Draft Summary Report

Phase 1: Risk Analysis

Delta Risk Management Strategy (DRMS)

Risk Analysis: Summary Report

Draft

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Prepared for:
Department of Water Resources

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DRMS Overview

Project Sponsors

The California Department of Water Resources, California Department of Fish and Game, and the U.S. Army Corps of Engineers serve as the project sponsors for DRMS. The sponsors are assisted by a stakeholder Steering Committee and a Technical Advisory Committee.

In accordance with requirements of Assembly Bill 1200 (Laird, Chaptered October 2005), the Delta Risk Management Strategy (DRMS) has completed the initial phase of its evaluation of levees in the Sacramento-San Joaquin Delta and Suisun Marsh of California. The overall purpose of Phase 1 of DRMS was to assess the performance of the levees and the potential economic, environmental and public health and safety impacts of levee failures to the Delta region itself, and California as a whole. Phase 2 of DRMS will develop and evaluate strategies to reduce risks from levee failures.

Delta and Suisun Marsh

Erosion of a Delta levee during a storm and high tide

Although the Delta and Suisun Marsh only cover about 1 percent of California's area, the region is at the heart of many of California's resource issues. Agriculture is the primary land use in the Delta and managed conservation land is the primary use in the Suisun Marsh. Portions of the periphery of the area are rapidly urbanizing. Today, about ¼ of the urban water used in California is diverted from the Delta; about 2/3 of Californians get some portion of their drinking water from the Delta. Also, approximately 3 million acres of agricultural land gets a portion of its irrigation water from the Delta. The area provides vital transportation and utility corridors to other regions of California. Wide expanses of open land, interlaced waterways, historic towns, and the feeling of a slower pace of life make the Delta and Suisun Marsh attractive for recreation and tourism. The Delta and Suisun Marsh, together with the greater San Francisco Bay, make up the largest estuary on the west coast of North America and support a unique ecosystem. The levees play a major role in protecting these uses and in contributing to local and state economics.

Hazards

Levee failures have flooded islands (areas of land surrounded by levees) and tracts 166 times since 1900 and some flooded lands were never recovered. Many Delta islands and tracts have flooded multiple times. Vast land areas lie many feet below sea level and can flood any day of the year if levees failed since most Delta and Suisun Marsh levees hold back the sea level.

Sand bags to temporarily control a sand boil on Staten Island on June 18, 2007. The muddy water indicates that material in the levee or its foundation is being washed away. If unnoticed, this could lead to a failure of the levee.

The hazards evaluated in this report include:

- Seismic events (earthquakes) that cause levees to fail
- Floods (high storm runoff into the Delta) that can rise above the tops of the levees or increase pressure for seepage through and under the levees and cause them to fail
- Sunny day events caused by undetected problems, such as rodent activity, that fail levees during normal, non-flood 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 flood

The hazards are expected to grow larger in the future such natural factors as sea level rise that put more pressure on the levees.

DRMS Risk Approach

The DRMS risk analysis provides a framework for evaluating major threats to the Delta levee system and the impact their failure can have within the Delta (damage to residential and commercial infrastructure, the ecosystem), the state's water delivery system, and those who rely on the export of fresh water from the Delta. This framework is unique in that it examines the challenges to the levee system and the impact of these failures in a number of dimensions that have never been considered:

Definition of Risk
In this analysis, risk is defined as the likelihood (frequency) of adverse consequences that could occur as a result of levee failures in the Delta

- What is the frequency or rate of occurrence of different magnitudes of hazards that can challenge the integrity of Delta levees? The analysis accounts for smaller hazard events that occur more often and larger events that occur less often.
- How vulnerable are different levee reaches are to hazards? All levees do not respond the same to hazards. Levees and their foundations are composed of highly variable materials (sands, silts, clays, and organic peat soils).

- How do the hazards and the levee vulnerabilities combine to produce levee failures? Two identical levees separated by 10 miles will respond differently during a given earthquake or flood event since these hazards vary by location.
- What are the economic and ecosystem impacts due to levee failure? The times required for emergency response and repair will vary depending on the locations and numbers of levee failures that occur at the same time. Likewise, the salinity in the Delta and water management will vary.
- The level of risk is determined by considering combinations of these.
- Finally, all these dimensions are increasing in the future so risks will become greater over time. Therefore, DRMS estimates how conditions are expected to change for 50, 100, and 200 years from now. These future conditions allow computation of future risks.

Assembly Bill 1200

Assembly Bill 1200 (Laird, Chaptered October 2005) required the Department of Water Resources to evaluate the potential impacts on water supplies derived from the Sacramento-San Joaquin Delta resulting from a variety of risks based on 50-, 100-, and 200-year projections for each of the following possible risks on the Delta:

- Subsidence of the land within the Delta
- Earthquakes
- Floods
- Changes in precipitation, temperature, and ocean levels
- A combination of theses hazards

The Phase 1 DRMS work presents a risk analysis. The future Phase 2 work will consider options for risk reduction and risk management

Findings

The risks from Delta levee failures are already high and are increasing. No significant risk factor has been identified that decreases the likelihood of Delta levee failures or decreases associated consequences.

Seismic Risk

The seismicity (earthquake related) of the Delta and Suisun Marsh is characterized as moderate to high compared to the Bay Area. It is expected that a moderate to large earthquake capable of causing failures of multiple levees could happen within the next 25 years. The greatest chance of failures will come from the Hayward, Midland, Calaveras, and San Andreas faults. Thousands, it not miles, of levees would be extensively damaged. The Delta islands most likely to fail are generally located in the central-west area of the Delta. This failure mechanism will cause rapid flooding of the affected islands, leaving little time for evacuation.

Considering the probability of all seismic levee breaches under existing (2005) conditions, about 115 failures can be expected during 100 years. Repairs could take up to 6.5 years and export of Delta water could be disrupted for up to 2 years, with a loss of up to 10 million acre-feet of water. Contra Costa Water District is likely the urban agency most at economic risk from disruption, particularly in dry years. The total economic costs and total economic impacts to the state could be tens of billion dollars each. The majority of these economic consequences will be to areas outside the Delta and Suisun Marsh.

The impacts on the ecosystem could be highly variable (many negative impacts and some benefits) depending on how many islands fail, locations, time of the year, and species affected. All seismically-induced levee-failure events that resulted in flooding of 20 or 30 islands produced beneficial effects for all species; scenarios involving fewer flooded islands had adverse population consequences for some species.

Flood Risk

Levee breaches from high flood flows into the Delta are the most common and most frequent types of failures. Considering the probability of all flood related levee breaches under existing (2005) conditions, about 209 failures in the Delta (exclusive of Suisun Marsh and the area west of the Sacramento River) can be expected during 100 years, an average failure rate of 2.09 failures per year. This can be compared to 166 historical failures in the Delta since 1900. About 870 failures can be expected in the Suisun Marsh during 100 years, a rate of 8.7 failures per year.

Protecting the land-side of a levee on a flooded island; Jones Tract (2004)

No significant export disruptions are expected. Economic costs and impacts would not be as large as with the seismic failures, but would still be tens of billions of dollars. Almost all of these economic consequences would be in the Delta. Like for the seismic failures, the impacts on the ecosystem could be highly variable (many negative impacts and some benefits) depending on how many islands fail, locations, time of the year, and species affected.

Sunny Day Levee Failure Risk

Sunny day failures are ones that occur during non-flood flow times. They occur one at a time, often during high tides, from a variety of causes such as animal burrowing. The 2004 failure of the Upper Jones Tract levee is the most recent example. The cost of damages and island recovery was nearly $100 million.

It is expected that on average there will be about 5.4 sunny-day breaches with 50 years or 10.7 breaches with 100 years of exposure in the Delta and 1.8 sunny-day breaches with 50 years or 3.6 breaches with100 years of exposure in Suisun Marsh.

The impacts to aquatic species of levee-failures on individual islands cannot be generalized from seismic and flood levee failure scenarios. The calculations of risk for terrestrial vegetation and wildlife depend entirely on area flooded, therefore, risk to terrestrial vegetation and wildlife as calculated here would be smaller than large breach scenarios. Because aquatics, terrestrial vegetation and terrestrial wildlife, have a complex spatial distribution, the particular island flooded in a sunny day failure would influence the magnitude of the impact.

Future Risks

The overall likelihood of a major event is increasing and the magnitudes of consequences from a given event are also rising:

- By 2050, the frequency of island flooding from seismic events is expected to increase by 12 percent over 2005 conditions.
- By 2100, the frequency of island flooding from seismic events is expected to increase by 27 percent over 2005 conditions.
- By 2050, the frequency of island flooding from flood events is also expected to increase. The vulnerability of the levees to floods (due to seepage and stability from subsidence and sea level rise) is expected to increase by 10 percent over 2005 conditions. The flood frequency is expected to increase by 50 percent. The combined effect would be an 80 percent increase. An increase in overtopping would be additional.
- By 2100, the frequency of island flooding from flood events is expected to increase. The vulnerability of the levees to floods (due to seepage and stability from subsidence and sea level rise) is expected to increase by 20 percent over 2005 conditions. The flood frequency is expected to increase by 100 percent. The combined effect would be a 240 percent increase. An increase in overtopping would be additional.

Next Step

The next phase of work will include development of risk reduction strategies for long-term management of the Delta and Suisun Marsh levees.

More information on the uses of the Delta and Suisun Marsh can be found in the report, *Status and Trends of Delta-Suisun Services (2007)*, on the DWR Delta Vision web portal: http://www.deltavision.ca.gov/

Table of Contents

Most Delta levees hold back water 365 days per year

Thoughts about the California's Sacramento-San Joaquin Delta (Delta) and the Suisun Marsh often turn to the levees that line the area's channels and sloughs. Approximately 1,115 miles of levees in the Delta and 230 miles of levees in the Suisun Marsh define the configuration of the waterways, landform, and uses of the area. Unlike typical levees along rivers designed to hold back water only during times of high water, most Delta and Suisun Marsh levees also hold back the sea level. Vast land areas lie many feet below sea level and can flood any day of the year if levees failed. A growing concern about the long-term viability of this levee system led the project sponsors to initiate this Delta Risk Management Strategy (DRMS) to evaluate the risks associated with the Delta and Suisun Marsh Levee system and to devise strategies to manage the risks.

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

This draft report is a summary of information from the Public Draft Phase 1: Risk Analysis Report (June 2007).

1. Purpose

The overall purpose of the Delta Risk Management Strategy (DRMS) is to assess the performance of Delta and Suisun Marsh levees and the potential economic, environmental and public health and safety consequences of levee failures to the Delta region itself and California as a whole and to develop and evaluate strategies to reduce risk. This report presents the methodology and results for Phase 1 of the work, the risk assessment.

The Record of Decision for the CALFED Bay-Delta Program (CALFED, 2000) called for a DRMS to be completed by 2001. The project sponsors, 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.

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:

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"

A future report (Phase 2 in Fall 2007) will evaluate strategies to reduce risk from Delta and Suisun Marsh levee failures including ways to:

1. Prevent the disruption of water supplies
2. Improve the quality of drinking water supplies
3. Reduce the amount of salts contained in Delta water and delivered to, and often retained in, agricultural areas
4. Maintain 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
8. Preserve, protect, and improve levees

DRMS Objectives

Objectives for the DRMS work are 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 breaking the risk down for individual islands.
2. Propose risk criterion for consideration of 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 failure

Input to Others

DRMS will become a major source of scientific and technical information on the Delta and Suisun Marsh levees for other studies and initiatives. It is expected that DRMS results will prove useful to other studies and initiatives in the region including:

- The Delta Vision initiative (Governor Schwarzenegger's Executive Order S-17-06)
- The Bay Delta Conservation Plan (BDCP)
- CALFED End of Stage 1 Assessment (first 7 years of implementation)

DRMS and Delta Vision

While the DRMS focuses on the Delta levees and the consequences of flooding, the Delta Vision Process will directly consider the needs of a wide variety of resources and activities within the Delta and Suisun Marsh.

- Delta Regional Ecosystem Restoration Implementation Plan (DRERIP)
- Habitat Management, Preservation, and Restoration Plan for Suisun Marsh (Suisun Marsh Plan) currently being prepared by the Suisun Marsh Charter agencies
- Planning activities by state and federal agencies and local entities
- Other new initiatives

2. Background

The Area

The Delta and Suisun Marsh sit at the confluence of the Sacramento and San Joaquin rivers, which provide drainage to about 40 percent of California. Unlike the Mississippi River Delta and other river deltas that form where rivers drop their sediments at the ocean, the Sacramento-San Joaquin Delta is located inland, with its western side about 50 miles upstream from the Golden Gate. The Delta and Suisun Marsh together include approximately 1,315 square miles in portions of 6 California counties. Although the Delta and Suisun Marsh only cover about 1 percent of California's area, the region is at the heart of many of California's resource issues.

> More information on the uses of the Delta and Suisun Marsh can be found in the report, *Status and Trends of Delta-Suisun Services (2007)*, on the DWR Delta Vision web portal: http://www.deltavision.ca.gov/

Agriculture is the primary land use in the Delta and managed conservation land is the primary use in the Suisun Marsh. Portions of the periphery of the area are rapidly urbanizing. Today, about ¼ of the urban water used in California is diverted from the Delta; about 2/3 of Californians get some portion of their drinking water from the Delta. Also, approximately 3 million acres of agricultural land gets a portion of its irrigation water from the Delta. The area provides vital transportation and utility corridors to other regions of California. Wide expanses of open land, interlaced waterways, historic towns, and the feeling of a slower pace of life make the Delta and Suisun Marsh attractive for recreation and tourism. The Delta and Suisun Marsh, together with the greater San Francisco Bay, make up the largest estuary on the west coast of North America and support a unique ecosystem. The levees play a major role in protecting these uses and in contributing to local and state economics.

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 (see Figure 1):

- 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

The study also includes any other areas that would be flooded or otherwise impacted by levee failures. The consequences of levee failure within the Delta can extend well beyond the boundary defined above to other regions of the state. For example, while outside the Legal Delta, parts of Sacramento could be flooded as a result of levee failure in the Delta. Water supplies to portions of the San Francisco Bay Area and Southern California could be disrupted by levee failures. Therefore the economic impacts of levee failures are evaluated for the entire area that could be impacted by failures of any levees within the Delta and Suisun Marsh.

