DELTA LEVEES INVESTMENT STRATEGY

FINAL REPORT

July 2017

Delta Stewardship Council
A California State Agency

DELTA LEVEES INVESTMENT STRATEGY

Final Report

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TABLES

FIGURES

ACRONYMS AND ABBREVIATIONS

AEP	annual exceedance probability
AGI	adjusted gross income
Arcadis	Arcadis U.S., Inc.
ATP	ability to pay
BLS	Bureau of Labor Statistics
Caltrans	California Department of Transportation
CCT	Construction Cost Trend
CCWD	Contra Costa Water District
CDFA	California Department of Food and Agriculture
CEQA	California Environmental Quality Act
CHARG	San Francisco Bay Regional Coastal Hazards Adaptation Resiliency Group
cm	centimeters
Council	Delta Stewardship Council
CPI	Consumer Price Index
CVFPB	Central Valley Flood Protection Board
CVFPP	Central Valley Flood Protection Plan
CVP	U.S. Bureau of Reclamation Central Valley Project
.csv file	comma separated value file
CWC	California Water Code
Delta	Sacramento-San Joaquin Delta
DEM	digital elevation model
DLIS	Delta Levees Investment Strategy
DPC	Delta Protection Commission
DRA	Delta Reform Act
DRMS	Delta Risk Management Strategy
DST	Decision Support Tool
DWR	California Department of Water Resources
EAD	Expected Annual Damages
EAF	Expected Annual Fatalities

EFH	Expected Flooding of High-Value Non-Tidal Habitat
EIFD	Enhanced Infrastructure Financing District
EIP	Early Implementation Program
ENR	Engineering News-Record
FEMA	Federal Emergency Management Agency
FESSRO	FloodSAFE Environmental Stewardship and Statewide Resources Office
FHWA	United States Department of Transportation, Federal Highway Administration
GIS	geographic information system
GDP	gross domestic product
HAI	Housing Affordability Index
HMP	Hazard Mitigation Plan
IMF	International Monetary Fund
LMA	Local Maintaining Agency
LOP	level of protection
M	Million
NAR	National Association of Realtors
NOAA	National Oceanic and Atmospheric Administration
NRC	National Research Council of the National Academies
O&M	operations and maintenance
OMRR&R	operations, maintenance, repair, rehabilitation, and replacement
OPC	Ocean Protection Council
%	percent
PAR	population at risk of flooding
pga	peak ground acceleration
PL 84-99	Public Law 84-99
PPI	Producer Price Index
RD	Reclamation District
ROM	rough order of magnitude
RR&R	repair, rehabilitation, and replacement
SCFRR	Small Communities Flood Risk Reduction Program
SLR	sea level rise

SPFC	State Plan of Flood Control
State	State of California
SWP	State Water Project
UFRR	Urban Flood Risk Reduction
ULDC	Urban Level Design Criteria
ULOP	Urban Level of Protection
USACE	United States Army Corps of Engineers
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
WSE	water surface elevation
WTP	willingness to pay

GLOSSARY/TERMINOLOGY

Asset. Property owned by a person or group—or any item that can be considered for the common good—that is regarded as having value.

Coequal Goals. The two goals of providing a more reliable water supply for California and protecting, restoring, and enhancing the Delta ecosystem. The coequal goals shall be achieved in a manner that protects and enhances the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place (CWC section 85054).

Costs. Refers to cash payouts by insurers and governments to reimburse losses suffered by individuals and businesses.

Damages. Physical destruction, measured by physical indicators, such as the numbers of deaths and injuries, or the number of buildings destroyed. When valued in monetary terms, damages become direct losses.

Delta as a Place. The evolving cultural, historical, recreational, agricultural, and economic values of the Delta that make it unique.

Direct Losses. See Losses.

Ecosystem. All the organisms in a given area that interact with the physical environment. The biotic and physical components in an ecosystem are interdependent, frequently with complex feedback loops. Among the physical components that sustain the biota of an ecosystem are the soil or substrate, topographic relief and aspect, atmosphere, weather and climate hydrology, geomorphic processes, nutrient regime, and salinity regime.

Expected Annual Damage. A risk-based calculation of the average expected annual damages in a region for a given set of potential flooding conditions.

Expected Annual Fatalities. A risk-based calculation of the average annual number of flood-related fatalities that would be anticipated in a region for a given set of potential flooding conditions.

EcoRestore. A California Natural Resources Agency initiative implemented in coordination with state and federal agencies to advance the restoration of at least 30,000 acres of Sacramento-San Joaquin Delta habitat by 2020.

Flood. A general and temporary condition of partial or complete inundation of normally dry land area from overflow of inland or tidal waters; rapid accumulation of runoff, or from failure of a levee embankment.

Floodway. The channel of a river or other watercourse and the adjoining floodplain required to reasonably provide for passage of the design flood without cumulatively increasing the water surface elevation more than a designated height.

Fragility Curve. A graphical representation that relates the magnitude of a hazard to the conditional probability of levee failure should that hazard occur. The joint probability of levee failure can be estimated by integrating, over all hazard levels, the probability of the hazard multiplied by the conditional probability of failure.

Hazard. A condition or circumstance that has the potential to cause harm to people or damage to assets.

Impacts. A broad term including both market-based and non-market effects of a disaster. For example, market-based impacts include destruction to property and a reduction in income and sales. Non-market effects include environmental consequences and psychological effects suffered by individuals involved in a disaster.

Indirect Losses. See Losses.

Legacy towns or communities. Bethel Island, Clarksburg, Courtland, Freeport, Hood, Isleton, Knightsen, Rio Vista, Ryde, Locke, and Walnut Grove are the Delta's legacy towns (Public Resources Code section 32301(f)). They are the residential, commercial, processing, and retail centers of the Delta, and resonate with its history and culture.

Legal Delta. The Sacramento-San Joaquin Delta as defined in Public Resources Code sections 29728 and 29731,

Level of Protection. The flood recurrence interval that a specific structure is designed to withstand.

Losses. Market-based negative economic impacts of a disaster. These consist of direct losses that result from the physical destruction of buildings, crops, and natural resources, and indirect losses that represent the consequences of that destruction, such as temporary unemployment and business interruption.

Maintenance. Routine activities (including minor repairs) that need to be performed to keep the system operational.

Metric. The means for measuring the extent to which objectives are (or can be) achieved. Some metrics are quantifiable, while others are qualitative in nature.

Non-project Levees. Levees generally under private ownership that are constructed and maintained by local maintaining agencies.

Operation. Daily activities needed to keep the system functioning properly and for a responsible agency to perform its duties.

Polder. A low-lying tract of land enclosed by levees that forms an artificial hydrological entity with no connection to outside water other than through manually operated devices. There are three types of polders: i) land reclaimed from a body of water, such as a lake or the sea; ii) flood plains separated from the sea or river by a levee; and iii) marshes separated from surrounding water by a levee and subsequently drained.

Project Levees. Levees constructed and maintained under the State Plan of Flood Control (CWC 9602(c)).

Rehabilitation. Non-routine activities needed to fix damage caused by prolonged wear and tear degradation.

Repair. Non-routine activities needed to fix damage caused by a specific event.

Replacement. Installation of new equipment and facilities needed when components have either failed or exceeded their useful life.

Residual Risk. The risk that remains after considering the mitigating effects of structural, non-structural, and other risk reduction measures.

Risk. The exposure someone or something valued has to danger, harm, or loss; *risk* is calculated as the probability of an event occurring times the consequences of that event. In this report, *risk* is equal to the *probability* of flooding times the *consequences* of flooding.

Seepage. Water flowing through or under a levee.

Stage-recurrence Curve. A graphical representation relating water elevation (stage) to annual probability of exceedance, or return period. A stage-recurrence curve for a specific location depends on the volume rate of flow, the hydraulic flow characteristics of the water channel at that location, and the magnitude of the tidal influence.

Tolerable Risk. The level of risk that society is willing to live with in order to secure certain benefits.

Urban Area. A developed area in which there are 10,000 residents or more (CGC 65007(j)).

Vulnerability. The likelihood of levee failure given conditions of the levees and the magnitude and frequency of current levee hazards.

EXECUTIVE SUMMARY

In the California Sacramento-San Joaquin Delta (Delta), levee failure could cause catastrophic flooding, potentially causing injury or loss of life, and possibly damaging property, water supply, infrastructure, and environmental resources of importance to the entire State of California (State). Though levee maintenance and improvements over the past three decades have reduced the frequency of levee failures, the State has no comprehensive method to prioritize its investments in Delta levees operations, maintenance, and improvement projects. The Delta Plan, adopted on May 16, 2013, recommends that the Delta Stewardship Council (Council), in consultation with the California Department of Water Resources (DWR), the Central Valley Flood Protection Board (CVFPB), the Delta Protection Commission (DPC), local agencies, and the California Water Commission, implement California Water Code (CWC) section 85306 by developing a Delta Levees Investment Strategy (DLIS) to identify funding priorities for State investments in Delta levees.

Today, the 1,100 miles of levees in the Delta play a crucial role in reducing risk to State interests. The Delta is home to more than 500,000 people and 200,000 jobs, and it contributes more than $35 billion to the State's economy (CWC section 32300(g)). In addition, the Delta provides water to more than 25 million Californians and three million acres of agricultural land (CWC section 32300(h)). It is a flood-prone area, and many of the Delta islands and tracts are below sea level. Levees reduce flood risk to people who reside in the Delta's urban, rural, and legacy communities as well as those who travel, work, and recreate in the Delta. The levees are also critical to maintaining water quality in the Delta, which provides water for in-Delta users and for export through the State Water Project (SWP) and the Central Valley Project (CVP). On some islands, the levees also protect valuable terrestrial habitat and nontidal wetlands for native species.

Suisun Marsh, the largest contiguous brackish marsh on the west coast of North America, is a critical part of the San Francisco Bay-Delta estuary ecosystem. The marsh encompasses 116,000 acres, including 52,000 acres of managed wetlands, 30,000 acres of bays and sloughs, 27,700 acres of uplands, and 6,300 acres of tidal wetlands. There are about 230 miles of levees that protect the marsh and help manage flows for wetlands in Suisun Marsh, but only about 80 miles of these levees protect State interests in terrestrial and aquatic habitat and Delta water quality.

The DLIS is an innovative approach for determining priorities for State funds for levee improvement in the Delta and Suisun Marsh. The DLIS, which considers the assets protected by levees, the threats to levees, and the multiple beneficiaries of levee investments, uses a risk analysis methodology to recommend priorities for State investments in levee operations, maintenance, and improvements. This methodology was developed in close coordination with State agency partners, local and regional flood management and emergency response planning agencies, and other interested parties. In total, the Council worked with 113 different stakeholders and conducted 10 public meetings, 60 stakeholder outreach meetings, and 60 interagency coordination meetings. The Council also discussed DLIS issues at 38 Council meetings and workshops, which provided opportunities for public comment.

The DLIS team developed a Decision Support Tool (DST) to enable the Council and stakeholders to review and update the data and analysis that form the basis of the risk evaluation. The DST supports deliberations by summarizing information about baseline and future risks, aggregating and displaying risks, and then identifying portfolios of investments that have the potential to reduce risk to State interests. The data components in the DST are designed to be updated as new information is collected or identified.

Risk Analysis

The risk analysis methodology estimates the risks for Delta islands and tracts using probabilities of flooding (described below) along with the consequences of flooding to State interests. The Council has defined the State's interests to include people, property and infrastructure, water supply reliability, the Delta ecosystem, and the Delta as a place. Table ES-1 summarizes the State interests, the definitions of risk for each interest, and the metric used to evaluate each risk.

Table ES-1 Summary of Risks to State Interests

State Interest	Definition of Risk	Metric	Unit
People	Loss of life from flooding	Expected Annual Fatalities (EAF), average annual loss of life	Lives lost per year
Property and Infrastructure	Flood damages to structures, infrastructure, and crops	Expected Annual Damages (EAD), average annual property damage	Dollars per year
Water Supply Reliability	Disruption of water deliveries or harm to Delta water quality	Composite risk score describing the probability of flooding for islands and tracts that are important for protecting Delta water quality, water conveyance, and water supply infrastructure	Unitless
Ecosystem	Harm to high-value habitat from flooding	Estimated annual loss of high-value non-tidal habitat protected by levees	Acres per year
Delta as a Place	Effect on Delta communities	Flooding probability for islands and tracts with legacy towns	Percent
		Estimated annual loss of prime farmland	Acres per year
		Flooding probability for islands and tracts with state and federal highways	Percent

The two most significant hazards that may cause a levee breach are water levels (hydraulic flooding caused by high water or seepage) and seismic activity. In general, islands in the Suisun Marsh (DLIS-46, DLIS-47, DLIS-63, DLIS-37, and DLIS-39) are most vulnerable to hydraulic flooding, though Holt Station, Little Egbert Tract, and Maintenance Area 9 South also have high hydraulic flooding probabilities (above 5 percent). Islands in the western and central Delta tend to have the highest probabilities of seismically induced flooding; Clifton Court Forebay, Fabian Tract, and Coney Island are the most vulnerable (probabilities over 3 percent). Most islands in the Delta have a 3.0 to 4.0 percent total baseline probability of flooding, with a Delta-wide average of 4.0 percent and median value of 3.2 percent.

The DLIS team examined present-day tide conditions as well as potential future tide conditions for all Delta and Suisun Marsh islands and tracts to identify the potential effects of sea level rise (SLR) by 2050. In general, the effect of SLR (increase in water surface elevation [WSE]) decreases with i) higher inflow to the Delta and Suisun Marsh; ii) distance from the point of known SLR; and iii) the difference between water level at the point of interest and water level at the point of known SLR. Despite the variations from island to island, SLR in general has a profound effect on the probability of flooding in the Delta. If levee conditions remain the same as today (i.e., the levees neither degrade nor are improved), the average increase in flooding across all islands is about 91 percent. In other words, the probability of flooding in the Delta under the 2050 high SLR scenario is roughly twice the probability of flooding in 2012.

Because of its agrarian nature, population is generally sparse throughout the Delta. Population is clustered on Bethel Island and along the eastern margin of the Delta where urbanized areas of Sacramento and Stockton are in the legal Delta (Public Resources Code sections 29728 and 29731). It is not surprising, therefore, that EAF is higher for Bethel Island and the polders along the east edge of the Delta. Areas showing higher EAF in less-populated areas of the Delta reflect higher probabilities of flooding. Since population centers tend to have denser clusters of real estate improvements, commercial areas, and infrastructure, EAD tends to follow EAF. However, EAD is also higher in other parts of the Delta due to the presence of infrastructure, more valuable crops, or polders with higher probabilities of flooding.

The western islands have a higher conceptual risk to water supply; however, islands like Hotchkiss Tract and Holland Tract show the highest conceptual risk because potential levee failure at these tracts can disrupt multiple water supply functions.

The islands with the greatest risk to ecosystem, or non-tidal habitat, include Grizzly Island in Suisun Marsh (private and public managed wetlands, including Grizzly Island Wildlife Management Area), Staten Island (conserved lands managed for sandhill cranes), Twitchell Island (public lands with EcoRestore projects for wetlands and subsidence reversal), and Maintenance Area 9 (Stone Lakes National Wildlife Refuge).

Risks to the Delta as a place are characterized by flooding of legacy towns, state and federal highways, and prime farmland. Legacy towns in the Delta and Suisun Marsh include: Bethel Island, Clarksburg, Courtland, Freeport, Hood, Isleton, Knightsen, Locke, Rio Vista, Ryde, and Walnut Grove (Public Resources Code section 32301(f)). These towns are generally located in the central and northern Delta, on islands that typically have a 2 to 5 percent probability of flooding. Islands in the central and northern Delta, including Grand Island, Staten Island, Netherlands, Terminous Tract, Brannan-Andrus, and Tyler Island, generally have the highest risk of flooding of prime agricultural land, though Middle and Upper Roberts Island also has an estimated annual loss of prime farmland of over 400 acres per year. Flooding of Little Egbert Tract, Glanville, Staten Island, and Maintenance Area 9 South poses the highest risk to public roadways.

Priorities

The Council's goal in applying the risk analysis methodology was to develop three tiers of islands showing Very-High Priority, High Priority, and Other Priority for State investments in levee improvements for islands and tracts in the Delta and Suisun Marsh.

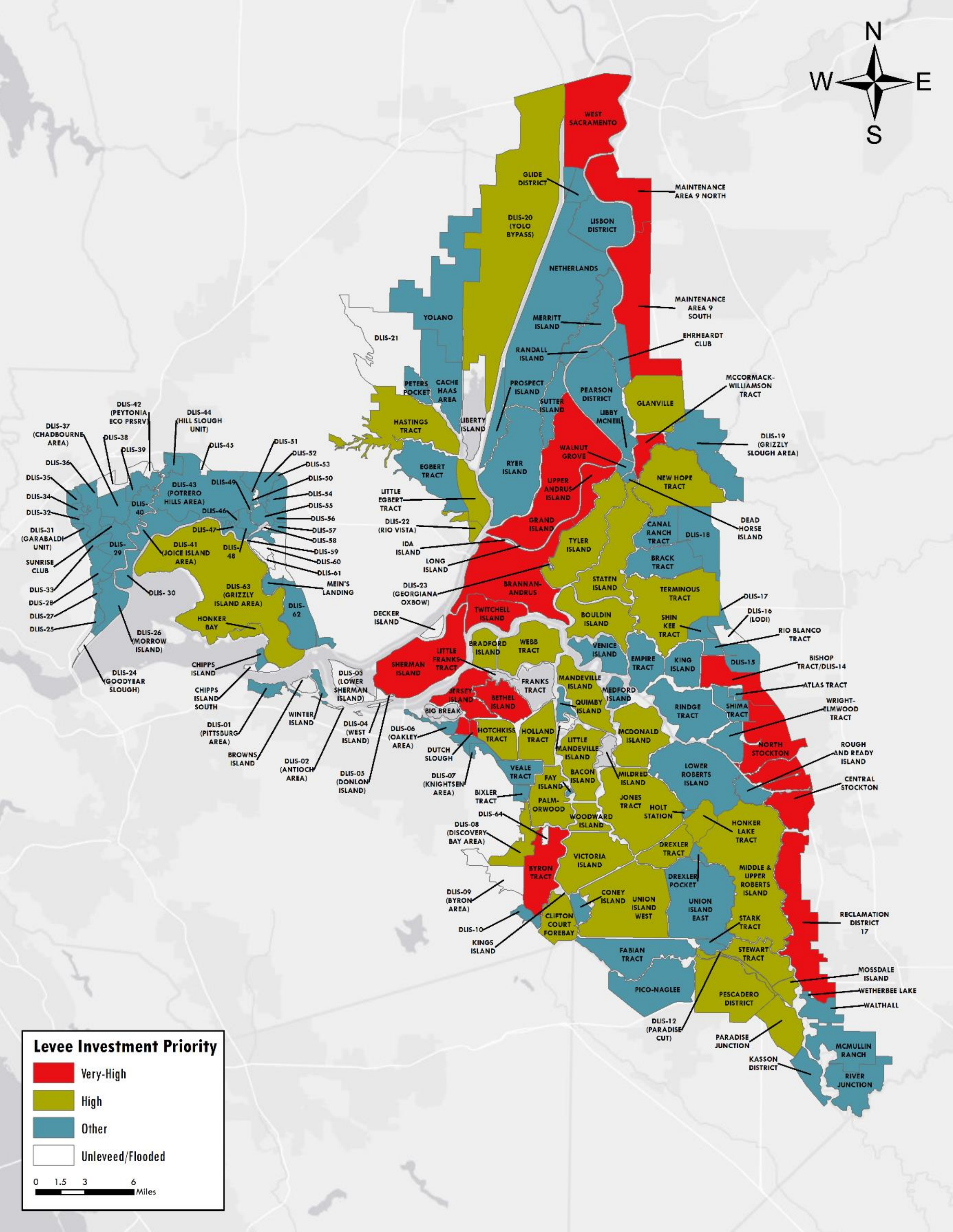
In keeping with the Council's directive to rank risk to loss of life in the Delta as most important, the DLIS team identified the islands and tracts that together comprise at least 90 percent of the total risk to life. For the other risk metrics, the DLIS team identified the islands and tracts that together comprise at least 80 percent of the risk in each category. The high-risk islands thus identified resulted in the following:

- **People** – 11 islands with EAF greater than 0.24 lives per year (at least 90 percent of Delta-wide EAF).
- **Property** – 11 islands with EAD greater than $3.5 million per year (at least 80 percent of Delta-wide EAD).
- **Habitat** – 11 islands with more than 89 acres of expected annual loss of habitat (at least 80 percent of Delta-wide expected loss of high-value, non-tidal habitat).
- **Water Supply** – 22 important water supply islands with a probability of flooding greater than 0.5 percent per year (1-in-200-year probability).

Islands and tracts were grouped into three categories based on their risk, and considering all metrics with equal weights: Very High Priority, High Priority, and Other Priority. Using the DST and the deliberation-with-analysis process, 15 islands characterized as high risk for two or more State interests were included in the Very-High Priority category. Twenty-six islands and tracts characterized as high risk to a single State interest were included in the High Priority category. The remaining islands and tracts were listed in the Other Priority category.

The deliberation-with-analysis process identified special considerations for assigning priorities. The types of special considerations were associated with hydraulic connection between adjacent islands, Delta as a place, ecosystem restoration opportunities, and Suisun Marsh levees. By taking these special considerations into account, the recommended list of State levee investment priorities developed for Council consideration includes 17 islands and tracts in the Very-High Priority category and 34 islands and tracts in the High Priority category. Figure ES-1 shows the proposed priority designation for each island and tract in the Delta and Suisun Marsh.

Figure ES-1 Priorities for State Investment in Delta and Suisun Marsh Levees



With these proposed levee investment priorities, the Council is initiating a program environmental review as required by the California Environmental Quality Act (CEQA). The environmental review will evaluate the potential impacts and identify mitigation opportunities related to the Council’s decision to update the Delta risk reduction policies in Chapter 7 of the *Delta Plan* (Council 2013). The environmental review may identify additional information to inform Council decisions about the priorities for State investment.

Considerations for Levee Improvements

In the 1980s, interim Hazard Mitigation Plan (HMP) design guidelines for non-project levees in the Delta were developed in negotiations between DWR and the Federal Emergency Management Agency (FEMA). The HMP geometry includes 16-foot-wide crests that are 1 foot above the water surface corresponding to the 100-year flood, and side slopes that are 1 Vertical to 1.5 Horizontal. Until recently, local communities that met the HMP guidance were eligible for FEMA disaster assistance if levees fail or islands flood. FEMA has since cancelled its agreement with DWR, making eligibility for FEMA disaster assistance uncertain (Council 2013).

More recently, non-project levee improvements have generally been aimed at meeting one of two levee design geometries: i) geometry requirements stipulated by the United States Army Corps of Engineers (USACE) in the Public Law 84-99 (PL 84-99) program; or ii) those developed for the DWR Bulletin 192-82 levee geometry. The most significant difference between the two is that PL 84-99 is a federal program that establishes guidelines for levee design geometry, construction, operations, and maintenance. Participants in the PL 84-99 program are eligible for federally funded emergency assistance, including flood fight support and rehabilitation of levees damaged by flooding. In contrast, there is no comparable emergency assistance program for Bulletin 192-82 geometry.

Due to this potential to receive federal aid, we focused further analysis on the effects of improving Delta levees to PL 84-99 requirements. Our analysis included estimating the scope and cost to improve certain non-project levees in the Delta to meet the requirements for PL 84-99 levee geometry, evaluating the risk reduction that can be achieved with such improvements, and assessing the effect of SLR on PL 84-99 cost estimates.

The final PL 84-99 levee investment strategy is based on making improvements at 59 islands and tracts. The cost estimates for completing this work range from $205 million (assuming $15 per cubic yard) to $515 million (assuming $1.5 million per levee mile). Such improvements reduce the probabilities of levee failure at all water levels, resulting in a 14 percent reduction to EAF, an 18 percent reduction to EAD, and an 11 percent reduction to ecosystem habitat loss. In addition, the PL 84-99 improvements would reduce the probability of flooding by 0.05 percent or more for five islands important for water supply and water quality (Bradford Island, Drexler Tract, Empire Tract, Holt Station, and Prospect Island).

Compared to present-day conditions, the rough order of magnitude (ROM) cost to achieve PL 84-99 Delta-specific geometry for a WSE corresponding to 2050 high SLR conditions is about 14 percent higher than the ROM cost for the 2012 WSE based on the $1.5 million per mile assumption, and about 26 percent higher than the ROM cost for the 2012 WSE based on the $15 per cubic yard assumption.

The DLIS team also estimated the flood risk reduction that may be achieved by implementing Urban Levee Design Criteria (ULDC) levee improvements (DWR 2012) to provide protection against a flood that has a 0.5 percent annual exceedance probability (AEP) by 2025, known as the Urban Level of Protection

(ULOP). Currently, six islands and tracts in the Delta are subject to the requirements for ULOP. The calculated residual risk, expressed as EAD and EAF, assumes that there are no changes between current conditions and conditions in 2025 in i) property and infrastructure asset value; ii) population; iii) peak Delta inflows; or iv) sea level. We estimate that EAD may be reduced by about 59 percent and EAF may be reduced by about 57 percent if ULOP is achieved for these six islands and tracts within the Delta.

After priorities were assigned, the DLIS team reviewed the failure probabilities of all islands in the DLIS Very-High Priority and High Priority categories. Of the 51 islands in these two categories, 31 islands (nearly two-thirds) have probabilities of seismically induced failure that are greater than their probabilities of hydraulic failure, including all eight western Delta water supply islands. These results warrant consideration in the development of a future levee improvement strategy. Delta islands with high probabilities of seismically induced failure will likely need to be improved using techniques that include increasing the levee's ability to withstand seismic ground motions without excessive deformation or liquefaction. Furthermore, non-structural measures (i.e., measures other than levees) and investments in emergency preparedness should be made an integral part of any risk reduction strategy for areas where seismic activity is likely.

Funding for Levee Maintenance

DWR (2016) indicates that operations, maintenance, repair, rehabilitation, and replacement (OMRR&R) of the State Plan of Flood Control (CWC section 9602[c])) levees is drastically underfunded, and funding will need to be substantially increased to realize long-term system performance. DWR (2016) estimates that the cost of levee OMRR&R should be about $59,000 per mile per year in the Sacramento basin and $46,000 per mile per year in the San Joaquin basin. These estimates are likely to understate the funding needed because the estimated costs assume fully functioning facilities that meet applicable standards, and the estimates do not include necessary costs for sediment, vegetation, and debris removal, or OMRR&R costs for structures.

Delta levees, many of which are legacy structures that were built before current levee design practices were implemented, face the same OMRR&R challenges including settlement, subsidence, erosion, vegetation management, and control of burrowing animals. In addition, many Delta levees were built with over-steepened slopes and inadequate crest widths. Because many levees in the Delta do not currently meet applicable standards, the DWR estimate (2016) likely also drastically understates required OMRR&R costs for Delta levees.

Over the past three decades, State expenditures on Delta levees have apparently greatly reduced the frequency of levee failures. The Delta Levees Maintenance Subventions Program is widely considered to have contributed to this reduction. Currently, Reclamation Districts (RDs) pay a deductible of $1,000 per mile to qualify for up to a 75 percent State and 25 percent local cost share for annual levee maintenance. Despite cost sharing, funds expended for levee maintenance are generally much less than budgets annually proposed by RDs. Data from fiscal years 2008-2014 indicate that RDs have been unable (or unwilling) to take full advantage of the subventions funds the State offers, and the State's subventions budgets were underspent during these years.

The $1,000 deductible, which has not been adjusted for inflation, is approximately equivalent to $2,500 in today's dollars. Because the ratio of levee length to area enclosed varies widely for the irregularly shaped islands in the Delta, there is little correlation between a deductible calculated on a per levee mile basis compared to a deductible calculated on a per acre of enclosed area basis. Regardless of how much the deductible is, or how the deductible is measured, an increase in the Delta-wide total deductible is likely to result in reduced maintenance expenditures because, above the current deductible, for every dollar the RDs spend, the State spends $3. If the RDs cannot (or will not) pay more than they are currently paying, then each additional dollar paid in deductibles will reduce the combined State and RD spending by $3.

The DLIS team performed an analysis to develop and test a practical method for estimating the Ability to Pay (ATP) for levee maintenance and improvements by RDs in the Delta, based on accessible financial and economic information for each RD.

The DLIS ATP analysis results in a practical approach to estimate RD-level ATP for levee maintenance and improvement expenses using basic and, in most cases, readily available information on RD levee expenses apportioned on a per-acre basis to agricultural parcels, and total RD agricultural income, on a per-acre basis. These data include:

- **Expenses** – RD net capital, operating, maintenance, and debt service expenses for levees and flood risk reduction systems.
- **Income** – agricultural acreage, assessed agricultural property value, crop type, and crop value.

RDs in the northern and southern Delta have the highest ATP classifications. The sources of variation in ATP are likely rooted in the natural configuration of Delta islands, the type and location of the physical components of the flood management system for which RDs are responsible, and the distribution of land uses and agricultural income-earning potential within the Delta.

Appropriate institutional and financial mechanism(s) for systemwide distribution of levee expenses could potentially provide for:

- Equitable distribution of financial burden among RDs in proportion to flood risk reduction and other benefits received.
- Efficient and adaptive allocation of State and federal funds, including subventions and subvention deductibles.
- Comprehensive information for coordinated planning of levee system improvements.

In this regard, a portfolio approach to cooperative financing of infrastructure investments known as Enhanced Infrastructure Financing Districts (EIFDs) may be a consideration.

The results of the ATP analysis indicate that some RDs would benefit from increased subventions funding (i.e., additional subsidies). On the other hand, some RDs could continue their current levee maintenance programs with less subventions support from the State. Adjusting the deductible amount for each RD based on its ATP (i.e., increasing some while decreasing others) could result in a more equitable distribution of State subventions funding for levee maintenance and improvement throughout the Delta. Implementation of the proposed methodology requires collection and analysis of RD expenses, and financial and economic data applicable to the agricultural sector. Data collection should be extended to as many RDs as possible, and – data permitting – to the residential, commercial, industrial, and private utility sectors as well. To reduce inter-annual variation, ATP estimates should be updated every five years using running-average expenditure, financial, and economic data.

Recommendations

Though the DLIS analysis has been developed using the best available data, the baseline analysis and results presented here represent only a snapshot in time, and risk is always changing. The database underlying the DST should be updated whenever significant changes occur that could affect risk, such as changes to the flood hazard or changes to potential consequences. As the database is updated following changes to available information or policies, risks should be reevaluated to enable a continuous, up-to-date understanding of risk that enables adaptive management of investment priorities.

Several efforts are underway to identify levee improvement projects and other risk reduction actions for the Delta. These efforts can be incorporated into the DST and evaluated for cost-effectiveness in reducing risks and other benefits and impacts.

The DST was designed to evaluate the effectiveness of projects at reducing risk and to compare the trade-offs across alternatives. The DST provides evaluation and visualization tools to support the deliberation-with-analysis process. The improvements to achieve the Delta-specific PL 84-99 levee design standard for non-project levees described in Section 5.0 demonstrate the approach for evaluating risk reduction options. A more robust set of options for High Priority islands and tracts could further inform decisions about the types, costs, impacts, and benefits of alternative approaches.

The DST can inform and facilitate discussion and decision-making regarding portfolios of risk reduction actions. For example, if a specified amount of funding is available for risk reduction, the DST can support evaluation of the most efficient and effective investments to reduce risks as well as evaluation of opportunities to include habitat enhancement in a portfolio of investments. Section 5.0 describes an evaluation of a single purpose portfolio, achieving Delta-specific PL 84-99 design geometry for non-project levees. The Council and its partners could expand this concept to develop and evaluate a variety of investment portfolios.

There are no national life safety, flood damage, or other risk-based standards or guidelines to determine if islands and tracts in the Delta and Suisun Marsh are at a level of flood risk that would be considered tolerable. The tolerable risk guideline, or threshold, is something that must be decided by those most closely involved in and affected by the DLIS. That is, those who will be affected by flooding in the Delta, and those who will make investments to reduce risk in the Delta must decide based on the understanding of risk and the available financial resources the level of risk they are willing to tolerate to secure the benefits of living, working, and recreating in the Delta.

A comprehensive investment strategy considers and implements both structural and non-structural measures, and what is considered tolerable today may not be considered tolerable tomorrow. If risks are determined to be unacceptable, or intolerable, stakeholders may choose to invest in structural measures like levee improvements, floodwalls, floodways, and bypasses, or non-structural measures and emergency preparedness policies, both of which should be made an integral part of any flood risk reduction strategy.

Risk communication is an essential part of any flood risk management strategy, and California's Flood Preparedness week could provide a suitable platform for regularly discussing flood risk with both decision-makers and the public. Risk communication is critical so that the public, stakeholders, and decision-makers fully understand the probability and the potential impacts both from flooding and from proposed risk reduction measures. Understanding risk is critical to informing an effective investment strategy that makes the best use of the State's limited resources to reduce risk to State interests. In addition, a full understanding of risk is necessary so that the State and stakeholders can determine whether residual risks are considered tolerable, or whether additional actions to reduce risk are warranted. Communicating residual risk is key to developing and implementing actions to reduce flood risk.

Three recommended actions describe the activities to maintain and further develop a risk-informed floodplain management approach that addresses risks to lives, property, and State interests in the Delta. The Council, in cooperation with its partner State agencies, could undertake these actions individually or together as a Delta-wide risk reduction program. These actions are:

1. Implement Tolerable Risk Guidelines.
2. Secure Capacity to Manage the DST.
3. Use the DST to Evaluate Grant Applications.

1.0 INTRODUCTION

The California Sacramento-San Joaquin Delta (Delta) is the largest estuary on the West Coast of the Americas and is the hub of the State of California’s (State's) major water supply systems. The Delta, which is the confluence of the Sacramento and San Joaquin Rivers, conveys water to San Pablo and San Francisco Bays and then to the Pacific Ocean. The legal Delta (Public Resources Code sections 29728 and 29731) is home to about 500,000 people and comprises about 1,300 square miles characterized by low-lying, flood-prone lands bound by 1,100 miles of levees. These levees reduce flood risk to people, property, water supply, the Delta ecosystem, and infrastructure of statewide importance. Within the Delta, about 380 miles are project levees, constructed and maintained under the State Plan of Flood Control (SPFC) (California Water Code [CWC] section 9602(c)), and about 720 miles are non-project levees, which are generally privately owned and are constructed and maintained by local maintaining agencies (LMAs).

Suisun Marsh, located immediately downstream from the Delta and north of Grizzly Bay, is the largest contiguous brackish wetland on the west coast of North America. The marsh is a critical part of the San Francisco Bay-Delta estuary ecosystem encompassing 116,000 acres, including 52,000 acres of managed wetlands, 30,000 acres of bays and sloughs, 27,700 acres of uplands, and 6,300 acres of tidal wetlands. Suisun Marsh includes about 230 miles of levees that reduce flood risk and help manage flows for wetlands, but only about 80 miles of these levees protect Delta water quality and terrestrial and aquatic habitat of statewide importance.

The Delta Reform Act (DRA) (CWC 85306) requires that the Delta Stewardship Council (Council), in consultation with the Central Valley Flood Protection Board (CVFPB), recommend in the Delta Plan priorities for State investments in levee operations, maintenance, and improvements in the Delta, including project levees that are part of the SPFC and non-project levees that are constructed and maintained by LMAs. The *Delta Plan,* adopted on May 16, 2013 (Council 2013), recommends that the Council, in consultation with the California Department of Water Resources (DWR), the CVFPB, the Delta Protection Commission (DPC), local agencies, and the California Water Commission, implement CWC section 85306 by developing a Delta Levees Investment Strategy (DLIS) to identify funding priorities for State investments in Delta levees[1].

Levee failure (such as a levee breach) could cause catastrophic flooding, potentially causing injury or loss of life, and possibly damaging property, water supply, infrastructure, and environmental resources of importance to the entire State. Though levee maintenance and improvements over the past three decades have reduced the frequency of levee failures, the State has no comprehensive method to prioritize its investments in operations, maintenance, and improvement projects for levees in the Delta and Suisun Marsh. Identification of priorities in a comprehensive levee investment strategy will help assure that public resources are used to improve and maintain Delta levees in a cost-effective long-term approach.

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[1] In this report, the term “Delta levees” should generally be understood to include levees within both the legal Delta and Suisun Marsh.

1.1 Purpose and Scope

This report demonstrates how a risk analysis methodology is being applied in the DLIS to identify funding priorities for State investments in Delta levees. Specifically, we explain i) how the risk analysis methodology was applied to assign islands and tracts to one of three tiers of priority for State investments in the Delta's levee system; ii) how the risk analysis methodology can be used to evaluate projects, beginning with an analysis of a levee improvement investment portfolio using levee geometries defined in Public Law 84-99 (PL 84-99); iii) how other funding issues should be considered in the levee investment strategy; and iv) how the risk analysis methodology and the Decision Support Tool (DST) can be used in the future to regularly update the evaluation of risks and recommendations for investment priorities. We also identify and discuss potential funding needs and challenges that will be necessary for implementing a flood risk management strategy in the Delta.

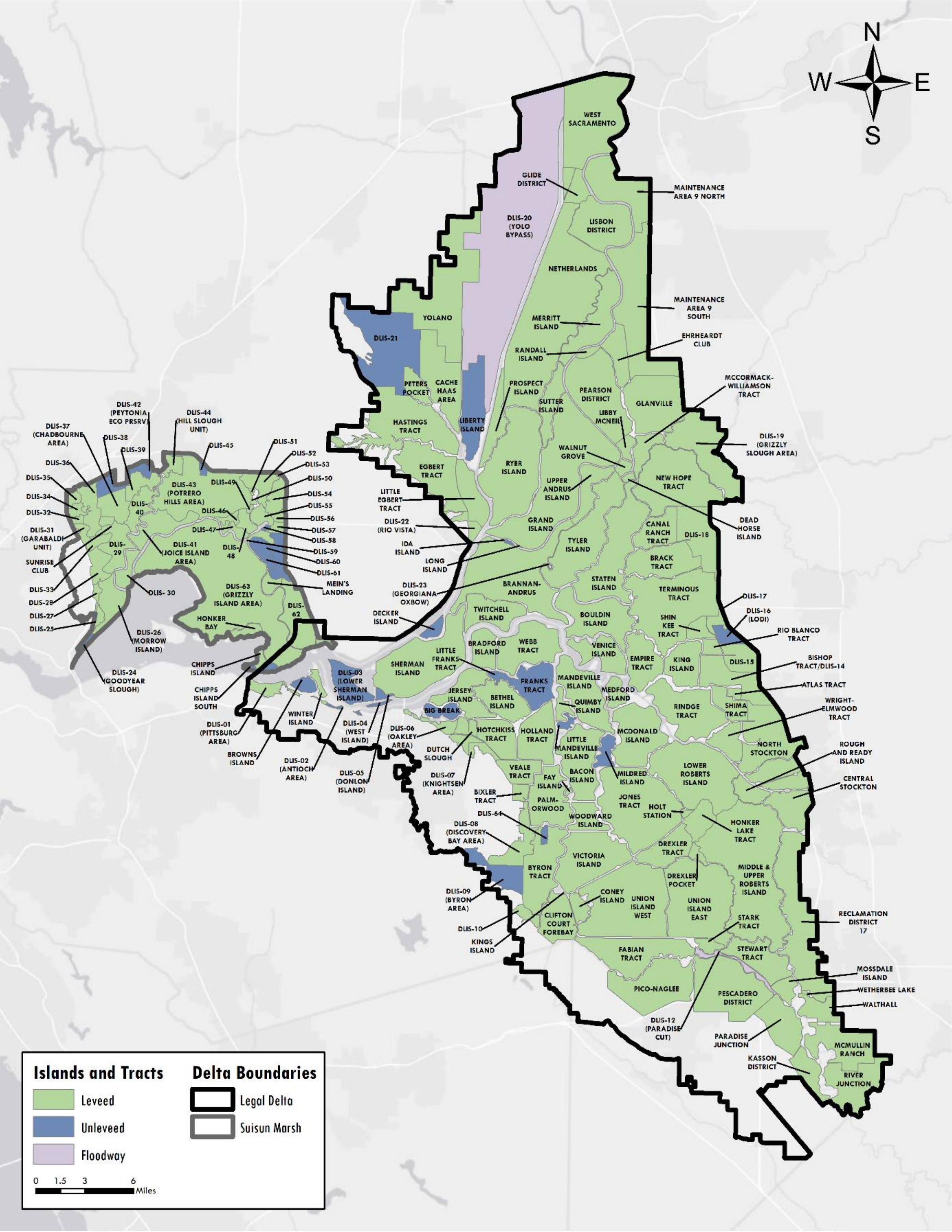
This report is based on and builds on information presented in the *Risk Analysis Methodology* (Methodology Report) for the DLIS (Council 2016b, revised July 2017). The Methodology Report explains the context of the DLIS and describes in detail each step of the risk analysis methodology, including the delineation of islands and tracts, collection of the data inventory, development of risk metrics, and estimation of risk. The Methodology Report also provides a detailed discussion on uncertainty in the risk analysis (Council 2016b).

