12 %. Third bullet, the "combined effect" of what?

We are unclear as to what is meant by "Explain why the frequency…" This is the summary of a summary report. This hardly seems the place to provide explanations – even brief ones.

For the third bullet we will revise the text so the meaning is clear.

Page 2: In the first objective of the DRMS charge, note that "risk" and "consequences" are listed as separate parts of the charge, whereas in the assessment effort, risk is defined in terms of the consequences. The authors need to be consistent. Also, this report should note that items 2 and 3 are to be performed in Phase 2.

We will revise the text to be clear and consistent in our use of terms.

We will make a distinction between the Phase 1 and 2 activities.

Page 6. Second paragraph: What are “appropriate” combinations? How treated in the risk framework? Our reading of subsequent chapters does not reveal how or if this was actually done.

The primary combination of events that was considered were island failures due to any cause and wind waves that result in levee interior erosion on flooded islands.

Page 8. Under “future conditions:” The last phrase in the first paragraph is not a complete sentence.

We will revise this sentence in the revision of this report.

Page 10: This is an important page, given that it contains the description of the risk analysis approach. We appreciate the authors’ use of sidebars. Note again that risk seems to be defined as the frequency of economic or ecological damage, instead of frequency of earthquake-induced levee failures, etc. Is this really what the authors intended to say? Also, the description makes some claims about including ranges of outcomes for all the dimensions of future risks. We do not see this in section 14, so we assume they are talking now in idealized terms? If the latter, then we think the summary report is misleading the reader as to what actually gets presented in the outcomes chapters.

The risk analysis does estimate the frequency of exceedance economic consequences and the frequency of exceedance of numbers of islands being flooded. These results are estimated for each hazard and they are combined to present a total.

We do not present ranges in Section 14. The reasoning for this is presented in our response to the Section 14 comments.

We certainly do not intend to mislead the reader. As we revise the report, we will take these comments into consideration.

Page 11: The scope of the analysis is helpful but we suggest the authors define “uncertainty” in a sidebar here to inform the reader as to how it will differ from the probabilistic representation of risk, which seems to also embed a type of uncertainty (the variability of outcomes). Also, in the last bullet, we agree with the challenge (futility) of trying to forecast many of these economic drivers out beyond 50 years but we are not sure we would say that the BAU is an “unbiased” measure, instead, it maybe less prone to error.

The point with respect to BAU is well taken. Certainly one cannot claim that the BAU analysis is unbiased in any sort of statistical sense. Our intent is to say that a BAU analysis is a known (reasonably understandable) basis for performing the analysis and can be used as a common baseline for the Phase 2 analysis. Further, the BAU is also consistent with the need to examine whether the Delta is sustainable in the sense that current and/or future risks may be considered by policy makers to be too high.

Page 12: This diagram is presented in chapter 4 and was also presented to the IRP in Sacramento. It appears to be a highly stylized portrayal of the integration process and does not help the reader much in terms of following through the step-by-step integration that goes from probabilistic-based information on certain events, to scenario-based states of nature, to the measurement of actual economic and other consequences. As we note in our review of chapter 4, a lot seems to be swept under the table.

The figure refereed to is a stylized figure. It is not intended to provide the details of the risk analysis, the interface between elements of the analysis, and the integration process. As we indicate in our response to comments on Section 4 we will be expanding the presentation of the risk analysis methodology and its implementation in the Phase 1 report. We do not however anticipate providing much if any of that information in this document.

Page 13: How "unique" is DRMS? More comprehensive? More innovative?

DRMS is unique in a number of ways. These include:

- *No study of its kind for the Delta has been carried out.*
- *New computational tools were developed (ERR model, the WAM model) that evaluate parts of the problem that had not been addressed previously or in the manner that is done in DRMS.*
- *A GIS database was compiled which previously did not exist.*
- *An economic model was developed to estimate the impact and costs associated with water export disruptions*
- *Refined fragility functions by class and reach within each island using more than 2000 geotechnical borings.*
- *No other study has made an estimate of the frequency of island flooding due to seismic, flood and sunny-day events.*
- *Performing hydrodynamic calculations to evaluate the effect of sea level rise on the position of X2 in the Delta*
- *Development of a flood hazard model that estimates the simultaneous spatial distribution of flood stages in the Delta.*
- *Development of spatial wind model.*
- *Development of a hydrodynamic modeling tool that has proven to be efficient and accurate.*
- *Consideration of the risk to the ecosystem (this model is being revised as requested by the IRP)*

Page 14: Need a "be" between "cannot and reduced" in the middle of the page. The last paragraph makes an important disclaimer regarding results: they should not be used for decisions about any specific levee reach or island. However, in other places the authors present localized effects. Given that the authors present results that they feel should not be used, how do they then intend to prevent them from being used inappropriately?

Our admonitions aside, we clearly have no means to prevent the misuse, misinterpretation, or misunderstanding of any of the results we have produced. This has and we expect will continue to occur.

Page 14. Figure 6: We do not have wind information out to 2100.

Current climate change models which have made estimates out to 2100 do not predict significant changes in wind speeds in the future. As a result one can assume that current wind models remain applicable.

Page 16: Last paragraph notes that a levee has never failed in the Delta due to earthquakes. How does this square with the forecasts of a major failure within the next 25 years? Are the authors hyping earthquake risks because it is emotionally charged in California?

The concern related to the estimate of the seismic frequency of levee failures we have addressed in our response to the Phase 1 report. Also see below in the response to comments for page 20.

In our opinion, the last sentence of the comment is unsubstantiated conjecture, and an unprofessional remark that should not be part of an objective scientific review. We are puzzled by the IRP observations on the seismic issues. No major earthquakes have truly tested the Delta in the last 100 years, hence no seismic-induced levee failures. The body of work on the seismic hazard in the Bay Area indicates that there is a 62% chance in 30 years that a large earthquake (M6.7 or higher) could occur in the next 30 years. Under such events our model shows substantial levee failures in the Delta.

Page 17. Under "methodology:" Please explain how the analysis treats uncertainty in the forecasts of risks of earthquakes?

Is this comment suggesting this explanation should be provided in this summary report? If this is the case, we would disagree. This level of detail is not appropriate for this report. The answer to the question is provided in the seismic hazard TM.

Page 20: How can one defend a forecast of an average failure rate from earthquakes of over one per year for the next 100 years when there has not been one in the past 100 years? Also, at this point, the risk analysis becomes scenario based. But the scenarios seem to be treated as equally likely; so at this point, the analysis departs from the described risk analysis framework.

The logic implied by the comments suggests a result other than zero is incorrect. The primary reason there is a difference is the fact the last hundred years has been a seismically quiet period in the Bay Area and in the Delta in particular. As a result, there have been no significant earthquakes. This said, the USGS, the Torres, et al. (2000) study all estimate there is a non-zero probability of ground motions of engineering interest (PGA > 0.05g) that can occur in the Delta. Based on the estimate of the seismic fragility *of Delta levees, ground motions greater than 0.05g have a non-zero probability of producing a levee breach.*

We have used a set of scenarios to evaluate the consequences for a given number of flooded islands. These scenarios represent a sample of the large number of cases that could involve levee failures. In principal these scenarios are not a departure from the risk analysis framework. They model the consequences given the specified number of flooded islands.

Page 21: There is a lot of equivocating language here ("might be", "usually will be", "generally additive," etc.), which differs from the tone of other sections. The authors need to be consistent, unless they have suddenly become more cautious?

The use of the equivocating language is not needed here. We will modify the text in the revision of this report.

Page 22: We suggest the authors use the word economic *damage*, rather than cost. Both terms can convey economic efficiency effects. This would apply to the subsequent tables in which economic "losses" are reported. Also, under "ecosystem consequences:" "the percent of the population" of what?

We will revise the text to use the appropriate terms.

The percent of the population refers to; the percent of the aquatic species population that is in the Delta.

Page 23: Where is this "risk index?"

The risk index is a measure of impact that was developed. We are revising this evaluation and will not be using this index in the next revision of the analysis.

Page 24. Near top of page: what is "ruderal?" Also, at bottom of page the authors present information on probabilities of failure at each island and explain that table 5 is a "convenient" way for a landowner to assess their risk. This flies in the face of the earlier, and important cautionary note that this should not be done!

Ruderal is a plant that grows in rubbish, poor land, or waste. All scientific terms will be defined in the revised report.

The statement on the individual island risk to local land owners will be removed.

Page 27. First sentence: The seismic "risk" (the probability of an earthquake) is not going to increase, only the resources at risk will. This odd language is the outgrowth of the way the authors choose to define risk. Also, in table 6 and others that report economic damages, we believe that it is important to note that this is not an EMV, but some other type of estimate.

We agree the first sentence is not clear. We will revise as part of our revision of this report.

The comment is not correct in stating only the resources at risk will increase. The frequency of earthquake ground motions increase, as does the seismic fragility of the levees, as do the resources in the Delta and the state.

The results in Table 6 are an estimate of the increase in the expected annual losses. This is the only place where we deal with expected values for risk results.

Page 28: How do the authors know that "non-historical floods" are a more accurate measure? Also, in the first paragraph, delete "the" between "may" and "cause."

The sentence referred to is a bit unclear. The point we are trying to make is that an historic record which is relatively short provides us with a limited set of realizations of the natural processes that contribute to flooding in the Delta. There are combinations of factors and events that are possible (they may have been observed individually), but as yet have not occurred jointly. The probabilistic analysis evaluates the probability that all possible combinations of events could occur and as a result this type of assessment, which is used for all types of natural hazards probabilistic modeling, gives a more complete (accurate may not be the best word to use) estimate of the frequency and magnitude of future events.

We will make the revision to the text that is suggested.

Page 29: Last paragraph, insert "one island" between "than" and "fail."

We will make this revision to the text.

Page 30: Under consequences of flood events, the authors again mix scenarios into the probabilistic analysis. Why not use probabilities of these three types of events?

We are unclear as to the meaning of this comment. We have provided in the response to Section 13 a detailed answer and our proposed expansion of the consideration of the scenarios in the consequence modules versus the probabilistic analysis in the earlier modules.

Page 31: On the vertical axis of Figure 16, why not use "billions" instead of millions?

We will make this revision to the axis label.

Page 32: The authors again report individual island failure projections. In view of earlier admonitions about why these should not be used, why present them? Also, in the last line, need a "the" before "historical."

We agree there is a bit of a disconnect with respect to the presentation of individual island results and our admonitions. On the one hand we have been requested to provide this information by DWR and the Steering Committee. On the other hand individual island frequency of failure estimates have their limitations – thus our admonitions. For instance, it can be argued that we have not done island specific assessments – DRMS is a regional scale study. As a result the scale and level detail in the analysis is different. Further, even if a island specific assessments were performed (more detailed island specific evaluations conducted for each island), individual island results are self limiting because of the inter-connected nature of island failures during major events (floods and earthquakes) and the consequences of these failures.

We will re-examine our presentation of the island results and our cautions for their use.

Page 35. First line: authors should refer to this as the "*expected*" climate change (since they do not know what the change will actually be). Later in the same paragraph, "to be" is repeated.

The word "expected" actually implies to us a level of certainty that we do not want to convey. We will consider the spirit of this suggestion in our revision of the report.

Page 36. Methodology paragraph: "data *were*…". Also, this is the first use of scientific notation (need for consistency?). Under "Levee Failure" "[…] few available data" *sets*? *Points*? The next paragraph and following page have more equivocating language, e.g., "seems," "seemed to be."

We will make the corrections noted and consider the revisions to the text that are suggested in our revision of the report.

Page 37: How are these problems calculated for the sunny day events?

Is this intended to say "probabilities"?

In our reading of this page sunny day failures are not discussed.

The evaluation of the increase in the frequency of sunny-day failures in future years is described in Section 14 of the Phase 1 report and is based on the estimated increase in the hydraulic head against the levees as a result of sea level rise and subsidence.

Page 38. Middle of page: where are these conditional probabilities provided in the report and upon what are they conditioned?

The discussion of future risks is discussed in Section 14 of the Phase 1 report.

Page 39: For perspective, it would be useful to provide the historical rate of failures from all causes.

This information is reported four times prior to this page.

Page 41. Last bullet: The combined effect of *what* would be a 240% increase?

All statements related to risks in future years are with respect to the base year, 2005, results. In the revision of this report, the presentation of the future risks will be revisited and improved, taking into account these comments and our new work.

Page 42: It would be useful for the authors to provide a definition of uncertainty here so the reader can contrast uncertainty with how the authors chose to define risk.

We can provide a definition of uncertainty.

Sections 1 & 2 (Introduction & Sacramento/San Joaquin Delta and Suisun Marsh)

General Comments:

The *Delta Risk Management Strategy Phase I Report* (DRMS I) reviews the context for the report in the "Topical Areas: Risk Analysis" section and "Introduction." It is not clear what the purpose of the first section is and could easily be omitted.

Section 1 of the report introduces the purpose of the study and the scope of the work. It introduces the topical areas compiled for the risk analysis, and informs the readers of the technical memoranda and their relationship to the risk analysis report. It introduces and briefly describes the main topics of the risk analysis. It also introduces the team and the program functional and organizational structure and their relationship to the project.

Upon review of this section we think this introductory section has relevant information and, as a result, will not be omitted in our revised version of this section.

The report lists the goals and objectives in section 1.1.2. One of the IRP's objectives is to assess whether they met these goals. In general, this section does not lay a strong foundation for the report that follows. It states that much of the information supporting DRMS Phase I is in the technical memoranda. This created problems throughout the report, because arguments were commonly not developed in the report or substantiated with data, information, or citations where they could be easily evaluated.

We can not bring up all the significant data and analysis developments from the TMs to the risk report. Doing so would make the report much more voluminous, complicated, and disproportionate. We will make specific references to the TMs where necessary on any source of data, model development, or results of analyses.

The "Introduction" also did a minimal job of describing a complex system and there were minimal citations of the established literature on the area, and problem.

The introduction was not intended to describe the Delta. This is addressed in Section 2.

There are inconsistencies throughout this section. One place they say that they can make confident predictions 200 years out, in other place they say these predictions are limited by uncertainty. They need to state very clearly what was given to them by AB 1200, etc., and then establish what they can and cannot do.

The comment suggests that the Phase 1 Draft Report makes a general claim where it says "One place they say that they can make confident predictions 200 years out," is incorrect. No such claim is made for the entire study. Perhaps we say that about some topics such as seismic hazard but that may not be true with other topics such as economics and ecosystem.

We do not see where the inconsistencies exist. We stated the requirements of AB 1200 and outlined the scope of work. Section 1 is not meant to address the methodology and assumptions used to carry out the risk analysis. In Section 4 we defined what can be done with the current state of the science and what is not possible to predict. Section 4 describes exactly how far the future predictions were carried out in each topic. Not all topics could project to 200 years from now. See Table 4-5 for the topical areas and their future projections.

There is much inconsistency in this section and a large number of statements of "fact" that cite no references or data sources. Such statements as: "The scale and complexity of DRMS for the Delta and Suisun Marsh has likely not been attempted by another evaluation of risk from flooding." Is not substantiated and not put in the broader context of work in many other areas or countries. This gives the impression that the authors have not "done their homework" on the topic. This feeling is enhanced by the lack of references throughout this section.
There is no statement of fact in Section 1 except the claim in the DRMS' unique scope. Our research of previous studies did not turn up a risk study with similar scope for a similar region. Please refer to our responses to comments on the Summary Report (June 26th version), and to page 7-Summary in particular, where we provide a list of reasons that the DRMS work is unique. We will reference any study with similar scope work the IRP can provide. The numbers (levee length, areas, etc…) cited in page 1-5 come from the project database used in the various GIS applications supporting the project. We will therefore add a reference to the project database.

The presentation of the various working groups and advisory groups needs more clarification. How were these used and how were review comments incorporated into the final report? It is not at all clear how this structure worked and who exactly made comments and how those comments were considered and incorporated into the final report.
More description of the roles and review processes of the various working groups will be provided in the next version of the report.

Many comments from reviewers (listed on the DRMS webpage) appear to not have been incorporated into the final document when reading through the responses to comments; but it is not clear why and what process was used to determine what was modified and what was not.
To the best of our knowledge <u>we addressed every reviewer's comments</u>. Copies of the comments and response have been included herewith as Attachment 1. If for some reason we omitted a comment or a reviewer please indicate which or whom. It is our obligation to respond to every reviewer.

These shortcomings are more common in "Section 2."

See response to comments on Section 2 below.

This is a very poorly referenced section. The authors make very specific statements and present information without citations to the source.

See response regarding references above.

There are many repetitions and in general, the section is very wordy and difficult to read. *The section has been edited as a response to the first draft. It will be further edited in response to these comments.*

The authors present many conclusions without any substantiation. They offer no data or references for nearly all the statements made. Many statements are unconstrained and they present a large amount of material that is superfluous. This section contains a large amount of conjecture with no data or citations to back it up.

There are no conclusions presented in Section 1 "Introduction" except the claim about the unique nature of the DRMS project. We have provided an answer to this question to a similar comment above. We can not find where these comments apply to Section 1. Again, Section 1 introduces only the objectives of AB 1200, the scope of work, the project team structure, and other related studies.

There is no effort to present uncertainty, even when it is established in the published literature that the authors may have used (which they do not cite).

We have not addressed or talked about how uncertainties are characterized in Section 1. These topics are discussed in the other sections of the report. We will address those comments in their respective sections.

Pages 2 through 7 are a severe example of this. These pages present conclusions about the Delta with no data presented and no references cited.

We honestly do not see where conclusions about the Delta are present in Pages 1-2 to 1-7. These pages and their sections are descriptive. Section 1.1.2 describes the goals and objectives, Section 1.2 describes the overview of what will be addressed in Phase 1 and references the 12 TMs, Section 1.2.1 describes the hazards addressed in Phase 1, Section 1.2.2. describes the consequences of levee failures to be addressed, Section 1.2.3 describes the risk under present conditions, Section 1.2.4 describes the risk under future conditions to be addressed, Section 1.2.5 presents the limitations of the study, and Section 1.3 presents the project team.

This makes it appear that the authors have preconceived ideas about the system without justifying them.

We take exception to this statement. Only the findings from the analyses are presented.

The report very much needs a "previous work" section. As written, it is as if nothing has been done on the Delta when there is a huge literature base. There are vague references to other ideas but they are minimally cited. The authors need to do a much better job at establishing the framework for this work.

They need a simple statement of the goals, past work, concerns, etc. They need a coherent description of the system (names, boundaries, etc.) so that the reader will be oriented for the information and discussion that follows. They have to cite where data comes from for statements, as well as for figures. They need to limit material to what is needed. There is too much extraneous information with no obvious need for it in the "Introduction" and then a lack of what is needed or has been done.

Section 1.1 discusses the purpose, Section 1.1.1 references AB 1200 and Section 1.1.2 describes the goals and objectives. Each section is one paragraph long.

Reference to any similar risk studies will be added. It should be noted that we reference any study/report we used, both in the risk report and the TMs. By mistake, we may have missed a few references we used, and those will be added.

There are no data, tables, figures (except for the program function chart), or other extraneous material in Section 1 "Introduction".

Specific Comments:

Section 1.0

Section 1.2.3. Page 1-4: A consistent set of words should be used when discussing risk. Throughout the draft, the words frequency, likelihood, and probability, rate and even risk are used interchangeably. We would recommend frequency when talking about a measurable rate of occurrence (that is, the aleatory part) and probability when talking about how likely something is to happen (that is, including the epistemic part). We have been told by technical writers that the public is generally unfamiliar with the word "likelihood." We strongly recommend against using the word "risk" to represent frequency (as it is in the box labeled "Definition of Risk"): risk is an integration of the probability and the consequence of occurrence (as stated clearly elsewhere in the draft).

Terminology will be defined clearly and consistently in the report.

Section 1.2.4. Page 1-4: The title "Future Risk" is confusing. All risk corresponds to the future, whether it is tomorrow, next year, or 100 years from now. We recommend making the titles more descriptive, something like "Risk Under Present Conditions" and "Risk Under Future Conditions."

They will be changed to "Risk Under Present Conditions" and "Risk Under Future Conditions."

Page 1-5: The comparison with New Orleans seems out of place. Also, the statement that the study "needed to be completed in about 1 year using only readily available information" seems out of place. It calls into question the credibility of your results, which we do not think was the intent.

As indicated in the comment, a comparison with similar large scale risk studies needed to be drawn. That was the intent.

The project schedule is part of the project definition (scope and schedule). It is as important to mention the scope of the work as it is to mention the schedule. The readers need to understand that this is not an infinite research project with infinite schedule. Scope and schedule are the critical project constraint. More work can be done given more time. The review should be made in the context of the scope and schedule (see the scope provided to the IRP) .

Page 1-6. Section 1.3.2 and 1.3.3: We suggest that you name the players. This same comment applies to pages 1-10 where you might name the Blue Ribbon Task Force.

The SC members, TAC members will be listed. The function of the BRTF and it members will also be mentioned and the same applies for the IRP members.

Page 1- 11: We did not find a Chapter 15 or a Chapter 16 as named on this page.

You identified an error in the Table of Contents. We will correct it.

Page 1- 12: Are we the Panel of "Independent Subject Matter Experts?"

No, the IRP is not mentioned in the report.

Section 2.0

Page 2-1. End of second paragraph: A brief explanation of what is meant by "resource issues" is warranted.

An explanation will be provided in the revised report.

Page 2-1: A graphical representation of the development of the Delta over the past 100,000 or 5,000 years would be very helpful to complement the narrative.

A graphic representation of the Delta 5000 years ago will be added.

Page 2-3. Second paragraph: A figure would be helpful showing the locations of these water development features.

A map with water development features will be added.

Page 2-3: We cannot find Locke, or Ryde on figure 2-2. Is it there?

The missing towns will be added in the revised figure/report.

Page 2- 5: What is the difference between wildlife viewing and bird watching?

They are the same.

Pages 2- 6 and 2-7: We like your bullets. They are clear and concise.

No response required.

Page 2- 6: We suggest you look at your bullet that is next to the bottom and add a sentence or two about the need for future flood plain management and land use zoning in the area.
This report is not the place to suggestions of the type recommended.

Figure 2- 3: The color scheme is hard to differentiate. We suggest the use of more contrasting colors.

The color scheme on Figure 2-4 (you mean 2-4 not 2-3?) will be changed.

Page 2-8. Top of page: Was there any evidence of liquefaction, either in the foundation soils or the levees themselves, in the 1906 earthquake? Has an analysis been performed to support the apparent hypothesis that this specific earthquake event wouldn't have been expected to cause problems with the levee system as it existed in 1906 but would have caused problems today?

In 1906 the word liquefaction was not defined yet and hence was not used in any literature or eyewitness reports at that time. We do not know if liquefaction occurred. There were no specific reports in recorded testimonies to confirm or refute the occurrence of liquefaction.

Yes, an analysis of seismic stability was performed on today's levees in the Delta using a model earthquake similar to the 1906 earthquake. The calculations indicate that liquefaction has a high potential of occurring during an earthquake similar to the 1906 San Francisco earthquake.

Page 2-8: bullet starting "CALFED is currently reevaluating…" we don't know what "preferred alternative" means.

This bullet will be expanded and better defined.

Page 2-8: Define what is meant by a 100-year, and a 1,000-year earthquake.

A 100-year earthquake has an annual mean rate of occurrence of 0.01 or, equivalently, a return period of 100 years. A 1000-year earthquake has an annual mean rate of occurrence of 0.001 or, equivalently, a return period of 1000 years. We will add these definitions to the revised report.

Figure 2-3: What does the phrase "Levee Fragility" mean in the title?

It does not belong to that figure and it will be removed.

Section 3 (Risk Analysis Scope)

General Comments

Much of this section is repetitious and could be removed. It is difficult to see what the purpose of this section is. It appears that someone who had not read the sections before wrote this. The "new" information presented in this section should be moved to the two previous sections and consolidated into one comprehensive, coherent, and well-referenced introduction.

We appreciate the suggestions and will consider them in our revision of this section.

As above, there are many speculative statements that are not referenced, nor is data presented to support them.

On review of this section we do not find any speculative statements. However, we would agree there are some places in this section, such as the discussions regarding climate change, a reference should be cited.

We are a bit puzzled by this statement. It suggests there are "many speculative statements," yet not one such statement is called out in the specific comments provided below.

The problem with this is that it makes it look like the authors have decided on what they will find before they present the results of their work.

We disagree with this statement. We find no indication in this section to suggest that we have apriori decided what we will find in the analysis.

It is not clear what the authors did compared to past work and it is certainly not set in the present framework of knowledge (both on the Delta and risk analyses). There are no methods presented or even an allusion to methods.

The purpose of this section is to discuss the overall scope of the analysis. It was not the intent here to discuss previous work, methods that would be used in the DRMS analysis, etc.

As we mentioned to the IRP members in our phone discussion after submittal of the written review, we did not ask the authors of the TMs or report sections to provide an exhaustive review of past work on all subjects related to the DRMS analysis and to provide a discussion of what was relevant/irrelevant, useful or of no use, etc. We did not have the luxury of time to carry out this sort of an effort (such as might be undertaken by a graduate student working on, and eventually writing a thesis). The report should document what existing information and data were used. Where this was not done, it will be corrected.

Through three sections there is no substantial information given, only very general statements that are not backed by data or citations. The problem has not been put in context of this area (previous work and other studies) or other areas. This in no way covers the information needed to put this work in a broader or even local context.

As intended, this section defines a number of the factors that determine the scope of the DRMS Phase 1 analysis. For instance, the geographic scope of the study, the concept of Business-As-Usual, hazards to be considered, etc. all need to be defined and are discussed in this section. It is our view these topics should be defined early in the report. For instance, Business-As-Usual was an important topic for DWR and the Steering Committee and one that was not easily understood by most when they were first introduced to it. This section describes the scope of work not the framing of the work in the context of past studies. It is a standard practice to state of scope of work in any engineering report consults produce.

Specific Comments:

Page 3-1: The statement “By itself, this information will not be the basis for future decisions…” seems overly negative. We recommend saying something like “This work, together with other studies and information, will provide input to the decision makers…”
We appreciate the suggestion and will consider it in our revision of this section.

