MAY 2024

DLIS Risk Reduction Analysis

Reporting Years 2020-2023

Delta Stewardship Council

A CALIFORNIA STATE AGENCY

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Purpose

The purpose of this report is to assess and quantify the change in the likelihood of levee failure, loss of life, property, and other state interests resulting from Sacramento-San Joaquin Delta (Delta) levee improvements carried out during the fiscal years 2019-2023.

Introduction

Levees in the Delta play a crucial role in reducing flood risks to people, property, natural resources, and infrastructure systems of statewide importance to all Californians. A levee failure, such as a breach, could lead to devastating floods, potentially causing injury or loss of life, significant damage to property and infrastructure, disruption of water supply, and harm to environmental resources.

The Sacramento-San Joaquin Delta Reform Act of 2009 (Wat. Code, § 85000; Delta Reform Act) tasked the Delta Stewardship Council (Council), in consultation with the Central Valley Flood Protection Board, to develop and recommend priorities for discretionary State investments in Delta levees to reduce flood risks while supporting the coequal goals of water supply reliability and Delta ecosystem

restoration. (Wat. Code, § 85306.) In collaboration with various agencies and the public, the Council has formulated the Delta Levees Investment Strategy (DLIS) to prioritize State investments in the Delta's levee system.

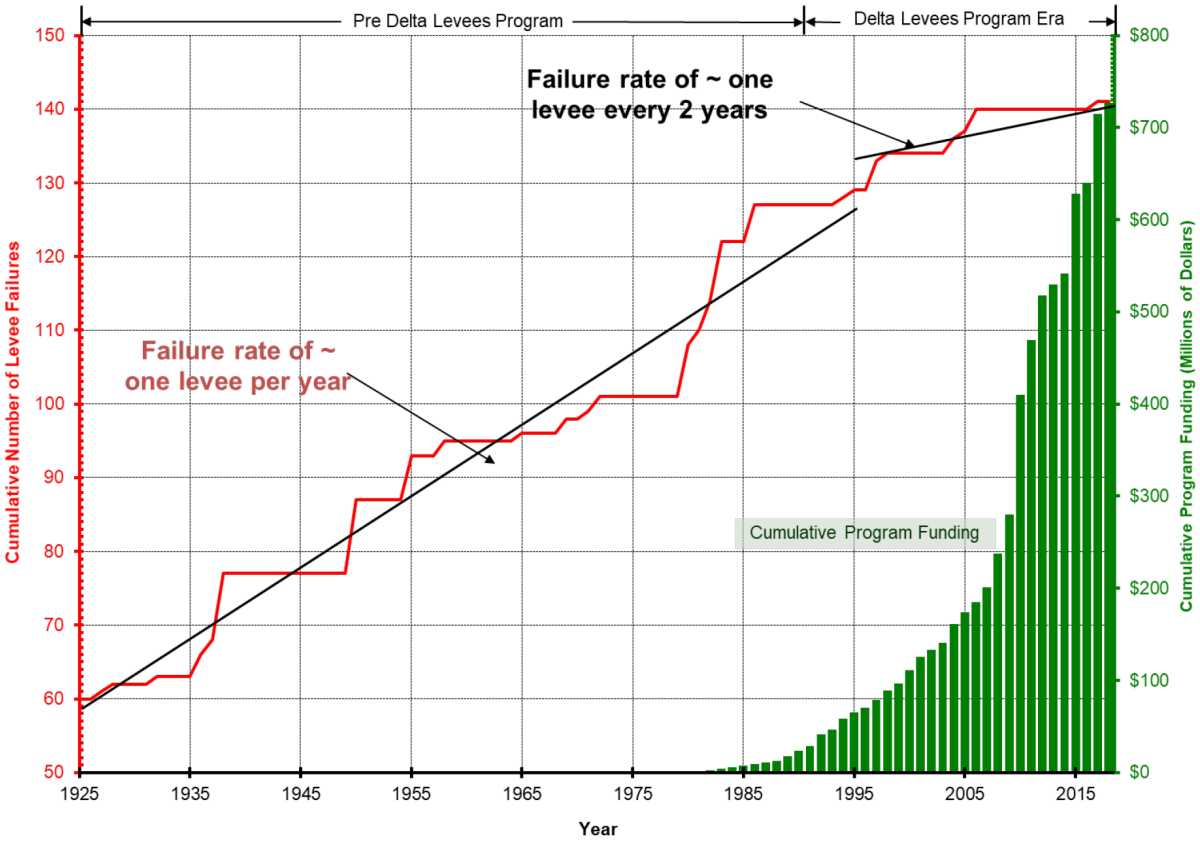
The Role of Funding in Reducing Flood Risk

The Delta is the heart of the State's water supply network, and home to legacy communities, prime farmland, transportation corridors and a critical ecosystem. It is safeguarded by an extensive network of over 1,100 miles of levees that preserve its unique agricultural landscape and cultural heritage. These levees face constant challenges from the forces of river flows, tides, and wind waves, distinguishing them from typical river levees that are primarily stressed during flood events. Built predominantly over 150 years ago using materials available at the time, many of these levees rest on a foundation of low strength and stability, including organic peat soil and alluvial sands. This type of construction, coupled with threats such as subsidence, climate change, and sea level rise, places the levees at risk. Climate change is expected to compound these challenges, with more precipitation falling as rain rather than snow, increasing flood risks, and altering reservoir management needs. Additionally, sea level rise places added pressure on the levee systems, underscoring the importance of continuous funding for levee strengthening and maintenance.

