Decision Support Tool for the San Francisco Bay-Delta Levees Investment Strategy

Documentation and Use

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Sponsored by the Delta Stewardship Council
Preface

The Delta Stewardship Council (Council) initiated the Delta Levees Investment Strategy (DLIS) project to develop a transparent strategy for prioritizing State-funded levee investments in the Delta. This project is in support of the requirements of California Water Code § 85305(a), which states:

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.

85306. The Council, in consultation with the Central Valley Flood Protection Board, shall recommend in the Delta Plan priorities for state investments in levee operation, maintenance, and improvements in the Delta, including both levees that are a part of the State Plan of Flood Control and nonproject levees.

The DLIS project supported this Council charge by (1) developing an analytical framework to evaluate flood risk to each Delta tract or island with current maintenance and with additional levee upgrades; (2) creating a decision support tool (DST) to enable the Council and stakeholders to explore flood risk results for each island across different time frames and future scenarios; and (3) using the DST with the Council to develop a prioritized list of islands for levee investment, which informed a revision to the policy on “Prioritization of State Investments in Delta Levees and Risk Reduction,” as described in a March 2017 draft update of Chapter Seven of the Delta Plan (Delta Stewardship Council, 2013).

This report describes use of the DST, along with its methodological basis. This report complements the main project report (Arcadis, 2017a).

Community Health and Environmental Policy Program

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Questions or comments about this report should be sent to the project leader, David Groves (groves@rand.org).
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Summary

The Sacramento–San Joaquin Delta comprises over 100 islands and tracts northeast of the San Francisco Bay. Most are below sea level and are protected by levees, but some are tidal or above sea level. The Delta supports a unique ecosystem, communities, and agricultural land, and plays a key role in the California water distribution system. The flood risks facing the Delta are complex and varied. Some islands are at highest risk from flood damage to human life or structures and property, whereas others are at risk of impacting the state’s water supply, flooding important habitat, or compromising the Delta’s historic towns, prime agricultural land, or public roadways. The possible investments to mitigate these risks are numerous, and they will affect Delta risks differently. The Delta Stewardship Council (Council) commissioned the development of a risk modeling framework and decision support tool (DST) to aid in the formulation of a Delta Levees Investment Strategy (DLIS). This report provides documentation on how to use the DST, complementing the Delta Levees Investment Strategy final project and methodology reports (Arcadis, 2017a, 2017b).

Chapter One provides an overview of the DLIS project and the DST, highlighting how the DST supports deliberations over analysis related to flood risks and investment priorities (Figure S.1). Chapter Two then summarizes the methodology used to estimate levee flood risk with respect to life, property, water supply, habitat, and Delta as Place (DAP), with and without additional levee investments. Chapter Three then describes each of the eight sections of the DST:

1. Instructions and Guide
2. Islands and Vulnerable Assets
3. Assessing Risk (Risk Maps)
4. Identify High Risk Islands
5. Ranking Islands by Risk
6. Levee Investments and Change in Risk
7. Draft Delta Levees Investment Priorities
8. Developing a Portfolio of Levee Investments

Chapter Four presents the conclusions and describes how the tool was used by the Council to update Chapter Seven of the Delta Plan (Delta Stewardship Council, 2013) by revising the policy on “Prioritization of State Investments in Delta Levees and Risk Reduction.” Figure S.2 shows the investment priorities developed using the DST, as documented in the DLIS project report (Arcadis, 2017a).
Figure S.1. Overview of DST

Data/Inputs
- Islands
- Vulnerable assets
- Hazards
- Investments
- Costs

Analyze
- Estimate risks
- Evaluate investments
- Generate portfolios

Discuss
- Risk thresholds
- Stakeholder risk concerns
- Sensitivity to uncertainty
- Investment trade-offs

Outputs
- Island risks
- List of high-risk islands
- List of ranked investments
- Groupings of investments ("Portfolios")
Acknowledgments

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<th>Description</th>
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<td>CDFW</td>
<td>California Department of Fish and Wildlife</td>
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<tr>
<td>CE</td>
<td>cost-effectiveness</td>
</tr>
<tr>
<td>DAP</td>
<td>Delta as Place</td>
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<tr>
<td>DLIS</td>
<td>Delta Levees Investment Strategy</td>
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<tr>
<td>DST</td>
<td>decision support tool</td>
</tr>
<tr>
<td>DWR</td>
<td>California Department of Water Resources</td>
</tr>
<tr>
<td>EAD</td>
<td>Expected Annual Damage</td>
</tr>
<tr>
<td>EAF</td>
<td>Expected Annual Fatalities</td>
</tr>
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<td>SLR</td>
<td>sea level rise</td>
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1. Introduction

Sacramento–San Joaquin Delta Levees

The Sacramento–San Joaquin Delta comprises over 100 islands and tracts northeast of the San Francisco Bay (Figure 1.1). Most are below sea level and are protected by levees, but some are tidal or above sea level. The Delta supports a unique ecosystem, communities, and agricultural land, and plays a key role in the California water distribution system.

The flood risks facing the Delta are complex and varied. Some islands are at high risk from flood damage to human life or structures and property, whereas others are at risk of impacting the water supply, flooding important habitat, or compromising the Delta’s historic towns, prime agricultural land, or public roadways. The possible investments to mitigate these risks are numerous, and they will affect Delta risks differently.

Delta Levees Investment Strategy

Understanding which islands bear the most risk provides a starting point for considering how to invest in levee improvements to reduce flood risk. The ranking of islands by risk alone, however, cannot identify where the State should focus its investments to advance State interests. Alternative views about the importance of different types of risks will affect how one might prioritize investments. It is also critical to account for the cost-effectiveness (CE) of various investments. As State resources are limited, a guiding principle for allocation should be those investments where the most benefit can be achieved. Importantly, uncertainty about future risks could lead to ambiguity about the best investment prioritization.

Decision Support Tool

A decision support tool (DST) has been developed to help the Council understand the risks that Delta islands and tracts face from levee failure and flooding, and then develop a strategy to reduce those risks through levee investments. The DST is designed to support a deliberation-with-analysis process by which quantitative analysis is used not to provide a single answer but rather to frame and illuminate key policy trade-offs (National Research Council, 2009). The DST uses a methodology that was successfully deployed to support the development of the Louisiana Coastal Protection and Restoration Agency’s 2012 Coastal Master Plan (Groves, Sharon, and Knopman, 2012; Groves and Sharon, 2013).

Specifically, the DST supports deliberations by summarizing information about baseline risks and the effects of different investments on baseline risk, and then identifying portfolios of investments that reflect State interests. The user (e.g., the State or stakeholder) can specify his or
Figure 1.1. Sacramento–San Joaquin Delta Islands and Tracts

her priorities over the different performance metrics (e.g., risk to life vs. risk to property vs. risk to water supply vs. risk to habitat) and assumptions about future risks to enable a transparent comparison of results across different metrics. Such an exploratory modeling approach is suited for long-term policy questions in which there is significant uncertainty, there are many diverse views of what constitutes desirable outcomes, and there is disagreement about how the system will respond to future stressors (Lempert, Popper, and Bankes, 2003).

The DST supported the Council in developing a levee investment strategy through four key steps:

1. Compiling and displaying information about vulnerable assets 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 different types of risks to define high-risk islands
4. Assimilating and displaying results of analyses of how different levee investments would reduce risk.

To support these steps, the DST assimilates information about flooding hazards (hydrologic and seismic events), vulnerable assets, and levee configurations and condition. It then estimates flood risks to lives, property, non-tidal habitat, water supply, and Delta as Place (DAP) considerations for each island and tract with and without levee investments. For lives, property, and non-tidal habitat, formal risk metrics characterize the expected annual loss of lives, property, and habitat (respectively). For water supply and DAP considerations, proxy risk metrics are developed that describe islands or island attributes that are vulnerable to flooding. The DST provides interactive visualizations of this information.

The DST then performs basic calculations to summarize risk information across the range of metrics and enables users to specify weights for different risk metrics to aggregate risks for each island. Lastly, the DST provides different ways to develop portfolios of investments that best reduce risk to State interests given various planning constraints. To develop portfolios, the DST uses a simple and transparent approach to multicriteria decision analysis (Keeney and Raiffa, 1993; Kiker et al., 2005; Lahdelma, Salminen, and Hokkanen, 2000; Linkov et al., 2006). Specifically, the DST enables the user to include investments that are cost-effective based on a user-defined threshold for at least one of four risk metrics. The DST tracks the total cost of the proposal by the Council-defined priority tiers. For example, the DST enables the user to specify budgets and then evaluate which investments reduce the different risks the most across the Delta.