The DLIS is an innovative approach for determining priorities for State funds in Delta levees that considers the assets protected by Delta levees, the threats to Delta levees, and the multiple beneficiaries of Delta levee investments. The work builds on the results of previous Delta levee planning efforts and collects and uses the best available existing data and information from several federal, state, and local reports, plans, and analyses. To assist in developing the DLIS, the Council retained a DLIS team comprising Arcadis U.S., Inc. (Arcadis), the Catalyst Group, Convey Inc., Environmental Science Associates, RAND Corporation, RiverSmith Engineering, and Shannon & Wilson.

The islands and tracts used in the DLIS project, shown on Figure 1-1, were developed from a variety of sources described in detail in the Methodology Report (Council 2016b). The unit of analysis employed in the DLIS is a specific hydrologic unit, or polder, subject to flooding in the event of a levee breach. The polders, most often referred to as islands and tracts in this report, generally conform to islands and tracts with common names on Delta maps, and to LMA, or Reclamation District (RD) boundaries, but not in all cases. Islands and tracts identified as "DLIS-##" are polders in the study area that do not have common names.

As the DLIS analysis is focused on an investment strategy for Delta levees, the area of analysis is limited to those polders that would be flooded by a breach of a project or a non-project levee located within the legal Delta and Suisun Marsh. The DLIS analysis does not consider incidental flooding from breaches that occur on levees upstream of the legal Delta or Suisun Marsh, and does not consider flooding caused by interior drainage or stormwater issues. Similarly, consequences are limited to the legal Delta and Suisun Marsh. The DLIS does not consider flood damages outside of the legal Delta and Suisun Marsh even if that flooding is caused by the failure of a levee within the Delta or Suisun Marsh. Risk calculations in the DLIS project are limited to i) levee failures and ii) the consequences of flooding within the legal Delta and Suisun Marsh.

Figure 1-1 Map of the Delta and Suisun Marsh



1.2 Tolerable Risk

Flood risk can never be eliminated, and *residual risk* will always remain even after all reasonable and practicable measures have been taken to reduce flood risk. Decisions concerning Delta flood risk management, then, should consider what level of residual risk is considered *tolerable* to the State and to the beneficiaries who rely on Delta levees, or *how safe is safe enough*? That is, decisions regarding investments in levee maintenance and improvement, and regarding other non-structural risk reduction measures in the Delta should consider not only cost, but should also be informed by the *level of risk that the State and the Delta's communities and stakeholders are willing to live with to secure the benefits of living, working, and recreating there, and of using water from the Delta (i.e., tolerable risk).*

Most decisions on present-day flood management fail to consider residual risk because flood management tends to focus on achieving a specified level of protection (LOP). The LOP approach, which generally forms the basis of flood management policy in the United States today, unintentionally communicates that risk can be eliminated by focusing on the flood hazard while ignoring the consequences. A certain LOP, for example, the 1 percent LOP that is the basis of the National Flood Insurance Program and California's 0.5 percent LOP design criteria for urban areas, can be achieved if the levees are tall enough to accommodate the probable water level associated with a 1 percent or 0.5 percent annual chance flood, respectively. While the LOP approach often considers levee performance, it omits consideration of the consequences that would occur if a levee fails or is overtopped.

The LOP approach is not a *safety* standard because it is not based on assessment of risk, nor is it developed following discussions regarding *"how safe is safe enough*?" While the LOP approach is often applied to achieve an "appropriate level of protection," it unintentionally creates the false impression that flood risk can be eliminated. On the other hand, the tolerable risk approach requires assessing and communicating both the *probability* and the *consequences* of a flood, and deciding whether the residual risk is acceptable or tolerable.

Given the increasingly limited financial resources at the federal, state, and local levels, a levee investment strategy must make efficient use of those resources, a process that requires identifying the most urgent risks and evaluating the benefits and trade-offs of risk reduction alternatives. The LOP methodology, however, only identifies those levees that either will or will not accommodate a given water surface elevation (WSE); it does not quantify or communicate residual risk, which can lead to a false sense of security. Furthermore, when residual risk is quantified, alternatives to reduce risk can be compared for trade-offs and cost effectiveness. Both decision-makers and stakeholders are in a better position to determine if the residual risk is tolerable, or if additional actions to reduce risk are warranted. See the Methodology Report (Council 2016b) for more detailed discussions on tolerable risk.

The major steps in applying tolerable risk to flood risk management are: i) characterizing risk; ii) identifying options to reduce risk; iii) evaluating and comparing those options; and iv) implementing the strategy, which includes continuous review of risks, risk communication, and operations, maintenance, repair, rehabilitation, and replacement (OMRR&R). In this report, and in the Methodology Report (Council 2016b), the DLIS is focused on characterizing risk in the Delta and Suisun Marsh, and then using risk as the basis for identifying priorities for State investment in levee maintenance and improvement. The DLIS also includes limited discussions on: i) identifying, evaluating, and comparing options to reduce risk, ii) communicating risk; and iii) OMRR&R issues.

Flood risk in the Delta cannot be eliminated. The DLIS identifies areas with the greatest risks, potentially warranting urgent action, and these priorities form the basis of a levee investment strategy. Through its use of risk assessment, mapping, and public engagement with the DST, the risk analysis methodology enables improved understanding and clearer communication of flood risks, including the residual risk. This enables decision-makers and stakeholders to determine whether the residual risk is tolerable, and whether additional action is warranted. A comprehensive strategy ultimately relies on levees *and* non-structural options that include emergency preparedness and response, and land use considerations. The risk analysis methodology enables a transparent evaluation and comparison of all potential actions to reduce risks.

1.3 Limitations

The levees in the Delta and Suisun Marsh face many hazards from high water and earthquakes in a dynamic environment. The risk analysis methodology developed for the DLIS is based on readily available, existing data, which vary in age and quality and are occasionally incomplete in some respects. The DLIS also relied on the expertise of agency personnel, local levee managers, and many others with special knowledge and experience with Delta levees. In addition, completion of some analyses required use of simplifying assumptions. Nonetheless, the underlying risk analysis methodology, as described in this report, is considered robust and appropriate for describing *relative* risk throughout the legal Delta and Suisun Marsh; i.e., the data limitations and simplifying assumptions have similar effects throughout the study area, making it reasonable to compare relative risks to develop funding priorities for State investments in levee improvements. The risk analysis methodology and the DST developed by the DLIS team recognize these limitations and have been specifically designed to be continuously improved and updated as new and better data become available.

2.0 STAKEHOLDER ENGAGEMENT

The Council worked with the DLIS team to build a transparent risk analysis methodology and decision-making process that was developed in close coordination with State agency partners, including the DWR, the DPC, the California Water Commission, and the CVFPB; local and regional flood management and emergency response planning agencies; LMAs; and other interested parties. Stakeholders were engaged during the development of the DLIS and in sharing and deliberating the results of the analyses. Outreach materials, including a Fact Sheet, *Setting Priorities with a Delta Levees Investment Strategy,* are available on the Council's website (see http://deltacouncil.ca.gov/).

2.1 Identification of Key Stakeholders

Stakeholders in the DLIS process generally fell into one of 11 major categories: academia, energy and utilities, environmental groups, federal agencies, flood control agencies, local Delta interests, local governments, State agencies, transportation interests, water interests, and other stakeholders. The groups included technical experts, non-governmental organizations, RD engineers, Delta landowners and residents, and local and regional leaders and officials. The outreach and engagement effort sought input and review from the following organizations:

Academia

- University of California, Berkeley
- University of California, Davis
- University of California, Los Angeles
- University of the Pacific

Energy and Utilities

- Calpine
- Chevron Pipeline
- GWF Energy
- Kinder Morgan
- Mariposa Energy
- Modesto Irrigation District
- Northern California Power Agency
- Pacific Gas and Electric Company
- Sacramento Municipal Utility District
- Shell Energy
- Trans Bay Cable
- Transmission Agency of Northern California
- Western Area Power Administration

Environmental Groups

- American Rivers
- CalTrout
- Natural Heritage Institute
- Planning and Conservation League
- River Partners
- Solano Land Trust
- The Bay Institute
- The Nature Conservancy
- Trout Unlimited
- Yolo Basin Foundation

Federal Agencies

- Bureau of Reclamation - Mid Pacific Region
- Federal Emergency Management Agency
- National Marine Fisheries Service
- U.S. Army Corps of Engineers
- U.S. Coast Guard, 11th District
- U.S. Fish and Wildlife Service
- U.S. Geological Survey

Flood Control Agencies

- Central Valley Flood Control Association
- Sacramento Area Flood Control Agency
- San Joaquin Area Flood Control Agency
- West Sacramento Area Flood Control Agency

Local Delta Interests

- Bethel Island Municipal Improvement District
- Central Delta Water Agency
- City of Stockton Municipal Utilities Department
- Contra Costa County Sheriff's Office
- Contra Costa County Water Agency
- Cosumnes Community Services District
- DCC Engineering
- Delta Wetlands Properties
- Hultgren Tillis Engineers
- Kjeldsen, Sinnock, Neudeck
- MBK Engineers
- Nomellini, Grilli & McDaniel
- North Delta Water Agency
- Northwest Hydraulic Consultants
- RD 2084 Solano
- RD 552 Pearson District
- RD 563 Tyler Island
- RD 744
- RD 2068
- South Delta Water Agency
- Suisun Resource Conservation District
- The Freshwater Trust
- Town of Discovery Bay Community Services District

Local Governments

- City of Isleton
- City of Lathrop
- City of Lodi
- City of Manteca
- City of Oakley
- City of Rio Vista
- City of Sacramento
- City of Stockton
- City of Tracy
- City of West Sacramento
- Contra Costa County
- Sacramento County
- San Joaquin County
- Solano County
- Yolo County

State Agencies

- CA Department of Fish and Wildlife
- CA Department of Transportation
- CA Department of Water Resources
- CA Energy Commission
- CA Independent System Operator
- CA Office of Emergency Services
- CA Public Utilities Commission
- CA State Transportation Agency
- CA State Water Resources Control Board
- California EcoRestore
- Central Valley Flood Protection Board
- Delta Protection Commission
- Sacramento-San Joaquin Delta Conservancy

Transportation Interests

- Bay Planning Coalition
- BNSF Railway Company
- California Association of Port Authorities
- Port of Oakland
- Port of Richmond
- Port of Stockton
- Port of West Sacramento

Water Interests

- Alameda County Water District
- Association of California Water Agencies
- California Urban Water Agencies
- Contra Costa Water District
- East Bay Municipal Utility District
- Kern County Water Agency
- Metropolitan Water District of Southern California
- San Francisco Public Utilities Commission
- San Juan Water District
- San Luis Delta Mendota Water Authority
- Santa Clara Valley Water District
- Southern California Water Committee
- State and Federal Contractors Water Agency
- State Water Contractors
- Zone 7 Water Agency

Other Stakeholders

- Public Policy Institute of California
- Sacramento County Farm Bureau

2.2 Methods and Topics of Stakeholder Engagement

At key milestones, the Council conducted public meetings and workshops in and around the Delta to review project activities, gather input, and refine the investment priorities. Project reports were made available for review and comment. Stakeholders were engaged in this process through public Council meetings; meetings among Council staff, the DLIS team, and specific stakeholder groups; and through the public review of various components of the risk analysis methodology. In total, the Council conducted 10 public meetings, 60 stakeholder outreach meetings, and 60 interagency coordination meetings. The Council also discussed DLIS issues at 38 Council meetings and workshops, which provided opportunities for public comment.

2.2.1 Data Sources and Validation

The DLIS was developed using the best available data. Data from multiple and diverse sources were made available to the DLIS team, including publicly available datasets and data used in prior similar analyses. Information on the data used is described in the Methodology Report (Council 2016b). The data used in the analyses were made available to the public and shared with many stakeholder groups for validation i) by means of the Asset Inventories (Methodology Report Appendix A, Council 2016b), and ii) through individual meetings with specific groups (i.e., oil and gas interests, water supply interests, ecosystem interests, etc.).

Data are also available for public viewing and validation through the DST—users of the DST can hover the mouse over an island to count assets and asset types (see Section 4.2 for more information regarding the DST). Stakeholder groups and the public were encouraged to alert the Council and the DLIS team of any data inconsistencies or inaccuracies. If data inconsistencies could not be corrected or verified, the associated errors or uncertainties were explained in the Methodology Report (Council 2016b).

2.2.2 Hydraulic Connectivity and Island/Tract Determination

RD engineers, city managers, and flood managers provided input on the configuration of polders within islands and tracts. Based on coordination with flood managers in the Stockton area, several islands and tracts were combined to align with hydraulic units evaluated in the United States Army Corps of Engineers (USACE) Lower San Joaquin River Feasibility Study (USACE 2016) and expected hydraulic connections during flooding. Likewise, Upper and Lower Jones Tracts were combined, as well as Middle and Upper Roberts Islands. Levee locations and island boundaries were adjusted for Byron Tract and portions of Discovery Bay, based on input from its RD engineer. The DLIS team also adjusted flood risk calculations for Maintenance Area 9, North and South, and Brannan-Andrus and Upper Andrus to reflect hydraulic connectivity if the upstream island/tract were to flood (see Section 4.4.1).

2.2.3 Climate Change

In the same way that stakeholders and the public were engaged and encouraged to provide input on various components of the risk analysis methodology, the DLIS team also sought input on the effects of climate change in the analysis. Stakeholders provided feedback to a DLIS Technical Memorandum (reformatted and included as Section 3.2 of this report) that described sea level rise (SLR) predictions. In addition, users of the DST can visualize how SLR predictions in 2030 and 2050 affect the probability of flooding and flood risk and how SLR considerations might affect a levee investment strategy.

2.2.4 Metrics Development

Early in the DLIS process, the Council and DLIS team met with multiple stakeholder groups to obtain input and feedback on the metrics to be used to evaluate risks to water supply, ecosystem, and for the Delta as a place. The DLIS team then used feedback, data, and other information to modify and improve the risk metrics.

2.2.5 Levee Improvements

The DLIS team provided stakeholders with the data used for determining the probability of levee failure and the results of the analysis of levee failure. On occasion, recent levee improvements were not captured in the data that were used. In these cases, RD engineers provided updated information, which was included in the database and the DST (see Section 5.2.4).

2.2.6 Investment Priorities

The DLIS team gathered information on stakeholder priorities for investment and presented this information to the Council. In addition, the Council solicited input on which risks should be prioritized, what thresholds should distinguish “high risk” for each metric, and how stakeholders would allocate funds if given the opportunity. See Section 4.0 for further discussion on investment priorities.

Results of the baseline risk analyses, presented via a series of risk maps and priority lists, were shared with stakeholders in individual and public meetings. In these instances, stakeholders provided input and feedback on the priority lists or on the justifications used to identify island and tract priorities for investments. In addition, the results of the baseline risk analysis were made available through the Council’s publicly available DST online so stakeholders and the public could visit and review the results at any time (see Section 4.2). The design of the DST enables users to state preferences and to isolate various components of risks. To achieve transparency, the DST also provides the baseline information used to calculate risks.

3.0 DEVELOPMENT OF RISK ANALYSIS METHODOLOGY

The DLIS uses a risk-informed approach to recommend priorities for State investments in levee operations, maintenance, and improvements in the Delta and Suisun Marsh. Risk is defined as the product of the probability and the consequences of flooding. The risk analysis methodology therefore estimates the risks of flooding Delta islands and tracts using the probability of levee failure caused by hydraulic flooding or seismic hazards, and the consequences of flooding to State interests. Estimates of current and future flood risks in the Delta have been developed based on existing data, and they provide the baseline needed to evaluate i) potential increases in risk due to future conditions, and ii) the risk reduction that may be achieved with various levee investment portfolios. See the Methodology Report for more detail (Council 2016b).

The DLIS includes analysis of the baseline probability of flooding (i.e., data current as of 2012) in the Delta and Suisun Marsh and the estimated probability of flooding in 2050. To estimate the probability of future flooding, the DLIS team assessed the impact of predicted SLR as described in Section 3.2. The impacts of both present-day and future flooding on State interests are discussed in Section 3.3.

3.1 State Interests in the Delta

The DLIS is intended to support the Council’s efforts to meet a key requirement of the DRA (CWC section 85305), which states that “the Delta Plan shall attempt to reduce risks to people, property, and State interests in the Delta by promoting effective emergency preparedness, appropriate land uses, and strategic levee investments.” The Council has identified the State’s interests to include:

- People
- Property and infrastructure
- Water supply
- The Delta ecosystem
- The Delta as a place.

Today, the 1,100 miles of levees in the Delta play a crucial role in reducing risk to State interests. The Delta is home to more than 500,000 people and 200,000 jobs. It contributes more than $35 billion to the State’s economy (CWC section 32300(g)). In addition, the Delta provides water to more than 25 million Californians and three million acres of agricultural land (CWC section 32300(h)). It is a flood-prone area, and many of the Delta islands and tracts are below sea level. Levees reduce flood risk to people who reside in the Delta’s urban, rural, and legacy communities as well as those who travel, work, and recreate in the Delta. Levees are also critical to maintaining water quality in the Delta, which provides water for in-Delta users and for export through the State Water Project (SWP) and the Central Valley Project (CVP). On some islands, the levees also protect valuable terrestrial habitat and nontidal wetlands for native species including the sandhill crane.

3.2 Sea Level Rise Considerations

Sea level rise will change water levels by varying amounts throughout the Delta. The approach used to account for changing water levels caused by future SLR is based on spatial variation of tide effects in the Delta and Suisun Marsh. The approach to estimating the effects of SLR, its impacts on flood risk, and prediction uncertainties are described below.

3.2.1 Sea Level Rise

Water levels in the Delta and Suisun Marsh at any given time are the result of a complex interaction between tide level at the Golden Gate and the variable inflow of the rivers and streams that enter the Delta and Suisun Marsh. An increase in the average sea level at Golden Gate will alter the hydraulic conditions in the Delta and Suisun Marsh, which will increase the hydraulic stress on the levees and, assuming other levee conditions remain unchanged, will increase the annual likelihood of levee failure.

To address potential sea level change in the Delta, the DLIS team adapted the methodologies presented in Sections 5 and 6 of the *Delta Risk Management Strategy (DRMS) Phase 1, Topical Area: Flood Hazard* report (DWR 2009). Section 5 describes a method of determining water levels in the Delta or Suisun Marsh based on present-day tide levels at Golden Gate and total Delta and Suisun Marsh inflows. Section 6 details a process to determine the effect of future SLR at any location in the Delta or Suisun Marsh based on a simplified hydraulic flow model and an assumed sea level increase (DWR 2009).

To calculate the probabilities of levee failure and risk to people and assets, the DLIS team developed stage-recurrence curves[2] for all Delta and Suisun Marsh islands and tracts for the present-day and potential future tide conditions shown in Table 3-1. The values in Table 3-1 are sea level increases relative to baseline (year 2012) sea levels at Golden Gate and were obtained from a National Research Council of the National Academies (NRC) report of potential future SLR (NRC 2012). The 2012 NRC report is the basis for updated SLR guidance to State agencies.

The *Delta Plan* (Council 2013) cited anticipated SLR at the Golden Gate of 14 inches by 2050 and 55 to 65 inches by 2100 based on the interim guidance adopted by the California Ocean Protection Council (OPC) in March 2011. In March 2013, OPC updated the guidance for State agency project planning based on the 2012 NRC report. The OPC noted that the purpose of the guidance is “to help state agencies incorporate future sea-level rise impacts into planning decisions.” The OPC further noted that the guidance “has now been updated to include the best current science, as summarized in the NRC report” (OPC 2013). The California Coastal Commission also adopted these NRC SLR projections as the best available science (California Coastal Commission 2015).

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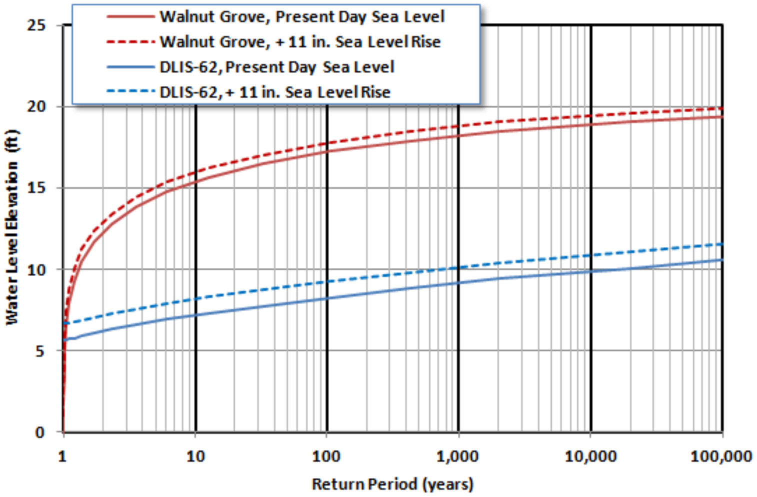
[2] Stage-recurrence curves define the return period (by annual probability of occurrence) for each potential water level at a location.

Table 3-1 Sea Level Rise Scenarios

Year	Average Estimate	High Estimate
Current	+2.0 inches (+5.0 cm)	Not applicable
2030	+5.7 inches (+14.4 cm)	+11.7 inches (+29.7 cm)
2050	+11.0 inches (+28.0 cm)	+23.9 inches (+60.8 cm)

Examples of two stage-recurrence curves are shown on Figure 3-1. The solid lines denote present-day sea level and were developed using the method described in Section 5 of the DRMS report. The dashed lines represent an average estimated sea level in 2050 (+11.0 inches from 2000 baseline) and were developed by adding the estimated SLR calculated by the method described in Section 6 of the DRMS report to the present-day recurrence water elevations (solid lines). In general, the effect of SLR (increase in WSE) decreases with i) higher inflow to the Delta and Suisun Marsh; ii) distance from the point of known SLR; and iii) the difference between water level at the point of interest and water level at the point of known SLR. Hence, potential future SLR will have the greatest effect on the Suisun Marsh and western Delta islands and tracts.

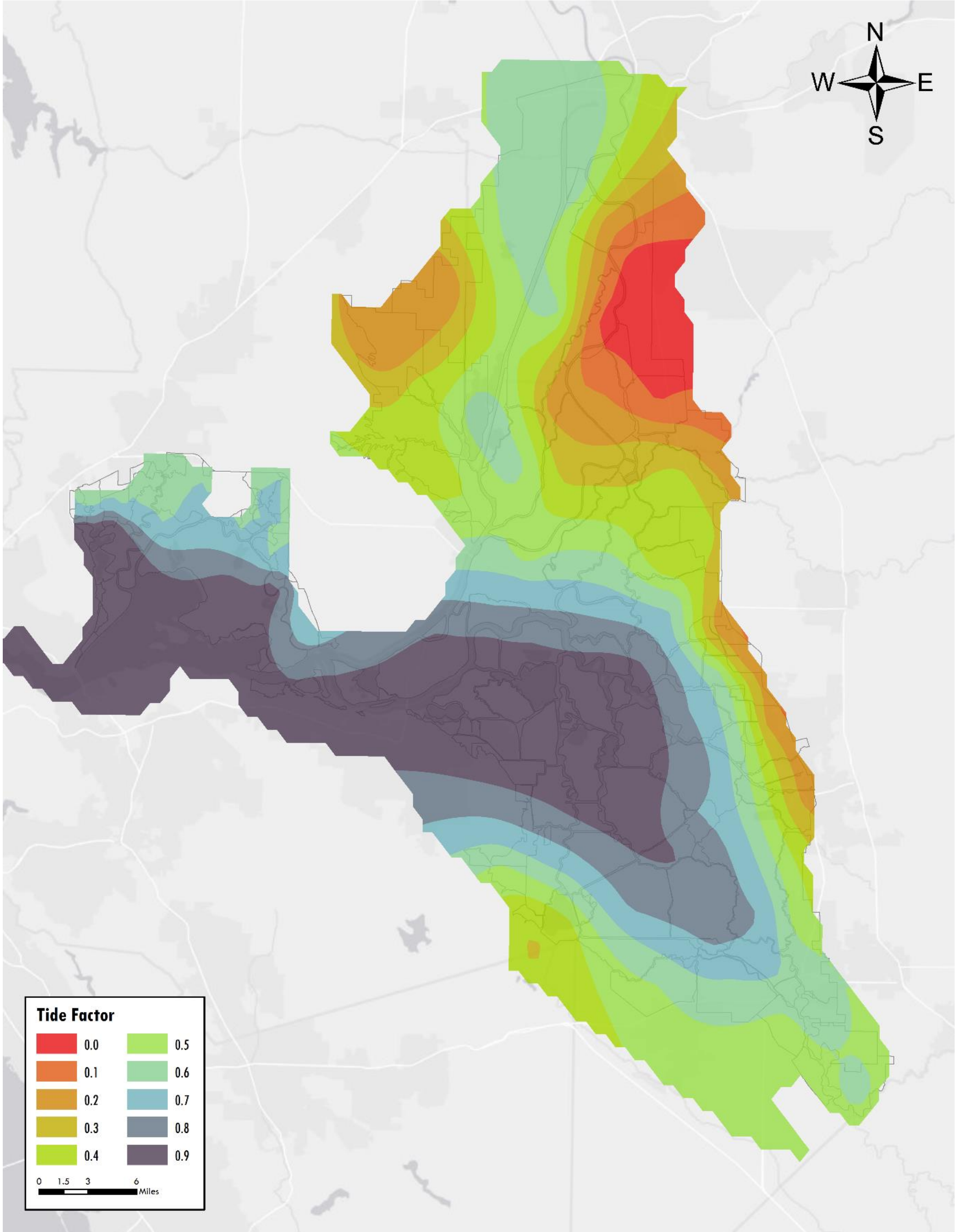
Figure 3-1 Stage-Recurrence Curves



Stage-recurrence curves are combined with levee fragility curves, which define the probability of levee failure given the hazard level, to compute probabilities of levee failure at each water level and compute an annual probability of levee failure by integrating the two curves over all water levels. The implication of this integration is that, even if a levee fragility curve does not change with time, the annual probability of levee failure can increase because of SLR alone.

Because the increment of water level change due to SLR depends on distance, inflow (which is heavily regulated because of upstream reservoir operations), and other variables, the DLIS team has not prepared a contour plot of the influence of the projected Delta and Suisun Marsh increases. However, the general pattern of water level increases due to SLR will be similar to the pattern of tidal effects shown on Figure 3-2.

Figure 3-2 Tide Factor Contours



3.2.2 Spatial Variation of Tide Effects in the Delta and Suisun Marsh

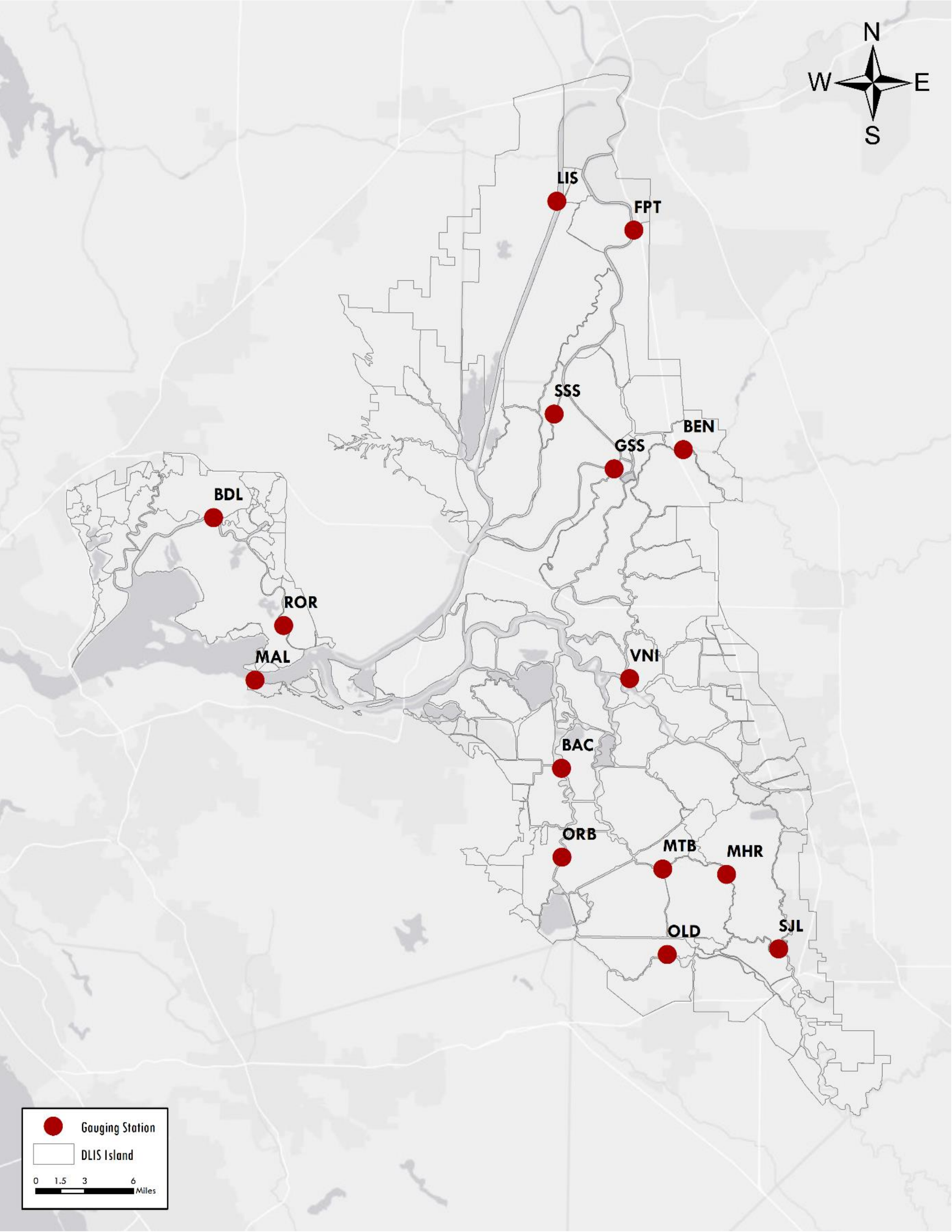
The tide cycle creates daily and seasonal variations in the Delta and Suisun Marsh water levels that, to varying degrees, mimic the daily and seasonal tide cycles at Golden Gate. The degree to which Delta and Suisun Marsh water levels mimic Golden Gate tide cycles depends on location within the Delta or Suisun Marsh. Water levels at islands and tracts in Suisun Marsh and the western Delta islands, near relatively large bodies of open water, have daily and seasonal variations that are essentially equal to local tide cycles. Water level cycles at islands and tracts farther inland and upstream from the open bodies of water are muted in approximate proportion to their distance from an open body of water.

In the DRMS study (DWR 2009), a simplified model of channel hydraulic characteristics and multiple regression methods were used to develop equations that relate Delta inflow and tide level to water level at 15 gauging stations in the Delta. Among the regression coefficients in this analysis is a tide factor that defines the effect of tide level at Golden Gate on water level at each gauging station. For example, a tide level of 5 feet at Golden Gate would contribute 4.55 feet (5 x 0.91) to the water level at the Sacramento River at the Mallard Island gauging station. The tide factors from the DRMS analysis are shown in Table 3-2, and the locations of the gauging stations used in its analysis are shown on Figure 3-3.

Table 3-2 Gauging Stations

Station ID	Location	Tide Factor
BAC	Bacon Island at Old River	1.00
BDL	Beldon Landing	1.00
BEN	Benson’s Ferry	0.38
FPT	Sacramento River at Freeport	0.00
GSS	Georgiana Slough at Sacramento River	0.34
LIS	Yolo Bypass at Lisbon	0.67
MAL	Sacramento River at Mallard Island	0.91
MHR	Middle River at Howard Road Bridge	0.88
MTB	Middle River at Tracy Blvd.	0.90
OLD	Old River near Tracy	0.81
ORB	Old River at Byron	0.79
ROR	Roaring River	0.94
SJL	San Joaquin River between Old River near Lathrop	0.77
SSS	Steamboat Slough	0.19
VNI	Venice Island	0.97

Figure 3-3 Gauging Stations (Source: DWR 2009)



The DLIS team used a planar interpolation concept to estimate tide factors for each Delta and Suisun Marsh island and tract. Figure 3-2 presents a contour map generated by the DLIS team that shows the general distribution of the estimated tide factors. The contours were developed from the individual island and tract tide factors and provide a general indication of the influence of tide throughout the Delta and Suisun Marsh.

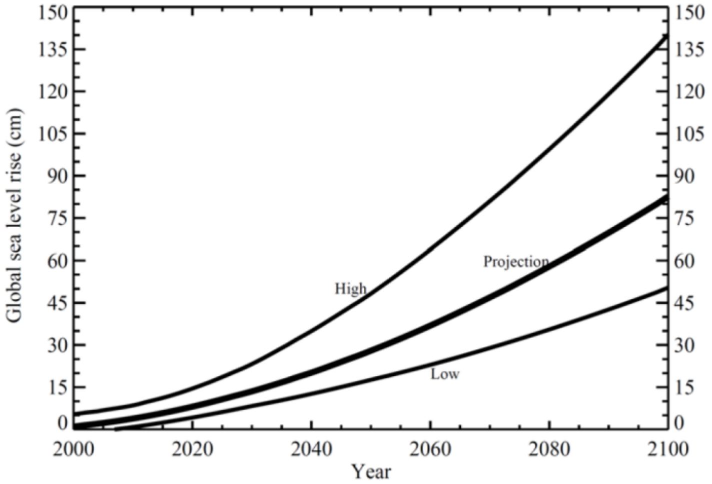
As noted above, the distribution of sea level change effects in the Delta and Suisun Marsh will follow a pattern similar to that shown on Figure 3-2. The increase in water level at any location in the Delta and Suisun Marsh due to an increase in mean sea level at Golden Gate will be approximately equal to the mean sea level increase near Carquinez Strait multiplied by the value shown on the contour map at that location. For example, a mean sea level increase of 1 foot at Golden Gate will create a water level rise of 0.2 to 0.3 foot at Walnut Grove. Similar calculations were performed for all islands and tracts for the DLIS analyses of 2030 and 2050 conditions.

3.2.3 Sea Level Prediction Uncertainties

The prediction of future water levels in the Delta and Suisun Marsh based on potential SLR at Golden Gate has several sources of uncertainty, including: i) uncertainty in predicting future sea levels at Golden Gate; ii) uncertainty in predicting the hydrodynamic effects between Golden Gate and the Delta and Suisun Marsh; and iii) uncertainty in predicting the hydrodynamic and hydraulic changes in the Delta and Suisun Marsh over time.

The uncertainty in predicting future sea levels is illustrated on Figure 3-4. The predicted increase in sea level in year 2100 (NRC 2012) applicable to Golden Gate ranges from 50 to 140 centimeters (approximately 20 to 55 inches) with an average predicted rise of about 82 centimeters (approximately 32 inches). The uncertainties in SLR predictions for years 2030 and 2050 (DLIS analysis years) are less than for year 2100, but will contribute approximately 6 inches (year 2030) to 12 inches (year 2050) of uncertainty to the prediction of water levels in the Delta and Suisun Marsh.

Figure 3-4 Sea Level Rise Predictions Applicable to Golden Gate (Source: NRC 2012)



An example of the hydrodynamic effects between Golden Gate and the Delta and Suisun Marsh is presented on Figure 3-5. This graph shows the relationship between tide ranges at Golden Gate and at Martinez-Amorco Pier near the eastern end of Carquinez Strait. The plotted data are the differences between daily high-high and low-low tide levels for December 2014 and June 2015. Total Delta inflows for December 2014 were above median December inflows, but well below flood stage. Total Delta inflows for June 2015 were only about 30 percent of median June inflows. While these data have a relatively high correlation coefficient (r ≥ 0.97), flood-level inflows to the Delta and extreme tide levels at Golden Gate will introduce additional uncertainty into this relationship.

Figure 3-5 Carquinez Strait vs. Golden Gate Tide Range (Source: NOAA 2015)

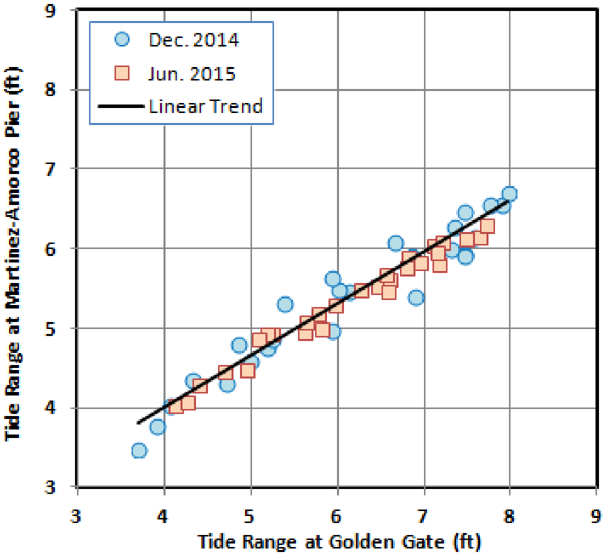


Figure 3-5 illustrates that the tide range in Carquinez Strait is 60 to 65 percent of the tide range at Golden Gate for the two months shown. While this small sample is not a definitive measure of the hydrodynamic effects between Golden Gate and the Delta and Suisun Marsh, it illustrates the order of magnitude that the hydrodynamic effects will have on predictions of water levels in the Delta and Suisun Marsh.

It is also important to note that this relationship is only applicable to current sea level. Increases in average sea level at Golden Gate may alter the hydrodynamic effects between Golden Gate and the Delta and Suisun Marsh. Additional studies of the influence of SLR on the hydrodynamics of San Francisco Bay are underway by the San Francisco Bay Regional Coastal Hazards Adaptation Resiliency Group (CHARG 2015) and the City of San Francisco (San Francisco 2014). The results of these studies may require adjustments to the method described above to evaluate SLR effects on the prediction of water levels in the Delta and Suisun Marsh.

3.3 Risk Analysis

Understanding risk, and understanding the effectiveness of risk reduction strategies, requires first estimating risk. As described in the Methodology Report (Council 2016b), the DLIS team used the probability of flooding to assess risk to each of the State interests identified in Section 3.1. Although it is not possible to know precisely when a flood will occur, it is possible to estimate the probability that a flood of a given severity *will* occur, under assumptions about current and future conditions. This, combined with the various consequences of flooding (in this case, consequences to State interests), leads to estimates of risk.

This section describes the baseline risk (i.e., risk based on data from the year 2012) to each of the State interests in the Delta and Suisun Marsh. In addition, this section compares the probability of flooding in 2012 to the probability of flooding in 2050. The risk analysis methodology enables stakeholders and decision-makers to determine the islands and tracts that pose the greatest risk to State interests. Those found to pose high risk for several State interests may warrant action before those that pose high risk for a single State interest or those that do not pose high risk for any State interests. This information can help facilitate deliberation with analysis among stakeholders and can be used to inform investment priorities.

The DLIS team developed metrics to use in estimating risks to the State interests defined in Section 3.1. These metrics are summarized below and described in more detail in the Methodology Report (Council 2016b). They include the probability of flooding, expected annual fatalities (EAF), expected annual damages (EAD), risk to water supply reliability, harm to the ecosystem, and damage to Delta as a place. The metrics enable estimating risk for each island or tract, with and without additional investment, for three time horizons (2012, 2030, and 2050). Baseline (2012) risks for each metric are discussed in Sections 3.3.2 through 3.3.6 and summarized in Table 3-3.

Table 3-3 Summary of Risks to State Interests

State Interest	Definition of Risk	Metric	Unit
People	Loss of life from flooding	Expected Annual Fatalities (EAF), average annual loss of life	Lives lost per year
Property and Infrastructure	Flood damages to structures, infrastructure, and crops	Expected Annual Damages (EAD), average annual property damage	Dollars per year
Water Supply Reliability	Disruption of water deliveries or harm to Delta water quality	Composite risk score describing the probability of flooding for islands and tracts that are important for protecting Delta water quality, water conveyance, and water supply infrastructure	Unitless
Ecosystem	Harm to high-value habitat from flooding	Estimated annual loss of high-value non-tidal habitat protected by levees	Acres per year
Delta as a Place	Effect on Delta communities	Flooding probability for islands and tracts with legacy towns	Percent
		Estimated annual loss of prime farmland	Acres per year
		Flooding probability for islands and tracts with state and federal highways	Percent

3.3.1 Probability of Levee Failure

For a given island i, the annual probability of a flood of level d is written as $p_{flood_{i,d}}$. This probability is itself a product of the probability of a hazardous event of severity h and the conditional probability of a levee breach (failure) if that event were to occur:

$$p_{flood_{i,d}} = p_{hazard_h} \times p_{breach_h} \qquad \text{(Equation 3-1)}$$

The two most significant hazards that may cause a Delta levee breach are hydraulic flooding (caused by high water or seepage) and seismic activity. Because the time at which a given hazard level will occur is uncertain, the probabilities are represented by *stage-recurrence* (see Section 3.2.1) and *peak ground acceleration-recurrence*[3] relationships. A levee's vulnerability to each possible hazard level is represented by a *fragility* curve (see Section 3.2.1) and the condition of the levee. In addition, the DLIS team approached levee vulnerability by applying a *weakest link* concept and a *length effect*.