Despite legislative efforts to address these concerns, funding for the maintenance and improvement of the Delta's levee system remains a significant challenge for both local agencies and the state. Historical data demonstrates a direct relationship between the level of funding allocated to levee maintenance and improvements, and the frequency of levee failures in the Delta. Prior to the Delta Levees Maintenance Subventions Program and Delta Levees Special Flood Control Projects Program, the area experienced an average of one levee failure per year. However, with increased investment through the program, the rate of failures has been cut by half, highlighting the effectiveness of sustained financial support in reducing incidents and enhancing levee resilience. This trend underscores the critical need for ongoing and increased funding to ensure the long-term sustainability and safety of Delta levee infrastructure.

The chart below provided by the Department of Water Resources (DWR) demonstrates how funding for the Delta Levees Program correlates with a marked decrease in levee failures, illustrating fewer failures following program initiation and cumulative financial investment. This underscores the critical link between funding and levee integrity, suggesting that consistent and sufficient financial

support is pivotal for bolstering levee resilience, enhancing performance, and safeguarding the Delta against the risks of infrastructure failure.



Delta Levees Investment Strategy

DLIS established a transparent strategy for prioritizing State-funded levee investments in the Delta. In alignment with Water Code section 85305, subdivision (a), DLIS aided the Council by developing an analytical framework to assess flood risks to State interests for each Delta island or tract. Risk is defined as the probability of a flood event multiplied by the consequences of that event. State interests were defined by the Council to be:

- Human life.
- Property.
- Water Supply Reliability.
- The Delta's Ecosystem.
- Delta as Place – represented by Legacy Towns, State Highways and Prime Agricultural Land.

If an island or tract has a high probability of flooding, but minimal State interests, then the Risk posed from flooding is low. Conversely if the levee system is protecting a population center, the risk could be high, even if expected flooding is infrequent.

DLIS-Decision Support Tool

DLIS introduced a Decision Support Tool (DST) to help the Council and stakeholders explore flood risk outcomes across different timeframes and scenarios, ultimately guiding the development of a prioritized list of islands for levee investments to mitigate flood risks. The DST employs a comprehensive approach to evaluate the potential consequences of levee failure and flooding. By leveraging detailed data analysis and interactive visualizations, the DST supports the Council in formulating effective strategies for levee investments aimed at reducing these risks.

The DST facilitates strategic planning through a four-step process.

1) It assimilates and displays information regarding assets at risk throughout the Delta, laying the groundwork for a thorough risk assessment.
2) Following this, the DST estimates the probability of flooding and assesses the associated risks to various Delta assets, including lives, property, water supply, and habitat. This probabilistic analysis is crucial for understanding the magnitude and scope of potential impacts.

DLIS Regulation

The DLIS categorizes Delta islands and tracts based on risk-based priorities (very-high, high, or other) to guide the allocation of discretionary funds for levee improvements by DWR. The DLIS regulation (Cal. Code Regs., tit. 23, § 5012.) directs State funding to levee improvement projects where they can most effectively protect state interests. Additionally, DLIS requires DWR to annually report its funding decisions, detailing the rationale behind them, especially when funding decisions vary from established priorities. This reporting ensures transparency and accountability, focusing investments on safeguarding critical state interests even when short-term priorities shift.

3) The third step involves providing interactive visualizations, which play a pivotal role in supporting the Council's deliberations on prioritizing high-risk islands based on the weighted risks.
4) Lastly, the DST assimilates results from analyses of different levee investment scenarios, demonstrating how these investments could mitigate the identified risks, while facilitating understanding and tradeoffs for the given scenarios.

The DST uses risk models that draw upon extensive databases to predict the likelihood of flooding resulting from levee breaches, whether caused by water overtopping or seismic events. By calculating flood probability as a function of levee fragility—which is influenced by factors like river stage heights and ground acceleration—the DST offers a robust framework for understanding and managing flood risk.

The DST uses various metrics to assess risks to people, assets, water supply reliability, the Delta ecosystem, and the Delta as a place. These metrics consider both the probability and consequences of flooding, utilizing hazard recurrence curves and fragility curves to inform the analysis.

Expected Annual Fatalities (EAF):

EAF provides insight into the average annual number of flood-related fatalities expected in the Delta region across different flood scenarios. It considers the differential impact of flood levels on fatalities, calculating EAF for each island by multiplying the annual probability of flooding by estimated fatalities at potential flood levels. Overall, EAF offers a comprehensive assessment of flood-related mortality risks in the region.

Expected Annual Damages (EAD)

EAD evaluates the average annual monetary value of damages expected due to flooding in the Delta region's infrastructure and assets. It focuses on direct losses to residential and commercial properties, transportation systems, agricultural facilities, and more. Despite its usefulness, EAD may not capture all indirect consequences, but it serves as a foundational metric for understanding flood impacts.

Risk to the Delta Ecosystem:

Risk to the Delta ecosystem is evaluated by assessing the expected flooding of leveed habitats, including natural communities, conservation areas, and seasonal floodplains. This metric calculates the expected flooding of high-value non-tidal habitat for each island, considering the annual probability of flooding multiplied by the area of existing and potential high-value habitat.