Page 3-2. Top of page: The statement “making an assessment of risk uncertain” is confusing. Risk includes uncertainty. Estimates for the frequency of occurrence or the average consequence in the event of an occurrence or the actual consequence in a particular occurrence can all be uncertain. However, the idea of risk is to integrate all of this information together into an expected consequence given all of the available information.

The statement which is being quoted in the text says, “making an assessment of risk ***is*** *uncertain.” We agree, this statement is a bit confusing as written. The whole sentence is, “To the extent the present state of knowledge is incomplete, making an assessment of risk is uncertain.” The point we attempted to make is; there is epistemic uncertainty in estimating risk due to our incomplete knowledge about the Delta. As we revise this section we will provide a better discussion of this subject.*

The last sentence in this comment regarding “the idea of risk” seems to be a bit of a generalization and one that does not apply here. The suggestion that a risk analysis is intended to estimate “expected consequences” only is not the focus of the DRMS analysis.

Page 3-2. Section 3.3, 1st paragraph: We suggest rewording to change “[...] exists given existing [...]” to read “[...] no single oversight is in place given existing regulatory [...]” or something similar.

We appreciate the suggestion and will consider it in our revision of this section.

Page 3-3. Second Bullet at the top of the page: We like it. It is clear and to the point.

No response required.

Page 3-4. Second paragraph: What is the basis for saying that the "resources and funding required […] will clearly exceed the current and expected future available resources?" Have these costs been estimated?

The simple answer is yes, these costs are generally known.

This statement is made in the context of the discussion of Business-As-Usual. We know (from DWR) what the current spending has been to maintain levees and to make minor repairs over time. Based on general experience as well as project specific experience and previous studies, work by CALFED, etc. we also know the current maintenance level of funding is not adequate to stay ahead of sea-level rise (raise levees substantially and maintain performance). This is self-evident, since maintenance programs were not intended to stay ahead of sea level rise.

Page 3-4: Defined *(sic)* "Primary" and "Secondary" Zones.

We appreciate the suggestion and will add these definitions in the next revision of this section.

Page 3-5. Section 3.6: To be consistent, the first bullet should be phrased "Death and Injuries to Humans."

We appreciate the suggestion and will make this change in the next revision of this section.

Page 3-6: Since risk captures uncertainty, why is it "impossible" to estimate some aspects of risk 10 years into the future?

The statement is intended to reflect the fact there are areas where we have poor information about current conditions and limited or no information about the future. The use of the word "impossible" may be strong. Our experience is, given the practical realities of this project, it was ***not possible*** *to evaluate these uncertainties. This was true for current conditions and certainly applies for future conditions. In addition, certainly it is difficult to make an assessment of risk in the future where there is no data and even more difficult to cite a source.*

For example, as one of the panel members indicated in his comments at our meeting in March, the uncertainties in the assessment of impacts to aquatic species are so great, it is best not to evaluate/present them. We would expect similar concerns to be expressed regarding projections in the future where there is no data. However, in principle we *believe it is possible and appropriate to estimate these uncertainties and present them, for current and future conditions where possible.*

We will review and revise this statement to better reflect the view we wish to express.

Section 4 (Risk Analysis Methodology)

General Comments:

This is a critical section in terms of understanding the mechanics of quantifying the risks of levee failure. It may assume greater importance, depending on what the authors chose to do with respect to the revision of the "Summary" section. As such, it is important that the discussion be transparent in terms of how the pieces (models, assumptions, etc.) fit together and the robustness of the subsequent estimated consequences. As we noted in our comments on the *Draft Summary*, we were unable from the presentation in the "Summary" to fully understand what is occurring in the risk assessment. Unfortunately, this section does not remedy that situation. Instead, it raises more questions than it answers.

We agree the Summary document does not describe how the pieces (model, assumptions, etc.) of the risk analysis fit together. Our directive from DWR and the SC suggests the Summary document is not the place for such a discussion.

We also agree this section does not provide the expected level of detail. It is our plan to expand the presentation of the risk methodology that is used in DRMS. This expanded presentation will be provided in this section as well as in appendices to this report.

This section is very opaque. In the original reading of this material, panelists had no idea what the project team was doing. It was only after extensive panel discussion that the IRP was able to piece together the elements of the analysis. This should not be the case. Anyone knowledgeable in the risk assessment area should be able to easily follow the method steps documented in the report. It also repeats much of the material presented in previous sections, including some of the same sentences, giving the feeling that it was written by someone who had not read the previous sections. There are again many unsubstantiated statements. They have slightly more references in this section – still not adequate – but some of them are not in the "references cited" section (e.g., Bazzuro and Baker, 2006). This shows a very poor effort on editing. Some of the references, particularly as they relate to risk analysis, are old and effort should be made to utilize new methods and common practices. There is a reliance on jargon instead of actually explaining the work conducted giving the reader a sense that the project team is not well versed in the methods they are applying. Given that the project team was supposed to rely on existing reports and studies, we would have expected an extensive reference list, particularly for this section.

As indicated above, the discussion of the methodology will be expanded. We also agree there needs to be an improvement in the clarity of the presentation.

The reference to unsubstantiated comments is general and without reference to examples where this is the case.

The final sentence in this paragraph suggests there is an extensive list of risk studies for the Delta that we could have made use of and thus should have referenced. As we discuss below, there are no such studies that could be adopted.

As we noted previously, where we have used existing information and data, these will be referenced.

The reference to jargon is general and without reference to examples where this is the case.

There are many basic questions that need answering in this section. The authors do a minimal job of presenting what they used for seismic analyses. They would probably say "it is in the Technical Memoranda," but that is not a reasonable response. This is a report for the public and it has to stand-alone. It is fine to check details in the TMs but the basics need to be presented here. For example, there are a large number of tools to estimate earthquake hazard and damage built by the USGS (e.g., HAZUS Earthquake). What did they use, and why or why not?

As noted above we will be expanding the presentation of the risk methodology.

The HAZUS methodology, or any other (a pre-packaged method or otherwise) for that matter, does not address all (if any) of the topical areas in a manner that were considered/required in DRMS. As an analysis tool (with built in modules and datasets) or simply as a software tool (calculator only) HAZUS is not suited for the DRMS risk analysis. Note, we did use some of the datasets available in HAZUS and the flood loss estimation functions as part of the Delta infrastructure part of DRMS.

Note, HAZUS was not developed by the USGS. It was created under the management of FEMA (now a part of DHS) and developed by companies working under contract to FEMA or their administrator.

There is also some sloppy use of terminology throughout this section. For example, there is a seismic hazard that produces a risk of levee damage and failure. It is not clear how seismic hazard, seismic fragility, and seismic event are used or meant in the authors' discussion. They again make many statements that are not corroborated.

The statements made here are a bit surprising. We suspect this may be some of the "jargon" a previous comment was referring to.

The terms seismic hazard, seismic fragility and seismic event are standard terms in earthquake engineering and seismic risk analysis. We believe these terms were used consistently in the report.

In general, we will review the document with an eye to the consistent use of terms and where appropriate, provide clear definitions of terms that may not be known to the reader.

In these four sections (or preferably combined in one section) they need to:

1) State the charge and objectives given.

2) Describe the Delta system (briefly)—what it is now, important underlying framework (e.g., stratigraphy, faults, land use, etc.) including geography and names used, size of islands, etc., making it all easily accessible and readable.

3) Describe the approach of the risk assessment with detailed information on individual and aggregated risk, etc. Then describe each process (e.g., floods, earthquakes, etc.) that levees can fail under and the potential effects (what is lost). These are independent of the cause of failure.

4) Give detailed methods used for each "process/forcing" analysis, separating the failure analyses from the response analyses. The two are mixed up in this presentation and it is very confusing and difficult to follow. Results, conjecture, methods, approaches – are all mixed up. They have especially mixed up both results and conjecture in this section, which is supposedly a methods section.

We appreciate the suggestions for making revisions to these sections and will consider them as we move forward.

The authors definitely need to put all this in the context of previous work. Much of this has been proposed or done previously (e.g., Torres et al. 2000; Mount & Twiss 2005; Lund et al. 2007; etc.). They have cited none of this work, or how their approach is different, or how it builds on that previous work.

A risk analysis for the Delta such as has been carried out in DRMS has not been done before.

The work by Torres, et al. (2000) could not be used in DRMS since in all aspects of their analysis, the seismic hazard model and the fragility analysis are out of date. In addition, Professor Ray Seed (member of the DRMS Technical Advisory Committee and Steering Committee), Dr. Les Harder (Deputy Director of DWR), or Mr. Gilbert Cosio (consultant and member of the DRSM Technical Advisory Committee and Steering Committee), all members of the team that worked on the Torres, et al. (2000) study, never suggested the use of or adoption of any part of that work. Also, Dr. Norm Abrahamson (consultant, member of the DRMS Technical Advisory Committee and Steering Committee) who also worked on the Torres, et al. (2000) study and who performed all of the risk calculations for that effort, did not suggest we use that work.

The work of Mount and Twiss (2005), while interesting, is not a risk analysis, nor is it a detailed assessment of any of the issues/topics we are addressing in DRMS. This work looks to bring to the readers' attention enough information to make the case that the Delta is at risk. As a result, there is nothing in this work we can make use of. We also not that Professor Twiss, a member of the DRMS Steering Committee, never suggested there were elements of his paper with Professor Mount that should be used in any part of DRMS.

We believe the Lund, et al. (2007) work that is cited (full reference not provided) is the PPIC report. This work was published after the work for the TMs, the input to the risk analysis, were completed. In addition, it too is not a risk analysis.

All of this said, as we mentioned in a response in Section 3 we did not ask the authors of the TMs or report sections to provide an exhaustive review of past work on all subjects related to the DRMS analysis and to provide a discussion of what was relevant/irrelevant, useful or of no use, etc. We did not have the luxury of time to carry out this sort of an effort (such as might be undertaken by a graduate student working on, and eventually writing a thesis). The report should document what existing information and data were used. Where this was not done, it will be corrected.

We also note that DWR and our Steering Committee, agencies and/or individuals who are well aware of the work that has been done with regard to the Delta and the analysis of risks did not suggest that any of the references noted have any direct relevance to or should be used as part of the DRMS effort.

It is also not clear why the authors did not just use available information (as charged).

Indeed we did use available information. Presumably the suggestion here is that we might have used some of the studies identified above, which as we point out are not relevant to this work. We do note however, there are a number of cases where we did in fact gather new information. In these cases we spoke to and got the approval of the DWR project manager. Examples where this was the case included the collection of thousands of boring logs from a number of different sources, taking field measurements to update subsidence estimates, and the gathering of proprietary geophysical data which expanded our geosciences knowledge base as part of the seismic source characterization effort.

The USGS produces maps of ground motion predictions, etc. They could have used this for their impact analysis. They have not explained why it was important for them to redo all the USGS work (assuming they did, which is also not entirely clear). It appears that the authors have developed models for earthquakes on every fault (already done by USGS), but they have left off the foothill faults. Why not just use the probability for ground acceleration (PGA) maps constructed by the USGS? That is the only factor used and the maps they present later are very similar to the USGS maps. Again, it is not clear what they have done in the broader context of decades of work on seismic hazard and damage by the USGS and California Geological Survey.

The USGS ground motion maps are of no use in modeling a spatially distributed system such as the Delta. These maps are a collection of individual site probabilistic seismic hazard results. The ground motions at these sites are computed on the basis that motions from the earthquakes that are modeled (in the integration process) are independent from site-to-site. If these maps were used, one would be ignoring the inter-event and intra-event ground motion dependencies that should be modeled in regional risk analyses (Bazzuro and Baker, 2006). That is, the maps provide no assessment of the joint probability of ground motions at different levees from the same seismic event. A failure to consider these correlations leads to an unconservative estimate of the risk.

We did use the USGS seismic source model for the major Bay Area faults (see the Seismic Hazard TM for more discussion of the seismic source characterization model).

It should also be noted the suggestion that the USGS and CGS have done decades of work in the Delta proper that would provide input to the seismic hazard model is erroneous.

Lastly, the USGS or the CGS did not suggest we use their ground maps for the DRMS effort.

The authors present a very repetitious, incomplete, and incoherent description of the methodology used in their assessment. It is extremely difficult to determine what methods they used because they give very little detailed information. They cite very few references on methods, and so it is difficult to even place the approach in the broader context of accepted methodology. The technical memoranda help at some level but many of those are also poorly organized and it is not clear exactly what was used, and what was not in the final analyses. They seem to have used a risk model combining some aspects of the traditional concept of risk with other approaches. Any readers of this report need to understand how risk was assessed for the Delta.

Around page 4, the project team claims that the risk analysis can only be performed on an event-by-event basis. This statement is incorrect and should be rephrased to clarify that this was simply the approach taken by the project team. Currently it implies there is only one method for conducting the analysis.

It is not clear what statement around page 4 is being referenced. We do not believe we say the event approach is the only way to perform the analysis and we do not intend to imply that an event-based approach is the only way the analysis can be done. It is the approach that we have taken since it offers an effective way to model the dependencies in the sequence of events and the consequences that result.

There are different ways to consider risk. Classically, risk is defined as "*Risk = Probability X Impact.*" The authors present a variation of this as the start of the section. In the Delta, this can be represented in the simplest form as breaching and flooding an island. Risk is simply the probability that any island will flood and the impact of that flooding. These are separate. The impact of flooding for each island (houses, people, pipelines, wells, power lines, agricultural production, people affected, etc.) can be determined now. With projections of growth and development, impacts can be projected into the future for 2050, 2100, and 2200. These numbers have a certain uncertainty for the present that will increase in the future. The impact outside of the islands (Delta) will be some function of which and how many islands are flooded. It will range from small for one non-strategic island to very large for many strategic ones. This evaluation is straightforward, given the limitations of valuing goods, jobs, services, etc. now, with uncertainty increasing into the future. The authors need to present exactly what they did, how the analyses were done, and uncertainties carried through. It is extremely difficult to determine what the authors did to get to the final risk.

We agree risk can be calculated as indicated. We did not use this particular approach. Our quantification of risk is presented equation 4-1.

In our revision of the report we will present a more comprehensive discussion of the risk methodology and its implementation.

There is another way to think about risk. That people will not just stand around when something happens but will try to mitigate any potential risk. It is not at all clear the authors of DRMS Phase 1 have considered this but it seems to fit some of their discussion later in the report. This is a much more realistic but complicated approach. Under this approach, the system has warning and can respond with controls and mitigation. This will be the case for floods – there is a very good prediction system that will get better in the future – so this will definitely be part of any risk to the Delta. Response to a potential flood (control and mitigation) will have some effect on the final risk. It is not clear to what level this sort of response was considered in the risk analyses presented in the DRMS *Phase I Report*. It would make a difference in the final assessment and needs to be clarified throughout the report. In the end, there are three important questions that the report needs to answer:

1. What is the cost (all impacts) of *1 to n* islands flooding? Now, and in 2050, 2100, and 2200. What is the uncertainty of these estimates?
2. What is the probability of *1 to n* islands flooding from each hazard (floods, earthquakes, random, wind)? Now, and in 2050, 2100, and 2200. What is the uncertainty of these estimates?
3. What is the probability of *1to n* islands flooding due to a combination of hazards? For now, and 2050, 2100 and 2200.

The first part of the section (pages 4-1 to 4-6) does a reasonable job of describing the nature of the problem. However, in the discussion of the conceptual risk framework and its implementation, there continue to be gaps and inconsistencies in the presentation. As noted previously, a detailed example of the process, starting with one state of nature and one event, carried through to the calculation of the error bars on the economic damage function would be very helpful. Since one of the charges to the IRP is to critique the validity of the risk approach, we think this type of information is needed by the reviewers. We would note that at least one reviewer on the DRMS internal review committee (Kimmerer) made a similar request to have the authors lead the reader through a simple example showing how the analysis is actually implemented.
The earlier suggestion, while interesting, is inconsistent with the Business-as-Usual approach that guided the Phase 1 analysis.

In the expanded explanation of the methodology and its implementation, we will present a simple example.

The use of vulnerability classes needs to be fully explained early in this section. The underlying assumption that the entire levee section breaches if in the same vulnerability class should have some sort of sensitivity analysis given that the assessment of vulnerability class is a somewhat subjective determination.
The definition of vulnerability classes is provided in Section 7. We do not assume that the entire levee section breaches if it is in the same vulnerability class. Our assumption is that a

breach may occur somewhere within a levee reach that belongs to a vulnerability class and the probability of such a breach varies as a function of the vulnerability class.

The scenarios generated for flooding are insufficient. It should have been a straightforward task to calculate the risk for a variety of scenarios.

Additional hydrologic studies will be considered as part of the additional work we are conducting. These results will be reported in Section 13.

Specific Comments:

Page 4-1. Last paragraph: This list is a confusing mis-match of different items (effects, failures, accidents, risks, etc.). Also, what is meant by, "Among numerous others?"

What is provided is a simple list of events that put the Delta at risk. This is part of discussion to point out that DRMS does not address all events that put people, property and the environment at risk in the Delta. We will re-word the sentence as follows: "A partial list of events that put the Delta at risk includes:".

Among others might include vandalism, terrorist strikes, tsunami, upstream dam failures, meteor strikes, etc. We will add these as "for example".

Page 4-2: Suggest re-wording "Each earthquake and the spatial field of ground motions it generates, is random and at the same time…" to "Each earthquake, including the spatial field of ground motions it generates, is variable and at the same time unique from one event to the next."

We appreciate the suggestion and will consider it in our revision of this section.

Page 4-3. Second full paragraph: Are events of levee damage between vulnerability classes assumed to be statistically independent?

The performance of levees in different vulnerability classes are assumed to be (conditionally) independent, given the ground motion that occurs as a result of a seismic event or the flood stage from a flood event.

Page 4-4. Last paragraph: A reference supporting the assumption that salinity intrusion is not significant for hydrologic events would be helpful.

In the next revision of the report we will document the hydrodynamic calculations that are the basis for this statement.

Page 4-5. Third paragraph: Given that there has been an instance where "significant salinity intrusion and a noticeable water supply disruption occurred" when a single island failed, it seems inappropriate to neglect this possibility in the analysis. Since single island failures are the most frequent, they could very well dominate the risk, and more attention should be devoted to these consequences.

Single failures do not dominate the risk. Although such failures would be more frequent, their consequences are many times to orders of magnitude lower than a simultaneous failure of multiple islands. Hence their risk contribution is insignificant. The suggestion that single failures could well dominate the risk, fails to recognize the historic and prevailing flood experience with regard to levee failures and certainly ignores the potential for multiple, seismically initiated failures.

Page 4-6. First full paragraph: It is not clear how the time of year that an event occurs was included in the analysis.

The time of year was considered in the flood hazard analysis (implicitly), in the wind analysis, and in the evaluation of the hydrodynamic response of the Delta to levee failures, in the aquatics impact analysis, and in the economic analysis.

Page 4-7. First paragraph under Section 4.3: Here is an example where probability and rate are being used in place of likelihood and frequency.

In the last sentence in the first paragraph under Section 4.3 (and in other similar places), we will use "frequency of occurrence" in place of "probability or rate of occurrence".

Page 4-7: The authors' note in the second paragraph that this section "combines all the elements of the analysis and calculates the risk for a range of consequences…" Thus, this is the heart of the effort and readers need to be comfortable with what has been done. One question we have relates to the distinction between risk and uncertainty in their approach. This is somewhat different than what is normally done in economic modeling, where risk and uncertainty tend to mean the same thing (for example, the variability captured in the prob. distribution of outcomes is a measure of the uncertainty). What the authors do in this report is not necessarily incorrect, but later on in the report, the link between risk and uncertainty gets blurred in presenting such things as an economic damage function with error bars. Also, at the bottom of the page, delete "the" between "estimated" and "rate."
We believe we have been consistent in our definition of risk, our definition of uncertainty, and our implementation of them. Our definition of risk includes two elements: likelihood (chance, uncertainty) and consequence. Thus, uncertainty is a component of risk. Note, we do not combine uncertainty and consequence, the ultimate blurring, by computing and presenting risk as an expected value. Rather, we make a clear distinction between uncertainty and consequence.

As the reviewer notes, a probability distribution of outcomes (fatalities) is a measure of risk. We would say this probability distribution captures the aleatory variability in the number of fatalities. There is also epistemic uncertainty in the estimate of this probability distribution since there is epistemic uncertainty in the estimate of the number of fatalities (as might be produced by different, credible models) and there is epistemic uncertainty in the estimate of the probabilities of different numbers of fatalities (even if the fatality models were not uncertainty).

Page 4-8: The first sentence defining risk on 4-8 is actually not quite correct and should be revised to reflect exactly how risk is being defined in the report. The sentence on page 4-9 is correct and should be used as a replacement.

We believe the definition on page 4-8 is correct. We are unclear as to which sentence on page 4-9 is referenced. Is it equation 4-1?

Page 4-8. First full paragraph: The statement that the "distinction between what is aleatory and what is epistemic may be unclear" calls into question why so much effort was devoted to trying to distinguish them in the preceding discussion. Why not just describe all of the sources of uncertainty instead of trying to classify them in an "unclear" way? Furthermore, the introductions of the jargon laden terms, epistemic and aleatory, are completely unnecessary. And given that uncertainty is not carried forward (or estimated) in any reasonable manner, it's ridiculous to introduce a concept that is never used.

We disagree with the sentiment/views expressed in this comment.

Making a distinction between the different types of uncertainty is an important part of a risk analysis. The argument as to what is aleatory and what is epistemic uncertainty has been ongoing. We simply recognize the difficulties (see the debates of Bohr and Einstein for instance).

The assertion that we do not use this concept is incorrect.

We model and propagate aleatory and epistemic uncertainties in the seismic, flood, and wind hazard analyses. We also use them in the seismic fragility analysis and the sunny-day levee failures analysis. Further, we propagate these uncertainties through the estimate of the frequency of island flooding. As stated in the report, we were not able to implement it in the consequence parts of the risk analysis.

The suggestion that we have in some ad hoc manner introduced jargon in this work is incorrect and the terms we used have been in common use in the probabilistic risk analysis vernacular.

Page 4-8: In the last sentence in section 4.4, it is not clear what "an event-based approach" means. It would be helpful for the authors to add a sentence that gives an example.

We will add a description and an example to the text describing what an event-based approach means.

Page 4-9: In equation (4-1), we think that the "c" needs to follow the word "value", to avoid having it look like a constraint or integrand on/over lamda.

We will address this editorial suggestion in the next revision of this section.

Page 4-9: The implication is that a risk threshold has been set and events with impacts below a certain threshold are included in the summation. This makes sense, but what are the thresholds? How were they set for each consequence?

This comment is unclear. For example, the statement is made, "events with impacts below a certain threshold are included in the summation." The idea of the type threshold being implied would seem to indicate that impacts below the threshold ***would not*** *be included in the summation.*

Page 4-9: The sentence defining instantaneous and variation in frequency is nonsense and given that variation is actually never modeled over time, makes no sense.

In the analysis of systems that are exposed to natural phenomena such as earthquakes, floods, intrinsic events (normal loading), etc., stationarity is commonly assumed and/or demonstrated to be applicable. That is, the frequency of occurrence of events is constant over time. Further, events are often assumed to be Poissonian. As a result, given an estimate of the frequency of occurrence one can make probability statements regarding the events being modeled for a specified future time period. This paragraph is making the straightforward point that we cannot do that in DRMS because the frequency of occurrence of the events we are modeling, over the time periods that we are analyzing, is changing. Therefore for 2005, we make an estimate of the frequency of occurrence of events of interest. This estimate is based on the information and conditions at and up to that time (i.e., no major earthquake has occurred (which would change the frequency of earthquake occurrences), given the current condition of the Delta levees, etc.). We refer to this frequency as an instantaneous frequency occurrence (in 2005). In 2006, 2007, 2008, etc. we could update the model parameters and re-run the analysis and get a new "instantaneous" estimate of the frequency of occurrence of events of interest. Of course in DRMS we are not doing this, we are making the estimates at 2005, 2050, etc.

The estimates we are making in the individual years we refer to as instantaneous frequencies since they are estimated for a given year, for the conditions at and up to that time. We point out the limitations of this estimate in making probability statements for a limited period of time.

In Section 14 when we do consider the change in risk over the time period of interest, we estimate the adjustment, the change in the frequency of the hazards, and the frequency of levee failure.

Page 4-10. First full paragraph: Suggest rephrasing "the performance of the Delta levees is random (due to variability in their response…) to "the performance of the levees varies spatially due to variations in the hazard and in the properties of the levees…"

We appreciate the suggestion and will consider it our revision of this section.

Page 4-10. At the top: The correlation of ground motion between different levees is more than a function of distance. It is a function of site soil conditions, ground motion travel path, etc.

The statement is correct; all of the factors noted, soil conditions, and ground motion travel path are considered in the analysis. The point we were trying to make is the following; for a spatially distributed system, the ground motion correlation (given the other factors mentioned) due to distance (and the inter-event variability of earthquake events of the same magnitude) also needs to be modeled, which is not the case for 'point' systems.

Page 4-10: Second paragraph, 3rd line from the bottom "is use" should be "is used" This is just a typo.

We will correct this typo in the next revision of this section.

Page 4-10. Last sentence in first paragraph: We agree that incorporating these correlations is important but how are they measured? Do the authors know enough about levee integrity throughout the Delta to actually calculate these correlations? In the next paragraph, the text does a good job of defining the challenges in this effort, including the large number of outcomes to be realized. The text also notes that a decision-tree structure is employed. Unfortunately, the example provided in Figure 4-4 does not help much, for reasons noted later.

We do have information on the correlation of earthquake ground motions over relatively short distances (see Bazzuro and Baker, 2006). There is considerable uncertainty in the estimate of earthquake ground motions, which we model in the analysis. Note, the ground motion modeling is one area were we have a tremendous amount of data and modeling experience. Thus, the models are empirical. This said, there still remains a considerable amount of aleatory and epistemic uncertainty in the estimate of ground motions.

The statement that we are using a decision-tree structure is not correct. We are using an event tree approach. Figure 4-4 is an event tree as the caption notes.

Page 4-11. Section 4.4.6: Under combination of events – did the authors consider the following series of events:

–1. An earthquake occurs. We get some levee failures, some levee damage and some good levee performance.