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 particular performance metric or time period), set metric weights for island rank and investment rankings, define portfolios of levee investments, and explore different trade-offs across the portfolios. Figure 1.2 summarizes the inputs, discussion and analysis, and outputs of the DST. Inputs include the information and data
used to calculate risks as described above, including physical island and tract sizes, elevations, levee conditions, and so forth; the assets and replacement values on each island; and hazard information. Inputs also include information about proposed investments (or projects that reduce flood risk) as well as the costs in terms of both flood losses/damages and investments/projects to reduce flood risks.

The DST visualizations are made available via an interactive website (Figure 1.3). Different versions of the DST have been developed to support internal analysis by the Council, review by technical stakeholders, and interaction by the general public. The latest version of the DST is available on the RAND website (Groves, 2019).

The DST has been used to assist the Council in understanding the range of possible flood hazards and risks facing the Delta, develop a prioritized list of islands based on risk, and evaluate a set of investments designed to bring each island’s levees up to the Delta-specific PL84-99 guidelines (USACE, 1988). As described in Arcadis (2017b, pp. 12–13):

*Public Law 84-99 (PL 84-99) guidance is a minimum requirement established by the U.S. Army Corps of Engineers (USACE) for levees in its Rehabilitation and Inspection Program (33 Code of Federal Regulations 701n) (69 Stat. 186). Delta islands or tracts that meet this standard and have levee-maintaining agencies that participate in the USACE’s program may be eligible for federal funding for levee rehabilitation, island restoration after flooding, and emergency assistance. The PL 84-99 standard for levee geometry defines a minimum levee height and a factor of safety for slope stability, but is not associated with a flood recurrence interval or LOP [level of protection] (such as a 1 percent annual exceedance probability [AEP] flood). In 1987, the USACE developed a Delta-specific standard based on the Delta’s soil and levee foundation conditions. (Council 2013)*
Using these data and additional information in the DST, the Council developed a preliminary three-tier list of islands to prioritize for levee investments, and in March 2017 developed a draft amendment to the Delta Plan (Delta Stewardship Council, 2013).¹

The DST and the methodology have been designed to assimilate new information as it becomes available. For example, in the future, new information about levee stability; sea level rise (SLR) impacts in the Delta; precipitation timing and patterns, including extended periods of drought; earthquake hazards; ecosystem factors; or project costs could be assimilated into the DST to inform revised priorities.

¹ See the Project Documents section of the Delta Stewardship Council’s Delta Levees Investment Strategy (DLIS) website for a link to the draft revisions to the Delta Plan (Delta Stewardship Council, 2017a).
2. Summary of Risk Evaluation Methodology

The DLIS analysis seeks to prioritize investments based on how they meet important goals for the State—to reduce flood risks to lives and property, to water supply reliability, and to Delta ecosystem function—and to do so efficiently. The foundation for this analysis is estimates of flooding probability due to seismic and hydrologic events for each leveed island and tract in the Delta. These flooding calculations are then combined with estimates of different consequences of flooding (e.g., to lives, property, water supply, habitat, and DAP) using a classical “probability × consequence” framing to calculate risk. For water supply and DAP, however, reliable estimates for the consequences of flooding were not available for inclusion in this analysis. Therefore, proxy probability of flooding islands and assets of interest are used to represent the risk.

All risk calculations are performed for current conditions (using year 2012 sea levels, population estimates from 2010, and current asset inventories, including habitat and agricultural land); for near-term future conditions in the year 2030 (using two estimates of SLR and a single projection of lives, assets, and land use); and for longer-term future conditions in the year 2050 (using two estimates of SLR and a single projection of lives, assets, and land use).

Probability of Flooding

Estimates of current and future flood risks to the Delta are based on existing estimates of flood stage and seismic hazards and of levee fragility. The specific calculations are described in the project’s methodology report (Arcadis, 2017b).

Flood Risk Metrics

The Delta is complex; risks to its value or function can be measured in many ways, and finding the best metrics can be challenging. For instance, an ecosystem includes many biological, geochemical, and physical processes. Many of these characteristics—such as biodiversity, water quality, habitat structure and connectivity, food web dynamics, nutrient cycling, and species population dynamics—could be used to measure ecosystem function and flood risk to ecosystem function. Having too few metrics to describe risk means possibly failing to assess important impacts of potential levee investments. However, having too many metrics makes it difficult for decisionmakers and stakeholders to see trends and trade-offs between options and find portfolios that balance their concerns. Additionally, the complex interactions between potential levee investments and these characteristics are either poorly understood or so complex that they cannot be readily understood and effectively used for making policy decisions.

The DST uses simple but meaningful metrics to describe risk and prioritize levee investments. A small number of metrics represent risks in the Delta to four key interests: life and property, water supply, ecosystem function, and DAP (Table 2.1). Only metrics with credible relationships
that facilitate prioritizing investments are used. The planning framework and DST are flexible and can accommodate new metrics if supporting data are developed.

Table 2.1. Summary of Objectives and Metrics for Assessing Flood Risk

<table>
<thead>
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<th>What Are the Interests?</th>
<th>What Types of Impacts Are Measured?</th>
<th>What Metrics Measure Each Type of Risk?</th>
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<tr>
<td>Life and property</td>
<td>Fatalities</td>
<td>Expected annual fatalities (EAF) (fatalities/year)</td>
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<td></td>
<td>Asset damage, including agricultural losses</td>
<td>Expected annual damage (EAD) ($)</td>
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<td>Water supply</td>
<td>Flooding of islands important to water supply</td>
<td>Probability of flooding of islands important to water supply (%)</td>
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<tr>
<td>Ecosystem function&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Flooding of high-value habitat protected by levees</td>
<td>Expected flooding of high-value non-tidal habitat (acres flooded/year)</td>
</tr>
<tr>
<td>DAP</td>
<td>Flooding of islands with legacy towns</td>
<td>Probability of flooding of islands with legacy towns (%)</td>
</tr>
<tr>
<td></td>
<td>Flooding of prime agricultural land</td>
<td>Expected flooding of prime agricultural land (acres flooded/year)</td>
</tr>
<tr>
<td></td>
<td>Flooding of islands with important state highways</td>
<td>Probability of flooding of islands with public roadways (%)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Additionally, the potential tidal habitat affected by levee investments was estimated and considered as part of the prioritization process.

**Risk to Life**

Risk to life due to flooding events is measured by EAF, which is expressed as fatalities per year. Fatalities are used as proxy for death and injury consequences to humans. The calculation considers the probability of an island flooding because of a seismic or hydrologic event and the likelihood of a fatality given a flood event. Several components are used to estimate the likelihood of fatality given a flood. These include the estimated warning time given the river stage (in the calculations, warning time depends only on river stage), a population proportion at risk given the warning time, proportions of the population considered willing and able to evacuate given warnings, and a mortality function, which is used to estimate the mortality rate given the inundation depth (a function of stage) and given that a levee has failed. The EAF model, implementation, and supporting data are described in further detail in the main project report (Arcadis, 2017b).

Current population estimates are derived from the 2010 census. To develop population projections for 2030 and 2050, we used population growth rates based on county-specified California Department of Finance projections (DOF, 2013). For the most part, population growth was assumed to occur only in the secondary zone of the Delta.<sup>1</sup> See Arcadis (2017b) for more information.

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<sup>1</sup> The secondary zone of the Delta includes the urban areas of Stockton, Lathrop, Tracy, Oakley, and West Sacramento.
Risk to Property

Risk to property due to flooding events is measured by EAD. This measure reflects the annualized economic consequences of flooding, such as damage to homes, farms, and businesses as well as losses of crop value, expressed in terms of value lost (dollars) per year. The calculation considers the probability of an island flooding because of a seismic or hydrologic event, the subsequent average inundation depth due to the flood event, and any ensuing monetary damages that would be incurred given a flood event. The following assets are included in the EAD calculation:

- Aggregate mine
- Airstrip
- Cell tower
- Commercial structure
- Communications facility
- Confined animal facility
- County highway
- Drinking water intake
- Field crop
- Fire station
- Gas oil production field
- Gas storage
- Gas well active
- Historic place
- Legacy town
- Marina
- Mokelumne Aqueduct
- Nat gas pipeline
- National historic landmark
- Oil pipeline
- Operational power plant
- Police
- Port
- Prison
- Private school
- Public school
- Railroad
- Residential structure
- Rock stockpile, Department of Water Resources (DWR)
- Scenic highway
- State park
- Substation
- Terminal
- Transmission line tower
- Wastewater treatment plant

Damages to each asset are estimated based on depth-to-damage curves that map an inundation depth to a proportion of asset value, which is then used to estimate damages. Assets were mapped to one of 11 such depth-to-damage curves. Calculation of EAD, implementation, and supporting data are described in further detail in the main project report (Arcadis, 2017b).

Risk to Water Supply

The Delta’s complex configuration of waterways and associated levees supports a water supply conveyance system and helps ensure water quality and water supply reliability to water users south of the Delta and within the Delta. Levee breaches and resulting floods threaten to disrupt water supply.