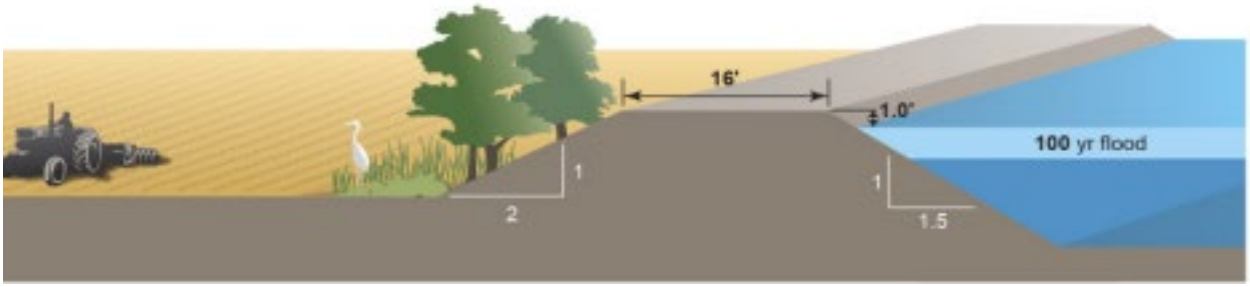
Delta as a Place:

Metrics for the Delta as a Place identify legacy towns, prime farmland, and roadways that could be damaged or disrupted by floods. Roadways include only those of interest to the State, such as county, state, and federal highways that cross the legal Delta, along with scenic Highway 160, which is also a state highway. These metrics represent the historical, cultural, and agricultural values in the Delta, providing insights into the potential impact of flooding on these important areas.

Levee Standards

Over time, various standards have been established for rural or agricultural Delta levees, detailing levee geometry and maintenance requirements. These standards include federal regulations such as 33 Code of Federal Regulations part 208.10, and the US Army Corps of Engineers' (USACE) Rehabilitation and Inspection Program under Public Law 84-99. (Delta-Specific Pub. L. No. 84-99; PL 84-99.) Notable among these standards are:

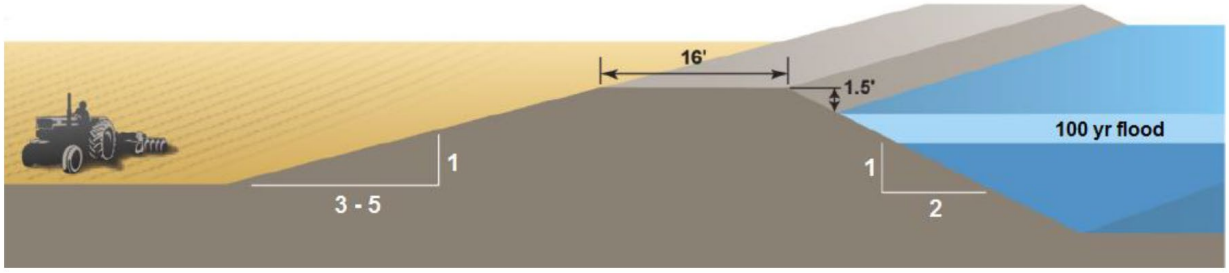
Hazard Mitigation Plan (HMP)



Delta-Specific Public Law

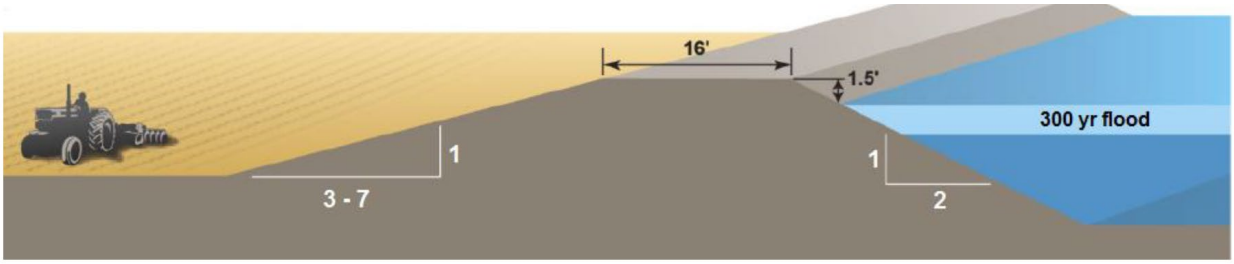
Most Delta levees target achieving the PL 84-99 standard, which offers enhanced flood protection compared to the HMP standard. PL 84-99 guidelines prescribe

levee side slopes of 3H:1V to 5H:1V landside and 2H:1V waterside, along with increasing freeboard to 1.5 feet above the one-percent annual chance (100-year flood) water level. However, this is still below FEMA accreditation requirements. Notably, PL 84-99 includes a provision for flatter landside levee slopes compared to the DWR Bulletin 192-82 standard, particularly on organic soil foundations.



DWR Bulletin 192-82

Developed for major central Delta islands safeguarding significant State interests, Bulletin 192-82 levee guidance is suitable where tides play a crucial role in determining design flood elevations. This standard aligns with PL 84-99 guidelines in many aspects, except that the design water level corresponds to a 0.33-percent (1 in 300) annual chance of occurrence. Under Bulletin 192-82 standards, freeboard for levees is maintained above the 300-year flood frequency elevation, as provided by the USACE.



In the Delta, there is minimal difference between the 100-year and 300-year water surface elevations, typically about 6 inches in most cases. It should be noted that the design water surface elevations are derived from the USACE1992 Special Study.

Impacts of Levee Improvements

Within the scope of DWR's various funding programs, including the Delta Levees Special Flood Control Projects program, efforts are underway to fortify the Delta's

levee infrastructure. A total of 24 levee improvement projects have been approved and allocated funding from fiscal year 2019 to 2023. As detailed in Table 5 of DWR's annual report to the Council on December 2023, these initiatives are dedicated to enhancing the levee systems to bolster flood protection and support ecosystem restoration. Out of the funded projects, only four have reached completion as of December 2023. These efforts are designed to mitigate immediate flood threats and to advance broader environmental sustainability and water supply stability, embodying a comprehensive approach to levee improvement.