–2. Next comes high winds and waves. This generates possible additional failures or some additional damage.

–3. Next comes a flood, which generates some additional failures and some additional damage.

It is not clear to us that a series of events, over say a 6-8 month period, was analyzed. Was it? If the answer is no, it was not; then should authors analyze for such a combination of events? The authors say such an analysis is included as general exposure during the period a damaged, unflooded island is awaiting repair. Where is this discussed?

We did not analyze the sequence of events described. When a group of islands is flooded and others are damaged, the repair priorities are set such that damaged, non-flooded islands are given the highest priority. These islands are stabilized first. It was assumed these efforts would limit the vulnerability of these islands to other events that could cause damage.

Wind waves that can erode the interior of flooded islands are modeled.

Page 4-11: Middle section of page refers to "Some technical people". Odd language – what are technical people? Also, the paragraph comes across as a speculation, given the use of "seems." Near the bottom of the page, need an "and" between "costs," and "environmental."

We agree with this comment, this paragraph will be re-written to better describe the perspective that we are trying to present.

We will make the editorial corrections noted.

Page 4-11: Fifth paragraph: The statement "It is only considered as a general exposure during the period…" is not clear. A better explanation of how this aspect was modeled is warranted.
The discussion as to how these events are modeled will be expanded.

Page 4-13: Fourth line from top, delete "they" between "have" and "been".
We will make this correction.

Page 4-14. Top of page: The concluding statement implies that it is fundamentally easier to assess seismic hazard versus economic and ecosystem consequences. This statement is only true in the context of the team that performed this particular risk analysis. Also, it seems irrational to treat the input that is difficult to assess as deterministic.

There is no statement or implication that a probabilistic assessment of seismic hazard is easier than it is in the areas of economics and ecosystems. The statement is straightforward in stating there are "different levels of probabilistic modeling experience in different topical areas."

Probabilistic modeling has been done in the fields of economics and ecosystems. We would certainly agree it can be done. As noted by one commenter in our meeting with the IRP in March, the uncertainties in the ecosystem area are difficult to estimate and potentially so large their assessment renders the results useless (our paraphrase of that comment). This sentiment does not seem inconsistent with our statement or our experience in dealing with our TAC and team experts in the ecosystem area.

In the economics area we had a similar experience with our team members and in separate discussions with two economics professors from U.C. Berkeley. When addressing the subject of probabilistic modeling and in particular modeling epistemic uncertainties, the response from the U.C. professors varied from "not really doable" to "such assessments can be done." In neither case was there an expression that such assessments are within the normative practice of the profession or academia for that matter.

Page 4-14: In the first two complete sentences on this page, the authors acknowledge (for the first and maybe only time in the report) the disconnect/disparity between the levels of robustness in the various components of the overall assessment. We encourage them to note this in the draft summary. The acknowledgement also raises questions about how the authors deal with the cascading effects of variability in each model.

We will expand on the different levels of maturity of the sciences with respect to conducting probabilistic modeling.

Page 4-14. Second full paragraph: Define "Poissonian" for the general reader.

We will add a footnote or glossary to the document to define terms that are used.

Page 4–14. Last bullet: This seems to contradict some of the above statements. Authors should be clearer regarding exactly what they mean?

The purpose of the risk analysis is to estimate the frequency of occurrence of events of interest (levee failures, island flooding, economic consequences, etc.). Based on current information we can make such an estimate. As part of the DRMS Phase 1 analysis we have also been asked to estimate the risk as it might change in the future, accounting for sea-level risk, the increased frequency of earthquake occurrences, etc. If we look ahead to 2100, we do not know what will occur in the intervening period. For instance, if a major seismic event occurs, it will relieve the strain build up on the causative fault, reducing the frequency of future events. If this event fails a number of islands, how will the island owners and the state respond; will some be abandoned and if so which ones? These "random futures" could not be modeled in this work.

As an alternative to modeling the random state of the Delta and the occurrence of future hazards and consequences that might be realized, we adopted the following approach:

- *The configuration of the Delta will not change in the future with respect to the number of islands (no islands are abandoned). Note, their configuration does change due to subsidence.*
- *A major event does not occur that would initiate changes to the configuration of the Delta such as abandonment of some islands.*
- *A major seismic event does not occur which would change the strain accumulation on causative faults, thus changing the frequency of occurrence of future seismic events.*

So, in 2050 our models will estimate the frequency of future earthquake ground motions, assuming in the intervening years (2005-2050) a major seismic event has not occurred (thus allowing us to use the current USGS model), and the potential for levee failures from these ground motions (accounting for subsidence and increased hydraulic head due to sea level risk) for all islands as used in the model for the present Delta.

We summarized the above by simply saying, "Assume that no major event (hazard or proactive policy) occurs in the intervening years that would result in a significant change to the integrity or configuration of the Delta system."

Pages 4-16 to 4-17: This lengthy table is helpful in terms of understanding the components of the assessment. However, we repeat an earlier request to have an example of how they actually interface and result in the "consequences" damage function.

As indicated in our previous response, we will be expanding the documentation of the risk analysis methodology.

Page 4-18: By the word "total" under metrics, we assume this to mean all hazards combined. Suggest the authors say that.

The word total here refers to the sum of the In-Delta and Statewide costs that are estimated.

Table 4-18: Why are National Costs not included in the economic costs?

National costs were not included in the DRMS scope of work.

Page 4-18. Table 4-2: Was loss of life included? Suggest they flag this table with an "*" or footnote.
Loss of life was not explicitly evaluated in the analysis. However, the population-at-risk from island flooding scenarios was evaluated.

Table 4-2 refers only to economic risk metrics; therefore, public health and safety risks were not included in this table.

Page 4–19: Are there no deer in the area? If yes, were they included?

The deer densities are very low in the Delta even though there is some deer habitat in the Delta even though the range maps show the area to be devoid of deer. Tule elk are also found in Suisun Marsh, including a herd on Grizzly Island and are known to cross the Montezuma Slough and Suisun Slough to the east and west of the wildlife area.

Both deer and tule elk are non-listed species which are regulated for sport harvest by the California Department of Fish and Game. Neither deer nor tule elk were included in the ecological risk assessment. Species examined in the risk assessment were selected to obtain a manageable number of species/species groups, while representing the range of the types of possible consequences on wildlife that could be associated with levee failures. Species selection was conducted through the following screening criteria described in the Ecosystem Consequences TM.

Page 4-20: In table 4-4, under "Topical Area," the only component that is described as "probabilistic" is the seismic hazard. If all other risk factors (and consequences) are handled as scenarios or individual events, how does this limiting of probabilistic information to one factor square with the definition in the *Draft Summary* about the analysis being a comprehensive risk assessment?

The hazards (seismic, flood, wind and sunny-day) and the performance of the levees were considered probabilistic in the analysis. In addition, the possible hydrologic conditions that might exist at the time of a levee failure were also considered probabilistically in the analysis.

The use of the word "probabilistic" solely in regards to the seismic hazard is misleading and will be corrected.

Best estimate (non-probabilistic) assessments of the consequences of island flooding and water export disruption (economic, ecosystem) were made in this analysis.

Page 4-22: In the first box in this table, it would be helpful if the authors linked this box to some text in which it is explained how "frequency of failure" and "frequency of sequence" are measured?
We will provide the definitions of failure and sequence and the frequency of failure and frequency of sequence in the text.

Page 4-23. Figure 4-1: Should be expanded to show the same sequences for flood and sunny day.

We appreciate the suggestion and will consider it in our revision of this section.

We note the figure is essentially the same for flood events, with the exception there is typically limited non-breach damage; therefore, this box would be eliminated from the figure. For sunny-day events, the figure would be simpler still.

Page 4-24: This schematic illustration appears several places in the report. However, we still are confused as to how the error bars around the damage function are obtained. Is it only from the probability of levee failure?

In the Phase 1 results evaluated to date, the epistemic uncertainties that have been propagated through to the final results are the uncertainty in the hazard (e.g., frequency of earthquake ground motions) and the levee fragility. Only best estimates were made of the consequences (economic, ecosystem).

Note, the use of the term "error bars" is incorrect. This is a term typically used in the context of statistical studies. The dashed lines represent the quantification of the epistemic uncertainty in the result (at a certain probability level).

Page 4-24: There is an irregular dark blob in one sub-figure that we do not understand. Can you explain it in a footnote?

The "blob" has two parts; one is a blue blob corresponding to a flooded island. The second part is a brown blob corresponding to an intact island.

We will revise this figure so the color coding does not result in the blob appearance in non-color printed copies.

Page 4-25: This is the first place where the authors describe a type of density function (Poisson). Is everything modeled as a Poisson process? Does this only apply to earthquakes?

The DRMS risk analysis does model hazards as Poisson events (earthquakes, floods, and winds). However, it is recognized these hazards are not stationary Poisson events since the rate of occurrence will change over time. Therefore, we estimate the "instantaneous" frequency of events (see the response to comments on page 4-9).

Page 4-26: This decision-tree figure is disappointing in that it does not make much sense. We had hoped that a decision tree would be presented showing the links (branches) connecting the states of nature, events, response variables, outcomes, etc. with some hypothetical probabilities at each decision node. As it is presented, it does not provide much help in understanding how one would solve the decision problem described at the beginning of this section. For example, it is not amenable to standard quantitative decision tools, such as stochastic programming, Markov processes, or similar tools. This reinforces earlier concerns about how the consequences (risks) in Chapter 13 were actually calculated.

As labeled, the figure shows an event tree, not a decision tree. The Phase 1 of DRMS is intended to analyze risks, thus there are no "decision nodes" being evaluated.

The figure is intended to provide a "schematic illustration of an event tree" as indicated on page 4-10. The figure is used to illustrate the type of events that must be considered to evaluate risk. As an illustration, the event tree does show the links (branches) connecting the states of nature, events, response variables, outcomes. It does not show the branch probabilities as suggested.

Event tree analysis is a standard modeling technique used in the risk analysis of systems (see for example the following books; Baecher and Christian (2003); Hartford and Baecher (2004); Ericson (2005). Further, it is quite amenable to standardized event tree software or coding in a spreadsheet (ETA, by Item Software; Sapphire, by INEL; Relex Reliability Studio; ETA by SAIC).

Section 5 (State of the State & the Delta)

General Comments:

The purpose of this section is not clear. There are excellent reviews of the Delta (Lund et al. 2007; USGS fact sheets; CALFED fact sheets; books; etc.) that are not referenced nor apparently used for their "overview."

The purpose of this section is to give a sense of what is at risk due to levee breaches and island flooding in the Delta. We do not intend to provide a complete Delta overview, nor a detailed inventory in this section, but we do want to provide summary information about the assets in the Delta and also activities outside the Delta that may be impacted by levee breaches. Because of the DRMS work, the Delta Vision process asked URS to produce the Delta Status and Trends report. The Status and Trends report is referenced by the Phase 1 Report and many of the other Delta inventories, overviews, summaries, and assessments are thereby incorporated into the Phase 1 Report. Readers who want extensive detail need to refer to this source. This will be explicitly stated in the revised introduction to this section.

The authors present nothing on the "State," so it is not clear why that is in the title.

We disagree with this review comment because it is untrue. The fourth and fifth paragraphs of Section 5.1 (Population) specifically discuss the relevance of the Delta to people outside its boundaries who depend on it for their water supplies. These paragraphs cite the importance of these water supplies to the state's economy and to practically all of the state's 37 million people. Furthermore, the following comments accurately reflect the reason that "the State" is in the title. A legitimate criticism has been overstated.

We do agree that the relevance of the Delta to the rest of the state needs to be better summarized. We need to say much more about the state's dependence on the Delta and what is at risk in the event of levee failures, especially related to the agricultural and general economies that depend on Delta water exports. We will further develop that aspect of the section in the next version of the Phase 1 Report. There is undoubtedly opportunity to take advantage of other Delta summaries that are available as we revise this section. We will do so and provide some direct citations even when they have already been summarized in the Status and Trends report, which we consider to be our comprehensive reference.

This section needs to present a very precise description of the infrastructure, ecologic resources, etc. in the Delta, itemized by island: also, the potential infrastructure outside the Delta that potentially can be affected by damage within the Delta. There is much extraneous information that does not inform the reader. Again very few references, even though lots of statements are made that require citations. They cite a personal communication (not in the references cited) when there are large amounts of information on this in the published literature and reports. This seems very weird. This section presents very little detailed data, only general statements. For example, the "Economy of the Delta" consists of two sentences. They cite one reference (PBS&J) that is not dated. This is not adequate. The Infrastructure section is somewhat better, but again it is not clear why some information is presented (depth of footings on transmission towers) and never mentioned or utilized again. The authors give names and sizes of pipelines but do not say what they transport. Again, they do not cite where any of this information comes from. The maps are interesting and would be useful if put into the broader context of the system (no references to origin of data on the maps). This needs to be a solid presentation of the essentials of the Delta and adjacent area, resources, and their evaluation with the uncertainties of those determinations. The authors need to present this in a detailed and accessible format, using tables and figures, for the Delta overall and individual islands. Readers need a simple way to determine what is in the Delta and what the situation is "now" (2005) as a starting point. All this should be combined with sections 1 and 2 into a readable "background" section. Describe the Delta, what work has been done, the major challenges, etc., then follow that with a detailed description of the resources (all of them). This has been done in many other reports and papers and could have been easily summarized in this report.

The detailed island-by-island inventory that is suggested has been created by DRMS, documented in the TM addressing Delta infrastructure and is used in the risk analysis. We note that much of this information was pulled together and put into a GIS system as part of the DRMS work. It did not exist previously in any unified accessible way. Much of the detail was pulled directly from the infrastructure TM. It will be summarized in the next version of the Phase 1 Report.

In the TM, infrastructure assets were itemized by island in tabular format (in "Excel" spreadsheets) for lookup in the context of the risk analysis. Infrastructure outside the Delta was considered within the economic consequences module where regional and statewide impacts were assessed. Infrastructure assets within the 100-year flood limits were considered for direct flooding impacts in Delta levee breach events.

The comments that are offered here are helpful and will guide us in updating this section. We agree that more work is required to summarize the detailed information and put it in perspective so a reader can discern its relevance to impacts from various scales of levee breach events. The details will be left in other documents, especially in the TM.

We note that another suggestion was made to combine this section with Sections 1 and 2. At the same time, this comment calls for greater detail. We find the suggestions to be ad hoc and somewhat random and they do not appear to be internally consistent.

We also note, other reviewers have suggested combining Sections 1 through 4.

The section seems to be mostly an inventory chapter. However, it's confusing because a lot of the noted inventory is never referred to again, even in the economic section. If this section is an inventory overview, title it as such and give context for what is used from the inventory, or why elements of the inventory were collected. Also, if this section represents a compilation of the inventory, it really should contain much more detail, and the GIS should be available for people to download and use.

The information discussed and represented in the maps is used directly in the Delta Infrastructure part of the DRMS risk analysis – specifically in the assessment of costs and impacts when islands are flooded (see the Delta Infrastructure TM and Section 12.2.2).

The issue of availability of this data online was not a part of the DRMS scope. However, the database and the GIS layers will ultimately become available when they are turned over to DWR.

We would have also expected a clear delineation of infrastructure between critical (or life supporting) and other. In the response module, there is no way to tell what infrastructure is considered and why. Also, in this section (if it is an inventory), we would have expected some age-related analysis. In other words, not all inventory matters and some is aged such that its loss may be mitigated with other options.

No specific delineation of critical and non-critical infrastructure was made.

We are not clear what is meant by "response module." The infrastructure data were considered in the Delta infrastructure damage module and in the assessment of costs and impacts when islands are flooded. It was assumed that all infrastructure would be repaired to pre-flood status and the costs and schedules for repairs (including loss of use) were estimated, given protracted flooded conditions, resultant delays, and competition for resources. These analyses were performed separately from the Emergency Response & Repair (ER&R) Module (which focuses on levee repairs and marine resource constraints). However, the economic consequences due to infrastructure damage do consider the levee repair and dewatering times calculated by the ER&R module.

An aging analysis was not conducted for any of the assets in the Delta; it was beyond our scope. Criticality of infrastructure was implicitly considered in the assessments of loss of use and repair costs.

Specific Comments:

Page 5-3. First paragraph under Section 5.5: Defined *(sic)* "infrastructure assets."

We will define this term or revise the wording in the report to explain our working scope for the term.

Page 5-7: Spell out the acronym MHHW.

The reader can refer to the list of Acronyms and Abbreviations provided at the beginning of the report. We will verify that the term was spelled out in its first use in the report – which is likely to be in an earlier section. After initially spelling out an acronym we use only the acronym.

Page 5-8. At the top of the page: We suggest you flag no loss of life costs.

This comment is not entirely clear, however we believe the suggestion is that we indicate that the asset values which are shown do not include loss-of-life costs. Assuming this is the case, we will make note of this in the next revision of this section.

Page 5-8. Third paragraph: Is the length of the scour zone very significant in assessing the risk? Figure 5-12 is not clear – how is a "scour zone" defined and how is it different from "scour limit"?

The length and width of the scour zones are not major contributors to overall risk, but the location of the scour can be a significant part of loss-of-use and repair cost estimates, depending on the location of a specific breach. The scour zone for an island is defined as a perimeter band that is 2000 feet wide from the center of the levee. The scour limit uses the same 2000-foot distance from the levee centerline. However, scour limit is usually used in analyzing a specific levee breach. In such a case the scour limit is the edge of the scour zone; i.e., 2000 feet landward of the levee (perpendicular to the island perimeter/levee), 500 feet wide (parallel to the island perimeter/levee), and 50 feet deep. These dimensions are based on historical scour events.

We will review this section to ensure these terms are adequately defined and used properly.

Page 5-8. Fourth paragraph: Define and describe the "GIS data."
This statement refers to the GIS database that was compiled by DRMS from a number of sources, which was used to estimate the Delta infrastructure losses in the risk analysis. The GIS data includes attributes or characteristics of the infrastructure assets (which, in some cases, are missing). Attributes include pipeline diameters, number of stories of buildings, number of tanks in a tank farm, etc. These attributes are needed to develop replacement cost estimates for the various assets that may be damaged by flooding or scour. The initial GIS database and its augmentation with data from other sources is described in more detail in the infrastructure TM.

Figure 5-1: Showing Frank's Tract as "Conservation Lands" instead of "Water" is confusing.

Noted.

Figure 5-1: Discussion of this Figure presents a great future opportunity to flag the need for flood plain management and land use zoning.

No response required.

Section 6 (Seismic Risk Analysis)

General Comments:

It is not clear how this approach (determining seismic hazard) compares or differs from the USGS information already available. The authors cite few references. From reading the technical memoranda it appears that this section has received the most resources and effort, but it is not clear why they did not just use the available information from the USGS and previous published reports (e.g., Torres et al. 2000). For example, there are available seismic hazard maps available from the USGS and the State of California: why not use those maps and then apply the ground acceleration predicted to the damage criteria for the levees?

The USGS ground motion maps are of no use in modeling a spatially distributed system such as the Delta. The USGS and CGS maps are a collection of individual site probabilistic seismic hazard results. The ground motions at these sites are computed on the basis that motions from the earthquakes that are modeled (in the integration process) are independent from site-to-site. If these maps were used, one would be ignoring the inter-event and intra-event ground motion dependencies that are important to model in regional risk analyses (Bazzuro and Baker, 2006) and would be making an unconservative estimate of the seismic risk.

Lastly, the USGS model was not based on the most recent attenuation relationships. As such it is out of date.

We did use the USGS seismic source model for the major Bay Area faults (see the Seismic Hazard TM for more discussion of the seismic source characterization model).

We note, the USGS and the CGS did not suggest we use their ground maps for the DRMS effort.

The work by Torres, et al. (2000) could not be used in DRMS since all aspects of that analysis, the seismic hazard model and, the fragility analysis are out of date. In addition, neither Professor Ray Seed (member of the DRMS Technical Advisory Committee and Steering Committee), Dr. Les Harder (Deputy Director of DWR), and Mr. Gilbert Cosio (consultant and member of the DRSM Technical Advisory Committee and Steering Committee) all members of the team that worked on the Torres, et al. (2000) study, never suggested the use of or adoption of any part of that work. Also, Dr. Norm Abrahamson (consultant, member of the DRMS Technical Advisory Committee and Steering Committee) who also worked on the Torres, et al. (2000) study and who performed all of the risk calculations for that effort did not suggest we use that work.

Also, Torres, et al. (2000) have already done an analysis of the seismic risk to the levees. Why not just use that data? This report shows different faults in the area (compare maps in DRMS Phase I to Torres). Why are those different? Why are ground acceleration maps different from Torres and USGS and is that significant? This seems like a very simple effort (in many ways): use the available data to determine ground acceleration for the Delta region at some reasonable probability (or several probabilities). Then apply the failure criteria (probably the hard part) for that acceleration to determine what levees will fail. Again, Torres did this so the authors need to also show how their new analysis is different and better.

One concern is that in Torres (pp. 23, 24) they present results on determining levee failures from earthquakes in the area that are different than the results presented in the *DRMS Phase 1 Report*. The figure 5-2 (below)

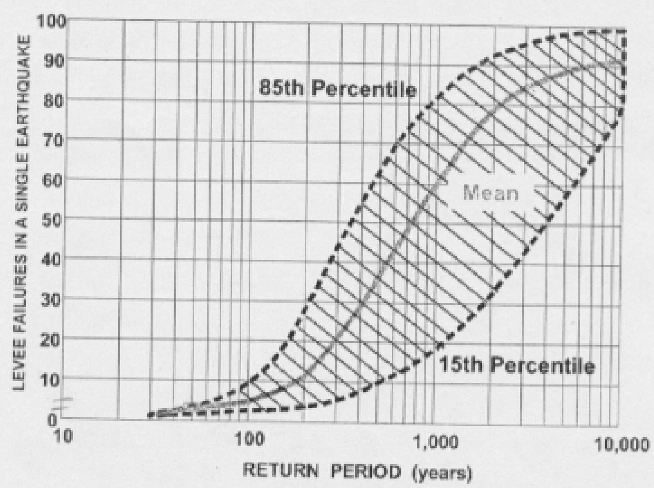

Figure 5-2: Number of Levee Failures in a Single Earthquake-Fault Models Combined
Note: Number of Levee Failures does not equate to Number of Islands Flooded

Figure 1: Figure 5-2 from the Torres report

shows that for a 50 year return interval (roughly out to 2050), we would expect from 2 to 5 levees to break (15-84 percentile). That changes to 3 to 10 at 100 years and about 4 to 29 for 200 years. This appears to be much lower than the values given in the DRMS *Phase I Report*. The Torres figure (below, Figure 2) shows what is really needed. For example, at 90% confidence (typical statistics value) we see that in the next 50 and 100 years there is <5 failures expected (cannot read the 200 year plot because it was cut off in the copy received from CALFED). The even chance (50%) is about 5 to 7 failures for 50 years and 5 to 20 for 100 years. So given these plots and others in the report showing aerial response, it is not clear how the DRMS Phase I seismic hazard analysis differs, why it differs, and why they even did it with Torres and the USGS hazard maps available. There may be some value in redoing what is already done, but the authors need to lay out exactly what knowledge existed before, why they decided not to use it, and how their analyses differ from those of the past.

The seismic sources in the Bay Area are updated regularly, as well as the attenuation relationships. For this study we used the most recent updates for both the seismic sources and the new attenuation relationships (NGA). This is customarily done for any PSHA *work in the area. The studies you cite are not current for use in this region and this project.*

Comparisons are being made to other similar studies in the region and the results of the comparison will be added to the risk report.

The study cited above (Torres, et al. 2000) is being used in the comparisons we are conducting There are, however, differences both in the probabilistic ground motions (although small) and the way the Delta levee vulnerability was carried out. The Torres (2000) study groups the Delta levees in four regional groups while the DRMS (2007) defines vulnerability classes for each island and for each reach within each island. The Torres (2000) study calculates the number of breaches (with possible multiple breaches in one island) while the DRMS (2007) calculates the probability of an island being flooded (taking into account the possibility of multiple levee breaches on an island). Furthermore, the DRMS (2007) study includes the Suisun Marsh levees (more fragile) while the Torres (2000) study does not. Therefore a direct comparison with the chart shown below is not possible.

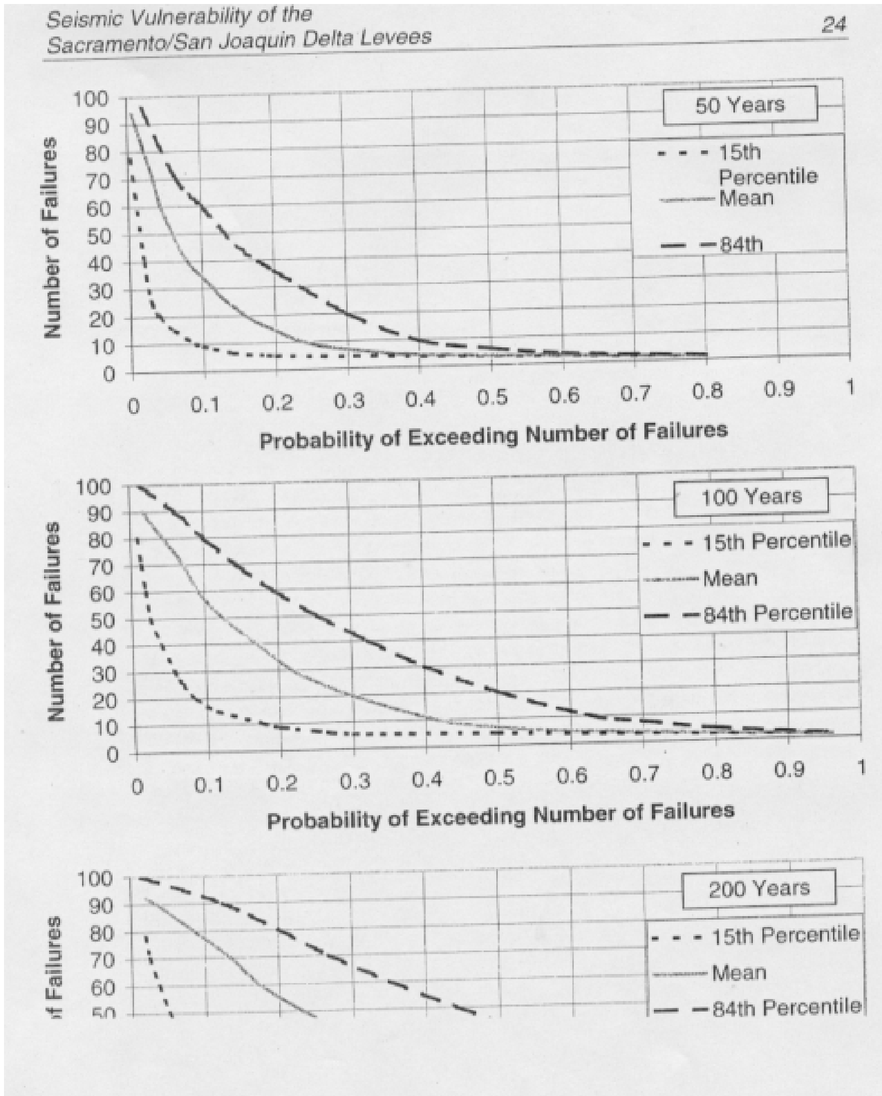

Figure 2

In this section as in the previous ones, the authors make statements without justifying them. There is a vast compendium of earthquake research in California so they should be able to cite anything done on this topic. They do a poor job of showing how they determined when (under what ground acceleration) a levee would fail. They need to give the details of this analysis. The authors make many statements (nearly all) without citations of where that information came from. Computer code is cited in the text but no reference is given for it: so, it would be impossible for anyone who did not already know what this was to find it or evaluate it. They make statements about levees failing in other areas and do not give references for those. The authors give minimal detail in nearly all the sections.