The weakest link concept assumes that a levee will tend to fail first at an inherent weakness, which may be at a low point in the levee crest if failure is by overtopping, or perhaps at a structurally weak point if it is susceptible to slope instability or sliding. The weakest link may also be at a section vulnerable to through

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[3] Peak ground acceleration-recurrence curves define the annual probability of each possible level of peak ground acceleration (pga) from seismic activity.

seepage or underseepage. Though the location of the weakest link in a levee is generally not known, it can be inferred from examination of available survey and geotechnical data and consideration of the magnitude and frequency of the hazards that the levee faces. The length effect is based on the premise that two levees with similar conditions but different lengths (for example, the first 1 mile long and the second 5 miles long) will have different probabilities of failure due to their difference in length. Refer to the Methodology Report (2016b) for additional discussions of levee fragility, and application of the weakest link concept and length effects to levee vulnerability.

Certain consequences of flooding depend on the severity of the flood. For example, flood damage to property and fatality rates generally depends on how deep the water is when an island is flooded[4]. The annual probability of flooding can be calculated by integrating Equation 3-2 over all possible levels of hazard severity. In practice, the range of hazard levels is divided into small, equal-size increments; probabilities are defined for each increment, and the integration is approximated as:

$$p_{flood_i} = \sum_h \; p_{hazard_h} \times p_{breach_h} \qquad \text{(Equation 3-2)}$$

Where p_{flood_i} is the annual probability of a flood, p_{hazard_h} is the annual probability of that hazard event occurring, and p_{breach_h} is the conditional probability of a levee breach if that hazard were to occur. These values, $p_{flood_{i,d}}$ from Equation 3-1 and p_{flood_i} from Equation 3-2, are used throughout the calculations of risk.

The probabilities of flooding for Delta islands in 2012 (for hydraulic, seismic, and total hazards) and in the 2050 high SLR scenario along with the corresponding return periods are shown in Table 3-4 and summarized on Figures 3-6 and 3-7. The probabilities of flooding assume that the levees neither degrade nor are improved between 2012 and 2050; i.e., the same levee fragility curves and the same levee crest elevations were used in both analyses.

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[4] Other consequences are generally independent of flood depth.

Table 3-4 Probability of Flooding

Island	Probability of Flooding[1]						Return Period (years)	
	2012 Baseline			2050 High SLR	Difference	Percent Difference	2012 Baseline	2050 High SLR
	Hydraulic	Seismic	Total	Total				
Atlas Tract	1.1%	2.0%	3.1%	3.5%	0.4%	12%	32	29
Bacon Island	1.1%	2.8%	3.8%	6.2%	2.4%	62%	26	16
Bethel Island	1.0%	2.6%	3.6%	4.8%	1.2%	34%	28	21
Bishop Tract/DLIS-14	1.2%	2.0%	3.2%	3.7%	0.5%	16%	31	27
Bixler Tract	0.1%	1.4%	1.4%	1.8%	0.4%	26%	70	56
Bouldin Island	2.5%	2.3%	4.8%	8.6%	3.8%	79%	21	12
Brack Tract	2.9%	2.0%	4.9%	6.7%	1.8%	38%	21	15
Bradford Island	1.7%	2.8%	4.5%	8.9%	4.4%	97%	22	11
Brannan-Andrus	1.9%	3.0%	4.8%	5.8%	1.0%	20%	21	17
Byron Tract	0.8%	3.0%	3.8%	4.2%	0.4%	12%	27	24
Cache Haas Area	0.7%	2.2%	2.9%	3.1%	0.2%	7%	35	32
Canal Ranch Tract	2.0%	1.9%	3.8%	4.8%	1.0%	26%	26	21
Central Stockton	0.9%	0.8%	1.7%	4.0%	2.3%	138%	60	25
Chipps Island	1.5%	1.8%	3.3%	6.7%	3.4%	101%	30	15
Clifton Court Forebay	0.4%	3.9%	4.3%	4.6%	0.3%	6%	23	22
Coney Island	0.7%	3.0%	3.7%	4.2%	0.5%	13%	27	24
Dead Horse Island	3.4%	1.9%	5.3%	6.3%	1.0%	19%	19	16
DLIS-01 (Pittsburg Area)	< 0.1%	1.8%	1.9%	2.6%	0.7%	38%	53	38
DLIS-06 (Oakley Area)	< 0.1%	1.3%	1.3%	1.4%	0.1%	6%	75	71
DLIS-07 (Knightsen Area)	< 0.1%	1.4%	1.4%	1.6%	0.2%	16%	73	63
DLIS-08 (Discovery Bay Area)	< 0.1%	1.4%	1.5%	1.5%	< 0.1%	2%	68	67
DLIS-10	0.2%	1.5%	1.7%	1.9%	0.2%	11%	59	53
DLIS-15	1.0%	0.8%	1.7%	2.4%	0.7%	39%	58	42

Island	Probability of Flooding[1]						Return Period (years)	
	2012 Baseline			2050 High SLR	Difference	Percent Difference	2012 Baseline	2050 High SLR
	Hydraulic	Seismic	Total	Total				
DLIS-17	0.3%	0.7%	1.0%	1.4%	0.4%	42%	101	71
DLIS-18	0.4%	0.7%	1.2%	1.4%	0.2%	21%	87	71
DLIS-19 (Grizzly Slough Area)	0.2%	0.7%	0.9%	1.0%	0.1%	6%	106	100
DLIS-22 (Rio Vista)	0.1%	1.1%	1.1%	1.2%	0.1%	7%	90	83
DLIS-25	1.1%	2.0%	3.1%	4.2%	1.1%	38%	33	24
DLIS-26 (Morrow Island)	1.4%	2.0%	3.4%	5.8%	2.4%	73%	30	17
DLIS-27	0.5%	1.9%	2.3%	4.1%	1.8%	76%	43	24
DLIS-28	1.5%	1.9%	3.4%	6.2%	2.8%	82%	29	16
DLIS-29	1.8%	2.0%	3.8%	7.1%	3.3%	88%	27	14
DLIS-30	1.4%	2.0%	3.3%	4.6%	1.3%	39%	30	22
DLIS-31 (Garabaldi Unit)	1.0%	1.8%	2.7%	4.3%	1.6%	57%	37	23
DLIS-32	1.4%	1.7%	3.1%	5.6%	2.5%	81%	32	18
DLIS-33	3.7%	1.8%	5.4%	23.3%	17.9%	329%	18	4
DLIS-34	5.0%	1.8%	6.6%	26.9%	20.3%	305%	15	4
DLIS-35	6.3%	1.6%	7.7%	32.3%	24.6%	317%	13	3
DLIS-36	2.8%	2.0%	4.7%	25.6%	20.9%	441%	21	4
DLIS-37 (Chadbourne Area)	10.3%	1.8%	11.9%	49.5%	37.6%	317%	8	2
DLIS-39	2.3%	1.6%	3.9%	12.7%	8.8%	227%	26	8
DLIS-40	3.3%	2.0%	5.2%	15.6%	10.4%	198%	19	6
DLIS-41 (Joice Island Area)	4.8%	2.0%	6.7%	8.9%	2.2%	33%	15	11
DLIS-43 (Potrero Hills Area)	< 0.1%	1.6%	1.6%	1.8%	0.2%	13%	63	56
DLIS-44 (Hill Slough Unit)	4.6%	1.6%	6.1%	10.0%	3.9%	64%	16	10
DLIS-46	34.5%	1.7%	35.6%	79.9%	44.3%	124%	3	1
DLIS-47	26.4%	1.6%	27.5%	60.9%	33.4%	121%	4	2
DLIS-48	0.9%	1.6%	2.5%	2.9%	0.4%	18%	41	34

Island	Probability of Flooding[1]						Return Period (years)	
	2012 Baseline			2050 High SLR	Difference	Percent Difference	2012 Baseline	2050 High SLR
	Hydraulic	Seismic	Total	Total				
DLIS-49	1.2%	1.5%	2.6%	3.0%	0.4%	13%	38	33
DLIS-50	1.6%	1.4%	2.9%	3.3%	0.4%	12%	34	30
DLIS-51	1.0%	1.4%	2.4%	2.8%	0.4%	19%	42	36
DLIS-52	1.3%	1.4%	2.7%	3.1%	0.4%	14%	37	32
DLIS-53	< 0.1%	1.3%	1.3%	1.5%	0.2%	11%	74	67
DLIS-54	1.7%	1.4%	3.0%	3.4%	0.4%	12%	33	29
DLIS-55	1.9%	1.6%	3.5%	4.1%	0.6%	16%	28	24
DLIS-56	1.8%	1.4%	3.2%	3.7%	0.5%	15%	31	27
DLIS-57	1.2%	1.4%	2.7%	3.0%	0.3%	13%	38	33
DLIS-59	1.7%	1.5%	3.2%	3.5%	0.3%	9%	31	29
DLIS-62	2.1%	1.9%	4.0%	4.4%	0.4%	11%	25	23
DLIS-63 (Grizzly Island Area)	19.1%	2.9%	21.4%	89.5%	68.1%	318%	5	1
Drexler Pocket	1.6%	1.0%	2.6%	4.9%	2.3%	89%	39	20
Drexler Tract	2.4%	2.9%	5.2%	11.0%	5.8%	111%	19	9
Dutch Slough	0.9%	1.2%	2.2%	3.7%	1.5%	71%	46	27
Egbert Tract	0.9%	2.4%	3.2%	3.4%	0.2%	6%	31	29
Ehrheardt Club	2.6%	0.7%	3.3%	3.7%	0.4%	12%	30	27
Empire Tract	4.1%	2.4%	6.4%	15.6%	9.2%	145%	16	6
Fabian Tract	0.8%	3.6%	4.4%	4.7%	0.3%	7%	23	21
Fay Island	1.9%	1.2%	3.1%	7.4%	4.3%	136%	32	14
Glanville	4.6%	2.0%	6.5%	7.5%	1.0%	15%	15	13
Glide District	0.6%	0.6%	1.3%	1.4%	0.1%	10%	79	71
Grand Island	2.2%	1.7%	3.8%	4.0%	0.2%	5%	26	25
Hastings Tract	0.7%	2.6%	3.3%	3.5%	0.2%	6%	30	29
Holland Tract	1.1%	2.6%	3.6%	5.5%	1.9%	52%	28	18

Island	Probability of Flooding[1]						Return Period (years)	
	2012 Baseline			2050 High SLR	Difference	Percent Difference	2012 Baseline	2050 High SLR
	Hydraulic	Seismic	Total	Total				
Holt Station	17.1%	1.0%	17.9%	46.9%	29.0%	162%	6	2
Honker Bay	1.6%	1.9%	3.5%	3.8%	0.3%	10%	29	26
Honker Lake Tract	1.5%	1.0%	2.5%	3.0%	0.5%	19%	40	33
Hotchkiss Tract	0.9%	1.2%	2.1%	3.3%	1.2%	58%	48	30
Jersey Island	1.0%	1.8%	2.7%	4.2%	1.5%	53%	36	24
Jones Tract	1.3%	1.0%	2.3%	5.6%	3.3%	140%	43	18
Kasson District	4.0%	1.2%	5.1%	8.3%	3.2%	63%	20	12
King Island	1.7%	2.0%	3.6%	5.5%	1.9%	51%	27	18
Libby McNeil	0.9%	1.0%	1.9%	2.1%	0.2%	9%	52	48
Lisbon District	1.0%	0.6%	1.6%	1.7%	0.1%	6%	62	59
Little Egbert Tract	8.2%	2.4%	10.4%	18.7%	8.3%	80%	10	5
Lower Roberts Island	0.7%	0.9%	1.6%	2.2%	0.6%	37%	62	45
Maintenance Area 9 North	1.4%	0.7%	2.1%	2.1%	< 0.1%	-1%	47	48
Maintenance Area 9 South	6.5%	0.7%	7.2%	8.1%	0.9%	12%	14	12
Mandeville Island	1.3%	2.3%	3.5%	6.2%	2.7%	76%	28	16
McCormack-Williamson Tract	3.8%	1.9%	5.6%	6.6%	1.0%	17%	18	15
McDonald Island	1.2%	2.7%	3.9%	5.1%	1.2%	32%	26	20
McMullin Ranch	1.3%	1.3%	2.6%	3.0%	0.4%	17%	39	33
Medford Island	1.5%	2.4%	3.9%	7.7%	3.8%	96%	25	13
Mein's Landing	1.4%	1.7%	3.0%	3.5%	0.5%	15%	33	29
Merritt Island	1.2%	0.8%	2.1%	2.1%	< 0.1%	2%	49	48
Middle and Upper Roberts Island	1.4%	0.9%	2.3%	2.8%	0.5%	21%	43	36
Mossdale Island	1.3%	1.0%	2.3%	2.9%	0.6%	28%	44	34
Netherlands	1.2%	0.9%	2.1%	2.4%	0.3%	14%	48	42
New Hope Tract	1.0%	1.8%	2.8%	3.1%	0.3%	11%	36	32

Island	Probability of Flooding[1]						Return Period (years)	
	2012 Baseline			2050 High SLR	Difference	Percent Difference	2012 Baseline	2050 High SLR
	Hydraulic	Seismic	Total	Total				
North Stockton	1.7%	1.0%	2.7%	6.6%	3.9%	147%	37	15
Palm-Orwood	0.6%	1.2%	1.8%	2.7%	0.9%	52%	56	37
Paradise Junction	1.7%	1.2%	2.9%	3.8%	0.9%	33%	35	26
Pearson District	1.7%	1.1%	2.8%	2.8%	< 0.1%	1%	36	36
Pescadero District	< 0.1%	1.2%	1.2%	1.2%	< 0.1%	1%	84	83
Peters Pocket	1.2%	0.4%	1.6%	2.1%	0.5%	29%	61	48
Pico-Naglee	< 0.1%	1.4%	1.5%	1.5%	< 0.1%	3%	69	67
Prospect Island	4.0%	1.2%	5.2%	8.9%	3.7%	72%	19	11
Quimby Island	0.8%	2.4%	3.2%	4.2%	1.0%	31%	31	24
Randall Island	0.9%	0.8%	1.7%	1.7%	< 0.1%	1%	60	59
Reclamation District 17	0.8%	1.1%	1.9%	2.1%	0.2%	13%	54	48
Rindge Tract	1.6%	2.2%	3.7%	5.9%	2.2%	58%	27	17
Rio Blanco Tract	3.3%	2.0%	5.2%	8.0%	2.8%	52%	19	13
River Junction	< 0.1%	1.1%	1.2%	1.3%	0.1%	12%	86	77
Rough and Ready Island	0.7%	2.1%	2.7%	3.0%	0.3%	10%	37	33
Ryer Island	1.8%	1.6%	3.3%	3.6%	0.3%	8%	30	28
Sherman Island	0.7%	2.8%	3.5%	4.1%	0.6%	17%	29	24
Shima Tract	1.5%	2.0%	3.5%	4.5%	1.0%	29%	29	22
Shin Kee Tract	4.7%	2.1%	6.8%	10.9%	4.1%	61%	15	9
Stark Tract	0.2%	1.3%	1.4%	1.6%	0.2%	13%	71	63
Staten Island	3.7%	2.9%	6.5%	8.5%	2.0%	31%	15	12
Stewart Tract	0.7%	1.0%	1.7%	2.1%	0.4%	22%	58	48
Sunrise Club	1.1%	1.7%	2.7%	3.3%	0.6%	20%	36	30
Sutter Island	1.7%	1.3%	2.9%	3.0%	0.1%	2%	34	33
Terminous Tract	3.4%	1.0%	4.4%	7.2%	2.8%	65%	23	14

Island	Probability of Flooding[1]						Return Period (years)	
	2012 Baseline			2050 High SLR	Difference	Percent Difference	2012 Baseline	2050 High SLR
	Hydraulic	Seismic	Total	Total				
Twitchell Island	1.5%	2.8%	4.3%	6.5%	2.2%	51%	23	15
Tyler Island	2.8%	2.1%	4.9%	6.3%	1.4%	29%	21	16
Union Island East	0.8%	2.4%	3.2%	3.5%	0.3%	10%	31	29
Union Island West	0.6%	1.7%	2.2%	2.7%	0.5%	21%	45	37
Upper Andrus Island	1.9%	2.0%	3.9%	4.1%	0.2%	6%	26	24
Veale Tract	1.0%	2.8%	3.7%	5.3%	1.6%	43%	27	19
Venice Island	2.0%	2.5%	4.5%	9.0%	4.5%	99%	22	11
Victoria Island	0.5%	1.7%	2.2%	2.8%	0.6%	30%	46	36
Walnut Grove	1.5%	1.9%	3.4%	3.6%	0.2%	6%	29	28
Walthall	1.9%	1.0%	2.9%	4.2%	1.3%	45%	35	24
Webb Tract	1.7%	2.8%	4.4%	8.2%	3.8%	85%	23	12
West Sacramento	0.8%	0.9%	1.7%	2.3%	0.6%	35%	59	43
Wetherbee Lake	2.3%	0.9%	3.2%	4.7%	1.5%	48%	31	21
Winter Island	4.7%	1.8%	6.4%	35.8%	29.4%	462%	16	3
Woodward Island	0.7%	2.5%	3.2%	4.3%	1.1%	34%	31	23
Wright-Elmwood Tract	1.0%	2.1%	3.1%	3.8%	0.7%	22%	32	26
Yolano	< 0.1%	0.9%	0.9%	0.9%	< 0.1%	0%	111	111
Average	**2.3%**	**1.7%**	**4.0%**	**7.6%**	**3.6%**	**91%**	**25**	**13**

Note:

1. The implied level of accuracy probabilities of flooding shown is subject to the data limitations described in this report and in the Methodology Report (Council 2016b).

Figure 3-6 Summary of Total Flooding Probabilities for Present-Day Conditions

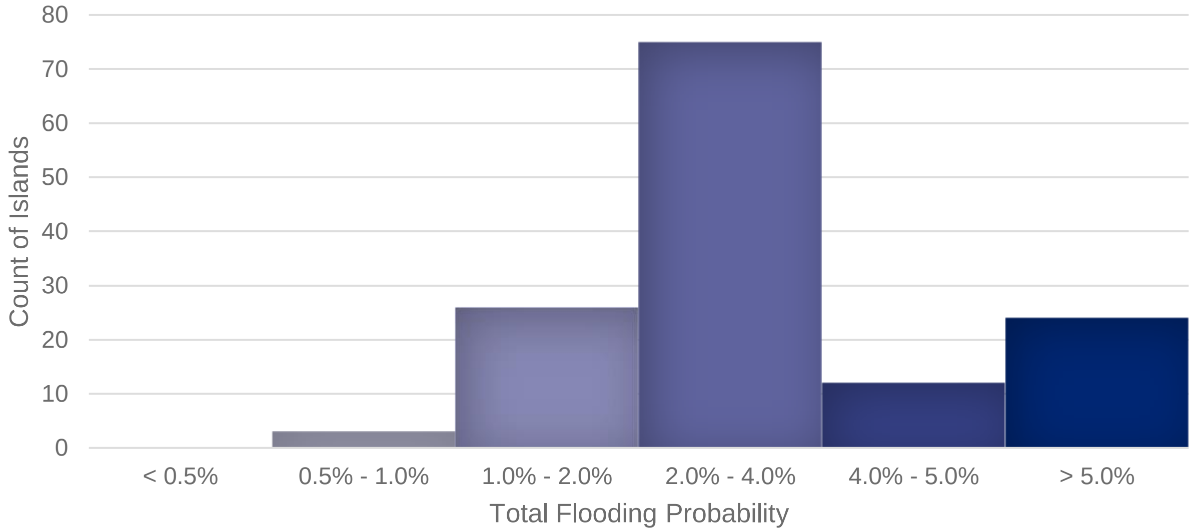
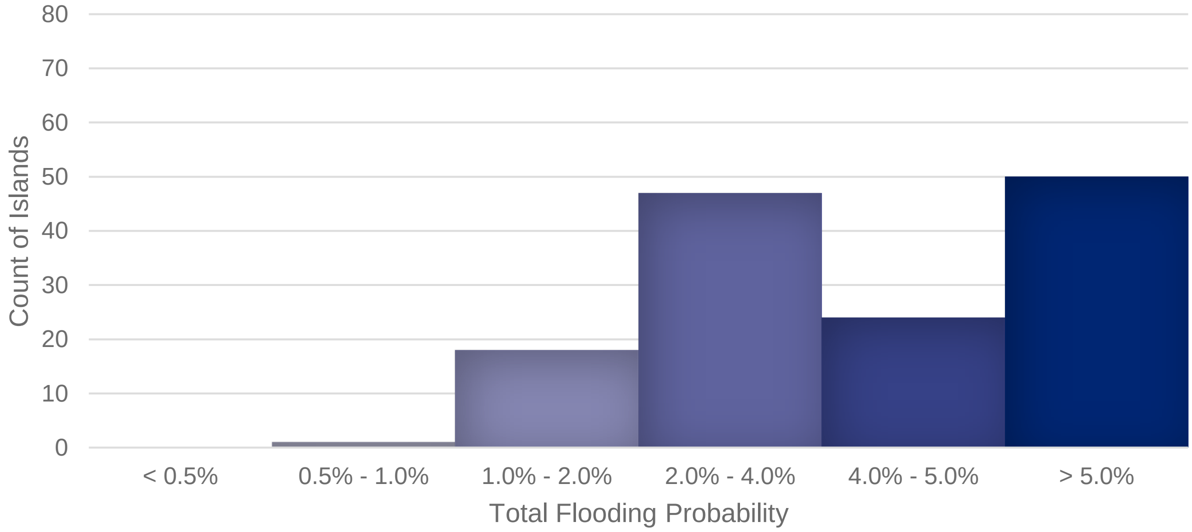


Figure 3-7 Summary of Estimated Total Flooding Probabilities for the 2050 High SLR scenario



Present-day hydraulic flooding probabilities range from near 0 to 34.5 percent, with an average of 2.3 percent and a median value of 1.3 percent. In general, islands in the Suisun Marsh (DLIS-46, DLIS-47, DLIS-63, DLIS-37, and DLIS-39) are most vulnerable to hydraulic flooding, though Holt Station, Little Egbert Tract, and Maintenance Area 9 also have high hydraulic flooding probabilities (above 5 percent). Present-day seismically induced flooding probabilities range from 0.4 to 3.9 percent, with both an average and a median value of 1.7 percent. Islands in the western and central Delta tend to have the highest probabilities of seismically induced flooding, while Clifton Court Forebay, Fabian Tract, and Coney Island are the most vulnerable (probabilities over 3 percent). Overall, total flooding probabilities range from

0.9 to 35.6 percent. Most islands in the Delta have a 3.0 to 4.0 percent total baseline probability of flooding, with a Delta-wide average of 4.0 percent and median value of 3.2 percent.

As explained in Section 3.2, the difference in water stage attributed to SLR in the 2050 high SLR scenario ranges from about 1.7 foot in the western Delta to about 0.7 foot in the southern Delta and about 0.1 foot in the northern Delta. There is considerable variation in the increase in the probability of flooding from island to island. For example, there is essentially no increase in the probability of flooding between the 2012 and 2050 high SLR scenarios for Maintenance Area 9 North. On the other hand, there is more than a 250 percent increase in the probability of flooding for Central Stockton. Although some variation may be attributed to the change in water stage due to SLR throughout the Delta, the probable key reason for the variability in the increased probability of flooding is the variability in fragility curves from island to island compared to water stage.

Despite the variations from island to island, SLR in general has a profound effect on the probability of flooding in the Delta. The average increase in flooding across all islands is about 91 percent. In other words, the probability of flooding in the Delta under the 2050 high SLR scenario is nearly twice the probability of flooding in 2012.

Figure 3-8 shows the present-day (2012) probability of hydraulic flooding of the Delta and Suisun Marsh islands and tracts due to hydraulic hazards, while Figure 3-9 shows the present-day probability of seismically induced flooding. Figure 3-10 shows the total present-day probability of flooding due to both seismic and hydraulic hazards, and Figure 3-11 shows the estimated total probability of flooding in 2050.

Figure 3-8 Present-Day Probability of Flooding due to Hydraulic Hazards

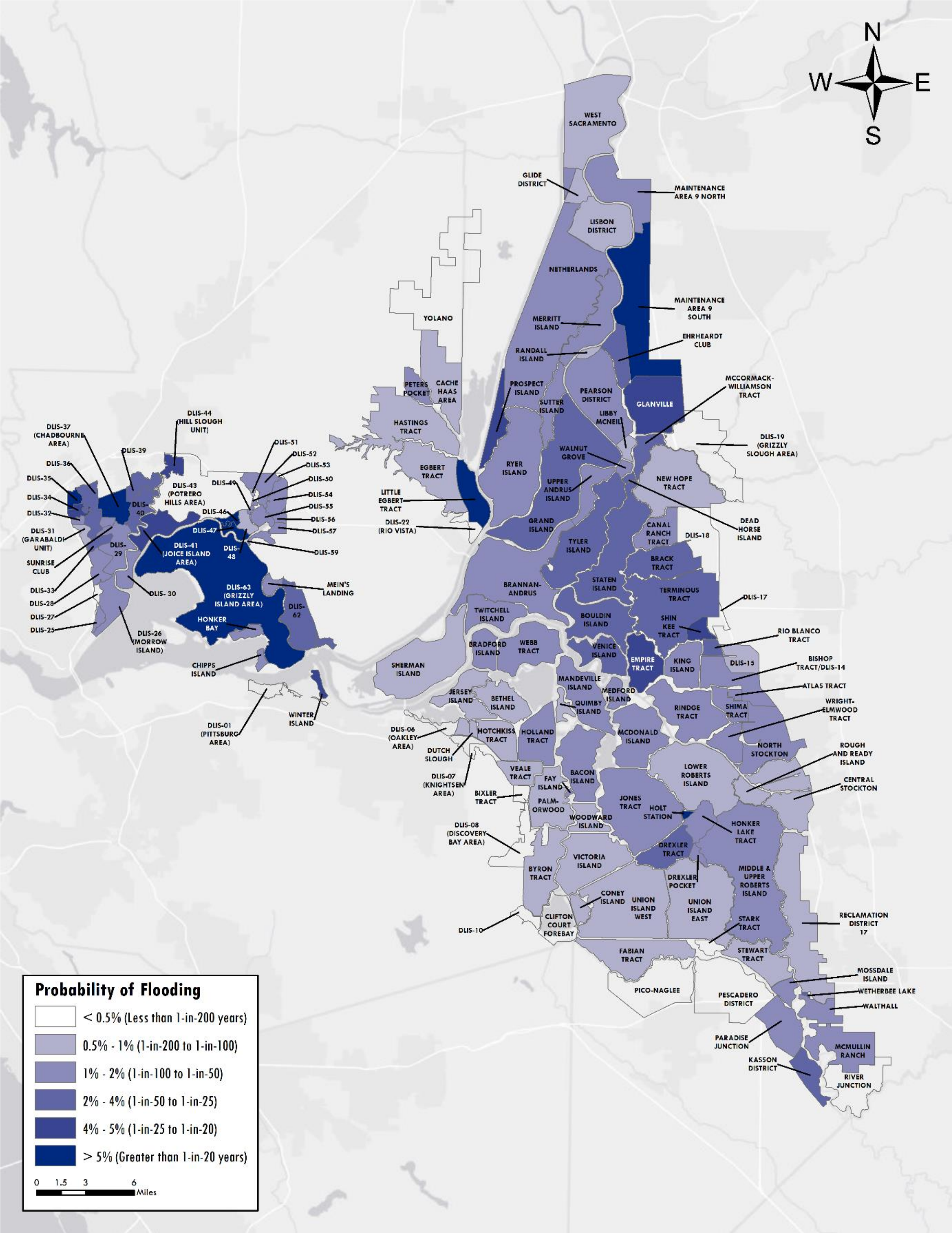


Figure 3-9 Present-Day Probability of Flooding due to Seismic Hazards

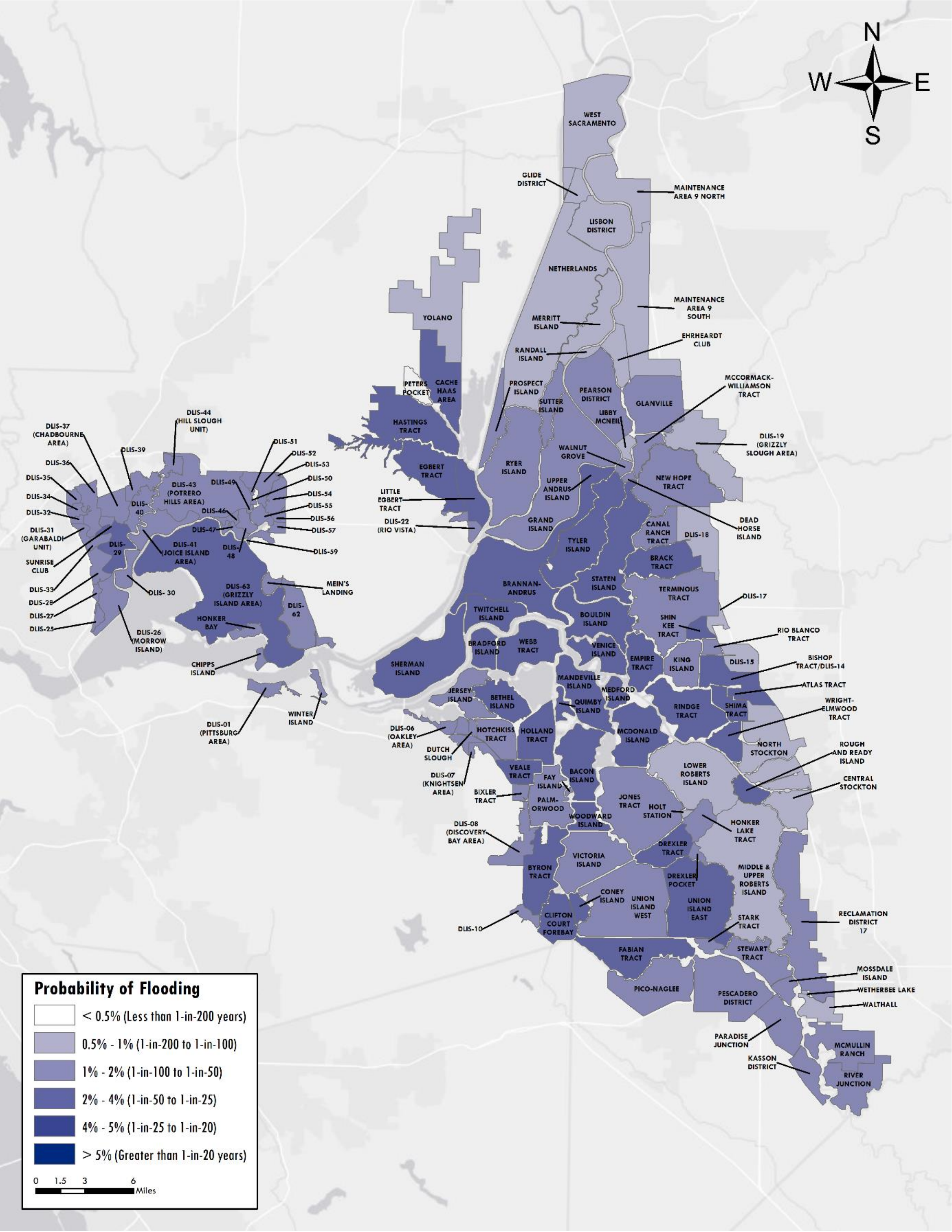


Figure 3-10 Present-Day Probability of Flooding due to Hydraulic and Seismic Hazards

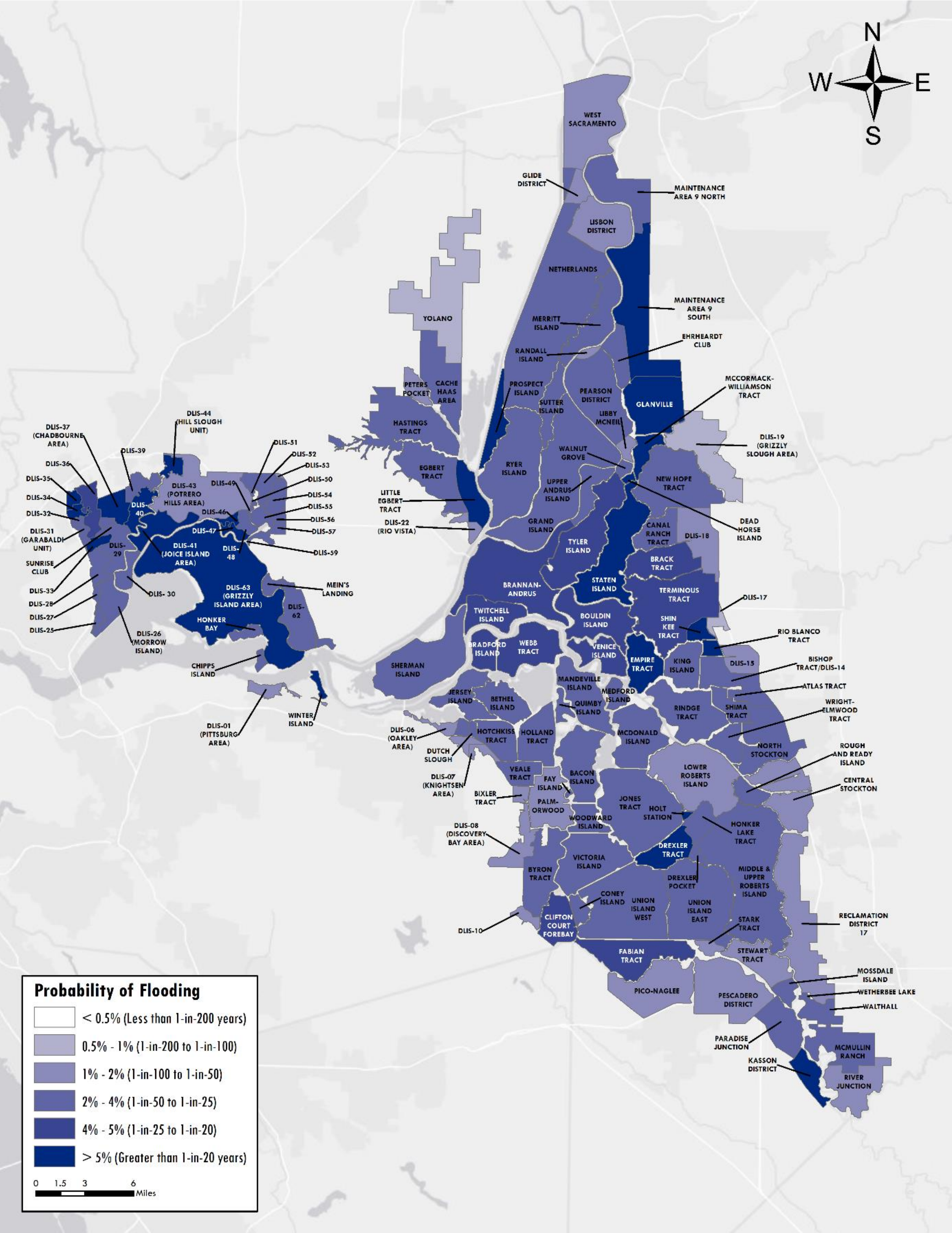
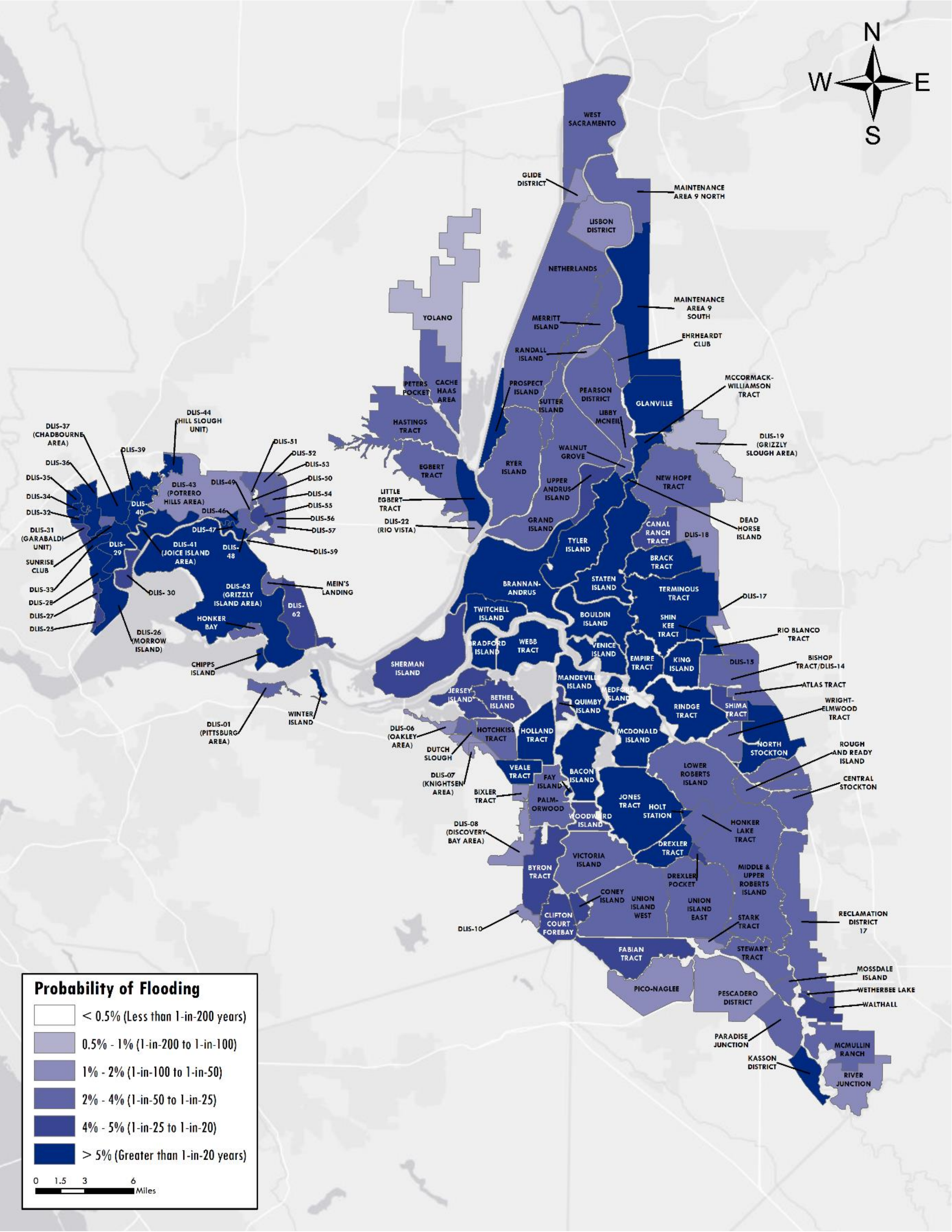


Figure 3-11 Estimated Probability of Flooding due to Hydraulic and Seismic Hazards in 2050



3.3.2 Expected Annual Fatalities (Risk to Life)

EAF is a risk-based calculation of the average annual number of flood-related fatalities that would be anticipated in a region for a given set of potential flooding conditions. The population at risk in the Delta and Suisun Marsh includes permanent residents and a variable population of workers, recreation users, and travelers who are at risk only during the time they are in the Delta or Suisun Marsh.

