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SUPERIOR COURT OF THE STATE OF CALIFORNIA

COUNTY OF SACRAMENTO

COUNTY OF SACRAMENTO, a California county, Petitioner and Plaintiff, **v.** **CALIFORNIA DEPARTMENT OF WATER RESOURCES, a California State Agency,** Respondent and Defendant.	Case No. 24WM000014 (Related to 24WM000006; 24WM000008; 24WM000009; 24WM000010; 24WM000011; 24WM000012; 24WM000017; 24WM000062; 24WM000076) **COMPENDIUM OF EVIDENCE IN SUPPORT OF CAL. DEPT. OF WATER RESOURCES' EX PARTE APPLICATION FOR ORDER TO MODIFY OR STAY THE PRELIMINARY INJUNCTION – VOLUME II OF IV** **(CEQA case: California Environmental Quality Act, Pub. Resources Code, § 21000 et seq.)** Dept: 36 Judge: Hon. Stephen Acquisto Action Filed: January 22, 2024
DOES 1 through 50, Real Parties in Interest.	

Respondent California Department of Water Resources (DWR) hereby submits the following evidence in support of the DWR's ex parte application for order to modify or stay the preliminary injunction (Ex Parte Application). For ease of reference, DWR's Ex Parte Application contains citations to both the declarations themselves (and any exhibits, where relevant), and to the Bates numbered pages referenced in this Compendium of Evidence in Support of DWR's Ex Parte Application (COE). This is DWR's second Compendium of Evidence, and the Bates numbered pages continue from DWR's first Compendium of Evidence in Support of DWR's Opposition to All Petitioners' Motions for Preliminary Injunction.

Volume	**Declaration**	**Exhibit**	**Exhibit Description**	**Bates Nos.**
I	Decl. of Graham Bradner			291-305
I		A	2024 Cost Estimate, titled "Total Project Cost Summary Memorandum"	306-371
I		B	Finch, M. 1985. Earthquake Damage in the Sacramento–San Joaquin Delta, Sacramento and San Joaquin Counties. February. California Geology 38(2):39–44	372-380
I		C	Tsai, Y. 2018. Characterizing Seismic Performance of Levees on Peaty Organic Soils from Case Histories and Simulations. PhD dissertation. University of California, Los Angeles. Los Angeles, CA	381-715
II		D	U.S. Geological Survey. 2016. Earthquake Outlook for the San Francisco Bay Region 2014–2043. Fact Sheet 2016-3020. Version 1. August	716-722
II		E	California Department of Water Resources, October 2018, Supplement C – Water Project Export Disruptions for Multiple-Island Breach Scenarios using the Delta Emergency Response Tool	723-804
II		F	California Department of Water Resources, February 2009, Delta Risk Management Strategy, Phase 1, Executive Summary	805-837
II		G	Sunding, D. and Browne, O. 2024. Benefit-Cost Analysis of the Delta Conveyance Project. Berkeley Research Group	838-913

Volume	Declaration	Exhibit	Exhibit Description	Bates Nos.
III		H	California Department of Water Resources, December 2023, Delta Conveyance Project Final Environmental Impact Report, Chapters 6, 7, 10, 25, 26 and 30	914-1260
III	Decl. of Carolyn Buckman			1261-1267
III		A	Map of 2024-2026 Proposed Geotechnical Activities that are subject to temporary entry permits voluntarily entered by landowners to date or are located on DWR-owned property	1268-1269
III		B	Map of 2024-2026 Proposed Geotechnical Activities that will require court-ordered entry, assuming additional landowners do not enter temporary entry permits	1270-1271
III		C	Delta Conveyance Project - Modernizing California's Water Infrastructure - 2024 Fast Facts	1272-1274
III		D	Facts About the Economic Value of the Delta Conveyance Project	1275-1283
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IV	Decl. of Andrew Finney			1360-1364
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IV	Decl. of Jeff Henderson			1369-1371
IV		A	Delta Stewardship Council's "Delta Plan's regulatory policies in PDF format"	1372-1382

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IV		B	"Draft Determination Regarding Appeals of the Certification of Consistency by the California Department of Water Resources for California WaterFix" (November 8, 2018)	1383-1539
IV	Decl. of Katherine Marquez			1540-1557
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Dated: July 24, 2024

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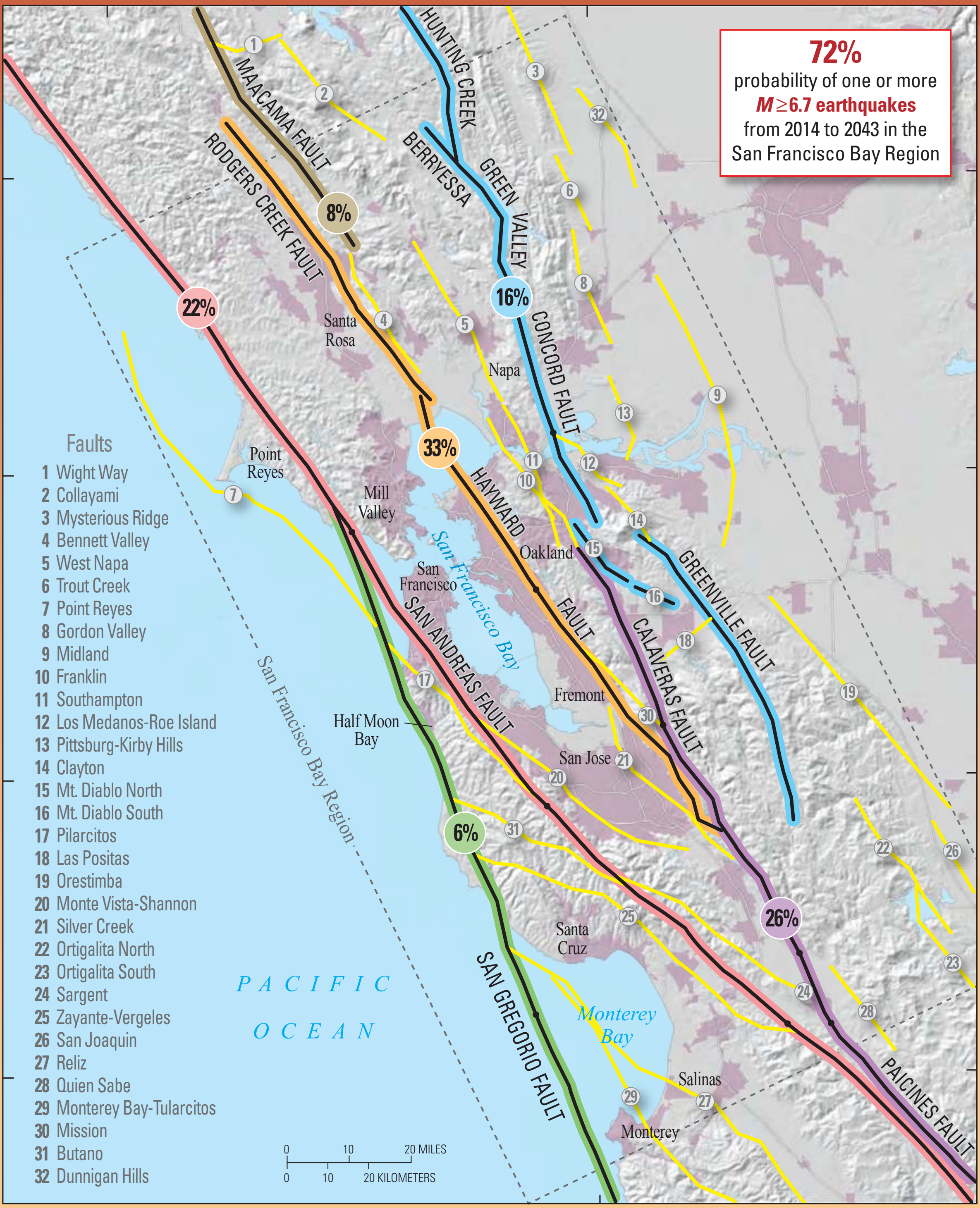
EXHIBIT D
TO BRADNER
DECLARATION

Earthquake Outlook for the San Francisco Bay Region 2014–2043



EXPLANATION

- Major plate boundary faults
- 3 Lesser-known smaller faults
- Urban areas

Map of known active faults in the San Francisco Bay region. The 72 percent probability of a magnitude 6.7 or greater earthquake includes the well-known major plate-boundary faults, lesser-known faults, and unknown faults. The percentage shown within each colored circle is the probability that a magnitude 6.7 or greater earthquake will occur somewhere on that fault system by the year 2043. The probability that a magnitude 6.7 or greater earthquake will involve one of the lesser-known faults is 13 percent.

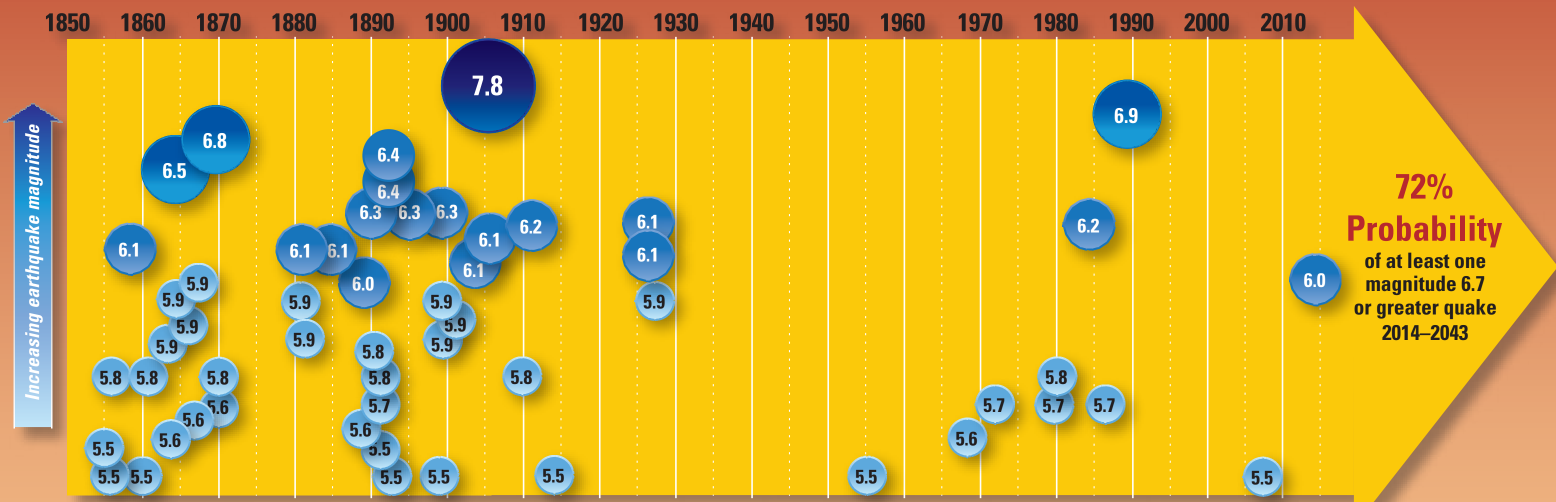
Using information from recent earthquakes, improved mapping of active faults, and a new model for estimating earthquake probabilities, the 2014 Working Group on California Earthquake Probabilities updated the 30-year earthquake forecast for California. They concluded that there is a 72 percent probability (or likelihood) of at least one earthquake of magnitude 6.7 or greater striking somewhere in the San Francisco Bay region before 2043. Earthquakes this large are capable of causing widespread damage; therefore, communities in the region should take simple steps to help reduce injuries, damage, and disruption, as well as accelerate recovery from these earthquakes.