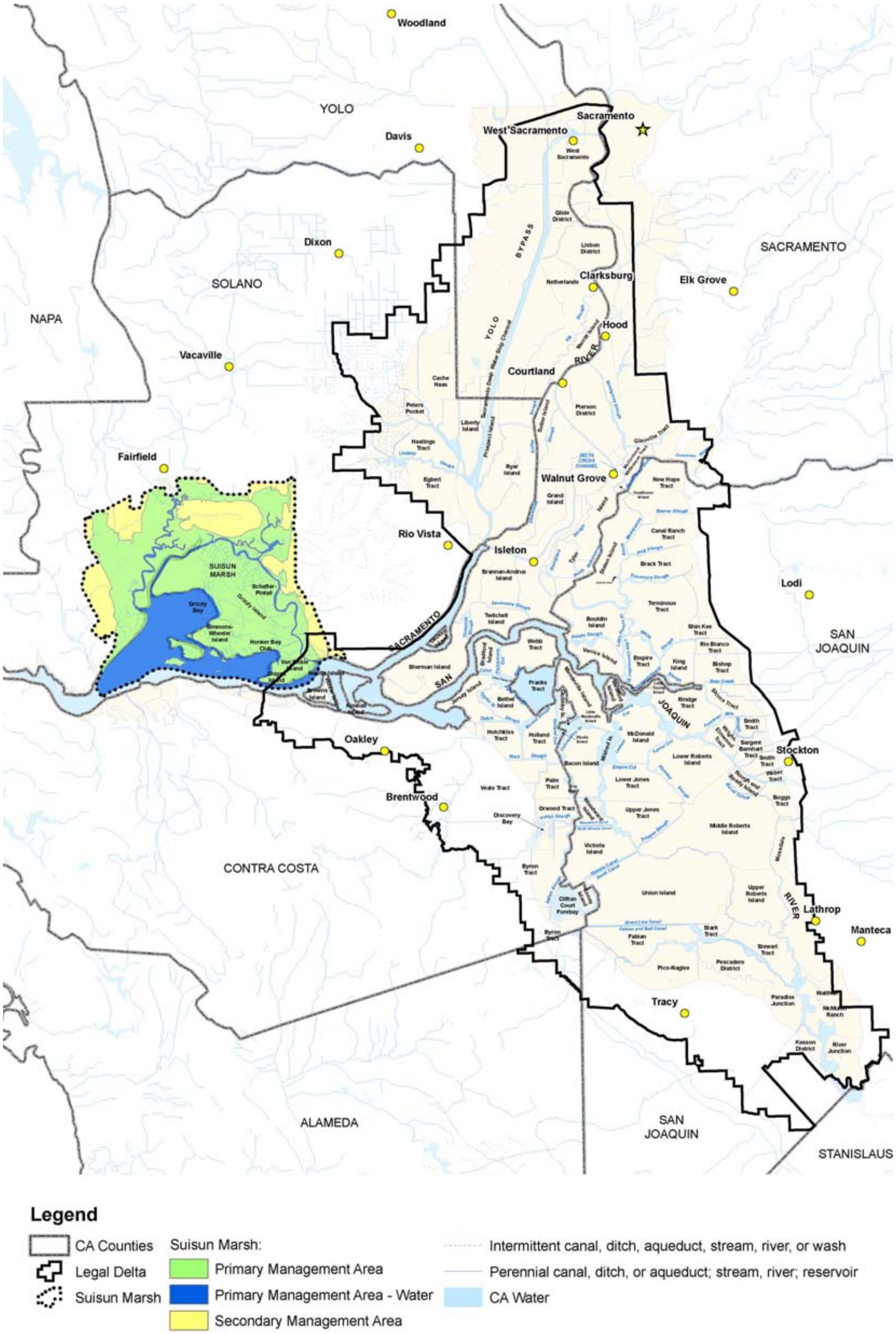

Figure 1 - Delta Islands and Sloughs. *Delta "islands" are land areas, mostly below sea level, surrounded by levees. About 1,345 miles of Delta and Suisun Marsh levees border over 700 miles of channels and sloughs.*

The Hazards

The hazards evaluated in this report include:

- Seismic events (earthquakes) that cause levees to fail
- Floods (high storm runoff into the Delta) that can rise above the tops of the levees or increase pressure for seepage through and under the levees and cause them to fail
- Sunny day events caused by undetected problems, such as rodent activity, that fail levees during normal, non-flood 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 flood

Wind waves at Twitchell Island during a 60 mph wind

Levee Vulnerability

Levee failures have flooded islands and tracts 166 times since 1900, and some flooded lands were never recovered (see Figure 2). Many Delta islands and tracts have flooded multiple times. High flood flows into the Delta during major storms in the upstream watershed have caused most levee failures. Some levees have failed during the summer when river flows were relatively low (sunny day failures). Water overtopping levees during high water, erosion, seepage through the levee embankment, seepage through the levee foundation, burrowing animals, and high

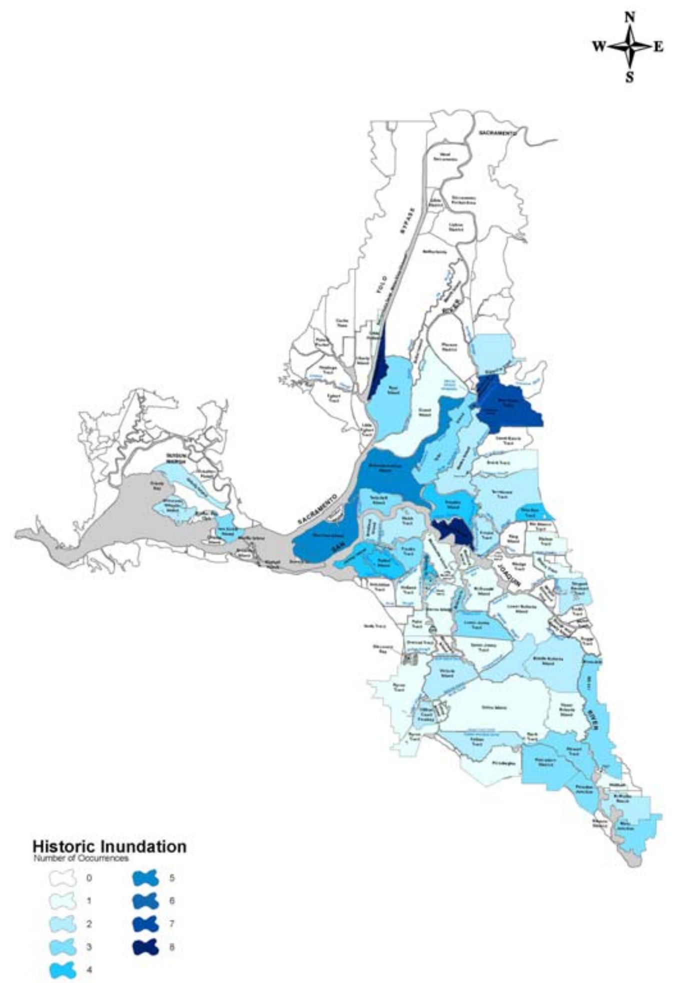

Figure 2 – Historical Island Flooding in the Delta and Suisun Marsh Since 1900. *Most Delta islands and tracts have flooded at least once since 1900, and many have flooded multiple times.*

tides have contributed to levee failures.

Most of these levees were built before modern engineering techniques, and many rest on organic peat soil foundations that have settled with the added weight. Levees were originally constructed of sands, silts, clays and organic soils, often by mounding up nearby excavated or dredged material. Some sandy areas within the levees and their foundations are particularly vulnerable to damage during an earthquake. Levees originally built in the 1860s through the 1920s to allow draining of swamp land for agriculture now protect a wide variety of valuable uses. The levees have been periodically widened and raised to keep pace with subsidence on Delta islands.

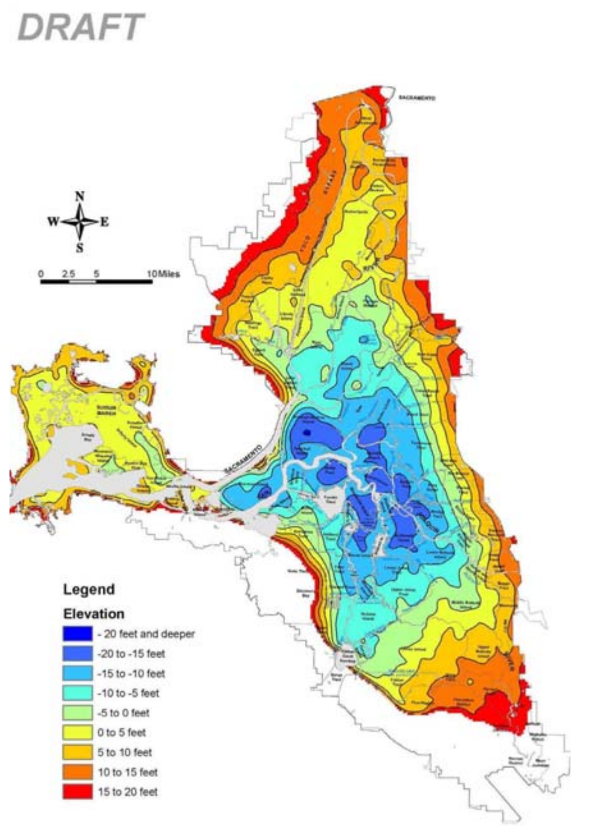

Figure 3 - Surface Elevation Map. *Most of the area is below sea level.*

The analysis considers appropriate combinations of these hazards (e.g., an earthquake followed by high flows or a wind/wave event). Future changes, such as continued sea level rise, climate change and land subsidence will alter the frequency and severity of future hazards.

Much of the area lies below the mean higher high water (MHHW) tide elevation. Figure 3 shows the land surface elevations in the Delta and Suisun Marsh.

The Consequences of Levee Failure

The consequences of levee failures are many:

- **Risks to life.** Based on the 2000 census, the Delta islands and tracts had a population of about 26,000 people. Many Delta roads are on the levees and islands are connected by bridges and auto ferries, which complicates evacuation during an emergency. The legal boundary of the Delta and Suisun Marsh contains a population of about 470,000 people based on the 2000 census.
- **Damage to residences.** Residences are scattered throughout the Delta; however, not all islands are populated or have residential structures. Urban areas (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.

- **Damage to businesses.** The Delta includes about 15,900 businesses with sales of about $35 billion annually. These businesses employ about 205,000 people.
- **Damage to services.** Hospitals, police, fire, wastewater plants and other public services could be disrupted by levee failures.
- **Damage to utilities.** Oil and gas wells could become flooded and temporarily inaccessible for service. Millions of people in Northern California and Nevada could have natural gas supplies and petroleum supplies affected by levee failures in the Delta. Electrical transmission lines to other regions cross the Delta and Suisun Marsh.
- **Damage to transportation corridors.** Several major highways and railroads cross the Delta and Suisun Marsh. Flooding can disrupt transit between major urban areas beyond the Delta. Local roads on levees may become damaged or may be unusable due to obstruction from levee repair equipment. The Sacramento and Stockton deepwater ship channels could become impassible from damage or because barges used in levee repair could block the channels.
- **Change in Delta salinity.** Salt water from Suisun Bay can flow upstream to fill and flood islands, changing conditions for ecosystem and human use.
- **Changes in ecosystem conditions that can have a wide variety of impacts.** The Delta and Suisun Marsh provide habitat for a diverse estuarine community including fish, wildlife, and other aquatic and terrestrial species. Levee failures could create new opportunities for some species and be a detriment to other species.
- **Disruption or cessation of in-Delta and export water supplies.** Salt water from the bay can flow upstream to fill islands after a levee failure making Delta water too salty for use. This can require stopping in-Delta diversions for agriculture and exports for agriculture and urban uses. About 500 thousand people in the Contra Costa Water District use water diverted from the Delta. About 18 million people in Metropolitan Water District of Southern California count on the Delta as part of their drinking water supply. The Mokelumne Aqueduct that crosses the Delta and serves 1.3 million people in the Bay Area could be severed from a levee breach. Many other water agencies and districts could have a portion of their supplies interrupted by Delta levee failures. In all, about 27 million people currently could have water supplies affected by Delta levee failures.
- **Loss of crops.** In 2004, about 67 percent of the Delta was agricultural land. Flooding will create direct crop damage in the Delta. Disruptions to export water supplies can also result in crop damage south of the Delta from lack of irrigation water.
- **Loss of use for recreation, jobs, etc.** Many activities could lose use of the Delta services. Recreation within the Delta and Suisun Marsh could be disrupted for extended periods of time due to levee failure(s). Jobs in the Delta would be lost due to the direct effects of flooding and jobs in other parts of the state could be lost from disruptions to water supply, petroleum transport, shipping, etc.
- **Loss to the economy.** California is now the sixth largest economy in the world, at about $1.5 trillion annually. 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. Much of the population of the state has an interest in the Delta and Suisun Marsh.

- **Potential long-term loss of land use.** Depending on the number and locations of levees that fail during an earthquake or a flood, it may be impractical or expensive to attempt to recover them all, and some may remain permanently flooded. In addition, the scour hole created at the breach location is generally too large to refill, and the land is lost from its previous use. One of many such examples is shown in the following photograph.

Bradford Island *- Example of a scour hole (center) remaining today on Bradford Island from a levee breach in December 1983. Investigations for DRMS showed a typical scour hole extends about 2000 feet on to the flooded islands, is 500 feet wide, and 20 to 40 feet deep. The land on the island is often unusable because it is infeasible to fill the hole.*

Future Conditions

In the future, the magnitude of the hazards, the frequency that they occur, and the consequences are expected to increase. 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 floods flows into the Delta. Increases in the population within the Delta will place more people and property at risk from levee failures and flooding. The conditions that are expected to change over time due to several factors.

Subsidence. Current Delta agricultural practices require an aerated root zone for crop production and therefore promote land subsidence. Land subsidence, primarily through microbial oxidation, has placed most of the Delta land below sea level, some as much as 15 feet or more. The reduction of land elevation on Delta islands has increased the difference between the interior of islands and water elevations in the channels. Over the next 200 years, some areas, especially in the central Delta, could subside by another 18 feet if current land use practices continue. Land uses such as permanently flooded wetlands or flooded agricultural lands can stop subsidence and even begin to rebuild the soil. The lower land surface provides more room for inflowing salt water from Suisun Bay when levee failures occur.