EAF is the product of the percentage of fatalities among those who come in contact with the floodwater and the probability that a flood event will occur. The flood level directly affects the rate of fatalities; in general, greater inundation depths cause higher fatality rates. The number of fatalities on a given island or tract i for a given flood depth d is a product of the total population at risk of flooding (PAR) on that island ($PAR_{i.}$), the percentage of the PAR that will come in contact with the floodwater ($p_{contact,d}$), and the percentage of fatalities among those who come in contact with floodwater of a given depth ($p_{fatalities,d}$):

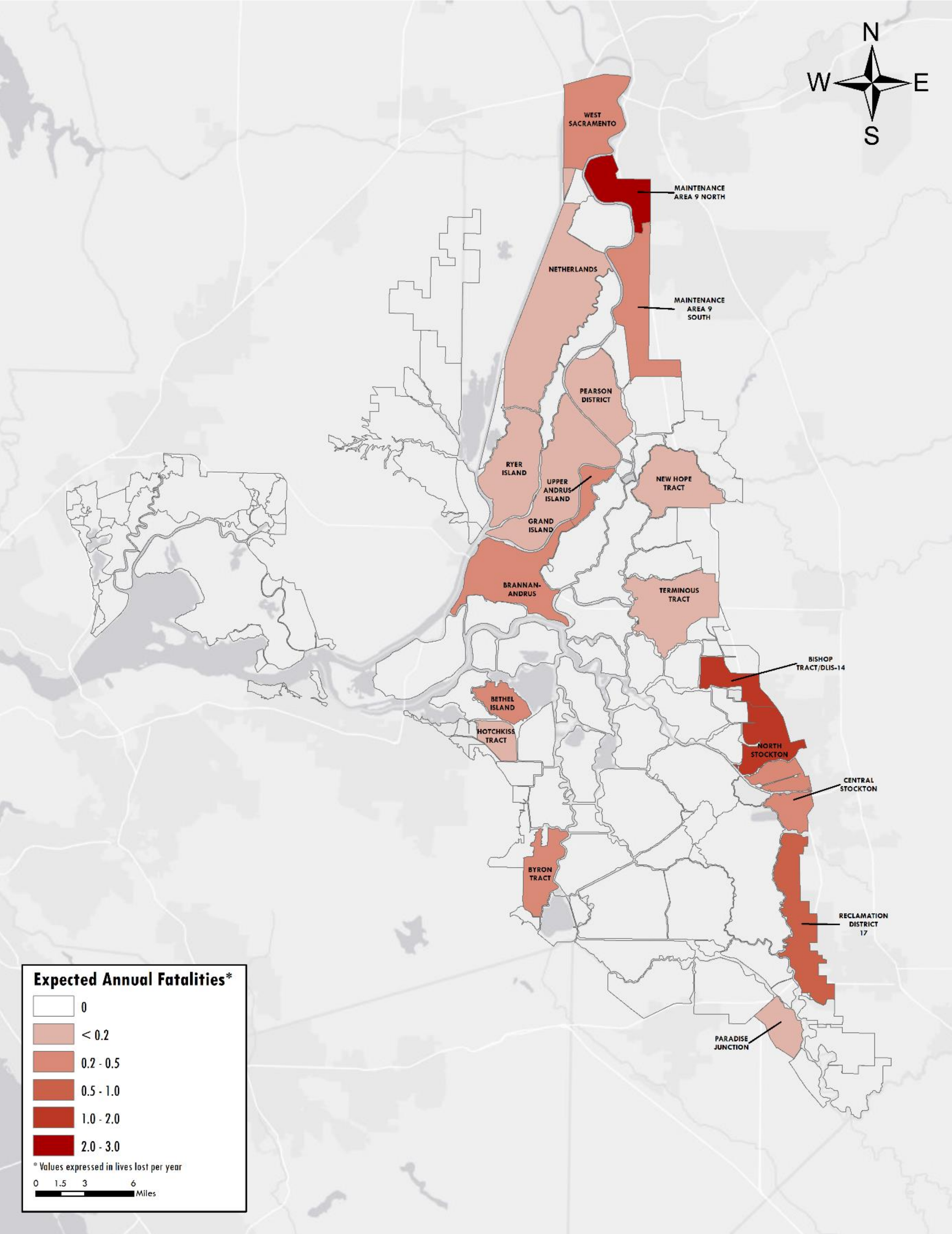
$$fatalities_{i,d} = PAR_i \times p_{contact,d} \times p_{fatalities,d}$$ (Equation 3-3)

In turn, EAF for island i is calculated as the sum of the product of the annual probability of flooding (Equation 3-1) and the estimated fatalities at each potential flood depth d:

$$EAF_i = \sum_d p_{flood_{i,d}} \times fatalities_{i,d}$$ (Equation 3-4)

Figure 3-12 shows the calculated risk to life as EAF, in lives lost per year, for each island and tract. Because of its agrarian nature, population is generally sparse throughout the Delta. Population is clustered on Bethel Island and along the eastern margin of the Delta where the urbanized areas of Sacramento and Stockton are in the legal Delta. It is not surprising, therefore, that EAF is higher for Bethel Island and the polders along the east edge of the Delta. Areas showing higher EAF in less-populated areas of the Delta reflect higher probabilities of flooding.

Figure 3-12 Risk to Life



3.3.3 Expected Annual Damages (Risk to Property and Infrastructure)

One of the objectives of the DLIS project is to develop a methodology to estimate the losses of property and infrastructure resulting from levee failures in the Delta and Suisun Marsh. The DLIS team used the concept of EAD as the measure of risk to the Delta and Suisun Marsh property and infrastructure. Details on the derivation and basis for using EAD are provided in the Methodology Report (Council 2016b).

EAD is a monetized metric and is measured in dollars. Calculating EAD requires estimating the dollar value of assets and the fraction of the value that would be lost in a flood. If an island or tract is inundated because of a levee breach, the DLIS risk analysis methodology assumes that the island or tract will be rehabilitated by repairing the levee breach and draining the island or pumping it free of floodwater. The incremental costs or losses from flooding consist of the cost of repairing or replacing assets, the cost of lost agricultural production, and the cost of repairing the levee. For islands and tracts where the ground surface is below the normal water level in the adjacent channel, the cost of pumping floodwater out of the island or tract is also included.

EAD is the product of the total estimated economic losses (damage) and the probability that a flood event will occur. Like fatality rates, damage to infrastructure and assets increases with inundation depth. The damage is the sum of the product of the value of each asset a and the percent loss in value of that asset due to a flood of level d:

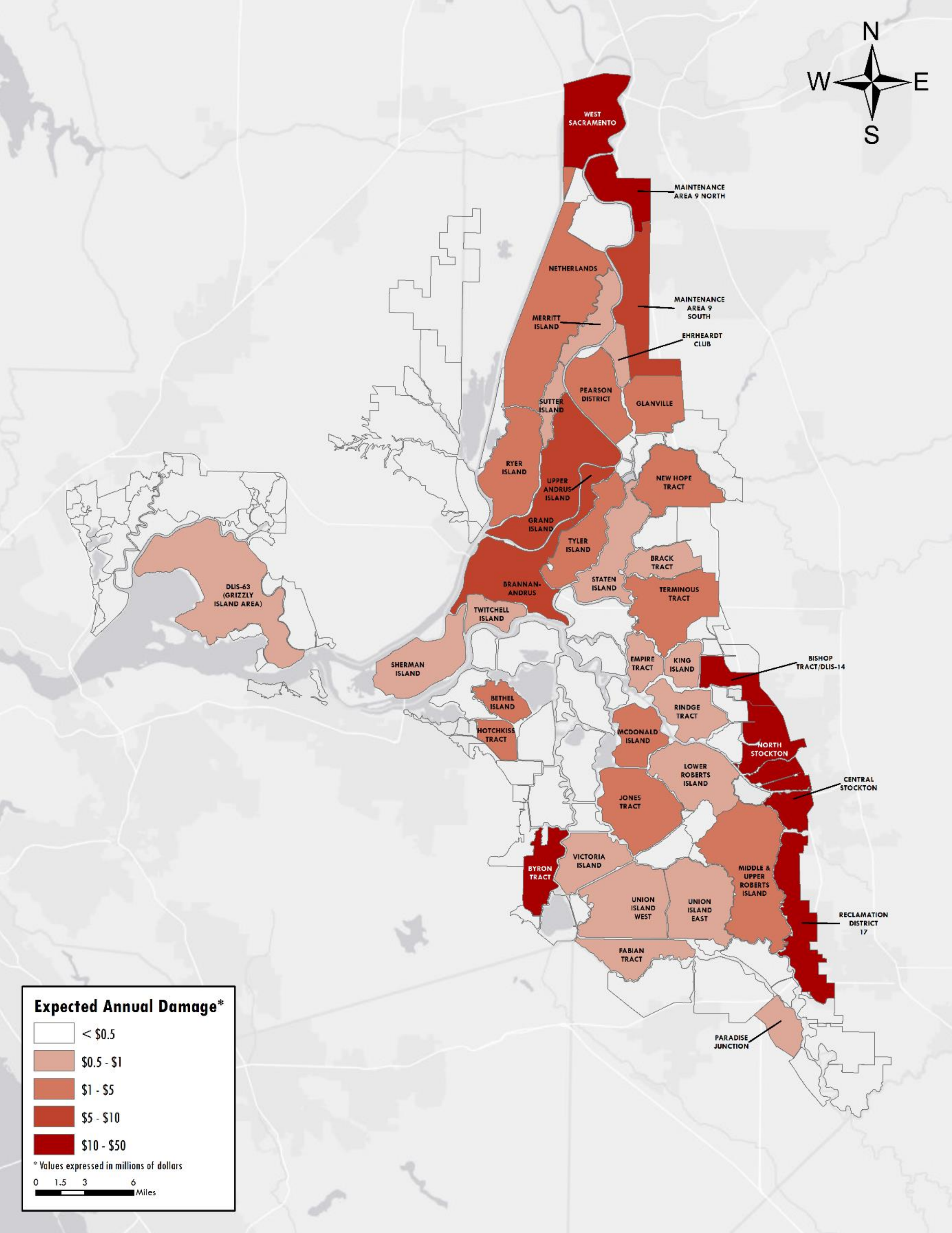
$$damage_{i,d} = \sum_a value_a \times percentloss_{a,d} \qquad \text{(Equation 3-5)}$$

Therefore, EAD for island i is calculated as the sum of the product of the annual probability of flooding (Equation 3-1) and the estimated economic losses at each potential flood depth d:

$$EAD_i = \sum_d p_{flood_{i,d}} \times damage_{i,d} \qquad \text{(Equation 3-6)}$$

Figure 3-13 shows the calculated risk to property as EAD, in millions of dollars per year, for each island and tract. Because population centers tend to have denser clusters of real estate improvements, commercial areas, and infrastructure, EAD tends to follow EAF. However, EAD is also higher in other parts of the Delta due to the presence of infrastructure, more valuable crops, or polders with higher probabilities of flooding.

Figure 3-13 Risk to Property and Infrastructure



3.3.4 Risk to Water Supply

Delta islands and levees perform three complex functions to support a water supply system whose reliability is threatened by levee breaches and resulting floods: i) freshwater conveyance to intakes; ii) salinity protection (water quality); and iii) protection of on-island water supply infrastructure, such as intakes, pumps, or aqueducts. These functions are described more fully in the Methodology Report (Council 2016b).

The best available information does not enable us to quantify the link between islands flooding and the consequences of water supply disruption. DWR is developing methods to estimate the duration of disruption for various users, and the quantity of water that would be disrupted, for various configurations of flooded islands. It is not, however, currently possible to calculate water supply risk in a classical sense (i.e., as the product of probability times consequence) because the consequence cannot be readily determined and quantified in dollars or other units.

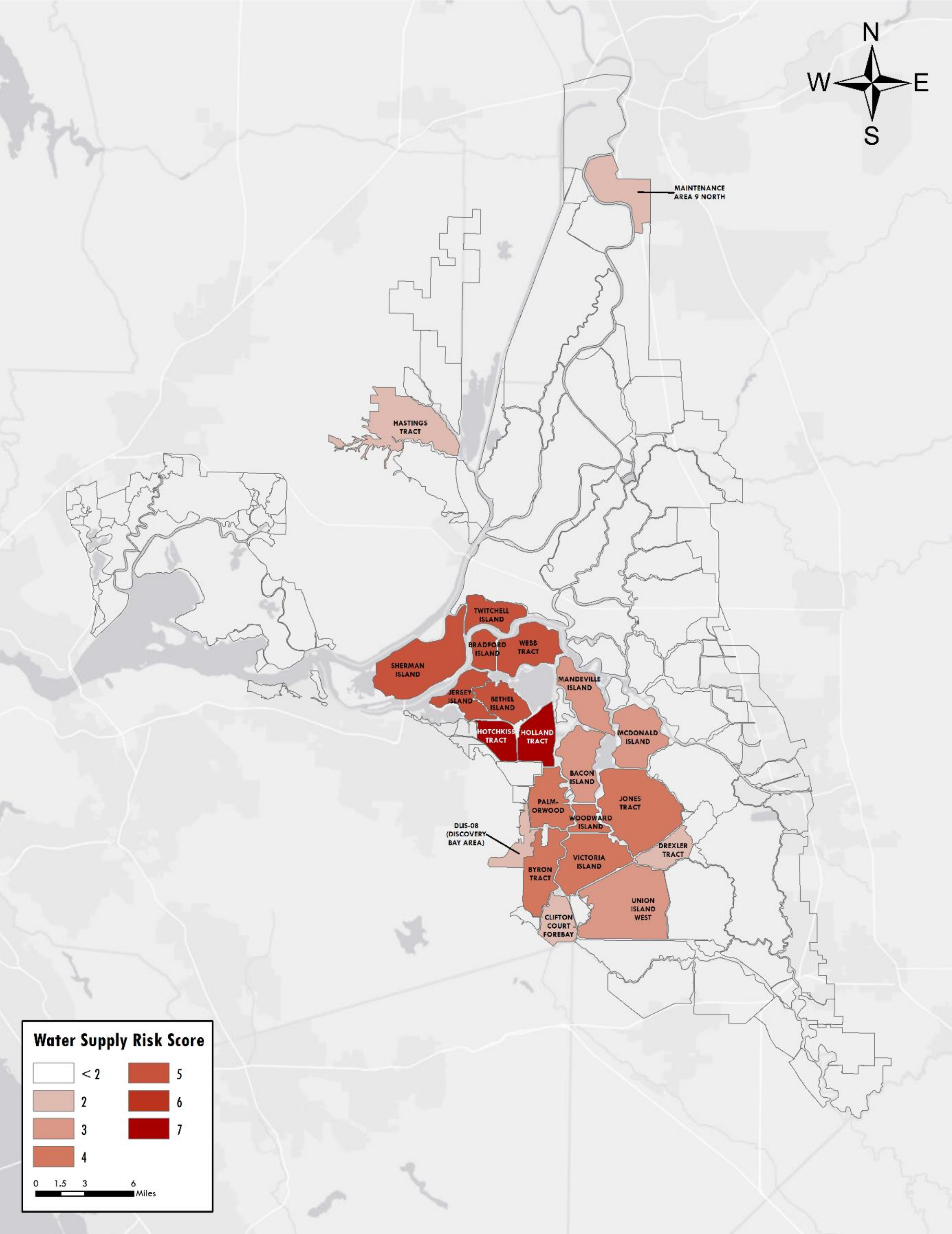
Instead, the best available data can identify those islands that perform one or more water supply functions for various groups of users, and which islands are at the greatest likelihood of flooding. These data enable us to develop a conceptual assessment of risk by identifying those islands that play a significant role in ensuring a reliable water supply and that also have a high risk of flooding.

The conceptual risk to water supply reliability comprises two components. The first component is the probability of flooding, which is determined for each island through calculations described in Section 3.3.1. The second component is the relative importance of an island to water supply, which is determined by the combination of: i) the number of water supply functions (conveyance, salinity barrier, or infrastructure) an island performs; and ii) the number of water user groups that an island supports through any of the three water supply functions.

These components are combined to produce a risk score for each island. Islands that have flooding probabilities lower than 0.5 percent or that do not perform any water supply functions receive a score of 0. On the other hand, each pairing of user and function adds one point to the risk score. For example, Holland Tract scores seven because it acts as a salinity barrier for five water user groups (South of Delta users, Antioch, Stockton, Contra Costa Water District [CCWD], and South and Central Delta users); it supports conveyance for one water user group (CCWD); and it contains infrastructure for one water user group (CCWD). Similarly, McDonald Island scores three because it supports freshwater conveyance for three water user groups (South of Delta users, South and Central Delta users, and CCWD), but it does not serve as part of the salinity barrier and it has no water supply infrastructure.

Figure 3-14 illustrates the islands in the Delta and Suisun Marsh that have a total risk score of two or more. Not surprisingly, the western islands have a higher risk score, or higher conceptual risk to water supply; however, islands like Hotchkiss Tract and Holland Tract show the highest risk score because potential levee failure at these tracts can disrupt multiple pairings of water supply functions and users. Similarly, DLIS-46 and DLIS-47 do not pose a threat to water supply because, even if they have a higher probability of failure, these islands do not support water supply functions.

Figure 3-14 Conceptual Risk to Water Supply



3.3.5 Risk of Harm to the Ecosystem

While determinations of ecosystem value and function are complex, the amount of habitat at risk of damage by flooding is a straightforward element that decision-makers and stakeholders can use to understand and evaluate the impacts of flooding on the ecosystem. The DLIS team considered two types of high-value habitat:

- *Non-tidal habitat* that occurs in areas currently bound by levees, or in areas that could be protected by levees.
- *Water-side habitat* (including tidal habitat, riparian habitat, seasonal floodplains, and transitional habitat) that does not receive or require flood protection from levees.

An island may have both non-tidal and water-side habitat. For example, Grizzly Island has over 23,300 acres of managed wetlands behind levees and about 600 acres of tidal wetlands, which is the fourth largest amount of water-side habitat in the Delta and Suisun Marsh. In addition, Grizzly Island holds great potential for restoration; much of this large tract is at suitable elevations for future tidal wetlands and transitional habitat in the priority Suisun Marsh restoration area. For more details on how non-tidal and water-side habitats were identified and mapped, refer to the Methodology Report (Council 2016b).

Because levee investments have the potential to reduce flooding on islands that include or could be restored to include non-tidal habitat, the DLIS team considered both existing habitat (including lands in conservation ownership or easements) and potential future habitat (such as EcoRestore projects). The primary ecosystem metric is the expected flooding of high-value non-tidal habitat, measured in acres.

The risk analysis methodology assumes that, if an island is flooded, the effect will be uniform for all high-value non-tidal habitat on the island. Harm to the ecosystem is expressed as Expected Annual Flooding of High-Value Non-Tidal Habitat (or EFH). For island $i,$ the EFH is calculated as the product of the annual probability of flooding, p_{flood_i}, (see Equation 3-2) and the area of existing and potential high-value non-tidal habitat, $habitat_i$:

$$EFH_i = p_{flood_i} \times habitat_i \qquad \text{(Equation 3-7)}$$

Figure 3-15 shows risk to high-value non-tidal habitat that could be flooded if levees fail, in average acres that could be flooded annually. The islands with the greatest risk to non-tidal habitat include Grizzly Island (private and public managed wetlands, including Grizzly Island Wildlife Management Area), Staten Island (conserved lands managed for sandhill cranes), Twitchell Island (public lands with EcoRestore projects for wetlands and subsidence reversal), and Maintenance Area 9 (Stone Lakes National Wildlife Refuge).

Some areas of the Delta have been identified as having the potential for restoration of habitat on the water side of levees, or unleveed habitat. The DLIS team considered opportunities for both existing and potential future unleveed habitats because levee investments could i) adversely impact or restrict restoration of unleveed habitats (e.g., armoring levees where ecosystem restoration is planned), or ii) provide opportunities for water-side habitat restoration (e.g., setback levees). The DLIS team identified lands within the priority restoration areas specified in the *Delta Plan* (Council 2013) that are at suitable elevation for restoration as tidal habitat, riparian habitat, seasonal floodplains, and transitional habitat. The possibility of restoring habitat on the water side of levees should be a consideration in the development of the investment strategy. Figure 3-16 identifies the acres of existing and potential high-value unleveed habitat associated with islands and tracts in the Delta and Suisun Marsh.

Figure 3-15 Risk to High-Value Non-Tidal Habitat

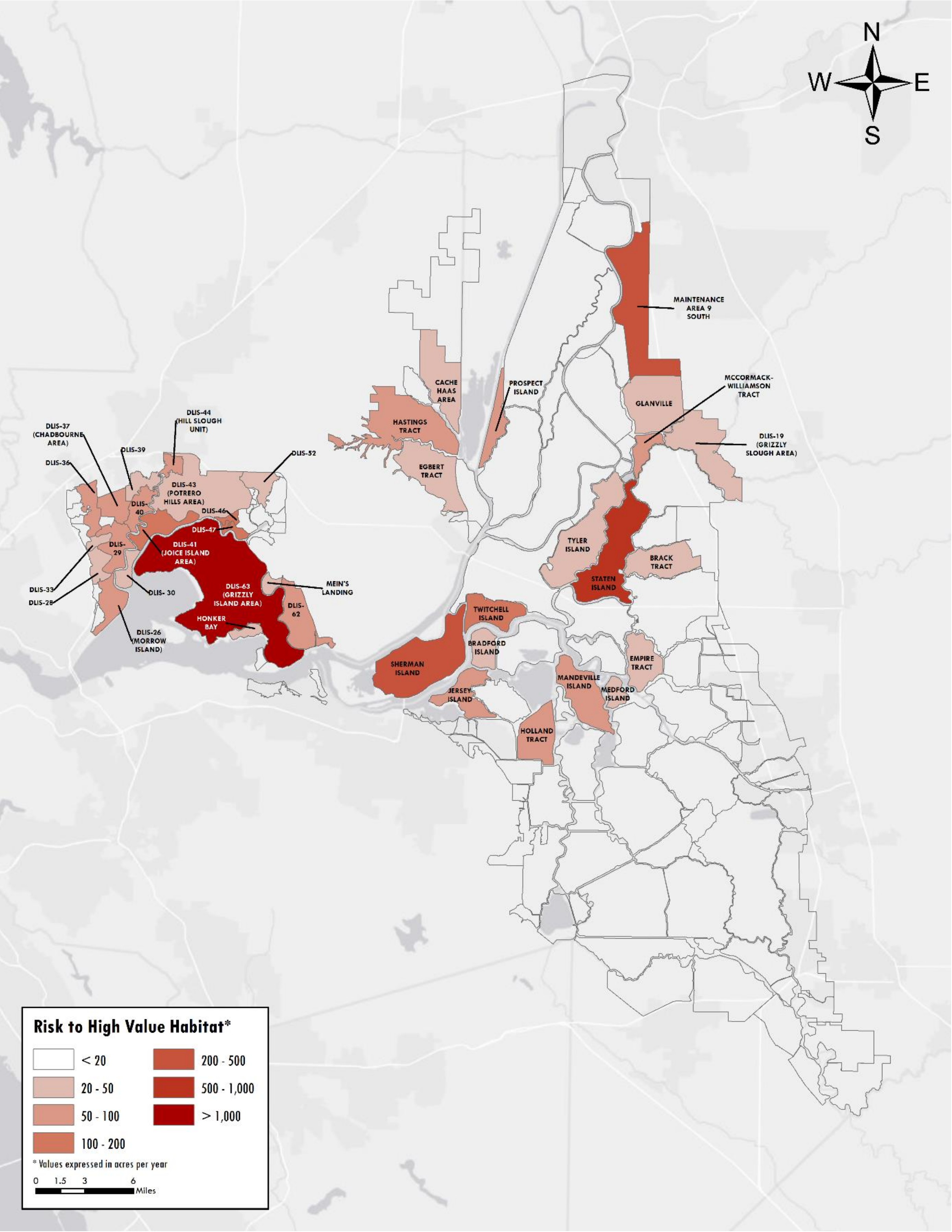
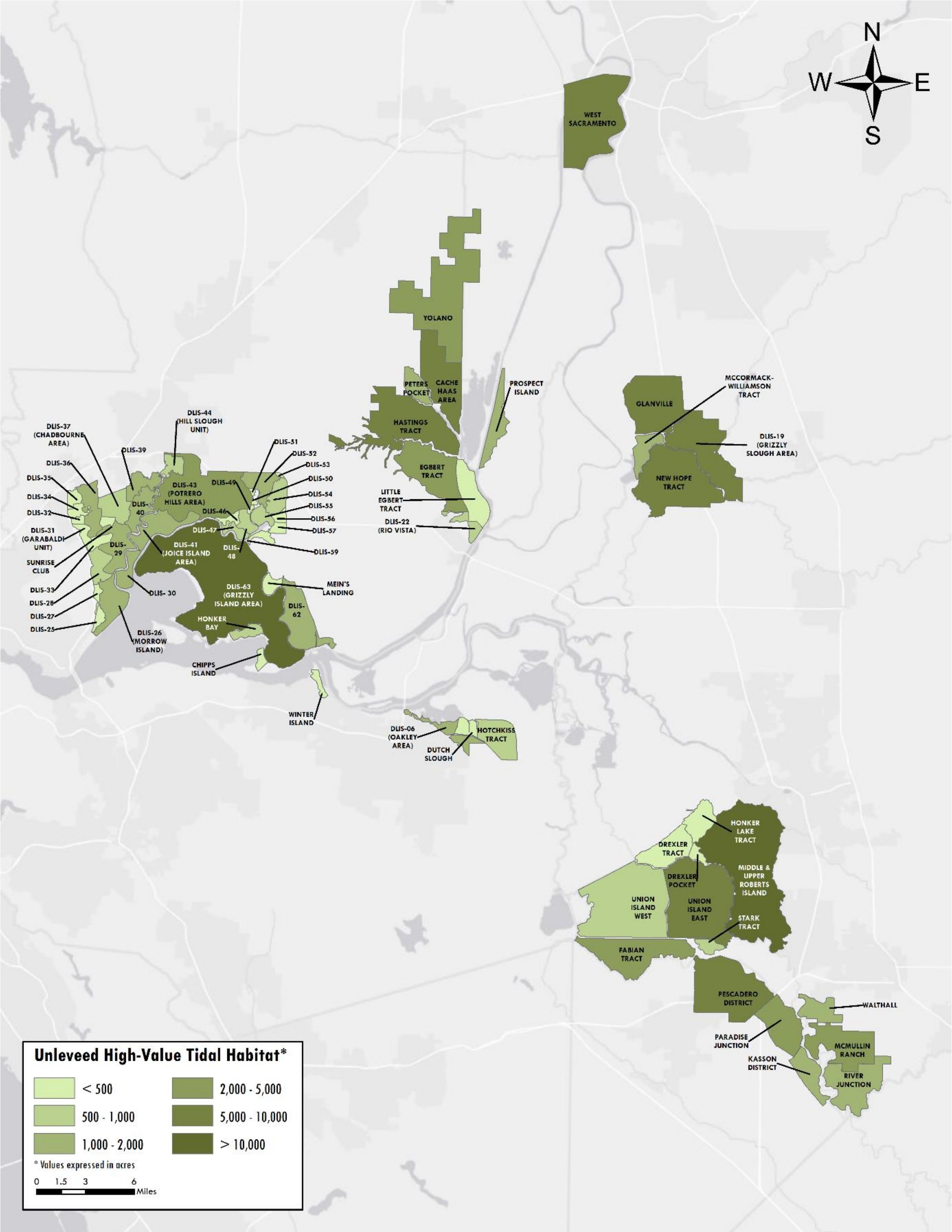


Figure 3-16 Location of Unleveed High-Value Tidal Habitat



3.3.6 Delta as a Place Metrics

Changes to the Delta are inevitable. A levee investment strategy (no-action or otherwise) will impact legacy towns, scenic resources, farmland, and roads, thereby affecting the “special qualities that distinguish (the Delta) from other places” (23 CCR 5001 (h)(3)), or the “Delta as an evolving place.” While the EAF and EAD metrics account for damages to life, property, and infrastructure in the Delta, the “Delta as a place” metrics provide an additional way to gauge the effects of flooding and levee investments on Delta communities, and offer a way to measure potential changes to the Delta’s special qualities. The DLIS team relied on input and feedback from Delta stakeholders to develop three “Delta as a place” metrics, which measure risk to i) legacy towns, ii) valued farmland (prime farmland, farmland of statewide importance, and unique farmland) in acres, and iii) important roads.

The first component of the Delta as a place metrics is a conceptual assessment of risk measured as the annual probability of flooding for islands and tracts with legacy towns. Legacy towns in the Delta include: Bethel Island, Clarksburg, Courtland, Freeport, Hood, Isleton, Knightsen, Locke, Rio Vista, Ryde, and Walnut Grove (which is on three islands). These towns are generally located in the central and northern Delta, on islands that typically have a 2 to 5 percent probability of flooding. Figure 3-17 shows the conceptual risk to legacy towns expressed as the probability of flooding for islands that have one or more legacy towns.

Risk to prime farmland, the second component of the Delta as a place metrics, is measured as the annual probability of flooding an island times the acres of prime farmland, farmland of statewide importance, and unique farmland, as noted by the Farmland Mapping and Monitoring Program (California Department of Conservation 2012). Figure 3-18 displays the risk to total prime farmland, expressed as the average number of acres flooded per year. Islands in the central and northern Delta, including Grand Island, Staten Island, Netherlands, Terminous Tract, Brannan-Andrus, and Tyler Island, generally have the highest risk to prime agricultural land, though Middle and Upper Roberts Island also has a risk value of over 400 acres per year.

The third component of the Delta as a place metrics is again a conceptual assessment of risk, this time measured as the annual probability of flooding for islands and tracts with important roads. Important roads include the state and federal highways that cross the Delta, which are vital for moving people and goods that support the Delta economy and for emergency access and egress in the event of flooding. As shown on Figure 3-19, Little Egbert Tract, Glanville, Staten Island, and Maintenance Area 9 South pose the highest risk to public roadways.

Additional details on Delta as a place metrics are available in the Methodology Report (Council 2016b).

Figure 3-17 Conceptual Risk to Legacy Towns

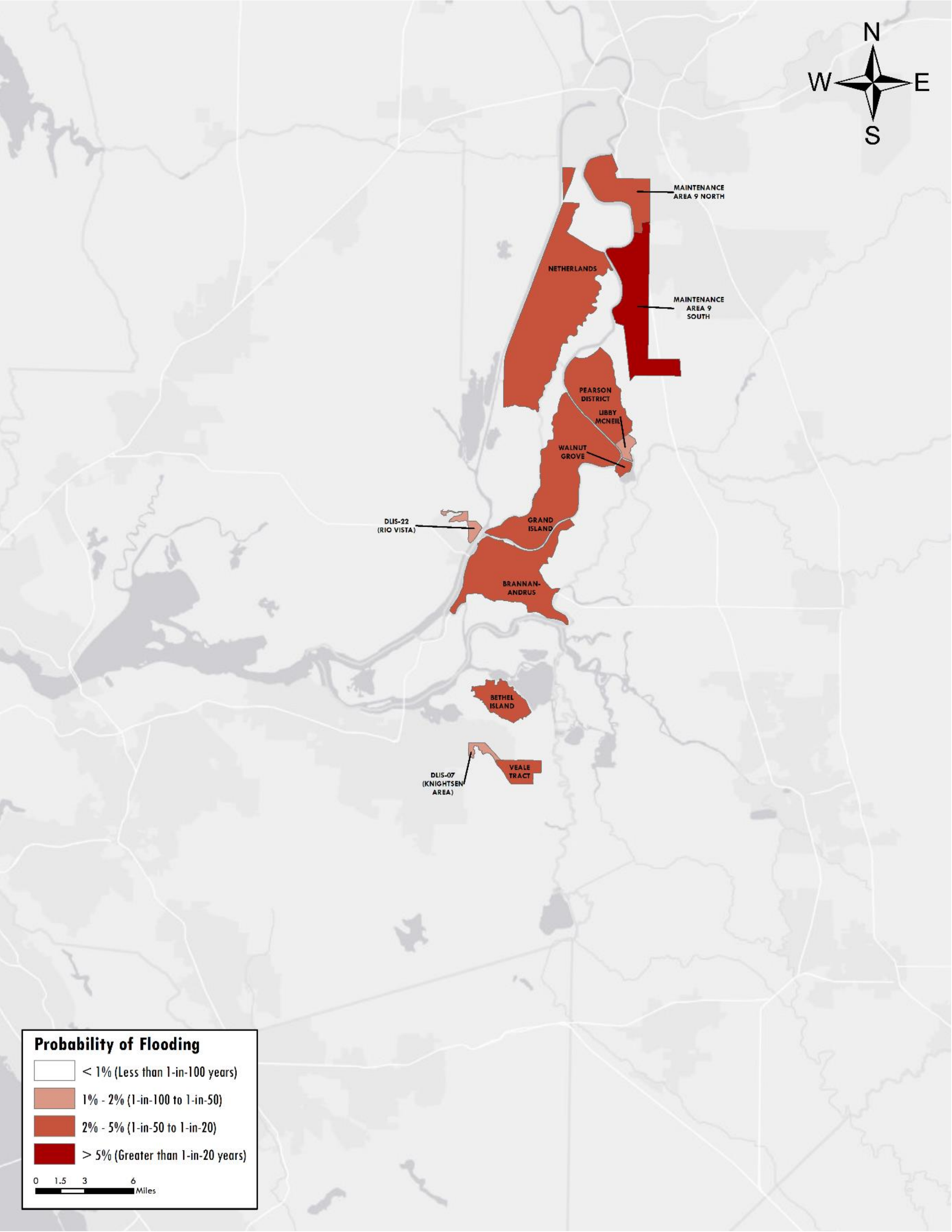


Figure 3-18 Risk to Total Prime Agricultural Land

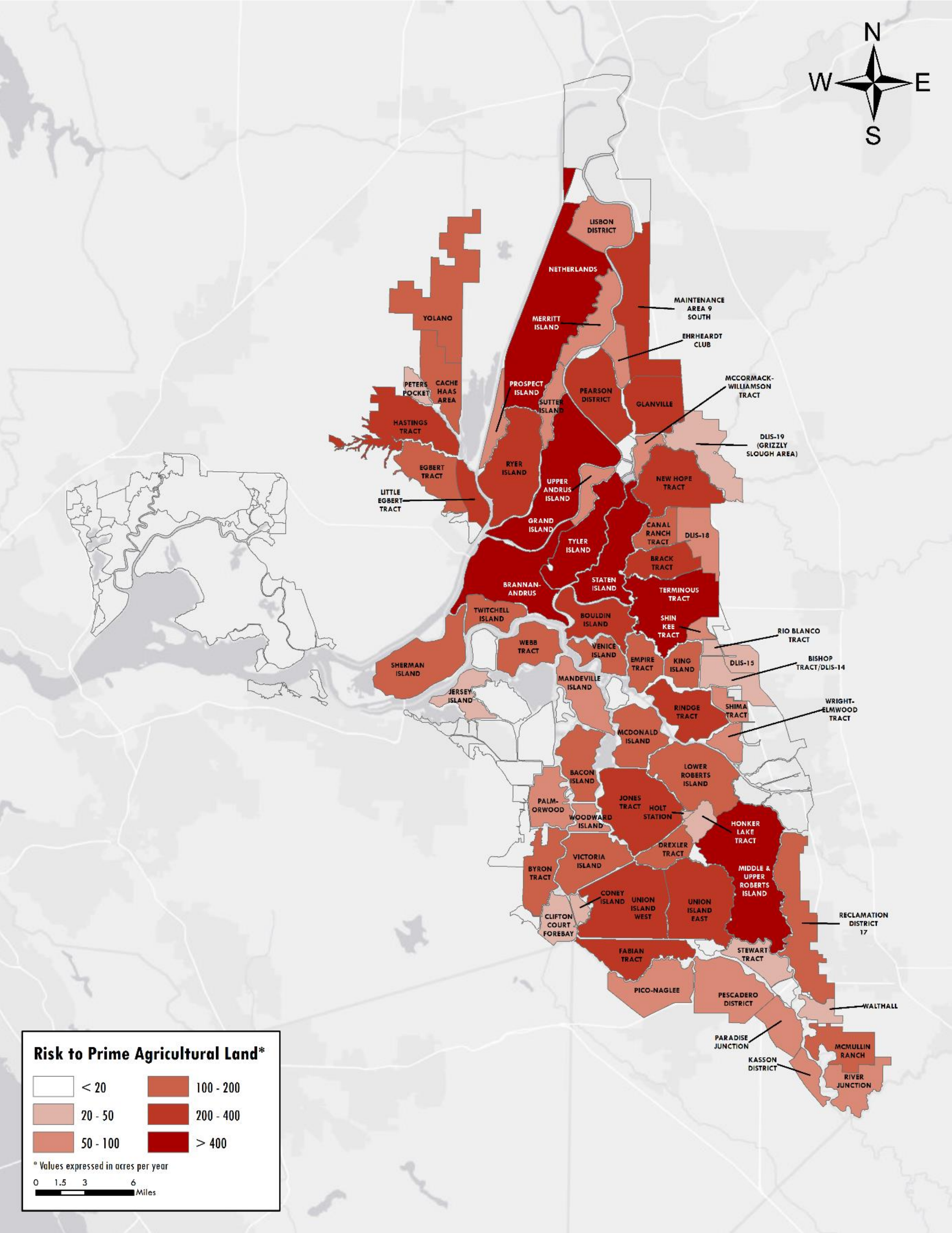
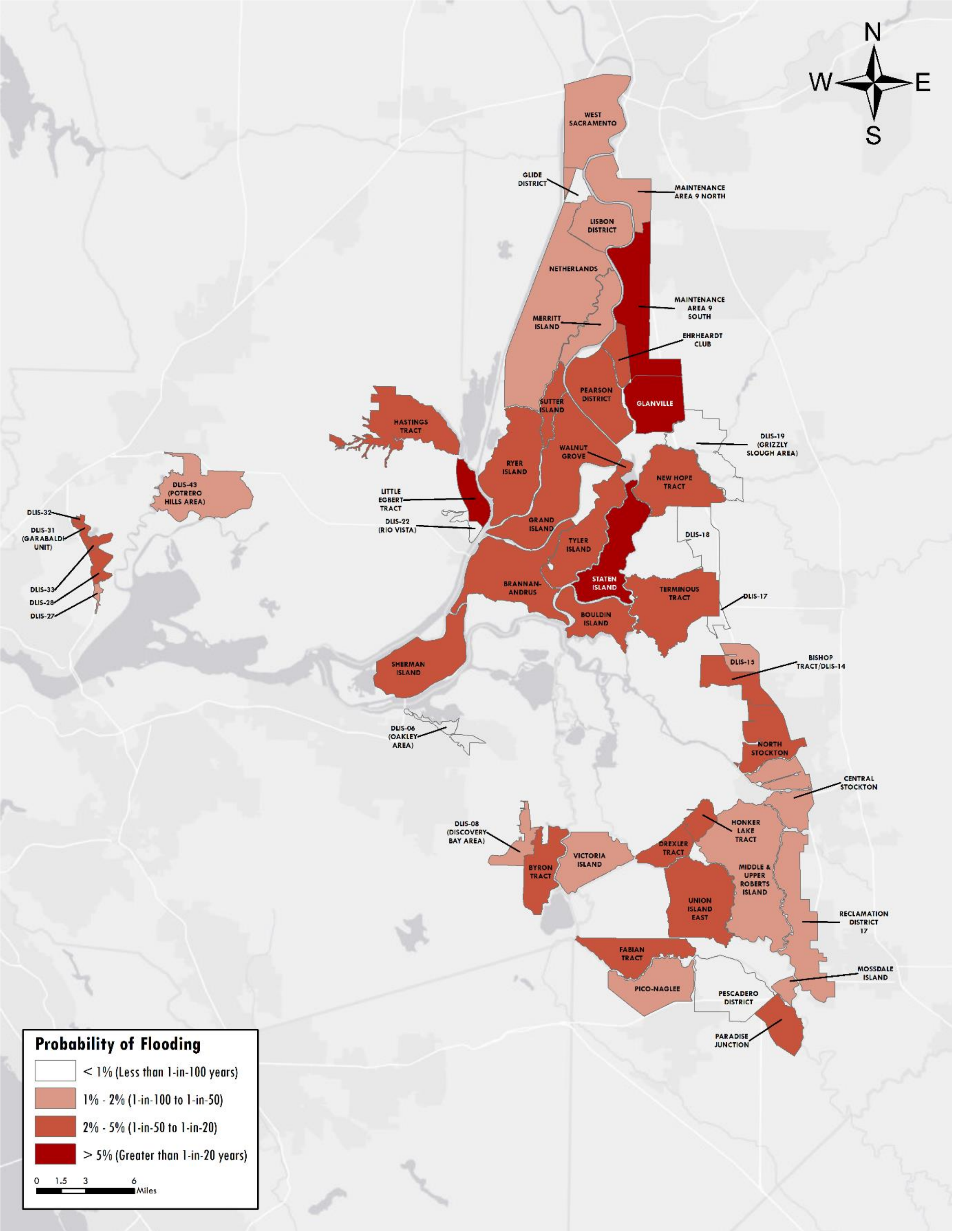


Figure 3-19 Conceptual Risk to Public Roadways



4.0 PRIORITIES FOR STATE INVESTMENTS IN DELTA LEVEES

The Council undertook the DLIS to update the interim levee investment priorities in the *Delta Plan* (Council 2013) and to report to the State Legislature on the priorities for State investment in Delta levees. The 2009 DRA directed that the *Delta Plan* "reduce risks to people, property, and state interests…by promoting…strategic levee investments" (CWC section 85305(a)). The DRA further directed that "the Council, in consultation with the Central Valley Flood Protection Board, shall recommend…priorities for state investments in levee operation, maintenance, and improvements" (CWC section 85306). With this direction, Council staff and the DLIS team developed a risk analysis methodology to identify risks to State interests, including lives and property, to inform Council deliberations on priorities for State investment in Delta levees, as described in Section 3.0.

The DST enabled the Council and stakeholders to review and update the data and analysis that formed the basis of the risk evaluation. The results of the risk analysis, together with special considerations described in Section 4.5, were used to develop a prioritized list of islands and tracts for State investment in levee improvements. The approach included extensive outreach and engagement as described in Section 2.0 to review methods, data, results, and policy recommendations.

As with any forecast of probability and risk, there is a level of uncertainty. One cannot perfectly predict when, where, and of what magnitude a flood or earthquake may occur. The understanding of levee conditions and fragility and how they might perform in a hazard is not fully known. The DLIS team evaluated the uncertainties in the risk evaluation and concluded that, despite uncertainties, the results provide sufficient understanding of the relative risks among Delta islands and tracts to inform Council decision-making about priorities for State investment (refer to the Methodology Report, Council 2016b). As noted below, new information identified and collected in the future can further inform the risk reduction strategy and reduce uncertainty.

The Council's goal in applying the risk analysis methodology was to develop three tiers of islands showing Very-High Priority, High Priority, and Other Priority for State investments in levee improvements for islands and tracts in the Delta and Suisun Marsh. Section 3.0 describes how those islands and tracts in the Delta that have a high risk to each State interest were identified. To determine priorities, then, it is necessary to aggregate risks and to identify those islands and tracts that may have considerably higher risk relative to others. This section describes the DLIS process for determining levee investment priorities and summarizes the results on Figure 4-1 and in Table 4-2.

4.1 Risk to State Interests

The Council reviewed and identified the important risks to State interests relative to Delta levee investment priorities regarding people, property, and the coequal goals for the Delta. Consistent with the DRA, the Council also considered potential effects on the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place.