Building damaged in 2014 South Napa earthquake. Photograph by Erol Kalkan, U.S. Geological Survey.

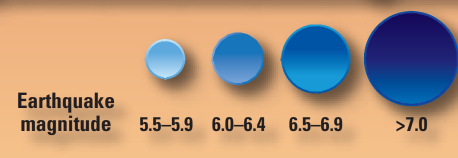
U.S. Department of the Interior
U.S. Geological Survey

Fact Sheet 2016–3020
Revised August 2016 (ver. 1.1)

San Francisco Bay Region Earthquake Timeline



1850–1966 earthquakes from Bakun, W.H., 1999, Seismic Activity of the San Francisco Bay Region: Bulletin Seismological Society of America, v. 89, p. 764–784 and 1967–2014 earthquakes from the Northern California Seismic Network.



Likelihood of at least one earthquake greater than a given magnitude in the San Francisco Bay region between 2014 and 2043.

Magnitude (M)	30-year likelihood of at least one earthquake in the San Francisco Bay region
$M \geq 6.0$	98 percent
$M \geq 6.7$	72 percent
$M \geq 7.0$	51 percent
$M \geq 7.5$	20 percent

Timeline of magnitude 5.5 and greater earthquakes in the San Francisco Bay region 1850–2014. In the 50 years prior to 1906, there were 13 earthquakes with a magnitude between 6 and 7, but only 6 earthquakes of similar magnitude in the 110 years since 1906. The rate of large earthquakes is expected to increase from this low level as tectonic plate movements continue to increase the stress on the faults in the region.

Earthquake Preparedness Helps

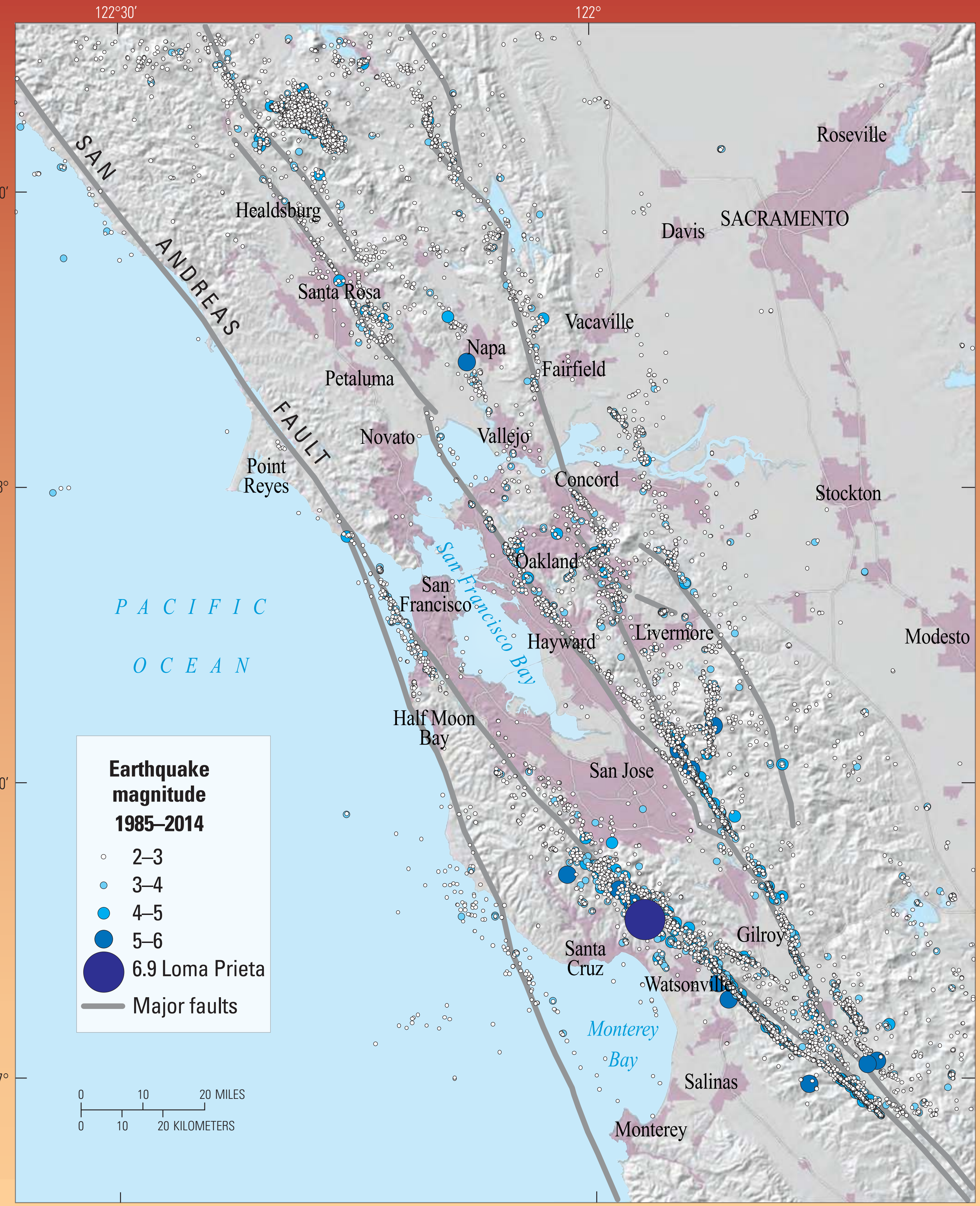
Early Sunday morning on August 24, 2014, the residents of Napa, California, were jolted awake by a strong, magnitude 6.0 earthquake. Within 30 minutes, the staff of Becoming Independent, a non-profit organization that helps adults with intellectual disabilities lead independent lives, called the people they serve in the affected area. The staff quickly visited all of the clients that needed help with cleanup and making their homes safe, a task made easier because both groups were trained in disaster preparedness and the clients had emergency kits with needed supplies on hand. The South Napa earthquake shifted houses off their foundations, damaged chimneys, started fires, and broke water mains throughout the city, causing hundreds of millions of dollars in economic losses. Many historic masonry buildings in downtown Napa were damaged. The earthquake was the largest in the San Francisco Bay region since the 1989 magnitude 6.9 Loma Prieta earthquake and a clear reminder of the seismic vulnerability of the region. The staff and clients of Becoming Independent showed that understanding and preparing for these events can improve how we live with future earthquakes.

Why Does the San Francisco Bay Region Have Earthquakes?

The same geologic process that is responsible for the San Francisco Bay region's beautiful coastlines, bays, hills, and valleys is also the primary driving force for earthquakes along faults in the region. The Bay region is located within the active boundary between the Pacific and the North American tectonic plates, where the Pacific plate slowly and continually slides northwest past the North American plate. The San Andreas Fault, on which two magnitude 7.8–7.9 earthquakes have occurred in historical time, including the 1906 San Francisco earthquake, is the fastest slipping fault along the plate boundary. Other major plate boundary faults in the San Francisco Bay region include the Hayward, Rodgers Creek, Calaveras, Maacama, San Gregorio, Concord, Green Valley, and Greenville Faults.

How Do Scientists Calculate Earthquake Probability?

Scientists rely upon a variety of techniques to help understand the rate and magnitude of past earthquakes in order to estimate the likelihood of future earthquakes. The Global Positioning System (GPS) and other land surveying and geologic techniques have allowed scientists to make more accurate measurements of how the current plate motions—totaling 1.6 inches per year across the San Francisco Bay region—distribute stress onto these individual faults. Balancing plate motions with the slip during large earthquakes and slow creep on faults allows scientists to calculate average rates of earthquake occurrence over periods of hundreds to thousands of years. (Continued on page 4)



Map of earthquakes greater than magnitude 2.0 in the San Francisco Bay region from 1985–2014. Small earthquakes occur on both major faults (shown by the gray lines) and minor faults (not shown). Because of the variability of fault geometry, earthquakes at depth do not always coincide with the mapped faults at the Earth's surface. There are sections of major faults, particularly the San Andreas Fault, with few or no small earthquakes but they will produce large earthquakes in the future. Compiled from the Northern California Seismic Network.

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(Continued from page 2). A trench excavated across the Hayward Fault in Fremont revealed evidence of 12 large earthquakes over the past 1,900 years. The time interval between these earthquakes ranged from about 100 to 210 years. Historical records indicate that the most recent large earthquake on this fault occurred in 1868. However, detailed information about other past earthquakes in the San Francisco Bay region is difficult to obtain because seismograph records only go back to about 1900, historical accounts are sparse before 1850, and there are limited locations where faults can be trenched to identify and date prehistoric earthquakes.

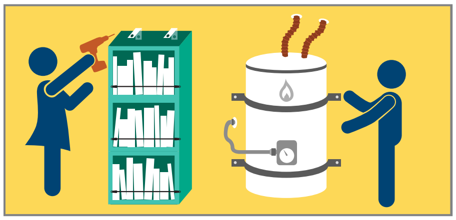
Calculating accurate earthquake probabilities for short periods, such as 30 years, is also challenging. Although the 30-year time interval is convenient for humans, it is much less than the average time between large earthquakes on these faults, which can range from hundreds to thousands of years. The rate of large earthquakes in the San Francisco Bay region was high in the late 1800s but dropped abruptly after the 1906 San Francisco earthquake on the San Andreas Fault. Scientists believe that the post-1906 earthquake rate decreased because the large amount of slip along the San Andreas Fault in 1906 temporarily reduced the stress on many of the faults in the region. However, the ongoing motion of the tectonic plates began rebuilding stresses after the 1906 event, and earthquakes larger than magnitude 5.5 resumed during the second half of the 20th century. Future large, damaging earthquakes in the San Francisco Bay region, similar in size to the 1989 Loma Prieta and 1906 San Francisco earthquakes, may or may not be accompanied by the level of earthquake activity observed in the late 1800s.

The 2014 Uniform California Earthquake Rupture Forecast version 3 (http://pubs.usgs.gov/fs/2015/3009/) provides an updated estimate of the likelihood of large earthquakes in California over a 30-year time window from 2014 to 2043. The forecast accounts for how fast stress is accumulating on each fault due to plate motions and the time since its most recent large earthquake(s). In updating the probability calculations, scientists used a more complete set of faults for the San Francisco Bay region than those used in the previous (2008) calculations, adding 32 smaller faults to the 5 major fault systems. The new study has also incorporated more options for how multiple faults might rupture together in large earthquakes.