We made sure that any computer model or other work used in our analysis is cited. We are currently revising the report and will add any references that should be cited.

They establish ‘vulnerability classes’ without saying where they came from, how they were developed, how they differ from those established by Torres, and why they needed new ones when they were already established. It is difficult to determine how their analysis fits into the broader understanding of levee engineering and failure. When looking at the technical memoranda, it appears that there was an inordinate amount of effort spent on the seismic section. Considering all that information outside the report, it appears that the analysis may be well founded. But it is not clear why it is different from previous analyses and why it had to be done.

We explained the difference between the DRMS (2007) and the Torres et al. (2000) study in a preceding response. In addition, the DRMS exhaustively used more than 2000 borings and cone penetration soundings to characterize the Delta and Suisun Marsh levee and foundation conditions to obtain a mesh (geographic discretization) that is small enough to be able to represent the variation of levee fragilities within each island. In the Torres et al. study (2000) the Delta was divided into four sub-regions. The description of the classes is included in the levee vulnerability TM.

There are no supporting discussions about what underlies assumptions made, nor does the project team carefully explain those elements of sunny day failures that carry through to the risk analysis.
Sections 9 and 13 address the sunny-day levee failures and their risk.

Specific Comments:

Page 6-1. Last paragraph: Risk is inappropriately defined again here as a probability instead of an integration of probability and consequences.

The text will be revised to be consistent with the definition of risk given in Section 4.

Page 6-1. Third paragraph: Spell out the acronym WGGEP please.

The second paragraph, Page 6-1 spells out the acronym WGGEP as Working Group on California Earthquake Probabilities.

Page 6-2. Bullet 3: The statement that "the seismic hazard results are defined for a stiff soil condition" requires more explanation. We presume you are saying that these ground motions are for an outcrop of stiff soil or rock. It would help to explain that the effect of soft soils directly underlying levee in potentially amplifying ground motion is included in the levee vulnerability assessment, and, therefore, the ground motions characterizing the hazard correspond to the ground motions of stiff soil or rock that underlie the softer foundation soils of the levee.

The reference ground motions were developed for an outcrop of stiff soil. The dynamic site response analyses of levees were part of the levee vulnerability where the dynamic response of soft soils was explicitly considered in the 2-D finite element analyses.

Page 6-2: The first word after 1), 2), 3) and 4) has a printing error. In bullet 4) you say you are assuming a stiff soil site condition. Do you have data that the shear wave velocity in the area in the top 30m of soil is about 1000fps? If so, where are the data discussed? See page 6- 5, where you talk about this but don't support it with any data.

The downhole seismic survey data will be added in the revised report (we did not have permission from the authors to publish that data at the time).

Page 6-3. First paragraph under 6.1.3: The rationale that a lack of data precluded modeling all of the faults with a time-dependent occurrence rate is not very strong. It would be more compelling to state either that (1) it doesn't matter or (2) a time-independent model is a reasonable assumption (versus the only possible assumption because you could model it however you want) based on the available information.

As a matter of standard practice in probabilistic seismic hazard analysis, a stationary Poisson model (time-independent) model is used to estimate the occurrence of earthquakes. It is unique to be able to model faults with a time-dependent model.

The time-dependent data are only available for the seven major San Francisco Bay Area faults and thus time-dependent hazard can only be calculated for these faults. The other faults in the region lack such data and therefore only time-independent hazard can be calculated.

Page 6-3. Second paragraph under 6.1.3: A list and qualifications for the experts should be provided.

We will add a list of the experts and their qualifications.

Page 6- 3. Last paragraph: You have a missing word or something. See "[...] take into account various degree physics, date, [...]."

The text will be revised.

Page 6-4. First full paragraph: What is a "time-predictable probability?"

Same as time-dependent probability. We will change the wording.

Page 6-4. Second full paragraph: This discussion about Reasenberg et al. (2003) and WGCEP (2003) is very confusing (such as referring to models A through F) and essentially requires the reader to go to the references to figure out what has been done.

The text will be revised.

Page 6-4. Section 6.1.3, last paragraph: Why is this paragraph in the report. What effect does this have on the results? More explanation would be helpful.

The text will be revised.

Page 6-5. First full paragraph: Again, it is confusing when you refer to the shear-wave velocity of the top 100 feet. We presume you are talking about the top 100 feet below the softer foundation soils that are below most of the levees.

Yes. This refers to the average shear wave velocity within the upper 30 m (100 ft) of "the" stiff reference site conditions for which the ground motions are calculated as an outcropping site. This site is indeed below the foundation peat and the loose sand deposits.

Page 6-5. Section 6.1.5: More discussion is warranted about Figures 6-13 to 6-18, since these are the primary input to the seismic risk analysis. There is discussion about the spectral acceleration at a 1.0-second period - where is this information shown, is the natural period for a typical levee system around 1.0 second? The blind thrust faults below the Delta are significant contributors to the seismic hazard. In the earlier CALFED (2000) study on seismic vulnerability, the existence of these faults was questioned (in fact, the most recent information that they cite, Lettis and Associates (1998), concluded that they do not exist in the Delta region). Was the uncertainty in their existence accounted for in this analysis?

The 1.0 sec spectral acceleration results were shown to indicate the long-period hazard in the Delta. The characterization of the Delta faults has been updated since 1998. This characterization was performed by Dr. Jeff Unruh who also did the evaluation in the 1998 (Torres, et al. 2000) report for Lettis and Associates. The uncertainty in the seismic source characterization for the Delta area sources was considered by assigning a probability of activity that was not equal to 1.0. That is, there is a non-zero probability these sources are non active. The text will be revised to make the presentation of this information clear.

Figure 6-19: The colors on the map do not correlate with those on the legend.

This figure will be revised.

Page 6-6. Last paragraph: The first sentence summarizing the review should be qualified as follows: "show that, if liquefaction occurs, then the earthquake-induced deformations…"

The text will be revised.

Page 6- 6: The first word after 1), 2), 3) and 4) has a printing error. In your second bullet "is" should be "was".

The text will be revised.

Page 6- 6: We suggest for consistency you change overtopping to overtop or breach to breaching - either is ok.

The text will be revised.

Page 6-7. Last paragraph: The statement that "The Levee Vulnerability team believes that levees that have granular materials with (N1)60-cs less than 15 would liquefy at a PGA of 0.05 g" requires more explanation and discussion. Based on the next paragraph on Page 6-8, the majority (about 75 percent) of the levees have (N1)60-cs values less than 15. Therefore, this statement is very significant. It warrants discussion for the following reasons:

· If (N1)60-cs is 15, then a cursory back-of-the-envelope check based on Seed et al. (1984) gives liquefaction for PGA values greater than 0.1g, not 0.05g. What is the average (N1)60-cs for sites where (N1)60-cs is less than 15?

· This statement is not consistent with the earlier CALFED (2000) study on seismic vulnerability. In that study, the worst class of levees (labeled Damage Potential Zone I) with a total length of only 20 miles in the 1,100-mile system (not 75 percent of it), was assigned a rate of failure of between 0.005 and 0.5 failures per 100 miles in the event of an earthquake with a peak ground acceleration of 0.05g. The resulting probability of failure for the most vulnerable stretch of levees is therefore between 0.001 and 0.1 for a PGA of 0.05g. This result is not consistent with the statement that levees with (N1)60-cs less than 15 would liquefy at a PGA of 0.05g.

Additional analyses and details, explicitly showing the characterization and representation of the uncertainties of all random variables considered in the development of the levee fragilities are being prepared for inclusion in the revised risk report. Some sensitivities analyses are also being carried out. The results of these evaluations will be presented in the revision of the report.

Page 6-7. Section 6.2.2, 4th paragraph: These are not really verification runs in the formal sense. The results of two different calculation methods are just being compared. Verification over-states what was done.

We will call them comparison runs.

Page 6-8. Section 6.2.3, 2nd paragraph: Authors pick a liquefaction threshold value of (N1)60-cs less than 15 but in Section 6.2.4 in the 4th bullet they divide the (N1)60 ranges up - 10.1-20 -. Why did they not choose a range that had a threshold at 15?

As indicated above, additional analyses are being carried out to model the uncertainties around the (N1)60. Ground motions, residual strengths, CSRs, and the liquefaction potential have been added to the analysis of the levee fragilities.

Page 6-10. First paragraph under 6.2.5: The statement that "[…] probability distribution functions of the input variables that exhibit random spatial variability were developed" requires more explanation. For which variables, over what spatial dimension, and how were these spatial variations modeled?

Additional explanation of these variables will be added to the report.

Page 6-10. First paragraph: Is it true that island side sliding surfaces control the deformations? Our guess is that it might control the downstream crest height.

The analyses that were performed show the island side moves more than the waterside during an earthquake. The crest settlement depends on the movement of both sides of the levee. The text in the report will be revised to clarify this point.

Page 6- 10. Second full paragraph: We could not find the results discussed on Figures 6.2 and 6.3. Are they presented?

These two graphics will be included in the final report.

Page 6-10. Section 6.2.5: The first word after 1), 2), and 3) has a printing error.

We will correct this.

Page 6-11. First paragraph: The logic behind relating the probability of failure during a seismic event to the ratio of the vertical deformation and initial free board is not clear. Isn't it the absolute difference between the vertical deformation and the initial free board that is important concerning overtopping and breaching (e.g., it would seem that a situation where the vertical deformation is 0.5 feet and the initial free board is 1.0 feet would be of more concern compared to one where the vertical deformation is 2.5 feet and the initial free board is 5.0 feet, even though they both have the same ratio of 50 percent)?

In your example both cases have the same ratio of 50%; however, the case where there is 2.5 feet of deformation may indicate more serious damage than the case with 0.5 feet of deformation. Using the absolute deformation was tried in the Torres (2000) studies and was found insufficient to represent the damaged state appropriately, by members of that team who also served in the DRMS team (Prof. Ray Seed, Dr. Les Harder, Mr. Michael Ramsbotham (USACE) and Mr. Gilbert Cosio (MBK)). This approach was adopted as a refinement from the absolute deformation used in the past to keep track of the deformation with respect to initial freeboard and the likely breaching of the island.

Also, Dv and Ini-FB in figure 6-41 should be defined. Finally, the y-axis in figure 6-41 should be labeled frequency or rate of failure, not probability of failure, since it is an uncertain parameter.

Concur.

Page 6-11. Start of 6.3.2: This discussion about the spatial behavior of the Delta levees is a stretch. The size of these "contiguous" zones will depend strongly on spatial variations in the geology and the properties of the levees in the Delta and will not necessarily be similar to other levee systems. The statement that "levee sections within a contiguous spatial zone around a given island with similar geotechnical properties are generally observed to behave as a single structural unit when subjected to a given earthquake" is not substantiated. What observations are available for this levee system subjected to an earthquake? How exactly are these "contiguous" zones defined for this levee system? Can they be shown on a figure?

Contiguous zones were defined based on the variables that were used to define the vulnerability classes. These variables were: waterside levee slope, (N1-60) Fill, (N1-60) Foundation, and peat thickness. Each 1,000-foot reach of a levee was assigned to one and only one vulnerability class based on the categories of these variables. All contiguous reaches that were in the same vulnerability class were combined to define a contiguous spatial zone. To show these contiguous zones for all islands would result in a cluttered figure, which, we believe, may not be very helpful.

The judgment that behavior of contiguous levee sections with similar geotechnical properties in an earthquake is likely to be similar is based on the damage patterns observed in past earthquakes. In the Kobe (Japan) earthquake, for example, several miles of contiguous levee reaches (that were presumably weak) were damaged/slumped, while intervening reaches (that were presumably stronger) survived without significant damage. Four photographs substantiating extensive damage of levee failures during past earthquakes were presented in Figures 6-27 to 6-31.

Page 6-11. Section 6.3.1, first paragraph: add an "s" on need so that it reads "needs."

Concur.

Page 6-12. Top of the page: Typo - the word breaches should be breach.
Same page, third paragraph we think it reads better to say - one and only one vulnerability class, than one and only vulnerability class. Suggest adding the word one.

Concur.

Page 6-12. First full paragraph: The assumption that levee sections across different contiguous zones behave independent of each other in a given earthquake seems extreme (although, it depends on how big these contiguous zones are relative to the total lengths of levees around each island and across the system). For example, if there are one hundred "independent" contiguous zones throughout the whole system, and the probability of failure for each zone in a given earthquake is only 10 percent, then it is essentially certain that there will be at least one breach in the system (99.999 percent). We are concerned that the system has been represented in the modeling with so many "independent" components that the results for the system are not realistic and are overly conservative.

The size of the contiguous zones is relatively large (several thousands of feet) and consequently, the average number of contiguous zones per island is relatively small *(about 3-12 is a general range). Therefore, we do not believe that the number of "independent" components per island is overly conservative.*

Page 6-13. Section 6.3.6: This section is very confusing. What is "m?" How many independent contiguous spatial zones are in the model (that is, what is "n")?

The number of independent contiguous spatial zones varies by individual islands. The discussion in this section is generic; it does not assume a specific number of zones. The discussion is meant to suggest that if the breach rate on a particular island is m/n (i.e., m zones are breached on the average out of n zones on an island in a given event), the damage rate is likely to be of the order of 2m/n (i.e., 2m zones out of n zones would be damaged on the average in the same event).

To simplify the discussion in this section, we propose to revise this section as follows: As stated above, when levees are damaged during an earthquake, the extent of damage spans a long distance, typically several miles. In the Kobe earthquake, for example, the length of slumped/damaged levees at various locations was 5 to 10 miles. An actual breach may occur at some location within a particular damaged zone. If an average levee contiguous spatial zone is assumed to be about 4 miles long, an event that causes a breach of one zone is likely to damage on the average about two spatial zones. Based on this assessment, the probability of damage on a given spatial zone was assumed to be twice the probability of a breach on the zone.

Page 6-22. Table 6-1, first two columns of the table: We suggest putting something continued here. It is presently blank.

Concur.

Page 6-27. Table 6-5: More explanation about increasing PGA and 1.0 sec spectral acceleration with time is needed.

Time-dependent hazard will always increase with time until the seismic sources controlling the hazard produce large earthquakes. This is simply the result of the elastic rebound theory, where strain accumulates with time on a fault until it releases that strain through a large earthquake. We will expand the discussion in the text.

Figure 6-19: Suggest more contrasting colors. Some panel members have difficulty reading.

Concur.

Figure 6-32: Do you have a problem on the far right margin with your printer?

The figure looks fine in our report.

Figure 6-33: The layers in the cross-section are not labeled and there are not units on the scales.

We will add labels on the axis.

Section 7 (Flood Risk Analysis)

General Comments:

This section has all the shortcomings of the previous sections in minimal citations, poor justifications of statements, attribution of sources for data, etc. These omissions and problems extend throughout the section. There are some other concerns related to technical issues. Also, there are very detailed comments from reviewers on the technical memoranda for this section (see those from the USACE by Keer, Jensen, and Burnham) that very precisely identify problems that still seem to remain in the DRMS *Phase I Report*. The statements below are reproduced from these reviews (Jensen and Burnham) and address some of the critical issues:

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1. The Draft *Flood Hazard Technical Memorandum* presents a means of:
   - Estimating the Delta total daily inflow for flood events and associated stages throughout the Delta.
   - Establishing existing or baseline frequency curves.
   - Adjusting those curves based on four climate change scenarios.

   The analyses are based on readily available data. To the extent that the analytical study constraints permit, the procedures adopted and applied are logical and accepted within the profession, with one exception: The climate change sections in which procedures used and assumptions made are not clearly presented in this Flood Hazard technical memorandum or in the Climate Change technical memorandum. Excluding the climate change analysis, the resulting procedures from the Flood Hazard technical memorandum can be used to conduct preliminary analyses in order to focus more detailed studies and identify reasonable alternatives.

An unnumbered table summarizing climate change assumptions has been added to Section 6.1 of the Flood Hazard Technical Memorandum (TM). More detail is presented in the Climate Change TM.

2. The assumptions made and constraints used in the *Flood Hazard Technical Memorandum* limit its utility for more detailed studies. The primary reasons are as follows:
   - The daily time interval used is too long to capture the peak flows, tidal effects, timing effects, outflows from the Delta, etc.

The method was not intended for more detailed studies, but was designed for use in the DRMS risk analysis, where thousands of different simulations were conducted. Thus, the method needed to be simple and easily implementable.

The intention of the analysis was not to capture short-term or transient effects. The intention was to provide a reasonable estimate of the peak stage in the Delta for each of the scenarios simulated in the risk analysis. Hourly stage and tidal data were used in the analysis.

- The presented procedures do not take into account reservoir operations; bypasses, weirs, and diversion operations; other non-controlled diversions; pumping operations; levee failures; and with-project base and future conditions that effect flows throughout the system.

The method was meant to be simple enough to be implementable in real time for thousands of potential simulations. An analysis of the stage data collected in the Delta indicate that stage could be estimated with reasonable accuracy for purposes of the risk analysis. The analysis incorporates Yolo Bypass diversions. Operation of Delta Cross Channel is, in general, constant during the wet season.

None of the upstream facilities is explicitly included. They are, however, implicitly included in our approach of using the historic Delta streams inflow. The contributions of all the upstream facilities are reflected in the downstream flows. We need to stress that an important aspect of selecting this approach is that we never planned to perform a comprehensive analysis of the storms-watersheds-reservoirs-stream channel dynamics-levees along the streams etc. comprehensively all the way into the Delta. This work would be out of the scope of this risk study, and would require, in our estimation, 10 years or more to complete. Currently the USACE is working on this project deterministically and for today's condition. Think about the additional efforts required to capture the flow regimes and stage frequencies in probabilistic terms and do it again three more times for 2050, 2100, and 2200.

- The procedures do not provide adequate hydrographs required for unsteady and multidimensional flow analyses and interior flood analyses with respect to the Delta.

The analysis in the Flood Hazard TM was not intended for transient or multidimensional analysis. See the Water Analysis Module (WAM) TM for details on the modeling.

- The results presented are not accurate enough for the sizing and designing of Corps levees, or for FEMA levee certification analysis.

The flood hazard modeling was not intended for design purposes; it was only designed to provide input to the risk analysis. FEMA certification requires protection against a specific event at a specific location, not a specific inflow into the Delta.

It was never the intent for this study to support any design and we recommend it not be used for design. This is a risk study to assess the vulnerabilities of the system and estimate their probability of failure and the consequences of these failures.

- While the procedures applied for estimating flow-frequency curves associated with the four climate change scenarios are logical, the assumptions and data used do not enable consideration of different reservoir and system operations strategies to be studied. These strategies will need to reflect changes in the snow pack and runoff predicted by the climate change models (see *Climate Change Technical Memorandum*). The assumption that the 23 large watersheds' 100-year (or other) frequency flows can be added together to produce the 100-year Delta flow is invalid. Furthermore, there is no documentation of the assumptions, procedures, and results of the climate change analyses.

The Flood Hazard TM has been updated to provide a more accurate description of the procedure followed. Although future reservoir operations may be different than they are today, the purpose of the flood hazard analysis was not to analyze reservoir operations, but to estimate how the flood frequency curve may change in the future. It would be speculative to try and operate the reservoirs under future, uncertain conditions and would be unlikely to provide a better, more certain estimate of the future flood frequency needed for the Risk Analysis inputs.

We agree with the first point raised, we do not explicitly include reservoir operation for the reasons cited in the previous response on modeling upstream facilities.

We do not iterate the flood model for each flood event analyzed. We have rather used the first results from the flood model (frequencies and associated stages) and calculated the probability of levee failure. After the levees breach, then we use the WAM model to track the reservoir releases (CALSIM model) and the hydrodynamic changes (RMA model) in the Delta post- event and during repair.

In the technical memoranda's comments and replies to comments, the authors of DRMS Phase I address these issues sufficiently. Other specific concerns and comments on this section follow:

There are much longer records for some of the gages in the basin than the 1955-2005 data the authors used. This is especially of concern because there were quite variable flows in some of the early 20th century records. If there is some reason for limiting the flow analysis to this shorter record, the authors need to explain why.

The 50 years of data used in this analysis were selected because the data were readily available for all major delta inflows.

They state that, " […] it is believed that changes related to reservoirs and watershed development are associated with water supply and environmental flow releases from the reservoirs and have minimal impact on flood inflows into the Delta" (page 7-1). The Sacramento-San Joaquin watershed is one of the most regulated, large-scale watersheds in the world. The overall effects are shown in the figures below from Kondolf (U.C. Berkeley).

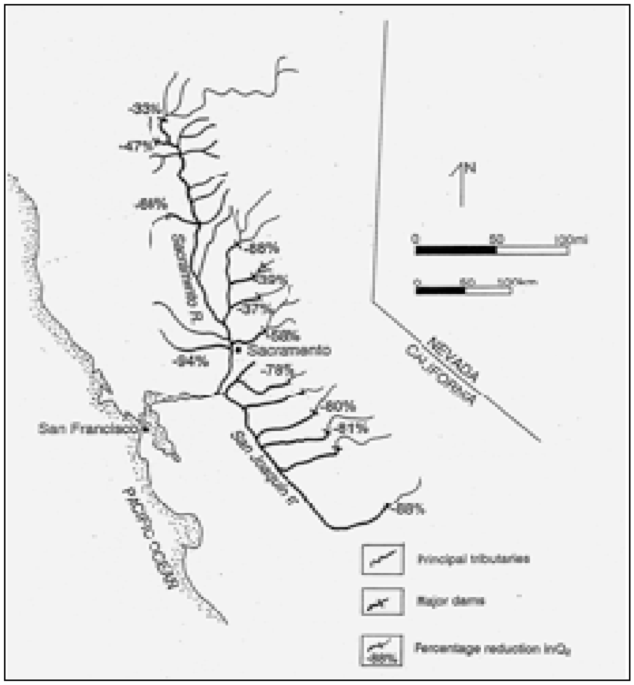


Figure 1: Watershed effects, Kondolf.

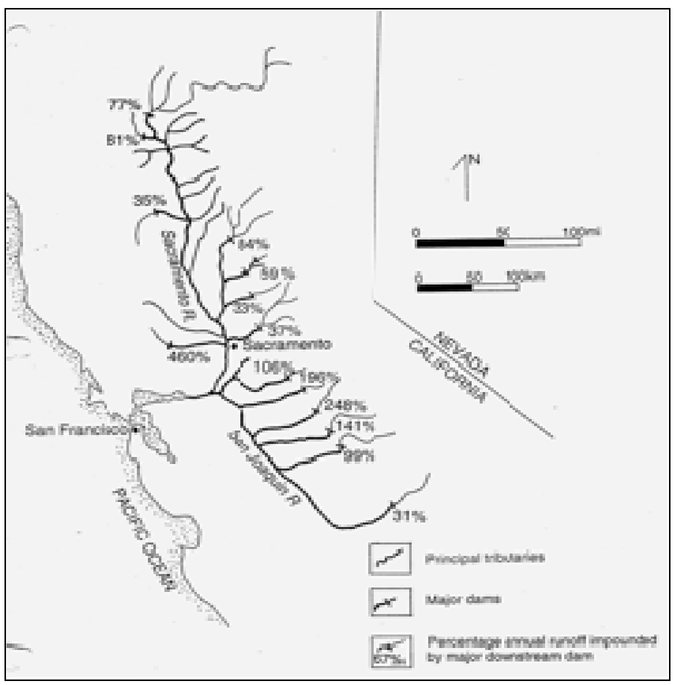


Figure 2: Watershed effects, Kondolf.

> These figures show that flows have been reduced in the main rivers from 33-94% and the percentage of annual runoff impounded behind dams ranges from 35-460%. That this large amount of storage and diversion does not affect flood flows seems highly unlikely. The analyses that they do on the Oroville Dam to show that dams do not effect the hydrograph is not convincing. The record of pre-dam flow is too short (12 years) to capture variability from potential drivers on flow, like ENSO and PDO. Also, looking at Oroville alone ignores the system. Shasta Reservoir is the 9th largest reservoir in the country. It was completed in 1945, so any effect it has on Sacramento River flow would be well before their records that start in 1955. Then there are the inter-basin transfers from the Trinity River into the Sacramento River. It is not clear how it is possible that the peak flows are not affected by all the dams and water diversions in the basin (e.g., look at the number of diversions on their maps in the DRMS *Phase I Report*).

The text will be modified to better reflect the intention of the analysis of reservoir effects of flood flows into the Delta. During the 50 years of data used in the analysis several reservoirs were constructed on the Sacramento and San Joaquin river systems. If construction of the reservoirs had a significant effect on flood flows into the Delta it would not be possible to use the entire 50-year record. In that case we could only use that portion of the record that occurred after construction of the last significant storage project. This would eliminate about half the data. The intention of the analysis is to show that the entire data set could be used as is, without adjustment. The text will be modified to remove the statements that the reservoirs do not provide flood control benefits as that was not the intention.