The reduction in levee fragility, which significantly influences the probability of flooding and the resultant losses, was quantified using the DST for each of the islands associated with the four completed improvements. Metrics, such as EAD and EAF, were compared for conditions both before and after the projects, isolating the effects of enhanced flood protection measures. All variables remained constant except for the levee fragility, ensuring that observed changes could be directly attributed to the four completed projects. It should be noted that, although the DST is capable of projecting future impacts, this particular analysis was conducted based on the current conditions in 2020.

Below is a detailed summary of the levee improvement projects completed on four specific islands, highlighting DLIS priorities, associated costs, State interests, and projected outcomes including annual damage, fatalities, and levee failure probabilities for each island or tract.

Project Analysis

Bethel Island (DLIS Priority: Very High)

Bethel Island has an 11.5-mile levee system managed by the Bethel Island Municipal Improvement District (BIMID). These levees are crucial for protecting the island's residents, agriculture, water quality, and natural habitats from flood risks. All of the levees comply with FEMA's HMP design standards, offering a basic level of flood protection. However, a segment of approximately one mile, known as the Horseshoe Bend project, was upgraded to meet the Bulletin 192-82 standard.

The Horseshoe Bend project enhanced the existing levees along a one-mile segment, spanning stations 130+00 to 180+00. This project involved raising the levees to meet Bulletin 192-82 standards while enhancing waterside habitat. By achieving the higher standard, the levees are better equipped to anticipate challenges, such as sea level rise, while still ensuring protection against floods exceeding a 100-year event. Completed in December 2020 with a budget of $5.3 million, the Horseshoe Bend project represents a crucial step in bolstering the resilience of Bethel Island's levee system.

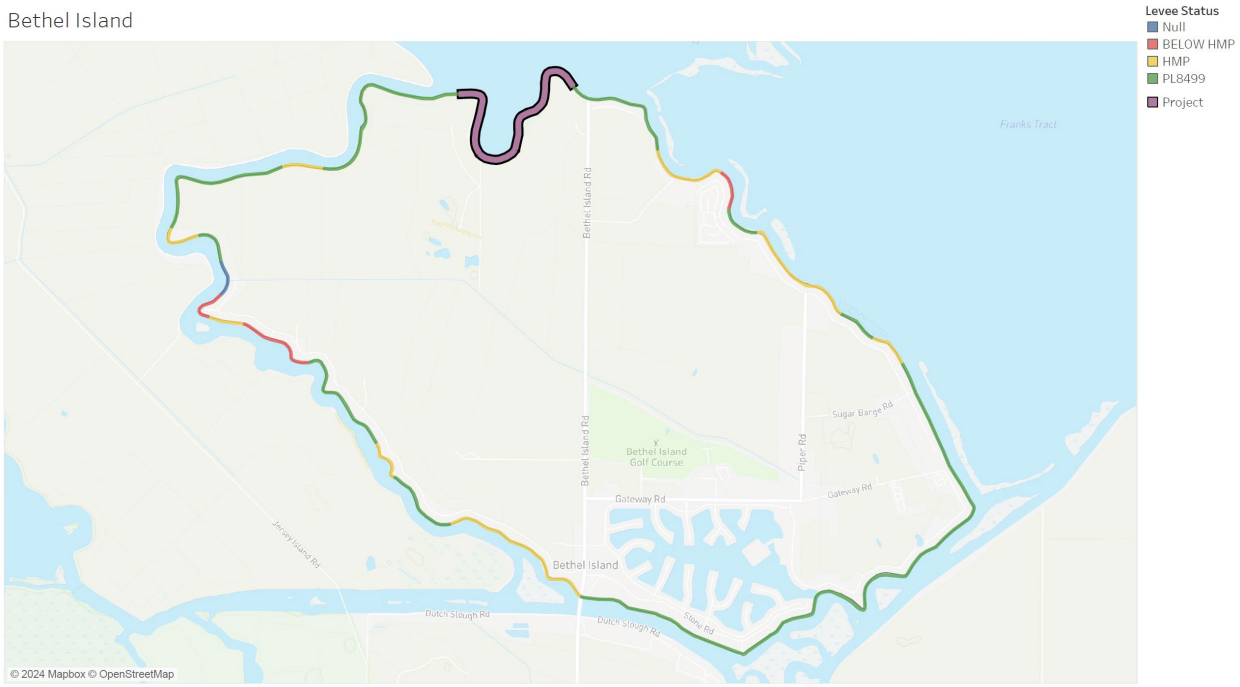
Key improvements made through the Horseshoe Bend project include:

- **Levee Modification:** The project involved setting back the landside of the levee and strengthening the overall structure to improve flood resilience.
- **Emergency Access:** Installation of a 22-foot-wide crown atop the levee, incorporating an all-weather road to facilitate access for emergency vehicles.
- **Seepage Management:** Introduction of measures to alleviate and/or reduce seepage along the levee, which improves levee stability.
- **Habitat Creation:** Development of a unique waterside, a fish-friendly habitat bench designed to support a diverse range of wildlife, particularly aquatic species beneficial to the Delta ecosystem.

The design of the Horseshoe Bend project considered the daily tidal inundation of the intertidal zone and the subsurface wetting of the soils in the riparian zone. The 18-foot-wide habitat bench is divided into two zones: an eight-foot-wide riparian zone elevated one foot above mean high water, and a 10-foot-wide intertidal zone sloping down to mean low water elevation. The design caters to the needs of various fish species by providing spawning, cover, and forage habitat. These efforts have culminated in the creation of a thriving new habitat area, now dense with vegetation and offering valuable resources for insects, birds, wildlife, and fish.