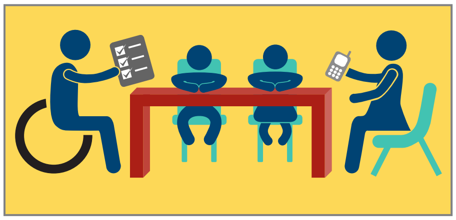
Seven Steps to Earthquake Safety

PREPARE

Before the next big earthquake we recommend these four steps that will make you, your family, or your workplace better prepared to survive and recover quickly:

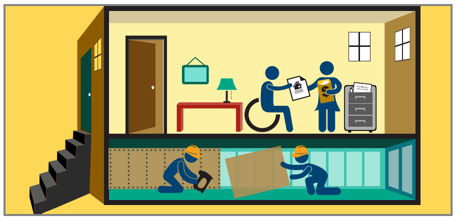


Step 1: Secure your space by identifying hazards and securing moveable items.



Step 2: Plan to be safe by creating a disaster plan and deciding how you will communicate in an emergency.

Step 3: Organize disaster supplies in convenient locations.



Step 4: Minimize financial hardship by organizing important documents, strengthening your property, and considering insurance.

SURVIVE

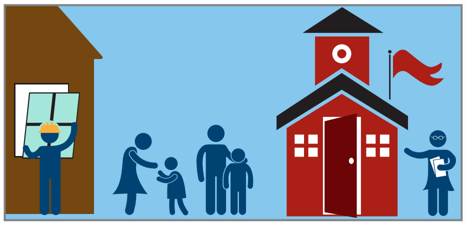
During the next big earthquake, and immediately after, is when your level of preparedness will make a difference in how you and others survive and can respond to emergencies:

Step 5: Drop, Cover, and Hold On when the earth shakes.

Step 6: Improve safety after earthquakes by evacuating if necessary, helping the injured, and preventing further injuries or damage.

RECOVER

After the immediate threat of the earthquake has passed, your level of preparedness will determine your quality of life in the weeks and months that follow:



Step 7: Reconnect and Restore. Restore daily life by reconnecting with others, repairing damage, and rebuilding community.

Adapted from Seven Steps To Earthquake Safety
http://earthquakecountry.org/sevensteps/

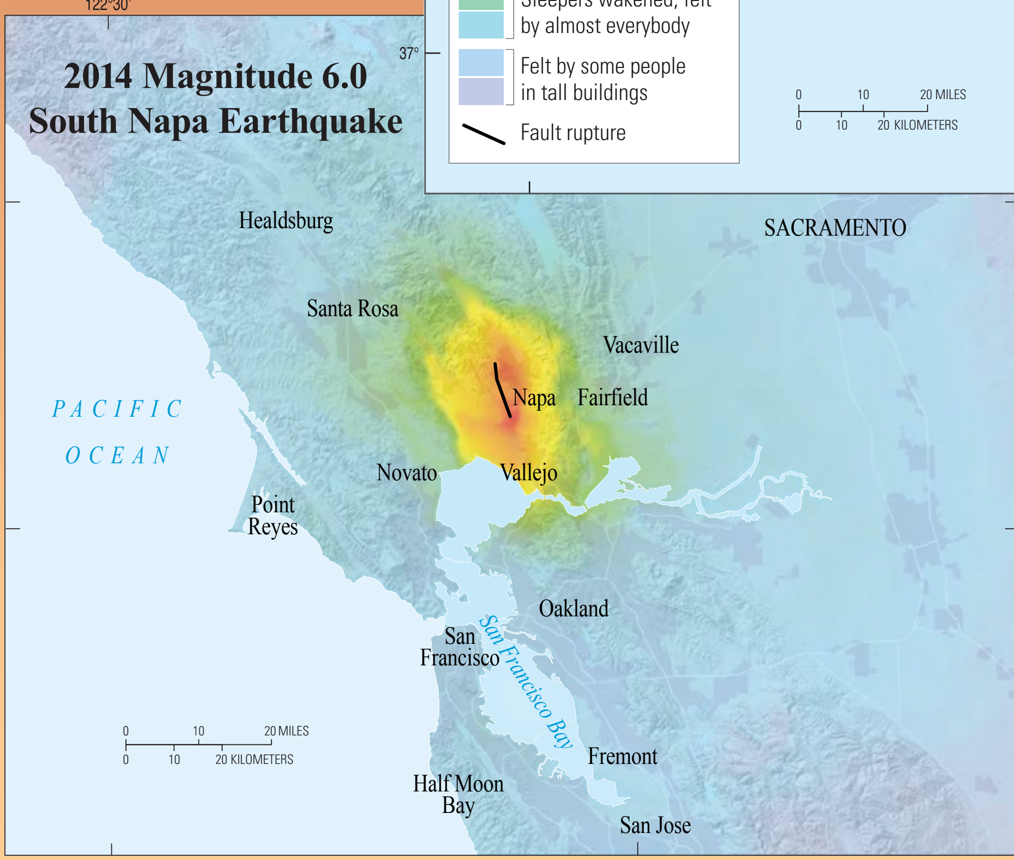
Probabilities of Earthquakes in the San Francisco Bay Region

Smaller earthquakes occur more frequently than larger earthquakes. The probability that an earthquake of magnitude 6.0 or larger will occur before 2043 is 98 percent. The probability of at least one earthquake of magnitude 6.7 or larger in the San Francisco Bay region is 72 percent, and for at least one earthquake of magnitude 7.0 or larger it is 51 percent. These probabilities include earthquakes on the major faults, lesser-known faults, and unknown faults.

The probability of a large earthquake occurring on an individual fault in the San Francisco region is lower than the probability of an earthquake occurring anywhere in the region. The faults in the region with the highest estimated probability of generating damaging earthquakes between 2014 and 2043 are the Hayward, Rodgers Creek, Calaveras, and San Andreas Faults. In this 30-year period, the probability of an earthquake of magnitude 6.7 or larger occurring is 22 percent along the San Andreas Fault and 33 percent for the Hayward or Rodgers Creek Faults. Individual sections of these faults have lower probabilities for large earthquakes to occur (continued on page 6);

Maps showing intensity of ground shaking for the South Napa and Loma Prieta earthquakes. The black lines show the location of fault slip at depth. The maps illustrate how the area subjected to strong shaking increases with increasing earthquake magnitude.

Road damage from the Loma Prieta earthquake. Photograph by H.G. Wilshire, U.S. Geological Survey.



Damaged building in downtown Napa. Photograph by Erol Kalkan, U.S. Geological Survey.

Additional Earthquake Resources

American Red Cross – Bay Area (http://www.redcross.org/local/northern-california-coastal)
Association of Bay Area Governments (http://resilience.abag.ca.gov/earthquakes/)
Bay Area Earthquake Alliance (http://bayquakealliance.org/)
California Earthquake Authority (http://www.californiarocks.com/)
California Geological Survey
(http://www.consrv.ca.gov/cgs/geologic_hazards/earthquakes)
Did You Feel It? (http://earthquake.usgs.gov/earthquakes/dyfi/)
Earthquake Country Alliance (http://earthquakecountry.org/)
Putting Down Roots in Earthquake Country (http://pubs.usgs.gov/gip/2005/15/)
ShakeAlert – An Earthquake Early Warning System for the United States West Coast
(http://pubs.usgs.gov/fs/2014/3083/)
ShakeMap (http://www.cisn.org/shakemap/nc/shake/index.html)
ShakeOut.org (http://www.shakeout.org/california/bayarea/)
Uniform California Earthquake Rupture Fault version 3 Fact Sheet
(http://pubs.usgs.gov/fs/2015/3009/)
United Policyholders (http://www.uphelp.org/)
USGS Real-Time Earthquakes (http://earthquake.usgs.gov/earthquakes/map/)

Damaged building in downtown Napa. Photograph by Erol Kalkan, U.S. Geological Survey.

(continued from page 5) however, an earthquake of magnitude 6.7 or larger will cause strong shaking over a broad area. Therefore, it is important to estimate the probability of a large earthquake occurring anywhere in the San Francisco Bay region.

What is the Likelihood That an Earthquake Will Affect You?

Earthquake probabilities are only one component in the evaluation of earthquake hazards. Higher magnitude earthquakes have broader areas of intense shaking and cause more damage than lower magnitude earthquakes. In a magnitude 6.0 earthquake, strong shaking and damage are confined to a localized area, as illustrated by the 2014 South Napa earthquake. In comparison, the 1989 magnitude 6.9 Loma Prieta earthquake caused damage over a region nearly 100 miles long. Local soil and geologic conditions, bedrock type, quality of building construction, and susceptibility to flooding (caused by dam or levee failure) can also affect the amount of damage at a particular site. This was dramatically demonstrated by the 1989 Loma Prieta earthquake, which devastated vulnerable parts of Oakland and San Francisco, more than 50 miles from the fault rupture.

How Can You Protect Yourself and Your Family?

Taking simple steps before and during earthquakes can help protect you and your family, as well as speed your recovery from an earthquake.

Before the next earthquake:

- Assess your home and work space, identify hazards, and secure moveable items.
- Create an emergency plan and organize disaster supplies to sustain you and your family for 72 hours or longer.
- Practice “Drop, Cover, and Hold On” to protect yourself when the ground begins to shake. Learn and practice what to do at home, work, or in school.
- Stay prepared by repeating these steps on a regular basis. For example, reassess your preparedness every year and participate in the annual Great California ShakeOut drill on the third Thursday in October.

Lack of adequate shear walls on the garage level exacerbated damage to this building at the corner of Beach and Divisadero in the Marina District, San Francisco, during the October 1989 Loma Prieta earthquake.