Ideally, one would measure the risk to water supply as a product of the probability of levee failure and the consequence of that failure on water supply. The former is available from the probability of flooding metric outlined previously and is used in the EAF and EAD risk metrics. However, the literature on the impact on water supply of islands flooding, and the resulting disruption consequences, is very limited. In consultation with the Council, the DWR, and other stakeholders, it was determined that existing science could not adequately estimate these consequences.

Instead, the risk to water supply is not a true measure of risk; rather it consists of two measures that identify islands that both face a high probability of flooding and have particular
importance to water supply. The high probability of flooding is determined by prior calculations. For the baseline, this risk score is estimated for current conditions, near term (2030), and long term (2050).

In consultation with stakeholders, it was determined that an island is important to water supply if it performs any of the following three water supply functions that would be adversely affected by flooding: (1) it attenuates the intrusion of saline water from the ocean (water quality), (2) it is part of a conveyance corridor of fresh water through the Delta, or (3) it contains water supply infrastructure that would not function properly if the island flooded. An island’s importance is also affected by how many users depend on it for performing those functions. It was determined that users should be counted based on the number of water supply agencies or water user groups that depend on the island for a function.2

In sum, the importance of an island is measured as the combination of the functions it performs for the user groups it serves, called a “user function” score. This number of user functions is the sum of the number of individual functions an island performs for each user. For example, if an island serves as a salinity barrier and holds infrastructure for one user and also serves as a salinity barrier for a second user, its score is three. This semiquantitative score is not a measure of risk but an indicator of the factors that would contribute to higher risk. Given an absence of data suggesting otherwise, the number of user functions is assumed to remain the same in the future (2030 and 2050) as it is today.

Risk to Habitat

According to the Delta Plan, achieving the coequal goal of protecting, restoring, and enhancing the Delta ecosystem means successfully establishing a resilient, functioning estuary and surrounding terrestrial landscape capable of supporting viable populations of native resident and migratory species with diverse and biologically appropriate habitats, functional corridors, and ecosystem processes (Delta Stewardship Council, 2013). The elements that create ecosystem value are complex. For decisionmakers and stakeholders to understand and trade off the impact of projects on the ecosystem, the ecosystem metrics must be relatively simple and understandable and still capture the essential elements of ecosystem value.

For this analysis, we consider high-value non-tidal habitat that would be adversely affected under a flooding event. Current high-value non-tidal habitat was estimated from two sources. We relied on California Department of Fish and Wildlife (CDFW) vegetation mapping (2014) of certain habitat types (riparian, seasonal floodplain, managed wetlands, vernal pools, alkaline seasonal wetlands) prepared for the Delta Plan Environmental Impact Report (EIR) (Council, 2011) plus any other areas subject to protection and conservation (protected areas and conservation easements databases [GreenInfo Network (2015a, 2015b); California Resources Agency (2003,

2 Other approaches were also considered, including measuring use in terms of the population of each user group or the amount of water withdrawn in total by each group. However, these options gave overwhelming importance to south-of-Delta users relative to other users, including in-Delta users. Stakeholders felt that measuring importance based on the number of groups resulted in more equitable consideration of users’ needs.
Future non-tidal habitat was any proposed non-tidal restoration projects identified by the EcoRestore Program (CRA, 2015), although most of these lands were already accounted for as currently conserved lands.

The DST also considers current and potential tidal habitat that could be adversely impacted by levee investments. This risk is not quantified. Instead, we identify islands that have significant tidal habitat as estimated from CDFW vegetation mapping (Council, 2011). For future tidal habitat, we estimated those areas in priority habitat restoration areas (defined in the Delta Plan) that would be inundated if unleveled (modeled as intertidal, seasonal floodplain, or transitional habitat), based on elevations and SLR scenarios (Ecosystem Restoration Program’s Delta Conservation Strategy [CDFG, 2011; CDFW, 2014]). Future tidal habitat restoration projects identified by EcoRestore were also included (CRA, 2015).

The DST uses these data to estimate risk to high-value non-tidal habitat as the product of the annual probability of flooding and the acres of high-value non-tidal habitat. The DST then identifies those islands that are at high risk of flooding and have significant potential tidal habitat. Levee investments on these islands should take care not to jeopardize either current or potential tidal habitat.

**Risk to DAP**

The State Legislature recognizes “the unique cultural, historical, recreational, agricultural, and economic values of the Delta as an evolving place” (California Water Code Section 29702). As such, the Council provided guidance for the DLIS project to include metrics related to DAP in recognition of these additional Delta characteristics. The DLIS risk analysis and the DST consider three flooding risks related to DAP:

- Probability of flooding of islands with legacy towns
- Expected annual flooding of prime agricultural land
- Probability of flooding of islands with important state and federal highways (“public roadways”).

While these metrics are considered in addition to the risk metrics to lives and property, the user should be aware that in some cases these metrics are not independent. For example, flooding of a legacy town is undesirable and reflected by the DAP metric. The monetary damage of flooding of the structures of a legacy town is also captured by the EAD metric.

For the legacy towns and public roadways metrics, the DST reports the probability of flooding for islands indicated as supporting legacy towns and public roadways. Legacy towns include the following:

- Bethel Island
- Clarksburg
- Courtland

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3 Legacy towns are defined in California Public Resources Code section 32301(f).
4 Public roadways are state and federal highways including U.S. Interstates 5 and 205, and several major state routes.
• Freeport
• Hood
• Isleton
• Knightsen
• Locke
• Rio Vista
• Ryde
• Walnut Grove.

For risk to prime agricultural land, the DST multiplies the annual probability of flooding by the current amount of prime agricultural land on each island, as classified by the Farmland Mapping and Monitoring Program (FMMP) (California Department of Conservation, 2012). The FMMP defines prime agriculture as “[i]rrigated land with the best combination of physical and chemical features able to sustain long term production of agricultural crops. This land has the soil quality, growing season, and moisture supply needed to produce sustained high yields. Land must have been used for production of irrigated crops at some time during the four years prior to the mapping date.” This formulation assumes that all prime agricultural land on an island would be impacted by a flooding event.

Changing and Uncertain Risks over Time

The DLIS analysis evaluates risks at three time periods:

• Current—2000–2015
• Intermediate term—2030
• Longer term—2050.

These time periods were selected to be long enough to span the length of California bond funding that would be used in many cases to fund State levee investments and correspond to standard time periods of reporting for data such as SLR and land use projections.

The analysis of risks over time addresses two questions. First, what are the risks now, and what will they be in 2030 and 2050 if the State does not make levee investments? This is the risk in a future without action. Second, what would the risks be now and what would they be in 2030 and 2050 if the State were to support the implementation of a particular project or a portfolio of projects now?

Estimates of future risk depend on assumptions about how risk drivers will change in the future. For example, SLR over time will affect the height of water impinging on the Delta’s levees. Because sea level changes can affect the probability and consequences of levee failure, the estimates of risk over time vary due to projected SLR.

Table 2.2 identifies key future risk drivers used in the DST and summarizes how these future risk drivers could affect outcomes. The key future drivers are based on the expert

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5 The time period for the data representing current conditions varies between the years 2000 and 2015.
judgment of the broader project team and are those that could significantly affect risks to State interests as defined by the key performance metrics. The size of the effects of these drivers on risks, however, is uncertain.

There is much uncertainty about how future risks will evolve over time. For instance, while sea levels will increase, the magnitude and timing of these increases are uncertain. As another example, the likelihood of the magnitude, location, and timing of seismic events or levee breaches is uncertain: various studies suggest different plausible probabilities for these events. The effects of levee breaches on the Delta are also uncertain. For example, the effects of individual levee breaches on water quality and ecosystem function are complex and not fully understood.

Rather than using a single set of assumptions about these conditions, the performance of projects and portfolios (as measured by the metrics) is assessed in different plausible futures. Suppose, for example, that there are \( n \) different conditions and characteristics that are uncertain.
A plausible future has one plausible value for each of those \( n \) conditions and characteristics. While there are an infinite number of plausible futures, only a small number of futures derived from two key future risk drivers are considered (Table 2.3).

### Table 2.3. Alternative Assumptions About Future Risk Drivers

<table>
<thead>
<tr>
<th>Future Risk Drivers</th>
<th>Alternative Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLR</td>
<td>Current sea levels: +2.0 inches (+5 cm) from year 2000</td>
</tr>
<tr>
<td></td>
<td>2030, nominal SLR: +5.7 inches (+14.4 cm) from year 2000</td>
</tr>
<tr>
<td></td>
<td>2050, nominal SLR: +11.0 inches (+28.0 cm) from year 2000</td>
</tr>
<tr>
<td></td>
<td>2030, high SLR: +11.7 inches (+29.7 cm) from year 2000</td>
</tr>
<tr>
<td></td>
<td>2050, high SLR: +23.9 inches (+60.8 cm) from year 2000</td>
</tr>
<tr>
<td>Development and future assets at risk</td>
<td>Current development (Arcadis, 2017b)</td>
</tr>
<tr>
<td></td>
<td>2030 development</td>
</tr>
<tr>
<td></td>
<td>2050 development</td>
</tr>
</tbody>
</table>

**SOURCES:** SLR assumptions for current levels are consistent with the DRMS study (Department of Water Resources, 2009) and assumptions for 2030 and 2050 are consistent with guidance from NAS (2012).