Sea Level Rise. Over the last 100 years, the sea level at California's Golden Gate has been rising by an average rate of about 0.08 inches per year and now sits about 0.6-foot higher than it did in 1920 (see Figure 4). Recent scientific evidence suggests the trend to warmer global temperatures will accelerate melting of glaciers, which will release more water into the oceans. In addition, warmer ocean temperatures cause the water to expand, further raising the sea level. Different assumptions about future greenhouse gas emissions and use of different models lead to different estimates of sea level rise in the 21st Century. Current estimates by the Intergovernmental Panel on Climate Change (IPCC, 2007) indicate that sea level will rise by about 0.6 foot to 1.9 feet over the next 100 years, with an additional 0.5 foot rise if Greenland ice melts faster. The DRMS technical memorandum on climate change presents a possible range from 0.7 to 4.6 feet.

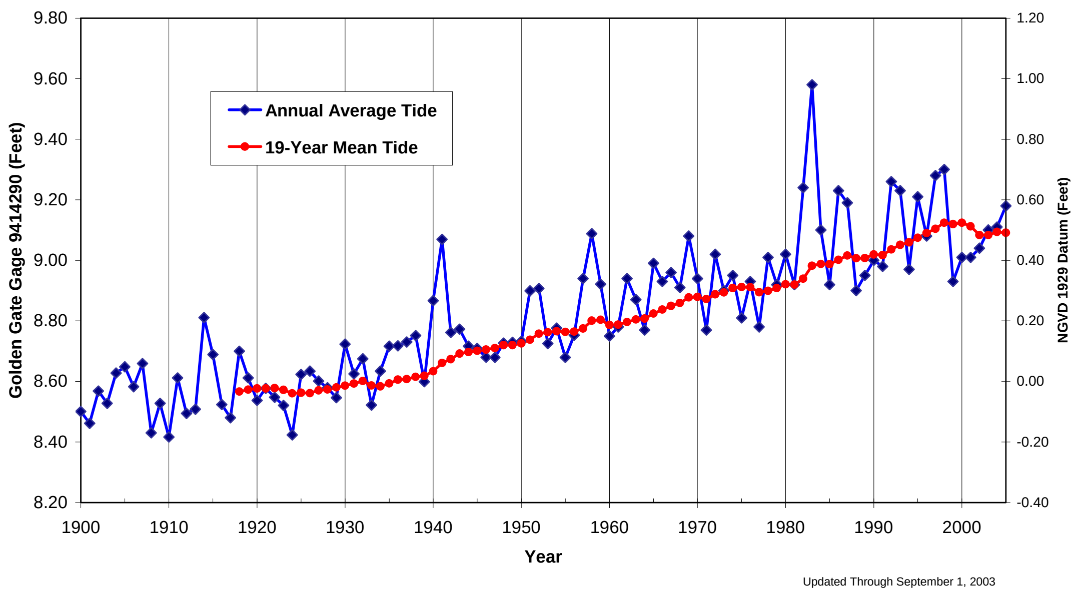

Figure 4 Golden Gate Annual Average and 19-Year Mean Tide Levels

More Winter Flooding. California's climate is expected to become warmer (3 to 10.5°F) during this century. Increases in water temperature may hurt spawning and recruitment success of native fishes. Storms are likely to become more intense with more winter precipitation falling in the mountains as rain rather than snow. Average winter flood flows to the Delta are likely to become larger in the future. The change in rain/snow mix, particularly in the northern Sierra Nevada, is predicted to shift Central Valley peak runoff earlier (towards the winter).

Seismic Activity. The Delta and Suisun Marsh lies in proximity to major faults that are capable of generating moderate to strong ground shaking, particularly in the western Delta. The more time that passes without a moderate to major earthquake, the greater chance of an earthquake occurring.

3. Risk Analysis Approach

The DRMS risk analysis provides a framework for evaluating major threats to the Delta levee system and the impact their failure can have within the Delta (damage to residential and commercial infrastructure, the ecosystem), the state's water delivery system, and those who rely on the export of fresh water from the Delta. This framework is unique in that it examines the challenges to the levee system and the impact of these failures in a number of dimensions that have never been considered:

> **Definition of Risk**
> In this analysis, risk is defined as the likelihood (frequency) of adverse consequences that could occur as a result of levee failures in the Delta

- What is the frequency or rate of occurrence of different magnitudes of hazards that can challenge the integrity of Delta levees? The analysis accounts for smaller hazard events that occur more often and larger events that occur less often.
- How vulnerable are different levee reaches are to hazards? All levees do not respond the same to hazards. Levees and their foundations are composed of highly variable materials (sands, silts, clays, and organic peat soils).
- How do the hazards and the levee vulnerabilities combine to produce levee failures? Two identical levees separated by 10 miles will respond differently during a given earthquake or flood event since these hazards vary by location.
- What are the economic and ecosystem impacts due to levee failure? The times required for emergency response and repair will vary depending on the locations and numbers of levee failures that occur at the same time. Likewise, the salinity in the Delta and water management will vary.
- The level of risk is determined by considering combinations of these.
- Finally, all these dimensions are increasing in the future so risks will become greater over time. Therefore, DRMS estimates how conditions are expected to change for 50, 100, and 200 years from now. These future conditions allow computation of future risks.

The risk assessment looks at all these dimensions in terms of probability, or chance, that they will occur. There are unlimited combinations of the magnitude and frequencies of the hazards and how they vary by location in the Delta and Suisun Marsh. Levees vary widely throughout the area and different numbers of islands can flood. One island may flood from during a high river flow or many may fail. An earthquake has the

> **Example Probability**
> To help the understanding of probability, assume that you want to try to roll a number 3 with a six sided die. For each role of the die, there is a 1 out of 6 chance of rolling the 3. On average, with enough rolls of the die, a 3 will appear for every 6 rolls of the die. However, there is no guarantee that a 3 will appear with 6 rolls, 10 rolls, or even 20 rolls.
>
> Given the 1/6 chance for every roll, what is the probability of rolling the 3?
>
> 17 % chance with 1 roll
> 28 % chance with 2 rolls
> 57 % chance with 5 rolls
> 81 % chance with 10 rolls
> 96 % chance with 20 rolls
>
> It would be a pretty good bet that you could roll a 3 with 20 rolls of the die.
>
> The levee failures can be presented in similar terms; the chance that a levee will fail in within 10 years or within 100 years.

potential to fail numerous islands. The consequences of failure depend on where and how many levee fail during a hazard event.

The analysis quantifies and puts into context whether ongoing, relatively frequent events and levee failures are a significant threat to the future of managing the Delta, and/or whether the state is faced with a high chance of a major catastrophe – our version of Hurricane Katrina and the flooding of New Orleans.

Some Other Probabilities

Chance of :	
Flipping a heads the first time on a coin toss	1 in 2
American male getting cancer in lifetime	1 in 2
Rolling a 3 with one toss of a 6 sided die	1 in 6
Getting the flu this year	1 in 10
Being killed next year in any type of transportation accident	1 in 77
Being born a twin in North America	1 in 90
Being audited this year by IRS	1 in 175
Hitting a hole in one	1 in 5,000
Earth being struck by an asteroid in next 100 years	1 in 5,000
Being struck by lightning	1 in 280,000
Becoming President of United States	1 in 10,000,000
Shark attack	1 in 300,000,000

Scope of Analysis

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 analysis includes an assessment of uncertainty.
- The analysis includes estimates of how risks might change in the future. Such events include the likely occurrence of future earthquakes of varying magnitude in the region, futures rate of subsidence given continued farming practice, 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 analysis includes measures of risk called for in AB 1200 for public health and safety, economic, environmental consequences.
- The analysis assumes that existing regulatory and management practices are carried forward into the future. This “business-as-usual” approach guides the analysis for modeling current risk as well as in making projections of future risks. Furthermore, setting a business-as-usual scenario helps establish an unbiased measure of risk for the Delta and removes potential speculations.

Risk is first evaluated under 2005 base year conditions assuming that existing management practices (policies, funding, maintenance, etc.) continue in their current form. The risk analysis is also conducted for future conditions to show how risk grows with time.

The main Public Draft Risk Analysis Report (2007) draws information from 12 technical memoranda (TMs). 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.

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/Erosion
3. Seismic Hazard	9. Hydrodynamic/Water Management
4. Wind Wave Hazard	10. Ecological Impacts
5. Subsidence	11. Impact to Infrastructure
6. Geomorphology	12. Economic Impacts

Risk Model

The elements of the analysis are shown in Figure 5. All parts of the "equation" come together in the in the Risk Quantification and Analysis.

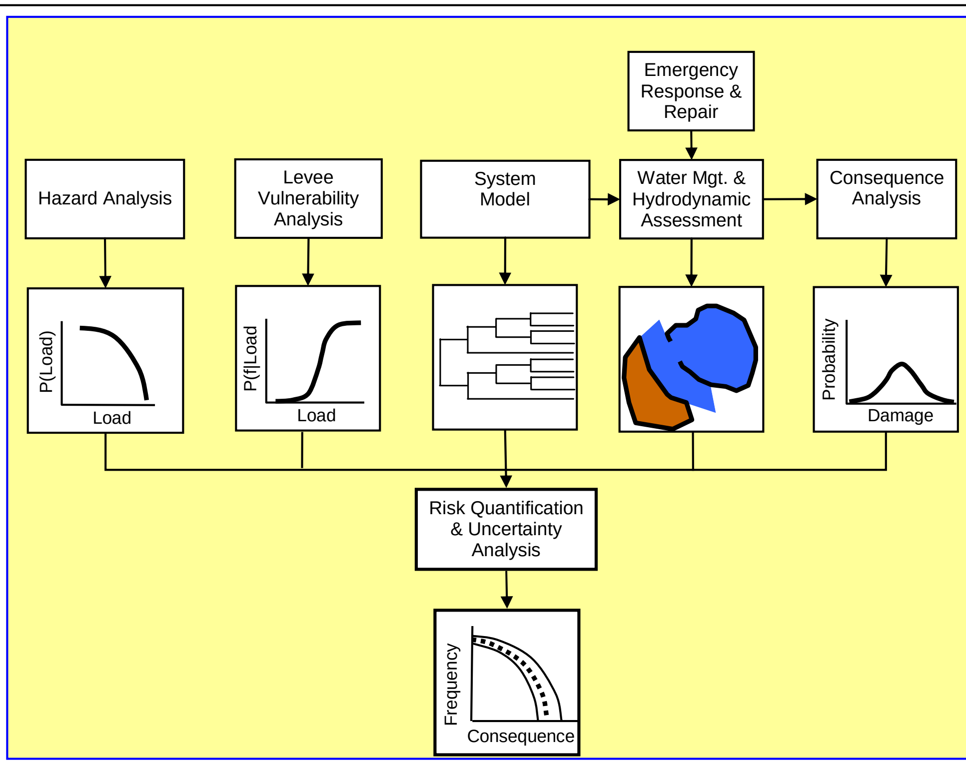

Figure 5 Risk Model. *Many separate elements are brought together in the risk model. The final product of the risk analysis is a relationship showing the frequency of the consequences of levee failures.*

Limitations

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

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). DRMS includes an analysis of uncertainty.

Some Data Needs

- Comprehensive topographic survey for existing conditions
- Comprehensive bathymetric survey for existing conditions
- Detailed documentation of historical levee failures

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.

Unlike other risk analyses involving the potential of flooding, DRMS is unique. Most flood risk analyses consider a single stressing event, like a major flood. For example a similar evaluation for New Orleans, would consider the risk associated with a hurricane on 350 miles of levees. The scale and complexity of DRMS for the Delta and Suisun Marsh has likely not been attempted by another evaluation of risk from flooding. The DRMS evaluations are conducted for:

- About 1,345 miles of levees, over 3 times the length for New Orleans
- An area of 1,315 square miles, almost 4 times the size of New Orleans
- Highly variable foundation conditions including compressible organic 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

To complicate the analysis even more, the Phase 1 risk analysis needed to be completed in about 1 year using only readily available information. The schedule for Phase 2 of the work, the evaluation of risk reduction actions, provides only about one-half year for that portion of the analysis.

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.

This assessment is based on existing information (models and data), which in many cases is limited. The following timeline (Figure 6) shows the availability of information related to making future quantitative projections for hazards and environmental effects in the Delta.

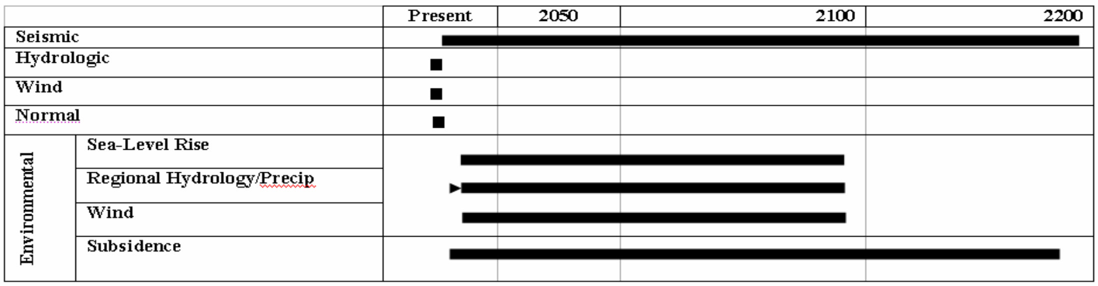

Figure 6 Timeline of Available Information. *Much of the information available for estimates of future risk is limited. Even when estimates of future conditions can be made, the uncertainty increases with time from the present.*

One of the reasons for conducting a risk analysis is to quantitatively consider the uncertainties that relate to the performance of levees. There are fundamentally different sources of uncertainty that affect the analysis. The first source is attributed to the inherent randomness of events in nature. This source of uncertainty cannot reduced by collection of additional information, but can be predicted in terms of probability. The second source of uncertainty is attributed to lack of knowledge due to lack of data or lack of understanding. In principle, this type of uncertainty can be reduced with improved knowledge and/or the collection of additional information.