The modified section of the TM now describes the statistical differences between pre and post- dam construction flows in the Sacramento and San Joaquin rivers. Results of an Anova analysis between the pre- and post- dam eras have been added to the report. The analysis indicated that at the 5% significance level there is no statistical difference between the pre- and post- dam construction peak annual flows. A figure comparing the temporal distribution of the largest events on record was also added, providing additional verification that the general nature of the flood flows into the Delta has not obviously changed over the 50-year period of record.

The comments from a USACE reviewer (Kerr) of the technical memorandum also capture these concerns:

> Investigation assumes New Melones and Oroville dams have no significant impact on Delta inflows. This assumption will have a significant impact on the analysis – suggest either rethinking this approach or quantifying the impacts. If, "the average number of days per year with high Delta inflows from SJR is greater during current conditions [record reflected with regulation]" then NML is impacting Delta inflows (more comments below in Section 2.3, paragraph 4). This assumption appears to be in conflict with a statement made in Section 6.1 that "[…] estimated inflows into the Delta in some streams during some storm events may be significantly attenuated by reservoirs[…]"

The discussion in Section 2 on the effect of reservoirs on flood flows into the Delta was used to decide if all 50 years of available data could be used in the analysis or if only data collected after construction of New Melones could be used. Before the analysis it was hypothesized that the reservoirs would decrease flood flows into the Delta and therefore there would be a noticeable decrease in the size of inflows into the Delta after construction of the reservoirs. As described in Section 2, that did not seem to be the case, so it was decided that all 50 years of data could be used in generating the frequency distribution of flows into the Delta.

> Section 2.3, paragraph 4: I believe the assumption that ORO and NML have no impact on Delta inflows is incorrect. The comparison made is over simplified and misleading. Simple comparisons between regulated and unregulated frequency curves contradict this assumption.

The analysis is simple yet it does indicate that the reservoirs have not had the effect on Delta inflows that might be expected. The purpose of the analysis is not to determine the level of impact of reservoir operations on flows in the tributaries to the Delta but determine if the use of 50 years of data that encompasses an era of dam building is reasonable. The analysis indicates that the use of the 50-year data record is reasonable for the purpose of the Risk Analysis.

> Section 2.3, paragraph 5: the suggestion that "fewer peak daily inflows would be expected after the addition of reservoirs in the watersheds if the reservoirs were reducing flood flows" cannot be directly supported without a statistical comparison of reservoir inflows, storm patterns, and ungauged contributions.

We disagree with this comment. It is not unreasonable to anticipate that the construction of reservoirs will reduce peak flood flows downstream of the reservoirs. That is often why they are built.

The authors make another statement of concern, "although the total volume of available flood control storage in the watersheds during the flood events is not known, it is possible that runoff preceding the peak day filled whatever flood control storage was available and inflow into the reservoirs was not significantly greater than outflow on the peak day." This is also an unsubstantiated statement. The storage in all the reservoirs in the basin is known (most can be obtained real-time). The paragraph that follows this is also unsubstantiated, that reservoirs only provide a portion of the storage in floodplains. It may have been true in the long-distant past that the Sacramento and San Joaquin rivers had vast floodplains (before European colonization) that stored tremendous amounts of water, but that certainly is not the case now. Nearly every river in California is separated from its floodplain by levees. This extends well into the upper reaches of the watersheds and certainly is the case for all the lowland river channels.

It is possible to look back at the data and determine what the available storage was for a given historic flood event. It is not possible to look forward and predict what storage will be available for an unknown future event. It may also be true that nearly every river in California is separated from its floodplain by levees. But it is during the large flood *events that levees fail and floodplain storage becomes available. In many cases it is not the size of the storm above the reservoirs that determines the size of inflows into the Delta, but the capacity of the channels feeding the Delta to convey that flow to the Delta. The larger the storm the more likely levees will fail somewhere in the system and reduce the flows into the Delta. However, as we said, the intent of the analysis was not to describe the flood control capabilities of the reservoir system in California but to determine if it was possible to use the entire 50-year dataset.*

This section contains a large number of these types of problems. We will list them without explanation because of the lack of time:

Arbitrary 200,000 cfs cutoff to eliminate non-storm events – unsubstantiated and certainly arbitrary and effects the outcome of analyses (see USACE comments for details). Although they say in their reply to this comment that this has been removed, it is still in the report. This implies they have not made changes they say they have in response to reviewers.

The 200,000 cfs cutoff was reduced to 80,000 cfs for purposes of calculating the distribution of flows in each tributary for a given total Delta inflow. Although a rigorous analysis was not undertaken it was felt that the distribution of flows in the major tributaries to the Delta could be divided into two populations; distributions that represent large storm events, and distributions that represent small storm events and non-storm periods. We were only interested in the storm event data and therefore wanted to eliminate from the dataset those flow distributions that represented non-storm periods.

Figure A, attached, shows a plot of daily average flow from October 1, 1955 to September 30, 2005. A line representing 80,000 cfs is also shown. Using a cutoff of 80,000 cfs captures all the significant storm events and excludes the small and less significant events. It is true that picking a value such as 80,000 cfs is arbitrary and could affect the outcome. But a review of Figure A shows that picking any flows from about 60,000 cfs to about 140,000 cfs would not have made a significant difference in the outcome. Not picking any cutoff value would have affected the outcome by trying to develop a relationship that represented both populations (storm and non-storm). This would likely result in a less reliable relationship for storm events than was used in the analysis.

Regression of total flow to individual river flows oversimplifies the system, e.g., assumption that Sacramento River always has 85% of flow. This is not supported by the data and plots presented.

It was not assumed that the Sacramento River is always 85% of the flow. It was stated that on average the Sacramento River provides 85% of the inflow to the Delta. The actual inflow used in any given scenario was calculated from the logistic regression that was developed as described in Section 4 of the Flood Hazard TM. The regression relationships have associated with them a mean square error for the regression so the inflow from each tributary could be calculated for any selected confidence limit.

It is not at all clear why they did not use existing work. Much work has been done by USACE, etc. on the flood stages of rivers throughout the region. They again cite no previous work and do not put their work in context.

We are not aware of any other studies by the USACE or others on a probabilistic risk analysis of levee failure in the Delta. The flow and stage data and procedures developed in this study were specifically developed as inputs to the risk analysis. We did review the USACE Comprehensive Study. The purpose of that study was considerably different from the purpose of this study and therefore the information contained in the report did not appear to be relevant.

It is worth noting that the purpose of this study was not to develop frequency information on stages in the Delta. The purpose of the study described in the Flood Hazard TM was to develop a relationship for flood stages in the Delta for a given occurrence probability of Delta inflow.

For the given Delta inflow the stage everywhere in the Delta was predicted. The probability of those stages occurring (or of being exceeded) may or may not be equal to the probability of occurrence of the Delta inflow and likely would be different for different parts of the Delta. The procedures used in the risk analysis did not require the selection (or knowledge) of the probability of occurrence of a particular stage in the Delta. This is a departure from typical flood studies and that distinction helps explain why no other studies were identified as having relevant information.

The authors do not cite sources of data or have references to a website. They need complete references to all data used so that the reader can obtain it.

There is a major difference between the FEMA 100-year flood elevation and the authors determination. What are the causes of these differences? In general, their floods are much higher in about half of the Delta, especially the south end. They give no discussion of this. This is a very big deal. For example, Stockton is 0-10 feet from FEMA and 15-20 feet from their analyses. Those are huge differences and they need to be explained because they affect all aspects of their hazard (and ultimately risk) determination.

FEMA 100-year flood is a single deterministic water surface elevation in the Delta. In theis risk analysis each flood frequency (10-year, 20-year,…, 100-year etc.) have multiple surface elevations associated with it. Comparisons with Corps stage curves and historic data will be added in the revised report.

Throughout the report, the authors present information and make statements that are not attributed to a source. This is very frustrating because the validity cannot be determined without citations or sources.

Please provide the specific location of those statements so we can address them. All the specific comments below have been addressed.

Another very important aspect of long-term flow is the past (late Holocene) record. There have been major changes in flow over the last few hundred to few thousand years. There is no reason to not expect these to occur in the future, but there is no mention or discussion of this in the "flooding" section. This is as important (maybe more so because it is data and not model output) that the projections from climate models used to make future predictions of flow. This is a major oversight in this analysis that needs to be addressed or discussed.

We are only considering flood risk in the next 200 years. In the thousands of years more changes will take place. In the late Holocene the hydrology was certainly very different from now when most of the rivers are damed and flow are regulated. These changes are beyond the scope of our work. We will attempt to describe the changes that have occurred in late Holocene in the Geomorphology TM.

Specific Comments:

Page 7-4. First full paragraph: What is significant about "1/34th of the difference in the natural logarithms of the total range of inflows considered?"

The analysis method developed for the risk analysis uses probability of occurrence of total Delta inflow rather than probability of exceedance. This requires that the probability distribution for total Delta inflow be discretized into bins with each bin representing an inflow range with an estimated probability of occurrence. Seventeen bins were considered sufficient to adequately represent the probability distribution for Delta inflow. The 1/34 is half the width of a bin (the range above and below the flow used to represent the bin).

Page 7-4. Second full paragraph: Suggest revising "Because uncertainty exists in the estimate of the annual probability…" to "Because uncertainty exists in the estimate of the annual frequency…"

We will take this suggestion into consideration as part of the revision of the report.

Page 7-4. Third paragraph under 7.3: What time corresponds to the coefficient of variation of 0.084 in flow in the Sacramento River: daily, monthly, annually?

The coefficient represents daily flows. The text will be changed to clarify this.

Page 7-7. Last paragraph of 7.4.3 and figure 7-18: Some discussion is needed about the comparison in 100-year flood elevations between DRMS and FEMA. Why are they different? Why is there such a large difference near Stockton? What is the point of the third map in figure 7-18?

We will remove Figure 7-18. The figure is misleading. The DRMS project did not develop 100-year water surface elevations. The figure showed predicted water surface elevations in the Delta for the case of the 50% confidence level estimate for a 100-year total Delta *inflow, with the flow distributed to all the tributaries at their mean values (for that total Delta inflow). This is not the same as a 100-year water surface elevation, so the comparison to the FEMA values provided in the report is misleading. The third map shows the predicted water surface elevations in the Delta for the same total Delta inflow as the second map but with a different distribution of flows to the tributaries.*

For the risk analysis it was necessary to determine the water surface elevations throughout the Delta for any given flow condition. The prediction method used needed to be simple enough that it could be performed as many times as needed within a relatively short period of time (1000s or millions of times per day, for example). The probabilities used in the DRMS analysis are based on the probabilities of total Delta inflow, not the probabilities associated with any given river inflow or water surface elevation. Because the total Delta inflow is made up of contributions from several sources, there are multiple ways to represent the 100-year total Delta inflow (the last two maps in Figure 7-18 represent two of the ways). For a 1% probability of occurrence of total Delta inflow, the sum of the probabilities for each different distribution of flows is 0.01, the probability of a 100-year total Delta inflow. (It is worth noting that there is a distribution used to represent the 100-year Total Delta inflow. Each value in the distribution has associated with it a set of possible flow distributions in the Delta tributaries. This results in a larger number of possible 100-year events, each with its own probability of occurrence). The goal of the DRMS analysis is to incorporate all these possible conditions in the risk analysis.

None of the ways of achieving the 100-year total Delta inflow is more or less representative of the 100-year total Delta inflow than any other. Also, the water surface elevations predicted for each flow distribution do not represent the 100-year water surface elevations in the Delta. The risk analysis never actually calculates or needs to calculate the 100-year water surface elevation at any point in the Delta.

Because the analysis method used for the flood hazard in the DRMS project is different than is typically used in a flood or design study, it is an example of how the method can be used to generate a frequency distribution of water level at a point in the Delta.

Page 7-7. Last paragraph: What does “attend to maintain stability” mean?

The authors meant to say that if a stability-related problem arises, action will be taken to fix it. The text will be revised to be clearer.

Page 7-8. Figures 7-21 and 7-22: They show two linear regression lines on figure 7-21 that are arbitrary. There is no substantial difference between early and later years. This division should not be used. The “difference” in the slopes of their regression lines is driven entirely by the 1903-1908 changes in earlier years. The “correlation” between storms (assuming they mean peak runoff, not actual storms) and failure was not measured statistically and does not appear to exist from the data presented. They present figures that do not show this relationship and do no statistical analyses to prove it. Peak discharge did not change substantially during any of the major increases in failure rates.

The plot of "cumulative number failed" is not as useful as a plot of "number failed" and obscures the actual relationships. They have completely overstated this and there is no evidence to prove it, they make this statement without support from their own data. The fitting of lines to the data in figure 7-22a is arbitrary. The changes in the data are steps and show no linear trend. They maintain that there is a "correlation" between flow and failures, however, the "big" change in failures occurs more or less as a step from about 1979 to 1986 (the scale on the figures is very inadequate), while the one "big" flow event outside the previous typical highs was in 1987, after this failure increase. Their statements in the text are not justified by these plots. Similarly, during another "big" flow event in about 1997 (again the scales are inadequate to read the graphs easily), the failure rate was flat flowing a step up previous to the high flow during a time of very low peak flows (the droughts of the late 1980s to mid 1990s).

These figures show the raw data for the number of failures through time obtained directly from the database provided by DWR. The lines are simply trend lines averaging the total number of failures for the period of observation (slope of the line = number of failures/the duration of the period of observation). The time break (1980) was used to differentiate between the older and the current state of the levees (new geometry and the start of the funding program) and was requested by the Steering Committee Members. The readers are welcome to use the data and analyze it for any period of interest.

The data is provided only as a historic record of the levee failures and the available historic flow hydrograph. We will add to the discussion some details on how many and when a large number of levee failures occurred.

None of these data were directly used in the flood hazard model development. They were rather presented as historic data to compare to the model results.

In Section 7.5.1 we report some key observations directly from the data without interpretation or analysis. We revisited the reported information from the chart and could not find anything misstated, or a wrongly reported statement. The record of historic island failures obtained from the DWR data does not include days, months and time of failure. The only information available is the year of the failure. So, if failures occurred in 1986, we inferred that they were associated with the high Delta inflow during the storm of 1986.

As requested, we will plot the non-cumulative chart of historic failure with larger scale so it will be readable.

Page 7-8. First paragraph under 7.5.2: What does considering erosion and slope stability as a "fraction of total mode of failures" mean?

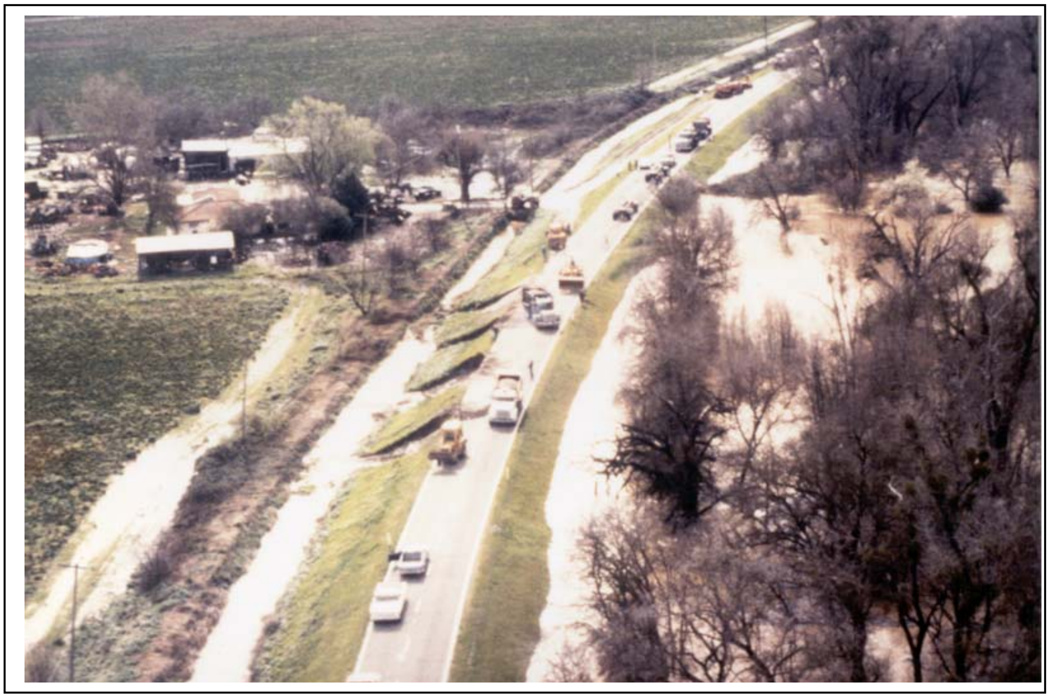
Slope instability and erosion are addressed in other topical areas (Seismic and Emergency Response). The sentence will be revised appropriately.

Page 7-9. First paragraph under 7.5.2.2: The description, “Often, water is seen exiting the landside slope of the levee, above the landside toe. As this increases, slumping of the levees slopes is often seen progressing from surficial slumps to complete rotation and/or translation of the levee prism and eventual breach of the levee,” seems to indicate a slope failure due to seepage pressures lowering the effective stress in the soil AND not internal erosion. However, the discussion and the subsequent analysis of this mode of failure emphasize internal erosion (i.e., the vertical gradient) versus slope stability. Why?

Slope stability and seepage are two separate failure mechanisms and are not necessarily correlated. However, one can lead to the other (for through seepage, enough material removed from the DS face of the levee and toes will lead to oversteep slopes which will fail ultimately by instability of the slope).

There are many instances where the long term steady-state effective stress analyses show a factor of safety greater than 1.4, and yet we experienced through-seepage and under-seepage failures (consider the case of the Natomas levees). Very low existing gradients (less than 0.4) have resulted in through seepage failures as documented by the 2007 and 1997 events (see pictures below). For through-seepage, low exit gradients can move particles from the face of the slope without much effort (Photo of through seepage failure in 1986 along the Sacramento River). The same holds true for through seepage.

Picture of sand boil at Staten Island (ejecting ~250 gpm) during the near levee failure 6-21-2007 (Picture by DWR 6-21-2007)



Picture of Sacramento River Levee Through-Seepage failure (USACE 1986)
Soil particles were observed moving down the landside slope while water was oozing from the slope face.

Page 7-9. To end of section: This page has a large amount of unsubstantiated material that is critical for their final analysis of failure. They simplify the failure modes but do not say how and why. The second paragraph basically says they do not have the information to determine how levees failed and they based the allocation to a failure mode on “judgment and experience.” But they do not give any criteria on how that judgment was made. They need to give the reader the criteria used. If they had no criteria, than this is a major shortcoming of the approach. They have no information to support some of the statements made on this page. For example, they “[...] believe […] that both through-, and underseepage-induced failures occurred in equal numbers. The remaining […] failures can be attributed to overtopping.” They give no data to support this or any information of how they came to such conclusions. Yet, these are used to determine the potential failure later in the report. They need to give data, summaries of interviews with experts, reports, dreams, whatever they used to get this information.

They make similar statements about permeability without any attribution to source or data. They make statements, “[…] because of their high permeability and layering […]” with no supportive information or data. This is partially the pervasive problem of poor referencing throughout the report, but is critical for knowing if their analyses are reasonable.

It is not possible to determine that from this report. Again, the USACE reviews of the technical memoranda note similar or identical concerns and those were not addressed in the final report.

They also make contradictory statements in this and following pages about "seepage model analyses." Again, they talk about models but do not give the reader any information on the validity of those models. They give a list of "variables" or "classes" but say nothing about how, or why these were picked or cite references that would support this choice. This mostly looks like their "opinion" not a scientific analysis based on data.

Without the presentation of data and support from previous work and substantiating research, this is mostly conjecture. It is extremely difficult to determine the validity of the failure analyses and response to floods, etc. Much of this is "conceptually" okay – that is it seems reasonable – but it is not backed by data or citations. It therefore becomes supposition not science.

We agree that more explanation and detail should be provided on this subject. All the mathematical models used to calculate expected performance are based on data and logical development of the model. The data, the interpretation and the model development are in the risk report and relevant TMs. When data and information were absent we used a formal expert's elicitation. Again, expert elicitation is a formal and accepted SCIENTIFIC process.   When expert elicitation is used, we will provide a detailed description of the format and the process followed.

Page 7-11. Second paragraph: What was the basis for assuming a 50 percent chance of occurrence for the presence of sediment in the slough and the presence of a toe drainage ditch?

The presence of slough sediment and a ditch affect the calculated seepage gradients and therefore valuable parameters to include in the seepage calculations. The shortcoming is that we do not have reliable data (i.e., per each slough mile by mile data). Also, during high velocity flows the slough sediment is removed and the reverse occurs during low velocity flows. No continuous survey of slough bottoms are performed regularly and every where along the Delta Sloughs. Based on the absence of that specific knowledge we assumed 50% chance for the slough sediment to be present or absent. The same applies to toe drainage ditches.

Section 7.5.5: We have the following concerns about the approach used to model and analyze seepage-induced failures:

- The model predicts that the vulnerability to seepage-induced failures goes up if there is a ditch to control seepage flow and pressures on the inboard side of the levee. From the standpoint of water pressure and stability, it seems like the ditch would help not hurt. Also, the model predicts that for the same levee section, the deeper the interior of the island, the less vulnerable the section is. Again, this result seems counter-intuitive to me because the water pressures relative to the total overburden stress would be greater (smaller effective stresses, smaller shear strengths, greater potential for instability).

We disagree with this comment and maintain our prior statement. The local engineers and maintenance Districts report that the worst underseepage problems are at the location of the ditches. Sand boils form in the ditches, undermine the foundation sands, and ultimately result in formation of sinkholes through the levee or levee slumps.

- We don't think using the vertical gradient is necessarily a good indicator for seepage-induced vulnerability. An artificial and questionable set of conditions (very high permeability for peat relative to lab measurements and very high ratio of horizontal to vertical permeability) is needed in order to come up with apparent vertical gradients that seemed high enough to the Levee Vulnerability Team to explain observed failures. We would like to see these observed failures analyzed in terms of stability using reasonable properties to see if the failures could be explained (e.g., showing effective stresses in addition to gradients and heads in the FEM results in the technical memorandum).

It is not clear what this comment intends regarding the stability issue versus underseepage. We addressed the question of seepage versus stability previously.

- It would be very helpful to analyze the available near-miss data for seepage failures. For example, how many times do boils appear at a location in years prior to a seepage-induced breach? How many times have boils appeared at various locations that have never manifested themselves as breaches? How have areas where they have consistently collected sediment from the inboard ditches (or seen gradual increases in sediment load with time) performed in terms of breaches? These data would be helpful not only for assessing the risk but for understanding how to manage the risk.

The reasons for past failures are not documented. Even the failure of Jones Tract (June 2004) is not documented and well understood. There is still debate on whether it was: high tide, rodent holes, a continuous pervious layer through the levee or through the foundation, human activities, or a combination of those. Most, if not all failures did not have witnesses or witness reports that we can refer to.

- If seepage-induced failures are related to internal erosion, then it seems like the model should account for conditions getting worse with time (which is one explanation for the "sunny day" failures). Again, an analysis of the near-miss data would be valuable.

Definitely! Conditions worsen with time as far as seepage is concerned. See the answer to the preceding comment.

Section 7.6.1: This approach for modeling spatial variability is flawed, specifically, equations (1) and (2) are not correct. The probability of the union of failure events is theoretically bounded to be greater than or equal to the maximum probability of any one of those events. For example, if there were three reaches in an island and the probabilities of failure for these reaches were $P(F_1) = 0.9$, $P(F_2) = 0.05$ and $P(F_3) = 0.1$, then the $P(F_1$

U F_2 U F_3) cannot be any smaller than 0.9 (the case where the events F_2 and F_3 are completely contained within F_1. However, equations (1) and (2) would give P(F_1 U F_2 U F_3) equal to $(0.9^2 + 0.05^2 + 0.1^2)/(0.9 + 0.05 + 0.1) = 0.78$, which is not possible. If the intent is to include correlations between reaches, then the maximum probability for any individual reach provides a lower bound on the probability of failure for this case and is commonly used as a simplified approximation to more complicated relationships.

The model we have used assumes that a failure occurs on the weakest link (i.e., the weakest levee reach). We just do not know which reach is the weakest link with certainty. Thus, if there are n reaches on an island, there is only one "trial (i.e., one unknown reach subject to a failure)" and not n *different "trials." We are trying to find the probability. The outcome of the single trial is a failure. This is not the same as the probability that there will be a failure on at least one of* ***n*** *different trials. Each reach has some probability of being the weakest link. This probability is set proportional to the conditional failure probability for that reach given that it is the weakest link (f_{ijk}). The probability that a particular reach is the weakest link is given by w_{ijk} in Equation 1. Equation 2 follows the total probability theorem. Each reach has a probability of being the weakest link (calculated from Equation 1). Furthermore, if a particular reach is the weakest link, it has a certain probability of failure f_{ijk}. Therefore, the total probability of a failure considering all reaches is the product of w_{ijk} x f_{ijk} summed over all reaches.*

For the example noted in the review comment, let us assume that an island has 3 reaches with conditional failure probabilities of 0.9, 0.05, and 0.1. Then, the probability of being the weakest link would be 0.9/((0.9+0.05+0.1) = 0.857 for the first reach, 0.048 for the second, and 0.095 for the third reach. Finally, the total probability of a failure would be (0.857x0.9 + 0.048x0.05 + 0.095x0.1) = 0.783.

Section 7.6.2: Why are the events of underseepage and through-seepage treated as statistically independent? It seems that they would be highly correlated (e.g., both depend on the presence of sediment in the slough, the presence of a toe drainage ditch, the geology beneath the levee, the properties of the levee, etc.). Are failure events between multiple islands treated as statistically independent?