As described in Section 3.0, the methodology for evaluating risks to State interests considered the key factors that comprise risk: hazards, levee conditions, probabilities of levee failure, and assets or resources that could be damaged by flooding. The risk-based approach enables decision-makers to consider both the probability of levee failure from floods and earthquakes and the value or importance of the assets that are protected by the levee. The risk metrics for each State interest are described in detail in Section 3.0 and those used in the DST to identify priorities for State investment in Delta levees are summarized in Table 4-1 below:

Table 4-1 Summary of Risks to State Interests Used in the DST

State Interest	Definition of Risk	Metric	Unit
People	Loss of life from flooding	EAF, average annual loss of life	Lives lost per year
Property and Infrastructure	Flood damages to structures, infrastructure, and crops	EAD, average annual property damage	Dollars per year
Water Supply Reliability	Disruption of water deliveries or harm to Delta water quality	Composite risk score describing islands and tracts that are vulnerable to flooding and important for protecting Delta water quality, water conveyance, and water supply infrastructure	Unitless
Ecosystem	Harm to high-value habitat from flooding	Estimated annual loss of high-value non-tidal habitat protected by levees	Acres per year

4.2 Decision Support Tool

The DST is designed to support a deliberation-with-analysis process by which quantitative analysis frames and illuminates key policy trade-offs (NRC 2009) using a methodology successfully deployed to support the development of Louisiana Coastal Protection and Restoration Agency's 2012 and 2017 Coastal Master Plans (Groves and Knopman 2012; Groves and Sharon 2013). Such an exploratory modeling approach is suited for long-term policy questions in which i) uncertainty is significant, ii) there are many diverse views of what constitutes desirable outcomes, and iii) there is disagreement about how the system will respond to future stressors (Lempert et al. 2003).

Inputs to the DST include the information and data used to calculate risks as described in Section 3.0, including physical island and tract sizes, elevations, and levee conditions; the asset counts and replacement values on each island; and hazard information. The output of the DST is a series of interactive visualizations in which the user can specify information of interest (e.g., risks with respect to a performance metric or time period), set metric weights for island rank and investment rankings, and explore different trade-offs across investment portfolios. The DST is accessible through the Council website (http://deltacouncil.ca.gov/dlis-decision-support-tool).

The DST supports deliberations by summarizing information about baseline risks and then identifying portfolios of investments that reflect State interests. The user (e.g., the State or stakeholder) can specify priorities vs. performance metrics (e.g., risk to life vs. risk to property vs. risk to habitat) and assumptions about future risks to enable a transparent comparison of results across different metrics.

The DST supported the DLIS team in developing a levee investment strategy through three key steps:

1. Assimilating and displaying information about islands and tracts and assets at risk throughout the Delta.
2. Estimating the probability of flooding and the associated risks to lives, property, water supply, habitat, and other Delta assets.
3. Providing interactive visualizations to support deliberations over how to weigh distinct types of risks to define high-risk islands.

The DST also enables the user to include investments that are cost effective based on user-defined thresholds for risk metrics. The DST tracks the total cost of each proposed investment portfolio by the Council-defined priority tiers.

When new or better information was identified, the DLIS team updated the underlying data driving the DST. Examples of updates include the hydrologic connectivity among islands and tracts, levee improvements made since levee condition assessments in 2006, and corrections to asset counts. The data components in the DST are designed to be updated as new information becomes available.

4.3 High Risk Islands and Tracts

For each risk metric, the DLIS team identified which islands were at highest risk for the given State interest (as presented in Section 3.0). The Council directed that the risk to people (potential loss of life) is the most important risk to State interest, consistent with state and federal flood management policy and practice.

To identify the islands and tracts that comprise the highest risk to each of the State interests, and to therefore merit consideration for priority investment, it was necessary to determine a threshold, above which risks can be considered “high,” and below which the risks, though important, are of lesser priority. In keeping with the Council’s directive to rank risk to loss of life in the Delta as most important, the DLIS team identified the islands and tracts that together comprise at least 90 percent of the total risk to life across the Delta. For the other risk metrics, the DLIS team identified the islands and tracts that together comprise at least 80 percent of the risk in each category. The high-risk islands thus identified resulted in the following:

- **People** – 11 islands with EAF greater than 0.24 lives per year (at least 90 percent of Delta-wide EAF).
- **Property** – 11 islands with EAD greater than $3.5 million per year (at least 80 percent of Delta-wide EAD).
- **Habitat** – 11 islands with more than 89 acres of expected annual loss of habitat (at least 80 percent of Delta-wide expected loss of high-value, non-tidal habitat).
- **Water Supply** – 22 important water supply islands with a probability of flooding greater than 0.5 percent per year (1-in-200-year probability). Important water supply islands and tracts are those that provide a water supply function (water quality protection, water conveyance corridor, or water supply infrastructure) for two or more user groups (Antioch, CCWD, East Bay Municipal Utility District,

North Delta, Sacramento, Solano and Napa, Stockton, Central/South Delta, CVP/SWP, or Suisun Marsh).

The Council also considered and provided direction on the relative importance of risks to State interests. That is, should different weights be assigned to each of the risks to State interests? The weighting analysis showed that assigning equal weights to the risk metrics identified above enabled capturing at least 90 percent of EAF in the Delta, which met the Council criterion regarding risk to life. Therefore, all risks to State interests were assigned equal weights.

Islands and tracts were grouped into three categories based on their risk, and considering all metrics: Very High Priority, High Priority, and Other Priority. Using the DST and the deliberation-with-analysis process, 15 islands characterized as high risk for two or more State interests were included in the Very-High Priority category. Twenty-six islands and tracts characterized as high risk to a single State interest were included in the High Priority category. The remaining islands and tracts were listed in the Other Priority category.

In the deliberation process, the Council also identified special considerations for additional evaluation as described more fully in Section 4.4 below. By taking these special considerations into account, the recommended list of State levee investment priorities developed for Council consideration includes 17 islands and tracts in the Very-High Priority category and 34 islands and tracts in the High Priority category. The recommended list of State levee investment priorities is included in Table 4-2 and is displayed on Figure 4-1.

4.4 Special Considerations

The deliberation-with-analysis process identified special considerations for assigning priorities: hydraulic connection between adjacent islands, ecosystem restoration opportunities, Delta as a place, and Suisun Marsh levees. The evaluation of these special considerations resulted in changing the priority of several islands and tracts as described for each type below.

4.4.1 Hydraulic Connection

The geographic unit of analysis for risk to State interests is an island or tract that functions as a distinct polder. In some cases, two islands or tracts are separated by a cross levee or a dry levee that may provide only limited opportunity to reduce flood risk. For example, Upper Andrus Island and Brannan-Andrus Island are separated by a dry levee; if Upper Andrus Islands floods, the lower-elevation Brannan-Andrus Island will also likely flood. However, if Brannan-Andrus Island were to flood, the dry levee between the two islands would likely protect the higher-elevation Upper Andrus Island. Upper Andrus Island and Maintenance Area 9 South are listed in the Very-High Priority category, in part because of these circumstances. DLIS-22 (Rio Vista) was also included in the High Priority category due to the anticipated increased probability of flooding resulting from proposed modifications to Yolo Bypass flood operations.

4.4.2 Ecosystem Restoration Opportunity

Two tracts, Dutch Slough and McCormack-Williamson Tract, were included in the Very-High Priority category because there are plans and funding for habitat restoration currently in place. Eight islands and tracts were included in the High Priority category because of potential multi-benefit flood management and ecosystem restoration opportunities in the lower Yolo Bypass and Paradise Cut (DLIS 20-Yolo Bypass, Hastings Tract, Little Egbert Tract, Mossdale Island, Paradise Cut, Paradise Junction, Pescadero District, and Stewart Tract). Tyler Island was listed in the High Priority category due to its high-value crane habitat.

The DLIS team also identified all islands that are within priority restoration areas (Council 2013) and that have lands at an elevation suitable for restoration of tidal habitat, riparian habitat, seasonal wetlands, or transitional habitat (refer to the Methodology Report, Council 2016b). Each of these islands and tracts is identified in Table 4-2 (Tidal Habitat Improvement Opportunity column) so that specific levee improvement projects can consider habitat restoration opportunities such as setback levees or cross levees (Council 2016a).

4.4.3 Delta as a Place

The DLIS team worked with the DPC and Delta landowners and residents to identify unique features of the Delta that should be considered in prioritizing State investment in Delta levees in addition to the considerations of risk to lives, property, high-value habitat, and water supply.

The state and federal transportation network was identified as a key resource for supporting and maintaining the regional economy and facilitating emergency response and evacuation. Accordingly, the DLIS team evaluated the probability of flooding for islands and tracts that include Interstates 5 and 205 and State Highways 4, 12, and 160. The United States Department of Transportation, Federal Highway Administration (FHWA) uses the 2 percent annual exceedance probability (AEP) as a criterion for roadway flooding (23 CFR 650A; FHWA 1994). Based on this criterion, the DLIS team identified six islands and tracts in the Other Priority category that included one or more of these highways, and that had an annual probability of flooding greater than 2 percent. These islands and tracts were reclassified in the High Priority category. This information was also provided to California Department of Transportation (Caltrans), which is independently conducting a vulnerability assessment of state and federal highways in California.

The DLIS team also considered Delta legacy towns and prime agricultural land as key features of Delta as a place. The DLIS team determined how these Delta assets would be addressed in each of the three priority categories. State investment in levee improvements for the Very-High Priority islands and tracts would reduce flood risk to six of the 13 islands with legacy towns. In addition, State investment in levee improvements for islands and tracts in the Very-High Priority and High Priority categories would reduce the probability of flooding to 50 percent of prime agricultural land in the Delta.

4.4.4 Suisun Marsh Levees

Many of the islands and tracts in Suisun Marsh are at high risk for damage to habitat from flooding. The DLIS team assigned the “outboard” levees along Suisun Bay (DLIS-63 [Grizzly Island Area] and Honker Bay) to the High Priority category for State investment to reduce flood risk to Suisun Marsh and associated water management facilities, including the Suisun Marsh Salinity Control Gates and Roaring River Distribution System. Because many of the levees surrounding internal Suisun Marsh islands and tracts are privately owned, these islands and tracts were included in the Other Priority category for State investment, even if the results showed high risk for habitat flooding.

4.5 Priorities for State Investment in Delta Levees

As shown in Table 4-2 and on Figure 4-1, the risk analysis and evaluation of special considerations described above resulted in a list of State levee investment priorities that includes 17 islands and tracts in the Very-High Priority category and 34 islands and tracts in the High Priority category. Table 4-2 provides the following information:

Island or Tract Name – Islands and tracts that represent individual polders.

Priority – Very-High Priority, High Priority, or Other Priority categories.

Risk to State Interests – Islands at high risk of flooding together represent more than 90 percent of total Delta risk for life and more than 80 percent of the total Delta risk for each of the risk metrics for property and infrastructure, water supply, and ecosystem.

Transportation Infrastructure at Risk – Islands with Interstates 5 or 205 or State Highways 4, 12, or 160 that currently have more than 2 percent annual probability of flooding.

Tidal Habitat Improvement Opportunity – Lands identified within the *Delta Plan* Priority Restoration Areas (Council 2013) and determined to be at elevations suitable for tidal, riparian, transitional, or seasonal habitat.

Flooding Probability – Combined probability of flooding due to hydraulic and seismic events.

Comments – Special considerations for adjusting priorities.

Figure 4-1 Priorities for State Investment in Delta and Suisun Marsh Levees

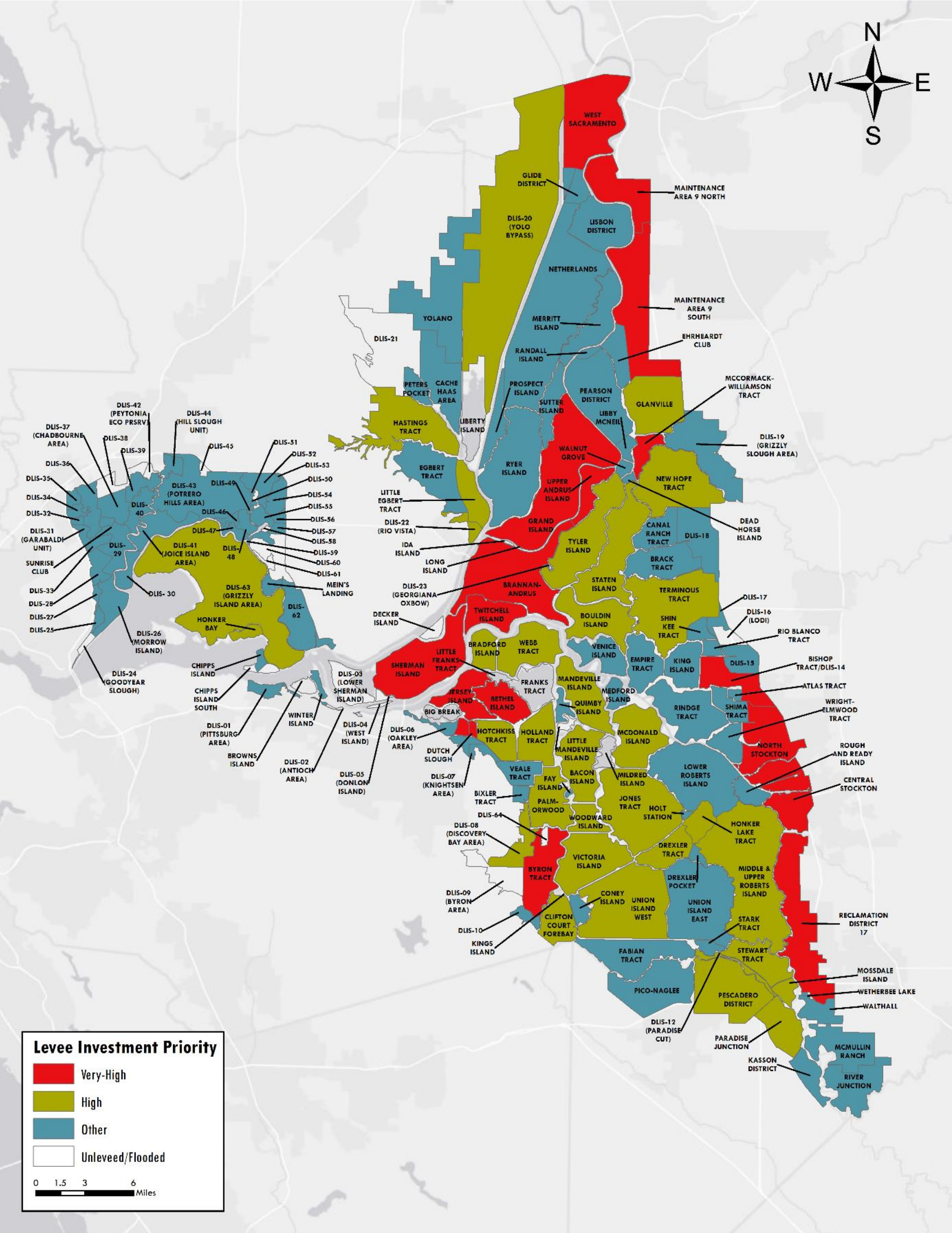


Table 4-2 Priorities for State Investment in Delta and Suisun Marsh Levees

Island or Tract	Priority	Risk to State Interests				Transportation Infrastructure at Risk	Tidal Habitat Improvement Opportunity	Flooding Probability[1]	Comments
		Life	Property	Water Supply	Ecosystem				
Bethel Island	Very-High	🟦		🟦				3.6%	
Bishop Tract/DLIS-14	Very-High	🟦	🟦			🟦		3.2%	
Brannan-Andrus	Very-High	🟦	🟦			🟦		3.9%	
Byron Tract	Very-High	🟦		🟦		🟦		3.8%	
Central Stockton	Very-High	🟦	🟦					1.7%	
Dutch Slough	Very-High						🟩	2.2%	See Note 2
Grand Island	Very-High	🟦	🟦					3.8%	
Jersey Island	Very-High			🟦	🟦			2.7%	
Maintenance Area 9 North	Very-High	🟦	🟦	🟦		🟦		2.1%	
Maintenance Area 9 South	Very-High	🟦	🟦		🟦	🟦		7.2%	
McCormack-Williamson Tract	Very-High				🟦		🟩	5.6%	See Note 2
North Stockton	Very-High	🟦	🟦			🟦		2.7%	
Reclamation District 17	Very-High	🟦	🟦					1.9%	See Note 3
Sherman Island	Very-High			🟦	🟦			3.5%	
Twitchell Island	Very-High			🟦	🟦			4.3%	
Upper Andrus Island	Very-High	🟦	🟦					3.9%	
West Sacramento	Very-High	🟦	🟦				🟩	1.7%	
Bacon Island	High			🟦				3.8%	
Bouldin Island	High					🟦		4.8%	See Note 4a
Bradford Island	High			🟦				4.5%	
Clifton Court Forebay	High			🟦				4.3%	
DLIS-08 (Discovery Bay Area)	High			🟦				1.5%	
DLIS-20 (Yolo Bypass)	High							N/A	See Note 5
DLIS-22 (Rio Vista)	High						🟩	1.1%	See Note 6
DLIS-63 (Grizzly Island Area)	High				🟦		🟩	21.4%	See Note 7
Drexler Tract	High			🟦		🟦	🟩	5.2%	
Glanville	High		🟦			🟦	🟩	6.5%	
Hastings Tract	High			🟦			🟩	3.3%	See Note 5
Holland Tract	High			🟦				3.6%	
Honker Bay	High							3.5%	See Note 7
Honker Lake Tract	High					🟦	🟩	2.5%	See Note 4b

Island or Tract	Priority	Risk to State Interests				Transportation Infrastructure at Risk	Tidal Habitat Improvement Opportunity	Flooding Probability[1]	Comments
		Life	Property	Water Supply	Ecosystem				
Hotchkiss Tract	High			🟦			🟩	2.1%	
Jones Tract (Lower and Upper)	High			🟦		🟦		2.3%	
Little Egbert Tract	High						🟩	10.4%	See Note 5
Mandeville Island	High			🟦				3.5%	
McDonald Island	High			🟦				3.9%	
Middle and Upper Roberts Island	High					🟦	🟩	2.3%	See Note 4b
Mossdale Island	High					🟦		2.3%	See Notes 4c, 9
New Hope Tract	High					🟦	🟩	2.8%	See Notes 4c, 10
Palm-Orwood	High			🟦				1.8%	
Paradise Cut	High							N/A	See Note 8
Paradise Junction	High					🟦	🟩	2.9%	See Notes 4c, 9
Pescadero District	High						🟩	1.2%	See Note 9
Staten Island	High				🟦			6.5%	See Note 11
Stewart Tract	High							1.7%	See Notes 9, 12
Terminous Tract	High		🟦			🟦		4.4%	
Tyler Island	High				🟦			4.9%	See Note 11
Union Island West	High			🟦			🟩	2.2%	
Victoria Island	High			🟦		🟦		2.2%	
Webb Tract	High			🟦				4.4%	
Woodward Island	High			🟦				3.2%	
Atlas Tract	Other							3.1%	
Bixler Tract	Other							1.4%	
Brack Tract	Other							4.9%	
Cache Haas Area	Other						🟩	2.9%	See Note 5
Canal Ranch Tract	Other							3.8%	
Chipps Island	Other						🟩	3.3%	
Coney Island	Other							3.7%	
Dead Horse Island	Other							5.3%	
DLIS-01 (Pittsburg Area)	Other							1.9%	
DLIS-06 (Oakley Area)	Other						🟩	1.3%	
DLIS-07 (Knightsen Area)	Other							1.4%	
DLIS-10	Other							1.7%	

Island or Tract	Priority	Risk to State Interests				Transportation Infrastructure at Risk	Tidal Habitat Improvement Opportunity	Flooding Probability[1]	Comments
		Life	Property	Water Supply	Ecosystem				
DLIS-15	Other							1.7%	
DLIS-17	Other							1.0%	
DLIS-18	Other							1.2%	
DLIS-19 (Grizzly Slough Area)	Other						🟩	0.9%	
DLIS-25	Other						🟩	3.1%	
DLIS-26 (Morrow Island)	Other						🟩	3.4%	
DLIS-27	Other						🟩	2.3%	
DLIS-28	Other						🟩	3.4%	
DLIS-29	Other						🟩	3.8%	
DLIS-30	Other						🟩	3.3%	
DLIS-31 (Garabaldi Unit)	Other						🟩	2.7%	
DLIS-32	Other						🟩	3.1%	
DLIS-33	Other						🟩	5.4%	
DLIS-34	Other						🟩	6.6%	
DLIS-35	Other						🟩	7.7%	
DLIS-36	Other						🟩	4.7%	
DLIS-37 (Chadbourne Area)	Other				🟦		🟩	11.9%	See Note 13
DLIS-39	Other						🟩	3.9%	
DLIS-40	Other						🟩	5.2%	
DLIS-41 (Joice Island Area)	Other				🟦		🟩	6.7%	See Note 13
DLIS-43 (Potrero Hills Area)	Other						🟩	1.6%	
DLIS-44 (Hill Slough Unit)	Other						🟩	6.1%	
DLIS-46	Other				🟦		🟩	35.6%	See Note 13
DLIS-47	Other				🟦		🟩	27.5%	See Note 13
DLIS-48	Other						🟩	2.5%	
DLIS-49	Other						🟩	2.6%	
DLIS-50	Other						🟩	2.9%	
DLIS-51	Other						🟩	2.4%	
DLIS-52	Other					🟦	🟩	2.7%	
DLIS-53	Other						🟩	1.3%	
DLIS-54	Other					🟦	🟩	3.0%	
DLIS-55	Other						🟩	3.5%	

Island or Tract	Priority	Risk to State Interests				Transportation Infrastructure at Risk	Tidal Habitat Improvement Opportunity	Flooding Probability[1]	Comments
		Life	Property	Water Supply	Ecosystem				
DLIS-56	Other						🟩	3.2%	
DLIS-57	Other						🟩	2.7%	
DLIS-59	Other						🟩	3.2%	
DLIS-62	Other						🟩	4.0%	
Drexler Pocket	Other						🟩	2.6%	
Egbert Tract	Other						🟩	3.2%	
Ehrheardt Club	Other							3.3%	
Empire Tract	Other							6.4%	
Fabian Tract	Other						🟩	4.4%	
Fay Island	Other							3.1%	
Glide District	Other							1.3%	
Holt Station	Other							17.9%	
Kasson District	Other						🟩	5.1%	
King Island	Other							3.6%	
Libby McNeil	Other							1.9%	
Lisbon District	Other							1.6%	
Lower Roberts Island	Other							1.6%	
McMullin Ranch	Other						🟩	2.6%	
Medford Island	Other							3.9%	
Mein's Landing	Other						🟩	3.0%	
Merritt Island	Other							2.1%	
Netherlands	Other							2.1%	
Pearson District	Other							2.8%	
Peters Pocket	Other						🟩	1.6%	
Pico-Naglee	Other							1.5%	
Prospect Island	Other						🟩	5.2%	
Quimby Island	Other							3.2%	
Randall Island	Other							1.7%	
Rindge Tract	Other							3.7%	
Rio Blanco Tract	Other							5.2%	
River Junction	Other						🟩	1.2%	
Rough and Ready Island	Other							2.7%	

Island or Tract	Priority	Risk to State Interests				Transportation Infrastructure at Risk	Tidal Habitat Improvement Opportunity	Flooding Probability[1]	Comments
		Life	Property	Water Supply	Ecosystem				
Ryer Island	Other							3.3%	
Shima Tract	Other							3.5%	
Shin Kee Tract	Other							6.8%	
Stark Tract	Other						🟩	1.4%	
Sunrise Club	Other						🟩	2.7%	
Sutter Island	Other							2.9%	
Union Island East	Other						🟩	3.2%	
Veale Tract	Other							3.7%	
Venice Island	Other							4.5%	
Walnut Grove	Other							3.4%	
Walthall	Other						🟩	2.9%	
Wetherbee Lake	Other							3.2%	
Winter Island	Other						🟩	6.4%	
Wright-Elmwood Tract	Other							3.1%	
Yolano	Other						🟩	0.9%	

Notes:

1. The implied level of accuracy probabilities of flooding shown is subject to the data limitations described in this report and in the Methodology Report (2016b).
2. Very-high priority restoration action. Improve or breach levees consistent with planned construction and management of restored area.
3. Island required to provide protection for areas designated for urban development in the *Delta Plan* (Council 2013).
4. Flood probability for this island exceeds the federal guideline for Interstate highways (2 percent AEP), warranting further investigation of appropriate flood risk reduction measures for:
    a. Highway 12
    b. Highway 4
    c. Interstate 5
5. Yolo Bypass mid- and long-term restoration opportunity.
6. Increased flood risk from Yolo Bypass improvements to protect Sacramento.
7. Flood risk reduction for perimeter of Suisun Marsh and water supply facilities.
8. Flood bypass/restoration opportunity.
9. Paradise Cut floodway/restoration opportunity.
10. Cosumnes/Mokelumne confluence restoration opportunity.
11. High-value crane habitat at risk.
12. Island not currently eligible for State funding to reduce risk to life and property.
13. Island contains interior levees in Suisun Marsh; current State priorities for levee funding in Suisun Marsh are for the exterior levees (levees exposed to tidal action) rather than the private levees internal to Suisun Marsh.

4.6 Future Considerations

With these proposed levee investment priorities, the Council is initiating a program environmental review as required by the California Environmental Quality Act (CEQA). The environmental review will evaluate the potential impacts and identify mitigation opportunities related to the Council's decision to update the Delta risk reduction policies in Chapter 7 of the *Delta Plan* (Council 2013). The environmental review may identify additional information to inform Council decisions about the priorities for State investment.

As described in Section 4.2, the DST is designed to incorporate such new information as it becomes available to inform State levee investment priorities. Examples of potential new information include the following:

- Updated data on population, assets, and infrastructure.
- Updated forecasts of hydrology and SLR resulting from climate change.
- Updated levee conditions from levee improvements or new assessments of levee fragility.
- Evaluation of the cost-effectiveness of proposed levee improvements, or other risk reduction actions.
- Additional information regarding habitat restoration plans or priorities.

5.0 CONSIDERATIONS FOR LEVEE IMPROVEMENTS

This section describes i) a comparison of levee improvement guidelines; ii) a preliminary evaluation of potential PL 84-99 levee improvements for non-project levees; iii) potential improvements for urban levees in the Delta; and iv) seismic considerations for the Very-High and High Priority islands and tracts. The analysis and results demonstrate an approach for further evaluation of levee improvement options, risk reduction, and cost-effectiveness. These results were not used to determine levee investment priorities or the priority categories.

5.1 Levee Improvement Guidelines

In 1983 and 1987, DWR and the Federal Emergency Management Agency (FEMA) negotiated interim Hazard Mitigation Plan (HMP) design guidelines for non-project levees in the Delta (Council 2013). The HMP provides for levees with crowns 1 foot above the water surface corresponding to the 100-year flood, crests 16 feet wide, and side slopes of 1V:1.5H (Vertical:Horizontal). At the time HMP levee design guidelines were negotiated, RDs that met the HMP guidance were eligible for FEMA disaster assistance if levees fail or islands flood. However, FEMA has cancelled its agreement with DWR making eligibility for FEMA disaster assistance uncertain (Council 2013).

More recently, non-project levee improvements have generally been aimed at meeting one of two levee design guidelines: i) geometry requirements stipulated by USACE in the PL 84-99 program (Figure 5-1); or ii) those developed for the DWR Bulletin 192-82 levee geometry (Figure 5-2). Because there are many similarities, these two types of levee improvement are often used interchangeably in discussions about reducing flood risk in the Delta. There are, however, meaningful differences between the two that we discuss in this section.

The most significant difference is that PL 84-99 is a federal program that establishes guidelines for levee design geometry, construction, operations, and maintenance. LMAs must apply to participate in the program, and must regularly demonstrate that their levees and levee operations meet or exceed the program's requirements. Participants in the PL 84-99 program are eligible for federally funded emergency assistance, including flood fight support and rehabilitation of levees damaged by flooding. However, because many consider the requirements to be onerous, few RDs in the Delta currently participate in the PL 84-99 program. For example, to qualify for rehabilitation of flood-damaged levees, participants in the program must demonstrate a benefit cost ratio greater than one. In contrast, there is no comparable program for emergency assistance for Bulletin 192-82 geometry.

Below, we provide a brief comparison of these two levee improvement guidelines. Figures 5-1 and 5-2 as well as the information in Table 5-1 were obtained from *A Framework for Department of Water Resources Integrated Flood Management Investments in the Delta and Suisun Marsh*, prepared by DWR FloodSAFE, Draft V9, September 24, 2013 (DWR 2013); from the USACE Sacramento District *Guidelines for Rehabilitation of Non-federal Levees in the Sacramento-San Joaquin Legal Delta* (USACE 1988); and from the *Delta Plan* (Council 2013).

Figure 5-1 USACE Delta-specific PL 84-99 Levee Guidance (Adapted from Council 2013)

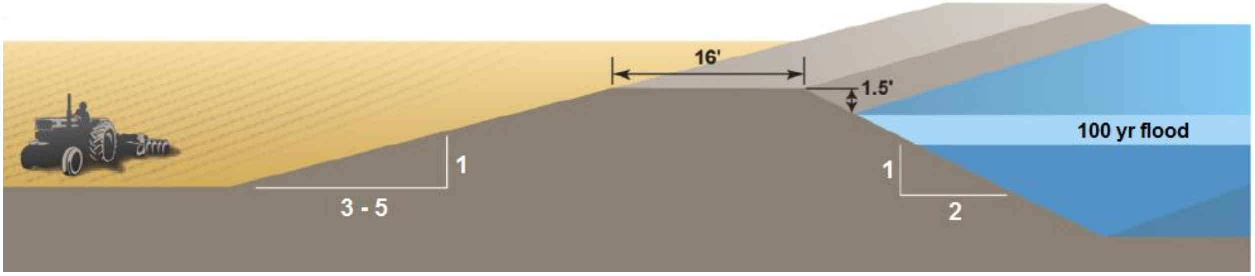
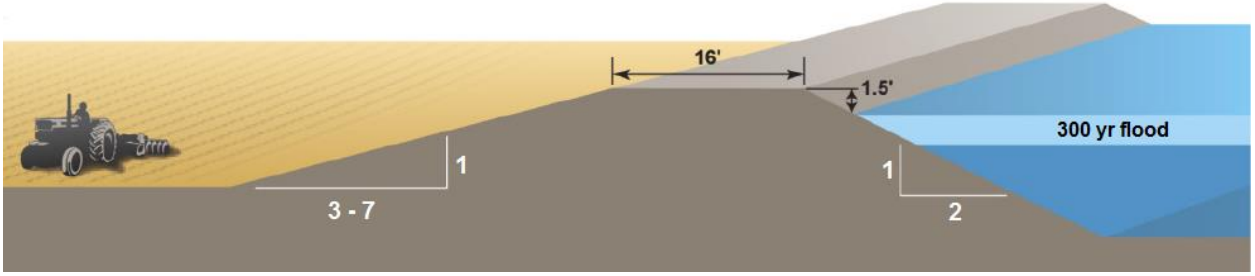


Figure 5-2 DWR Bulletin 192-82 Levee Guidance (Adapted from Council 2013)



In general, there are two major differences between the two guidelines:

1. The USACE developed Delta-specific levee geometry that includes a provision for flatter landside levee slopes when the levee is sited on a foundation of peat or organic soil (USACE 1988). The USACE Delta-specific levee geometry is normally 1V:2H, which flattens to 1V:5H over foundations with a thick layer of peat or organic soil. The DWR Bulletin 192-82 does not include this provision for flatter slopes on organic soil. The DWR Bulletin 192-82 specifies a 1V:3H landside slope and permits the designer to use stability berms when desired. Figure 5-2 shows the horizontal component of slope geometry varying between 3 and 7, which approximates stability berms that may be used at the designer's discretion.
2. The water surface metric in the USACE Delta-specific levee geometry is the 1 percent AEP (100-year) flood. The DWR Bulletin 192-82 uses a water surface metric of the 0.33 percent AEP (300-year) flood. Both guidelines use 1.5 feet of freeboard in rural areas. As demonstrated by flood recurrence curves in the Delta, the water surface metric for 0.33 percent AEP (300-year) flood is about 0.5 to 1 foot higher than the 1 percent AEP (100-year) flood in the Delta. In other words, following the DWR Bulletin 192-82 guidance will result in levee crest elevations that are generally 0.5 to 1 foot higher than those given by the USACE Delta-specific PL 84-99 geometry.

Table 5-1 Comparison of USACE Delta-Specific PL 84-99 and DWR Bulletin 192-82

Feature	Delta-Specific PL 84-99	Bulletin 192-82
Berm presence	Unspecified	Landside berm where necessary
Construction method	Unspecified	Stage construction, levee setback, or sheet pile (resulting in three different geometries)
Crown features	16-foot width, all weather patrol road	16-foot width, all weather patrol road
Freeboard: agricultural areas	1.5 feet	1.5 feet
Freeboard: urban areas	1.5 feet.	3 feet
Levee toe drain	Located 30 feet landward from landside slope levee toe	Unspecified
Slope: landside	Varies depending on peat thickness (1V:2H – 1V:5H, with a safety factor of 1.25)	1V:3H (with provisions for stability berms, resulting in a range of 1V:3H – 1V:7H)
Slope: waterside	1V:2H	1V:2H
Water surface metric	1 percent exceedance (100-year)	0.33 percent exceedance (300-year)

5.2 PL 84-99 Investment Alternative

Because participation in the PL 84-99 program offers the potential to receive federal aid following a flood, we i) estimated the scope and cost to improve certain non-project levees in the Delta to meet the requirements for PL 84-99 levee geometry; ii) evaluated the risk reduction that can be achieved with PL 84-99 geometry; iii) assessed the effect of SLR on PL 84-99 cost estimates; and iv) compared results to other PL 84-99 analyses.

Developing the PL 84-99 investment alternative included:

- Using available data to identify levee reaches within the Delta and Suisun Marsh that do not currently meet the minimum levee geometry requirements.
- Identifying the location-specific geometry required for PL 84-99 compliance at each of these reaches.
- Estimating the rough order of magnitude (ROM) construction costs associated with bringing each of these reaches up to the PL 84-99 geometry.

5.2.1 Data Sources

The PL 84-99 investment analysis addressed non-project levees in the Delta (shown on Figure 5-3) and relied on the following available data.

Existing levee and hydrologic conditions were established using geographic information system (GIS) data compiled by the DWR for *Analysis of Delta Levees Compliance of HMP [Hazard Mitigation Plan] and PL 84-99 Design Geometry* (DWR 2011). These data were used to define levee reaches, reach locations, reach lengths, and existing levee elevations; to calculate required levee elevations; and to identify adjacent land uses and habitat types.

Elevation data were derived from a digital elevation model (DEM) compiled by DWR for *Analysis of Delta Levees Compliance of HMP [Hazard Mitigation Plan] and PL 84-99 Design Geometry* (DWR 2011). These data were used to calculate existing landside and waterside levee slopes, levee crest widths, and required levee heights.

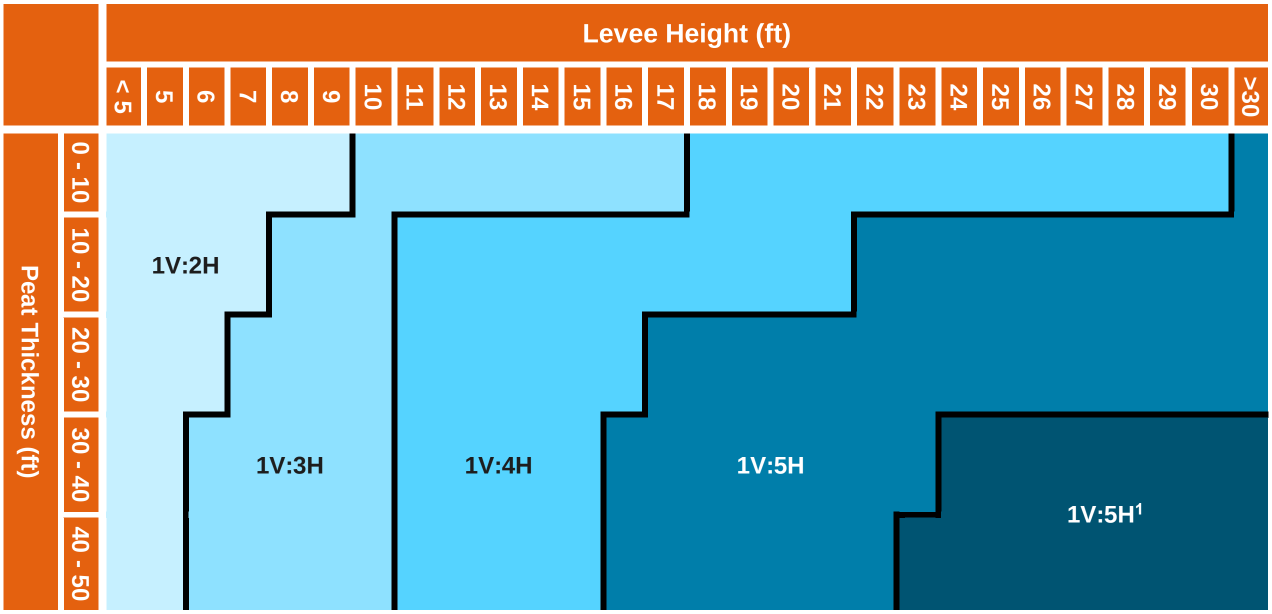
Landside slope requirements were established using data presented in *Guidelines for Rehabilitation of Non-federal Levees in the Sacramento-San Joaquin Legal Delta* (USACE 1988). These data were used to create a matrix (Table 5-2) establishing the relationship between levee height, thickness of underlying organic soils, and the required landside slope. The required slopes are indicated as 1V:2H, 1V:3H, 1V:4H, or 1V:5H.

The extent and thickness of **underlying organic soils** (Figure 5-4) were derived from the *Organic Isopach Map* prepared by DWR (DWR 1976). Although more recent data on organic soil thickness in the Delta have been published (e.g., Deverel, Lucero, and Bachand 2015), the DWR data were selected for this analysis because the DWR data cover the entire study area and have greater detail on organic soil thickness in the areas near levees.

Per cubic yard and per mile **unit rates for levee construction cost** were derived from ranges cited in the *Economic Sustainability Plan for the Sacramento-San Joaquin Delta* (ESP) (DPC 2012). The unit rates cited in the ESP are i) $13 to $16 per cubic yard of fill required, and ii) $2 million to $3 million per mile of levee construction. For the DLIS analysis, we used a unit rate of $15 per cubic yard, toward the upper end of the range cited (DPC 2012).

However, based on our review of the ESP and on information from the Independent Panel Review (Adams et al. 2011), we selected a unit rate of $1.5 million per mile of levee construction. Though lower than the unit rates cited in the ESP, we selected $1.5 million per mile of levee construction because i) the ESP included a 50 percent contingency (DPC 2012), and ii) recent construction costs reported by RDs for PL 84-99 projects have averaged $1.5 million per mile, with some instances of less than $1 million per mile (Cosio 2015).