Brad T. Aagaard, James Luke Blair, John Boatwright, Susan H. Garcia Ruth A. Harris, Andrew J. Michael, David P. Schwartz, and Jeanne S. DiLeo

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https://twitter.com/USGS

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EXHIBIT E
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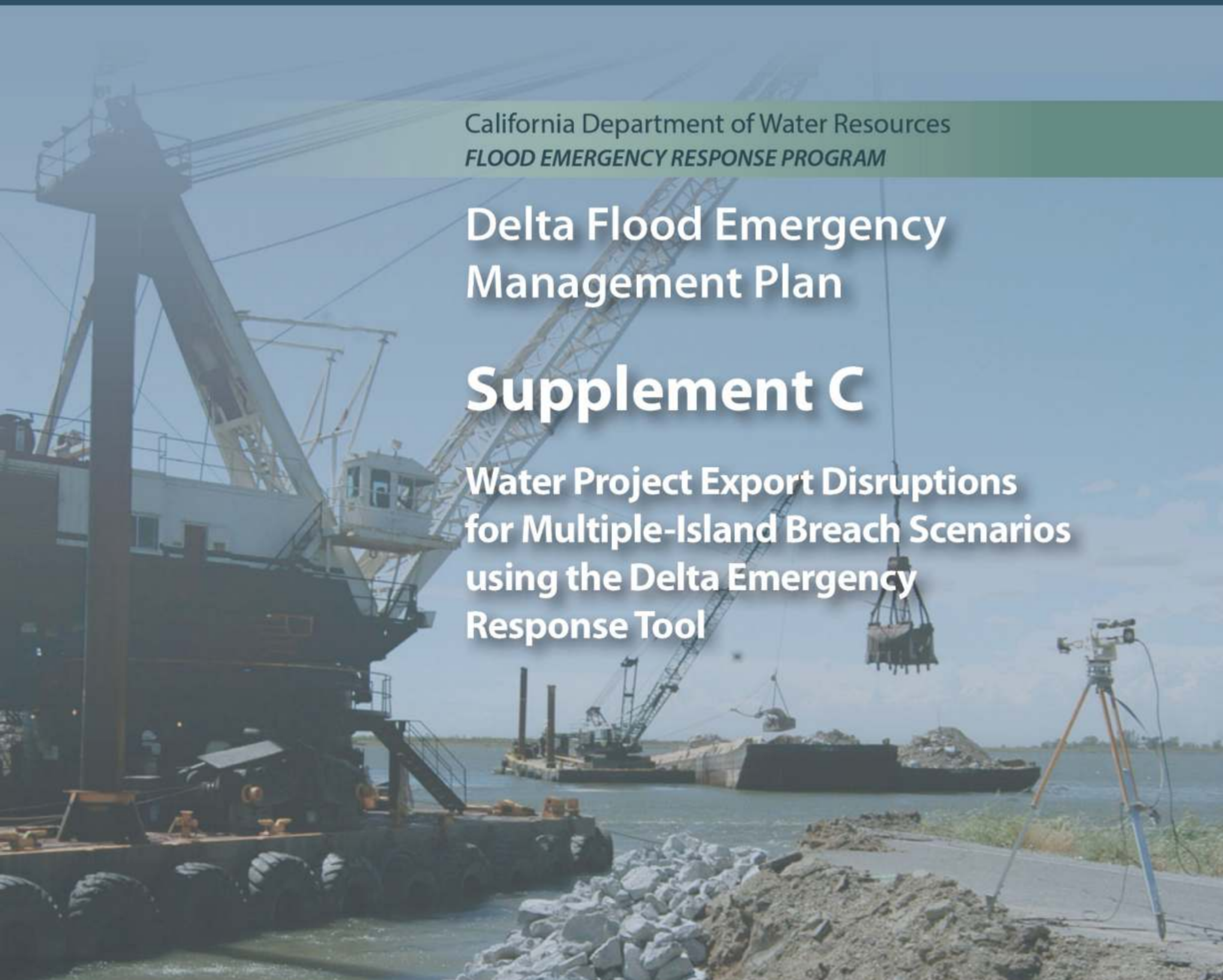
October 2018



California Department of Water Resources

FLOOD EMERGENCY RESPONSE PROGRAM

Delta Flood Emergency Management Plan

Supplement C

Water Project Export Disruptions for Multiple-Island Breach Scenarios using the Delta Emergency Response Tool

Supplement C – Water Project Export Disruptions for Multiple-Island Breach Scenarios using the Delta Emergency Response Tool

Preface

Levee failures in the Sacramento-San Joaquin Delta (Delta) can have a significant impact on the State's water supply. Degradation of the supply due to saltwater intrusion from the San Francisco Bay could make it unsuitable for use by approximately two-thirds of California's population.

In anticipation of this potential problem, this Supplement attempts to quantify the range of impacts that could occur and identify effective mitigation strategies. This is accomplished by analyzing a range of potential breach scenarios, response activities, and hydrologic conditions and then evaluating their coupled influence on Delta salinity.

Supplement C has been organized into the following Sections:

- Sections 1 - 3 further describe the potential impacts associated with Delta levee failures and briefly discuss the existing body of literature related to the topic.
- Section 4 provides a *conceptual* overview of the *Delta Emergency Response Tool* (Delta ERT), which was the modeling tool used to perform this analysis. Chapter 5 discusses the calibration and corroboration efforts that were used to validate the Delta ERT.
- Sections 6 - 9 describe the levee breach scenarios, response strategies, and hydrologic conditions tested, as well as their assumptions and limitations.
- Sections 10 - 14 discusses the findings of the study and takes a closer look at the sensitives of various response strategies.
- Section 15 attempts to summarize the implications of the findings and results.

This Supplement is not intended to be used as a mechanism for selecting specific response actions to address Delta levee failures. Rather, the intent is to inform the reader of the key parameters that influence water quality and highlight the Delta's sensitivities to various response actions. Although there are many constituents that affect water quality, this Supplement only focuses on degradation due to increased salinity.

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1 Introduction

The Delta Emergency Response Tool (ERT) was developed to support operational decision making following Sacramento-San Joaquin Delta (Delta) levee breaches. Historically, breaches have occurred in the Delta due to many different failure modes. These failure modes include high water/overtopping, geotechnical/ structural failure, wind-wave erosion, and sunny day - which refers to sudden catastrophic failures typically associated with seepage or animal burrow issues. From 1900 to 2000, there were over 161 breaches of Delta levees (DWR, 2007). Since 2000, there have been very few breaches; however, the risk persists which was demonstrated during the Upper Jones Tract levee failure in June 2004.

One failure mode that presents the greatest risk to the integrity of the Delta is a seismic (earthquake) event triggering multiple levee breaches. The risk is increased by land subsidence and the fact that the underlying levee soils are poor, highly organic, and subject to liquefaction and settlement. Also, there are many active faults near the west Delta levees that could produce significant ground accelerations that would contribute to potential failures. If the earthquake event occurred during periods of low freshwater inflows to the Delta, then the breach islands could fill with highly saline water from the bay, instead of freshwater. Depending on the breach location and progression of successive breaches, the water quality in the Delta could be degraded such that the water exports for the State Water Project (SWP) and Central Valley Project (CVP) could be shut down or disrupted for several months. Additionally, in-Delta water use and other water exports, such as Contra Costa Water District, would likely be disrupted.

Due to the complex nature of the Delta estuary, each failure event results in a unique series of impacts. The Delta ERT allows the user to estimate the impacts to water exports, based on a particular event, and to test different response strategies to mitigate the disruption times. These response strategies include: stopping exports, operating the Delta Cross Channel (DCC), releasing water from upstream reservoirs, and installing channel barriers. The tool allows the user to test different combinations of response options in rapid succession, to screen out less-effective options. Thus, the Delta ERT is intended to be used as a quick diagnostic tool that can narrow-down the response strategies to a reasonable number which can be validated by more-detailed, multi-dimensional hydrodynamic models.

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2 Purpose

The purpose of this Supplement is to demonstrate the estimated water export disruption times associated with certain large-scale events. The events simulated represent various combinations of levee breach scenarios and initial conditions in the Delta. This report includes estimates of disruptions for various scenarios when response strategies are implemented. Also, for a given very large event, the report describes the potential response strategies and their incremental impact on the disruption times. The results from these simulations are intended to be used solely for informational or planning purposes. For a real-world event, the model should be re-run to determine the appropriate response.

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3 Previous Studies

a. Sacramento-San Joaquin Delta Emergency Water Plan (1986)

This plan was created by the Department of Water Resources (DWR) in response to the implementation of Assembly Bill 955 (AB 955). This Bill required the formulation of a plan that would allow the continuance or quick resumption of usable water exports from the Delta in the event of one or more levee failures. The plan investigates previous levee failures and the existing emergency plans as well as available actions that may be taken to restore exports. The plan concludes by detailing emergency plans for four possible scenarios.

b. Preliminary Seismic Risk Analysis Associated with Levee Failures in the Sacramento-San Joaquin Delta (2005) (Seismic Risk Study)

This study was conducted in 2004 as part of the CALFED Bay-Delta Program. The study presents the results of a preliminary seismic risk analysis to estimate the effects of seismically initiated levee failures on Delta water quality, exports, and the economic consequences to the state. The purpose of the study was to conduct a preliminary analysis that provides an initial insight to the level of economic risk to the state and the risk-reduction opportunity associated with undertaking seismic upgrades of the Sherman Island levees. Two earthquake scenarios were simulated for 30 and 50 levee breaches, respectively. The 50-breach scenario was used for the analysis in this Supplement as well (see Section 6).

The main conclusion from this study was that the economic impact could be upwards of $10 billion for the 50-breach scenario. The study also highlighted the many uncertainties associated with this analysis, including: the number and location of breaches, sequence of levee repairs, timing of the earthquake, hydrologic conditions, and reservoir conditions. The study found that if severe earthquake damage occurs, including many Delta levee breaches (say 20, or more), a long period of water export disruption can be expected on the order of one year or more. The analysis included a recovery strategy of breach repairs and water releases from upstream reservoirs; however, no channel barriers were considered. Impacts increase with increasing length of the disruption period. Thus, the most important goal of mitigation strategies should be to decrease the length of export disruptions.

c. Delta Risk Management Strategy (DRMS, 2007 - 2009)

This study, initiated by DWR in 2005, included a detailed evaluation of the response of the Delta to a range of levee breach scenarios that could be initiated by floods, earthquakes, or intrinsic events (e.g., seepage, piping, levee instability). DRMS also evaluated the consequences and developed recommendations to manage the risk. Several tools were developed to model the hydrodynamic and water quality response of the Delta following breached levees and flooded islands. Similar to the *Seismic Risk Study*, DRMS identified the large variations in impacts for each scenario. The study also identified the unpredictability of levee performance during flood or seismic events which leads to considerable variability in the number of levee breaches that could occur and the combination of islands that would be flooded.

As part of the DRMS study, the Emergency Response and Recovery (ERR) and Water Analysis Module (WAM) were developed. The ERR simulates the levee repairs based on material availability, placement rates, and other constraints. The WAM simulates the coupled hydrodynamics and water operations response (i.e., reservoir releases, exports). These two modules would later be enhanced and integrated into the Delta ERT that was used for the analysis described in this Supplement.

d. Delta Flood Emergency Recovery Plan (DFERP, 2011)

This plan was developed as part of DWR's Delta Flood Emergency Preparedness, Response, and Recovery Program. The study evaluated the severity of levee breach events in the Delta and to plan recovery operations. The objective of the study was to develop response strategy guidelines that can be implemented by DWR's Flood Operations Center (FOC) staff in the early hours after an event occurs in the Delta. This includes evaluating the event's severity and providing guidance for the allocation of levee repair resources.