The result of this risk analysis is a better understanding of risks that the Delta and Suisun Marsh face today and in the future. The risk results should be considered on a regional basis rather than for any specific levee reach. Some readers may attempt to focus on an individual island or land tract for information – this tendency should be discouraged. The information in the report should not be used as a basis of 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 and 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.

Project Team

Project Sponsors - The DWR, CDFG, and USACE serve as the project sponsors for DRMS. The sponsors are assisted by a stakeholder Steering Committee and a Technical Advisory Committee.

Steering Committee - Steering Committee members are policy advisors that represent interests of the Delta and interests of those outside the Delta who rely on the Delta infrastructure. The role of the Steering Committee members is to assure proper coordination among agencies, the public, and the DRMS Consultant are maintained. The members are expected to speak with authority on the positions of their constituency and have access to policy makers within their organization when needed. The Steering Committee provides policy advice to the project sponsors and the DRMS Consultant.

Technical Advisory Committee - The Technical Advisory Committee, which is a de-facto member of the Steering Committee, has the same roles and responsibilities as those described above for the Steering Committee. In addition, the Technical Advisory Committee members are technical subject matter experts, and serve, at the direction of the project sponsors, as independent reviewers of the DRMS project work. The Technical Advisory Committee reviews interim and final work products of the DRMS consulting team. The committee provides written comments and advice on the appropriateness of the methods used in the development of the technical products. In its role as an independent reviewer, the committee does not produce or generate work on the DRMS project.

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 drafts of the Phase 1 work to be completed in Spring 2007 and drafts of the Phase 2 work to be completed in Fall 2007.

The consulting team includes 23 firms located in the Sacramento/Bay Area/Stockton region. These local firms bring extensive local experience with the Delta in their respective field of specialization. The firms and the services they provided are described below.

4. Seismic Risk

Setting

An earthquake (seismic event) happens when the land on one side of a fault moves relative to the land on the opposite side. This movement causes the ground to shake – locations closer to the source of the earthquake experience stronger shaking and locations farther from the source experience less shaking.

The Delta and Suisun Marsh are located in a seismically active region. Figure 7 shows known faults in the San Francisco Bay Region. Compared to the Bay Area, the seismicity of the Delta and Suisun Marsh is characterized as moderate to high.

Each fault shown on the map can produce earthquakes. The frequency and potential size (magnitude) of earthquakes vary among the faults. The San Andreas Fault (identified as SAF in Figure 7) is capable of producing the largest earthquakes in the region, but it is located farther from the Delta than many other faults.

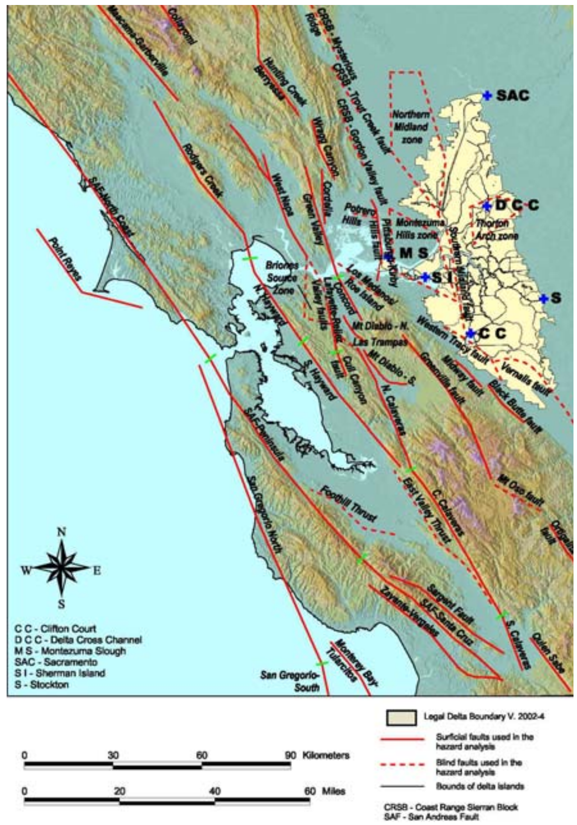

Figure 7 - Faults in the San Francisco Bay Region. Each fault in the area can produce earthquakes.

Earthquakes can be described in terms of Magnitude (M) on the Richter Scale and in the acceleration of gravity. The full acceleration of a body falling towards earth is 1.0 gravity (g). Depending on the movement of a fault, earthquakes can cause horizontal and/or vertical accelerations. The 1989 Loma Prieta earthquake was 0.64 g near the source – accelerations diminished farther from the source.

Delta or Suisun Marsh levees have never failed from an earthquake. However, the current network of levees has not experienced a large earthquake. The 1906 San Francisco earthquake was a significant event of magnitude 7.8, but levees were much shorter then. The last 100 years of land subsidence has deepened Delta islands. Therefore, these levees now are higher and more susceptible to failure during an earthquake than they were in 1906.

On the basis of research conducted since the 1989 Loma Prieta earthquake, the U.S. Geological Survey (USGS) and other scientists (WGCEP, 2003) estimated a 62 percent probability that at least one magnitude 6.7 or greater quake will strike the San Francisco Bay region before 2032. Such an earthquake could cause major damage to Delta and Suisun Marsh levees. The area that is considered potential vulnerable to levee failure during seismic events is the area below the mean higher high water elevation (MHHW). This is the average elevation of the highest of the two tides each day over a 19 year period. Figure 8 shows the area within the MHHW and 100-year flood boundaries.

Methodology

The seismic hazard was evaluated using a probabilistic seismic hazard analysis (PSHA), which is a standard practice in the engineering seismology/earthquake engineering community (McGuire, 2004). In a departure from standard methodology, time-dependent hazard was calculated from the major Bay Area faults using the range of models to calculate the seismic hazard at selected times over the next 200 years. The seismic hazard analysis generates probabilities of occurrence of all plausible earthquake events (defined by their locations, magnitudes, and ground motions) and considers uncertainties. The Phase 1 Risk Analysis Report and the Seismology Technical Memorandum present more information on elements of the seismic risk analysis.

Levee Failure Modes

The analysis considers two levee failure modes:

- **Liquefaction –** Delta and Suisun Marsh levees are composed of a wide variety of materials including silt, sand, clay, and organic peat. Saturated sandy areas within the levees can loosen and move (liquefy) during ground shaking, causing the levee to slump. In addition, saturated sandy areas under the levees can liquefy during ground shaking and weaken support for the levee above. Liquefaction is expected to be the primary mode of failure.
- **Inertia-induced deformation –** The ground movement during an earthquake can cause a levee to move and deform, even without liquefaction, due to the levees inertia.

The deformation from these failure modes can lead to levee overtopping as a result of crest slumping and settlement, internal piping and erosion, sliding blocks of levee material, cracking, and exacerbation of existing seepage problems. All of these can lead to levee breaches and flooding of islands.

Seismically induced levee failures tend to extend for thousands of feet if not miles. There is considerable evidence worldwide of long sections of levees failing because of liquefaction (see photo). The Delta includes large areas where the ground is susceptible to liquefaction during an earthquake.

A levee at Kobe, Japan, failed during a Magnitude 6.9 earthquake in 1995, at a time when it was not holding back water

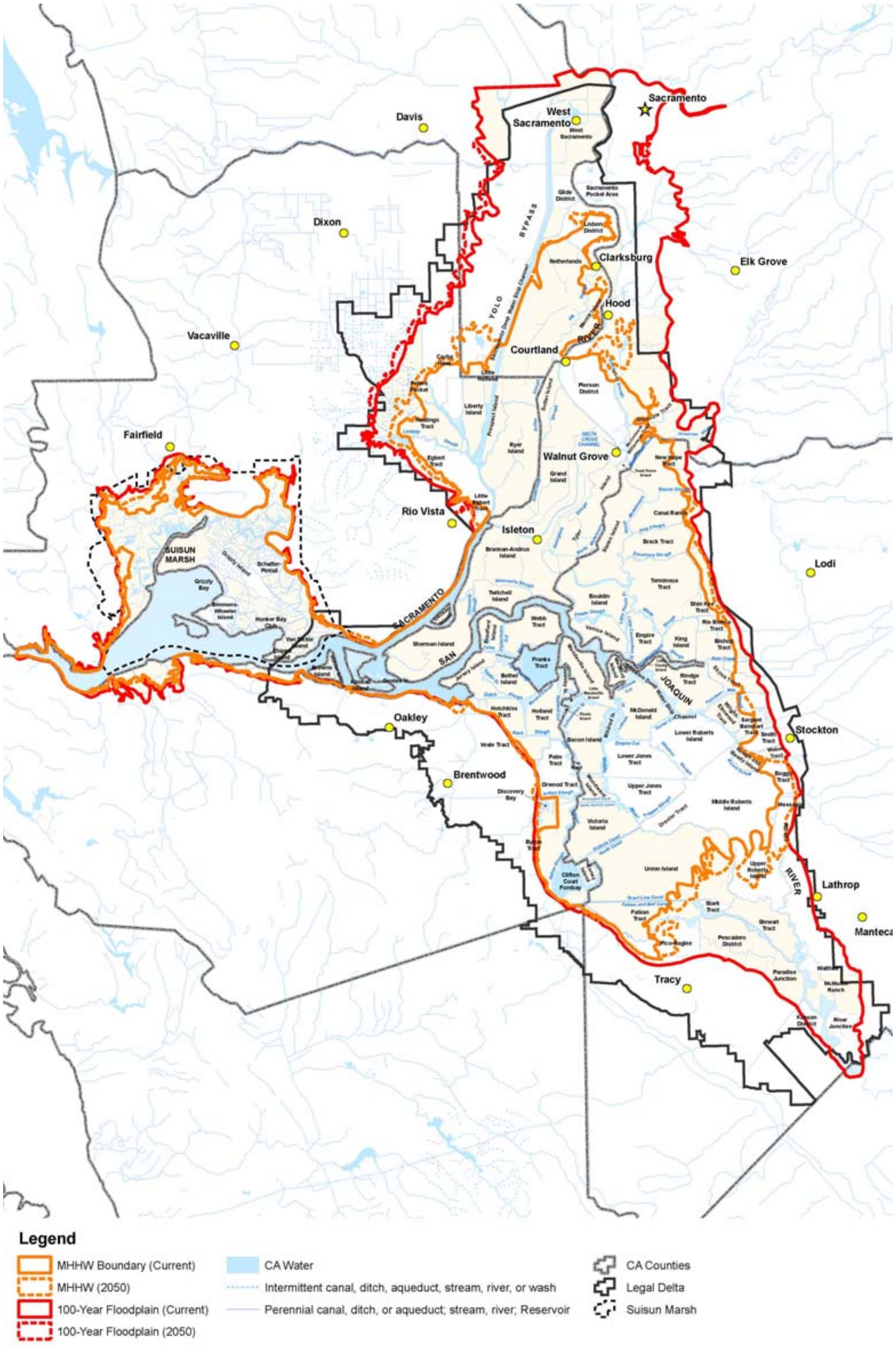

Figure 8 - MHHW and 100-Year Flood Boundaries. The area that is considered at risk from seismic failures of levees is the MHHW boundary.

Determining which levees would fail during an earthquake depends on the magnitude of the earthquake and the ground acceleration at a given location. Since larger magnitude earthquakes cause ground shaking for long periods of time, lower ground acceleration can cause levee failures. Since smaller magnitude earthquakes cause ground shaking for shorter periods of time, levees can withstand higher ground acceleration before they fail. A broad generality of the analysis is that levee damage and breaching can be expected in locations where sands can liquefy when earthquake magnitude and acceleration reach the following values:

- Accelerations greater than 0.3 g with a magnitude 5.5 earthquake
- Accelerations greater than 0.2 g with a magnitude 6.5 earthquake
- Accelerations greater than 0.1 g with a magnitude 7.5 earthquake

Considering the likelihood of all earthquakes on all faults over a 200-year period provides a good indication of ground acceleration that can be expected. Figure 9 shows the peak ground acceleration (PGA) for a 200-year return period. The acceleration values in the figure are for the mean condition (about a 50 percent chance of happening in the 200-year period.

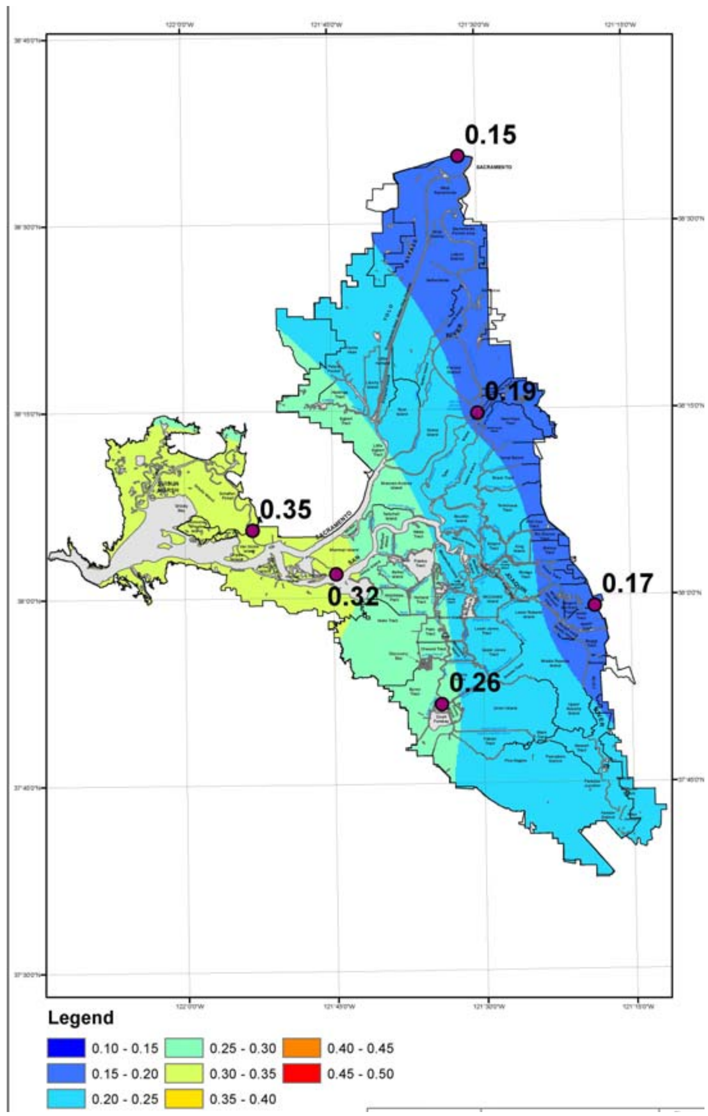

Figure 9 PGA, 200 year return period. The aggregation of all earthquakes on all faults in the region provide an estimate of peak ground acceleration for the Delta and Suisun Marsh for a mean (about 50 percent) chance of occurrence over a 200-year period).