Table 5-2 Delta-specific Landside Slope Requirements



	Levee Height (ft)																											
Peat Thickness (ft)	< 5	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	>30
0 - 10	1V:2H	1V:2H	1V:2H	1V:2H	1V:2H	1V:2H	1V:3H	1V:3H	1V:3H	1V:3H	1V:3H	1V:3H	1V:3H	1V:3H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:5H
10 - 20	1V:2H	1V:2H	1V:2H	1V:2H	1V:3H	1V:3H	1V:3H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H
20 - 30	1V:2H	1V:2H	1V:2H	1V:3H	1V:3H	1V:3H	1V:3H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H
30 - 40	1V:2H	1V:2H	1V:3H	1V:3H	1V:3H	1V:3H	1V:3H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]
40 - 50	1V:2H	1V:2H	1V:3H	1V:3H	1V:3H	1V:3H	1V:3H	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]	1V:5H[1]

Note:

1. Slopes in this region were not explicitly specified in the USACE guidelines, and were assumed to be 1V:5H for these levee height/peat thickness combinations

Figure 5-3 Non-project Delta Levees in the DLIS PL 84-99 Investment Analysis (Adapted from DWR 2011)

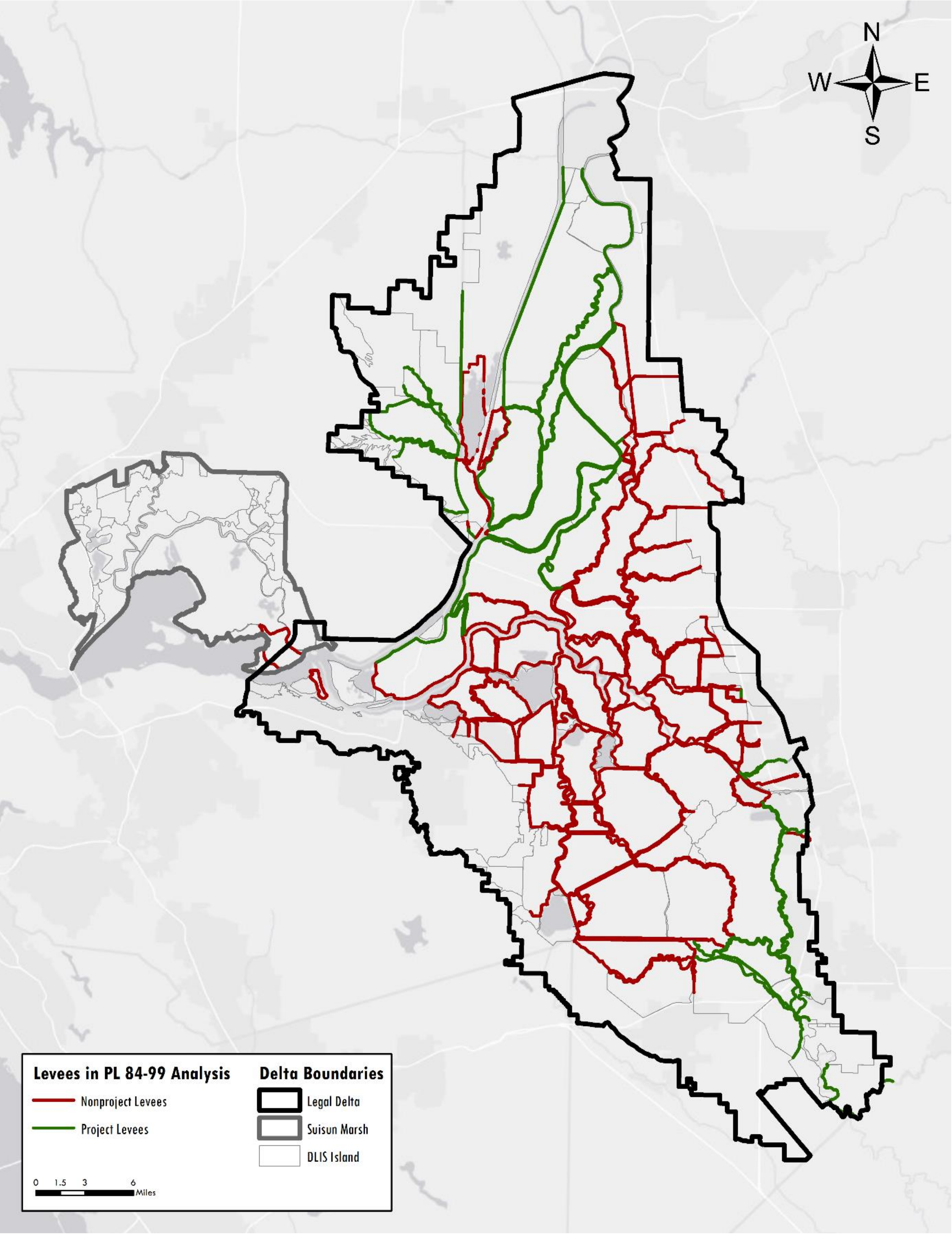
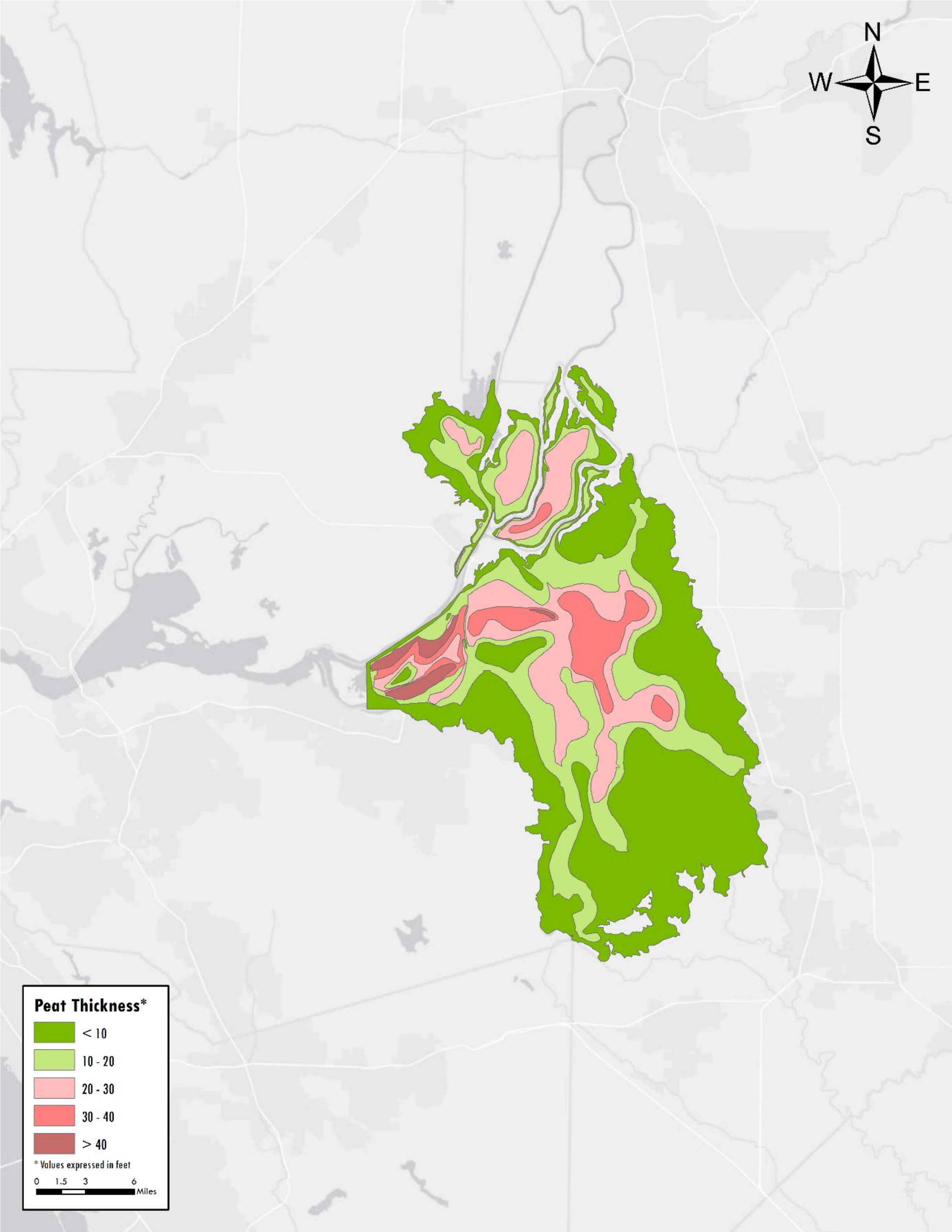


Figure 5-4 Organic Soil Distribution and Thickness in the Delta (Adapted from DWR 1976)



5.2.2 Levee Geometry Analysis and Construction Cost Estimate

To identify the levee segments needing improvement and to estimate the construction costs, we used the following approach:

1. Determine existing conditions (average crest elevations, slopes, and crest widths) for non-project levee reaches.
2. Calculate the required conditions (levee crest elevations and slopes) for these reaches.
3. Compare the existing conditions to required conditions, thereby identifying those reaches that do not currently meet one or more PL 84-99 levee geometry guidelines.
4. Calculate the volume of fill (in cubic yards) required to bring each non-conforming reach to PL 84-99 geometry.
5. Calculate any increase in levee footprint (in acres) to bring each non-conforming reach to PL 84-99 geometry.
6. Calculate the ROM construction costs to bring each non-conforming reach to PL 84-99 geometry.

To develop ROM construction cost estimates, the DLIS team assumed that all work to achieve the PL 84-99 Delta-specific geometry would be on the landside of the levee to avoid: i) additional expenses associated with over-water construction; and ii) costs and schedule impacts caused by environmental considerations. Instead of disturbing the waterside slope, levee improvements would be accomplished by shifting the levee cross-section to the landside as illustrated on Figures 5-5 and 5-6.

Figure 5-5 Required Improvements to Achieve PL 84-99 Delta-Specific Levee Geometry

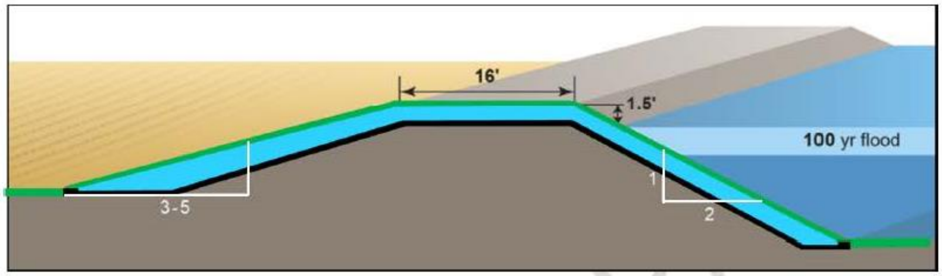
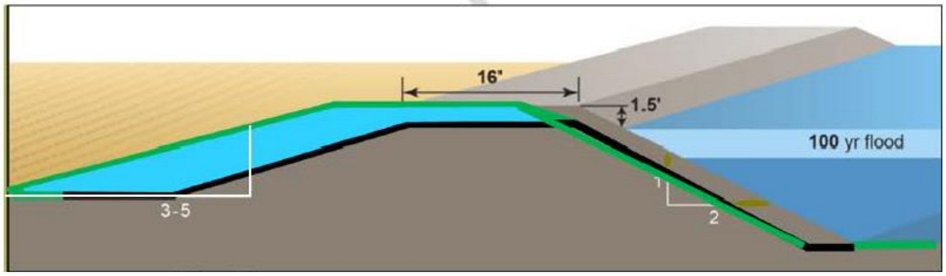


Figure 5-6 Shifting Improvements to the Landside to Avoid Over-Water Construction



5.2.3 Significant Assumptions

The following significant assumptions were made to develop the PL 84-99 investment estimates.

1. Estimated unit construction costs include:
    a. An “overbuild factor” for levees constructed over poorly consolidated sediments.
    b. Removal of vegetation on the levee.
    c. Removal of encroachments on or near the levee (such as fences, structures, and pipelines).
2. The ROM costs for the PL 84-99 investment are for construction only and do not include costs for land acquisition, engineering, permits, or construction management. In addition, no contingency was included in this analysis. For this type of ROM cost estimate, a contingency of -25 percent to +75 percent may be appropriate.
3. Because the DEM does not include bathymetric data, waterside slopes can only be calculated for portions of the slope above the water surface. It is possible that waterside slopes below the water surface are steeper than assumed. Because the extent of over-steepening cannot be determined with the available data, the potential impacts on the construction cost estimates are unknown.

5.2.4 Summary of Results

Work in the Delta has progressed since the DEM data used for this analysis were collected between 2007 and 2008, and PL 84-99 geometry has been achieved on several levees in the subsequent years. Therefore, the DLIS team coordinated with local RD engineers to screen the initial results of this analysis.

The RD engineers reported necessary levee improvements that were not initially identified by the PL 84-99 geometry analysis on three islands in the analysis area (Central Stockton, Grand Island, and Stark Tract). The costs for this work on Grand Island and Stark Tract (as estimated by the RD engineers) were included in the overall construction cost estimates, but costs for PL 84-99 improvements on Central Stockton, along with Bishop Tract/DLIS-14, North Stockton, and Reclamation District 17, were *not* included, as these islands are designated for Urban Level of Protection (ULOP) improvements (see Section 5.3). These four islands are, however, counted in the *Comparison to Other PL 84-99 Analyses* summary in Section 5.2.7.

The DLIS team found that the levees on Rough and Ready Island are at PL 84-99 geometry. RD engineers identified three additional islands (Atlas Tract, Bishop Tract/DLIS-14, and Byron Tract) that do not require any additional levee improvements. These islands were removed from the construction cost estimates in Tables 5-3 through 5-6, but are included in the summary in Section 5.2.7.

The final PL 84-99 levee investment strategy is based on making improvements at 59 islands and tracts. The cost estimates for completing this work range from $205 million (based on $15 per cubic yard) to $515 million (based on $1.5 million per levee mile). The projected land associated with expanded levee footprints under a PL 84-99 investment strategy is approximately 605 acres across the islands/tracts with levees that would be improved. These results are shown in Table 5-3.

Table 5-3 Rough Order-of-Magnitude Construction Cost Estimates to Implement PL 84-99 Levee Improvements

Island	Length of Existing Levees			Estimated Construction Cost		Notes
	Total	Not Currently at PL 84-99 Requirements		Based on $15 per cubic yard	Based on $1.5 million per mile	
	Miles	Miles	Percentage			
Bacon Island	14.4	11.0	76%	$8,051,000	$16,428,000	
Bethel Island	11.5	4.5	39%	$1,057,000	$6,732,000	
Bouldin Island	18.0	14.4	80%	$11,088,000	$21,542,000	
Brack Tract	11.6	7.0	61%	$3,499,000	$10,568,000	
Bradford Island	7.4	6.3	85%	$3,840,000	$9,437,000	
Brannan-Andrus	29.4	20.1	68%	$10,564,000	$12,500,000	
Canal Ranch Tract	7.5	3.2	43%	$1,410,000	$4,858,000	
Coney Island	5.5	1.3	24%	$253,000	$1,989,000	
Dead Horse Island	2.6	2.6	100%	$1,938,000	$3,880,000	
DLIS-22 (Rio Vista)	1.9	0.6	34%	$156,000	$966,000	
Drexler Pocket	1.5	0.6	43%	$306,000	$966,000	
Drexler Tract	7.7	4.2	55%	$5,275,000	$6,370,000	
Dutch Slough	5.4	2.8	52%	$407,000	$4,219,000	
Ehrheardt Club	9.5	8.2	86%	$7,459,000	$10,873,000	
Empire Tract	10.5	10.5	100%	$7,783,000	$15,744,000	
Fabian Tract	18.8	10.8	58%	$4,003,000	$16,208,000	
Fay Island	1.6	1.4	89%	$445,000	$2,126,000	
Glanville	10.1	6.5	64%	$6,384,000	$9,685,000	
Grand Island	29.5	19.6	67%	$11,440,000	$11,440,000	See Note 1
Holland Tract	11.0	6.4	58%	$1,929,000	$9,611,000	
Holt Station	1.3	0.9	71%	$642,000	$1,357,000	
Hotchkiss Tract	8.9	8.9	100%	$66,000	$13,363,000	

Island	Length of Existing Levees			Estimated Construction Cost		Notes
	Total	Not Currently at PL 84-99 Requirements		Based on $15 per cubic yard	Based on $1.5 million per mile	
	Miles	Miles	Percentage			
Jersey Island	15.5	7.6	49%	$2,417,000	$11,335,000	
Jones Tract	18.2	10.8	59%	$6,328,000	$16,160,000	
King Island	9.1	3.9	43%	$780,000	$5,921,000	
Libby McNeil	4.1	2.0	49%	$1,008,000	$3,040,000	
Little Egbert Tract	4.8	4.6	97%	$2,319,000	$6,975,000	
Lower Roberts Island	14.5	3.4	24%	$1,357,000	$5,149,000	
Mandeville Island	14.3	12.0	84%	$6,325,000	$18,067,000	
McDonald Island	13.8	5.1	37%	$2,399,000	$7,671,000	
Medford Island	5.9	4.1	69%	$956,000	$6,151,000	
Middle and Upper Roberts Island	25.3	9.5	38%	$574,000	$2,273,000	
New Hope Tract	17.4	5.7	33%	$1,687,000	$8,537,000	
Palm-Orwood	14.5	3.0	21%	$1,016,000	$4,517,000	
Pearson District	14.0	6.9	49%	$981,000	$1,435,000	
Pescadero District	8.6	2.5	29%	$80,000	$568,000	
Pico-Naglee	8.7	1.1	12%	$11,000	$1,619,000	
Prospect Island	9.8	9.8	100%	$3,433,000	$14,735,000	
Quimby Island	7.0	2.1	30%	$515,000	$3,124,000	
Rindge Tract	15.8	10.2	65%	$4,381,000	$15,370,000	
Rio Blanco Tract	4.3	1.7	41%	$689,000	$2,599,000	
Sherman Island	19.5	8.4	43%	$1,281,000	$5,923,000	
Shima Tract	6.9	6.9	100%	$1,084,000	$10,313,000	
Shin Kee Tract	3.9	3.9	100%	$1,035,000	$5,787,000	
Stark Tract	3.7	1.1	29%	$47,000	$47,000	See Note 1

Island	Length of Existing Levees			Estimated Construction Cost		Notes
	Total	Not Currently at PL 84-99 Requirements		Based on $15 per cubic yard	Based on $1.5 million per mile	
	Miles	Miles	Percentage			
Staten Island	25.4	19.7	78%	$11,608,000	$29,589,000	
Terminous Tract	16.1	15.6	97%	$18,069,000	$23,423,000	
Twitchell Island	11.9	9.1	76%	$4,204,000	$12,472,000	
Tyler Island	22.4	12.5	56%	$6,198,000	$12,088,000	
Union Island East	15.1	7.6	50%	$2,476,000	$9,659,000	
Union Island West	16.3	13.4	82%	$11,546,000	$20,057,000	
Veale Tract	5.0	1.3	26%	$152,000	$1,989,000	
Venice Island	12.4	10.5	85%	$10,770,000	$15,820,000	
Victoria Island	15.1	4.6	30%	$2,079,000	$6,847,000	
Walnut Grove	2.8	2.2	77%	$1,895,000	$2,653,000	
Webb Tract	12.9	10.0	77%	$3,781,000	$15,000,000	
Winter Island	4.7	4.7	100%	$1,132,000	$7,082,000	
Woodward Island	8.9	4.8	53%	$1,928,000	$7,159,000	
Wright-Elmwood Tract	8.2	2.1	26%	$532,000	$3,173,000	
Grand Total	**683.4**	**400.9**	**59%**	**$205,068,000**	**$515,189,000**	

Note:

1. Construction costs at this island/tract were added to the estimate because RD engineers reported that work was required to improve levees at this location to PL 84-99 geometry.

5.2.5 Comparison to Baseline Risk

The analysis of levee improvements to achieve the PL 84-99 Delta-specific design geometry also included evaluation of the potential risk reduction to lives, property, ecosystem, and water supply from these levee improvements. The risk analysis methodology and the DST were used to determine the amount of risk reduction that could be achieved with PL 84-99 levee improvements for 59 islands that do not currently meet the PL 84-99 geometry. The DLIS team developed revised levee fragility curves for each of the 59 islands to account for reduced probability of levee failure resulting from levee improvements. The modifications to fragility curves were based on increases in levee crest height and levee base width that are required to meet the PL 84-99 guidelines. These increases in levee dimensions result in a decreased probability of levee failure at all water levels. No adjustments were made for SLR, population growth, future development, or other future conditions.

The total risk reduction in EAF, EAD, and habitat achieved with PL 84-99 levee improvements for the 59 islands evaluated is shown in Table 5-4. In addition, the PL 84-99 improvements would reduce the probability of flooding by 0.05 percent or more for five islands important for water supply and water quality (Bradford Island, Drexler Tract, Empire Tract, Holt Station, and Prospect Island).

Table 5-4 Summary of DLIS Risk Reduction Analysis from PL 84-99 Investments

Risk Measure	Life – EAF (Lives Lost per Year)	Property – EAD ($M)	Ecosystem Habitat Loss (Acres per Year)
Baseline	1.705	$58.6	1,898
With PL 84-99 Improvements	1.498	$49.5	1,704
Reduction	0.208	$9.0	194
Percent Reduction	14%	18%	11%

Table 5-5 shows the changes in flood probability and risk to lives, property, and habitat for the 59 islands and tracts analysed. The largest reductions in risk are highlighted in yellow for lives, property, and habitat risk. The 17 islands with one or more functions for water supply and water quality are identified in blue; the change in flood probability for these islands is shown in the flooding probability columns.

Table 5-5 Risk Reduction to State Interests due to PL 84-99 Improvements

Island	Priority	Flooding Probability[1]		Risk Reduction to State Interests						
				Life – EAF (Lives Lost per Year)		Property – EAD ($M)		Water Supply	Ecosystem Habitat Loss (Acres per Year)	
		Baseline	With PL 84-99 Improvements	Baseline	Reduction[2]	Baseline	Reduction[2]	Islands Essential to Water Supply	Baseline	Reduction[2]
Bethel Island	Very-High	3.6%	3.5%	0.284	0.010	$3.09	$0.11	■	12	0
Brannan-Andrus	Very-High	3.9%	3.5%	0.358	0.042	$5.38	$0.62		10	1
Dutch Slough	Very-High	2.2%	1.9%	0.000	0.000	$0.01	$0.00		16	2
Grand Island	Very-High	3.8%	3.1%	0.249	0.051	$6.06	$1.20		12	2
Jersey Island	Very-High	2.7%	2.6%	0.000	0.000	$0.18	$0.01	■	95	5
Sherman Island	Very-High	3.5%	3.4%	0.035	0.001	$0.83	$0.03	■	322	12
Twitchell Island	Very-High	4.3%	4.0%	0.008	0.001	$0.89	$0.06	■	127	8
Bacon Island	High	3.8%	3.6%	0.010	0.001	$0.20	$0.01	■	1	0
Bouldin Island	High	4.8%	4.2%	0.010	0.001	$0.35	$0.04		4	0
Bradford Island	High	4.5%	4.0%	0.003	0.000	$0.11	$0.01	■	40	5
Drexler Tract	High	5.2%	3.9%	0.006	0.002	$0.33	$0.09	■	0	0
Glanville	High	6.5%	3.1%	0.010	0.007	$3.57	$2.44		28	15
Holland Tract	High	3.6%	3.4%	0.003	0.000	$0.42	$0.02	■	66	4
Hotchkiss Tract	High	2.1%	2.0%	0.059	0.003	$1.64	$0.09	■	10	0
Jones Tract	High	2.3%	1.9%	0.009	0.002	$1.29	$0.26	■	4	1
Little Egbert Tract	High	10.4%	6.0%	0.002	0.001	$0.40	$0.17		0	0
Mandeville Island	High	3.5%	3.3%	0.006	0.000	$0.26	$0.01	■	54	3
McDonald Island	High	3.9%	3.8%	0.023	0.001	$2.49	$0.07	■	15	0
Middle and Upper Roberts Island	High	2.3%	2.1%	0.027	0.003	$2.56	$0.26		3	0
New Hope Tract	High	2.8%	2.6%	0.055	0.009	$1.15	$0.19		11	1
Palm-Orwood	High	1.8%	1.7%	0.005	0.000	$0.49	$0.02	■	1	0
Pescadero District	High	1.2%	1.2%	0.001	0.000	$0.07	$0.01		1	0
Staten Island	High	6.5%	5.8%	0.011	0.001	$0.57	$0.06		584	66
Terminous Tract	High	4.4%	2.8%	0.082	0.032	$3.27	$1.17		16	5
Tyler Island	High	4.9%	4.0%	0.029	0.005	$1.54	$0.27		41	7
Union Island West	High	2.2%	2.0%	0.012	0.001	$0.68	$0.07	■	1	0
Victoria Island	High	2.2%	2.1%	0.000	0.000	$0.65	$0.01	■	0	0
Webb Tract	High	4.4%	4.1%	0.000	0.000	$0.30	$0.02	■	13	1
Woodward Island	High	3.2%	3.1%	0.000	0.000	$0.41	$0.01	■	0	0
Brack Tract	Other	4.9%	4.2%	0.002	0.000	$0.70	$0.11		21	3
Canal Ranch Tract	Other	3.8%	3.5%	0.006	0.001	$0.32	$0.03		0	0
Coney Island	Other	3.7%	3.7%	0.000	0.000	$0.09	$0.00		0	0

Island	Priority	Flooding Probability[1]		Risk Reduction to State Interests						
				Life – EAF (Lives Lost per Year)		Property – EAD ($M)		Water Supply	Ecosystem Habitat Loss (Acres per Year)	
		Baseline	With PL 84-99 Improvements	Baseline	Reduction[2]	Baseline	Reduction[2]	Islands Essential to Water Supply	Baseline	Reduction[2]
Dead Horse Island	Other	5.3%	3.8%	0.001	0.000	$0.06	$0.02		0	0
DLIS-22 (Rio Vista)	Other	1.1%	1.1%	0.000	0.000	$0.00	$0.00		3	0
Drexler Pocket	Other	2.6%	2.1%	0.001	0.000	$0.01	$0.00		1	0
Ehrheardt Club	Other	3.3%	1.6%	0.002	0.001	$0.53	$0.31		1	1
Empire Tract	Other	6.4%	4.5%	0.008	0.003	$0.79	$0.23		27	8
Fabian Tract	Other	4.4%	4.1%	0.005	-0.001[3]	$0.77	$0.07		2	0
Fay Island	Other	3.1%	2.3%	0.000	0.000	$0.00	$0.00		0	0
Holt Station	Other	17.9%	3.5%	0.011	0.009	$0.31	$0.25		0	0
King Island	Other	3.6%	3.4%	0.014	0.001	$0.70	$0.04		0	0
Libby McNeil	Other	1.9%	1.6%	0.003	0.001	$0.05	$0.01		8	1
Lower Roberts Island	Other	1.6%	1.5%	0.013	0.001	$0.83	$0.05		2	0
Medford Island	Other	3.9%	3.7%	0.000	0.000	$0.02	$0.00		43	2
Pearson District	Other	2.8%	2.5%	0.067	0.007	$2.37	$0.25		3	0
Pico-Naglee	Other	1.5%	1.4%	0.001	0.000	$0.12	$0.01		1	0
Prospect Island	Other	5.2%	3.0%	0.000	0.000	$0.05	$0.02		87	36
Quimby Island	Other	3.2%	3.2%	0.000	0.000	$0.04	$0.00		3	0
Rindge Tract	Other	3.7%	3.5%	0.012	0.001	$0.64	$0.04		0	0
Rio Blanco Tract	Other	5.2%	3.4%	0.000	0.000	$0.03	$0.01		0	0
Shima Tract	Other	3.5%	3.2%	0.001	0.000	$0.35	$0.03		1	0
Shin Kee Tract	Other	6.8%	4.8%	0.000	0.000	$0.07	$0.02		1	0
Stark Tract	Other	1.4%	1.4%	0.000	0.000	$0.00	$0.00		0	0
Union Island East	Other	3.2%	2.9%	0.008	0.001	$0.65	$0.06		4	0
Veale Tract	Other	3.7%	3.6%	0.003	0.000	$0.10	$0.00		1	0
Venice Island	Other	4.5%	3.9%	0.000	0.000	$0.10	$0.01		6	1
Walnut Grove	Other	3.4%	2.8%	0.040	0.008	$0.49	$0.09		1	0
Winter Island	Other	6.4%	3.1%	0.000	0.000	$0.00	$0.00		0	0
Wright-Elmwood Tract	Other	3.1%	3.0%	0.002	0.000	$0.14	$0.00		3	0

Notes:

1. The implied level of accuracy probabilities of flooding shown is subject to the data limitations described in this report and in the Methodology Report (Council 2016b).
2. The largest reductions in risk are highlighted in yellow.
3. EAF is increased with PL 84-99 improvements on Fabian Tract because the island has a relatively low hydraulic failure probability compared to its seismic failure probability. Warning time is used to determine the exposed population used to calculate the EAF. For hydraulic failures, the warning time can vary from 24 to 48 hours, but for seismic failures the warning time is essentially zero. Because a weighted warning time that considers the relative magnitude of hydraulic and seismic failure probabilities is used to combine the effects of these failures on EAF, a large seismic failure probability, relative to the hydraulic failure probability, yields a smaller warning time and can cause an apparent increase in EAF.

5.2.6 Effect of Sea Level Rise on PL 84-99 Costs

The DLIS team also investigated the effects of SLR on the construction costs associated with improving levee reaches in the Delta to meet the PL 84-99 Delta-specific levee geometry. Table 5-6 summarizes the ROM construction cost estimates to achieve PL 84-99 Delta-specific geometry for islands categorized as High Priority and Very-High Priority (see Section 4.0 of this report).

Table 5-6 summarizes present-day ROM costs to achieve PL 84-99 Delta-specific geometry based on the current 100-year WSE using the two unit-cost rates described in Section 5.2.1. The table also includes present-day costs to achieve PL 84-99 Delta-specific geometry based on the predicted 100-year WSE conditions using the 2050 high SLR scenario.

Not all islands and tracts included in the DLIS Very-High Priority and High Priority categories will be improved to the PL 84-99 Delta-specific geometry. For example, eight islands and tracts in the Very-High Priority and High Priority categories will likely be improved to either ULOP (as defined by DWR in its *Urban Levee Design Criteria* [DWR 2012]) or to FEMA 100-year level-of-protection (as defined by the National Flood Insurance Program in 44 CFR 65.10). These eight islands and tracts include: Bishop Tract/DLIS-14, Brannan-Andrus, Central Stockton, Grand Island, Maintenance Area 9 North, North Stockton, Reclamation District 17, and West Sacramento. ROM costs are not provided for ULOP or FEMA 100-year improvements. Three other islands and tracts in the Very-High Priority and High Priority categories have special considerations as floodways or SWP facilities: DLIS-20 (Yolo Bypass), DLIS-12 (Paradise Cut), and Clifton Court Forebay.

In addition, the DLIS team does not have data on levee geometry for seven High Priority islands, and earthwork volume estimates were not available for one island in the Very-High Priority category. These eight islands and tracts include: Byron Tract, DLIS-08 (Discovery Bay Area), Hastings Tract, Honker Bay, Honker Lake Tract, Mossdale Island, Paradise Junction, and Stewart Tract.

Compared to present-day conditions, the ROM cost to achieve PL 84-99 Delta-specific geometry for a WSE corresponding to 2050 high SLR conditions is about 14 percent higher than the ROM cost for the 2012 WSE based on the $1.5 million per mile assumption, and about 26 percent higher than the ROM cost for the 2012 WSE based on the $15 per cubic yard assumption.

Table 5-6 Comparison of Rough Order-of-Magnitude Construction Costs for PL 84-99 Delta-specific Levee Geometry with Water Surface Elevation (WSE) Conditions in the 2012 Baseline and 2050, High Sea Level Rise Scenarios

Island	Priority	SLR Increase (ft) 2050 High	2012 Baseline		2050 High SLR		Cost Difference ($)		Cost Difference (Percent)	
			Based on $15 per cubic yard	Based on $1.5 million per mile	Based on $15 per cubic yard	Based on $1.5 million per mile	Based on $15 per cubic yard	Based on $1.5 million per mile	Based on $15 per cubic yard	Based on $1.5 million per mile
Bethel Island	Very-High	0.73	$1,057,000	$6,732,000	$1,108,000	$7,300,000	$51,000	$568,000	5%	8%
Dutch Slough	Very-High	0.73	$407,000	$4,219,000	$507,000	$5,653,000	$100,000	$1,434,000	25%	34%
Jersey Island	Very-High	0.72	$2,417,000	$11,335,000	$3,451,000	$15,327,000	$1,034,000	$3,992,000	43%	35%
Sherman Island	Very-High	0.72	$1,281,000	$5,923,000	$1,822,000	$10,256,000	$541,000	$4,333,000	42%	73%
Twitchell Island	Very-High	0.62	$4,204,000	$12,472,000	$6,163,000	$13,608,000	$1,959,000	$1,136,000	47%	9%
Bacon Island	High	0.75	$8,051,000	$16,428,000	$11,901,000	$21,243,000	$3,850,000	$4,815,000	48%	29%
Bouldin Island	High	0.61	$11,088,000	$21,542,000	$15,127,000	$24,965,000	$4,039,000	$3,423,000	36%	16%
Bradford Island	High	0.71	$3,840,000	$9,437,000	$5,393,000	$10,289,000	$1,553,000	$852,000	40%	9%
Drexler Tract	High	0.69	$5,275,000	$6,370,000	$6,134,000	$7,791,000	$859,000	$1,421,000	16%	22%
Glanville	High	0.21	$6,384,000	$9,685,000	$6,628,000	$9,685,000	$244,000	$0	4%	0%
Holland Tract	High	0.75	$1,929,000	$9,611,000	$2,686,000	$13,887,000	$757,000	$4,276,000	39%	44%
Hotchkiss Tract	High	0.74	$66,000	$13,363,000	$152,000	$13,363,000	$86,000	$0	130%	0%
Jones Tract	High	0.71	$6,328,000	$16,160,000	$8,385,000	$19,896,000	$2,057,000	$3,736,000	33%	23%
Little Egbert Tract	High	0.49	$2,319,000	$6,975,000	$3,226,000	$6,975,000	$907,000	$0	39%	0%
Mandeville Island	High	0.74	$6,325,000	$18,067,000	$9,266,000	$20,936,000	$2,941,000	$2,869,000	46%	16%
McDonald Island	High	0.72	$2,399,000	$7,671,000	$2,399,000	$7,671,000	$0	$0	0%	0%
Middle and Upper Roberts Island	High	0.54	$574,000	$2,273,000	$574,000	$2,273,000	$0	$0	0%	0%
New Hope Tract	High	0.35	$1,687,000	$8,537,000	$2,060,000	$12,216,000	$373,000	$3,679,000	22%	43%
Palm-Orwood	High	0.69	$1,016,000	$4,517,000	$1,268,000	$6,193,000	$252,000	$1,676,000	25%	37%
Pescadero District	High	0.51	$80,000	$568,000	$80,000	$568,000	$0	$0	0%	0%
Staten Island	High	0.45	$11,608,000	$29,589,000	$12,396,000	$31,606,000	$788,000	$2,017,000	7%	7%
Terminous Tract	High	0.52	$18,069,000	$23,423,000	$20,899,000	$23,707,000	$2,830,000	$284,000	16%	1%
Union Island West	High	0.62	$11,546,000	$20,057,000	$11,546,000	$20,057,000	$0	$0	0%	0%
Victoria Island	High	0.63	$2,079,000	$6,847,000	$2,377,000	$7,983,000	$298,000	$1,136,000	14%	17%
Webb Tract	High	0.69	$3,781,000	$15,000,000	$7,420,000	$17,989,000	$3,639,000	$2,989,000	96%	20%
Woodward Island	High	0.70	$1,928,000	$7,159,000	$2,360,000	$8,864,000	$432,000	$1,705,000	22%	24%
Grand Total			**$122,681,000**	**$321,668,000**	**$154,042,000**	**$368,009,000**	**$31,361,000**	**$46,341,000**	**26%**	**14%**

5.2.7 Comparison to Other PL 84-99 Analyses

The *Delta Plan* reports that 25 RDs comprising 516 levee miles meet PL 84-99 geometry (Council 2013). This information was based on analyses performed by DWR (California Natural Resources Agency 2012) employing the same elevation data used in the DLIS analysis. In its analysis, DWR used Delta-specific PL 84-99 levee geometry; however, DWR used standard landside levee slopes and did not provide flatter landside levee slopes for levees sited on peat or organic soil foundations.

The DLIS PL 84-99 analysis using Delta-specific geometry was performed for polders that generally coincide with RDs, but not in all cases. The DLIS PL 84-99 analysis accounted for landside slopes that meet Delta-specific PL 84-99 geometry and adjusted the data for levees that have been improved since 2008. The results of the DLIS PL 84-99 analysis indicate that five islands comprising 323 miles meet the PL 84-99 Delta-specific geometry.

To account for this discrepancy, the DLIS team re-performed its PL 84-99 analysis to compare results more closely with those reported in the *Delta Plan* (Council 2013). In this analysis, the DLIS team attempted to duplicate the DWR analysis reported in the *Delta Plan* (Council 2013). In other words, the DLIS team did not use Delta-specific PL 84-99 geometry and instead analyzed the levees assuming the basic PL 84-99 landside slope.

In addition, the DLIS team considered Delta-specific PL 84-99 landside geometry both with and without adjustments for levee improvements since 2008 as reported by RD engineers. The results are summarized in Table 5-7, which shows 34 islands and 619 levee miles meet the requirements for basic PL 84-99 geometry compared to DWR's results of 25 RDs and 516 levee miles[5]. The table also identifies the number of islands with 50 to 75 percent of the island's levee miles meeting both PL 84-99 basic and Delta-specific geometry, and those with at least 75 percent but less than 100 percent of the island's levee miles meeting both PL 84-99 basic and Delta-specific geometry.

The five islands with at least 75 percent but less than 100 percent of non-project levee miles meeting the Delta-specific PL 84-99 geometry include: Central Stockton, Coney, Lower Roberts, Palm-Orwood, and Pico-Naglee.

Though the comparison shows that the results of the DWR analysis and DLIS analysis are reasonably close, the principal sources of the apparent discrepancy can be attributed to the following:

- DWR based its analysis on basic PL 84-99 Delta-specific levee geometry, but did not include flatter landside levee slopes for levees sited on peat or organic soil foundations.
- The hydraulic units analyzed by DWR are reported as RDs whereas DLIS used the hydraulic units (polders) developed for the DLIS project, reported as islands or tracts. The DLIS analysis was based on 66 islands; the number of RDs considered in the DWR analysis is not known.
- The DWR analysis was based on levee improvement information available in 2011 whereas the DLIS analysis is based on information reported by RDs in 2015.

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[5] Note that DLIS results are reported for islands while DWR results are reported by RD.

- There may be small but meaningful differences in the rigor applied to analytical techniques and in assumptions made during the analysis.

Table 5-7 Summary of DLIS PL 84-99 Analysis

Type of Analysis	Currently at PL 84-99 Requirements				Not Currently at PL 84-99 Requirements	
	Miles of Levees	Number of Islands where *X*% of Levees			Miles of Levees	Number of Islands
		50%-75%	75-99%	100%		
Basic PL 84-99 Slopes *No RD Corrections*	619	13	16	34	105	32
Delta-specific PL 84-99 *No RD Corrections*	308	20	6	1	416	65
Delta-specific PL 84-99 *With RD Corrections*	323	19	5	5	401	61

5.3 Urban Level of Protection

To inform the development of risk reduction performance measures for the *Delta Plan*, the DLIS team estimated the flood risk reduction that may be achieved by implementing Urban Levee Design Criteria (ULDC) levee improvements (DWR 2012) for six islands and tracts in the Delta. The ULDC provides engineering criteria and guidance to meet the requirements of California Government Code sections 65865.5, 65962, and 66474.5, which state that levees and floodwalls in the Sacramento-San Joaquin Valley must provide protection against a flood that has a 0.5 percent AEP, or a 1-in-200 chance of occurring in any given year, known as the ULOP. According to Code sections 65865.5, 65962, and 66474.5, levees protecting urban areas must achieve ULOP by 2025.

Currently, six islands and tracts in the Delta are subject to the requirements for ULOP as identified in Table 5-8. To estimate flood risk reduction, the DLIS team compared EAD and EAF based on current conditions (2012) versus conditions in 2025 if levees have been improved by implementing ULDC. Table 5-8 shows the probability of flooding caused by both hydraulic (i.e., overtopping or seepage) loading and by seismic loading. The probabilities of flooding for current conditions were obtained from the DST, whereas the probabilities for flooding in 2025 are based on estimating the levee fragility curves that may be obtained by improving the levees for these six islands and tracts to ULDC. Such improvements reduced estimated hydraulic flooding probabilities to 0.5 percent. We also assumed that improvements similarly reduced the probability of seismic failure to 0.5 percent (DWR 2012). The calculated residual risk, expressed as EAD and EAF in Table 5-8, assumes that there are no changes between current conditions and conditions in 2025 in i) property and infrastructure asset value; ii) population; iii) peak Delta inflows; or iv) sea level.

We estimate that EAD may be reduced by about 59 percent and EAF may be reduced by about 57 percent if ULOP is achieved for these six islands and tracts within the Delta.

Table 5-8 Estimated Reductions to EAD and EAF by Achieving Urban Level of Protection by 2025

Island	Probability of Flooding[1]						Expected Annual			
	Current			2025[2]			Damages ($M)		Fatalities	
	Hydraulic	Seismic	Total	Hydraulic	Seismic	Total	Current	2025[2]	Current	2025[2]
Maintenance Area 9 North	1.39%	0.70%	2.08%	0.5%	0.5%	1.0%	$47.6	$17.1	2.53	1.14
North Stockton	1.73%	0.92%	2.63%	0.5%	0.5%	1.0%	$42.5	$12.3	1.34	0.50
Bishop Tract/DLIS-14	1.16%	2.02%	3.15%	0.5%	0.5%	1.0%	$26.8	$11.6	1.25	0.40
Reclamation District 17	0.81%	1.03%	1.84%	0.5%	0.5%	1.0%	$15.4	$9.5	0.61	0.33
West Sacramento	0.84%	0.82%	1.65%	0.5%	0.5%	1.0%	$11.8	$7.0	0.34	0.20
Central Stockton	0.92%	0.74%	1.65%	0.5%	0.5%	1.0%	$10.5	$5.7	0.38	0.22
Total							**$154.7**	**$63.2**	**6.45**	**2.79**

Notes:

1. The implied level of accuracy probabilities of flooding shown is subject to the data limitations described in this report and in the Methodology Report (Council 2016b).
2. 2025 is the required date of completion to achieve Urban Level of Protection.

5.4 Seismic Considerations

While reviewing flood probabilities for 2012 and 2050, the DLIS team noted that Byron Tract ranks in the DLIS Very-High Priority category even though RD engineers report that the levees on Byron Tract currently meet the requirements for FEMA 100-year protection and PL 84-99 geometry. The levees on Byron Tract are estimated to have a 0.8 percent probability of hydraulic flooding (return period of 125 years) along with a 3.0 percent probability of flooding by seismically induced failure (return period of 33 years). The threat of seismically induced failure was enough to rank Byron Tract in the DLIS Very-High Priority category.