These two uncertainties and alternative assumptions provide the basis for four futures in addition to current conditions:

- Current conditions (roughly 2012)
- 2030, nominal SLR
- 2030, high SLR
- 2050, nominal SLR
- 2050, high SLR.

Estimates of future risk are also uncertain because of incorrect or incomplete data and/or understanding about the risk drivers now and in the future. For example, the fragility of levees can only be estimated and represented simplistically in risk models. There is also uncertainty about the assets that are vulnerable to flooding or the effect that flooding would have on them. Therefore, the estimates of flooding probability and impacts of flooding on Delta assets and interests are inherently uncertain, even for specific assumptions about future conditions, such as SLR or population.

The effect of this uncertainty on the probability of flooding and risk estimates presented in the DST are discussed at length in Chapter Five of the DLIS Risk Analysis Methodology Report (Arcadis, 2017b). Specifically, the report describes six uncertain factors that could affect the calculations of probability of flooding:

- **Discharge-Recurrence:** frequency of peak river flows
- **Stage-Discharge:** relationship between the river flows and the water surface height
- **Sea Level and Water Level Prediction:** future sea levels and resulting water levels in the Delta
- **Seismic-Recurrence:** recurrence of seismic events of different magnitudes
• **Hydrologic and Hydraulic Levee Fragility**: probability of a levee failure for a given water level
• **Seismic Levee Fragility**: probability of a levee failure for a given seismic event.

The report also highlights additional uncertainties related to the vulnerable assets, such as the population, flood warning time and evacuation, and so forth.

Lastly, the report evaluates the sensitivity of key risk metrics for each island to these uncertain factors. Most relevant to the analysis presented in the DST is the overall sensitivity of the risk calculations to the various uncertainties. Figure 2.1, for example, shows the range of EAD estimates (based on 2012 conditions) when considering uncertainty for the top 19 islands. In general, the higher the estimated EAD, the higher the uncertainty range. The uncertainty bands for the top EAD islands also overlap, suggesting that a ranking based on EAD is also uncertain. A more detailed analysis that reflects the correlations of uncertain parameter values across the islands would be required to determine the sensitivity of the rankings. Therefore, the uncertainty analysis suggests that rankings based on risk should be viewed as suggestive only. For this reason and others, the DST uses risk thresholds to identify high-risk islands. This approach, while still sensitive to the uncertainty of the risk calculations, is not sensitive to the relative rankings.

The methodology, risk models, and DST are designed to support the evaluation of numerous futures reflecting, for example, the following factors:
- Frequency, duration, and intensity of high-inflow conditions, as reflected by discharge-recurrence curves
- The strength and integrity of the levees, as reflected by the relationship between levee fragility and flood stage
- The economic damage sustained during flood conditions, as reflected by the relationship between flood stage and damage.

**Ranking Islands/Tracts by Risk**

The DST helps users compare risks across the islands and develop rankings based on individual risk metrics. This step enables a better understanding of how islands compare across multiple risks considered simultaneously.

There is no single, correct way to combine multiple metrics of different units and scale into a single ranking metric. Therefore, the Planning Tool uses thresholds and a set of user-specified weights to develop an aggregate risk metric. The aggregate risk ranking is then used to classify the islands into three priority categories, per Council request:

- Very High Priority
- High Priority
- Other Priority.

To aggregate risk across the metrics, the DST first applies a user-defined threshold for each metric, above which an island is defined as high risk. For example, after this step, an island might be defined as high risk for two metrics, risk to property and risk to habitat. Second, user-specified weights are used to develop a composite risk score—the weighted sum of the number of metrics for which an island is high risk. In this step, a user might weight risk to habitat as half as important as risk to property, resulting in a score of 1.5. Finally, two additional thresholds are used to assign each island to one of the three risk categories. At this step, a user might define a Very High Priority island as one that has a composite risk score above two, and a High Priority Island as one that has a composite risk score between one and two. The example island cited above would fall into this category.

**Evaluating Levee Investments**

The Delta Plan indicates that it is necessary to prioritize investments “so that limited public funds are expended responsibly for improvements critical to State interests” (Delta Stewardship Council, 2013, p. 262). The DLIS project developed a single set of investments based on Delta-specific PL84-99 guidelines. For each island that does not meet Delta-specific PL84-99 guidelines, the project estimated a range of costs to upgrade the entire levee to meet PL84-99 guidelines. The DST then also evaluated all risks under the upgraded condition. The DST then enables the user to see the risk reduction potential from PL84-99 upgrades as well as develop portfolios of investments that most cost-effectively reduce risks to life, property, water supply, and non-tidal habitat.
A cost-effectiveness score, $CE$, for each of four risk metrics, $m$, and island with PL84-99 investment, $i$, is calculated as the difference in risk, $R$, between the baseline condition and the with-PL84-99 investment condition, divided by the investment cost:

$$CE_{i,m} = \frac{(R_{i,m}^{\text{baseline}} - R_{i,m}^{\text{PL84-99}})}{\text{cost}_i}$$

Table 2.4 lists the four metrics along with the units used to convey risk reduction and cost-effectiveness.

### Table 2.4. Risk Reduction and CE Metrics

<table>
<thead>
<tr>
<th>Risk</th>
<th>Risk Metric</th>
<th>Risk Reduction Units</th>
<th>CE Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lives</td>
<td>EAF</td>
<td>Fatalities reduced/year</td>
<td>Fatalities reduced/year/billion dollars invested</td>
</tr>
<tr>
<td>Property</td>
<td>EAD</td>
<td>$ damage/year</td>
<td>$ damage reduced/year/$ invested</td>
</tr>
<tr>
<td>Water supply</td>
<td>Probability of flooding of islands important to water supply</td>
<td>Probability of flooding/year</td>
<td>Flood probability reduced/million dollars invested</td>
</tr>
<tr>
<td>Non-tidal habitat</td>
<td>Expected flooding of high-value non-tidal habitat</td>
<td>Acres flooded/year</td>
<td>Reduction in flooded acres/million dollars invested</td>
</tr>
</tbody>
</table>

The DST ranks investments first by their effect with respect to risk reduction. Then the DST allows the user to construct portfolios by including projects that are cost-effective above a user-specified threshold. The total cost of the portfolio is calculated simply by summing up the included investments.
3. Overview and Use of DST

The current version of the DST is organized around the following sections:

1. Instructions and Guide
2. Islands and Vulnerable Assets
3. Assessing Risk (Risk Maps)
4. Identify High Risk Islands
5. Ranking Islands by Risk
6. Levee Investments and Change in Risk
7. Draft Delta Levees Investment Priorities
8. Developing a Portfolio of Levee Investments.

The latest version of the tool is available on the RAND website (Groves, 2019). The following sections describe how to use each screen of the DST.

Section 1. Instructions and Guide

Section 1 of the DST—Instructions and Guide—includes two panels. The DST Overview panel provides basic information about the DST (Figure 3.1). The Navigating an Information Panel provides interactive tools to display information. Click on the major tab or an information panel to view the information of interest to you.

It is best to review the information in sequence. Once you have seen how all the pieces fit together, you can move to the tabs and panels of most interest, in any order.

![Figure 3.1. DST Overview (Panel 1.1)](image-url)
Section 2. Islands and Vulnerable Assets

Section 2 of the DST—Islands and Vulnerable Assets—includes nine interactive panels that focus on what is at risk to flooding within the Delta. The first panel—2.1) Islands and Tracts—provides a map of the Delta study area and allows the user to highlight islands and tracts by name and to filter the islands shown by levee status (e.g., unleveed, leveed, or flooded) and area (Figure 3.2). There are 170 islands and tracts included in the study—141 are leveed and 29 are either unleveed or flooded.

The second panel—2.2) What Are State Interests in the Delta?—defines the State interests in terms of lives, property, water supply reliability, and ecosystem function (not shown). The third panel—2.3) Delta Assets—lists the State assets in terms of lives, property, infrastructure, water supply, ecosystem, and other DAP considerations (i.e., legacy towns, prime agricultural land, and public roads).