The findings of this study were used to inform the *Delta Flood Emergency Management Plan* (DFEMP). Similar to the previous studies listed here, the findings were that the actions needed to recover the Delta and restart exports are dependent on the severity of the event and hydrologic conditions. This study simulated a wide range of scenarios and hydrologic events which were used to develop ranges of impacts. The study also evaluated when the different response strategies would be effective. The study found that the total flooded island volume and *X2*[1] are the most important parameters for evaluating the appropriate response strategy.

e. Delta Emergency Channel Closure Locations Study (2012)

In this study, DWR evaluated the site conditions, material quantities, and costs to construct channel barriers to minimize water quality impacts and create a fresh water corridor following a multiple-island levee failure event. Twelve potential channel barriers were evaluated throughout the Delta (shown on Figure 6). Many of these barriers were included in the analysis for this Supplement. The study also identified the most effective materials for the channel barriers (i.e., rock, sheet piles, flexible intermediate bulk containers (FIBC), geo-tubes and transportation methods (i.e., barges, trucks).

f. Long-term Salinity Impacts from Permanently Flooding Delta Islands (2013)

In this study, DWR evaluated the long-term impact to salinity at the entrance to Clifton Court Forebay (CCFB) due to permanent flooding of individual or groups of islands in the Delta. A computer model of Delta flows and water quality, the Delta Simulation Model 2 (DSM2), was used to investigate several scenarios of long-term flooding of

[1] *X2* is the location in the Delta where the tidally averaged bottom salinity is two parts per thousand. It is expressed as the distance in kilometers from the Golden Gate Bridge.

Delta islands. For these scenarios, island levees were breached in multiple locations and never repaired. Analysis focused on long-term impacts to salinity and did not look at short-term salinity impacts due to levee breaches.

The key findings of the study were that Sherman Island is the most important barrier to salinity intrusion at CCFB and the western Delta is the most critical region in preventing salinity intrusion at CCFB. Another finding was that certain breaches on certain islands could *reduce* salinity at CCFB. Also, the study found that if an island is permanently flooded at only one breach location and the other levees remain intact, the location of the opening may affect the salinity at Clifton Court. The groupings of flooded islands evaluated as part of this Supplement (as described in Section 6 and on Figure 5) were chosen to be consistent with this 2013 study.

g. Technical Evaluation for Delta Levees - Emergency Freshwater Pathway (2015b) and Technical Evaluation for Delta Levees - Old River Levees Conveyance (2016)

These two studies, completed by AECOM for the Metropolitan Water District (MWD) of Southern California, evaluated the potential for slumping along the Old and Middle River corridors for a given earthquake scenario. These studies found that significant slumping could occur along both rivers' levees due to the generally poor foundation soils. The slumping conditions identified in these studies are likely conservative estimates and additional studies are being conducted to hone in on more precise estimates. Until new results become available, the findings of these studies will be used to make assumptions on the extent of slumping for the 20 island/50 breach scenario simulated for this Supplement.

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4 Delta Emergency Response Tool (ERT) Overview

The Delta ERT is a computer simulation tool that is intended for use following Delta levee failures to forecast impacts and develop response strategies to mitigate those impacts. It can simulate a large number of response strategies quickly which can then be verified with more-detailed, multi-dimensional Delta models (e.g., DSM2, RMA2 Bay-Delta Model, SELFE). The Delta ERT computational engine is based on foundational tools that were developed for the DRMS study, including the ERR and WAM modules. Those modules were enhanced by adding features that allow DWR to test various response strategies and extract results from the simulations to support decision-making. Also, the hydrodynamic model has been calibrated and validated as explained in Section 5. The tool's graphical user interface (GUI) was developed to integrate the modules into a user-friendly computer application.

The Delta ERT can also be used for planning studies, such as this one, because it can run simulations very quickly (about 1 - 2 minutes per simulation) and post-process the results. The analysis performed for this Supplement is similar in approach to the DFERP, although smaller in scope. This analysis was needed to be re-done due to the many enhancements to the Delta ERT since 2011, including: additional response strategy options, updated island volumes, and re-calibration.

The Delta ERT overview provided in this section is intentionally high-level, as not to differ the reader from the focus of this report, which is the result of the scenarios and response strategies tested. For more detail on the Delta ERT, WAM and ERR, the following documents can be references:

- Operating the tool – Delta ERT User's Manual - The Delta Emergency Response Tool. Version 1.3.0.120. January 2018. (RMA, 2018.b)
- Hydrodynamic simulation – Delta ERT WAM Technical Documentation - The Delta Emergency Response Tool. Version 1.3.3.120. January 2018. (RMA, 2018.a)
- Repair and recovery simulation – Delta ERT ERR Technical Documentation - The Delta Emergency Response Tool. Version 1.3.0.120. January 2018. (JBA/GEI, 2018)

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5 Calibration and Validation

The Delta ERT's WAM was calibrated and validated most recently in 2016 to ensure that the results were accurately replicating observed data in the Delta. The calibration and validation is documented in *Numerical Modeling in Support of the Delta Emergency Response Tool - WAM Model Corroboration Technical Memorandum* ("*Corroboration Report*") (RMA, 2016). As described in the *Corroboration Report*, the WAM was compared with gaged data from 2001 to 2012. The flow and electrical conductivity (EC)[2] values were compared between the WAM and observed data for this period. The critical locations in the south Delta (near the SWP and CVP export facilities) matched well. For some portions of the western and central Delta, flow and EC values did not match as well-computed values either overestimated or underestimated observed data depending on the location. These errors were deemed acceptable due to the simplified nature of the model and the prioritization for getting the south Delta data to match well.

Currently, there is no continuous record of water quality data associated with Delta levee breaches that had an immediate and significant effect on water quality. Therefore, there's no data to use for calibrating levee breach events in the WAM. Instead, the RMA Bay-Delta model was used to corroborate the results with the WAM for several hypothetical levee breach events. The RMA Bay-Delta model is a two-dimensional (2D) hydrodynamic finite element model of the Delta channels and islands. It runs primarily on a 7.5-minute time step, whereas the WAM runs primarily on a daily step and is tidally-averaged. Four cases were simulated in the WAM and RMA Bay-Delta model for comparison. For the cases, the models were run for both with- and without-channel barriers. The export disruption times and Delta recovery[3] times were compared. For smaller flooded island scenarios (e.g., cases 1 and 2 as described in Section 6) the results were close, but the WAM computed longer export disruption times. Conversely, for very large scenarios, the WAM computed shorter export disruption times. Cases 1 - 3 from the *Corroboration Report* were also used for this study. The results in this Supplement differ from the *Corroboration Report,* because 20 different hydrologic start times were used instead of just one.

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[2] Electrical conductivity (EC) is a measure of the ability of water to conduct an electric current and thus is a measure of the amount of dissolved salts. The units are in µS/cm (microsiemens per centimeter).

[3] Delta recovery is identified in the Delta ERT when all of the following conditions apply:

- Exports have been restarted for at least one day.
- 14-day running average of each of three locations along Old River and three locations along Middle River are individually at or below the reference EC.
- *X2* position is less than or equal to the base simulation at least once during the simulation after the peak salt intrusion.
- Average export EC (CVP and SWP) is less than the base export EC 1.05 (a 5% tolerance).

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6 Base Scenarios Tested

Table 1 lists the 11 base scenarios that were simulated for this effort. The scenarios range from 4 to 20 breached islands. Except for Scenario 1, these scenarios were run using "Earthquake Basic" and "Middle River Corridor" strategies (which define the repair priorities and are defined in Section 7) and defaults for breach widths, expansion rates, DCC operations, and ERR options (i.e., resource availability, placement rates, constraints). Additionally, the automated management of reservoir releases and exports for in-Delta water quality was enabled. Exports were stopped on the first day of the event and restarted when the default restart criteria were met (i.e., 1000 µS/cm at set locations in the Old and Middle Rivers). For Scenario 1, instead of the three macro response strategies listed above, eight different response actions were simulated incrementally. The eight different incremental response actions are described in Table 2. Section 8 provides more detail on each response strategy. Automated management of reservoir releases and exports was disabled for Scenario 1. Scenario 1 can be found on Figure 1.

Cases 1 through 3 (Scenarios 2 - 4) are consistent with the corroboration runs that were described in Section 5 and documented in the *Corroboration Report*. The sensitivity analysis runs were completed on geographical regions in the Delta (and combinations of groupings). Scenarios 2 - 4 can be found on Figures 2 - 4.

For each scenario, the locations of the breaches were selected somewhat arbitrarily. In cases where an island is bordered by typically higher quality water on one side versus the other(s), the side adjacent to lower quality water was breached. For example, the scenarios with breaches on Brannan-Andrus were breached on the San Joaquin River side instead of the typically fresher Sacramento River side. The location of the breaches for given islands was made consistent across the various scenarios. For example, Sherman Island was breached in the same location for all the scenarios that included that island flooding. The one exception, is for Scenario 1 (20 island/50 breach), where there were multiple breaches for several of the islands.

For Scenario 1, initial delays were included based on the assumption that in a large earthquake, there will be other demands and travel delays for barges due to bridge collapses and other infrastructure impacts. This is considered by changing the rock and soil availability rates to account for a two-week delay immediately following the event. Rock and soil placement rates increase to full production in four weeks.

The Scenario 1 event is intended to approximately represent a 500-year earthquake and includes slumping along the Old and Middle River corridors based on the *Technical Evaluation for Delta Levees* reports (AECOM, 2015b and 2016). 4 feet of slumping was configured along 40% of the Middle River Corridor. Slumping lengths were distributed along each of the Middle River Corridor levees.

Table 1: Breach Scenarios

Breach Scenario	Description	No. of Flooded Islands	Flooded Volume (TAF)[1]	Islands Flooded
1	20 Island/ 50 Breach Event[2]	20	1296	Bacon (2), Bethel (2), Bouldin (1), Bradford (1), Brannan-Andrus (2), Byron (1), Holland (2), Jersey (4), Jones (2), Mandeville (1), McDonald (1), Palm-Orwood (4), Quimby (1), Sherman (20), Twitchell (1), Venice (1), Victoria (1), Webb (1), Woodward (2)
2	Case 1 from Corroboration Report	5	142	Empire, Quimby, Pierson, New Hope, Canal-Ranch
3	Case 2 from Corroboration Report	15	1071	Bradford, Quimby, Holland, Woodward, Palm, Victoria, Union, Rindge, Mandeville, Venice, Roberts, Canal-Ranch, Bouldin, Brannan-Andrus, Ryer
4	Case 3 from Corroboration Report	20	1072	Bradford, Bethel, Quimby, Bacon, Jones, Woodward, Victoria, Hotchkiss, Byron, Merritt, Netherlands, Mandeville, Venice, Medford, Roberts, New-Hope, Brannan-Andrus, Sherman, Wright-Elmwood, Fabian
5	Western Group	7	302	Sherman, Twitchell, Bradford, Jersey, Bethel, Hotchkiss, Holland
6	Central Group	5	308	Webb, Mandeville, Venice, Empire, Medford
7	Old River Group	4	206	Bacon, Palm-Orwood, Woodward, Victoria
8	Middle River Group	4	371	Jones, Wright-Elmwood, Roberts, Union
9	Western + Central Groups	12	610	Sherman, Twitchell, Bradford, Jersey, Bethel, Hotchkiss, Holland, Webb, Mandeville, Venice, Empire, Medford
10	Western + Central + Old River Groups	16	816	Sherman, Twitchell, Bradford, Jersey, Bethel, Hotchkiss, Holland, Webb, Mandeville, Venice, Empire, Medford, Bacon, Palm-Orwood, Woodward, Victoria
11	Western + Central + Old River + Middle River Groups	20	1187	Sherman, Twitchell, Bradford, Jersey, Bethel, Hotchkiss, Holland, Webb, Mandeville, Venice, Empire, Medford, Bacon, Palm-Orwood, Woodward, Victoria, Jones, Wright-Elmwood, Roberts, Union

[1] TAF = Thousand Acre Feet

[2] 50 breaches total with multiple breaches occurring on several islands which are shown in parentheses in the "Islands Flooded" column. All other scenarios have one breach per island.