The properties of the levee are different and uncorrelated with the foundation. The events of underseepage and through-seepage are assumed to be ***conditionally independent****. That is, given a levee reach with certain geotechnical properties subjected to a given hazard event and loading (e.g., water head), the two failures are assumed to be independent. For a vulnerable levee reach, probabilities of both events would be high using our model. However, the information that one is high would not change (the already high) probability of the second.* ***Unconditionally****, these events would be highly correlated; and that correlation is preserved in our analysis.*

Failure events between multiple islands are again assumed to be ***conditionally independent****. That is, they are assumed to be independent given a particular hazard event and loading. Given a high loading, the failure probabilities for vulnerable islands are* *likely to be high using our model. However, the information that the failure probability for one island is high would not change (the already high) failure probability for another island*.

Section 7.6.4: This section is very confusing. If equations (1) and (2) were formulated adequately, then we suspect this scaling factor would not be needed.

Equations 1 and 2 calculate the probability of a failure based on the vulnerability of each levee reach on an island. This calculation does not explicitly account for the length of an island. Some fine-tuning of the calculated failure probability based on the island length was considered to be necessary to distinguish between long versus short islands. That was the reason for developing the length-based scaling factor. Note that the scaling factor was relatively small for most islands in the range of 20 to 40 miles long.

Section 8 (Wind and Wave Risk Analysis)

General Comments

The authors make unsubstantiated statements throughout this section. They seem to limit their analyses to a very small subset (8.1) of the important factors causing levee failures or damage from wind and waves. They do not justify this omission. How can one get the data the authors refer to? Again, no reference or detailed information of how to get the data they used. Where the authors do cite references they are not in the references cited section. Most of the references cited in this section were not in the reference section, or they were in a different format. Extremely poor editing.

This section is to provide a brief overview and summary of the more detailed DRMS report on wind and waves and their relevance to the risk analysis as documented in the "Wind-Wave Hazard TM". In the process of creating this summary, material from the TM was abstracted rather than summarized and many citations were omitted. An explicit reference to the TM should have been stated to facilitate reader access to more detail, the relevant citations, and how to obtain the data. This will be done in the next revision of the Phase 1 Report and the presentation of this summary will be improved.

The authors assume deep-water wave conditions when all the "lake islands" would be very shallow. It seems that all waves would be shallow-water waves and interact with the bottom. They do not say why they assumed this. Again, the authors did not explain their methods, or give any citations.

The deep-water assumption is explained in somewhat more detail (but still inadequately) in the TM. It is correct to identify this as an important assumption that should be reviewed. It will be reviewed and more clearly explained and justified in the next version of the Risk Analysis report – or it will be changed.

In presenting the wind and wave model, the authors do not cite any references to the origin of this information or approach, why it is important, how it is to be used to determine levee failure, or how it fits into the overall determination of risk. Some of the terms are ambiguous, poorly defined, or of unknown importance. Why do we need to know "timing," "met event," etc.? This is all presented with no context.

Again better context is presented in the TM. We will review the importance of these concepts to the present summary and either explain them adequately or delete them from this discussion.

Specific Comments

Page 8-1. First paragraph: It is not clear where this information fits into the overall risk model.

The comment is correct. This will be clarified in the next version of the Phase 1 Report. Several potential impacts of wind-waves were candidates for inclusion in the risk analysis *and they were initially being addressed in the wind-wave studies. For information, the present risk analysis considers the wind-wave damage to the interior slopes of flooded islands from low level as well as major, regional wind events.*

Page 8-1. Fourth paragraph: This paragraph is very confusing, particularly following the preceding paragraph where the important factors are outlined. Why wasn't wave run-up considered during high-water events?

The limitations stated in that paragraph apply only to the task of wind/wave development model. The application of the impacts of wind wave induced erosion and overtopping are discussed in their own sections. This statement will be revised to direct the reader to the proper sections of the report where the impacts of wind/wave are analyzed or discussed. The wind/wave levee erosion model was used in the emergency response module (Section 10 which will expand the discussion of the erosion model used). Overtopping is addressed in the flood hazard in Section 7.

Page 8-2. Second full paragraph: What duration was associated with the peak wind speeds in the data set (e.g., gusts, 1-minute, etc.)?

As stated in the subject paragraph, the DRMS risk analysis needed to consider region-wide, sustained winds. Three key regional meteorological conditions were identified and extreme winds with durations of several hours were of interest. Gusts were considered to be of limited relevance to potential wind-wave damage of levees. Additional detail on durations is provided in Figure 9 of the TM. The regional wind events considered relevant and their durations will be more clearly described in the next version of the Phase 1 risk analysis report.

Page 8-4. Description following equation 8-4: What is the basis for assuming that the spatial wind speed pattern is perfectly correlated in space? Does this assumption really matter in the results?

Correlation in space follows from consideration of major, region-wide wind events. Ultimately, this does matter because occurrence of a major, regional wind-wave events in the context of a levee breach event will have damaging effects Delta-wide, increasing the damage to already flooded islands and extending the overall repair schedule.

Page 8-10. Fourth paragraph: What does the following statement mean: "The 2-percent wave run-up height is not related to the probability of a given wind speed or wind wave condition"? Why wouldn't the run-up height depend on the wind speed?

The comment omits a crucial word from the above quotation. The accurate quotation is: "The 2 percent wave run-up height is ***otherwise*** *not related to the probability of a given wind speed or wind wave condition." The prior sentence states that "The 2 percent run-up height was calculated for each wind wave height and period." These two parameters (height and period) fully incorporate the influence of wind speed.*

Section 9 (Sunny Day High Tide Risk Analysis)

General Comments:

This should be a very straight-forward section presenting the past data on failures and the probability of them continuing. But, it is poorly supported by references to past work, data, information, etc.

This Section is meant to present the historic record of failures as they are maintained in DWR files. No other reference was judged necessary. There are no references we are aware of that address the frequency of occurrence of sunny-day levee failures in the Delta except the database from DWR and discussions with the Suisun Marsh maintenance personnel.

Note, this section discusses the assessment of the frequency or rate of occurrence of levee failures and not "the probability of them continuing."

The organization is difficult to follow and why they used certain reference elevations or databases is not discussed.

NAVD88 is the reference datum that DWR preferred.

They arbitrarily define "sunny day" failures as occurring from June through October but do not say why. They also do not give that definition until they have presented a bunch of undocumented data on failures.

The term 'sunny-day failure' is a commonly used term to denote the general class of failures of water-retaining structures such as dams and levees that fail under normal, non-transient load conditions. Further, in the Delta typically winter storm events and floods do not occur during the period June to October.

It is difficult to separate their conjecture and results.

Everything that is presented in this section is related to the historic record of levee performance and is based on available data provided by DWR. When details of an event are not fully known we state so. In interpreting some events, engineering interpretations are proposed to explain them. These interpretations are based on our experience working in the Delta. The reviewers can disagree and propose better explanations. We are open to any suggestions.

They again make statements without corroboration: "It seems like well engineered levees may be less vulnerable to failure than older non-engineered levees." Seems to whom? It may be conceptually reasonable, but they should not make sure statements unless they back them up with some data (interviews with long-time residents, engineers, etc., something).

We will revise the wording to indicate that we have a basis in review of the available data for making such a statement.

They use terms like "unusually high tide" without defining them. Was this from a storm surge? Higher runoff corresponding with spring tides? What exactly? This section is very short and does not present any aspect of risk analysis.

This is related to the sunny-day events (the period between June and October) and is related to astronomical tides and/or remote ocean-induced storm surges that end up raising the tide in the Delta after some elapsed time.

Specific Comments:

Page 9-2. Top of page: The effect of cumulative deterioration is not necessarily captured by "sunny day" failures. If the levees are deteriorating with time, then they will be more susceptible to all failure modes with time, not just failures where there isn't a flood or an earthquake.

We agree that the effect of cumulative deterioration is not necessarily captured by the historic record of sunny-day failure only. A deteriorating levee will be more vulnerable to floods, earthquakes, and sunny-day conditions.

Page 9-2. Second paragraph: What is meant by an "unusual" high tide?

This phenomenon is associated with astronomical tides (coincident pull from both the moon and the sun when aligned) or remote ocean-induced storm surges that end up raising the tide in the Delta after some elapsed time. This was the case during the Jones Tract failure on June 4, 2004 and recently during the Staten Island near miss on June 21, 2007. In both cases the high tides were about 2 feet higher than normal.

Table 9-1: It seems like these failures could be included with the hydrologic events (they represent the left-hand tail of the fragility curve with probability of failure versus water level). This approach would both simplify the model and the presentation of the results.

We kept the two models (sunny-day failure and winter-storm failure) separate because the frequency of these events and their corresponding stages are different.

Section 10 (Responding to Levee Breaches)

General Comments:

This relatively brief section describes the prioritization process (decision model) for responding to multiple levee breaches and the associated time and cost of performing those repairs. It also contains a good discussion of assumptions and the possible biases introduced by them. The material is generally presented in a reasonable fashion, although some specific questions do arise concerning what and how this module fits into other models/modules in the overall risk analysis. Also, this chapter contains some of the odd, equivocating language used in other sections of the report that is inappropriate for a document of this type (see below). As with other chapters, this section lacks references and citations. The last pages of the chapter list a bunch of speculations but it is not clear what they mean to the analysis.

We will consider these general comments in the context of our specific responses, which follow these general comments and responses. We emphasize that this section was intended to be a summary. Any reader who wants more detail must refer to the TM. The TM includes appropriate references and citations; some may not have been carried through to this report. The references will be checked. Any that are missing will be added to the revised report.

Additionally, we note you ignored aftershocks. This needs to be emphasized.

It is standard practice in probabilistic seismic hazard studies and in seismic risk studies that aftershocks are not included in the analysis. In fact, if historic seismicity is used to estimate earthquake recurrence rates, one of the first tasks is to remove foreshocks and aftershocks from the catalog. Given that this is a standard practice, we did not feel it was necessary to identify or emphasize this fact.

In our revision of the report we will make note of the fact that aftershocks are not included in the analysis.

Specific Comments:

Page 10-2: Is it un-conservative to assume no constraints on future dewatering resources? If yes, say so.

We believe it is not un-conservative to assume that dewatering resources will be available as and when needed. Dewatering rates will be limited by levee stability considerations. With truck and rail transportation available in the region, the geographic territory accessible for dewatering resources is continent-wide. If this appears to be limiting, appropriate projection of needs should allow marine transportation to provide access to additional resources.

Page 10-1. Bullets at the bottom and top of page 10-2: We think the third and fifth bullets are not reasonable. In the fourth bullet the authors should emphasize this is not conservative.

Regarding bullet 3 – Trained labor, if insufficient locally, can be augmented via air transport. Gross availability of critical equipment was addressed in bullet 2. Other *equipment can be augmented by truck or rail. The critical material is expected to be rock loaded to marine transport, as described in the preceding paragraphs. Other material should be available via truck or rail. It is debatable whether the critical material (marine-based rock) or equipment (marine transport and placement equipment) will be pre-empted by other needs outside the Delta that occur due to the same seismic or flood event. We concluded that after an initial period of marine rescue and reopening of shipping channels, restoration of the state's water supply through the Delta would be the top priority need.*

Regarding bullet 4 – Assuming that aftershocks are of less magnitude than the primary event, we concluded that other forces (extreme tides and wind/wave events) were more likely to result in new levee failures that flood additional areas. It is correct to say that not considering aftershocks is slightly unconservative.

Regarding bullet 5 – We addressed this bullet (potential limitations of dewatering resources) in the first specific comment response.

Page 10-2. Section 10.4: So what? The report should state some finding or recommendation.

The single sentence following the Section 10.4 heading was intended as an introduction to the following four subsections, which address how assessment of ongoing damage and prevention of further damage are modeled. The next version of the Phase 1 Report will contain additional language to make this more obvious.

Page 10-3. First bullet: Although this section is describing wind erosion to the levees, we note that the analysis here divides each island into eight sectors, whereas some of the subsequent discussions concerning scour holes and their costs imply that levee vulnerability is treated as a continuous variable. If so, how is this reconciled in the linking of these modules?

Where a levee breach occurs in a failed reach is random. We have mapped the island sectors to the levee reaches that were modeled. The analysis identifies the sector where a levee breach or damage occurs. Dividing the islands into sectors was coordinated with the hydrodynamic modelers to ensure that the level of detail the WAM model required was passed along.

Note, to some level most if not all random variables in the analysis are discretized for numerical analysis.

At the bottom of the page, we commend the authors for noting that any prioritization performed in the report is likely to be different than what actually happens.

Under the BAU approach for emergency response, prioritization decisions are the responsibility of Incident Command. Obviously, higher authorities and political pressure will also be involved.

Page 10-3. Section 10.4.4: Yes, the statement is true. How was this evaluated in the analysis/study? It is not clear what was done. More discussion of this topic “Secondary Breaches on Non-flooded Islands” is suggested.

Additional language will be considered for the next version of the Phase 1 Report. Damaged non-flooded islands are discussed further in this draft of the report in the next section, which addresses repair priorities. They are given the first priority for repair. Discussion on the secondary breaches will be expanded.

Page 10-4. Bottom of page: The phrase “[…] the most important activity was thought to be controlling ongoing damage” is confusing. Do the authors not know what the current state response strategies are for these events? There must be some document prepared by some state agency defining this.

The BAU response strategy assigns prioritization decision making to Incident Command. The authors have searched state documents for current state response strategies. We have also participated in a separate project addressing state “emergency preparedness and response to Delta levee breach events.” We believe we are aware of relevant documents. Although some useful documents exist, they are not particularly helpful in providing guidance to Incident Commanders on prioritization decisions.

Page 10-5. Middle of page: What does the phrase “The scheduler looks through[…]” mean? Is this part of the optimization model, or are the authors talking here about an actual person?

“The scheduler…” means the scheduling function incorporated in the ER&R model. The model is not an optimization model. It is a simulation model that makes prioritization and scheduling decisions as necessary to proceed through any given event with a description of reasonable response and repair activities, given BAU assumptions and the needs of subsequent modules in the risk analysis (water analysis, economics, and ecosystem).

In the first line of the “Population” subsection, the word “only” seems redundant.

This language will be reconsidered in the revision of this section.

Page 10-6. Top of page: What is the source for the statement that flooding of McDonald Tract does not have a “crippling effect on the regional economy?”

The source of the statement was personal communication with the leader of the DRMS Economics Team.

Under “Salinity,” what does the phrase, “based on the hydrodynamic modeler’s judgment,” mean? Does this mean that the model is programmed this way or is there some sort of interactive analysis whereby the modeler plays around with different orderings?

This is not an interactive analysis. The priority order had to be established before the simplified hydrodynamic model was operational. Thus, the hydrodynamic modeler's judgment was used, based on a range of levee failure calculations that had been performed in earlier work using the two-dimensional Research Management Associates model.

Later in the paragraph, the text notes that multiple runs would be preferred but were not done due to time constraints. Does this mean that only one run was done with the repair module? If so, how then is this simulation outcome probabilistic?

This statement is referring to the fact that we would have preferred to make a series of hydrodynamic calculations in order to establish the salinity priority. As noted above, we did not have the WAM model available to do this at the time.

Note, we do not state that the levee repair analysis is probabilistic.

Later in the text on this page the authors use words such as "were thought to be" and "seems unreasonable" to justify what they did. We would prefer them just to say what they did and let the reviewers evaluate whether they are reasonable or not.

This language will be reconsidered.

Page 10-7. Second sentence: Does this mean that the category C islands are not part of the risk analysis?

In the seismic cases analyzed to date, Category C islands have not yet been included. In the two flooding cases analyzed, flooded Category C islands were prioritized based on a consideration of acreage, flood volume, and apparent existence of flood easements.

Later, in the bullets, the authors again use words like "probably", "may" etc. to describe situations where their assumptions may not hold. Since they are simply citing limitation here, we think they should just state what they are and not speculate as to whether or not some third party might interfere, etc.
This language will be reconsidered.

Page 10-7. Section 10.6: Why is this component of the risk model treated as deterministic? The consequence of breaches will depend strongly on the response, and there is substantial uncertainty in the effectiveness of the response (as the bullets clearly highlight).

The initial task for the Emergency Response & Repair model was to create an analytical process for addressing any Delta levee breach event – a few breaches or many. Uncertainties are recognized, but considering uncertainty was delayed until a deterministic model was in place as a first goal.

Page 10-7. Section 10.6, first bullet: The choice of no access constraints is not conservative and probably unrealistic. Last bullet same page: The state "will" have to make priority calls not "may" have to. They should start this process now.

The word "will" will be reconsidered. Telling the state that it should start this process now is not a role we have.

Page 10–7. Section 10.6: The last bullet calls for planning, prioritization and management. Why not say so?

Our contractual assignment is to assess the risks and consequences of Delta levee failures under BAU conditions and policies. In Phase 1, we have the added responsibility of highlighting the assumptions that are key to our assessment. Strategies to reduce risk are addressed in Phase 2.

Section 11 (Salinity Impacts)

General Comments:

By examining the technical memorandum (TM) for this section, more information could be found (that was not presented in the report itself) that justified the approach. These documents showed that the WAM model forms the core for the salinity impacts. The authors acknowledge that they have only included salinity, and that other water quality parameters may also be important. This decision is understandable, considering the time constraints. The Panel also agrees that other water quality parameters are important but that doing a good job on salinity is a high priority.

No response required.

It appears that the WAM collection of sub-models is reasonable, although there are aspects that are poorly documented so that definitive evaluation is difficult. The WAM is critical to the entire analysis because it the funnel point where the immediate effects of levee breach (flooding of an island) links to economic and ecosystem consequences. So the earthquake and flooding lead to island flooding, and the WAM follows the changes in water quality during the initial breach, repair and water management responses (e.g., reservoir operations, pumping), and then recovery.

This is an accurate statement of the WAM function.

We presume these sub-models involving the water management and pumping decisions are reasonable, and they likely are reasonable based on the WAM TM and the accumulated knowledge we have about water dynamics in the Delta. One could question the rules built into the decision-making in these sub-models but it seems what was done is reasonable. For example, how consumptive use might respond to a major breach is debatable; but the authors have seemingly made reasonable assumptions and have used available models. This is an example of some “trust me” from the authors that the Panel grudgingly accepts as the price of doing this type of analysis in a short period of time.

We would be the first to say that the WAM would benefit from further review and refinement of some aspects of the submodels and especially of the decision-making rules. We hope to be tasked with this additional work and with facilitating the needed external inputs (particularly from water project operators) in order to provide improvements in the form of a “Version 2.”

The hydrodynamic and water quality (salinity) modeling is of particular interest. The wide range of temporal and spatial scales inherent in simulating local responses of salinity to rapid changes in water levels (i.e., flooding) is a challenge. The authors then want to be able to do this with relatively quick computer time. There are several models that simulate salinity in the Delta region. Indeed, the Panel’s first reaction to the conclusion reached by the authors that yet another hydrodynamic-salinity model was needed (page 11-7) was disbelief and frustration. However, this changed upon further examination of the revised WAM TM. The reason put forth by the authors was the need for performing many model simulations. On page 11-7, the authors state, "[...] provide sufficient accuracy while maintaining the computational speed needed to simulate many thousands of levee breach events." As it turned out, only 18 earthquakes and even fewer flooding scenarios were actually done, so the authors could have used one of the existing models. But if an efficient model is needed for salinity simulation later (hopefully the problems and incompleteness of the analyses in the draft report are corrected), then the authors have a good tool available to them.

We appreciate this assessment and also hope there is opportunity to perform the thousands of simulations that were initially envisioned. As the initial Phase 1 work was being completed, the WAM was used to simulate five specific levee breach sequences produced by the Emergency Repair and Response module at 909 start times within the CALSIM baseline simulation period (over 4500 individual WAM simulations of up to 5 years each). These results are discussed in Appendix D of the WAM TM. The number of simulations performed by the WAM and Hydrodynamic were sufficient (4500 individual simulations, it was the number of consequences simulations (economic and ecosystem impacts) that was limiting. We are currently adding a number of breach scenarios to cover a reasonable range of economic and ecological impacts (from frequent to less frequent.)

But the Panel had to look at the new (revised) TM to find sufficient information to determine that the new, yet another, salinity model that had been developed, had been developed with careful thought, had been fairly well tested, and evaluated for its skill. The draft report was incomplete in its description and documentation of the new salinity model.

The draft report was written before the revised TM had been completed. During the present revision of the report, additional information will be brought forward from the TM.

Based on the new information provided in the revised WAM TM, the authors have done a pretty good job in developing a reasonable and computationally efficient salinity model. This was quite a challenge and the developers of the new model should be commended for what appears to be a thoughtful approach. The draft report does not do the new salinity model justice. For someone who is not well versed in the WAM model, it would be good to show a network diagram of how everything works together and what feeds into what element that then determines the output.

We will provide a network diagram in the next version of the report.

Within the report itself, and not considering the associated TM, there is minimal citation and discussion of previous work is given. They present results and comment on their model but do not explain how it works or what past work it is based on.

Additional detail and references to previous work will be provided in the next revision.

Many statements made were difficult to verify because there is no reference to previous work or data, etc. For example, they make the statement that the rush of water filling an island dominates Delta water flow. This is probably true in some situations, but certainly not all. It depends on the tide, runoff, etc. This is a general statement that is not always correct and not substantiated.

Additional detail on variabilities will be included and care to avoid inappropriate generalizations will be exercised.

Overall, this section is very disorganized. Subsection 11.5 should be at the front. They again start with presenting conjectures without substantiation or explanation. It is not clear what the figures show and why they are important.

We will consider these suggestions as we revise the report. In our view, the early sections (11.2 through 11.4) provide essential inputs to the hydrodynamic submodel and were therefore discussed first.

There is no determination of risk in this section.

This is as intended. Risk results are presented in Section 13.

The section on "Other Water Quality Impacts" says little other than additional variables to salinity could be included at a later date.

This is as intended, although specific concerns about organic carbon and toxics were highlighted.

The figures were readable, but having looked at the revised TAM, they do not reflect the amount of work that went into testing and evaluating the new salinity model.

The additional figures needed were not available at the time the report was prepared. They will be added in the next revision of the report.

Specific Comments:

Page 11-3: The text about WAM only using previous time step information, and the text about the mix of time steps that was used, is confusing. So, what was simulated on a daily time step and what was considered on a monthly time step? It seems from the example results presented that water quality (salinity) is predicted daily; yet, the authors state, "the overall results of Delta water quality […] are reported monthly." The revised WAM TM helped here but the text in the draft report should at least be understandable.

The text on page 11-3 will be revised.

Section 12 (Consequences Modeling)

General Comments:

One panel member found this section provided a good description of what the authors did, and did not measure in terms of consequences (resources at risk and the impacts of flood events to those resources) of flooding events. However, all other panel members thought that this section was disappointing: first because it is poorly written, and second because there are very important assumptions made and factors left out of the analysis. Understanding what is included or not included in the analysis is very difficult to ascertain because of the writing. The authors describe how various impacts were measured, along with caveats on the nature of those estimates. Of the three major categories of consequences (life and safety, ecosystem, and economics), the inventory of economic resources is most complete. It is unfortunate that more was not said or done with respect to the other categories. It is our understanding that there are standard safety models employed by USACE that could have been used to provide a better quantitative metric than simply listing populations. In that case, this section should be expanded to reflect such information. Similarly, treatment of ecosystem impacts could be revisited. The current "risk index" metric for species was confusing. Failure to say much about ecosystem impacts leaves a big hole in the overall risk assessment. Our specific comments relate primarily to the economic costs and impacts analysis.

We agree with the comment. The discussion on the life safety is being expanded to loss of life estimation using appropriate and applicable models. We recognize that ecosystem impact was complex and not well defined in terms of impacts metrics. We are currently revising and simplifying it using expert elicitation.

As with other sections, there is a disappointing lack of citations, previous work, context, etc. There is much seemingly extraneous material, or least it is not clear why it was presented. It is not clear how this section is different than "Section 5"; the two sections should be combined. There is much repetition from previous sections within this section. The authors need to put all this information in the context of previous work and experience. Jones Tract flooded not long ago, so it seems like an excellent example to present, or at least test their concepts and models. It is not clear what they did exactly and how they did it. There is a long list of items, poorly grouped and organized, and it is very difficult to determine how valid their approach is. For example, there is a lot of information in the lookup tables for each island, but it's nearly impossible to follow how the tables can be used. You'd expect that for each scenario, it would be easy to lookup impacts for each group of islands (rated by vulnerability if that's their classification scheme).

Overall, it would be very helpful to show what the models estimate the consequences to be for some example breaching scenarios.

Any redundancy between sections will be removed and the sections will be more focused. The ecosystem impact analysis is being revised to be simpler and clearer. We will add simple tables summarizing the main impacts for selected island flooding scenarios.

A large criticism of this section is that uncertainty really isn't propagated through the analyses. In other words, despite claims that uncertainty is in fact incorporated in the analysis, it is not. Some elements of the impacts will have high uncertainty, others low – there is not stated or described methodology for how the project team handled the uncertainty throughout the analysis (and then uncertainty basically disappears for future horizon years).

As we stated at the meeting with the IRP in March and in the report, we were not able to incorporate uncertainty in the consequences. The reasons for this and the limitations we faced were discussed in our response in Section 4. We repeated our response here.

We believe such assessments can be made in the consequence areas we addressed. As noted by Professor Rose in our meeting with the IRP in March, the uncertainties in the ecosystem area are difficult to estimate and potentially so large their assessment renders the results useless (our paraphrase of Professor Rose's words). This sentiment does not seem inconsistent with our statement or our experience in dealing with our TAC and team experts in the ecosystem area.

In the economics area we had a similar experience with our team members and in separate discussions with two economics professors from U.C. Berkeley. When addressing the subject of probabilistic modeling and in particular modeling uncertainties, the responses varied from "not really doable" to "such assessments can be done." In neither case was there an expression that such assessments are within the normative practice of the profession or academia for that matter.

There is a major disconnect between the introductory text to the report, and even the introductory text in this section, and what was finally done for assessing the risks to the ecosystem. Here, the focus of the Panel's comments is on the ecosystem impacts (aquatic species, terrestrial vegetation, and terrestrial wildlife species). In the subsections on ecosystem consequences (section 12.1), there are many examples of the authors saying words but not saying anything concrete. The authors spend most of the text in the draft DRMS report trying to explain how what was described for assessing risks to terrestrial plants, terrestrial wildlife, and fish in the *Ecosystem Consequences Technical Memorandum* was not ultimately done in the analysis. There is quite a bit of text in the already too brief "Section 12" of the draft report devoted to discussing stuff that was not used in the analyses.