In the DLIS, priority categories were determined by risk, where risk is equal to the probability of flooding times the consequences of flooding, as described in Section 3.0 of this report. The DLIS team reviewed the failure probabilities of all islands in the DLIS Very-High Priority and High Priority categories. Of the 51 islands in these two categories, 31 islands (nearly two-thirds) have probabilities of seismically induced failure that are greater than their probabilities of hydraulic failure, including all eight western Delta water supply islands. Table 5-9 shows the baseline probability of flooding from hydraulic and seismic levee failure for these 31 islands and tracts.

We also plotted the probability of seismically induced failure vs. the probability of hydraulic failure for the islands in the DLIS Very-High Priority and High Priority categories as shown on Figure 5-7. The figure shows the islands or tracts that have a probability of seismically induced failure greater than their probability of hydraulic failure, and shows the islands or tracts that have a probability of hydraulic failure greater than their probability of seismically induced failure.

Figure 5-7 Seismically Induced Failure vs. Hydraulic Failure

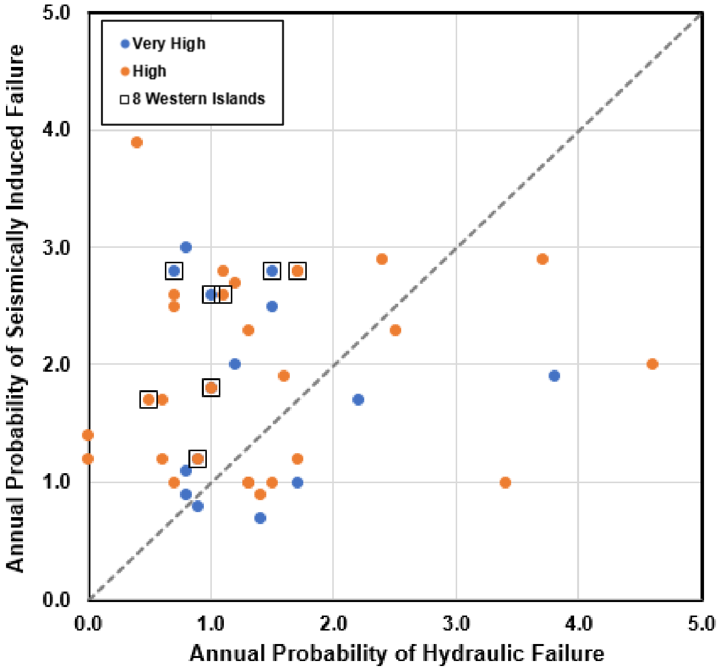


Table 5-9 Probability of Flooding for Very-High and High Priority Islands with Relatively High Seismic Risk

Island or Tract	Priority	Probability of Flooding[1]	
		Hydraulic	Seismic
Bethel Island	Very-High	1.0%	2.6%
Bishop Tract/DLIS-14	Very-High	1.2%	2.0%
Brannan-Andrus	Very-High	1.5%	2.5%
Byron Tract	Very-High	0.8%	3.0%
Dutch Slough	Very-High	0.9%	1.2%
Jersey Island	Very-High	1.0%	1.8%
Reclamation District 17	Very-High	0.8%	1.1%
Sherman Island	Very-High	0.7%	2.8%
Twitchell Island	Very-High	1.5%	2.8%
Upper Andrus Island	Very-High	1.9%	2.0%
West Sacramento	Very-High	0.8%	0.9%
Bacon Island	High	1.1%	2.8%
Bradford Island	High	1.7%	2.8%
Clifton Court Forebay	High	0.4%	3.9%
DLIS-08 (Discovery Bay Area)	High	0.0%	1.4%
DLIS-22 (Rio Vista)	High	0.1%	1.1%
Drexler Tract	High	2.4%	2.9%
Hastings Tract	High	0.7%	2.6%
Holland Tract	High	1.1%	2.6%
Honker Bay	High	1.6%	1.9%
Hotchkiss Tract	High	0.9%	1.2%
Mandeville Island	High	1.3%	2.3%
McDonald Island	High	1.2%	2.7%
New Hope Tract	High	1.0%	1.8%
Palm-Orwood	High	0.6%	1.2%
Pescadero District	High	0.0%	1.2%
Stewart Tract	High	0.7%	1.0%
Union Island West	High	0.6%	1.7%
Victoria Island	High	0.5%	1.7%
Webb Tract	High	1.7%	2.8%
Woodward Island	High	0.7%	2.5%

Note:

1. The implied level of accuracy probabilities of flooding shown is subject to the data limitations described in this report and in the Methodology Report (Council 2016b).

These results warrant consideration in the development of a future levee improvement strategy for two important reasons. First, levee improvement guidelines based on LOP (such as PL 84-99 and Bulletin 192-82) address only water stage and levee geometry; they do not account for levee performance under earthquake loading. Second, emergency preparedness policies and recommendations should account for seismically induced failures, which are likely to occur suddenly and without warning (compared to hydraulic flooding).

The ULDC (DWR 2012) provides engineering criteria and guidance for threats posed by seismically induced ground motions. These criteria and guidance must be applied for levees in urban and urbanizing areas by 2025 (California Government Code sections 65865.5, 65962, and 66474.5). Three of the 31 islands with higher seismically induced probabilities of levee failure are urban or urbanizing areas mandating application of these criteria.

It is unlikely, however, that reducing the probability of seismic failure for the remaining islands can be accomplished simply by improving their levees to current LOP guidelines. Delta islands with high probabilities of seismically induced failure will likely need to be improved using techniques that include increasing the levee’s ability to withstand seismic ground motions without excessive deformation or liquefaction.

Levee improvement investments should address levee vulnerability to both seismically induced failure as well as hydraulic flooding, and risks should be reduced to levels judged to be tolerable. For example, the levee performance criteria described in the ULDC (DWR 2012) could be used to evaluate all levees in the Delta with a significant threat of seismically induced failure.

There is a wide difference of opinion regarding the probability of i) a significant earthquake event occurring in the Delta; and ii) the anticipated performance of Delta levees subject to strong ground motion. Nevertheless, the DLIS results, which are based on the best available data, indicate that the risk reduction strategy should devote attention and additional research to earthquake threats and levee performance under seismic loading, particularly on populated islands with non-project levees such as Byron Tract and Bethel Island.

Because seismically induced levee failure will likely occur more rapidly than levee failure from hydraulic flooding, much less time will be available for flood fighting or evacuation. For this reason, non-structural measures and investments in emergency preparedness should be made an integral part of any risk reduction strategy for areas where seismic activity is likely. These measures include:

- Improved building codes.
- Actions, such as flood-proofing, to permit sheltering in place.
- Provisions for vertical evacuation for residential or high occupancy buildings (such as schools or senior centers) located in deep floodplains.
- Implementation of emergency warning systems such as civil defense sirens for especially vulnerable areas.
- Emphasizing identification, improvement, and implementation of emergency evacuation routes.
- Implementation of emergency preparedness and response programs designed to educate the public and to raise overall public awareness of flood hazards.

6.0 FUNDING CONSIDERATIONS FOR LEVEE MAINTENANCE AND IMPROVEMENT

Over the past four decades, the State of California has invested an estimated $700 million in Delta levee maintenance and improvement including funds approved by voters in Propositions 1E and 84 (Council 2015). Despite these investments, Delta flood risk remains significant as described in Sections 3.0 and 4.0 of this report. Section 5.0 of this report indicates that considerable work remains to improve levees and reduce flood risk in the Delta. Demands for continued levee improvements are substantial; previous estimates range from $1.3 to $3.0 billion (Council 2015). Resources are constrained, however, which led the Council to undertake the DLIS to develop a comprehensive method to prioritize State investments in Delta levee operations, maintenance, and improvement projects (Council 2013).

Despite recognition of substantial demand, the only State funds currently committed for Delta flood risk reduction are encumbered funds remaining from Proposition 1E and $295 million in new funds from Proposition 1 (Water Code 79781). This section discusses funding considerations for Delta levee maintenance and improvement and is intended to inform Council deliberation on potential risk reduction policies and recommendations in the *Delta Plan*, including levee OMRR&R; the Delta Levees Maintenance Subventions Program (Subventions Program); cost sharing; and ability to pay (ATP).

6.1 State Funding Programs for Delta Levees

State funding programs for levee improvements on Delta islands and tracts vary based on location and type of levee. Generally, State funds for Delta levees are available through the Urban Levees Risk Reduction Program, the Subventions Program, or the Delta Levees Special Projects Program. The specific levee improvements for islands and tracts in the Very-High Priority and High Priority categories should be determined by cooperative planning between local and State agencies.

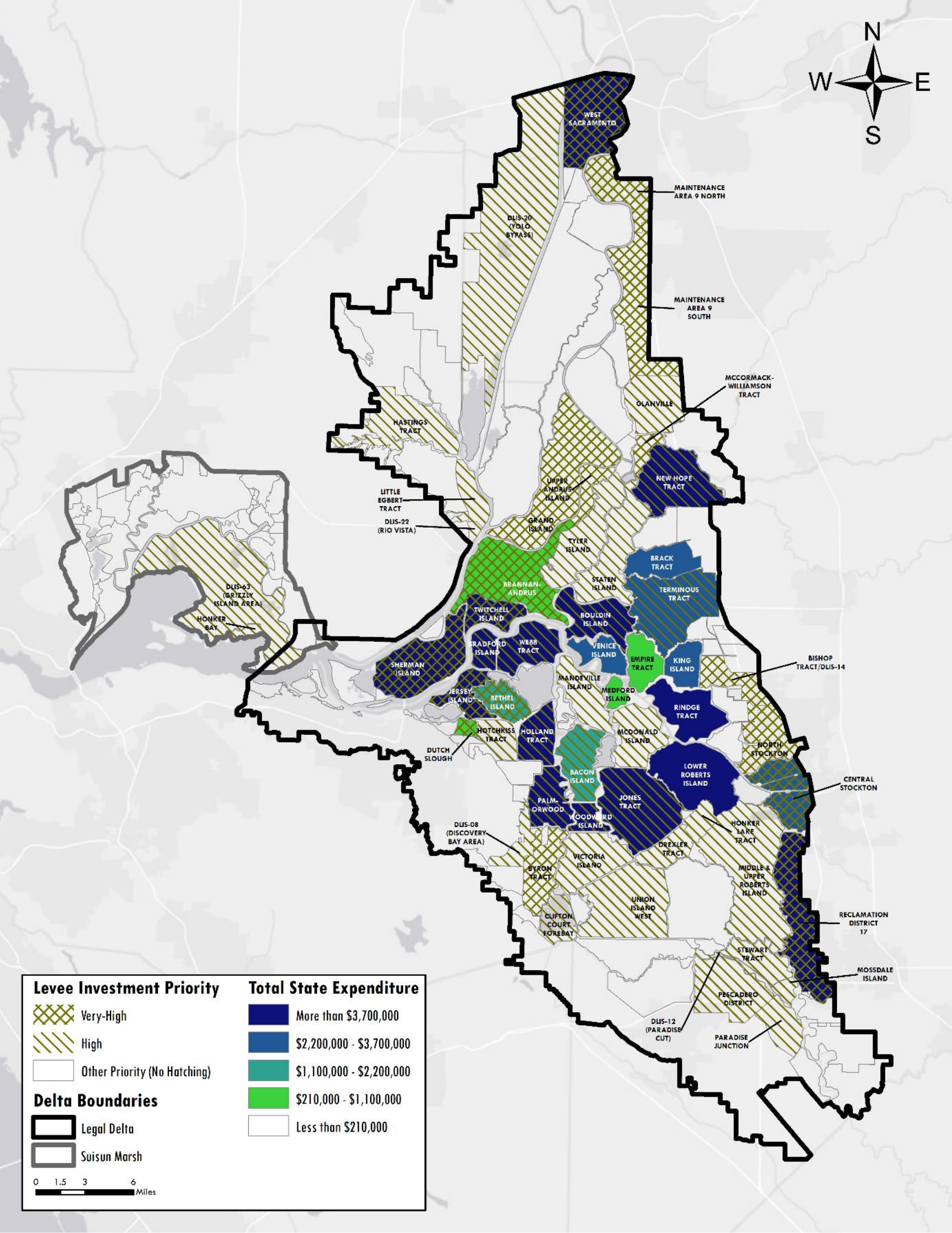
A summary of funding programs currently available for Delta levee maintenance and improvement is presented in Table 6-1. Except for Proposition 1, the funding available from other propositions is either already spent or is otherwise encumbered. All other State funding is dependent on annual appropriations from the State Legislature.

Figure 6-1 shows the relationship of historical State funding for Delta levees maintenance and improvements compared to the investment priorities that are described in Section 4.0.

Table 6-1 Summary of Delta Levee Funding Programs

Program	Activity	Funding Sources	Comments
Delta Levees Maintenance Subventions Program	Maintenance, Rehabilitation, Emergency Response, No net long-term habitat loss	Propositions 1, 1E, 84	LMAs, RDs, and other government agencies responsible for levees in the legal Delta may apply for funding (up 75 percent of eligible costs) for maintenance of non-project and eligible project levees.
Delta Levees Special Flood Control Projects Program	Protect water conveyance and quality, net long-term habitat improvement, drought relief	Propositions 1E, 84	LMAs, RDs, and other government agencies responsible for levees in the legal Delta may apply for funding. Intended to ensure net long-term habitat improvement in Delta. Originally authorized to address flooding in eight western Delta islands and in Thornton, New Hope, and Walnut Grove. Later expanded to entire Delta and portions of Suisun Marsh.
Early Implementation Program (EIP)	Repair, rehabilitation, reconstruction or replacement of levees, weirs, bypasses, and facilities of the State Plan of Flood Control (SPFC)	Propositions 1E, 84	Projects must be ready for implementation in the fiscal year the funds are authorized.
Flood Control Facilities Evaluation and Rehabilitation Program	Evaluation, repair, rehabilitation, reconstruction, or replacement of levees, weirs, bypasses, and other flood control facilities	Proposition 1E	Only applicable to project levees.
Flood Emergency Response Project Grants Program	Emergency Response	Propositions 1E, 84	Delta Emergency Communication Grant completed in 2012 (Proposition 84) and Delta Grant completed in 2014 (Proposition 1E).
Flood Protection Corridor Program	Nonstructural flood management solutions	Propositions 1E, 13, 84	
Flood System Evaluation and Rehabilitation Program	Evaluation, repair, rehabilitation, reconstruction, or replacement of levees, weirs, bypasses, and other flood control facilities	Proposition 1E	
Floodplain Evaluation and Modeling Program	Various flood management planning and improvement activities	Proposition 1E	
Non-urban Flood Risk Management Program	Structural and nonstructural improvements, levee extensions	Proposition 1E	Only applicable to small communities.
Small Communities Flood Risk Reduction Program (SCFRR)	Feasibility, Maintenance, Improvement	Created as result of 2012 Central Valley Flood Protection Plan	Cost shared between State and local communities with 200 to 10,000 residents to repair, rehabilitate, reconstruct, or replace current SPFC facilities. Minimum State cost share is 50 percent.
Urban Flood Risk Reduction (UFRR) Program	Addresses State investment priorities for urban areas in the Sacramento-San Joaquin Valley protected under the SPFC	Proposition 1E	The UFRR Program is designed to supersede the EIP. All projects are designed to achieve protection from a 200-year flood.

Figure 6-1 State Expenditures and Priority Ranking (Adapted from Council 2013)



6.2 Operations, Maintenance, Repair, Rehabilitation, and Replacement

To gain additional perspective of maintenance requirements for Delta levees, the DLIS team reviewed the Flood System Long-Term Operations, Maintenance, Repair, Rehabilitation, and Replacement Cost Evaluation, Draft Technical Memorandum ("the DWR TM"; DWR 2016). This review provided useful information under the broad umbrella of operations and maintenance (O&M) for i) DWR's definition of terms and ii) improved estimates of costs. At Council direction, the DLIS team also reviewed expenditures, cost sharing provisions, and deductibles in the Subventions Program.

The purpose of the DWR TM is to "help flood management planners, engineers, and budget analysts at the local, State, and federal levels estimate resource needs and understand the challenges related to the OMRR&R of the State Plan of Flood Control…and to [raise] awareness of the complex issues, challenges, and real costs related to maintaining the levees, channels, and structures in the Central Valley" (DWR 2016).

The DWR TM goes on to say: "While much progress has been made to address these issues through bond-funded large capital projects, necessary ongoing maintenance is still critically underfunded [emphasis added]. Within their budgets and assurances, maintainers must make difficult decisions and prioritize their work to sustain a functioning flood control system. Societal expectations, changing standards, regulatory requirements, and multiple uses of the flood management system have all influenced the current cost of OMRR&R. This TM attempts to comprehensively quantify the cost" (DWR 2016). It is important to note that the estimated, true long-term OMRR&R costs presented in the DWR TM assume fully functioning facilities that meet applicable standards [emphasis added] (DWR 2016).

The Subventions Program, which is authorized by the CWC section 12980 et seq., is a cost-share program that provides technical and financial assistance to local agencies in the Delta for the maintenance of non-project and eligible project levees. The Subventions Program is managed by DWR on behalf of the CVFPB. CVFPB reviews and approves DWR's recommendations and executes agreements with local agencies to reimburse eligible costs of levee maintenance. In general, the Subventions Program is very important in assisting LMAs in the O&M of Delta levees. For example, there were over 140 levee failures in the last century. The most recent failure, however, occurred on Upper Jones Tract on June 3, 2004, inundating 12,000 acres of farmland with approximately 160,000 acre-feet of water (Council 2015). The apparent reduction in the number of levee failures in the Delta is attributed, at least in part, to the Subventions Program.

6.2.1 Definitions

DWR (2016) defines O&M as "the traditional term used to describe the routine activities necessary for a healthy flood control system. 'Operation, maintenance, repair, rehabilitation, and replacement (OMRR&R)' is a more recently developed term used to describe and include the comprehensive set of non-routine activities needed to ensure an effective flood management system." DWR provides the following definitions (DWR 2016):

Operation. *Daily activities needed to keep the system functioning properly and for a responsible agency to perform its duties.*

Routine operation includes all activities performed by levee maintaining agencies to function as a viable organization. Such functions include staffing expenses, overhead, inspecting facilities, purchasing equipment, obtaining permits, conducting general management duties to ensure proper facility function, and operating facilities during high water events. Other functions include critical pipe closures, pumping plants, and flood fighting. Facilities inspections identify potential weaknesses in the system caused by encroachments and penetrations through levees, and the condition of dams and other facilities. Local agencies routinely inspect levee condition; in addition, DWR and USACE inspect State- or federally sponsored projects.

Maintenance. *Routine activities (including minor repairs) that need to be performed to keep the system operational.*

Routine or periodic maintenance includes activities that must be performed annually or semi-annually, including vegetation management (such as invasive species and channel snags), sediment removal, mowing, rodent and burrowing vector control to maintain levee integrity, minor erosion repair, levee crown repairs, crown road surfacing, and bank stabilization. Other typical activities include maintaining pumping plants, gates and closure structures, weirs and overflow structures, and other flood control facilities as necessary.

Repair. *Non-routine activities needed to fix damage caused by a specific event.*

Repair includes activities that address damage to portions of levees, channels, and other infrastructure caused by a storm or other event. Such activities can include minor, moderate, or major levee bank or channel repair and stabilization, and repairs to structures. In general, such activities are non-routine and bring a damaged element or portion of the flood control system back to original (or improved) condition. Given the age and condition of the current system and inadequate funding to conduct proper O&M over the last several decades, substantial facility repair is required throughout the system.

Rehabilitation. *Non-routine activities needed to fix damage caused by prolonged wear and tear degradation.*

Rehabilitation is generally considered activities that address significant facility issues associated with aging portions of levees, channels, and other infrastructure. Such activities can include major levee bank or channel rehabilitation and stabilization, and significant structure repairs. In general, such activities are non-routine and bring a deteriorated element or portion of the flood control system back to original (or improved) condition. Given the age and condition of the current system and inadequate funding to conduct proper O&M over the last several decades, substantial facility rehabilitation is required throughout the system.

Replacement. *Installation of new equipment and facilities needed when components have either failed or exceeded their useful life.*

Some flood control structures and systems are aging and approaching the end of their designed and useful life. Replacement of such facilities (by either a functionally equivalent or upgraded structure) is necessary where repair and rehabilitation is not an option, such as replacing metal culverts that are beyond their design life. In general, replacement activities are limited to minor flood management structures. Larger facilities and structures such as the major weirs operated by the State on the Sacramento River are consistently maintained and are anticipated to remain operational well into the future. Replacement of these and other facilities (or portions of facilities such as partial levee replacement) is generally considered a capital improvement project and is beyond the scope of typical OMRR&R.

6.2.2 Estimated Costs for Operation and Maintenance (O&M)

Importantly, the DWR TM states: “Estimated OMRR&R costs identified in this TM do not account for capital improvements or design repairs required to address known design deficiencies. These large investments needed to update the system have been brought about by historical patterns of limited funding availability and deferred maintenance, identification of system design deficiencies, land use changes, better understanding of Central Valley hydrology and potential climate change impacts, changing regulatory standards, and increasing environmental requirements…The costs identified in the TM are intended to assist flood management stakeholders in raising awareness of the need for substantial funding to address sustainable OMRR&R of flood control facilities within the SPFC” (DWR 2016).

DWR obtained cost information for both urban and non-urban levees by direct communication with numerous LMAs and through LMA responses to a questionnaire. In general, the costs obtained were determined to be what LMAs are currently spending with available funding, but do not necessarily represent spending levels to fully maintain their facilities. The reported O&M costs do not include costs for channel maintenance, vegetation and debris removal, or structures, which were tabulated separately. These costs were not reported by levee-mile, so cannot easily be correlated to per mile per year O&M costs (DWR 2016).

The results (DWR 2016) show that, for non-urban levees in the Sacramento River basin, LMAs currently spend an average of approximately $11,400 per levee mile per year on O&M, with costs ranging from $2,796 to $28,468 per levee mile per year across districts. LMA feedback regarding true costs for non-urban levee O&M indicated costs are significantly higher than shown by responses to the questionnaire. For example, LMAs in Lower Sacramento River/Delta North provided estimates of O&M between $6,642 and $82,000 per mile per year. LMA representatives provided estimates of costs at $46,000 per levee mile per year for each region, based on a detailed evaluation conducted in the Feather River region.

DWR (2016) received limited responses from the San Joaquin River basin to the LMA questionnaire; responses received, however, indicated that LMAs were spending approximately $5,000 per levee mile per year. Input provided by LMA representatives in the Lower San Joaquin study area indicated true costs for non-urban levee O&M were significantly higher than shown in the limited questionnaire responses and additional data obtained. For example, LMAs in Lower San Joaquin River/Delta South provided estimates of O&M at $50,000 per mile per year. LMA representatives suggested true costs were approximately $33,000 per levee mile per year for the regions within the San Joaquin River basin.

The DWR TM states that the “Delta Subventions Program is designed to help LMAs with the cost of levee maintenance and rehabilitation.” Annual claims from the ongoing Subventions Program were analyzed to develop an appropriate estimate for current levee O&M costs and repair, rehabilitation, and replacement (RR&R) costs. These data, using costs dating from fiscal Year (FY) 1993-1994, escalated to 2014 dollars, "result in an average cost-per-levee mile of $12,750, rounded up to $13,000 per levee mile, for routine levee O&M" (DWR 2016). The DWR TM reports these results are consistent with the average for the Sacramento River basin non-urban LMAs ($11,400 per levee mile per year) from the LMA questionnaire. Subsequent discussions with regional representatives indicated these data currently underestimate costs required to conduct full proper maintenance (DWR 2016).

6.2.3 Estimated Costs for Repair, Rehabilitation, and Replacement (RR&R)

The DWR TM reports that results of the LMA questionnaire provided cost information for RR&R for non-urban levees in the Sacramento River basin, but that no responses were received from LMAs in the San Joaquin River basin. Responses received from LMAs in the Sacramento River basin indicated that, on average, the cost for RR&R in non-urban areas is $5,570 per levee mile per year, with costs ranging from $42 to $39,823 per mile per year. The DWR TM indicates that responses to the questionnaire by LMAs likely capture only a portion of the RR&R costs associated with non-urban levees (DWR 2016).

According to the DWR TM, Delta levee districts annually and routinely analyze and rehabilitate deteriorating non-urban levees and track costs incurred for routine levee maintenance and levee RR&R. These data were determined to be the best available data for non-urban levees in both the Sacramento and San Joaquin River basins. The data indicate that the average annual RR&R cost identified in the Delta subventions data was $13,087 per levee mile per year, which was rounded to $13,000 per levee mile per year for estimating RR&R costs for all non-urban levees (DWR 2016).

These costs do not include RR&R costs for channels or structures, which were tabulated separately. These costs were not reported by levee-mile, so cannot easily be correlated to per mile per year RR&R costs.

In the coming years, climate change will also impact levee performance. DWR's results (2016) indicate that, in general, levee OMRR&R is seriously underfunded throughout the Central Valley, including the Delta. As levees deteriorate from inadequate or deferred maintenance, the residual risk to State interests in the Delta will increase. Based on this review, the true long-term OMRR&R costs for Delta levees are similarly underfunded by $33,000 to 46,000 per mile per year.

6.2.4 Cost Indices

During the DLIS project, the Council considered possible changes to the Subventions Program deductible (currently at $1,000 per levee mile) for levee maintenance and improvement, including updating the deductible to account for inflation since it was established in 1983. To inform discussions, the DLIS team assessed several methodologies for calculating cost indices to determine the best process for converting the 1983 deductible value to present-day dollars. The indices reviewed fall into three categories – agriculture, construction, or general. Based on this analysis, the DLIS team recommends that the Council consider the indices based on i) the Delta Counties agricultural data from the United States Department of Agriculture (USDA) National Agricultural Statistics Service, or ii) the construction costs from the U.S. Department of the Interior, Bureau of Reclamation (USBR) Construction Cost Trends for Earth Dams. Table 6-2 highlights these two indices and summarizes the advantages, disadvantages, projected deductibles, and index values for the 11 options evaluated.

Table 6-2 Summary of Cost Indices and Methodologies for Projecting Subvention Deductibles

Data Source	Category	Description	Advantages	Disadvantages	Year Representing "Present-Day"	Projected Deductible	Index Value
International Monetary Fund (IMF) All Corn Price Index - Global	Agriculture	Analysis of monthly IMF corn prices	May reflect farmer sentiment that corn prices have not seen growth consistent with the rest of the economy due to efficiencies, supply, etc.	Not specific to the Delta (or even California) and only reflective of a single crop	2015	$1,068	1.07
United States Department of Agriculture National Agricultural Statistics Service - Delta Counties	Agriculture	Analysis of the relative price paid for all crops harvested in five Delta counties available. The reported overall price index was determined by weighting relative price indices for each crop by the percentage of the total 2015 acreage.	Specific to the Delta counties, weighted by acreage, and includes prices for all available crops from a single data source	No significant disadvantages identified	2015	$2,230	2.23
United States Department of Agriculture National Agricultural Statistics Service - California	Agriculture	Analysis of the relative price paid in California for the top 10 crops harvested in the Delta, weighted by the 2012 acreage in the Delta	Focuses on largest crops by acreage in the Delta as of 2012 according to the University of California Division of Agriculture and Natural Resources	Uses statewide prices and is based only on top crops from 2012 in the Delta	2015	$1,940	1.94
Civil Works Construction Cost Index System - Levees and Floodwalls	Construction	Specifically designed for Civil Works construction, and specific for each of the major Civil Works features. Only indices for construction costs have been developed. Indices are used to escalate or inflate various project cost features to current or future price levels. There are state adjustment factors included that allow a project estimated in one state to be adjusted to a project in another state.	Includes an index specific to levees and a State adjustment factor specific to California; includes input data from USBR, USACE, Office of Management and Budget, United States Department of the Treasury, Producer Price Index (PPI), Engineering News Record (ENR), and RSMeans	Applicable only for USACE civil works projects, which may be less appropriate than USBR data that are noted as a source used across government and private sectors	2017[1]	$2,913	2.91
Production Worker Compensation	Construction	Restricted to production workers (also called blue-collar workers, hourly rated workers, or non-office workers). The series includes both money earnings and benefits. It is an average-hourly-compensation series and is expressed as the number of dollars per work-hour. This series covers only the manufacturing industry. Workers on salary (white-collar workers, office workers, nonproduction workers), such as clerks and executives, are excluded.	Includes average wages and benefits for production workers, which would appear definitionally to include construction workers such as those that might build a levee (although this is not specifically noted)	Not specific to building levees. Excludes material, energy, and other costs; data only available through 2015; thought to be inferior to Unskilled Wage because it does not account for changes in the composition of skills in the workforce nor the general cost of labor	2015	$2,723	2.72
United States Bureau of Reclamation Construction Cost Trends (CCTs) for Earth Dams	Construction	Developed to track construction relevant to the primary types of projects being constructed by the USBR. Consists of two elements: contractor labor and equipment costs and contractor-supplied materials and equipment. Sourced from a blend of actual project data along with BLS PPI and USDA land indices. The index selected from the construction types available is for earth dams for which the October 2016 value was indexed against the January 1984 value.	Blends a large sample of levee-specific base year data from actual projects and modeled project inputs from actual cost data sourced from ENR. Modeled inputs are further enhanced using BLS PPI (labor, equipment, materials) and USDA (land) cost inflators subjected to USBR engineering judgment. USBR notes that the CCTs, which were first published in 1940, are still considered valuable assets used by many within USBR, as well as numerous clients in other government entities and the private sector. The USACE General Design and Construction Considerations for Earth and Rock-Fill Dams note that "The general principles presented herein are also applicable to the design and construction of earth levees."	While this source is as specific to levees as is available, it remains true that some of the dams used in the index are likely of larger scale than those found in the California Delta. USBR notes that, because over time the number and magnitude of projects completed by them has declined, they currently substitute modeled costs data rather than actual cost data for current year inputs.	2016[2]	$2,439	2.44

Data Source	Category	Description	Advantages	Disadvantages	Year Representing "Present-Day"	Projected Deductible	Index Value
International Monetary Fund Nominal Gross Domestic Product (GDP) per Capita	General	Measure of the total output of a country divided by the number of people in the country. A rise in per capita GDP signals growth in the economy and tends to reflect an increase in productivity.	Analyzes a widely recognized national statistic that covers the entire economy	Overly broad in definition	2017	$3,825	3.83
United States Bureau of Economic Analysis Gross Domestic Product Deflator	General	Ratio of Nominal GDP to Real GDP times 100, using 2009 as the base year.	Analyzes a widely recognized national statistic that covers the entire economy.	Overly broad in definition	2016[3]	$2,060	2.06
United States Bureau of Labor Statistics Consumer Price Index (BLS CPI)	General	Monthly data on changes in the prices paid by urban consumers for a representative basket of goods and services. The 2016 estimate for a $1,000 deductible developed in 1988 was calculated using the BLS CPI calculator.	CPI is familiar to a wider audience as a measure of inflation.	Levees are not comparable to a basket of goods purchased by urban consumers. Critics of CPI have also cited the evolution of the CPI from a Cost of Goods Index to a Cost of Living Index through substitutability analyses as problematic and therefore suggest that CPI understates true inflation. Others have noted that commodity costs rather than consumer bundles would represent a more current inflation rate. CPI is less commonly used in the construction industry.	2016	$2,423	2.42
Unskilled Wage	General	Used to determine the relative cost of something in terms of the amount of work of unskilled labor that it would take to produce, or the relative time spent at work by unskilled workers to earn its cost. This indicator can also be useful in comparing different wages over time. The unskilled wage is a more consistent measure than the average wage for making comparisons over time. This is because the average wage changes both because of changes in the composition of skills in the workforce as well as the general cost of labor. The level of skills of the unskilled workforce is assumed to stay the same.	Superior measure of wage for unskilled labor when compared to average wage	Not specific to building levees; excludes material, energy, and other costs; data only available through 2015	2015	$2,348	2.35
Value of Consumer Bundle	General	Average annual expenditures of consumer units. Expenditures are for goods and services, including gifts and charitable contributions, as well as insurance premiums and pension contributions. The value of the consumer bundle is expressed in dollars and is not corrected for inflation.	Broader than the CPI because it is not limited to a representative basket of goods as it includes an average of all consumer expenditures plus select non-consumer goods and services	Levees are not comparable to consumer goods, data only available through 2015	2015	$2,940	2.94

Notes:

This analysis was based on data from a base year of 1983, with exceptions noted below.

1. Analysis based on data from FY83 (Oct 1982 - Sep 1983) and FY17 (Oct 2016 - Sep 2017)
2. Analysis based on data from Jan 1984 and Oct 2016
3. Analysis based on data from Dec 1983 and October 2016

6.2.5 Subventions Deductible and Cost Sharing

The current subventions deductible is $1,000 per levee mile; i.e., an LMA in the Delta is eligible for State support of its annual maintenance cost after it demonstrates that it has spent at least $1,000 in maintenance per levee mile within the LMA. To gain a better understanding of the impact of the subventions deductible on agricultural operations, the Council compared i) the current $1,000 per mile with an inflation-adjusted deductible of $2,500 per mile; and ii) a per-levee mile calculation of the deductible with a per-acre calculation. These comparisons are shown in Tables 6-3 and 6-4.

The dollar values shown are based on eligible levee miles and total acreage for each island without regard to whether these amounts have been claimed or paid in the past. Information for this analysis was taken from a spreadsheet provided to the Council by the DWR FloodSAFE Environmental Stewardship and Statewide Resources Office (FESSRO), State and Local Reimbursements, FY 2004-2013, dated November 13, 2014 (DWR 2014).

Tables 6-3 and 6-4 show the difference in the deductible at $1,000 per mile and $2,500 per mile in two ways. Table 6-3 shows the total deductible for an island in the highlighted column, while Table 6-4 highlights the per-acre deductible for each island. There is little correlation between a deductible calculated on a per-levee mile basis compared to a deductible calculated on a per-acre of enclosed area basis because the ratio of levee length to the area enclosed varies widely for the irregularly shaped islands in the Delta.

Both tables show the low, high, mean, and median deductibles based on $1,000 per mile and $2,500 per mile. The 75th percentile row is the estimated total deductible that is greater than the total deductibles calculated for 75 percent of the LMAs or islands (i.e., 25 percent of the LMAs are subject to a total deductible greater than the number shown). In the Islands column, the islands or LMA with the lowest and highest total deductibles are noted. The islands or LMAs associated with the mean, median, and 75th percentile rows have total deductibles closest to those numbers and are provided for reference.

These results indicate that 25 percent of the LMAs or islands are subject to a deductible of more than $3.69 per acre (or a $15,500 total) based on $1,000 per mile, or $9.22 per acre (or a $38,750 total deductible) based on $2,500 per mile. The islands or LMAs with the lowest and the highest deductibles per acre are noted, and the islands or LMAs associated with the mean, median, and 75th percentile have per-acre deductibles closest to those numbers and are provided for reference.

Table 6-3 Analysis of Total Deductibles

Statistical Measure	$1,000 per Mile		$2,500 per Mile		Island
	Total Deductible	Deductible per Acre	Total Deductible	Deductible per Acre	
Minimum	$1,600	$17.98	$4,000	$44.94	Fay
Median	$10,900	$1.79	$27,250	$4.48	Cache-Haas
Mean	$11,852	$3.35	$29,629	$8.37	Twitchell
75th Percentile	$15,500	$4.48	$38,750	$11.19	Jersey
Maximum	$32,400	$1.29	$81,000	$3.22	Netherlands

Table 6-4 Analysis of Per-Acre Deductibles

Statistical Measure	$1,000 per mile		$2,500 per mile		Island
	Total Deductible	Deductible per Acre	Total Deductible	Deductible per Acre	
Minimum	$2,500	$0.28	$6,250	$0.70	Pescadero
Median	$14,300	$2.66	$35,750	$6.64	Mandeville
Mean	$7,400	$3.45	$18,500	$8.66	Bradford
75th Percentile	$18,100	$3.69	$45,250	$9.22	Merritt
Maximum	$1,600	$17.98	$4,000	$44.94	Fay

6.2.6 Application Amounts and Expenditures

Information on budget application amounts (which includes subventions and levee rehabilitation), subventions deductibles, and maintenance expenditures comes from the budget application reports, which are compiled annually by DWR FESSRO. These reports, prepared for the CVFPB, provide detailed information regarding application amounts (proposed budgets) for the FY going forward, and a summary of actual expenditures. The DLIS team reviewed reports dating from FY 2008 to FY 2016[6]. In addition, the DLIS team reviewed an Excel file from DWR with a detailed summary of actual expenditures for FY 2004-2013.

There is, however, no information available on how the deductible was applied when reimbursement amounts were calculated and paid. The total budgeted Delta-wide deductible ranges between $750,500 (750.5 miles) in FY 2012 to $777,900 (777.9 miles) in FY 2016. In FY 2012, the maximum budgeted deductible was $32,400 for 32.4 miles of levees in Netherlands (RD 999) and the minimum was $1,600 for 1.6 miles in Fay (RD 2113), while the average was $11,371 and the median value was $10,500.

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[6] Reports are not yet complete for FY 2015 and FY 2016.

Because there is little fluctuation in total levee miles used each year, the FY 2012 numbers are considered representative.

Based on records dating back to FY 2008, our analysis finds that budget application amounts that RDs or LMAs submit for levee maintenance and rehabilitation greatly exceed the project expenditures each year, as summarized in Table 6-5. The highlighted rows identify periods during which sufficient data were available for calculating shortfall. The shortfall, or the amount of annual underfunding, is defined as the difference between the amount that RDs predict they need (application amount) and the actual amount of money spent on maintenance and rehabilitation projects (project expenditures) in each year.

Table 6-5 Summary of Application Amounts

Fiscal Year	Application Amount ($ M)	Project Expenditures[1] ($ M)	Shortfall ($ M)
2008		$23	
2009		$17	
2010		$13	
2011	*$73*	*$16*	*$57*
2012	*$72*	*$11*	*$61*
2013	*$46*	*$12*	*$34*
2014	*$54*	*$9*	*$45*
2015	$50		
2016	$52		

Minimum	**$46**	**$9**	**$34**
Average	**$58**	**$14**	**$49**
Maximum	**$73**	**$23**	**$61**

Note:

1. Project expenditures represent the State share of project costs and do not include the RD share

Based on records available to the DLIS team, Table 6-6 shows the maximum allowable reimbursement was $26 million in FY 2008, and has been flat at $12 million for the past five years. From FY 2008-2014, the local share of project funding ranged from $2 to 7 million, averaging $4 million per year. It is not clear from the reports whether these amounts include the subventions maintenance deductible ($1,000 per mile), which ranges from $0.75 to 0.78 million for FY 2011-2016.

From FY 2008-2014, actual state reimbursements paid for subventions ranged from $7 to 16 million. State money budgeted for subventions was under-spent ranging from $1 to 10 million, averaging $6 million per year. The reports indicate that, for FY 2013-2014, the unused State share reverted to its source, Proposition 1E.

Table 6-6 Summary of Subventions Expenditures

Fiscal Year	State Budget ($ M)	Total Project Cost ($ M)	Actual State Reimbursement		Local Share		Unused State Share ($ M)
			Amount ($ M)	Percent	Amount ($ M)	Percent	
2008	$26	$23	$16	70%	$7	30%	$10
2009	$20	$17	$12	71%	$5	29%	$8
2010	$18	$13	$9	69%	$4	31%	$9
2011	$12	$16	$11	69%	$5	31%	$1
2012	$12	$11	$8	73%	$3	27%	$4
2013	$12	$12	$8	67%	$4	33%	$4
2014	$12	$9	$7	78%	$2	22%	$5
Average	**$16**	**$14**	**$10**	**70%**	**$4**	**30%**	**$6**

If, during the years evaluated, the amount budgeted by the State each year for reimbursement was fully spent and was matched by the RDs (75 percent State funding, 25 percent RD funding), then the amount that could be made available for project funding would range from $16 to 35 million, averaging $21 million per year. Further, if the RDs were able (and willing) to spend an additional $2 million to take full advantage of State funding made available each year, the average annual shortfall in maintenance spending would be reduced by roughly $8 million from about $49 million to about $41 million.

6.2.7 Summary and Conclusions – OMRR&R

DWR (2016) indicates that OMRR&R of the SPFC (CWC section 9602[c])) levees is drastically underfunded, and funding will need to be substantially increased to realize long-term system performance. DWR (2016) estimates that the cost of levee OMRR&R should be about $59,000 per mile per year in the Sacramento basin and $46,000 per mile per year in the San Joaquin basin. These estimates are likely to understate the funding needed because the estimated costs assume fully functioning facilities that meet applicable standards, and the estimates do not include necessary costs for sediment, vegetation, and debris removal, and costs for structure OMRR&R.

Delta levees, many of which are legacy structures that were built before current levee design practices were implemented, face the same OMRR&R challenges including settlement, subsidence, erosion, vegetation management, and control of burrowing animals. In addition, many Delta levees were built with over-steepened slopes and inadequate crest widths. Because many levees in the Delta do not currently meet applicable standards, the DWR estimate (2016) likely also drastically understates required OMRR&R costs for Delta levees.

Over the past three decades, State expenditures on Delta levees have apparently reduced the frequency of levee failures. The Subventions Program is widely considered to have contributed to this reduction. Currently, RDs pay a deductible of $1,000 per mile to qualify for up to a 75 percent State and 25 percent local cost share for annual levee maintenance. Despite cost sharing, funds expended for levee maintenance are much less than RDs budget on an annual basis. RDs are also unable (or unwilling) to take full advantage of the subventions funds the State offers, and the State's subventions budget was underspent during the period analyzed.