**Figure 3.2. Islands and Tracts (Panel 2.1)**

Panel 2.4) Population Vulnerable in the Delta shows the 2010 population for each island and tract in map and list format (Figure 3.3). The dropdown menu allows the user to view population estimates for years 2030 and 2050. The most populous islands or tracts are North
and Central Stockton. For North Stockton, 7,330 out of the 50,570 people living on the island are considered vulnerable to flooding from levee failure (based on 2010 population estimates and assumptions about the effectiveness of flood warning and the population’s willingness and capability to evacuate). For Central Stockton, 6,950 out of 47,900 are considered vulnerable. Across the entire Delta region, 42,900 people are estimated to be vulnerable. Of that, 89 percent of them live on one of the nine most populous islands.

Panel 2.5) Value of Property Vulnerable in the Delta shows the value of property and infrastructure that is vulnerable to flooding for each island and tract in map and list format for the selected year (Figure 3.4). A 7-percent discount rate\(^1\) can also be applied to the future valuations using the radio button. The panel shows that about $30 billion of assets is vulnerable to flooding across the entire Delta. As with population, most of the assets are on the eastern edges of the Delta—namely North and Central Stockton and West Sacramento and Maintenance Area 9 North.

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\(^1\) A 7-percent discount rate is the U.S. Office of Management and Budget (OMB) recommended nominal discount rate to use when evaluating net benefits of public investments (OMB, 1992). This rate reflects assumptions about pretax rate of return on an average investment at the time of the document.
Figure 3.4. Value of Property Vulnerable in the Delta (Panel 2.5)

This map and list shows the total value of assets (structures, infrastructure, and crops) that could be damaged by flooding. Place your mouse over an island or click on it in the list to see total asset value. For additional details on the assets on each island see the Risk Methodology Report on the project web page: http://deltacouncil.ca.gov/delta-levees-investment-strategy.

Click on the "Important Islands for Protecting Water Supply" panel to continue.

Figure 3.5 shows Panel 2.6a) Important Islands for Protecting Water Supply and Panel 2.6b) Islands Important for Water Supply for Different User Groups. The map in Panel 2.6a highlights the islands and tracts that were determined to be important to water supply because of their water supply infrastructure, adjacency to a conveyance corridor, or role in providing a salinity barrier (i.e., attenuating saline tidal flows from the western portion of the Delta), as selected by the radio buttons on the left. The panel shows that 45 islands (leveed and unleveed) have at least one water supply function: 8 have a salinity barrier function, 17 support the water supply conveyance corridor, and 31 support water supply infrastructure. (This does not sum to 45 because many islands perform more than one function.)

The map in Panel 2.6b highlights the islands important to water supply by user. A user is defined as a water supply agency that obtains water from or through the Delta (e.g., Contra Costa Water District), or a group of users that obtain water directly from the Delta (e.g., South/Central Delta agricultural users). An island is noted as important to a user if it performs one of the three functions (salinity, conveyance, or infrastructure) that support the water supply of that user group. This was determined in consultation with the Council, DWR, user groups, and other stakeholders. The version below shows the many islands important to the State Water Project/Central Valley Project (SWP/CVP), colored by the various functions each plays for the SWP/CVP.
Figure 3.6 shows Panel 2.7) Estimate of Existing and Potential High-Value Non-Tidal Habitat. This panel shows a map and ordered bar chart of the amount of high-value non-tidal habitat, described in Chapter Two. These data are used to estimate the amount of high-value
non-tidal habitat vulnerable to flooding. The user can filter the islands by area of habitat to focus on islands with high amounts of habitat, for example.

The panel shows that DLIS-63 (Grizzly Island) has the most high-value non-tidal habitat—24,600 acres (about 22 percent of all the high-value non-tidal habitat in the Delta), mainly managed wetlands in private (duck clubs) or public conservation management (CDFW Grizzly Island Wildlife Area). Staten and Sherman Islands have the next most non-tidal habitat—about 9,000 acres each. Staten Island is in conservation ownership (The Nature Conservancy) and farmed for wildlife benefits. Sherman Island is in public ownership (DWR) and has several subsidence reversal projects currently or planned under EcoRestore.

Figure 3.7 shows Panel 2.8) Potential High-Value Unleveed Habitat. This panel shows a map and ordered bar chart of the amount of potential high-value tidal unleveed habitat, described in Chapter Two. This panel is used to highlight islands that could benefit from the improvement of unleveed habitat or leveed habitat if configured on the water side of levees, and therefore these potential benefits should be considered when investing in levees. The user can filter the islands by area of habitat to focus on islands with high amounts of habitat, for example. The default setting shows only islands with 25 acres or more of high-value unleveed habitat. The areas with the most unleveed habitat are generally located around the perimeter of the Delta and Suisun Marsh.
Figures 3.8, 3.9, and 3.10 show three variations of Panel 2.9) Delta as Place, highlighting legacy towns, prime agricultural land, and public roadways, respectively (as specified by the Delta as Place Assets radio button). The legacy towns results indicate the number of legacy towns on each island or tract.

**Figure 3.8. Legacy Towns (DAP) (Panel 2.9a)**
Figure 3.9. Prime Agricultural Land (DAP) (Panel 2.9b)

Delta as Place

Filters and Options

Delta As Place Assets
- Legacy Towns (9)
- Prime Agricultural Land (acres)
- Public Roadways

This tab shows three measures of "Delta as Place." Click on each of the radio buttons above to see maps of the islands with: (1) Legacy Towns; (2) acres of prime agricultural land; and (3) Federal, State, and county highways. For each map, place your mouse over the island to see details.

To advance, click on Tab "2. Assessing Risk (Risk Maps)" at the top of the page.

Data Sources: Delta Plan (2013); Dept. of Conservation Farmland Mapping and Monitoring Program (2015); DWR Delta Levees Program (2015).

Prime Agricultural Land (acres)

Island/Tract

0 10,000 20,000 30,000

NETHERLANDS
MIDDLE & UPPER ROB...
GRAND ISLAND
YOLAND
UNION ISLAND WEST
RYER ISLAND
JONES TRACT
UNION ISLAND EAST
BRANNAN-ANDRUS
TERMINOUS TRACT
LOWER ROBERTS ISL...
STATEN ISLAND
NEW HOPE TRACT
PEARSON DISTRICT
TYLER ISLAND
PESCADERO DISTRICT
HASTINGS TRACT
VICTORIA ISLAND
RINDGE TRACT
FABIAN TRACT
RECLAMATION DISTRI...
EGBERT TRACT
PICO-NAGLEE

24,112
18,382
15,569
13,027
12,810
11,634
11,470
11,034
11,031
9,753
8,810
8,623
8,436
8,320
7,602
6,961
6,624
6,610
6,393
6,154
5,814
5,809

Figure 3.10. Public Roadways (DAP) (Panel 2.9c)

Delta as Place

Filters and Options

Delta As Place Assets
- Legacy Towns (9)
- Prime Agricultural Land (acres)
- Public Roadways

This tab shows three measures of "Delta as Place." Click on each of the radio buttons above to see maps of the islands with: (1) Legacy Towns; (2) acres of prime agricultural land; and (3) Federal, State, and county highways. For each map, place your mouse over the island to see details.

To advance, click on Tab "2. Assessing Risk (Risk Maps)" at the top of the page.

Data Sources: Delta Plan (2013); Dept. of Conservation Farmland Mapping and Monitoring Program (2015); DWR Delta Levees Program (2015).

Public Roadways

Island/Tract

0 1

BISHOP TRACT/DLIS-14
BOULDIN ISLAND
BRANNNAN-ANDRUS
BYRON TRACT
CENTRAL STOCKTON
DLIS-06 (OAKLEY ARE...
DLIS-08 (DISCOVERY B...
DLIS-15
DLIS-17
DLIS-18
DLIS-19 (GRIZZLY SLO...
DLIS-22 (RIO VISTA)
DLIS-27
DLIS-38
DLIS-39
DLIS-40 (POTRERO HIL...
DREXLER TRACT
EHREHARDT CLUB
FABIAN TRACT
GLANVILLE
GUIDE DISTRICT

0

Delta As Place Asset [number; acres; 1/0]
towns on each island. Twelve islands support at least one of the 11 legacy towns included in the analysis (some legacy towns are on more than one island). The prime agricultural land results show the acres of prime agricultural land on each island, as defined above. Netherlands contains the most prime agricultural land—10,700 acres. Most other islands, outside of the Suisan Marsh area, contain some amount of prime agricultural land. Lastly, the public roadways results show islands that include public roadways, as defined above. Fifty-two of the 141 leveed islands are designated as having public roadways.

Section 3. Assessing Risk (Risk Maps)

Section 3 of the DST—Assessing Risk (Risk Maps)—presents the island-by-island assessment of flooding probability and associated flooding risks. Panel 3.1) Evaluating Risk provides a brief overview of the methodology used to calculate risk:

\[
\text{Risk} = \text{Probability of Flooding} \times \text{Consequences to Assets}
\]

Panel 3.2) Annual Probability of Flooding Leveed Islands presents estimates of the flooding probability for each island and tract (Figure 3.11). Flooding estimates from hydrologic events, seismic events, or both can be selected on the left. Flooding probabilities depend on the time period and SLR scenario selected in the upper-left corner. Lastly, the panel allows the user to filter results to focus on a specified range of flood risk.