Bethel Island DST Metrics	Pre-Project	Post-Project	Net Change ($ and %)
Expected Annual Damage ($/yr.)	$2,786,156	$2,740,630	-$45,526 (-1.6%)

Expected Annual Fatalities	0.256	0.251	-0.005 (-2%)
Probability of Levee Failure	3.23%	3.18%	-1.58%
Expected Annual Flooded Leveed Habitat (acres/yr.)	11.2	11.0	-0.2 (-1.8%)
Expected Annual Damage, Delta as Place ($/yr.)	$113,566	$111,772	-$1,794 (-1.6%)



Sherman Island (DLIS Priority: Very High)

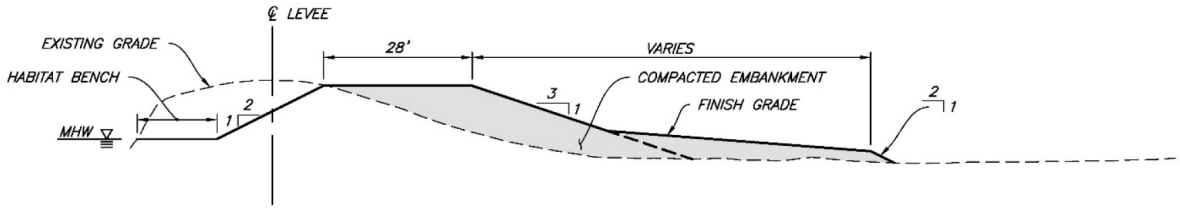
Sherman Island plays a vital role in the region's environmental health and water quality, as its levee system protects against salinity intrusion from the adjacent marsh. The island's 19.5-mile levee system is split into 9.7 miles of project levees (levees that are owned by the federal government), and 9.8 miles of non-project levees, or private levees. All non-project levees meet the HMP Standard, ensuring basic flood protection. Additionally, about 97% of the levee system meets the PL 84-

99 geometry standards, with around seven miles featuring counterbalance berms for enhanced stability (see below figure).

The completed project includes levee system enhancements between stations 368+00 and 700+00, spanning approximately six miles. Completed on July 22, 2020, this initiative, costing about $5.3 million, raised this portion of the levee to meet the PL 84-99 Standard.

Reclamation District No. 341 plans to improve the entire non-project levee system to the PL 84-99 Standard, with potential for further upgrades to the Bulletin 192-82 Standard. Meeting the PL 84-99 Standard facilitates subsequent enhancements and adaptation to climate-induced changes, such as variations in water surface elevation, storm surges, and wind wave actions.

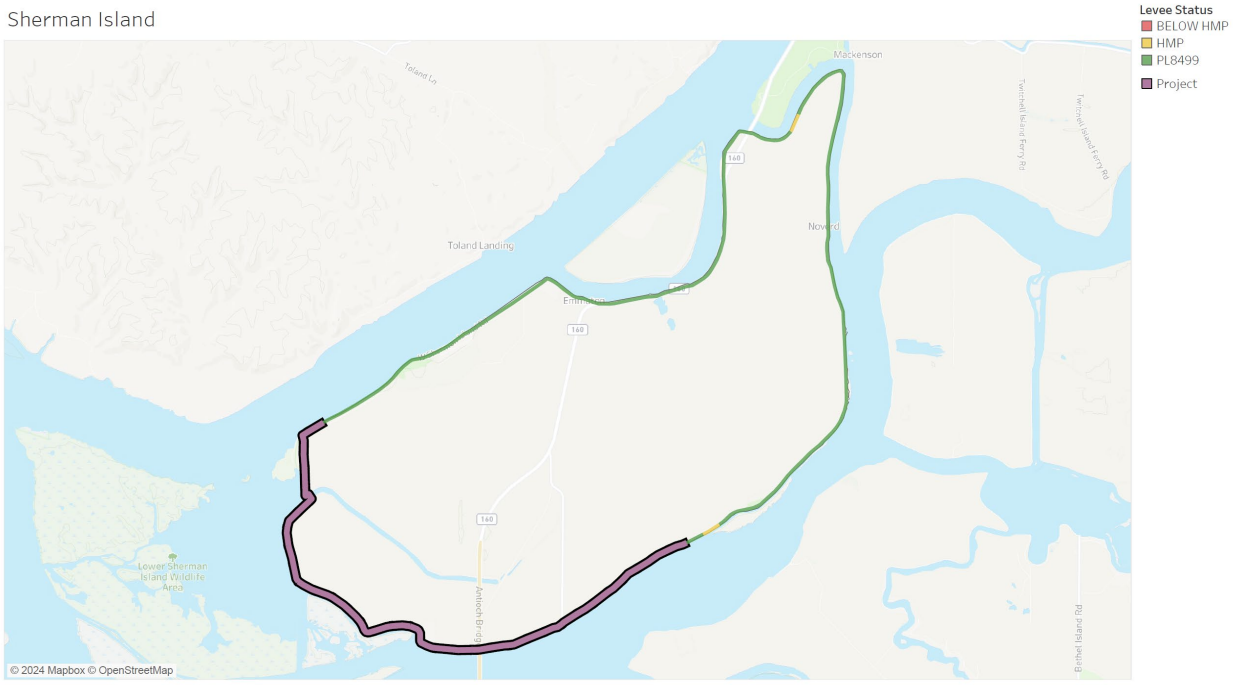
Counterbalance berms have been integrated into all six miles of improved levees, except for stations 640+00 to 660+00, enhancing levee stability and integrity. The district successfully upgraded the levee section from 368+00 to 690+00 to meet the PL 84-99 Standard. However, due to funding limitations, construction work from Sta. 330+00 to 368+00 remains incomplete. Completing this work would ensure the entire Sherman Island non-project levee system meets the PL 84-99 elevation requirements. Counterbalance berms play a crucial role in reducing the need for fill material and preventing levees from heightening due to peat soil subsidence (as shown below). Once constructed, these berms will cap the peat soils, preventing further subsidence near the levee.