Figure 1: Scenario 1 - 20 Island/ 50 Breach Scenario - Levee Breach Locations (JBA et al., 2005)

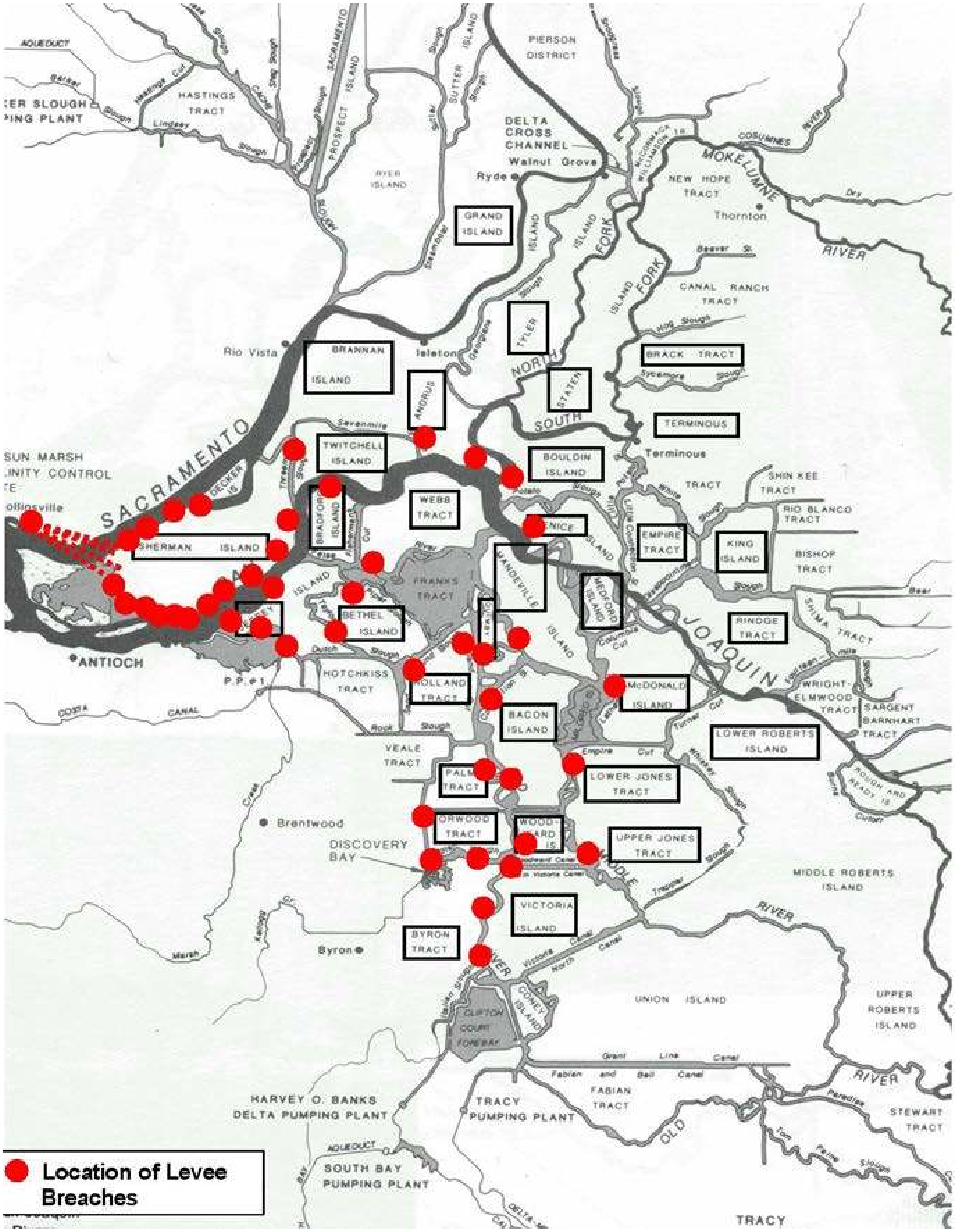


Figure 2: Scenario 2 - Case 1 from Corroboration Report - Flooded Islands (RMA, 2016)

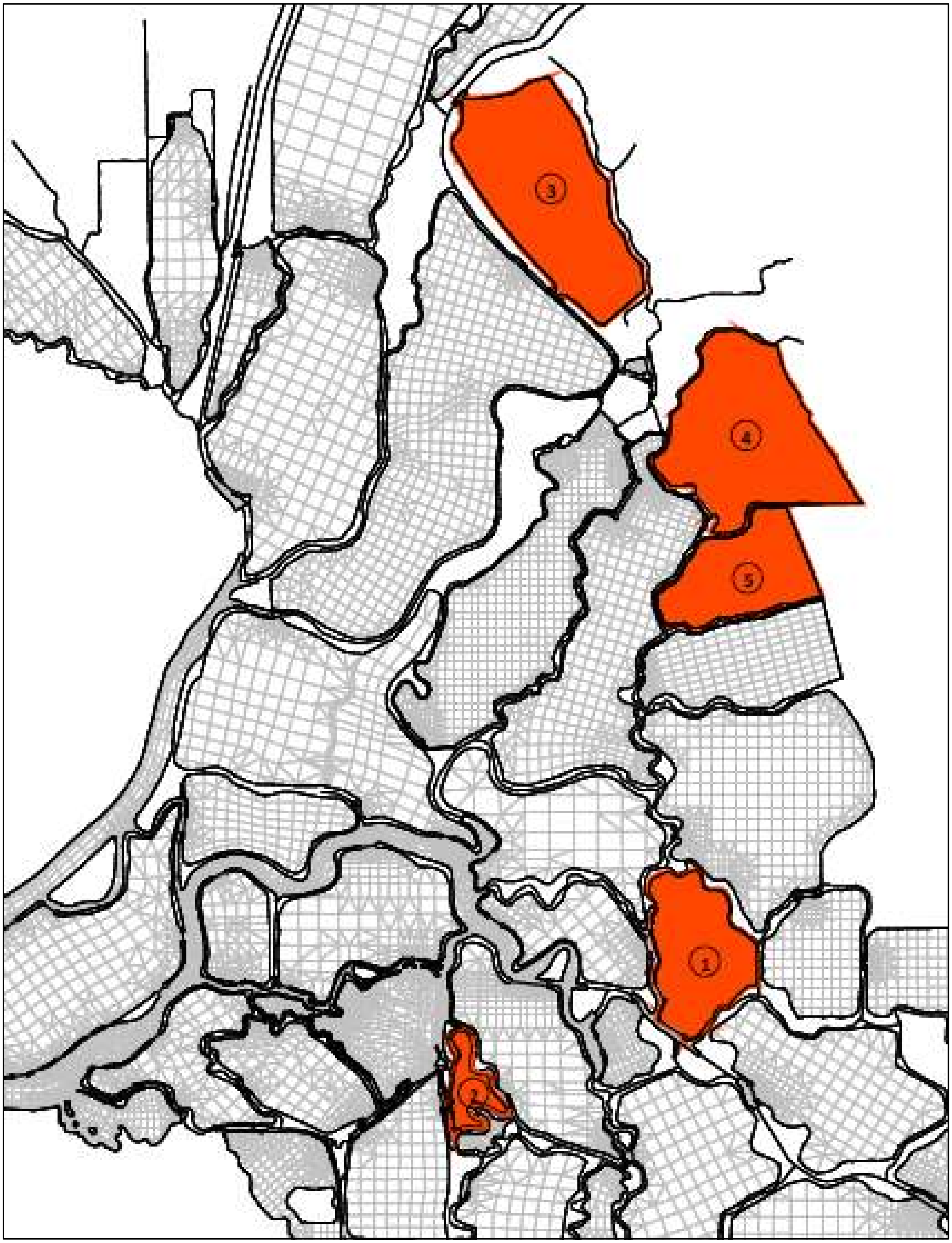


Figure 3: Scenario 3 - Case 2 from Corroboration Report - Flooded Islands (RMA, 2016)

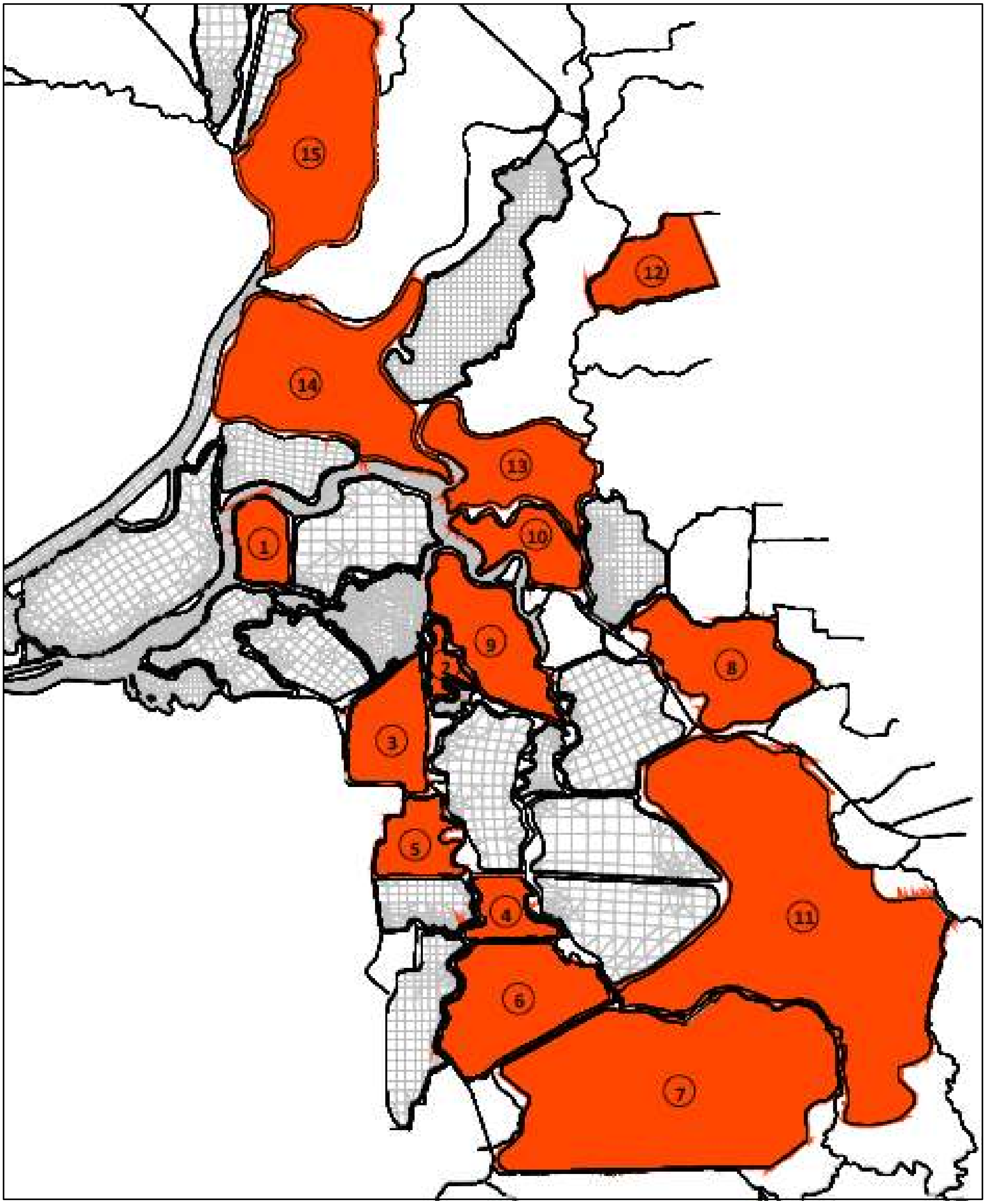


Figure 4: Scenario 4 - Case 3 from Corroboration Report - Flooded Islands (RMA, 2016)