The top figure shows that for 2012, baseline conditions, DLIS-46 (a small island in the central Suisun Marsh) has the highest probability of flooding—35.6 percent/year. Twenty-four islands have a 5-percent probability or greater of flooding in any given year. One of the most populous islands—Maintenance Area 9 South—has a current flooding probability of around 7 percent. Other populous islands—North Stockton and Central Stockton—have current probabilities of flooding of around 3 percent or less. The bottom figure shows the much lower, but more uniform, probabilities of flooding due to seismic events (i.e., earthquakes).

Figure 3.12 shows Panel 3.3) Risk to Life. Islands shaded darker red are estimated to have higher expected annual fatalities. In general, these risks increase under later years and the high SLR scenario, as selected on the left. Three islands under baseline conditions have EAF greater than one fatality/year—Maintenance Area 9 North, North Stockton, and Bishop Tract/DLIS-14.

Figure 3.13 shows Panel 3.4) Risk to Property. Islands shaded darker red are estimated to have higher expected annual damage. Risks increase under later years and the high SLR scenario, as selected on the left. Changing the asset discount rate from 0 percent to 7 percent decreases the risk estimates significantly for the 2030 and 2050 scenarios, as seen by the map shading. The bar chart on the right shows EAD results for both asset discount rates—they differ only for years 2030 and 2050. The results show that some islands with the highest EAD are those with high amounts of assets at risk—such as Maintenance Area 9 North and North Stockton.
Figure 3.11. Annual Probability of Flooding Leved Islands—All Hazards (top) and Seismic Only (bottom) (Panel 3.2)

Annual Probability of Flooding Leved Islands

This map shows the probability of flooding for each island, considering high water (hydrologic) and earthquakes. Click on the radio buttons above to see the two probabilities separately or together (All). Place your mouse over an island to see the probability.

Click on the "Risk to Life" panel above to advance.

Filters and Options

- Island/Tract
  - CLIFTON COURT FOREB.. 3.9%
  - FABIAN TRACT 3.6%
  - CONEY ISLAND 3.0%
  - BRANNAN-ANDRUS 3.0%
  - BYRON TRACT 3.0%
  - STATEN ISLAND 2.9%
  - DREXLER TRACT 2.9%
  - DLIS-43 GRIZZLY ISLAN. 2.9%
  - SHERMAN ISLAND 2.8%
  - BRADFORD ISLAND 2.8%
  - TWITCHELL ISLAND 2.8%
  - WEBB TRACT 2.8%
  - VEALE TRACT 2.8%
  - BACON ISLAND 2.8%
  - MCDONALD ISLAND 2.7%
  - HASTINGS TRACT 2.6%
  - BETHLEHEM ISLAND 2.6%
  - HOLLAND TRACT 2.6%
  - VENICE ISLAND 2.5%
  - WOODWARD ISLAND 2.5%
  - QUIMBY ISLAND 2.4%
  - MEDFORD ISLAND 2.4%
  - UNION ISLAND EAST 2.4%

- Probability of Flooding
  - < 0.5% or (less than 1-in-200)
  - 0.5%-1% or (between 1-in-200 and 1-in-100)
  - 1%-2% or (between 1-in-100 and 1-in-50)
  - 2%-4% or (between 1-in-50 and 1-in-25)
  - 4%-5% or (between 1-in-25 and 1-in-20)
  - > 5% (greater than 1-in-20 year)
Figure 3.12. Risk to Life (EAF) (Panel 3.3)

This map shows the risk to lives, including residents, workers, and visitors. Risk is displayed as expected annual fatalities (lives lost per year on average) from flooding. The risk considers the probability of flooding, population, warning and evacuation, and potential flood depths. The darker color indicates higher risk. Place your mouse over an island to see additional details.

Click on the "Risk to Property" panel above to advance.

Figure 3.13. Risk to Property (EAD) (Panel 3.4)

This map shows the risk to property (structures, infrastructure, and crops) that could be damaged by flooding. Risk is displayed as expected annual damages from flooding, in dollars. Darker colors on the map are higher risk. Place your mouse over an island to see additional details.

Click on the "Risk to Water Supply" panel above to advance.
However, other areas with relatively fewer assets at risk have high EAD due to high flooding probability—for example, Bishop Tract/DLIS-14 and Byron Tract.

Panel 3.5) Islands Posing Greatest Water Supply Risk, as shown in Figure 3.14, identifies the leveed islands that are important for water supply—those that have two or more water supply user functions—and that have a high annual probability of flooding, that is, >0.5 percent. These islands are shown in the map and listed in the bar charts to the right. For each of these islands, the probability of flooding is presented and the islands are listed in the bar chart in order of decreasing flood risk. Changing the time period and SLR scenario affects only the probability of flooding since the number of user functions is held constant over time.

Figure 3.14. Islands with Greatest Water Supply Risk (Panel 3.5)

The results show that 22 islands perform two or more user functions and have high probability of flooding, with Hotchkiss and Holland Tracts serving seven user functions. These two islands perform all three functions (salinity, conveyance, and infrastructure) for multiple users. The annual probability of flooding varies across these islands, from a low of 1.5 percent to a high of 5.2 percent.

Panel 3.6) Risk to High-Value Non-Tidal Habitat, as shown in Figure 3.15, reports the expected flooding of high-value non-tidal habitat in terms of acres flooded per year. Risks change under different year and SLR scenarios. The vast majority of risk to high-value non-tidal habitat is on DLIS-63 (Grizzly Island)—over 5,000 acres/year. Seven other islands have expected flooding rates greater than 100 acres/year.
Figure 3.15. Risk to High-Value Non-Tidal Habitat (Panel 3.6)

This map shows the risk to high-value non-tidal habitat that could flood if levees fail. Risk values are shown as the average annual acres that could be flooded. Darker colors are higher risk. Place your mouse over an island for additional details.

Click on the "Risk to Delta as Place" panels above to advance.

Figure 3.16. Risk to Legacy Towns (DAP) (Panel 3.7)

Figure 3.16 shows Panel 3.7) Risk to Legacy Towns. This panel shows the flooding risk for those islands that support one or more legacy towns. As shown by Panel 3.2) Annual Probability of Flooding Leveed Islands, probabilities of flooding increase under later years and the high SLR scenario, as selected on the left.

Figure 3.16. Risk to Legacy Towns (DAP) (Panel 3.7)
This panel shows that the legacy town in Maintenance Area 9 South (Hood) faces the highest probability of flooding—over 7 percent per year. The other towns all face probabilities of less than 5 percent per year. Grand Island, home to the legacy town of Ryde and a portion of Walnut Grove, is estimated to have a 3.8-percent chance of flooding under current conditions.

Figure 3.17 shows Panel 3.8) Risk to Prime Agricultural Land. This panel shows the expected annual flooding of prime agricultural land across the Delta. The expected flooding increases under later years and the high SLR scenario, as selected on the left.

This panel shows that the prime agricultural land on Grand Island faces the highest risk to flooding—about 600 acres/year on average. Twenty-one islands are estimated to face expected loss of prime agricultural land of more than 200 acres/year.

Figure 3.17. Risk to Prime Agricultural Land (DAP) (Panel 3.8)

Figure 3.18 shows Panel 3.9) Risk to Public Roadways. This panel shows the flooding risk for those islands that support public roadways. As shown by Panel 3.2) Annual Probability of Flooding Leved Islands, probabilities of flooding increase under later years and the high SLR scenario, as selected on the left.