Sherman Island DST Metrics	Pre-Project	Post-Project	Net Change ($ and %)
Expected Annual Damage ($/yr.)	$810,616	$810,612	-$5 (0%)

Expected Annual Fatalities	0.034	0.034	0.000 (0%)
Probability of Levee Failure	3.414%	3.414%	-0.001%
Expected Annual Flooded Leveed Habitat (acres/yr.)	313.0	313.0	0.0 (0%)
Expected Annual Damage, Delta as Place ($/yr.)	$17,151	$17,151	$0 (0%)

Sherman Island



Terminous Tract (DLIS Priority: Very High)

Terminous Tract consists of 10,000 acres of land, primarily used for agriculture. The 16.1-mile levee system has seen improvements over the last decade with State investment.

State Highway 12, a major route through the Delta, crosses Terminous Tract. The South Fork of the Mokelumne River and Potato Slough are key water conveyance channels, especially when the Delta Cross channel gates at Locke are open. A levee breach in this area could disrupt the flow of high-quality freshwater from the upper Sacramento River and increase saltwater intrusion from the Western Delta.

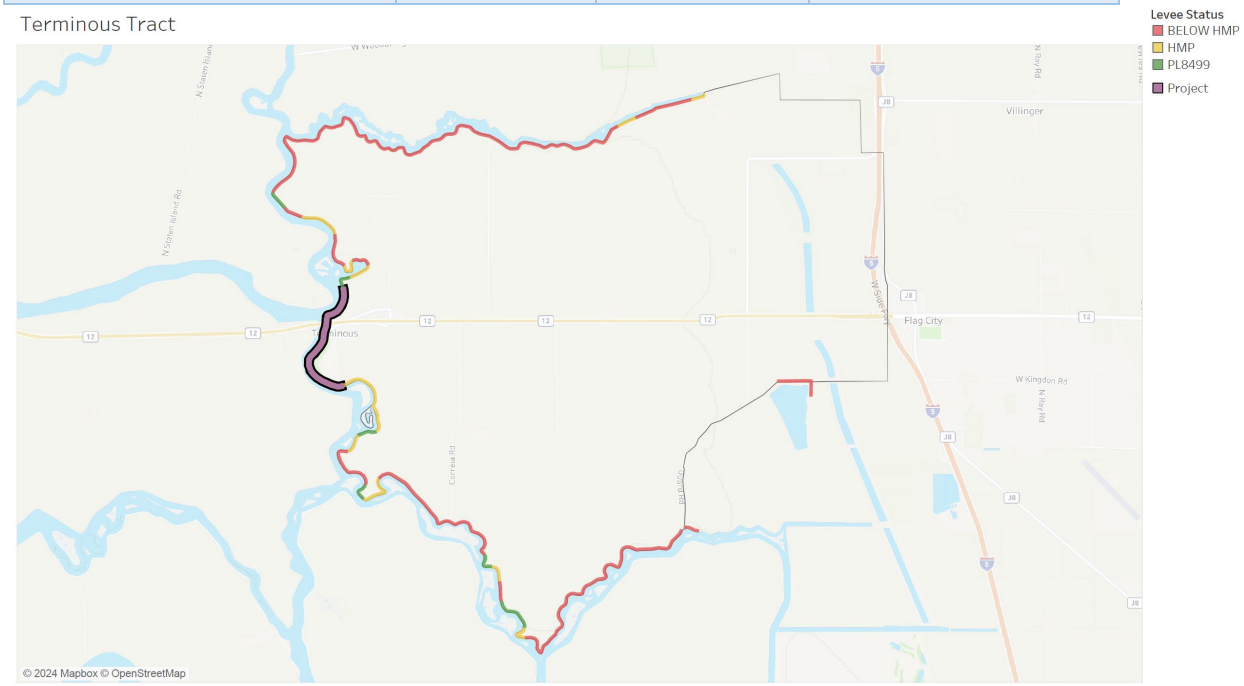
The project included enhancements between stations 520+00 and 583+00 to meet the HMP standard. This involved placing fill on the landside of the levee and the levee crown to improve the levees to the minimum HMP requirements, with half a foot of elevation overbuild, and constructing an all-weather road between Stations 520+00 and 583+00. This project was completed on January 10, 2023, at a cost of $2.072 million.

Reclamation District 548 initiated a five-year plan in 2012, funded by DWR's Delta Levees Special Flood Control Projects Program, aiming to upgrade the levees according to a district-adopted template. This template exceeds the 100-year flood elevation by two feet, includes a 22-feet wide crown, and adopts the PL-84-99 back slope, mirroring the Bulletin 192-82 levee template but with an additional six feet of crown width for two-way truck traffic and up to three feet of future freeboard for anticipated sea level rise. The total plan, spanning four phases, is estimated to cost over $25 million. It is unclear if all four phases of the project have been completed, as the December 2023 report from DWR does not provide sufficient information.

This series of projects aims to strengthen flood protection for Terminous Tract, addressing both current vulnerabilities and future risks, such as climate change and sea level rise.