Multiple Levee Failures

When an earthquake occurs, all Delta/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 impacting the study area could cause levee failures on several islands and there is a real prospect of multiple islands flooding at the same time.

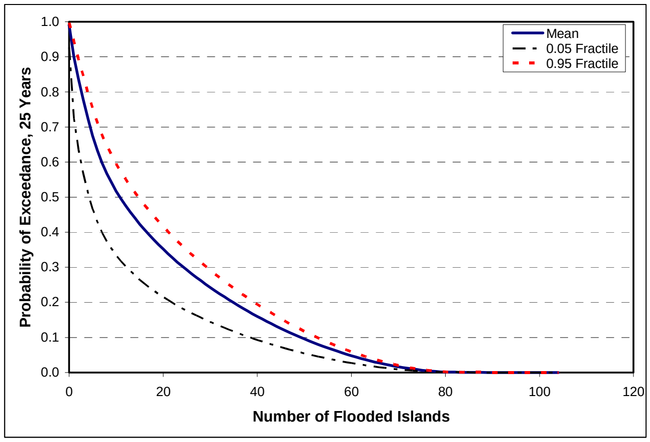

Figure 10 Probability distribution in 25 years of the number of simultaneous flooded islands due to seismic

Figure 10 shows the probability that different number of islands will fail simultaneously during the next 25 years due to seismic events in or in the vicinity of the Delta and Suisun Marsh. The vertical scale on the figure goes from 0 (no chance of failure) to 1 (100 percent certainty of failure). The relationship in the figure is for existing (2005) conditions and does not include changing future conditions.

Considering the probability of all seismic levee breaches under existing (2005) conditions, about 115 failures can be expected during 100 years. This is an average failure rate of 1.15 failures per year.

Consequences of Seismic Events

The consequences were estimated under three different water year types – wet, average, and dry -- to assess the variation in the resulting risk due to different hydrological conditions. Six representative island failure and damage scenarios were used to estimate the consequences. These are:

- Case 1 Seismic Scenario - 1 island flooded & 2 others damaged
- Case 2 Seismic Scenario - 3 islands flooded & no others damaged
- Case 3 Seismic Scenario - 3 islands flooded & 3 others damaged
- Case 4 Seismic Scenario - 10 islands flooded & no others damaged
- Case 5 Seismic Scenario - 20 islands flooded & 6 others damaged
- Case 6 Seismic Scenario - 30 islands flooded & 7 others damaged

The scenarios include different combinations of flooded islands. Some of the scenarios include damage, but un-flooded islands, because and earthquake can damage many miles of levees. The damaged islands complicate the emergency response and repair strategy.

Emergency Levee Response and Repair

The duration and cost of levee repairs rise as the number of islands flooded in a seismic event increase, as indicated in Table 1. Emergency repairs are estimated to take five years or more for 20 flooded islands and more than 6.5 years for 30 flooded islands. Repairs can cost billions of dollars.

Table 1 Duration and Cost of Repair for Seismic Cases

Seismic Case	Number of Flooded Islands	Duration of Repairs (months)	Cost of Repairs ($billion)
1	1	Up to 20	Up to 0.6
2	3	19	0.9
3	3	23	2.1
4	10	45	4.0
5	20	62	6.2
6	30	81	8.4

Export Disruption

When a levee breach occurs during the late spring, summer or early fall, saline water from Suisun Bay will usually be drawn into the Delta and the flooded islands. Water might not be of adequate quality use by the State and Federal water projects, Contra Costa Water District and in-Delta users. As shown in the Table 2, pumping could be stopped for several months, depending on the number of flooded islands, the timing of the earthquake and the wetness or dryness of hydrologic conditions. The disruptions shown in the table are due only to salinity.

Table 2 Duration of No Export Pumping for Seismic Cases

Seismic Case	Number of Flooded Islands	Duration of No Pumping (months)[1]	Water Not Exported (maf[2])
1	1	Up to 2	Up to 0.7
2	3	1 to 3	0.1 to 1.0
3	3	1 to 4	0.1 to 1.3
4	10	2 to 10	0.7 to 2.5
5	20	11 to 21	6.3 to 6.5
6	30	16 to 23	6.5 to 9.3

[1]Export disruptions will continue for an additional period, depending on the severity of the scenario, while only partial pumping is possible.
[2] million acre-feet

After pumping resumes, water may need additional treatment to make it safe for drinking. The primary contaminant of concern is organic carbon, which may react with disinfectants to form 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 urban users may have their Delta supplies unavailable.

Economic Consequences

Economic consequences were quantified in terms of *economic costs* and *economic impacts*. Economic costs are the net costs to the state economy without any consideration of who bears the cost. All economic costs are generally additive. Economic impacts include a variety of other economic measures such as lost output, lost jobs, lost labor income, and lost value added (the sum of wages and salaries, proprietor's 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.

Figure 11 shows the probability of an earthquake causing economic costs during a 25 year period. The relationship in the figure is for existing (2005) conditions and does not include changing future conditions. The majority of this cost will occur outside the Delta.

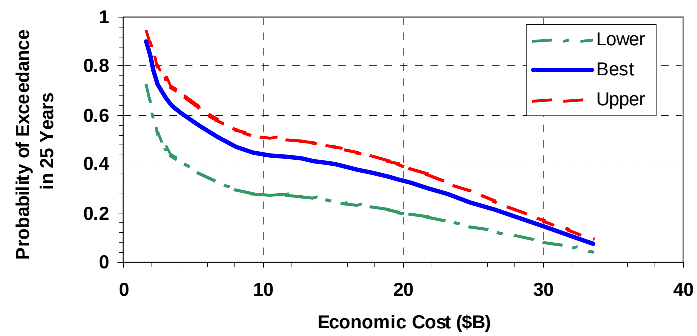

Figure 11 Probability of Economic Costs from Seismic Events

Figure 12 shows the probability of an earthquake causing economic impacts during a 25- year period. The relationship in the figure is for existing (2005) conditions and does not include changing future conditions. The majority of these impacts will occur outside the Delta.

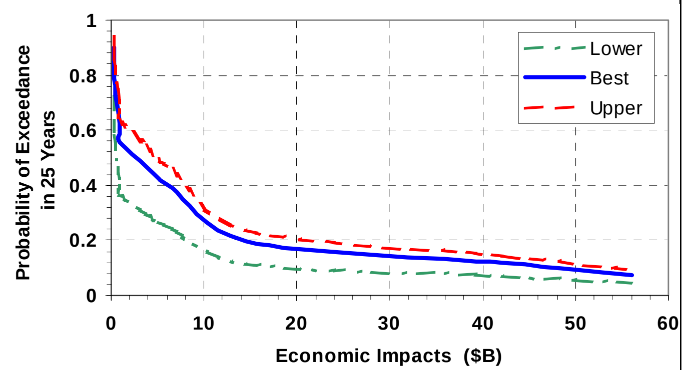

Figure 12 Probability of Economic Impacts from Seismic Events

Ecosystem Consequences

The percent of the population that is entrained influences the increase in risk of population extirpation following the levee breach event. Table 3 provides the percent of each species' total population that is found east of the Carquinez Straits (i.e., the percentage of the population that is potentially at risk from levee failure) in July and October. For example, the constant presence of the vast majority of the delta smelt population in the Delta increases the risk that a levee failure could increase the risk of species extinction, over that of fish such as silversides which have a small percentage of the population east of the Carquinez Straits in either month.

Table 3. Juvenile population potentially exposed to entrainment on flooded islands

Fish Species	Juvenile population potentially exposed to entrainment on flooding islands			
	Instantaneous Average Population in the Delta[a] (1995-2005) JULY	Percent of total juvenile population represented by population in Delta[a] JULY	Instantaneous Average Population in the Delta[a] (1995-2005) OCTOBER	Percent of total juvenile population represented by population in Delta[a] OCTOBER
Chinook salmon [b]	3,900	<1%	21,000	<5%
Delta smelt	6,492,000	100%	440,000	100%
Green Sturgeon[c]	0	20%	0	20%
Inland Silverside[d]	223,000	30%	21,000	30%
Longfin smelt[c]	4,904,000	5-40%	1,075,00	10-50%
Steelhead[c]	0	<5%	0	<15%
Striped Bass	19,755,000	75%	211,000	65%
Threadfin shad[d]	7,492,000	85%	3,300,000	85%

[a] The Delta includes aquatic habitats east of the Carquinez Straits
[b] Percentages of Chinook salmon juveniles in the Delta reflect estimated total number of juveniles in a given year class (all runs combined), including those that migrated to the ocean earlier in that year.
[c] Surveys used to obtain Instantaneous Average Population (Bay survey, 20 mm survey, Summer Townet Survey and Fall Midwater Trawl) are very poor at sampling steelhead and green sturgeon because steelhead can outswim the nets and the sampling gear does not target the epibenthic habitat of green sturgeon. Professional experience was used to estimate the percent of the total population in the Delta for these fish.

[d] Threadfin shad and inland silversides live along the edge in shallower water; sampling is done in center of the channel, but represents the populations fairly well

[e] Longfin smelt appear to use nearshore marine environments during summer months; the magnitude of these migrations is unknown. Percentages of longfin smelt in the Delta reflect the estimated total number of juveniles in a year class including those that have migrated to the ocean.

The risk index incorporates immediate and long-term impacts of levee failure which can be beneficial or adverse, depending on the species' response to the state of the Delta and flooded islands after a levee breach (i.e., the number of breaches on an island breach duration, distribution of high salinity water), and human response to levee failure (i.e., changes in river flow upstream, the pool of coldwater stored in reservoirs, and duration of curtailed in-Delta and CVP-SWP water diversions). The risk index scores reported expresses whether the impact of the levee failure is beneficial or adverse relative to a "worst-case" scenario for each species.

Results from all modeled seismic scenarios indicate that sturgeon would benefit from levee-failure events, reflecting the creation of foraging habitat created by levee-failures. Also sturgeon are not very susceptible to the negative impacts of levee-failure because the are highly dispersed in the Delta and most of the population is not in the Delta at any given moment (low *PEL*). The actual benefit of levee-failures to sturgeon must be interpreted with caution as impact factors are expressed as a percentage of the absolute value of the impact of the worst-case scenario; for sturgeon, the worst-case scenario represented a relatively small impact on sturgeon populations.

No seismic scenario resulted in the worst case scenario; In contrast, most of the seismically-induced levee-failure events (involving 3, 5, 10, 20, or 30 islands) resulted in *beneficial* population-level effects. All seismically-induced levee-failure events that resulted in flooding of 20 or 30 islands produced beneficial effects for all species; scenarios involving fewer flooded islands had adverse population consequences for some species. Threadfin shad and inland silverside suffered adverse impacts in more seismically-induced levee-failure scenarios than other species. Threadfin shad displayed the greatest adverse impact to any species in seismically-related levee-failure event (~47% of the worst-case scenario) when 10 islands flooded during a wet year.

In all seismic levee failure scenarios, impacted vegetation increased with area flooded, but the magnitude depended on the vegetation type, with loss of up to 39% of herbaceous wetland seasonal ruderal, 29% of non-native trees and 24% of shrub wetland in the Delta and Suisun Marsh. (Agricultural vegetation is not discussed here) Of critical vegetation types which harbor native vegetation and rare species of vegetation, native herbaceous upland (which comprises a small total area of the Delta < 500 acres), was not impacted by flooding in any of the cases. Less than 12% of critical intertidal and aquatic habitat was impacted in any scenario, however, shrub wetland lost 24% of its total habitat in the Delta and Marsh in the worst case. Overall, these results, while not incorporating the impacts of levee breaches on sensitive species, suggest that primary impacts of flooding are on vegetation types of non-native species. However, a considerable amount of critical habitat including alkali high marsh, shrub wetland and riparian trees are reduced by 10 – 24%.

Public Health and Safety Consequences

The primary public safety concern is for the population on flooded island who are endangered by flooding resulting from the earthquake. Table 4 presents the populations at risk from each scenario.

Table 4 Population at Risk for Seismic Scenarios

Seismic Scenario	Population of Flooded Islands
Case 1, 1 island flooded	1,837
Case 2, 3 islands flooded	2,241
Case 3, 3 islands flooded	2,241
Case 4, 10 islands flooded	5,359
Case 5, 20 islands flooded	5,978
Case 6, 30 islands flooded	9,554

Individual Island Failures

Estimates of the risk of seismic levee failure for each island are shown in Figure 13. The map is color coded to show groups of islands with similar ranges of failure rates. The expected frequency of failure for each island is shown as fitting into one of 5 bands (less than 1 percent, between 1 percent and 3 percent, etc.). When viewed collectively with other islands, some areas of the Delta and Suisun Marsh show patterns of the level of expected risk. These show areas with lower or higher frequencies of failures then other areas. The lower areas of failures tend to be in the Suisun Marsh and the eastern portion of the Delta. A relatively higher frequency of failure is expected to occur in the central and western Delta.

Table 5 provides a convenient method to convert the values in Figure 13 to other ways of viewing the chance of failure. For example if a landowner or other business wants to view their exposure to seismic failure over say a 50 year period, the table provides that conversion.

Table 5 Example Ways to View Chance of Failure

Annual Frequency of Failure (%) See Fig. 13 and Fig 18	Annual Mean No. of Failures	Average Number of Failures in 100 Years	Average Return Period Between Failures (years)	Percent Chance of Failure During Next			
				10 years	20 years	50 years	100 years
1	0.01	1	100	9.5	18.1	39.3	63.2
3	0.03	3	33.3	25.9	45.1	77.7	95.0
5	0.05	5	20	39.3	62.2	91.8	99.3
7	0.07	7	14.3	50.3	75.3	97.0	99.9
10	0.10	10	10	63.2	86.5	99.3	100.0

Note: All numbers in a given row are ways to describe the same chance of failure. For example, an island with an annual frequency of failure of 5% from Figure 13 could expect an average of 5 failures in 100 years, an average period between period of 20 years between failures, and a 62.2% chance that it will fail sometime during a 20 year period.