This panel shows that the roads on Little Egbert Tract face the highest annual probability of flooding—over 10 percent. Eleven islands with public roadways currently face probabilities of flooding of greater than 4 percent.
Section 4. Identify High Risk Islands

The DLIS DST first calculates which islands are high risk for each of the metrics using a set of threshold risk levels. Islands with risks greater than the threshold value are deemed high risk for the specific metric. The DST allows the user to adjust the thresholds and explore how the settings affect the analysis. Table 3.1 shows results for the default thresholds. These thresholds are set so that the islands indicated as high risk with respect to life, property, high-value non-tidal

### Table 3.1. Default Risk Metric Thresholds

<table>
<thead>
<tr>
<th>Risk Type</th>
<th>Metric</th>
<th>Default Threshold (percentage of risk captured)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Life</td>
<td>EAF</td>
<td>0.24 fatalities/year (90%)</td>
</tr>
<tr>
<td>Property</td>
<td>EAD</td>
<td>$3.5 million/year (81%)</td>
</tr>
<tr>
<td>Water supply</td>
<td>Probability of flooding of important water supply island</td>
<td>0.5% probability of flooding to islands with 2 or more user functions</td>
</tr>
<tr>
<td>High-value non-tidal habitat</td>
<td>Expected annual flooding of non-tidal habitat</td>
<td>89 acres/year (81%)</td>
</tr>
<tr>
<td>Legacy towns (DAP)</td>
<td>Probability of flooding of island with a legacy town</td>
<td>1% probability of flooding to islands with 1 or more legacy towns</td>
</tr>
<tr>
<td>Prime agricultural lands (DAP)</td>
<td>Expected annual flooding of prime agricultural land</td>
<td>115 acres/year (80%)</td>
</tr>
<tr>
<td>Public roadways (DAP)</td>
<td>Probability of flooding of island with public roadways</td>
<td>2% probability of flooding to islands with public roadways&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a</sup> The 2-percent standard is based on United States Department of Transportation Federal Highway Administration (1994).
habitat, and prime agricultural lands include 90 percent, 81 percent, 81 percent, and 80 percent of the total Delta-wide risk, respectively. For example, the islands indicated as high risk with respect to property account for 81 percent of the total $244 million expected annual flood damage Delta-wide (for the 2012 scenario). Thresholds for water supply, legacy towns, and public roadways are based on a probability of flooding deemed appropriate for the specific risk—0.5 percent, 1 percent, and 2 percent, respectively.

The risk metric thresholds are specified in Panel 4.1) Identify Islands that Have the Most Risk in Individual Metrics (Figure 3.19). The visualization shows the amount of risk for each island and metric (length of horizontal bars) and defined threshold (vertical red bars). Bars shaded in dark red represent risks that are greater than the threshold. The user can sort the islands by the individual risks by mousing over the horizontal axis label at the bottom of the chart and clicking the sort icon that appears.

Figure 3.19. Identify Islands that Have the Most Risk in Individual Metrics (Panel 4.1)
The DST next defines a composite risk score by summing the number of metrics for which each island is at high risk, weighted as specified by the user. Figure 3.20 shows *Panel 4.2) Identify Islands Have the Most Risk Across All Risk Metrics to Create a Composite Risk Score*. Each red square indicates a metric for which an island is at high risk. The bar chart on the far right reports the weighted sum of the number of metrics, using weights defined at the bottom of the figure, for a given year and SLR scenario and asset discount rate.

The default specification weights risks to life, property, water supply, and non-tidal habitat equally and risks to the DAP metrics—legacy towns, prime agricultural land, and public roadways—at a weight of one-third of the others. With these weightings, the island at highest risk is Maintenance Area 9 South, with a composite risk score of 4.0, followed by Byron Tract and Maintenance Area 9 North.

Section 5. Ranking Islands by Risk

The DST next maps and ranks the islands by the composite risk score (Figure 3.21, *Panel 5.1) Composite Risk Map*). The DST helps different users understand the risks based on their preferences, enabling the user to modify the risk metric weights, time period and SLR scenario, and asset discount rate.
Figure 3.21. Composite Risk Map (Panel 5.1)

Figure 3.22 shows *Panel 5.2) Tiered Risk Map*. This visualization allows the user to group the islands by risk priority using two additional thresholds (changeable on the right of the panel). The default specifies that islands with a composite risk score of 1.1 or greater are classified as Very High Priority. Islands with a composite risk score of 0.1 or greater are classified as High Priority. All remaining islands are classified as Other Priority.

At this stage of the analysis, the DST also includes an option to highlight high-risk islands that also have significant potential high-value tidal habitat, as described above. In this way, the users are alerted to those islands that face a high probability of flooding, but that may provide an opportunity for tidal habitat restoration. In these cases, levee improvements might be designed so that the tidal habitat opportunities are not overlooked or eliminated.

*Panel 5.3) Tiered Ranking of Islands*, shown in Figure 3.23, lists all the islands in each of the three priority tiers. The user can change the time period and SLR scenario, as well as the Very High and High-Risk Thresholds. Under the default settings, this visualization indicates that 25 islands are Very High Priority and 50 islands are High Priority.
Figure 3.22. Tiered Risk Map (Panel 5.2)

5.2) Tiered Risk Map

Discount Rate
- 0%
- 7%

Year & SLR Scenario
- 2012, baseline
- 2030, nominal
- 2050, high

Show High Tidal Habitat Potential
- Don't Show
- Show

Very High Priority Island Threshold
- (# of metrics high risk)
- 1.1

High Priority Island Threshold
- (# of metrics high risk)
- 0.1

This map displays the priority islands and tracts in three tiers: Very High, High, and Other Priority. You can adjust the breaks between tiers on the right side to change the number of islands in each tier. On the left side, your priorities (weights) carry over from the previous tab. You can adjust your risk priorities by entering numbers between 0 and 1 (including 0 and 1). By clicking on the “Show” button on the map, you can show areas that have high potential for habitat restoration (seasonal floodplains and tidal, riparian, and transitional habitat) based on Delta Plan high priority restoration areas and elevation. Islands and tracts with restoration potential will be shown in the darker color for each tier. Click on Tab “5.3) Tiered Ranking of Islands” at the top of the page to advance.

Figure 3.23. Tiered Ranking of Islands (Panel 5.3)

5.3) Tiered Ranking of Islands

This panel shows the list of islands in three tiers: Very High, High, and Other Priority. As with the previous panel, you can adjust how many islands appear in each tier by adjusting the Very High and High thresholds. Scroll down each list to see all islands in the tier. You can also choose to show the islands with high potential for habitat restoration by clicking on the “Show” button. Click on Tab “5.4). Impact on Delta As Place” at the top of the page to advance.
Panel 5.4) Impact on Delta as Place, shown in Figure 3.24, presents the composite risk map again, but this time also shows what percentage of the DAP assets (islands with legacy towns, prime agricultural land, or public roadways) are included in each classification of risk. For example, the figure shows that six legacy towns (or portions of legacy towns) are on islands that are classified as Very High Priority and seven legacy towns (or portions of legacy towns) are on islands that are classified as High Priority (some legacy towns are on more than one island).

Figure 3.24. Impact on DAP (Panel 5.4)

Section 6. Levee Investments and Change in Risk

Section 6 of the DST shows how risk could be reduced through individual investments to bring each island to meet the Delta-specific PL84-99 guidelines. It should be noted that the PL84-99 guidelines are primarily developed to reduce the probability of hydrological flooding through minimum standards for the geometry of levees. The guidelines will have a much lower effectiveness in reducing the probability of flooding from seismic events. See Chapter One for additional information on the PL84-99 guidelines. Panel 6.1) Islands and Tracts with Investments,
shown in Figure 3.25, identifies the islands that could be upgraded to various investment guidelines as selected on the left under “Investment” and shows the costs of the investments under a low or high assumption. PL84-99 investments for 60 islands are included in the DST. PL84-99 investments were not developed for the highly urbanized islands, as their levees are designed for or need to be updated to a higher standard appropriate for urbanized areas.

**Figure 3.25. Islands and Tracts with Investments (Panel 6.1)**

**Panel 6.2)** Reduction in Annual Probability of Flooding with Investments (Figure 3.26) shows the amount of risk reduction in terms of annual probability for each island with a PL84-99 investment. The largest reduction in probability of flooding is seen in Holt Station—about a 15-percent reduction. Reductions across all other islands are less than 4.5 percent. The north portion of the Delta contains the most islands that would benefit from PL84-99 investments with respect to reducing the probability of flooding.

Figure 3.27—Panel 6.3—shows the reduction in EAF with PL84-99 investments. The reductions are quite small, with only three islands expected to see reductions in fatalities greater than 0.03 lives per year—Brannan-Andrus, Grand Island, and Terminus Tract.

Figure 3.28—Panel 6.4—shows the reduction in EAD with PL84-99 investments. The reductions in EAD exceed $1 million for three islands—Glanville, Grand Island, and Terminus Tract. Reductions in the future and under the two asset discount rates can be explored on this panel as well.
Figure 3.26. Reduction in Annual Probability of Flooding with PL84-99 Investments (Panel 6.2)

Figure 3.27. Reduction in EAF with Investments (Panel 6.3)
Panel 6.5 (Figure 3.29) shows the reduction in flooding probabilities for islands identified as being at high risk to water supply. Of these islands, Drexler Tract shows the largest benefit from upgrades to meet Delta-specific PL84-99 guidelines—a 1.3-percent per year reduction in the likelihood of flooding under the 2012 baseline scenario. Half of the islands would show insignificant decreases in flooding—0.1 percent per year or less.