Terminous Tract DST Metrics	Pre-Project	Post-Project	Net Change ($ and %)
Expected Annual Damage ($/yr.)	$1,749,426	$1,518,951	-$230,475 (-13.1%)
Expected Annual Fatalities	0.046	0.039	-0.007 (-15%)
Probability of Levee Failure	2.33%	2.03%	-12.52%
Expected Annual Flooded Leveed Habitat (acres/yr.)	8.3	7.2	-1.0 (-12.0%)

Expected Annual Damage, Delta as Place ($/yr.)	$1,395	$1,221	-$175 (-12.5%)



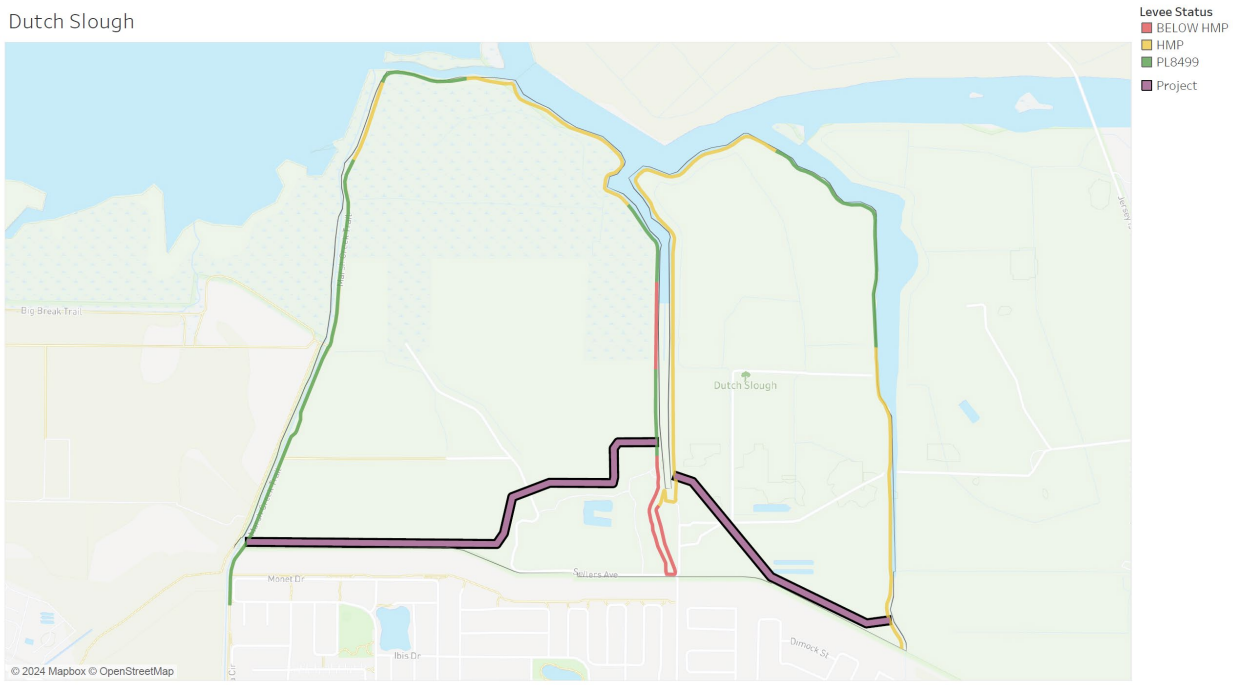
Dutch Slough (DLIS Priority: Very High)

The Dutch Slough Tidal Marsh Restoration Project is a significant effort to restore tidal marshes within the Sacramento-San Joaquin Delta, particularly near the city of Oakley. Initiated by DWR as part of the broader California EcoRestore initiative, this project focuses on over 1,100 acres of land, historically utilized for agriculture, and aims to convert them back into their natural marsh state.

Restoration activities, which started in May 2018 for the Emerson and Gilbert parcels, include grading and planting more than 40,000 trees and shrubs along with about 25,000 tule plugs. This work is part of the process to reintroduce natural tidal flows to the area, improving habitat conditions for fish species at risk and contributing to the ecological health of the Delta region. A critical component of the project is the flood control levee constructed at the southern end of the property, which provides essential flood protection to the new residential development located just south of the levee.

A new flood control levee, about 1.6 miles long and completed in 2020, now serves as the primary defense against flooding for the lands south of the project area. Designed to DWR's Urban Levee Design Criteria, this levee offers a 200-year level of flood protection and features a 20-foot crown width and an all-weather surface that doubles as an access road.

No one was residing in the Dutch Slough either before or after the project, and thus no reduction in expected annual fatalities will be observed. The configuration of levees within the Dutch Slough has undergone significant changes, making a reasonable comparison of metrics unfeasible. Consequently, the DST was not utilized to evaluate the impact of this project on flood risk reduction. This new configuration will form the new baseline for comparing future conditions.



Island or Tract	DLIS Priority	Total Project Cost ($)	State Cost Share ($)	Federal or Local Cost Share ($)	State Interests - Life	State Interests - Property	State Interests - Water Supply	State Interests - Delta as Place	State Interests - Ecosystem	Expected Annual Damage ($/yr)	Expected Annual Fatalities	Probability of Levee Failure	Expected Annual Flooded Leveed Habitat (acres/yr)	Expected Annual Damage, Delta as Place ($/yr)
Bethel Island	Very High	5,280,851	4,964,000	316,851	X	X	X	X		-45,526	-0.005	-1.58%	-0.18	-1,794
Sherman Island	Very High	5,300,000	5,300,000	-			X	X	X	-5	0.000	0.00%	0.00	0
Terminous Tract	Very High	2,072,175	1,968,566	103,609		X		X		-230,475	-0.007	-12.52%	-1.04	-175
Dutch Slough	Very High	42,355,977	DWR 28,405,977	2,900,000		X			X	N/A	N/A	N/A	N/A	N/A