The $1,000 deductible, which has not been adjusted for inflation, is approximately equivalent to $2,500 in today's dollars. Because the ratio of levee length to area enclosed varies widely for the irregularly shaped islands in the Delta, there is little correlation between a deductible calculated on a per levee mile basis compared to a deductible calculated on a per acre of enclosed area basis. Regardless of how much the deductible is, or how the deductible is measured, an increase in the Delta-wide total deductible is likely to result in reduced maintenance expenditures because, above the current deductible, for every dollar the RDs spend, the State spends $3. If the RDs cannot (or will not) pay more than they are currently paying, then each additional dollar paid in deductibles will reduce the combined State and RD spending by $3.

6.3 Ability to Pay (ATP) Analysis

The purpose of the ATP analysis was to develop and test a practical method for estimating the affordability of levee maintenance and improvements to RDs in the Delta, based on accessible financial and economic information. Lands protected by levees eligible for the Subventions Program are predominantly agricultural, and more detailed financial and economic data are typically available for agricultural than for other land-use categories (e.g., residential, commercial, and industrial). Consequently, ATP procedures used by the DLIS team were driven by:

- Levee maintenance and improvement expenses allocated on a per-acre basis to assessable agricultural properties in each RD.
- Per-acre assessed value of agricultural property.
- Per-acre annual income generated by agricultural production, classified by crop type, and by economic rent based on value of agricultural property.

Proposed ATP calculation procedures are based on the agricultural sector alone. However, the procedures are applicable in principle to all land-use categories within RDs for which sufficient expenditure, income, and property value information is available.

ATP is traditionally defined as affordability; i.e., a constraint on consumers' willingness to pay (WTP) for goods and services (Grassi 2010) – in this case for flood risk reduction and other benefits provided by levees. Affordability is measured by RD income relative to expenses for levee maintenance, independent of WTP. The composite Housing Affordability Index (HAI), published monthly by the National Association of Realtors (NAR), is an example measure of ATP. This index measures median household income relative to the income needed to purchase a median-priced house. A higher HAI ratio indicates greater affordability. For example, a ratio of 100 indicates that median family income is just sufficient, using NAR-defined criteria, to shoulder the financial expense (principal and interest) of a median-priced home. When the ratio falls below 100, typical household income is less than required, and ratios above 100 indicate income greater than needed to purchase a median-priced home (NAR 2017).

The DLIS-proposed procedure for estimation of ATP is limited to economic measures of affordability and does not address:

- Benefits-based measures of ATP.
- Legal constraints on the ability of RDs to generate revenue or apportion levee project costs to parcels.
- Legal distinctions in state and federal law pertinent to levee financing.
- Means of increasing local revenues.

The DLIS ATP analysis results in a practical approach to estimate RD-level ATP for levee maintenance and improvement expenses using basic and, in most cases, readily available information on RD levee expenses and agricultural income, both apportioned on a per-acre basis to agricultural parcels. These data include:

- **Expenses** – RD net capital, operating, maintenance, and debt service expenses for levees and flood risk reduction systems.
- **Income** – agricultural acreage, assessed agricultural property value, crop type, and crop value.

With similar data, the proposed methodology can be extended to other economic sectors represented within RDs, including residential, commercial, industrial, and private utilities.

6.3.1 Approach, Data, and Assumptions

The approach adopted for the ATP analysis computes the ratio of annual levee expenses (E) to annual agricultural income (I), both allocated on a per-acre basis to agricultural parcels within each RD. Expenses include levee and flood management systems capital, OMRR&R costs, and debt service. Annual income is calculated as the sum of income generated by sale of crops plus the annual annuity from rent or amortization of agricultural property based on its assessed value, and consequently embodies both the productive use and land value of agricultural parcels. The ratio of total expenses to total income $\left(\frac{E}{I}\right)$ is inversely proportional to affordability and ATP. However, no uniform standard analogous to the HAI exists relating the $\frac{E}{I}$ ratio to ATP for expenditures on levees and flood risk reduction. Relative financial positions of RDs may be compared, but absolute characterization of RD ATP is not possible using $\frac{E}{I}$ alone. To overcome this problem, the DLIS team proposes a normalized or common-scale measure of ATP for all RDs, computed as follows:

$$ATP = \frac{I-E}{I} = 1 - \frac{E}{I} \qquad \text{(Equation 6-1)}$$

The proposed measure incorporates the $\frac{E}{I}$ ratio and indicates the percentage of discretionary (i.e., available for non-levee expenditures) agricultural income remaining after deduction of levee expenses (allocated to agriculture on a per-acre basis). The upper limit of ATP by this measure is 100 percent, indicating maximum affordability because there are no levee expenses and all agricultural income is therefore discretionary; i.e., can be dedicated to expenditures other than levee maintenance. A value of 0 indicates that agricultural income is matched by expenses, and therefore no discretionary income remains. A negative value indicates that expenses exceed income and that levee maintenance is unaffordable. Because each RD is unique with respect to levee and flood risk reduction components and required expenditures, no “typical” values of levee expenses or agricultural incomes exist that can be used to support an HAI-type analysis. The value of a normalized measure in this instance is that it provides a rational basis for comparison of ATP among RDs with widely varying expenses and incomes.

6.3.2 Proposed ATP Methodology Pilot Application

A pilot application of the proposed ATP methodology was implemented using Equation 6-1 and data compiled from several sources, the most important of which include:

- RD-specific financial data spreadsheet prepared for the DPC as part of its levee funding strategy (M. Cubed 2016) containing annual levee expenses, debt service expenses, and revenues in the form of property taxes, assessments, inter-governmental payments, and leveraging (debt-carrying) capacity; the levee funding strategy was in progress at the time of our analysis, so these data are provisional and subject to change.
- A GIS database that contains parcel identifiers and parcel centroid locations for all assessed properties, intersected with DLIS polder and RD boundaries, and a table of attributes for each parcel that includes use code and both farm and non-farm assessed value.
- A parcel boundaries polygon shapefile used to calculate the surface area (acreage) of each parcel within each RD.
- An Excel spreadsheet developed to categorize parcel centroids previously identified in the above-cited shapefile into one of the following categories: agriculture, commercial, dairy, public, residential, utilities, or unknown.
- A GIS database containing crop type attributes (developed by Jeff Michael, University of the Pacific 2009) for agricultural properties within the region of interest; this layer was used to identify crop types on each of the farm parcels and subsequently to calculate annual income generated by acreage within each RD dedicated to specific crop types.
- A county polygon shapefile layer providing boundaries and populations of California counties (2010 Census, U.S. Census Bureau).
- DWR crop values for Contra Costa, Sacramento, San Joaquin, Solano, and Yolo counties (David Ford Consulting Engineers [Ford] 2013), used to calculate per-acre and RD-aggregate agricultural income for dedicated acreage.
- California agricultural statistics (California Department of Food and Agriculture [CDFA] 2016), used to fill gaps in crop incomes not shown in the Ford 2013 report (e.g., oats at $340 per year per acre).

The following assumptions apply to the pilot study:

- Levee maintenance and improvement expenses, revenues, and income for RDs are in constant dollars and escalate uniformly relative to each other.
- Levee maintenance and improvement expenses include construction and O&M of hydraulic structures, pump stations, storage, and conveyance systems used for interior drainage, all of which are integral to the overall functionality of the Delta flood management system.
- Utilities, public, and unknown property types are non-assessable, and associated property rents and income were not included in ATP calculations.

- No business income was assumed for residential properties; however, property rent was included in RD-aggregate income.
- While commercial property rents were included in aggregated RD income, insufficient data were available for determination of income from commercial property use for inclusion in aggregate RD income. Consequently, the pilot study considered only those agricultural income data available for selected crops (Ford 2013).
- Property rent was computed using assessed property value multiplied by the capital recovery factor for a 30-year payback period and the federal discount rate of 3.125 percent projected for fiscal year 2016 (USACE 2015).
- Crop types and dedicated acreage within RDs were assumed to be constant over time.
- Negative RD expenses were assumed to represent state or federal subsidies and/or inter-governmental transfers, and were added to RD income.

Application of Equation 6-1 in the pilot study was accomplished using levee expenses (capital, OMRR&R, and debt service) allocated on a per-acre basis, and per-acre agricultural property income consisting of crop values and annuitized rent. The following crop types were considered for determination of crop values (farm income):

- Category A – Truck crops (e.g., asparagus, tomato, potato, blueberry)
- Category B – Vineyard
- Category C – Orchard (e.g., almond, cherry, pear, walnut)
- Category D – Field crops (e.g., alfalfa, corn)
- Category E – Grain (e.g., wheat, barley, rice
- Category F – Mixed
- Category G – Other high-value crops
- Category H – Other low-value crops.

In general, Categories A-C and G represent higher value crops, and Categories D-F and H represent lower value crops. Category H includes unknown crop types and uncultivated fields.

The ATP analysis considers only the 55 RDs for which levee expenses and agricultural income data were simultaneously available. The financial data were averaged over five years – 2009 through 2013 – to dampen inter-annual variability in i) expenses (capital, operating, maintenance, and debt service); ii) federal and state subsidies; iii) inter-governmental reimbursements; and iv) income related to agricultural land values, crop type, crop yield, and crop market values. Computed agricultural incomes were also assumed to represent five-year averages over the same period.

Calculated expense-to-income ratios consider net RD spending on levee and related flood risk management services (including debt service), less offsets including use of property and federal, state, and other inter-governmental reimbursements. RD-aggregate income includes rent – assessed property value, in this case agricultural – recoverable over 30 years at 3.125 percent (federal discount rate for 2016), plus agricultural income based on crop type and acreage dedicated to each crop type.

Per-acre levee assessments by RDs were not applied in the ATP calculations principally because assessments lag expenses and thus may not accurately reflect combined capital, operating, maintenance, and debt service expenses for levee and associated flood protection system maintenance and improvement.

6.3.3 Results of ATP Pilot Application

The results of the pilot application of the proposed ATP methodology to the 55 RDs for which levee expenditure and agricultural income data were available are summarized in Table 6-7. We elected to classify ATP by quartiles as appropriate for a pilot application. This is due in part to the lack of a uniform affordability standard analogous to the HAI that would apply equally to all RDs despite widely varying income and expenditures. In addition, a single affordability criterion, whether derived from broader economic data (unavailable for this analysis) or from the statistical analysis of the 55 RDs with available economic data, would not serve to characterize degrees of ATP other than high or low. Classification by quartiles is also more consistent with DLIS risk categories (Very High, High, and Other) than a binary classification. Clearly, more categories (to the extent permitted by larger sample sizes) would be preferable -- for example, ATP categories delineated at 10th percentiles (deciles).

Sources of variation in ATP include the natural configuration of Delta islands; the type, location, and capital and operating costs of the physical components of the flood protection system for which RDs are responsible; and the distribution of land uses and agricultural income-earning potential within the Delta. Table 6-7 provides the following information:

Island or Tract Name – Islands and tracts that represent individual polders.

Reclamation District – RD associated with each island or tract

Agricultural Land Area – agricultural acreage

Income (I) – per-acre agricultural income (annuitized property value plus crop value)

Levee Expenditures (E) – per-acre agricultural levee maintenance and improvement expenses, including capital, operating, maintenance, and debt service expenses

$\frac{E}{I}$ **Ratio** – ratio of per-acre agricultural levee expenses to income

Normalized ATP – percentage of agricultural income remaining after levee expenses (discretionary income)

ATP Classification – characterization based on quartile ranking of RD per-acre agricultural discretionary income percentage: first (bottom) quartile (Very Low), second quartile (Low), third quartile (High), and fourth (highest) quartile (Very High).

Figure 6-2 shows the geographic distribution of the 55 RDs analyzed using the proposed ATP methodology, color-coded by quartile ranking, with dark red for Very Low ATP, light red for Low ATP, light green for High ATP, and dark green for Very High ATP.

Table 6-8 shows the normalized ATP range within each quartile decreasing rapidly moving from the first to fourth quartiles. Among the 14 RDs in quartile 1 (Very Low ATP), the difference between minimum and maximum ATP is about 225 percent (-137 to +88 percent). In quartile 2, representing the next 14 RDs (Low ATP), the range drops to 8 percent (89 to 97 percent). The range in quartile 3 (High ATP) is slightly more than 1 percent (98 to 99 percent), and the range is slightly less than 1 percent (99 to 100 percent) in quartile 4 (Very High ATP).

From Table 6-7, it is apparent that variation in normalized ATP among RDs in the top three quartiles is relatively small – ranging from 89 to 100 percent. As shown on Figure 6-3, the “break point” (indicated by the horizontal dotted line) below which ATP drops precipitously lies at the upper end of the first quartile (very low ATP).

Table 6-7 Per-Acre Agricultural Income, Expenditures, Normalized ATP, and ATP Classification

Name	Reclamation District	Agricultural Land Area (acres)	Income $[I]$ ($ per acre[1] per year)	Levee Expenditures $[E]$ ($ per acre[1] per year)	$\frac{E}{I}$ Ratio	Normalized ATP $\left[1-\frac{E}{I}\right]$	ATP Classification
Bacon Island	2028	5,528	$2,916	$154	5%	95%	Low
Bishop Tract	2042	666	$1,438	$1,321	92%	8%	Very Low
Bouldin Island	756	5,923	$2,337	$206	9%	91%	Low
Brack Tract	2033	4,354	$2,694	$86	3%	97%	Low
Byron Tract	800	3,518	$4,045	$376	9%	91%	Low
Cache Haas Area	2098	5,906	$2,003	$8	0%	100%	Very High
Canal Ranch Tract	2086	2,952	$6,568	$1	0%	100%	Very High
Coney Island	2117	972	$397	$46	11%	89%	Low
Egbert Tract	536	6,334	$1,780	$12	1%	99%	Very High
Empire Tract	2029	3,442	$7,631	$180	2%	98%	High
Fabian Tract	773	6,156	$2,870	$31	1%	99%	High
Glanville	1002	6,525	$3,580	$10	0%	100%	Very High
Glide District	765	1,289	$1,444	$27	2%	98%	High
Grand Island	3	16,182	$2,364	$57	2%	98%	High
Hastings Tract	2060	8,391	$2,353	$9	0%	100%	Very High
Holland Tract	2025	3,938	$4,643	$197	4%	96%	Low
Holt Station	2116	149	$1,945	$5	0%	100%	Very High
Jones Tract	2039	11,782	$1,489	$196	13%	87%	Very Low
King Island	2044	3,111	$3,916	$238	6%	94%	Low
Lisbon District	307	5,751	$2,493	$18	1%	99%	Very High
Little Egbert Tract	2084	3,014	$1,002	$13	1%	99%	High
Lower Roberts Island	684	9,423	$1,886	$295	16%	84%	Very Low

Name	Reclamation District	Agricultural Land Area (acres)	Income $[I]$ ($ per acre[1] per year)	Levee Expenditures $[E]$ ($ per acre[1] per year)	$\frac{E}{I}$ Ratio	Normalized ATP $\left[1-\frac{E}{I}\right]$	ATP Classification
Mandeville Island	2027	1,220	$1,582	$1,264	80%	20%	Very Low
McCormack-Williamson Tract	2110	1,714	$1,702	$17	1%	99%	Very High
McDonald Island	2030	5,151	$2,906	$788	27%	73%	Very Low
Medford Island	2041	768	$4,554	$288	6%	94%	Low
Merritt Island	150	4,639	$3,529	$46	1%	99%	High
Middle and Upper Roberts Island	524	18,189	$2,207	$6	0%	100%	Very High
Mossdale Island	2107	511	$3,651	$60	2%	98%	High
Netherlands	999	23,226	$2,935	$37	1%	99%	High
New Hope Tract	348	8,632	$2,656	$243	9%	91%	Low
Paradise Junction	2095	2,796	$3,511	$14	0%	100%	Very High
Pearson District	551	8,452	$2,684	$38	1%	99%	High
Pico-Naglee	1007	4,131	$2,213	$6	0%	100%	Very High
Randall Island	755	304	$4,807	$99	2%	98%	High
Reclamation District 17	17	4,874	$2,573	$1,231	48%	52%	Very Low
Rindge Tract	2037	6,800	$2,780	$82	3%	97%	Low
River Junction	2064	4,044	$3,002	$24	1%	99%	Very High
Ryer Island	501	11,577	$2,049	$50	2%	98%	High
Sherman Island	341	1,054	$3,586	$2,750	77%	23%	Very Low
Shima Tract	2115	1,837	$765	$30	4%	96%	Low
Stark Tract	2089	725	$1,106	$136	12%	88%	Very Low
Stewart Tract	2062	507	$1,488	$571	38%	62%	Very Low
Sutter Island	349	2,404	$3,814	$29	1%	99%	Very High
Terminous Tract	548	11,091	$4,054	$115	3%	97%	Low

Name	Reclamation District	Agricultural Land Area (acres)	Income $[I]$ ($ per acre[1] per year)	Levee Expenditures $[E]$ ($ per acre[1] per year)	$\frac{E}{I}$ Ratio	Normalized ATP $\left[1-\frac{E}{I}\right]$	ATP Classification
Twitchell Island	1601	1,095	$1,667	$3,950	237%	-137%	Very Low
Tyler Island	563	8,665	$2,754	$182	7%	93%	Low
Union Island East	1	11,268	$3,927	$25	1%	99%	Very High
Union Island West	2	13,041	$1,284	$18	1%	99%	High
Upper Andrus Island	556	2,354	$2,818	$42	1%	99%	High
Venice Island	2023	1,536	$1,357	$594	44%	56%	Very Low
Victoria Island	2040	7,135	$2,137	$59	3%	97%	Low
Walnut Grove	554	272	$2,343	$293	13%	87%	Very Low
Woodward Island	2072	1,826	$1,357	$1,841	136%	-36%	Very Low
Wright-Elmwood Tract	2119	1,991	$1,577	$445	28%	72%	Very Low

Note:

1. Measured in dollars per acre of *agricultural* land per year.

Figure 6-2 ATP Classification

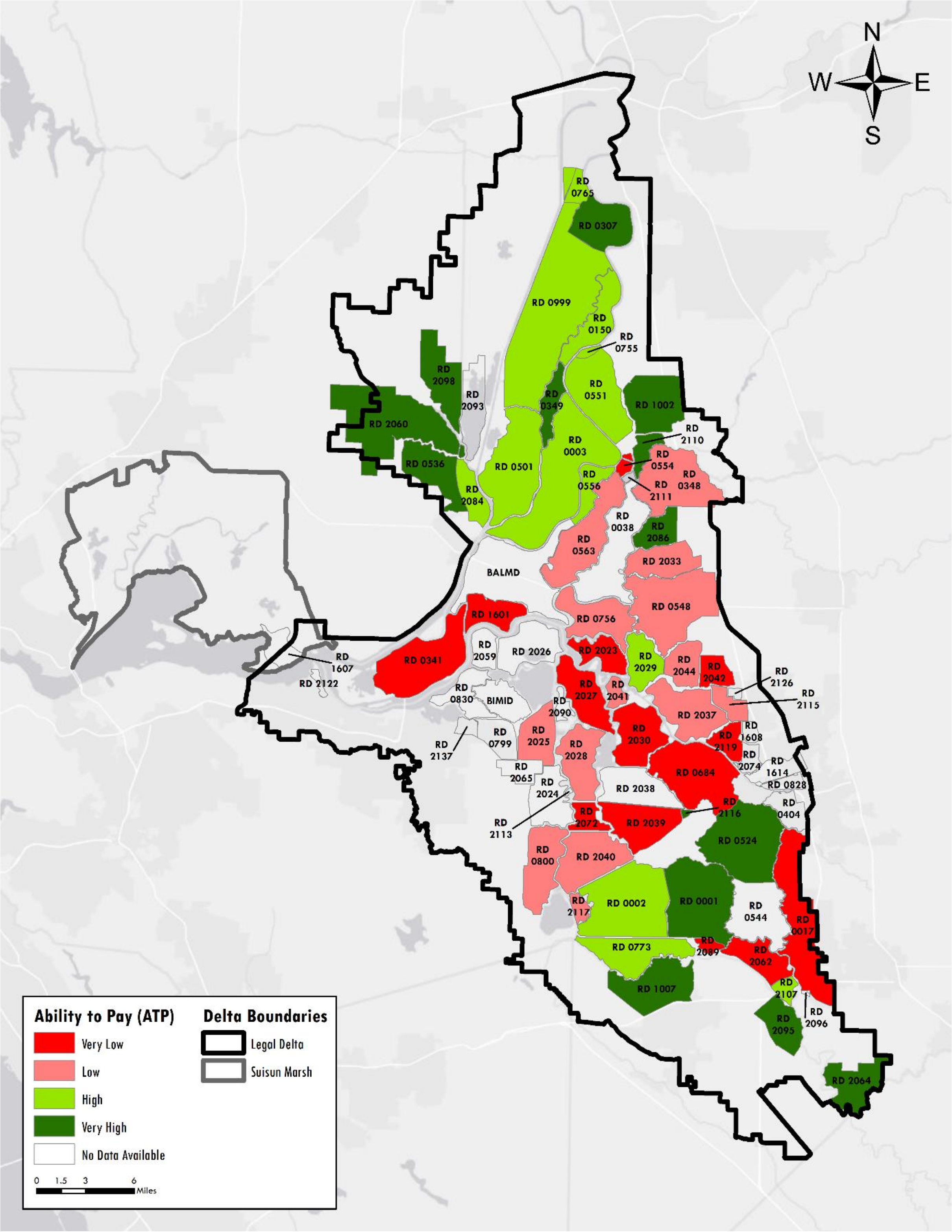
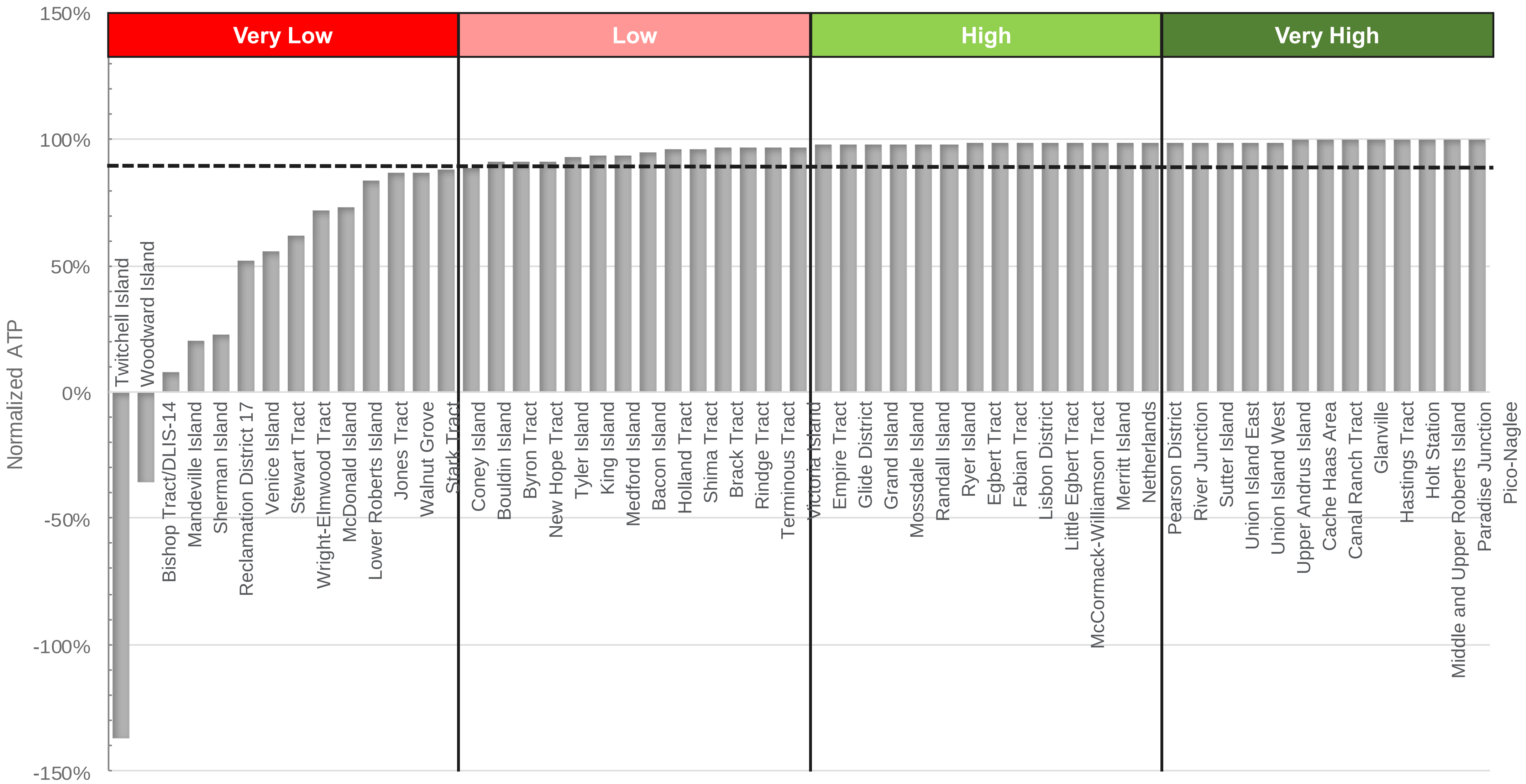


Table 6-8 ATP Quartile Statistics

Statistical Measure	All	1st Quartile (Very Low)	2nd Quartile (Low)	3rd Quartile (High)	4th Quartile (Very High)
Minimum	-137%	-137%	89%	98%	99%
Mean	82%	39%	94%	98%	100%
Median	97%	59%	94%	99%	100%
Maximum	100%	88%	97%	99%	100%
Range	237%	225%	8%	>1%	<1%
Count	55	14	14	13	14

Figure 6-3 RD Ranking by Normalized ATP



6.3.4 Summary and Conclusions – ATP Analysis

Because ATP classification by quartiles in the pilot application is relative to other RDs, the proposed ATP measure does not characterize affordability in the same manner as the HAI or other traditional income-based procedures such as i) income tax rates based on adjusted gross income (AGI), or ii) composite indices compiled based on a basket of income sources (property values, AGI, taxable retail sales) used in some jurisdictions to determine, for example, a school district's ability to pay education costs. Taxes and school assessments are common and undivided expenses, whereas, without institutional and financial mechanisms to distribute total costs of Delta flood management systems among all RDs, the financial burdens shouldered by some will inevitably exceed others – in some cases, as shown in Table 6-7, by orders of magnitude. The "break point" shown on Figure 6-3 suggests that when important or urgent levee investments are needed by RDs near the bottom of the ATP scale, i.e., those that can least afford them, the following aspects of levee funding decisions should be given careful consideration:

- Determination of achievable benefits of levee investments.
- Allocation of costs of levee system improvements.
- Formulation and implementation of subventions and subventions deductibles policies.

Under current arrangements for financing of levee maintenance and improvements, individual RD expenses and income must be jointly considered in determination of ATP. However, alternative institutional and financial mechanisms for redistribution of levee expenses could potentially provide for:

- Equitable distribution of financial burden among RDs in proportion to flood risk reduction and other benefits received.
- Efficient and adaptive allocation of State and federal funds, including subventions and subvention deductibles.
- Comprehensive information for coordinated planning of levee system improvements.

From this perspective, a portfolio approach to cooperative financing of infrastructure investments known as Enhanced Infrastructure Financing Districts (EIFDs) may be worthwhile. California Senate Bill 628 (SB 628 2014) authorizes the creation of EIFDs as a new governmental entity. One or more EIFDs may be created within a city or county and used to finance the construction or rehabilitation of a wide variety of public infrastructure and private facilities. An EIFD may fund these facilities and development with the property tax increment of those taxing agencies (cities, counties, special districts, but not schools) that consent. An EIFD may also use assessments, fees, and government grants to finance infrastructure investments such as levee maintenance and improvement.

The results of the ATP analysis indicate that some RDs would benefit from increased subventions funding (i.e., additional subsidies). On the other hand, some RDs could continue their current levee maintenance programs with less subventions support from the State. Adjustment to the deductible amount that each RD receives based on its ATP (i.e., increasing some while decreasing others) could result in a more equitable distribution of State subventions funding for levee maintenance and improvement throughout the Delta. Implementation of the proposed methodology requires collection and analysis of RD expenses, and financial and economic data applicable to the agricultural sector. Data collection should be extended to as many RDs as possible, and – data permitting – to the residential, commercial, industrial, and private utility sectors as well. To reduce inter-annual variation, ATP estimates should be updated every five years using running-average expenditure, financial, and economic data.

No matter how measured, there is a need for further analysis to identify appropriate methods and thresholds for consideration of ATP in levee funding decisions. ATP is closely aligned with WTP, the primary measure of benefits of investment strategies that, together with costs of provision, form the basis for cost allocation. The essential difference is that WTP is independent of budget constraints, whereas ATP is not (Grassi 2010). In this case, the pilot application shows significant constraints on levee expenditures by some of the RDs in the Very Low ATP category. Future strategies for investments in levees and other flood risk reduction measures would consequently be better informed by consideration of ATP as a constraint on achievable benefits than by benefit-cost analysis alone.

7.0 RECOMMENDATIONS

Though the DLIS analysis has been developed using the best available data, the baseline analysis and results presented here represent only a snapshot in time, and risk is ever-changing. Priorities can therefore shift as new data become available and as conditions change. The risk analysis methodology was developed to accommodate new data as they become available, to recalculate risks as needed, and to keep the DLIS current. The use of the DST enables the Council and the State to continuously evaluate risks, consider new project options as they become available, and update and manage priorities and investments as desired.

7.1 Update and Maintain the Risk Management Database

One goal of the DLIS project was to use the best available information and to update the analyses as new information becomes available and as conditions change. The database underlying the DST should be updated whenever significant changes occur that could affect risk, such as changes to the flood hazard or changes to potential consequences. Examples of changes to hazards include SLR, levee improvement or degradation, and changes in precipitation patterns and reservoir operations. Examples of changes to consequences include increases in population; residential, commercial, and industrial development; and construction of new infrastructure.

In addition, there may be important changes in habitat, water use, and cropping patterns. Modifications to the configuration of the Delta’s levee system will also affect a long-term investment strategy. For example, the Delta’s levee system will be affected by levees that fail and are not fixed, and by construction of major water supply infrastructure such as California WaterFix. As the database is updated, risk can be recalculated and risk reduction options can be evaluated, enabling the State to continue to manage priorities.

7.1.1 Hazards and Levee Conditions

Many factors will affect the probability of flooding in the Delta and Suisun Marsh, including SLR, climate change impacts on hydrology, modifications to upstream reservoir operations, and changes in levee conditions. For example, an increase in SLR or levee deterioration, which will occur if OMRR&R are not sufficient, will affect levee fragility and increase the likelihood of levee failure. Changes in the hydrologic regime in the Delta will affect stage-recurrence curves and the probabilities of levee failure. Lack of adequate maintenance or storm damage that is not repaired will adversely affect a levee’s ability to withstand hazards, while regular levee maintenance and improvements will enhance a levee’s fragility curve and decrease the probability of levee failure.

State and federal agencies, local flood management agencies, and others regularly evaluate levee conditions, forecasts of hydrologic conditions and SLR, and changes in seismic probabilities. As changes occur and new information is available on flood hazards, the Council can integrate this information into the analysis.

7.1.2 Inventory of Assets

The inventory of Delta and Suisun Marsh assets should be kept up to date. The consequences of flooding depend on the people, natural assets, and built infrastructure that could be exposed to floodwater. With all other factors being the same, an increase in built infrastructure or population growth will result in an increase in EAD and EAF in those areas. Changes to land use or cropping patterns may also affect EAD. Changes in habitat or ecological processes may positively or negatively affect high value and other types of habitat. Water supply and water quality, key Delta assets, will be affected by changing hydrodynamics, salinity intrusion, water availability and use, and water quality consequences from levee failures. As information on new infrastructure and a changing environment becomes available, the Council can integrate these data into the database.

7.2 Identify and Evaluate Risk Reduction Actions

As the database is updated following changes to available information or policies, risks should be reevaluated to enable a continuous, up-to-date understanding of risk. The DST can display the risks and revised priorities, as well as evaluate options for reducing risks.

7.2.1 Identifying Projects

Several efforts are underway to identify levee improvement projects and other risk reduction actions for the Delta, including the Central Valley Flood Protection Plan (CVFPP), regional flood management plans to contribute to the CVFPP, Subventions Program and Special Projects Program, and Suisun Marsh Management Plan. These and other planning efforts are identifying multi-benefit projects, such as those provided by proposals being considered for the Yolo Bypass and Paradise Cut. These projects and others identified through a future solicitation process can be incorporated into the DST, evaluated for cost-effectiveness in reducing risks, and assessed for trade-offs between benefits and impacts.

7.2.2 Evaluating Projects and Trade-offs

The DST was designed to evaluate the effectiveness of projects at reducing risk and to compare the trade-offs across alternatives. The DST provides evaluation and visualization tools to support the deliberation-with-analysis process. The improvements to achieve the Delta-specific PL 84-99 levee design standard described in Section 5.0 demonstrate an approach for evaluating risk reduction options. Evaluation of a more robust set of options for High Priority islands and tracts could further inform decisions about the types, costs, impacts, and benefits of alternative approaches.

7.2.3 Building Portfolios

The DST can inform and facilitate discussion and decision-making regarding portfolios of risk reduction actions. For example, if a specified amount of funding is available for risk reduction, the DST can support evaluation of the most efficient and effective investments to reduce risks as well as assessment of opportunities to include habitat enhancement in a portfolio of investments. Section 5.0 describes an evaluation of a single purpose portfolio, achieving Delta-specific PL 84-99 design geometry for non-project levees. The Council and its partners could expand this concept to develop and evaluate a multi-benefit portfolio of investments.

7.2.4 Managing Island Priorities

The initial list of island priorities will change as levee improvements or other flood risk management actions are completed, reducing the risk on those islands and tracts. Keeping the database up to date with changing hazard and asset information enables a reevaluation of risks that can be visualized in the DST.

7.3 Apply Tolerable Risk Guidelines

The application of tolerable risk to floodplain management is more fully described in the Methodology Report (Council 2016b). Currently. there are no national life safety, flood damage, or other risk-based standards or guidelines to determine if islands and tracts in the Delta and Suisun Marsh are at a level of flood risk that would be considered tolerable. The tolerable risk guideline or threshold is something that must be decided by those most closely involved in and affected by levees in the Delta. That is, those who will be affected by flooding in the Delta, and those who will make investments to reduce risk in the Delta must decide based on their own understanding of risk and the available financial resources the level of risk they are willing to tolerate to secure the benefits of living, working, and recreating in the Delta.

Based on the DLIS, the Council determined the islands and tracts that are currently Very High Priority or High Priority to receive State investment to reduce risks. However, stakeholders on all islands must decide whether the strategy identified for their island or tract reduces risk sufficiently to them, or to the collective society. If not, then stakeholders on that island should continue to make risk reduction investments to reduce risk to as low as reasonably practicable relative to their own risk tolerance.

A comprehensive investment strategy considers and implements both structural and non-structural measures, and what is considered tolerable today may not be considered tolerable tomorrow. For example, prior to Hurricane Katrina in New Orleans, there was rarely consideration for or calculation of risks to life in flood risk management evaluation. In a post-Hurricane Katrina world, however, the USACE has implemented a program of risk management that holds public safety paramount and has developed methods to characterize risk as a basis for decision-making for its dams and levees portfolio (USACE 2010).

7.3.1 Structural Options

Structural measures address the probability of flooding with physical features like levees. Ongoing levee maintenance by local RDs has been and will continue to be critical for reducing risks in the Delta. However, if risks are determined to be unacceptable, or intolerable by the State or by stakeholders, then stakeholders can invest in structural measures like levee improvements, floodwalls, floodways, and bypasses to reduce flood risk to tolerable levels.

7.3.2 Non-structural Options

If risks are determined to be unacceptable, or intolerable, stakeholders may also choose to invest in non-structural measures and emergency preparedness, both of which should be made an integral part of any flood risk reduction strategy. These measures may include:

- Improved building codes.
- Actions, such as floodproofing, to permit sheltering in place.
- Provisions for vertical evacuation for residential or high occupancy buildings (such as schools or senior centers) located in deep floodplains.
- Implementation of emergency warning systems, such as civil defense sirens.
- Improved crisis communications emphasizing identification, improvement, and implementation of emergency evacuation routes.
- Implementation of emergency preparedness and response programs designed to educate the public and to raise overall public awareness of flood hazards.

7.3.3 Calculating Risk Reduction

The risk analysis methodology and DST can calculate the risk reduction achieved by all measures considered, both structural and non-structural. The DST can also calculate the cost effectiveness of risk reduction, which enables a comparison of the trade-offs among different risk metrics or impacts of various projects. For example, some projects that improve levees may also increase the levee footprint, impacting prime farmland or high value habitat in that location.

7.3.4 Communicating Risk

Risk communication is an essential part of any flood risk management strategy, and California’s annual Flood Preparedness week could provide a suitable platform for regularly discussing flood risk with both decision-makers and the public. Risk communication is critical so that the public, stakeholders, and decision-makers fully understand the probability of failure and the potential impacts both from flooding and from proposed risk reduction measures. Understanding risk is critical to informing an effective investment strategy that makes the best use of the State’s limited resources to reduce risk to State interests.

In addition, a full understanding of risk is necessary so that the State and stakeholders can determine whether residual risks are considered tolerable, or whether additional actions to reduce risk are warranted. For example, communities that are trying to achieve levee accreditation through the National Flood Insurance Program, or trying to improve levees to participate in the PL 84-99 program, must understand their residual risk. The discussion of residual risk is often overlooked, which leaves communities with a false sense of security and often ill-prepared for flooding. Communicating residual risk is key to developing and implementing actions to reduce flood risk.

7.4 Recommended Path Forward

Our recommended actions describe the activities to maintain and further develop a risk-informed floodplain management approach that addresses risks to lives, property, and State interests in the Delta. The Council, in cooperation with its partner State agencies, could undertake these actions individually or together as a Delta-wide risk reduction program.

7.4.1 Secure Capacity to Manage the DST

The DST risk management database is built using readily available software (Microsoft Excel, Access, and open-source programming language R). Substantial effort has been expended to compile and rationalize existing data to populate the database. These data have ongoing value to the State and other stakeholders for flood risk reduction, ecosystem restoration planning, and other activities in the Delta. The State should secure resources and capacity to update data and incorporate new information as it is developed for the Delta and Delta levees.

7.4.2 Use DST to Evaluate Grant Applications

As existing State funding programs for Delta levee investments and risk reduction proceed, the DST can be used to evaluate proposed projects for cost-effectiveness and other benefits and impacts before approving grants to LMAs. Such an evaluation could ensure a balanced “portfolio” of investments within an individual program grant cycle or across a combination of programs in a grant cycle. The DWR, CVFPB, and Council should jointly define grant objectives and update the DST to incorporate appropriate evaluation criteria.

For more than three decades, State policy and local Delta interests have had a shared objective to achieve a minimum LOP for non-project levees in the Delta. Progress toward this objective has been slow, and the costs for achieving the objective are broadly debated. The DST offers an opportunity for a stakeholder-driven planning process to further define what is needed to achieve the Bulletin 192-82 or PL 84-99 levee geometries, how much the improvements would cost, and the risk reduction benefits achieved. Such an approach could also consider and include opportunities for ecosystem enhancement (e.g., setback levees and riparian corridors) in a portfolio approach to demonstrate a net habitat improvement for the Delta levees programs. A master plan for non-project levees should be complementary with the CVFPP planning for project levees and planning for enhancing the exterior levees of Suisun Marsh.

Activities to reduce flood risk in the Delta are currently underfunded. Increased investments by LMAs with assistance from DWR’s Special Projects and Subventions Programs are needed to reduce flood risk for non-project levees. Through the DLIS, the Council has identified priorities for State investment in Delta levees, which holds promise to improve special projects funding decisions for levee improvements and to direct funds where risk to State interests is greatest. The Subventions Program for OMRR&R of Delta levees could be enhanced by i) updating subventions deductible amounts and streamlining reimbursement procedures; ii) implementing a fair and equitable ATP process; iii) applying a system-wide process for efficiently and equitably allocating State funds for subventions; and iv) examining creative financing mechanisms such as EIFDs.

7.4.3 Implement Tolerable Risk Guidelines

The principles of tolerable risk, as applied in the DLIS, say that i) risk cannot be ignored; ii) life safety is paramount; ii) absolute safety cannot be guaranteed; and iv) risks should be reduced to as low as reasonably practicable without spending an inordinate amount of time, money, or resources. As developed in the DLIS, the DST quantifies the risk reduction that can be achieved by structural or non-structural means, and identifies residual risk. Using the DST, stakeholders most affected by flood risk can (and should) determine their own tolerance for the residual risk remaining after actions are taken to reduce flood risk.

Stakeholders who benefit from Delta levees can use the risk information from the DST to decide if risks are tolerable, or are not acceptable. By understanding risk, stakeholders can decide if actions to reduce risk are adequate and cost-effective, or if alternative measures should be taken. The risk analysis employed by the DST enables the Council, its partner agencies, and affected stakeholders to i) better understand, manage, and communicate risk; ii) explore costs, impacts, and benefits of alternative risk reduction strategies; iii) evaluate trade-offs and cost-effectiveness; and iv) establish priorities and assure fair treatment.

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