The ecosystem impact is being revised and simplified as indicated below in the specific comments section.

Page 12-12: The approach finally used for terrestrial vegetation and wildlife is reasonable. Despite the authors not doing everything that was described in the TM (e.g., they dropped time to recovery), what was finally done for the terrestrial species was relatively simple and conceptually understandable. Due to the limited nature of the available data on vegetation distributions, presence was used to determine the fraction of the total area impacted (assumed all organisms lost). For terrestrial wildlife, habitat was defined from vegetation types and the same metric of percent of total area affected was computed. So, the effects computed for terrestrial vegetation and terrestrial wildlife are correlated to some degree.

While the Panel was of the opinion that the simplified approach used for terrestrial taxa was reasonable, the simplified approach used for the fish ("Section 12.1.1") was inadequate. A brand new method was introduced for assessing the risks to key fish species that appears for the first and only time anywhere in the draft report, and that which does not share the intuitive appeal of the simplified approach used for terrestrial taxa. The method is, for some reason, described in the following section that shows the base year results. Table 13-26a describes the calculations used to determine what the authors call the "Risk Index." The Panel sympathizes with the authors trying to wrestle with the very difficult task of assessing the risk to fish of levee breeches and island flooding. The broad scientific community is presently under fire to explain the recent declines in several pelagic fish species, and the explanations are not easily forthcoming and will likely be complicated. So it appears that the authors doing the DRMS analysis for risks to fish backed-off on their approaches described in the TM. But what the authors then did in place of the habitat suitability and other approaches in the TM is not very helpful. Their risk index is the sum of risk factors weighted by weighting factors. No justification or rationale is provided for, what appears to be, a new method. The reader has no idea how the weights were determined, nor how the computed risk index behaves. What levels of the index should flag concern, and to what degree should we be concerned. The Panel had no idea how to interpret the changes in the risk index under the few earthquake and flooding scenarios that were performed, and "Section 13" showed that the authors also seemed to have little idea on how to interpret their own risk index. This is clearly a challenging problem, and given the range of methods presented in the TM and then the final method that was used, the authors have wrestled with this problem without a satisfactory resolution. The high importance of being able to assess the risks to the ecosystem (especially fish), and method of risk index used by the authors, caused the Panel to elevate evaluating ecosystem effects as a major deficiency in the draft report that must be corrected.

The Panel discussed what approaches might have been taken to assess the risks to fish, and in doing so, noticed that the experts in this area were listed, in one form or another, as part of the DRMS overall organization (Steering Committee, Technical Advisory Committee, Risk Resources Group) or having made comments on the TM. Were these people conferred with by the authors? It would seem the right people were involved but it is not clear to the Panel if the risk index model finally used was a result of these people's input or not. It is easy to criticize the approach taken by the authors, and the Panels appreciate the difficulty inherent in computing the consequences to fish in the Delta. The Panel would normally recommend that the authors assemble a group of experts to derive a feasible and interpretable method that balances the needs of the analysis to be population-level oriented with the high uncertainty we have about what governs population dynamics of key fish species in the Delta. But if the authors of the fish risk index used the expertise that seems to be involved with the DRMS process and review of TMs, then the Panel is unsure what to recommend. Pending additional clarification from the authors of the risk index of how the risk index was derived and who was consulted, the Panel assumes that the risk index is not the collective wisdom of these other experts. The Panel therefore recommends that these experts, plus others, be assembled and tapped for their opinions of effects and methods for quantifying ecologically-meaningful metrics of fish responses. Something better than the risk index needs to be developed, evaluated, and implemented.

Many of the experts listed in the Steering Committee and technical review groups did not have the chance to work on the ecosystem impact TM. We are currently taking a very different approach in estimating and quantifying the risk to the aquatic species. The approach used is focusing on simplification and the use of expert elicitation.

Specific Comments:

Page 12-1. Life and Safety Costs: Human life and safety should be treated the same as the other consequences. It is not true that “the quantitative models needed to assess these life and safety risks are not yet available.” One example is the Corps of Engineers LIFE Sim model to estimate life loss in natural and dam-break floods.

The statement in the text is in error. We recognize and are aware that this part of the analysis needs to be developed further (we just did not have enough time to complete the expected life loss part of the model). We are familiar with the LIFESim model.

Page 12-2: The text is confusing about what was actually done in the DRMS analysis versus what was described as going to be done in the TM.

The response to this comment was provided above to the general comments.

Page 12-2: The selection of species to analyze is a good balance among life histories, specificity to the Delta, etc. The Panel believes that the spatial and temporal distribution information on the fish species was included in the analysis via the entrainment factor in table 13-26a; but this is not clear. The authors mistakenly state that the “the impacts of these mechanisms were quantified and normalized for a score between -2 and 2.” What the authors finally did with the risk index was not a quantitative analysis. They also then say that a similar risk model was documented for terrestrial vegetation in the TM, but we could not find this. Then we think they later correct themselves again in the draft report and say but it was not used and a different risk model was used in the DRMS analysis for terrestrial vegetation. This is just one example of rambling and convoluted text. It continues later in the section as well. The authors were trying to relate what was described in the TM to what was finally done, but it gets very, very confusing. They should first say what was actually done, and then later can explain how it follows or differs from the TM.
See response on revised ecosystem impact model below.

Page 12-2: The authors recognize the difficulty in quantifying ecosystem effects. However, the Panel disagrees with the authors that the fish risk index somehow shows order of magnitude responses. The Panel could not determine what differences in the risk index mean and how to interpret high versus low values of the risk index across scenarios.

See response on revised ecosystem impact model below.

Page 12-3. Discussion of economic costs and impacts: We would encourage the authors to expand this discussion to help distinguish economic costs (efficiency effects) from impacts. We suspect that the lay reader will not fully understand the difference based on the terse discussion here. As an example, consider changing the definition of *economic costs* to read something like "In economic terms, the cost (damage) from a flood event is equivalent to the potential economic benefit of activities that eliminate that flood event (avoided damages). The more the authors can link the definition to examples (such as they do with *impacts)*, the more transparent the differences will be to the reader. The authors could borrow text from other economic studies meant for public consumption that spend more time on this difference.

To begin, economists attach different meanings to "cost" and "impact." The following changes are proposed:

The definition of economic cost has developed from the guidelines for analyses performed relative to federal water resource projects. Economic cost is the monetary value of resources or benefits that are dedicated, consumed or lost. Benefits are people's willingness to pay for goods or services, and economic costs are often a loss of these benefits. As examples, the cost of rebuilding a home and the loss of recreational willingness to pay when the Delta is closed to boating are both legitimate costs.

Economic impacts are measures that people often ask to see – the values of output, employment, labor income and value added that are changed by the flooding event. (Value added is the sum of wages and salaries, proprietors' incomes, other property income, and indirect business taxes.) However, even these economic impact measures can be misleading. For example, if Delta flooding were to prevent harvest of a local asparagus crop, that would have impact on local output, employment, labor income and value added. However, if this shortage of asparagus caused prices to rise and Imperial Valley farm net income to increase substantially, the adverse impact could result in positive economic benefit when considering the state as a whole. As another example, the cost of rebuilding homes can result in a positive economic impact through construction expenditures, but this depends on where the money comes from to pay for construction.

In summary, the economic costs are the net costs to the state economy without any consideration of who within the state bears the cost.

Page 12-3. Economic Costs, and Impacts: Given all of these uncertainties in the economic impacts, why weren't these consequences modeled probabilistically?

For most of these values, obtaining estimates of any sort was difficult. No information was available about probability distributions associated with these estimates. However, with more time, scenario analyses could be performed to investigate how alternative assumptions (such as groundwater availability, and availability of transfer water) might have resulted in a range of estimates.

Page 12-4: The authors decided to use the information in the TM but to simplify it for the DRMS analysis. Is there a particular reason this very significant strategic decision was made? The simplified version of the risk model for the fish species was considered inadequate by the Panel for assessing ecosystem risks. So the reasoning behind this decision should be provided.

The simplification was part of the effort to automate the evaluation scheme. However, This approach will not be used as we are revising the ecosystem impact model as described below.

Page 12-5: It is not clear how "season of breach" and "species and lifestage location in space and time" enter the risk calculation for the fish species. The Panel deduced that the location information entered in the entrainment on islands risk factor and maybe the authors were thinking about "season of breach" in terms of the different months in several of risk factors (table 13-26a). In section 12.1.1, the authors again explain the location aspects of the fish species but never say what was actually done and how the information on location was used.

See response on revised ecosystem impact model below.

Page 12-6: How do the items on this list of "things", such as species life histories, water temperature, etc., relate to the list of parameters on the previous page? So, the authors list water temperature and then say it was not used. This continues with many factors, some included, and most not included, until the reader gets lost as to what was actually done and why.

See response on revised ecosystem impact model below.

Page 12-6: How was the "level of suspended sediments" used in the risk index?

See response on revised ecosystem impact model below.

Page 12-7: The authors decided to group the possible factors under "Risk Model", which we presume to mean was actually included in the DRMS analysis, "Further Refinements", which we assume means was no included, and "Qualitative", which we think means the factor was thought about but not included in the risk index. This was quite confusing, as not all of the factors listed in "Risk Model" show up in the risk index calculation, and there was almost no interpretation of the results in Section 13, so how the qualitative information was used remains a mystery.

See response on revised ecosystem impact model below.

Page 12-9: The text associated with many of the factors does not really say much in terms of concrete information. It is more that here is factor and it varies and its effects vary. A noteworthy example is the statement at the end of the discussion on "Succession after a Levee Breach […]," which stated, "Succession in newly created habitat was crudely estimated in the risk assessment model." How? The entire discussion on contaminants culminates with the statement "[…] but these effects have not been quantified as part of this analysis." At this point, the Panel was confused as what was actually done and why selected topics seems to be highlighted, some included in the risk index, some included but not clear how, and some dismissed.

See response on revised ecosystem impact model below.

Page 12-12: The model used for assessing risks to terrestrial vegetation was also simplified from that presented in the TM, although not to the degree that the fish model was simplified. The actual calculations done, as best as could be inferred by the Panel, was reasonable. Presence maps were used to determine the percent of total area of species presence in the Delta and Suisun Marsh impacted by the island flooding.

See response on revised ecosystem impact model below.

Page 12-13: Again, as with the fish discussion, the authors then go into further refinements, which are fairly vanilla descriptions that basically say things vary and things affect things and the authors ignored them.

As a response to the above comments, the ecosystem is being revised completely. We plan to simplify and quantity the impacts in a simple, expert- elicitation-based approach. The main elements of the revised model are based on a simple cause and effect evaluation. The model will focus primarily on the impacts to the aquatic species from levee failures and entrainment. The failure mechanisms, timing of breach formation, turbidity, entrainment (percent of population entrained based on toe-net survey and density of population by region), island closing and pump-out models have been already developed by the DRMS technical team members. These will be defined and quantified in a manner suggested by the experts assembled to help with the development of the model. The quantification of impact (percent mortality and increase in the probability of extinction) will be developed based on input from the experts.

Currently the experts assembled for this effort include Professors Wim Kimmerer, Peter Moyle and Bill Bennett and Dr. Chuck Hanson. We are adding possibly two more experts on fishery from the DWR as suggested by the three experts.

Page 12-15: The risks to terrestrial wildlife were computed based on their habitat needs and the vegetation maps of habitat presence. The authors need to acknowledge that the risks to wildlife and risks to vegetation are therefore correlated.

We concur with this comment.

Page 12-16. Middle of page: We believe this is the first time in the report an actual solution model, or algorithm is defined. We are not familiar with this model. We would like to see how the probabilistic information (presumably from earthquakes) interfaces with the discrete events. Is there a flow diagram for this model?

The model will be described completely and clearly.

Page 12-16. Section 12.2: Please spell out the acronym ER & R.

ER & R refers to Emergency Response and Repair. It will be spelled out in the report.

Page 12-17. Bottom of page: How do the authors know where the scour hole will develop? This is a function of a host of factors and from earlier discussions in the report, it is not clear that the authors had the capability to define specifically where a levee would fail. This same comment applies to the second from bottom paragraph on page 12-18.

We do not know where the breaches are going to occur. We apply a probability of occurrence anywhere along a levee, differentiated only by the variation in the ground motions, flood stages, levee vulnerability, etc.

Pages 12-19 through 12-29: The remainder of the text describes the data and assumptions used to develop inventories of potential economic costs and impacts within the Delta. Unlike some of the other consequence categories, data on economic infrastructure and resources is abundant. The authors appear to have used the best available data to identify and quantify these potential costs and impacts on resources at risk. The assumptions employed in developing this inventory also appear reasonable.

No response required.

Page 12-22. In the section on urban water users: It is not clear that this is correct. It seems like that any disruption of supplies has a “cost.” Just because they can replace it with water stored in aquifers, does not mean it does not cost them anything to replenish that storage, etc.

The report did not mean to imply that there was not a cost to these agencies. The language of the report should be changed to make this clear, by including the following explanation:

These basins had largely recovered from overdraft conditions in the 1960s, and the agencies could be expected to be able to mine water from the basins over an extended SWP outage with very little effect.   They are not expected to experience shortages or incur shortage costs. However, there will be costs associated with the reduction in Delta export deliveries. First, the agencies and society as a whole will SAVE the incremental cost of transportation of the water from the Delta – that is, there will be a savings because of the reduced water transport costs. However, these savings will be more than offset by the increase in pumping costs because the water levels in the aquifers will remain lower than they would otherwise be. This net cost was felt to be small enough compared to the modeling effort necessary to estimate it that it would be best ignored in order to have the time to complete other parts of the analysis. It should be noted that these agencies could not maintain their water supplies during an indefinite closure of the Delta.

Section 13 (Risk Analysis 2005, Base Year Results)

General Comments:

This section is very, very important but fails to fulfill the standard level of documentation required in scientific and engineering reports. It took the collective expertise of the Panel, intensive discussion, detective work cross-referencing the TMs, and hypothesizing by the Panel to be able to deduce what was done sufficiently for the Panel to then intelligently comment on the technical aspects.

Because they have not defined their approach to determination of risk well, it is not clear what all this means. In this subsection, they say that "sunny day" failures will not have a forcing – they just multiply out the past rates into the future. This shows another problem with presentation. The probability of failure today (2005) is based on the annual frequency of events from the past. That is all they need to represent here. This is the "risk analysis" for the 2005 base year. There is no need, and in fact it is distracting, to present the number of failures in the next 50 and 100 years. These rates will change due to forcing from sea level rise, levee maintenance, etc. It is not clear why they make certain assumptions, e.g., no more than one failure on a high tide. They did not show that there was a significant correlation between tide and failure, so this seems arbitrary.

We agree this is a very important part of the report. We also agree this section needs revision and expansion.

The presentation of the probability of failure in the next 50 to 100 years can be confusing. Further, it does change as suggested by the comment. We will revisit the presentation of this information in our revision of this section.

Historically we have not had simultaneous sunny-day failures. While the Delta as a whole might experience a common high tide. There are other reasons why these failures occur that relate to the levee and its foundation and not to the tide. Our analysis assumes that levee performance is independent from one island and even one reach to the next, given a common high tide. As a result the joint probability of 2 or more sunny day failures occurring simultaneous (same day, week or month), while not zero, is very small.

The seismic risk seems over-stated based on the historical performance. Figure 1 and table 1 compare the DRMS estimate with the raw data from the past 100 years. While there are no known incidents of flooding due to a seismic event in the past 100 years, DRMS estimates that there is a 100 percent chance of at least one seismic-induced flooding incident in 100 years, and a 95 percent chance of an event where at least 10 islands flood. Even if we assume that only the last 20 years are representative of the present-day conditions in the Delta, then we would have expected two events with at least one island failing due to an earthquake and there is only a 16 percent chance that we would have had no failures due to an earthquake.

The seismic risk seems over-stated based also on the previous CALFED (2000) analysis. This study estimated the annual frequency of at least one earthquake-caused levee failure to be three times smaller than the DRMS estimate (a return period of 30 years versus 10 years).

This concern is noted and we have responded to it in a number of places.

We would like to know about any geologic evidence of liquefaction in the Delta soils over the past 5,000 years. We would also like to see a hindcast of the site response from the 1906 Earthquake to see if widespread liquefaction is predicted. Just because the levees were lower, there still would have been obvious signs and reports of ground liquefaction if it did occur.

We have responded to the question of evidence or lack of evidence of liquefaction during the 1906 earthquake. There is no information available to state either way. We do not believe that in the context of the DRMS scope and schedule we could conduct paleo-liquefaction investigations in the Delta. This task is a large investigative undertaking that may not yield any answer given that the Delta was mostly wetland and tidal marshes where silts and sand deposits may not be distinguished from liquefaction-induced sand boils. We have performed analysis of the levee and foundation responses using a 1906 earthquake and the information will be presented in the revised report.

The failure rates shown by cause (seismic or flooding) appear to be very high (tables 13-3, 13-6, and 13-8), so the probabilities, by island, of failure in 25 years, and in 50 years are scary, but perhaps unnecessarily so. Given the historical record of much lower instances of failures, and the recollection of the Panel of previous studies showing lower failure rates, these high failure rates shown for many islands need further evaluation. Unfortunately, more insight by the Panel into possible reasons why the high failure rates were estimated are not possible without further investigation.

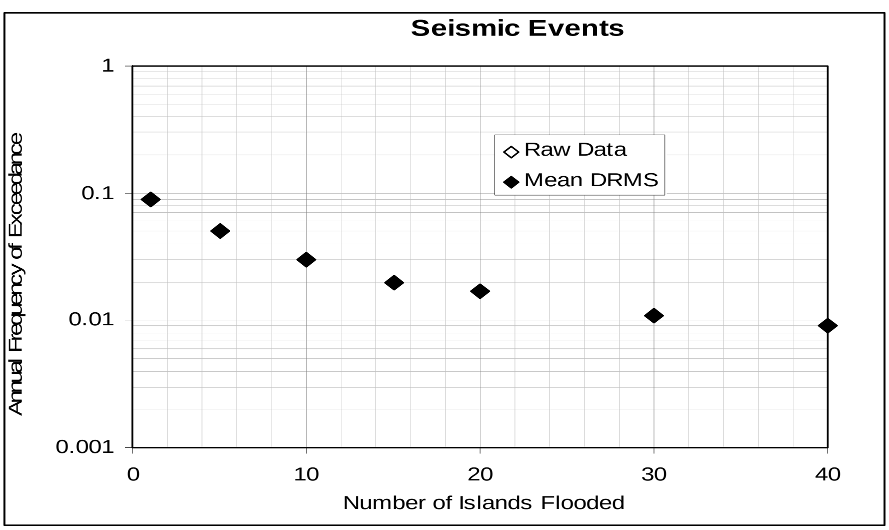


Figure 1: Comparison of DRMS Estimate and Raw Data for Seismic Risk

Table 1: Comparison of DRMS Estimate and Raw Data for Seismic Risk

	Seismic Events	
Number of Islands Flooded	DRMS Probability of Exceedance in 100 Years	Actual Frequency of Exceedance in 100 Years
1	***1***	***0***
10	***0.95***	***0***
20	***0.82***	***0***
30	***0.67***	***0***

There seems to be a very high failure risk of islands compared to previous work. For example, in table 13-3, Sherman Island has a annual mean number of failures of 0.043. That is about 4.3% chance of failure from an earthquake each year. Looking at the area of similar islands, this seems much higher than what Torres et al. (2000) found. In that region they simulated an M=7.1 earthquake on the Hayward Fault. That would be a very big event for this region. They determined that only 0.1 to 2 islands would fail in the region of Sherman Island. This is a different determination than in the report so it is difficult to compare, but Torres does present PGA maps. From looking at those maps, it appears that the probability of PGA of 0.2g (from 0.003-0.008 or 0.3-0.8% (depending on the model used). That is much different than the DRMS *Phase I Report* found. It is difficult to know if these probabilities are reasonable and why they are different from the Torres results because this was not discussed in the report. It is important to know how this affects their outcomes.

We are in the process of reviewing the levee seismic fragility work and conducting additional evaluations to verify the work that we have performed. We note that our conclusions, while numerically different from the Torres, et al. (2000) work, are the same. Further, our conclusion is the same as all other studies over the last fifteen years.

The quoted estimates from Torres, et al. (2000) which we are aware of, are not real clear. For instance, how does one fail a fraction of an island? Since they are working on the estimated number of breaches, this result does not compare directly to our assessment. Nonetheless, we are looking into the differences between these two studies.

Please note that we have offered answers to this question in response to comments in previous sections where we highlighted the main differences in the two studies.

The tables presented in this section confuse the issue. Some make projections into the future when this is supposed to be 2005 probabilities and impacts. They need to either stick to 2005 or bring in the future for each topic and completely describe the probabilities and impacts. Also, they use years that do not meet the charge. They should stick to 2005, 2050, 2100, and 2200. If there is some reason to use other years, they should explain why. They do this throughout the report and it makes it difficult to compare across topics/sections.

As noted above, the presentation of the probability of failure in the next 50 to 100 years can be confusing. We will revisit the presentation of this information in our revision of this section.

Much of the information presented here should be (or was) in the "consequences" section. The organization of this is very confusing. It would be much better if they first developed the potential losses and then took each major topic as defined by AB 1200 and fully addressed it: probability of occurrence in 2005, 2050, 2100, and 2200.

We will consider this suggestion in our revision of the report.

Public health and safety consequences from earthquakes seem very minimal (two sentences).

We will be expanding the assessment of public health and safety consequences and including these results in the report.

For subsection 13.3.2 (Flood Consequences), they seem to have changed how they do scenarios. This has been a confusing issue from the beginning. They present in one figure in "Section 4" that they have this model-based, "continuous" system that determines probability functions for each process. But we find here and in the seismic section that they present scenarios. They spent a huge amount of resources trying to develop some probabilistic approach and in the end fell back on scenarios that could have been used effectively from the beginning. If they would have set out with this approach and used existing data and information instead of doing new analyses, they would have produced a much more useable and understandable document. The fact that they fall back on scenarios in the end shows that they cannot make the other approach work.

We disagree with the characterization of the approach that was used in the risk analysis. When we expand the presentation of the risk analysis methodology and its implementation we believe the reader will have a clear understanding of the analysis that was performed.

The estimated hydrologic risk in terms of the frequency of flooding events seems reasonable based on the historical data for events where up to 15 islands flood. However, the estimated frequency for events with 20 or more islands flooding seems high based on the historical data. For example, there is estimated to be greater than a 50 percent chance of at least one event with more than 20 islands flooding in 100 years, and yet there have been no such events in the past 100 years. Some discussion of the reasons for and justification for this discrepancy is needed. We would like to see a sensitivity analysis to understand what types of events are driving the cases where 30 or more islands are flooded.

We are doing additional work on the hydrologic hazard analysis and the risk calculation. As part of the reporting of this work we will provide information about the events that contribute to the probability of levee failure and island flooding.

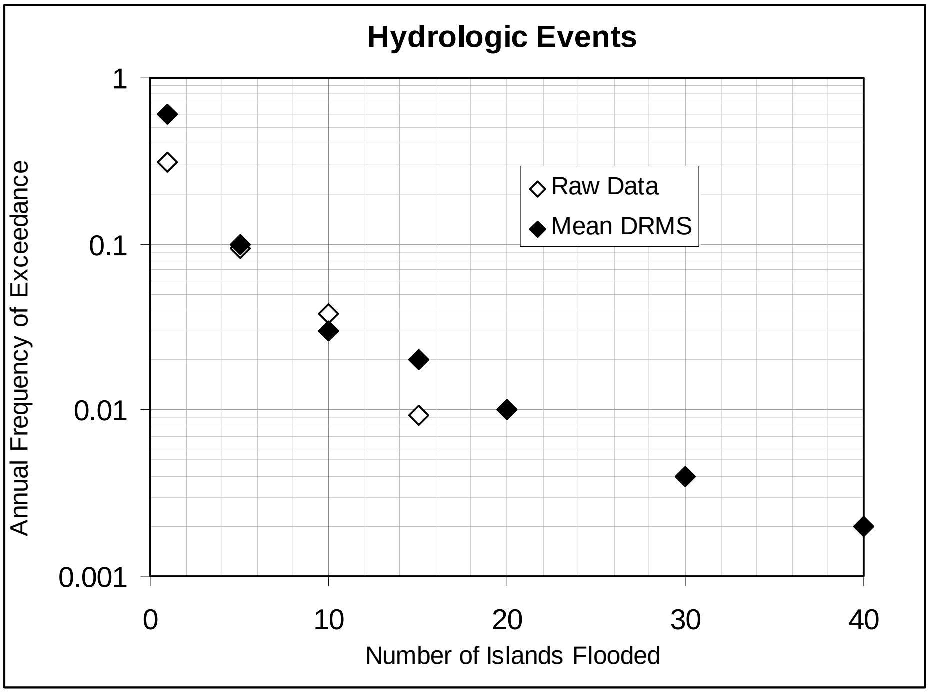


Figure 2: Comparison of DRMS Estimate and Raw Data for Hydrologic Risk

Table 2: Comparison of DRMS Estimate and Raw Data for Hydrologic Risk

	Hydrologic Events	
Number of Islands Flooded	DRMS Probability of Exceedance in 100 Years	Actual Frequency of Exceedance in 100 Years
1	1	1
10	0.97	1
20	***0.61***	***0***
30	***0.3***	***0***

Consequences: The treatment of consequences is not consistent with the treatment of the hazard. Why were the consequences estimated for only a handful of scenarios (18 for seismic cases and only 2 for hydrologic cases)? Why were the frequent, but smaller magnitude events (such as one island flooded), completely ignored for the hydrologic cases? Why wasn't uncertainty included in estimating the consequences? The consequence of $34 billion the worst-case scenario, 30 islands flooded due to an earthquake in a dry-water year, seems small relative to the significance that has been placed on this possibility. What are the associated probabilities with the wet, average and dry water years?

The issue dealing with the uncertainty (in particular epistemic uncertainty) in the assessment was discussed in our responses in Section 4.

Also as discussed previously in the response to comments in Section 12, we agree additional scenarios should be considered for the hydrologic cases.