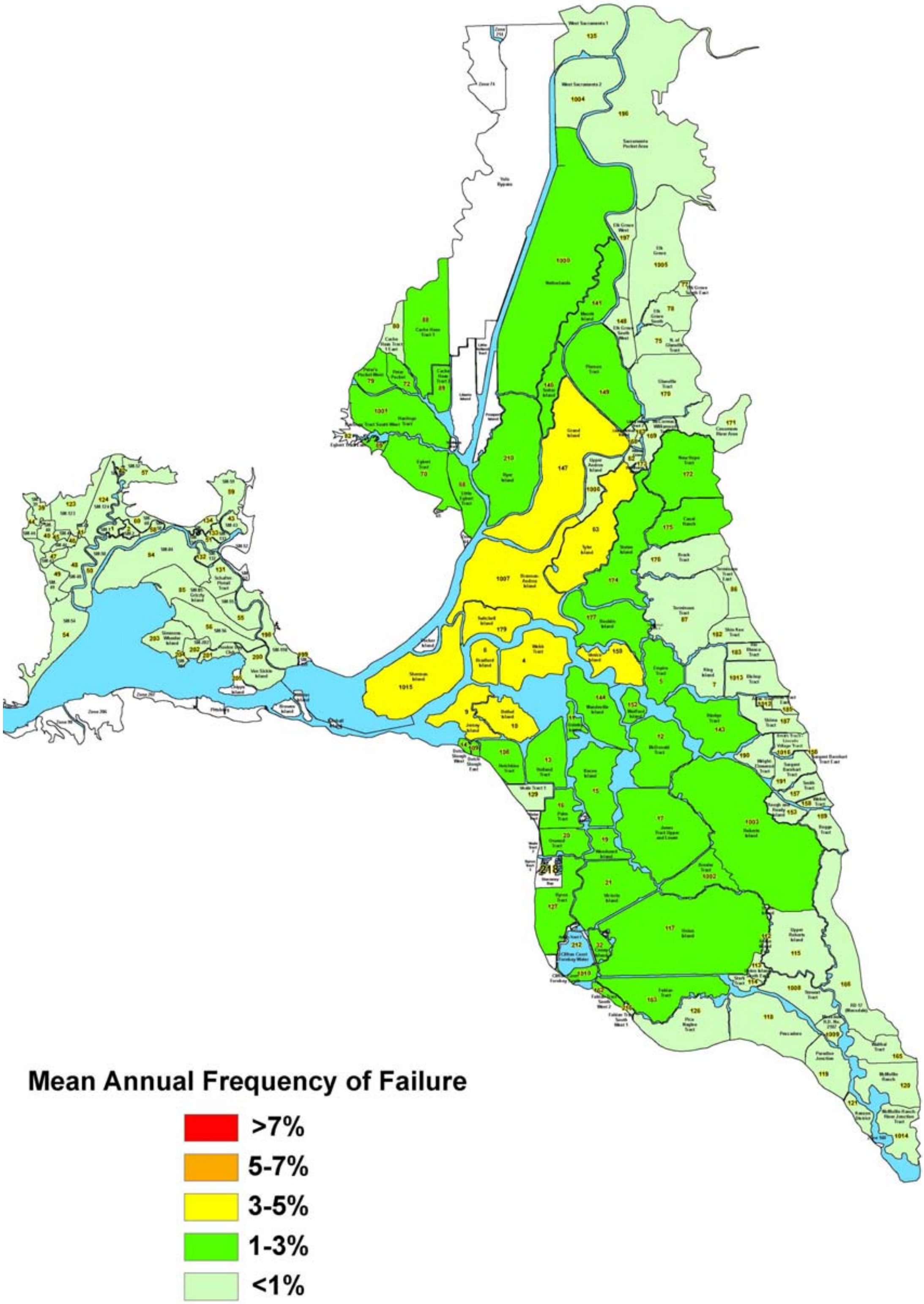

Figure 13 - Annual Frequency of Failure of Individual Islands Under Seismic Events.

Future Seismic Risk

For the future years 2050 and 2100, the seismic risk factors are expected to increase approximately as indicated in Table 6. The risk of levee failure (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. In total, the losses by 2050 are expected to be to be 90 percent to 150 percent of those in 2005. The losses by 2100 are expected to be to be 250 percent to 600 percent of those in 2005.

Table 6 Seismic Risk Factor Increases Relative to 2005

Risk Factor	***2050***	***2100***
Seismic Hazard (frequencies)	10%	20%
Seismic Fragility (due to sea level and subsidence loading)	2%	6%
Increase in Expected Frequency of Island Flooding[a]	12%	27%
Salinity (increased periods of disruption due to sea level, subsidence, less water supply available)	50%	100%
Consequences (population growth, land use, increased pressure on ecosystem, increased dependence on export water export supplies)	70%	200%
Estimated Increase in Expected Losses[b]	90% to 150%	250% to 600%

[a]Increased frequency in island flooding reflects increased hazard and fragility (e.g., 1.1 x 1.02).

[b]Lower bound reflects increase in expected frequency of failure and consequences. Upper bound includes the effects of subsidence, sea level and less available water supply on salinity intrusion and periods of disruption.

Levee breaches on the ecosystem will continue to have mixed impacts depending on the specifics of the event. However, for important native species, there are no expectations of positive changes from warmer temperatures, more flooding depth, additional salinity intrusion and less fresh water for low-flow season levee breach event management and recovery. Thus, on balance, it is expected that 2050 conditions will present increased ecosystem risks associated with a given levee breach event and that 2100 conditions will present yet further increases in risks.

5. Flood (Hydrologic) Risk

Setting

About 42,500 square miles drain to the Delta. During an average year, the Sacramento River contributes about 85 percent of the Delta's total inflow. The San Joaquin River is about 10 percent of the total inflow and three eastside tributaries makeup the remaining 5 percent. High flows into the Delta from these rivers depend on snowmelt, precipitation, and water management (reservoirs) in their individual watersheds. Since major storms crossing California take different paths, one or more rivers can be carrying high flood flows at a given time while flows in other rivers are lower. For example, high flows on the Cosumnes River may the cause high water levels in some eastern Delta channels while the southern Delta is seeing only moderate flows from the San Joaquin River.

Over the long-term, many different combinations of high flood flows in the various rivers are possible. DRMS considered magnitude and frequency of flooding in different parts of the Delta from these rivers to evaluate the probabilities of these high flows. This also allows estimating the magnitude and frequency of even larger floods that have not yet been experienced in the Delta. These non-historical floods help portray a more accurate estimate of flood risk than by simply using only historical data. A risk analysis is likely to underestimate the risk if relying only on historical data.

While the area that could be flooded by a seismic event was limited to the area below the MHHW level, floods can affect a larger area (see Figure 8). The larger area must be considered because the flood causes higher elevations where the rivers enter the Delta. Today, most of the Delta is within the 100-year floodplain, an area that can be expected to flood at least on the average of once in 100 years.

Figure 14 shows the 100-year flood elevations in the Delta and Suisun Marsh. Flood elevations are highest on the rivers entering the Delta and decrease as they flow towards the bay. Levees in the eastern and central

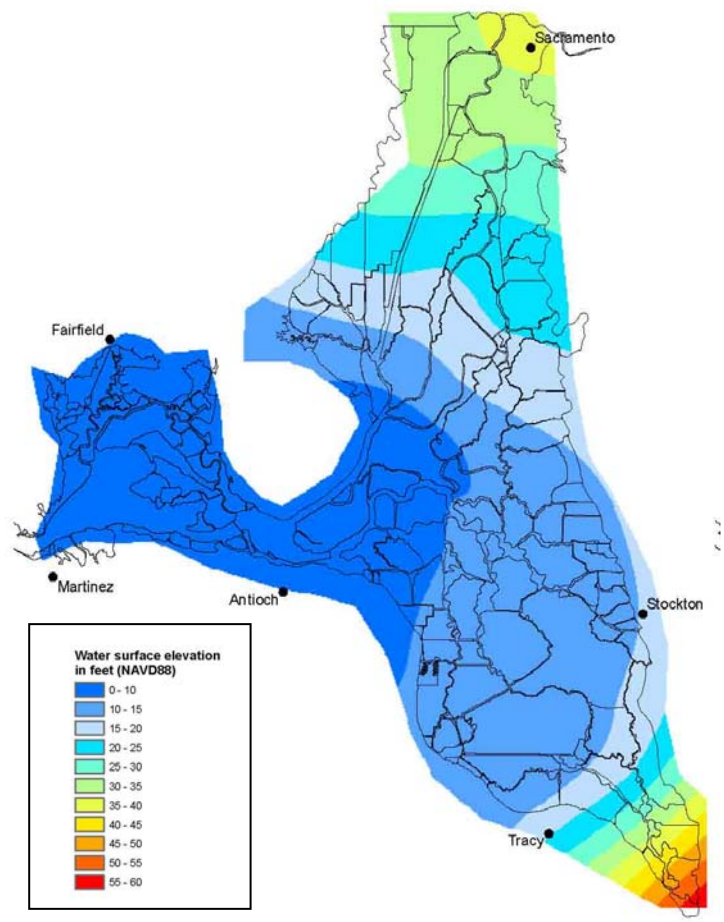

Figure 14 100-Year Flood Elevations in the Delta.

portion of the Delta are affected more by high flows then sea level. The levees in the western portion of the Delta are affected more by sea level and high tides then high flows.

Methodology

The flood vulnerability of the Delta and Suisun Marsh levees were assessed for a series of flood scenarios considering daily Total Delta Inflow (TDI), in cfs. The frequency of major flood inflows, the patterns of inflows from the various rivers, and Delta water surface elevations associated with these flows are all critical in determining flood risk. Water surface elevations in the Delta were estimated from data on historic water levels measured at selected Delta gauging stations.

Underseepage analyses were conducted using steady-state analysis procedures of the finite element program Seep/W (Geo-Slope International Ltd. 2004). The program can model characteristics for multiple soil types encountered in the Delta.

The majority of the Delta and Suisun Marsh levees have some pervious materials within the embankments and can therefore transmit water. It is believed that developing a failure model for predicting through-seepage induced failures considering the record of past failures is much more reliable than performing a series of seepage model analyses.

More information on flood vulnerability analysis is presented in the Phase 1 Risk Analysis Report and Levee Vulnerability Technical Memorandum.

Levee Failure Modes

Large inflows to the Delta and Suisun Marsh from upstream storm runoff raise the water level in the channels and place more pressure on the levees. This increased pressure can force more water to seep through the levee embankment and through the foundation under the embankment. If the pressure is too great, the movement of water can move particles of the levee or foundation with it and cause a portion of the levee to fail. Levees sitting on peat foundations periodically need to have their crest elevations raised as the foundation under the levee compresses. High water in the channels can also rise higher than the tops of the levees and can fail a levee as water flows over its top.

The erosion and slope instability were not considered as one of the main modes of failures but they were considered as fraction of total mode of failures. For example, the through-seepage emanating from landside slope of the levee could lead to slope instability. Given that there are about 1,345 miles of levees in the Delta and Suisun Marsh, and that the majority of the levees were built without the benefit of modern design and construction techniques, there are many unknown areas of deficiencies that can contribute to a levee failure.

Multiple Levee Failures

When a major flood occurs, it is likely that levees on more than will fail. Historical experience shows that two or more islands have failed from the same flood event in many separate years. The number of flooded islands tends to increase as the flood becomes larger. However, this is highly variable depending on the flows from the different tributaries to the Delta.

Figure 15 shows the probability that different number of islands will fail simultaneously during the next 25 years due to flood event in the Delta and Suisun Marsh. The vertical scale on the figure goes from 0 (no chance of failure) to 1 (100 percent certainty of failure). The relationship in the figure is for existing (2005) conditions and does not include changing future conditions.

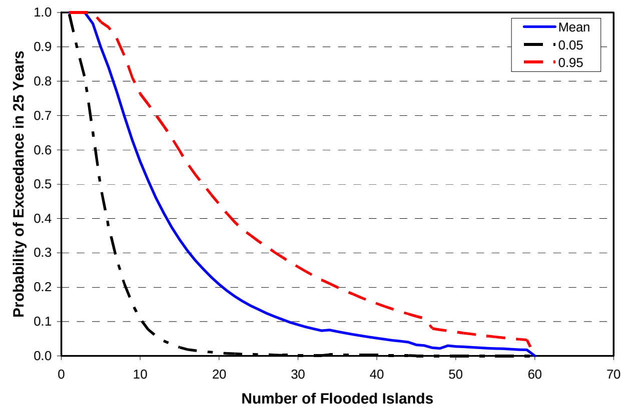

Figure 15 Probability distribution in 25 years of the number of simultaneous flooded islands due to hydrologic events

Considering the probability of all flood related levee breaches under existing (2005) conditions, about 209 failures in the Delta (exclusive of Suisun Marsh and the area west of the Sacramento River) can be expected during 100 years, an average failure rate of 2.09 failures per year. This can be compared to 166 historical failures in the Delta since 1900. About 870 failures can be expected in the Suisun Marsh during 100 years, a rate of 8.7 failures per year.

Consequences of Flood Events

The consequences were estimated under three different water year types – wet, average, and dry -- to assess the variation in the resulting risk due to different hydrological conditions. Two representative island failure scenarios were developed to analyze consequences from floods (assuming 2005 conditions):

- Case 7 - 20 islands flooded
- Case 8 - 30 islands flooded

The objective was to assume relatively large number of failures and assess the scale of impacts. No non-breach damage was assumed on the flooded islands.

Emergency Levee Response and Repair

The duration and cost of levee repairs rise as the number of islands flooded in a hydrologic event increases, as indicated in Table 7. Emergency repairs are estimated to take a little less than 13 months for 20 flooded islands and more than 13 months for 30 flooded islands. Repairs are estimated to increase from 4.8 to 6.8 billion dollars.