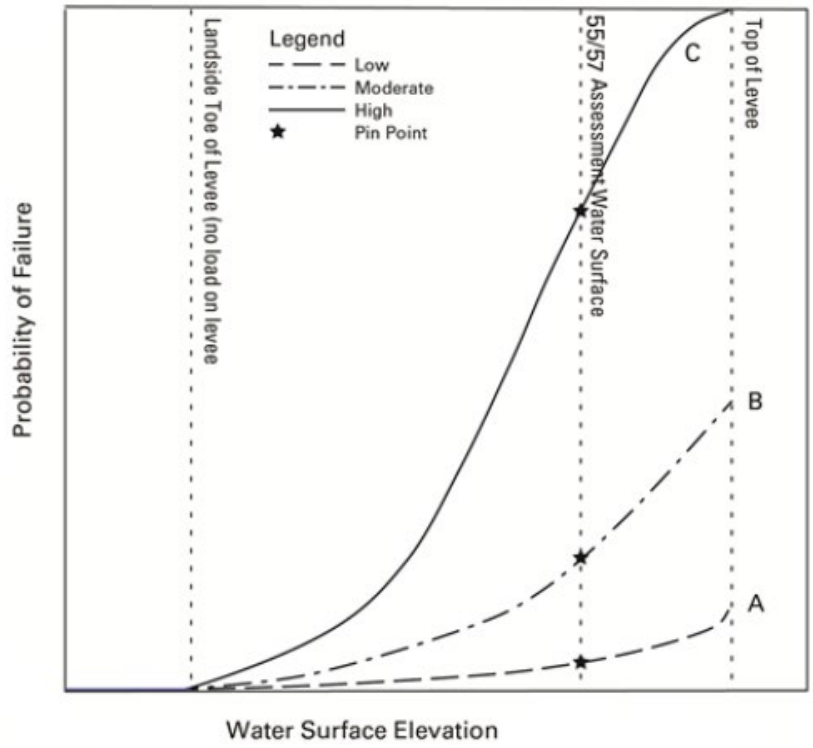
DST Risk Analysis

Note on Estimated Risk Reduction

In response to comments received during the DLIS rulemaking process, the Council refined the levee fragility methodology used by the DST. The revised methodology aimed for a consistent and accurate comparison of levee systems throughout the Delta. Central to this revision was the adoption of an alternative shape for the levee fragility curves, departing from the traditional S-shaped curve utilized in the 2016 DLIS assessment. This updated curve is notably flatter, a change based on extensive consultations with Delta levee reclamation district engineers. The rationale behind this modification was to accurately reflect the current conditions of Delta levees, informed by the lower-risk category from the 2012 Central Valley Flood Protection Plan (CVFPP) fragility curves.

Previously, the standard curve shape used in the 2016 DLIS closely resembled the high-risk category of the 2012 CVFPP's fragility curves (Curve C in Figure below), characterized by its S-shape. This shape has now been replaced with one that aligns with the low-risk category from the same plan (Curve A in the Figure below), marking a significant shift in how levee fragility is conceptualized. Notably, Curve A indicates a mere 0.5 percent probability of failure at the Adjusted Water Surface Elevation (AWSE), in stark contrast to the 85 percent failure probability associated with the high-risk Curve C. This adjustment suggests that, under the revised methodology, the risk of levee failure remains relatively low as water levels rise, with a significant risk materializing only in overtopping conditions.

This change in curve shape is supported by historical observations and recent improvements to Delta levees. Historically, Delta levees have withstood frequent high-water events, such as floods, tides, and storm surges, over the past century. However, it should be noted that substantial enhancements have been made to these structures in the last 30 years, including flatter back slopes, broader and flatter crests, the addition of rock revetments, and stability berms in many areas. These upgrades have effectively diminished the occurrence of levee failures in recent decades, contrasting with the more frequent failures observed over the previous century. The adoption of the flatter fragility curve thus reflects both a more accurate representation of current levee resilience in the Delta and a methodological improvement in assessing levee fragility across the region.



The revised methodology for assessing levee fragility across the Delta, while innovative, brings to light several concerns regarding its assumptions and comprehensiveness. A critical downside of this approach lies in its implicit assumption that all levees are in optimal condition, neglecting to account for variations in levee integrity due to maintenance efforts or structural improvements. This oversight means that the tool does not differentiate between the resilience of newly upgraded levees and those that are older, treating both as equally vulnerable despite the evident superior performance of the newer structures. For instance, according to the current methodology, a newly constructed setback levee on Bethel Island would be perceived to offer the same level of flood protection as its predecessor, suggesting an unchanged levee fragility curve regardless of the enhancements made.

While this methodology is simple and consistent, it fails to capture the nuances of levee improvements. For example, the practice of averaging levee crest elevations across an entire island fails to reflect localized enhancements accurately. If a section of a levee adjacent to a legacy town is raised, this improvement is diluted when averaged over the length of the island's levee, thereby minimizing the perceived impact of the upgrade. Similarly, the addition of stability berms or the

implementation of measures to reduce seepage—such as the construction of cutoff walls—are overlooked by the DST, which operates under the assumption that all levees are uniformly robust.

It should be noted that the DST methodology does not account for modifications that enhance levee stability but do not increase levee crest elevation, such as the flattening of landside or waterside slopes through the addition of fill. These changes improve the levee's stability while providing a more solid base for future levee crest raises, which allows for adaptation for changing hydrology and rising sea levels. In the DST's current framework, only direct raises to the levee crest are recognized as significant improvements and used in the risk reduction calculations.

References

1. DWR's Annual Report to the Delta Stewardship Council on Investments in the Delta Levees, December 2023.
2. Reclamation District 5-year Plans, December 2023