The reason the dry water year consequence results are as reported is due to the fact there already was limited water available, therefore the occurrence of the levee failure event was not as significant as might be anticipated.

The number of scenarios considered is being reviewed to insure a reasonable range has been considered.

We will report the probability of the different hydrology combinations in the revised report.

The consequences subsection ("Section 13.3") was disappointing, and especially for the ecosystem consequences. The panel presumes that the authors ran out of time, and not that the authors think this is a completed and documented analysis. Why so few earthquake and flooding scenarios were followed through to the end of the analysis is baffling. The authors failed to fulfill what was promised, and even what they described as coming in the beginning of the draft report.

- The results presented in this section seem out of step with what many of us would have expected. For example, failure rates seemed high (tables 13-3 through 13-8) to many of the panel members given historical records. Failure rates are critical and should be fully justified.

We will present further detail and the basis for the results that are provided.

- The eco risk index is incongruent with the methods presented in the earlier sections. How was this derived?

We are revising the ecosystem assessment and moving away from indexing methods.

- We don't understand why so few scenario runs for flooding scenarios (and really even for earthquakes) were conducted in the end? Maybe the earthquake scenarios cover at least the boundary conditions, but we are not even sure of that, and for certain, the flooding boundary conditions (based on frequency) have not been established. Without these, there really isn't a way to make trade-offs for infrastructure investment decisions.

Based on the hydrodynamic calculations that were performed, there are no water export impacts for flood events (disruptions are less than 3 months, which was judged by our economics team to be a level of disruption that was not necessary to quantify) even in the case of 20 and 30 flooded islands. Thus, for cases involving fewer islands there will also *be no water export impact. As a result, the only economic costs and impacts are those that occur in the Delta.*

- The population risk measure borders on silly. Tallying the entire population for any given life and safety risk inflates the true life and safety risk. The project team should use a standard approach.

We are revising the public health and safety modeling and the revised report will reflect this work.

- It seems like there should be enough information provided that a person could draw a line and say "here is what is catastrophic." There is just no way to do that with the current information.

The perception that a line can be drawn in the manner suggested is erroneous. First of all – what is the definition of a catastrophe for California? What are the parameters for defining a catastrophe: are they economic, public health and safety, legal, etc. and what are the limits that need to be crossed?

Technically, the answer to these questions is not a part of the Phase 1 analysis.

We have asked ourselves this question and have work ongoing that started in the summer that will at least lay out the framework for what might be considered a catastrophe in California. We have two professors, in economics and law, from U.C. Berkeley working on this.

- There aren't really any integrated models; text referring to integrated models should be dropped from the report.

This statement is incorrect. Our detailed presentation of the risk analysis methodology will show the elements of the risk analysis and how they are integrated.

Specific Comments:

Page 13-4. Last paragraph: What does the following passage mean: "Because of irregularities in the levee crest elevations (singular dips and spikes) the probability of flooding by overtopping were (*sic*) modified to correct for these artificial conditions. Overtopping was allowed to initiate only between the two points bounding the 100-year flood event."

The IFSAR survey of the crest of the levee has been a continuous source of artificial nodes that needed to be carefully removed so they do not present source of error in the calculation of overtopping. As an example the radar survey (IFSAR) with low grid resolution could miss the crest of the levee and shoot points on the side of the slope. These points can be misread as crest elevations wrongly and would cause early overtopping. On the other hand a point can be shut on the top of a structure and would show a higher crest elevation. We filtered out all these singularities for all crest surveys *before using them. These corrections were made by hand or were removed by developing a 1000-foot running average for each levee crest survey.*

Page 13-3. Table 13-2: We like this. We think it might be better (more useful) if you added a column for 10 years. Same comment for table 13-5.

We will consider this suggestion in our revision of the report.

Page 13-5. Table 13-7: In discussing this table the authors might just make the point that people who go to Las Vegas and gamble, place bets all the time on odds of 0.48 to .049 which is about the odds for failure of 20 islands in the next 25 years.

In this report we do not believe it is necessary to make such a comparison. Further, when we provided this type of information which can be helpful in presenting information to the public, we note in the review of the Summary Report the panel had the following comment:

> *"Probabilities of different events (hole-in-one, cancer, etc.) are cute but don't really have a place in a serious scientific report. These are not the funny pages of the Sunday newspaper. Not to mention deceptive – many more people have hit a hole-in-one than one in 5000 – that's per shot, not per lifetime."*

It appears the panel members have mixed views on this matter.

Page 13-8: The authors are unclear as to how the risk index "incorporates immediate mortality and as well as long-term impacts." One cannot deduce from the index calculations how these are weighted or how they influence the index. Indeed, we have no idea what how to interpret this risk index.

We agree, the indexing approach is confusing. We are revising the ecosystem assessment and moving away from indexing methods.

Page 13-9: Why the risk index method is here is puzzling. Table 13-26a should be in "Section 12" as part of the methods for ecosystem consequences.

We agree, this discussion is not required in this section.

Page 13-10. Table 13-26a: This risk index to measure ecological impacts seem like a reasonable approach, however it is not described anywhere. Examples of scenarios should be provided to gain insight into its meaning.

As we have stated previously in our response, we are changing the ecosystem aquatics analysis. As such, the presentation of the ecosystem risk will be significantly revised.

Page 13-12: The authors do not seem to know what to do with the risk index results. While the simple approach for terrestrial vegetation and wildlife is satisfactory, the Panel (and apparently the authors also) had no idea how to interpret risk index used for the fish species. What does the risk index of -62.5 under one scenario, and 3.2 under another for the same fish species mean? The authors then go on to conclude that adverse impacts on fish species were nearly universal under flooding but a mix of responses occurred under seismic. They say none of scenarios resulted in an index value close to the worse case. The interpretation goes nowhere past these generic statements. How will the risk index be used when (presumably) the analysis is completed? If this small subset of scenarios is any indication, interpretation of the risk index will be a challenge, bordering on the impossible. This is quite important because the other consequences result in dollar values, and the ecosystem consequences can get lost and swept aside if their effects are expressed in uninterruptible terms of an index whose value has unknown ecological relevance and whose sensitivity to environmental effects is undocumented.

As we have stated previously in our response, we are changing the ecosystem aquatics analysis. As such, the presentation of the ecosystem risk will be significantly revised.

Page 13-13: The impacts on terrestrial vegetation and wildlife provides more hope for a useful metric that can be interpreted and not get lost when places side-by-side with the economic losses. A 42% loss of crane habitat is worthy of notice.

No response required.

Page 13-14. Table 13-27: This table could easily be misinterpreted to indicate that the estimated number of fatalities in the case of one island flooding is 1,837 people. Additionally, flag no loss of life costs please.

We agree, this table can be misinterpreted. As indicated above, we are revising the public health and safety modeling and the revised report will reflect this work.

Page 13-16. Section 13.3.2.3: Authors should take the opportunity to highlight public health, and safety MUST come 1st in priority.

While we agree with the prime importance of public health and safety, we will not express a measure of the importance on this or any other consequence that is assessed.

Page 13-17: The poorly documented analysis that resulted in a very few scenarios actually being examined then culminates in the very dramatic statement "The population at risk and the economic and ecological consequences from a major event are expected to be severe." Where did this statement come from? Maybe one can go out on a limb and say the very limited analyses suggested economic costs would be such and such. That would be a large stretch. The portion of the statement related to ecological consequences is unsubstantiated by the analyses presented. In the end, the analyses in this report (with the gaps and details either taken on trust or filled in by the Panel), can only say that the ecosystem effects may be severe, or may not be severe (i.e., cannot say much of anything). The report seems to come to a sudden halt here prematurely.

We agree this presentation is overly dramatic and will revise the discussion accordingly.

As we have stated previously in our response, we are changing the ecosystem aquatics analysis. As such, the presentation of the ecosystem risk will be significantly revised.

Figure 13-1: The confidence bounds seem much too narrow given the significant uncertainty there is in predicting the occurrence, magnitude, and effects of potential earthquakes in this region. (Why does this figure show as many as 90 islands that could be flooded – we thought there were only 66 islands?)

The reason the "confidence bounds" are narrow is due to the fact the uncertainty in the seismic hazard, which typically dominates the uncertainty in seismic risk results, is relatively small at the low ground motions that are causing levee failures. These hazard curves with their uncertainty are shown in the seismic hazard TM.

Note, the fractiles that are presented are not "confidence bounds". The notion of confidence bounds is used on the context of statistical analysis – which this is not.

A total of 104 islands (analysis zones as we refer to them, but there are more 104 small islands and tracts that are mostly wetlands in the Delta and Suisun Marsh that we did not include in the analysis) in the Delta and Suisun Marsh are considered in the analysis. Note, this is one source of the difference between our seismic results and that of Torres, et al (2000).

Section 14 (Future Risk Analysis)

General Comments:

This section should be a solid presentation of what will change and how it will force the system.

Agreed.

It starts with more unsubstantiated statements. Many statements are sloppy and so appear biased. For example, they state on page 14-1 that, "There are two factors to consider when evaluating future years – (1) the likelihood that an event will occur in any future year is increasing and (2) the likelihood that an event will occur at least once over a number of years grows even higher." This is not true. The consideration is how will conditions change, therefore changing the likelihood of an event. It may increase or decrease. It is not foretold that it must increase.

We disagree that the referenced statements are unsubstantiated, sloppy, or appear biased. The comment seems to be applying a narrow standard and concept of appropriate style – one applicable to original scientific research reported in peer-reviewed journals. The work and the audience in the present case are different. This is not original research; it is a technical compilation (supported by the Climate Change TM) and analysis of available information for use by scientists, engineers and policy staff in support of decision makers and decision-making. One feature of such a report is to begin a section with an overview/ summary that is then substantiated by the details in the following subsections. As is indicated in the subsections of Section 14, although it is not preordained that only increases can occur, no example was found of expected future-years "Business as Usual" change that would decrease the likelihood or consequences of levee failures.

We disagree that the quoted statement is "not true," although we can accept that the suggested alternative statements are also true. However, those statements recognize only part of the story. Other important aspects (besides the likelihood of an event) are (1) the consequences of the event, and (2) the implications of an extended exposure to the risk of an event. One exposure to Russian roulette has a specific probability of an unfavorable outcome (0.167). However, 20 exposures have a dramatically different probability of an unfavorable outcome (0.974). Similar mathematics applies to 1 year of exposure to levee breach risks versus 20 years of risk exposure.

Statements like this run throughout this section. They need to be much more precise. It is not reasonable to make statements like, "[…] when exposure period of several years is also considered, the likelihood of an unwelcome event becomes high." What is "unwelcome," what is are "several years," what is "high"?

Again, this does not appear to allow for the purpose of this introductory overview and summary.

They also state on the first page of this section “[…] information is not available to conduct a comprehensive analysis of future risks.” This is amazing. Is that not what they have been doing for all this time? They are supposed to have done a precise, well-documented, statistical assessment of risk. Statements like these do not lead to confidence in their numerous figures.

We would have liked to provide a more-precise, better-documented, probabilistically-rigorous analysis of future risk. However, our scope of work was explicit. We were to use available data and projections and to provide a resulting assessment within a defined schedule. In the following paragraph the comments seem to recognize this context of our work.

As a point of clarification, the DRMS Phase 1 analysis is not a “statistical assessment of risk”; it is a probabilistic risk analysis.

This section reviews the assumptions embedded in the future analyses that the contractors were asked to perform as a result of AB 1200. This is very difficult charge to the contractors. This section outlines the various assumptions made concerning future events for 2050, 2100 and 2200, such as climate change, subsidence, population changes, and so forth. In general, the analyses here (mainly qualitative in nature) seem reasonable (to someone who is neither an engineer nor a hydrologist) and proper caveats are provided.

This is what we were trying to achieve as an initial assessment of the risks associated with levee failures under future conditions.

However, we have serious reservations about whether these analyses can even be performed, given the large uncertainties embedded in any assumptions the analysts would make concerning the state of the world 50 or 100 years in the future. Imposing some limited, future conditions, such as climate change, on the current state of the world (i.e. 2005 conditions) is a more defensible approach than trying to forecast economic or other conditions beyond more than one or two decades. Whatever approach the authors chose to use, we encourage them to provide strong cautionary statements concerning their use in the decision process.

We have these concerns and reservations as well. Our internal debate on what approach to take concluded that a “partial analysis” (e.g., addressing sea level rise and other drivers individually, including substantial discussions of uncertainties) would not be adequately helpful to decision makers. Instead, we concluded that a presentation centered around a medium future expectation for the many drivers of change taken together would be more useful as an initial assessment of future risk. Although we recognize the uncertainties, we concluded an intensive discussion of uncertainty would detract from an important message – namely that a reasonable, medium expectation for each driver indicates risks related to future levee failures are increasing and, when all these drivers are combined, there is certainly increased risk in the future.

We should also note here, a lower bound assessment of risks in future years would also indicate that risks are increasing. Thus, contrary to a reviewer's suggestion above, there are no indications, given Business-as-Usual in the Delta that risks may be decreasing.

Again, this section lacks citations to previous work, substantiation of statements, etc., all the things seen in the other sections. They also do not give ranges of results or outputs to put this in the context of uncertainty. In fact, the presentation throughout the report does not emphasize or even really mention uncertainty. They need to develop a much more transparent and inclusive presentation of what they have found with uncertainty on it. In areas where they developed uncertainty, they do not use it in the final analyses (e.g., climate change).

References to the TMs were assumed to be implicit. In the next revision, we will make the appropriate citations. The TMs do cite available literature, data and projections, and uncertainties.

With regard to the final comment, see the discussion above regarding the approach we decided to take. This said we are looking at alternatives to the analysis and presentation of future risks.

The authors seem to assume no, or minimal, mitigation for any of this. Business as usual does not mean nothing will be done. It is not clear what they considered would be mitigated in any of their analyses.

Business-as-Usual was carefully defined as a basis for the baseline (Phase 1) analysis (see Section 3.4 of the Phase 1 Report). In revising Section 14, we will include a more explicit statement of what this means relative to each type of future condition analyzed. This said, for the most part, Business-as-Usual means very little will be done with regard to current practices in the Delta, and that is the point. The case where we will keep up with sea-level rise will also be included in the revised report.

They do not show how they merged all the previous information to come up with these combined predictions. This is a problem throughout, but severe here.

As indicated above, we are re-examining the analysis of future risks. In revising this section we will consider these comments and provide the appropriate level of detail, rational and substantiation.

The authors continue to make general unsubstantiated statements when specific, detailed, and well-substantiated ones are needed.

We will reconsider each statement made and the degree of substantiation that should be provided.

They ignore previous work throughout. For example, they say that there is no indication that tidal amplitude will increase with time. That may be true astronomically, but there have been papers (e.g., at the CALFED Science Conference, by DWR scientists) that predict increased storms and increased storm surges and increased effective sea level in the Delta as ENSO events increase (article by Hansen in 2006 or 2007).

We disagree that previous work is ignored throughout. The example given on tidal amplitudes specifically considered astronomical tides and past work on astronomical tides (see the Water Analysis Module TM, Appendix H3). Additionally, we performed analyses of prospective increases in surges in the Delta, given a simulation of future tides at the Golden Gate that was part of the climate change scenario adopted for the DRMS analysis of future years (see the Climate Change TM). Although there were some indications of potential increases, and no indications of decreases, the indications of increases were not regarded to be strong enough to merit the label of a medium expectation of future conditions. We will reconsider our assessment with explicit reference to the cited papers. Thank you for the references.

This entire section has too much repetition and not enough substantiation. They need consistency. They need to present only predictions for 2005, 2050, 2100, and 2200. And they need to say why they ignore 2200 (reasonable, but they need to justify it).

The apparent repetition occurred in the context of a specific effort to be consistent in addressing changes that can be expected (relative to 2005) in 2050 and 2100. The present conditions (2005) are addressed elsewhere in the report and the risk results for 2005 are presented in Section 13.

The reason for not giving more attention to 2200 is explicitly addressed in Section 14.1.10.

The authors need to consider the range in future climate change not just the median value. Parse out major sources of uncertainty and address each one.

Our rationale for not providing an intensive discussion of each driver's range and uncertainties is provided in our response above. We are considering applying ranges in analysis outcome for the climate change.

The maps are very nice.

No response required.

Ecosystems - what ARE the risks?

To directly answer the above question, the present (2005) ecosystem risks are addressed in Section 13; they are not within the scope of this section. The change in the risks to ecosystems due to levee breaches is within the scope of this section and is addressed in Subsection 14.1.8. The relatively large uncertainties in present risks to ecosystems due to levee breaches and regarding the expected viability and health of ecosystems in the future make it difficult to say how future ecosystem risk consequences from a given levee breach event are likely to change. The obvious risk of concern is species extinction. The statement in

Section 14.1.8 indicates the absence of a basis for saying that such a consequence from a given levee breach event would be less likely in the future. This subsection and the related subsections in section 13 are being reviewed and revised as appropriate.

Specific Comments:

Page 14-2. Sea level rise bullets: The authors need to provide specific citations for their climate change-induced assumptions. For example, we believe a rise of .25 inches per year from 2005 to 2050 is several times higher than current rates reported earlier in the report. While this assumption may indeed be reasonable, some attribution would strengthen this, and other assumptions. This concern applies to many other sections of the report, where proper referencing is absent.

We will provide an explicit reference to the Climate Change TM and explain the derivation of the estimates used as a medium expectation.

Figure 14-3: Shows salinity response to a 90 cm increase in sea level. However, they do not consider a 90 cm increase, they consider at 1 foot and 2.5 foot (again without uncertainty) 30 cm and 75 cm, respectively. Considering the cost of this effort it seems like they could do the analyses needed, not give some estimates around one that that was not needed or they happened to have.

The analysis of salinity response to an increase in sea level (Water Analysis Module TM, Appendix H3) was performed prior to our establishing "a medium expectation" for 2050 and 2100 sea level rise. The alternative to including the 90 cm illustration was to include none.

Page 14-3. Bullets: More explanation is needed on why frequency of exceedance increases with time.

More explanation will be provided in the upcoming revision.

Page 14-4: They state that in 2050 there will be 50% more total runoff in the system. This seems very high. This increases even more for the 100-year predictions. Similarly, the predictions for changes in peak flow seem very high. Also, they present this data with no uncertainty. There is large uncertainty in climate predictions, especially when they get transferred to runoff, and that increases dramatically with time. They need to put these numbers in that framework. There are numerous concerns like this throughout "Section 14."

The statement relative to 2050 does not say "there will be 50% more total runoff in the system." It says "There will be approximately a 50% increase (over 2005 conditions) in the frequency of the total Delta inflow discharge that presently has an annual frequency of exceedance of 0.01….." Our decision relative to not providing detailed discussions of uncertainty was explained in the response to general comments.

Page 14-4. First bullet: As noted in previous comment, some source citations here would be helpful. Also, in first paragraph under "Floods, Part 2," we believe "levee" needs an "s" and the "s" after failures should be deleted.

The implicit reference to the Flood Hazard TM will be made explicit. Thank you for pointing out our error with the "s's."

Page 14-5. Sixth line from top: Delete "-ment" from "improvement"

Thank you for pointing out our error with the "ment."

Page 14-6: Citations to sources for these bulleted assumptions would be helpful.

References to TM's or other documents will be provided.

Page 14-8. Last sentence in first paragraph under subsection 14.1.6: This sentence reflects one of my concerns about mixing of "risks" and consequences in this report. We think this should read that increasing population "contributes to increased consequences of levee failure."

We have considered overall risk to be a combination of the probability of failure and the consequences given failure. We will consider this comment as we revise the report.

Page 14-9. Under "Business Activity:" Instead of saying "the entire state," we think, "the state as a whole" is more appropriate.

We will consider this suggestion in our revision of the report.

Page 14-10. Second complete paragraph: What does the sentence "However, as urban water use and tapping of local resources increase, demand hardening will occur" mean? By demand hardening, do you mean that demand becomes more inelastic because there are fewer possible adjustments? If so, then say that demand will become more inelastic.

You have interpreted the statement correctly. Your suggested revision has the same sort of "jargon" limitation as the original. We will explain the concept in the types of generally meaningful words that are incorporated in your question.

Page 14-12. Sentence near bottom of first paragraph: Needs a "the" between "In" and "future." Also, in subsection 14.1.10, the sentence reads, "Other factors were not so easy to predict." Do the authors really mean that these other factors were "easy" to predict?

We meant "easy" as a relative term rather than an absolute term.

Page 14-13. Last subsection: In the first sentence, we think it should read "The risks *of* Delta levee […]" not "from." Also, how high is "high" in terms of risk. What does this mean to a state decision-maker in terms of scientific or engineering advice?

One measure of risk could be the failure of the system itself. Other measures of risk can consider the consequences of the levee failure. We will consider this comment as we revise the report.

The second point expresses a valid point. The sentence suggests an evaluation of the risk relative to some standard, which of course does not exist. We will consider this comment in our revision of the report and attempt to avoid judgments or advice with respect to the level of risk. The main points from this section are that risks are increasing and that multi-year exposure periods are a major consideration.

Section 15 (Assumptions and Limitations)

General Comments:

Although brief, this is an important section in terms of how to interpret and use the results of this study. The list of assumptions and limitations is helpful. We would like to see the list expanded to include an item dealing with the "methodology," noting the problems inherent in using linked models of different structure and precision.
This is a very broad comment and it is not clear what point is intended by it.

Nowhere do the authors state that they do NOT consider the range of future climate change (!). This is a major assumption that we think is currently skewing the results.
Climate change is but one of the inputs to the risk analysis that has a range of prospective quantitative realizations. Since climate change is relevant to future conditions, it is discussed in Section 14. In Section 14 we noted that a range of prospective futures could occur due to climate change and other variables, including subsidence, population, land-use and the future state economy. Section 14 is being reviewed and consideration is being given to incorporation of a range of conditions for each of these future-condition variables.

Specific Comments:

Page 15-1. First bullet: Need a *the* before "ecosystem" and an *s* after "water export." In the third bullet, it is noted that the engineering studies were conducted with "[...] a coarse data grid, hence carrying less site specific detailed, etc […]." In some sections of the report, however, much attention is paid to what appears to be fine scale forecasts of levee failure. This bullet then raises questions of whether what is reported in the sections is consistent.
The editorial corrections are noted.

The studies performed by DRMS require a difficult balancing of coarse data (representative of conditions in the region and analyses that are based on specific inputs to estimate levee failure and island flooding. The bullet is meant to highlight the fact that regionally coarse (but generally appropriate) data were used in the analyses. But in considering a specific location, more precise data and finer resolution would be needed to calculate prospective results of specific projects.

Page 15-2. Second bullet, last sentence: Not clear what this is saying. In last bullet on page, need an *s* after "requirement."
We assume the comment refers to the CalSim limitation that "Also, the historical record includes less than half of the 125 potential 3-year sequences of water year types." This will be clarified in the next version. Briefly, there are five types of water years and, in a three year sequence, they can occur in 125 different orders. In the 83-year historical record some sequences occur more than once so less than half the possible sequences have occurred.

Other

Climate Change Technical Memorandum:

Why use Knowles & Cayan snow pack projections when the PNAS (Hayhoe et al, 2004) are more recent?

The projections of Knowles and Cayan were not used as inputs to any model or projection. Rather, we showed them in an introductory section to illustrate that future loss of snow, although uncertain, is likely to be very significant. For this purpose, it is not necessary to use the latest projections. The figure caption clearly states that the Knowles and Cayan results are merely an illustrative example: "This is a typical result based on one model … other models would give qualitatively similar but quantitatively different results." Thus, for our purpose, there would be no significant benefit to using newer projections.

It's A1fi not f1 (table 1)

This error does not appear in the latest version of the TM (that on the DRWM web site: http://www.drms.water.ca.gov/docs/Climate_Change_TM_Revised-updated07.pdf; thus, it seems that the IRP was reading an older version.

Typo p. 20 - 2050 and 2050 for SLR (instead of 2050 and 2100)

Noted.

Needs an executive summary highlighting the main findings; also no conclusions to section 3.1 on slr!

The request for an executive summary is noted. The conclusions and recommendations on sea level rise trend were presented in Section 3.1.4, which was then followed by a section on short-term sea level variability. This apparently led to some confusion.

Doesn't include results from multiple model simulations for river flow (why not?? they are available! didn't take my comments from March into consideration - maybe lack of time/funding?)

Because water levels in the Delta are strongly influenced by daily-timescale variations in river flows, we felt that it was desirable to have daily-timescale simulated flows for DRMS. We know of only one simulation of river flows that uses daily time resolution and incorporates the major rivers draining the west side of the Sierra. This is what we used.

Wind analysis is pointless - not integrated with approach for wind/wave chapter. Should be using the same approach as the wind/wave analysis. Wind projections by regional climate models have not yet been tested and are NOT ready for prime time. Should NOT be used here.

The first question relative to wind is whether climate change can be expected to cause changes in the frequency (or intensity or duration) of Delta-region, sustained wind events. Furthermore, if a change were expected, would one expect winds (or frequencies) to increase or decrease? This is a more limited objective than implied by the comment. This limited first objective will be stated more clearly in the next revision of the Phase 1 Report and in the Climate Change TM. The TM Section3.3 is aimed at answering that question. It looks at what can be done with global climate models and nested regional scale wind models and concludes that the results are not yet adequate to support conclusions, even on these limited questions. Thus, the TM basically agrees with the comment that such models are "not ready for prime time."

Does a good job of explaining what "should" be done in the final section but neglects the fact that a lot of that has already been done and you could do at least half of it with existing simulations but he does not.

Available time was an important limitation, even for using global climate simulations that are available.

We were asked, "What is the refutability of the models and what is the degree of confidence that they can predict future conditions?"
For the wind projections – NONE

Again, the original Tech Memo clearly states that climate model wind projections for the Delta are not reliable. So there is no disagreement here.

Levee Vulnerability Technical Memorandum

Page 44: The authors state that based on their judgment, they modified the permeability data of the peat by an order of magnitude and estimated the vertical permeability of the peat to be an order of magnitude less than the horizontal permeability. We do not necessarily disagree with the judgments, but it causes us to question the significant digits of the numbers in most of the tables.

The question on significant digits is understood and will be considered in conducting the review and revision of the Levee Vulnerability TM that is presently underway.