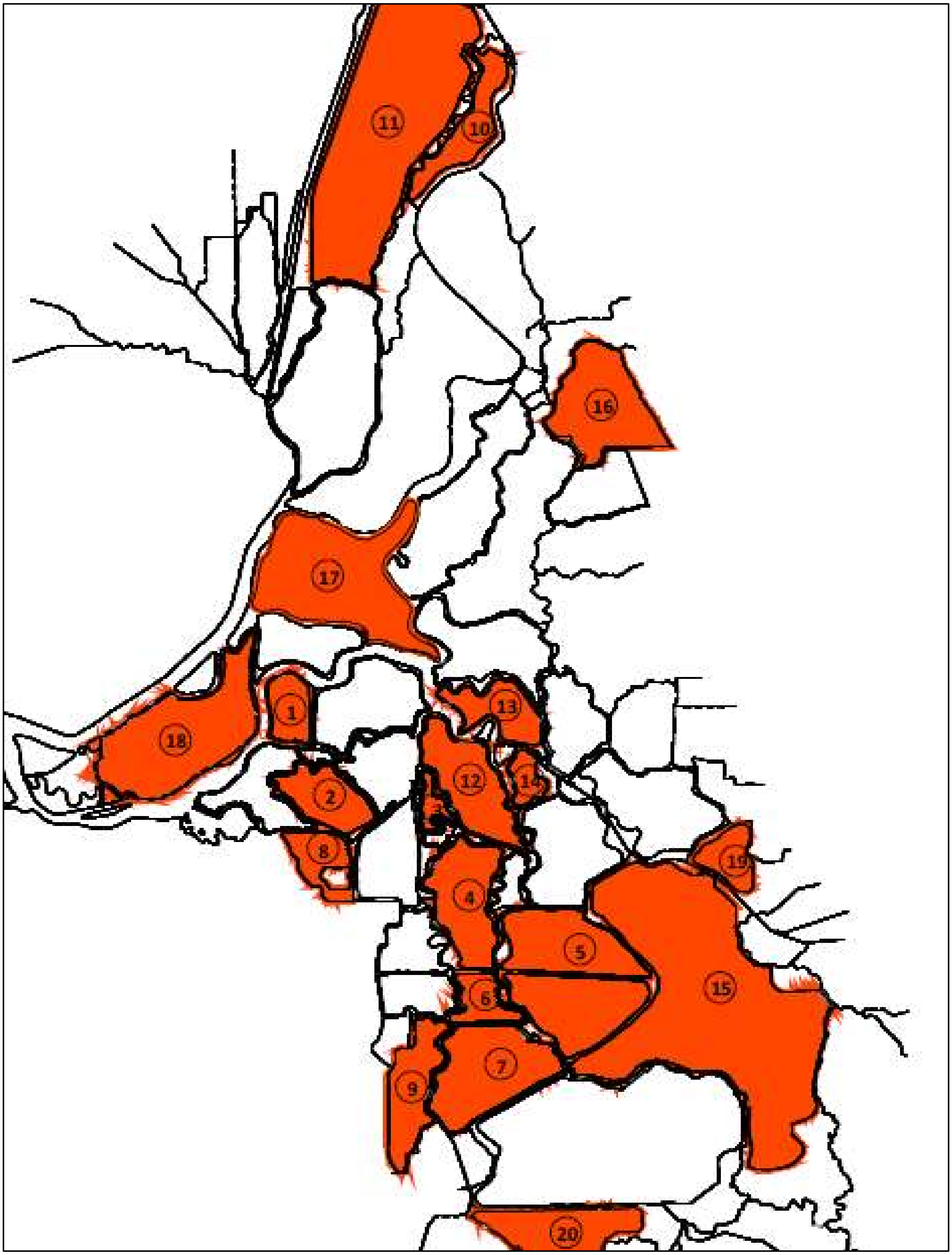
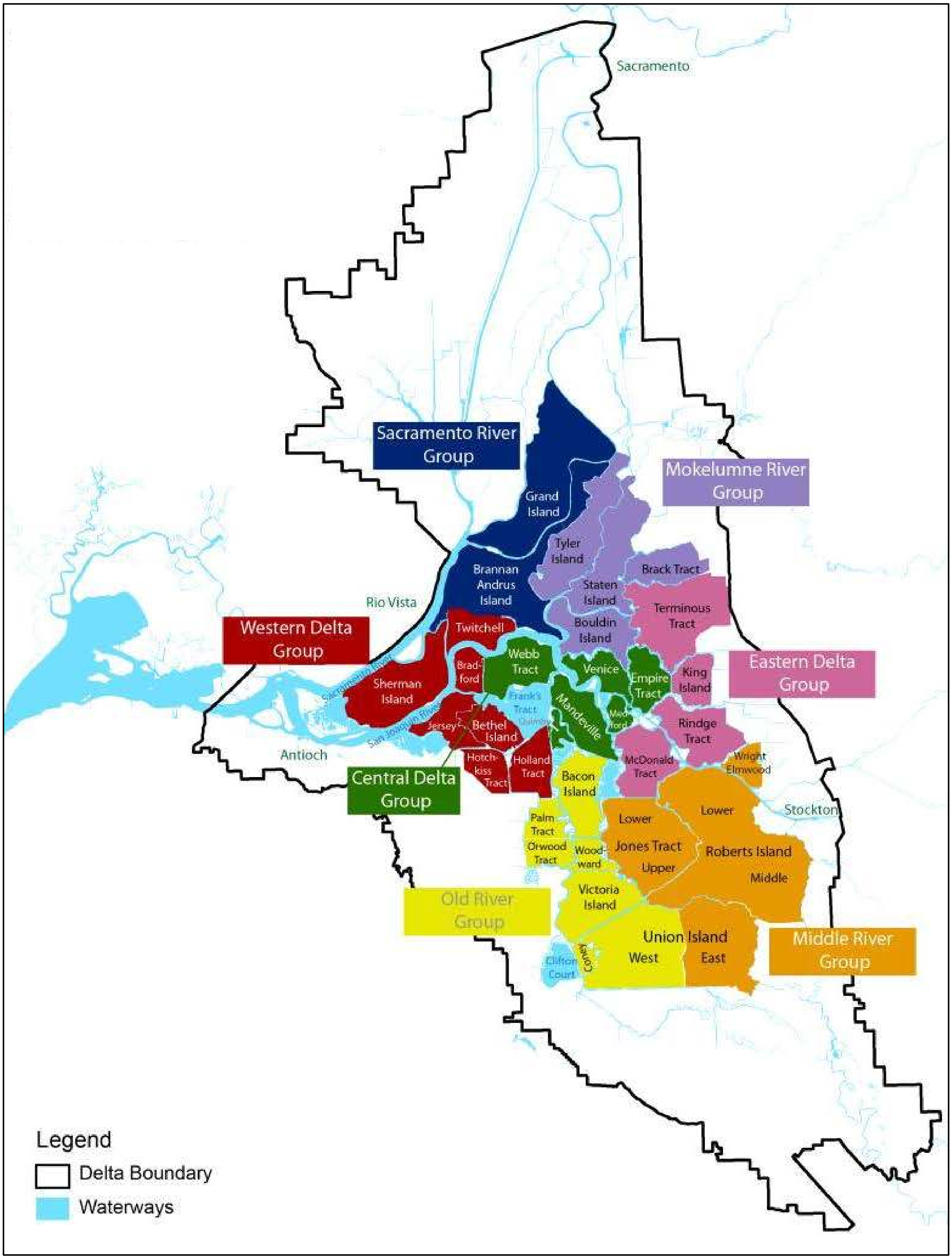


Figure 5: Island Groupings used for Scenarios 5 - 11



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7 Response Strategies

For scenarios 2 through 11 (Figures 14 - 23), three different response strategies were tested. These strategies were:

- **Basic Response Strategy** – considered to be the baseline response, this strategy prioritizes levee repairs and island dewatering based on impacts to the public and Delta infrastructure.
- **Middle River Corridor Strategy** – attempts to construct a freshwater pathway from the northern Delta to the pumps in the southern Delta. It accomplishes this by prioritizing the repair of levees along the Middle River and installing channel barriers to isolate the corridor from the rest of the Delta.
- **Cumulative Response Strategy** – consists of the implementation of all response actions listed in Table 2 . It is the most robust response strategy tested and builds upon the Middle River Corridor strategy by adding additional channel barriers, reservoir flushing releases, and DCC operations.