Table 7 Duration and Cost of Repair for Hydrologic Cases

Hydrologic (Flood) Case	Number of Flooded Islands	Duration of Repairs (months)	Cost of Repairs ($billion)
7	20	13-	4.8
8	30	13+	6.8

Export Disruption

When a levee breach occurs during a flood, the high flows tend to fill the flooded islands. This is in contrast with failures at times of low river flow times when salt water from Suisun Bay is drawn into the Delta to fill flooded islands. During these high flow events, there may be essentially no impact on water quality at the export pumps and no impact on reduction of water pumped. Depending on the number of flooded islands, the timing and size of the flood and whether high flows have already freshened the Delta and Suisun Bay this may be the most common occurrence. There were a couple of large floods in the historic record that did not have such negligible impacts, but those floods disrupted pumping for only one month and the maximum amount of water not pumped was 0.7 million acre-feet.

Economic Consequences

About 98% of the total economic cost from a multiple island failure in the Delta is expected to be in-Delta cost and the other 2% is due to lost use of infrastructure that is of statewide importance. The main elements of in-Delta costs are emergency response and repair cost, infrastructure repair cost, lost use of structures and services, agricultural losses, and lost recreation. About 80% of in-Delta costs are from the emergency response and repair cost and infrastructure repair cost, and 15% are from loss of use of structures and services. Other significant in-Delta costs were to agriculture. The main statewide infrastructure disruption was to Delta area highways. The economic costs are mainly controlled by losses in the Delta. Figure 16 shows economic costs for both analysis cases (20 islands flooded and 30 islands flooded). The economic impacts are again mostly controlled by the value of lost output, followed by lost value added, then lost labor income, as shown in Figure 17 for Case 8, the 30 island flood scenario.

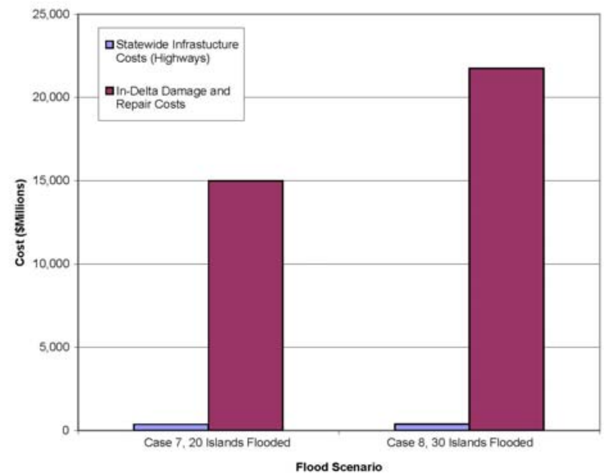

Figure 16 Economic Costs of Flood Failure Scenarios

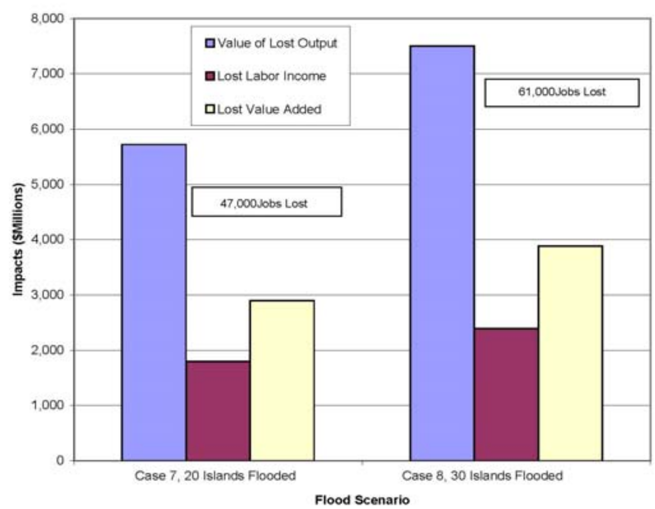

Figure 17 Economic Impacts of Flood Failure Scenarios

Ecosystem Consequences

Outcomes of the two flood-related levee-failure scenarios, revealed adverse impacts to every aquatic species studied except for green sturgeon and steelhead. As indicated above, green sturgeon benefited from every levee-failure scenario. Steelhead displayed a relatively small net benefit (~4% of the magnitude of the worst-case scenario) from both 20-island and 30-island flood scenarios when they occurred in December and April and adverse effects when these flood-scenarios occurred in other months. Adverse impacts to other species occurred without regard to the month, water year type, or magnitude of the levee-failure scenario. Delta smelt and longfin smelt displayed the greatest adverse impacts to any species in flood-related levee-failure events (~63% of the worst-case scenario). Terrestrial vegetation habitat loss was different for flood scenarios than seismic, with a much greater loss of all tree vegetation types (up to 45% of total area of native trees), and smaller (<15%) losses of other vegetations types. In contrast, the impacts of flood scenarios were similar for seismic levee breaches for terrestrial wildlife, although flood scenarios doubled the loss of area of sandhill crane habitat to 57% loss of total habitat in the Delta and Suisun Marsh.

Public Health and Safety Consequences

The primary public safety concern is for the population on flooded islands who are endangered by flooding resulting from the hydrologic event. Table 8 presents the populations at risk from each scenario.

Table 8 Population at Risk for Flood Scenarios

Flood Scenario	Population of Flooded Islands
Case 7, 20 islands flooded	20,548
Case 8, 30 islands flooded	34,887

Individual Island Failures

Estimates of the risk of flood induced levee failure for each island are shown in Figure 18. The map is color coded to show groups of islands with similar ranges of failure rates. The expected frequency of failure for each island is shown as fitting into one of 5 bands (less than 1 percent, between 1 percent and 3 percent, etc.). When viewed collectively with other islands, some areas of the Delta and Suisun Marsh show patterns of the level of expected risk. These show areas with lower or higher frequencies of failures then other areas. The higher areas of failures tend to be in the Suisun Marsh and throughout the central portion of the Delta, but it appears more variable than the similar seismic map in the previous section. Table 5 in the seismic section above can be use to convert the values in Figure 18 to other ways of viewing the chance of failure. For comparison with historical record, Figure 19 shows the number of actual levee failures for each island.

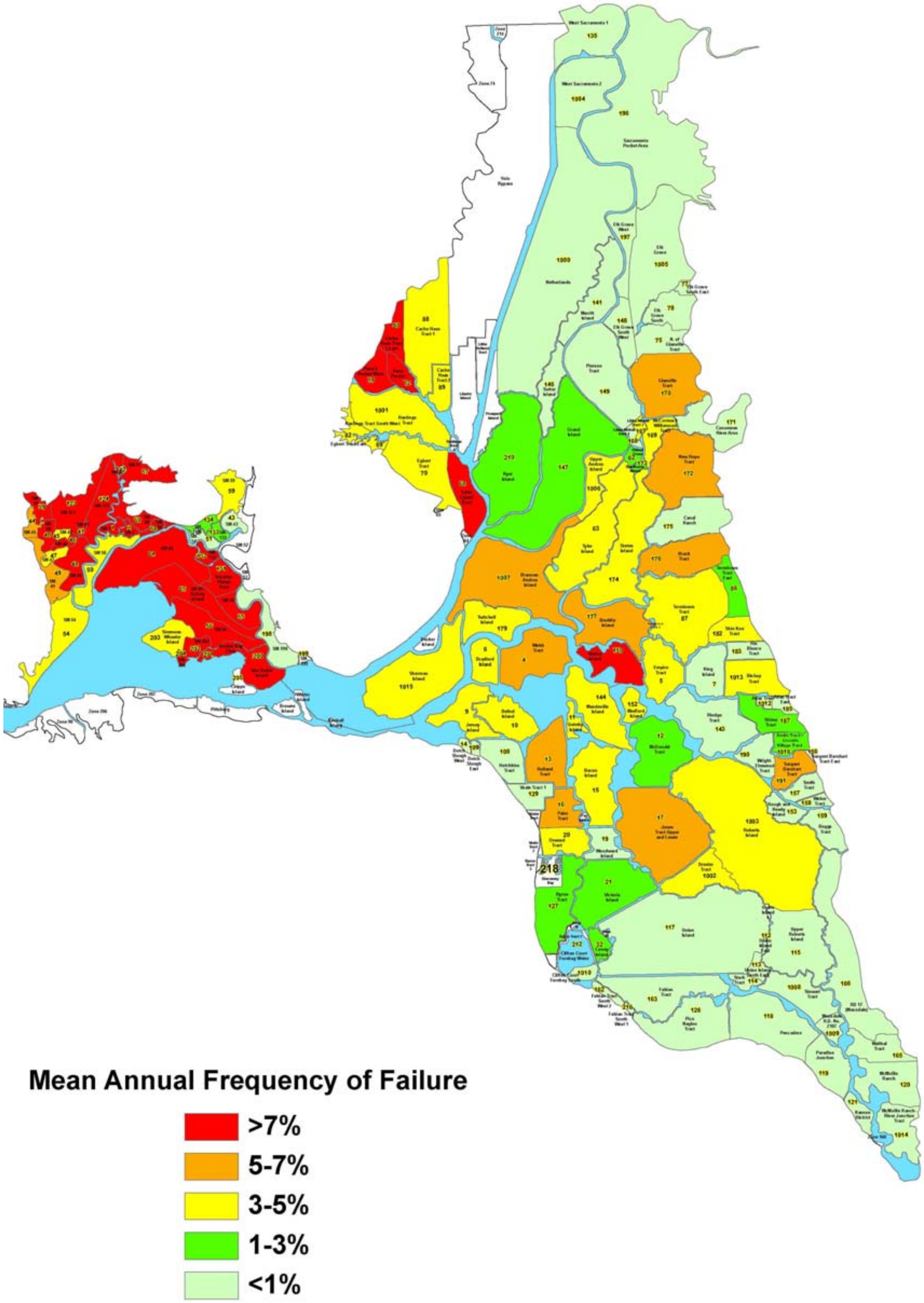

Figure 18 - Mean Annual Frequency of Failure for Individual Islands Under Flooding Events.

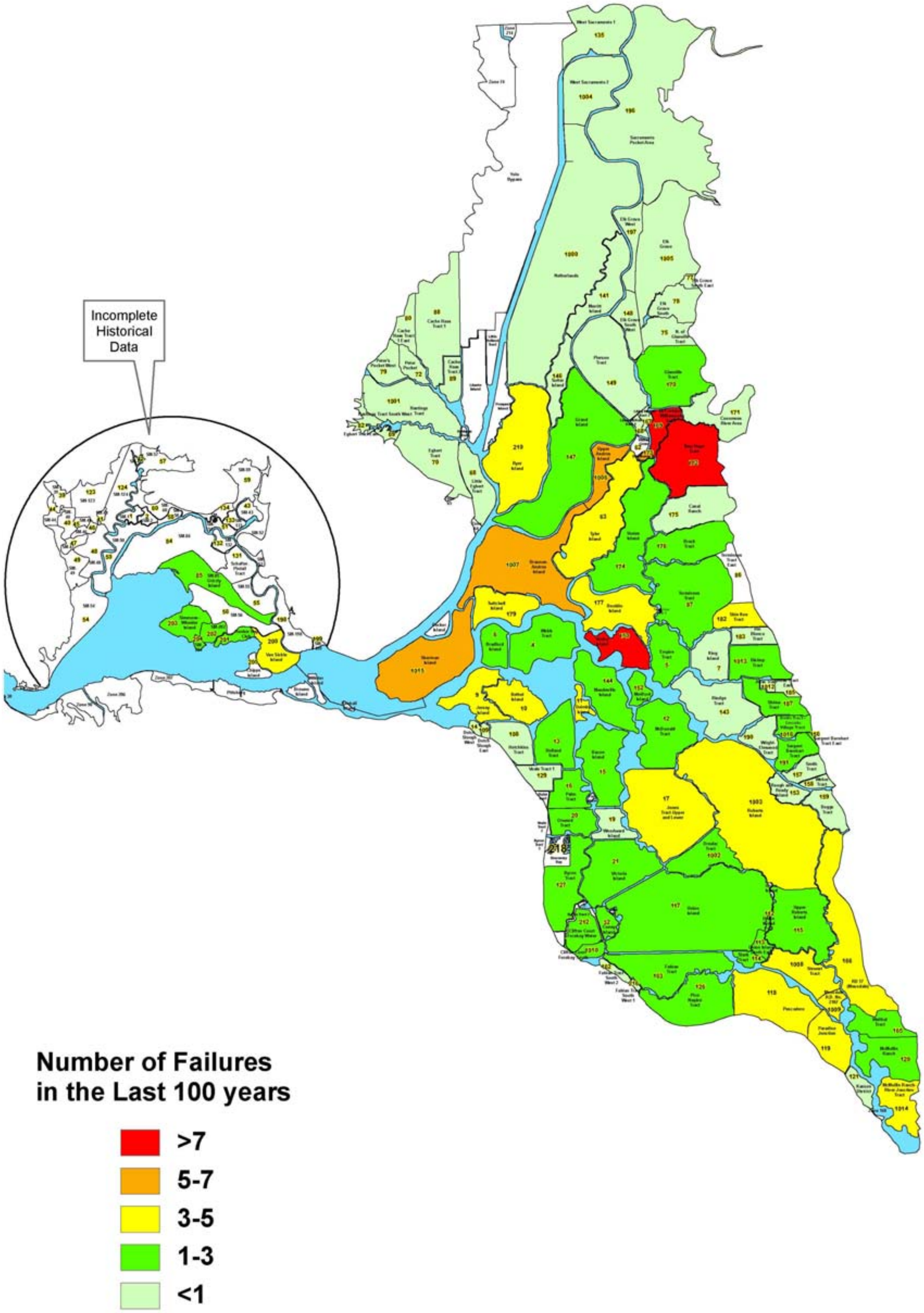

Figure 19 - Historical Number of Failures in the Last 100 Years for Individual Islands Under Flooding Events.

Future Flood Risk

As indicated in the Table 9, the climate change shift to more frequent major floods will be a major factor in increased future flood risk. In addition, sea level rise will increase the possibility of overtopping due to floods. 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. Large in-Delta impacts from additional flooding are expected, due especially to increased population and development and increased pressure on the ecosystem. In total, the losses by 2050 are expected to be to be 500 percent to 670 percent of those in 2005. The losses by 2100 are expected to be to be 1700 percent to 2100 percent of those in 2005.