Figure 3.30 shows Panel 6.6) Change in Expected Flooding of Non-Tidal Habitat with Investments. This panel shows that the biggest reduction in non-tidal habitat risk would be seen in Staten Island—a reduction of 66 acres/year. Four additional islands would see reductions in flood risk by more than 10 acres/year.
Figure 3.29. Reduction in Flooding for Islands Posing the Greatest Water Supply Risk with Investments (Panel 6.5)

Change in Flooding for Islands Posing Greatest Water Supply Risk with Investments

Filters and Options
- Year & SLR Scenario
  - 2012, baseline
  - 2030, nominal
  - 2030, high
  - 2050, nominal
  - 2050, high
- Investment
  - PL84-99

This panel shows the reduction in probability of flooding for islands specified to be important to water supply and with a defined investment.

Figure 3.30. Reduction in Expected Flooding of Non-Tidal Habitat with Investments (Panel 6.6)

Change in Expected Flooding of Non-Tidal Habitat with Investments

Filters and Options
- Year & SLR Scenario
  - 2012, baseline
  - 2030, nominal
  - 2030, high
  - 2050, nominal
  - 2050, high
- Investment
  - PL84-99

This panel shows the reduction in expected flooding of non-tidal habitat (acres per year) for islands with a defined investment.
Section 7. Draft Delta Levees Investment Priorities

Using this information, the Council developed a preliminary set of levee investment priorities. The Council developed three priority tiers—Very High Priority, High Priority, and Other Priority. In general, the Very High Priority islands were those with high risks to life (see Figure 3.12) and to property (see Figure 3.13). The High Priority islands included the remaining islands that were at high risk due to water supply. All but four islands with high risk to non-tidal habitat were included in the Very High or High Priority tiers.

The Council then factored in several additional considerations related to hydraulic connection between adjacent islands, DAP, ecosystem restoration opportunities, and Suisun Marsh levees (Arcadis, 2017a). By taking these special considerations into account, the recommended list of State levee investment priorities developed for Council consideration included 17 islands and tracts in the Very High Priority category and 34 islands and tracts in the High Priority category (Figure 3.31).

Section 8. Developing a Portfolio of Levee Investments

Section 8 of the DST—Developing a Portfolio of Levee Investments—allows the user to develop portfolios that cost-effectively reduce risk to lives, property, water supply, and non-tidal habitat. Figure 3.32 (Panel 8) shows a simple portfolio that includes all PL84-99 investments that have an EAF CE score of greater than four lives/billion dollars invested. Note that these
visualizations exclude investments that are less than $1.0 million—as those are relatively inexpensive and thus not comparable to the larger investments. With this simple specification, three Very High Priority islands, one High Priority island, and one Other Priority island would be included, at a cost of $27 million. Note that 4 Very High Priority islands and 18 High Priority islands would be excluded. The DLIS project final report describes additional investment considerations (Arcadis, 2017a).

Figure 3.33 shows the same Panel 8, but with revised CE thresholds for EAF, EAD, water supply, and non-tidal habitat. By reducing the thresholds to the following settings, many more investments are included for a total cost of $76 million:

- EAF CE threshold: 1.5 lives/billion dollars invested
- EAD CE threshold: $0.25 damage reduced/$ invested
- Water supply CE threshold: 0.25% flood probability reduced/million dollars invested
- Non-tidal habitat CE threshold: 5 acres reduced flooding/million dollars invested.
Figure 3.33. Portfolio Based on Four Metrics—$76 Million (Panel 8)

### 8) Portfolio of Investments

<table>
<thead>
<tr>
<th>DUS Tier</th>
<th>Mant or Tract</th>
<th>Investment Costs</th>
<th>Investment Flood Reduction</th>
<th>EAF CE Threshold</th>
<th>EAD CE Threshold</th>
<th>Water Supply CE Threshold</th>
<th>Habitat CE Threshold</th>
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<tr>
<td>Very High</td>
<td>BETHEL ISLAND</td>
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### Total Costs of Investments Included in Portfolio

- **$2B-$5B**
- **$5B-$10B**
- **$10B-$15B**
- **$15B-$20B**
- **$20B-$25B**
- **$25B-$30B**
- **$30B-$35B**
- **$35B-$40B**
- **$40B-$45B**
- **$45B-$50B**
- **$50B-$55B**
- **$55B-$60B**
- **$60B-$65B**
- **$65B-$70B**
- **$70B-$75B**
- **$75B-$80B**

---

### Instructions:
- Adjust the Cost Effectiveness Thresholds (colored red) to include investments in the portfolio. The smaller the threshold, the more projects are included.
- Default thresholds are set to only include investments with EAF cost effectiveness scores of greater than 4.0 fatalities reduced/$B. Adjust the other sliders to include investments that reduce the other risks as well.

---

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<thead>
<tr>
<th>Investment Costs</th>
<th>PL84-99 Upgrades</th>
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<tr>
<td>Year &amp; SLR Scenario</td>
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<tr>
<td>Minimum Investment Cost</td>
<td>From $1.0M</td>
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</table>

Bar thickness is proportional to risk reduction for investment.

- DUS Tier: Very High, High, Other Priority

---

<table>
<thead>
<tr>
<th>Portfolio of Investments</th>
<th>Investment Costs</th>
<th>Investment Flood Reduction</th>
<th>EAF CE Threshold</th>
<th>EAD CE Threshold</th>
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<td>4.0</td>
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<td>0.12%</td>
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<td>WALNUT GROVE</td>
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<td>4.0</td>
<td>$0.10</td>
<td>0.12%</td>
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---

43
By relaxing the EAF and EAD CE thresholds, Terminous Tract (High Priority) and Glanville Island (High Priority) are included. By additionally relaxing the water supply CE threshold, Drexler Tract (High Priority) is included. Lastly, by relaxing the non-tidal habitat CE threshold, Sherman Island (Very High Priority), McCormack-Williamson Tract (Very High Priority), Staten Island (High Priority), and Prospect Island (Other Priority) are included.
4. Conclusion

The DLIS DST was developed to assist the Council in evaluating Delta island and tract flood risks with respect to life, property, water supply, habitat, and DAP considerations. The DST was also used to evaluate and compare a set of investments—improving island levees to PL84-99—as a demonstration for how such a tool could help the Council prioritize specific investments.

By the conclusion of this effort, the Council had used the DLIS DST to update Chapter Seven of the Delta Plan (Delta Stewardship Council, 2013) by revising the policy on “Prioritization of State Investments in Delta Levees and Risk Reduction.” The specific draft text reads as follows:

The priorities listed below shall guide State discretionary investments in the improvement and major rehabilitation of Delta levees. As DWR selects levee improvement projects for funding through its levee funding programs, it should fund projects at the very high priority islands or tracts, subject to its consideration of the benefits, costs, engineering considerations, and other factors, before approving projects at high priority or other priority tracts. If available funds are sufficient to fully fund levee improvements at the very high priority tracts, then funds for improvements or major rehabilitation of levees on high priority islands and tracts may be provided, and after those projects have been fully funded, then projects at other priority islands and tracts may be funded.¹

Figure 4.1, developed by the DST (and included in the draft amendment), maps the levee investment priorities referenced above. This outcome provides significant new guidance for the Council and DWR and helps meet an important goal of the Delta Plan to provide guidance on prioritizing levee investments.

The DST and supporting risk models were developed to provide continuing support of the Council for setting levee investment priorities. In the future, this could be done by refining the risk estimates through improved data and reconsidering how the islands compare in terms of the different types of risks. This type of investment portfolio analysis could be conducted with a more robust set of alternative levee investments and other risk reduction options to develop a balanced portfolio of CE actions to reduce risk. The DST can also evaluate investments that would improve the performance of the levees and include other desirable features such as ecosystem enhancements.

¹ The draft amendment to the Delta Plan can be viewed on the Delta Stewardship Council’s website (Delta Stewardship Council, 2017b).
Figure 4.1. Delta Levees Investment Priorities

   As of October 2015:
   http://www.conservation.ca.gov/dlrp/fmmp

   http://www.dof.ca.gov/research/demographic/projections/


———, *Public, Conservation, and Trust Lands (PCTL) Database*, 2005. As of November 5, 2015:

———, *California EcoRestore Fact Sheet*, 2015.
   http://resources.ca.gov/docs/ecorestore/ECO_FS_Overview.pdf

Council—See Delta Stewardship Council.

CRA—See California Resources Agency.

   Dataset provided by Council to Arcadis on February 12, 2015.

———, *Delta Levees Investment Strategy*, 2017a. As of March 1, 2019:
   http://deltacouncil.ca.gov/delta-levees-investment-strategy

———, *Discussion Draft of Potential Revisions to Chapter 7 Policies and Recommendations*, March 23, 2017b. As of March 1, 2019:
http://deltacouncil.ca.gov/docs/delta-stewardship-council-march-23-2017-meeting-agenda-item-10-attachment-1-discussion-draft


———, *California Conservation Easement Database (CCED)*, 2015b. As of November 5, 2015: http://www.calands.org/cced


NAS—See National Academy of Sciences.

http://www.nap.edu/catalog.php?record_id=12626


https://www.whitehouse.gov/omb/circulars_a094