Table 9 Flood Risk Factor Increases Relative to 2005

Risk Factor	***2050***	***2100***
Flood Hazard (increased high water level frequencies and overtopping due to sea level rise and more frequent high flows)	200%	500%
Flood Fragility (due to extra hydraulic head and resultant seepage)	10%	20%
Increase in Expected Frequency of Island Flooding[a]	230%	620%
Salinity (increased periods of disruption due to sea level, subsidence, less water available)	Nil	Nil
Consequences (population growth, land use, and increased pressure on ecosystem)	100%	200%
Estimated Increase in Expected Losses[b]	500% to 670%	1700% to 2100%

[a]Increased frequency in island flooding reflects increased water level hazard, overtopping, and seepage.

[b]Lower bound reflects increased water levels and consequences. Upper bound includes the effects of seepage.

Levee breaches on the ecosystem will continue to have mixed impacts depending on the specifics of the event. Thus, on balance, it is expected that 2050 conditions will present increased ecosystem risks associated with a given levee breach event and that 2100 conditions will present yet further increases in risks.

6. Sunny Day High Tide Risk

Setting

Delta and Suisun Marsh levees can fail not only from extreme events like earthquakes and high flood flows, but during other non-seismic and non-flood events. To set these failures apart from those discussed earlier, they are referred to as “sunny day” failures. Eight sunny day levee failures have been recorded since the early 1950s. These often occur during high tides that have increased the pressure on the levees and found defects. Sometimes, even burrowing animals have been suspected of creating weak spots that have contributed to levee failures.

A levee on Upper Jones Tract failed (see photograph) from unknown reasons during the summer of 2004. Repair costs and flooding damages on the island totaled nearly $100 million.

Jones Tract levee breach, June 2004

Methodology

Because so little data was available on the causes of the historical sunny day levee failures, the historical rate was extrapolated to each island based on its levee length. The frequency of historical failures that occurred in the Delta and Suisun Marsh were determined from the 6 recorded sunny day failures in Delta and the 2 sunny day breaches in Suisun Marsh. Assuming 911 miles of Delta levees within the MHHW boundary, a failure rate of 1.18×10^{-4} /year/levee mile or 0.107 failure/year was estimated. 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. Each failure rate will be applied to all levees for its area within the MHHW boundary, assuming a uniform probability of occurrence.

Levee Failure Modes

Levee failure modes for the sunny day failures are due to a variety of undetected problems with the levees. The information provided in Table 10 is conjectural and relates to few available data and communication with DWR personnel and the reclamation districts’ engineers on suspected failure modes for the sunny day failures.

It seems like well-engineered levees may be less vulnerable to failure than older non-engineered levees. However sufficient data are not available to determine failure rates by levee classes. Also, the apparent good condition of the Upper Jones Tract levee before its failure in 2004 indicates that it is difficult to project this data to specific types of levees.

Table 10 Sunny Day Failures

Island/Tract	Year	Month	Day	Failure Mode	Water Level (NAVD-88)	Levee Crest (NAVD-88)
Webb Tract	1950		2	High Tide, Stability	6.1	10.8
Brannan-Andrus Is.	1972	June	22	Excavation at Landside Toe	6.2	10.8
Lower Jones Tract	1980	Sept.	26	Seepage & Rodents Activities	6	11
McDonald Island	1982	August	23	Seepage from Dredging at Waterside Toe	5.48	11.5
Little Mandeville	1994	August	2	High Tide, abandoned	6.1	11.5
Upper Jones Tract	2004	June	3	High Tide, Underseepage & Rodent Activity	6.85	11
Simmons-Wheeler	2005	July	20	High Tide, breach occurred between two water control structures. Beaver activities suspected	7.51	7.3
Sunrise Duck Club	1999	July	NA	High tide and possible beaver activities	NA	5 to 6

Sunny Day Levee Failures

It is expected that on average there will be about 5.4 sunny-day breaches with 50 years or 10.7 breaches with 100 years of exposure in the Delta and 1.8 sunny-day breaches with 50 years or 3.6 breaches with100 years of exposure in Suisun Marsh.

Sunny day failures are assumed to occur on only one island at a time. Thus, for 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 judged that the likelihood of increased seepage on adjacent islands leading to a levee breach resulting in additional islands flooding is small.

Consequences of Flood Events

Sunny day failures are assumed to occur as one flooded island at a time, for 2005 conditions. Consequences are expected to be similar to single-island consequences of floods or earthquakes. Since sunny day failures are defined to occur in the late spring, summer or early fall (i.e., during the low flow season) there seemed to be some possibility of salinity intrusion and Delta salinity / water export impacts. A single island failure for Brannon-Andrus was used to simulate impacts on export water supply for different months of levee

Peat blocks at edge of scour hole from the 2004 Jones Tract Levee breach. Peat soils underlying the Delta levees are one contributor to levee vulnerability.

failure. No significant impact on water exports was found. The maximum disruption was for less than three months with negligible economic impacts.

The impacts to aquatic species of levee-failures on individual islands cannot be generalized from seismic and flood levee failure scenarios. The calculations of risk for terrestrial vegetation and wildlife depend entirely on area flooded, therefore, risk to terrestrial vegetation and wildlife as calculated here would be smaller than large breach scenarios. Because aquatics, terrestrial vegetation and terrestrial wildlife, have a complex spatial distribution, the particular island flooded in a sunny day failure would influence the magnitude of the impact.

Future Sunny Day Failure Risk

As indicated in Table 11, sea-level rise is expected to increase the frequency of normal-day, high-tide failures. Frequency reflects the expected occurrence of extreme high tides relative to Mean Sea Level. However, given the BAU premise that a Delta-wide program of levee raises to keep up with sea-level rise will not occur, the conditional probability of overtopping failures will increase. They will rise gradually throughout the century. 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 future, assuming single island failures, these impacts are unlikely to increase in a substantial way.

In total, the losses by 2050 are expected to be to be 30 percent to 60 percent of those in 2005. The losses by 2100 are expected to be to be 80 percent to 250 percent of those in 2005.

Table 11 Sunny Day Factor Increases Relative to 2005

Risk Factor	***2050***	***2100***
High Tide Hazard (frequencies)	Nil	Nil
Fragility (due to sea level and subsidence loading and overtopping)	10%	20%
Increase in Expected Frequency of Island Flooding[a]	10%	20%
Salinity (increased periods of disruption due to sea level, subsidence, less water available)	20%	50%
Consequences (population growth, land use, increased pressure on ecosystem, increased dependence on export water supplies)	20%	50%
Estimated Increase in Expected Losses[b]	30% to 60%	80% to 250%

[a]Increased frequency in island flooding reflects increased hazard and fragility.

[b]Lower bound reflects increase in expected frequency of failure and consequences. Upper bound includes the effects of subsidence, sea level and less available water supply on salinity intrusion and periods of disruption.

7. Combined Risk of Island Inundation from Multiple Hazards

For an individual island, each of the 3 risks described above has its own probability of occurrence. The risks from seismic, floods and sunny day failures are independent from one another so their probabilities of occurrence can be combined. This can provide an indication of the total chance that an individual island will flood in the future. As mentioned before under the discussion of limitations, this information should be viewed regionally for perspective on the risks facing the entire Delta and Suisun Marsh or portions thereof.

Considering the probability of all levee breaches from all hazards under existing (2005) conditions, about 324 failures in the Delta (exclusive of Suisun Marsh and the area west of the Sacramento River) can be expected during 100 years, an average failure rate of 3.24 failures per year. About 873 failures can be expected in the Suisun Marsh during 100 years, a rate of 8.73 failures per year.

A composite of the expected annual frequencies of failure of individual islands is shown on Figure 20.

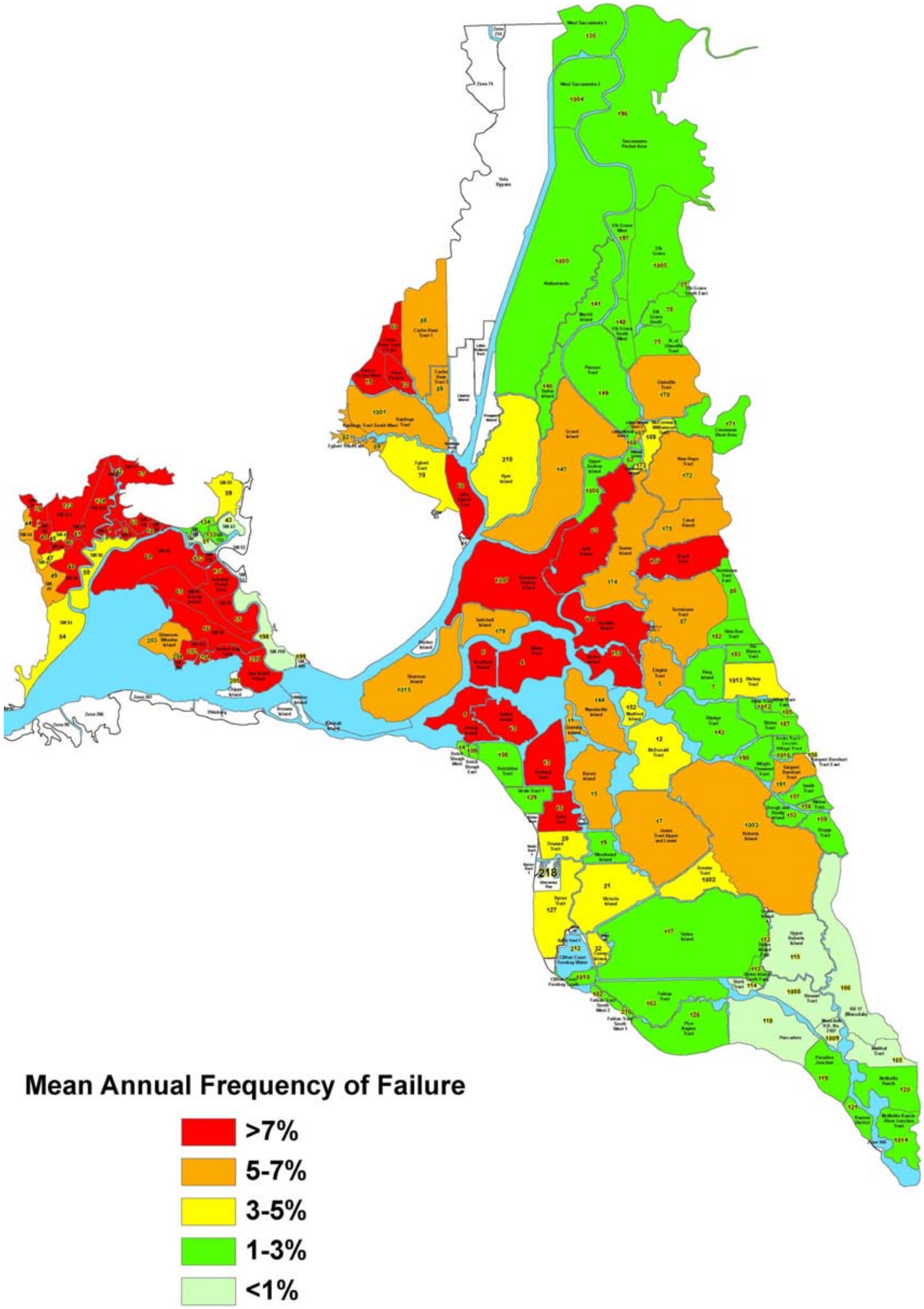

Figure 20 - Mean Annual Frequency of Failure for Individual Islands Under Combined Flooding and Seismic Risk.

8. Summary and Next Step

Summary

The risks from Delta levee failures are already high and are increasing. 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 (i.e., Delta population). The overall likelihood of a major event is increasing and the magnitudes of consequences from a given event are also rising. The increase in risks related to Delta levee breaches compared to the 2005 base case are estimated as follows:

- By 2050, the frequency of island flooding from seismic events is expected to increase by 12 percent over 2005 conditions.
- By 2100, the frequency of island flooding from seismic events is expected to increase by 27 percent over 2005 conditions.
- By 2050, the frequency of island flooding from flood events is also expected to increase. The vulnerability of the levees to floods (due to seepage and stability from subsidence and sea level rise) is expected to increase by 10 percent over 2005 conditions. The flood frequency is expected to increase by 50 percent. The combined effect would be an 80 percent increase. An increase in overtopping would be additional.
- By 2100, the frequency of island flooding from flood events is expected to increase. The vulnerability of the levees to floods (due to seepage and stability from subsidence and sea level rise) is expected to increase by 20 percent over 2005 conditions. The flood frequency is expected to increase by 100 percent. The combined effect would be a 240 percent increase. An increase in overtopping would be additional.

Next Step

Now that the risks and consequences from Phase 1 are better understood, the next phase of work will be development of risk reduction strategies for long-term management of the Delta and Suisun Marsh levees. The results of the Phase 2 work will not result in a new plan for the Delta, but will include a set of actions that could be expected to reduce the risks to the economy and the ecosystem from earthquake, floods, and sunny day failures.

The list of risk reduction measures is expected to be prioritized by those showing the most promise for use in long-term plans being developed for the Delta and Suisun Marsh under separate processes. This information will become a major source of scientific and technical information on the Delta and Suisun Marsh levees for other initiatives including Delta Vision, Bay Delta Conservation Plan (BDCP), Delta Regional Ecosystem Restoration Implementation Plan (DRERIP), CALFED End of Stage 1 Report, Suisun Marsh Plan, and other new initiatives. The exposure to risk deserves special consideration by decision makers.

References

See Draft 2 Phase 1 Risk Analysis Report (June 2007) for all references.

List of Acronyms

AB	Assembly Bill
BDCP	Bay Delta Conservation Plan
DRMS	Delta Risk Management Strategy
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
DWR	California Department of Water Resources
MHHW	Average elevation of the highest of the two tides each day over a 19 year period; about 5 feet above mean sea level in the Delta)
X2	Location of 2 parts per thousand of salinity

Glossary

Chance	Used interchangeably with probability
Delta	Sacramento-San Joaquin Delta
Frequency	The number of occurrences in a given period
Hazards	Events like earthquakes, floods, and wind waves that could damage the levees
Liquefaction	The process where loose and saturated sandy ground looses strength, much like a liquid, during shaking by an earthquake
Probability	The chance that something is likely to happen.
Return Period	Long-term average number of years between reoccurring events
Sunny day	Non-flood flow periods, generally during the late spring, summer, and early fall