For Scenario 1, a more-detailed response than the three strategies used for scenarios 2 through 11, was simulated. Each of the eight different response strategies listed in Table 2 were used in an incremental approach. The following matrix shows the strategies used for each scenario:

Table 2: Response Strategy Scenario Matrix

Response Strategy	Scenarios							
	1a	1b	1c	1d	1e	1f	1g	1h
Basic Response	x	x	x	x	x	x	x	x
Open DCC Gates		x	x	x	x	x	x	x
Freshwater Pulse Flows			x	x	x	x	x	x
Sutter and Steamboat Slough Channel Barriers				x	x	x	x	x
Closure of Channels adjacent to the Middle River Corridor & Changed Restart Criteria					x	x	x	x
San Joaquin River near Lathrop Barrier						x	x	x
San Joaquin River Pulse Flows							x	x
Sacramento River Barrier								x

The list below describes the response strategies in further detail:

a. **Basic Response Strategy** – is considered to be the baseline response. This response strategy prioritizes levee repairs and island dewatering based on impacts to the public and Delta infrastructure.

b. **Open Delta Cross Channel (DCC) Gates** – allows more water to travel down the Mokelumne River to the interior Delta rather than down the Sacramento River. This generally has the effect of improving water quality in the central and southern Delta. For simulations that do not include this response action, the DCC gates will either be opened or closed based on gate operations during the historical hydrologic start time being simulated.

c. **Freshwater Pulse Flows** – allows releases from Shasta, Oroville, and Folsom. For the sake of this analysis, a flushing flow totaling 30,000 cfs was used for one week (approx. 420,000 acre-feet (ac-ft) of volume) following the breach event. The 30,000 cubic feet per second (cfs) was achieved by simulating staggered releases from Folsom and Oroville to achieve the approximate flowrate at the model's northern boundary condition, which is on the Sacramento River near Freeport. Shasta was not used because of its comparatively long travel time of five days. Penstock capacities were allowed to be exceeded and ramping rate rules were followed.

d. **Sutter and Steamboat Slough Channel Barriers** – diverts more water down the Sacramento River and through the DCC (when open). The estimated cost of these two barriers is $4.1 million[4]. These barriers are shown in Figure 6 (barriers #1 and 2).

e. **Closure of Channels adjacent to the Middle River Corridor & Changed Restart Criteria** – prevents water mixing with the exterior channels and isolates the Middle River Corridor. The following barriers are included: Old River at Highway 4, Woodward Canal, Railroad Cut, Connection Slough, and Empire Cut. The estimated cost of these five barriers is $26.3 million[4]. These barriers are shown in Figure 6 (barriers #4, 5, 6, 7, and 8). Additionally, this allows the export pumps to restart based on different criteria (i.e., location, EC threshold). The location where the EC threshold was enforced was moved to the Middle River near the San Joaquin River (i.e., the head of the freshwater pathway). The threshold was set at 600 µS/cm. The max EC exported is included in Table 6 for comparison. The sensitivity of this threshold value was evaluated in Section 11.

f. **San Joaquin River at Lathrop Barrier** – diverts San Joaquin flows to travel down the Middle River, potentially helping to flush out the saline water that may be otherwise trapped there. The estimated cost of this barrier is about $240,000[4]. This barrier is shown in Figure 6 (barrier #12).

g. **San Joaquin River Pulse Flows** – provides for greater flows down the Middle River to better flush out the saline water prior to restarting the export pumps. The pulse flow was set at 10,000 cfs for seven days. The Delta ERT does not explicitly model reservoir pulse flows into the San Joaquin River, but instead uses an override of the San Joaquin River boundary inflows at Vernalis.

h. **Sacramento River Barrier** – diverts more water through the DCC (when open) and into the central Delta. The estimated cost of this barrier is $3.8 million[4]. This barrier is shown in Figure 6 (barrier #3).

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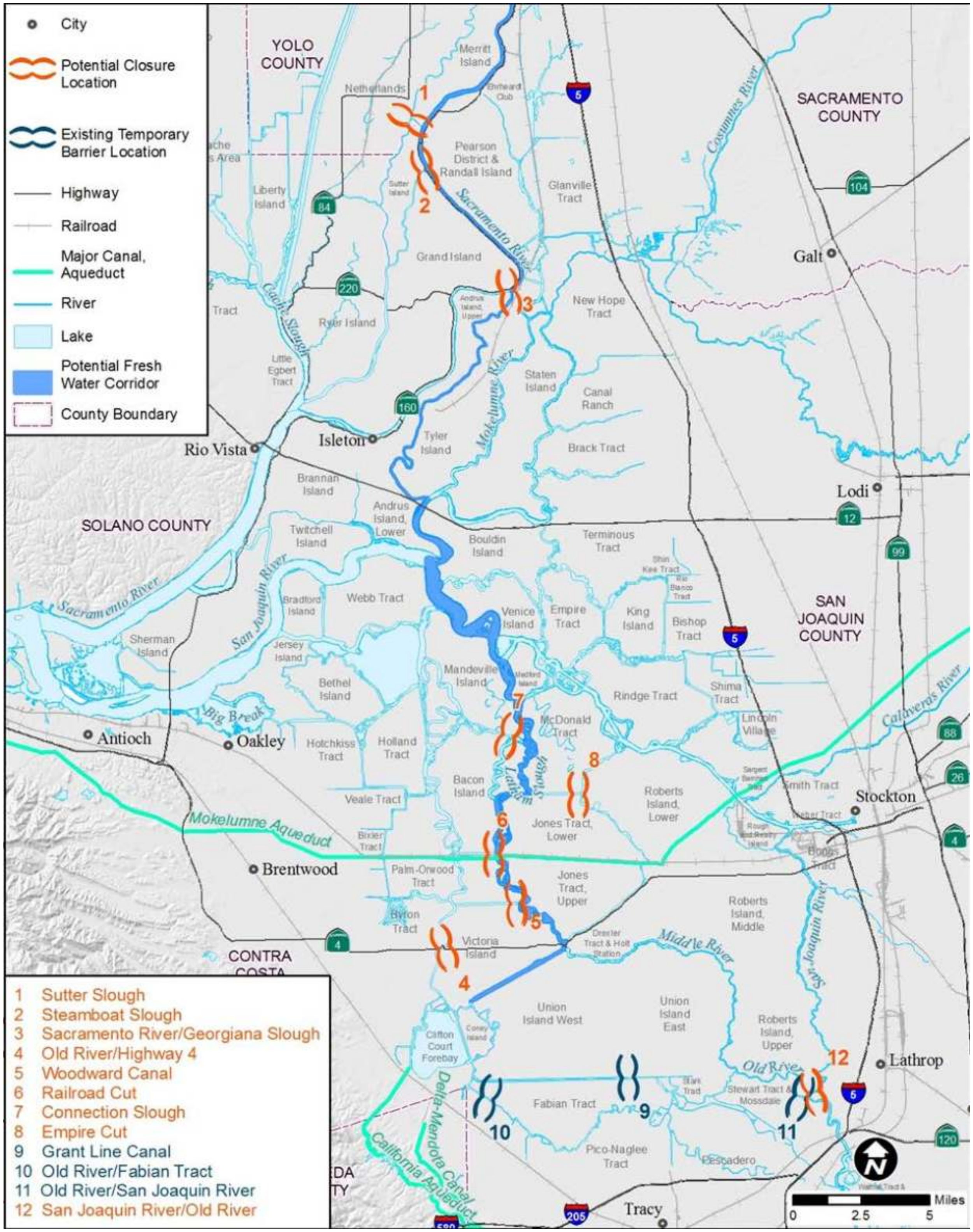
[4]Costs were computed based on barrier volumes and assuming a rate of $118/ton. For comparison purposes, the West False River Barrier cost approximately $147/ton.

Figure 6: Channel Barrier Locations



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8 Hydrologic Start Times

The Delta ERT has two operational modes that determine what boundary conditions will be used: CalSIM mode and Operational Forecast mode. The scenarios were simulated using the CalSIM mode in the Delta ERT. CalSIM mode allows the user to select from a subset of CalSIM-based initial hydrologic conditions. The CalSIM hydrology covers 1923 to 1996 and allows the user to pick a starting month. The simulation will use the CalSIM data going forward from that starting time as its boundary conditions. Since the water quality response is very sensitive to both the initial condition and conditions following the event, multiple hydrologic start times were used for each of the scenarios.

These start times were selected by using previous analysis completed for the DFERP that ranked the start times from the least to greatest impact on disruption times for a given multiple-island breach event (JBA et al., 2011). Similar to the analysis for the DFERP, the ranked start times were separated into 20 bins and one start time from each bin was chosen randomly to make up the range of 20 potential hydrologic start times. The rankings initially determined in the previous analysis were unchanged, however, the random sampling was recomputed for this analysis. The start times and their associated conditions are included in Table 3 below:

Table 3: CalSIM Start Times

Hydrologic Scenario	Year	Month	Month, Year	Initial X2 (km)	NOD Storage (TAF)	SOD Storage (TAF)	Current WY Type [1]	Next WY Type [1]	Rank [2]
1	1956	1	1,1956	43.1	6505	2632	Wet	Above Normal	29
2	1982	11	11,1982	59.2	6830	2467	Wet	Wet	77
3	1970	3	3,1970	60.7	7990	2281	Wet	Wet	100
4	1977	1	1,1977	86.5	3774	1425	Critical	Above Normal	175
5	1968	8	8,1968	84	5256	1188	Below Normal	Wet	211
6	1969	10	10,1969	78.6	6820	1833	Wet	Wet	253
7	1976	5	5,1976	86	6348	1280	Critical	Critical	290
8	1923	12	12,1923	85.9	4666	2139	Critical	Dry	325
9	1977	12	12,1977	81.3	5269	1788	Above Normal	Below Normal	375
10	1923	7	7,1923	79.6	5614	1240	Below Normal	Critical	408
11	1994	8	8,1994	82.6	2865	941	Critical	Wet	478
12	1957	6	6,1957	76	7331	885	Above Normal	Wet	518
13	1935	8	8,1935	85	4445	1310	Below Normal	Below Normal	559
14	1973	9	9,1973	86	5781	1472	Above Normal	Wet	601
15	1959	7	7,1959	77.2	4997	897	Below Normal	Dry	660
16	1929	11	11,1929	88.6	3926	1459	Dry	Critical	685
17	1949	8	8,1949	84.9	4856	1042	Dry	Below Normal	717
18	1927	12	12,1927	79.5	5891	1814	Above Normal	Critical	786
19	1971	9	9,1971	78.7	6077	1171	Wet	Below Normal	835
20	1970	10	10,1970	86.4	5006	1273	Wet	Below Normal	874

[1] The water year (WY) type used in this study are based on the Sacramento River Index

[2] Ranks for each Hydrologic start times are based on a previous analysis conducted in the DFERP

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9 Assumptions and Limitations

When interpreting the results, it is important to understand the sensitivities of the model inputs and parameters. As mentioned in Section 4, the model is very sensitive to both initial conditions and breach locations. For example, if the initial conditions are such that freshwater inflows to the Delta are high, a large breach event will likely only have a minimal effect on water exports. However, if that same event occurred during periods of low freshwater inflows (and a high *X2*), then the disruption could be substantial. Also, if a breach occurs on one side of an island versus another side, the impacts can be significantly different. For example, if the levee on the Sacramento River side of Brannan-Andrus Island breaches (where flows are typically large and predominantly fresh), the impacts could be much different than if the San Joaquin River side breaches (where flows are typically low and of lower quality).

Also, the repair methods and other response options can greatly impact the results. Model defaults for setting breach repair prioritization were used for the response strategies' methods (e.g., Earthquake Basic, Middle River Corridor). These default repair assumptions and prioritization were based on previous analysis done for DRMS and the DFEMP. Also, default values for ERR Options (i.e., material availability, placement rates, constraints, costs) were used. For all scenarios except Scenario 1, the breach widths and expansion rates used were the defaults (440 feet and 2 in/day respectively). For all scenarios, the exports were stopped immediately and only restarted when the restart criteria were met. The restart of exports was allowed before breach repairs (and slumping repairs for Scenario 1) were completed. Scenario 1a - 1d used the Basic strategy defaults, while Scenario 1e - 1h used the Middle River Corridor strategy defaults, adding all incremental response actions listed in Table 2. All strategies analyzed in this study completely repaired all levee damage and dewatered all flooded islands.

The timing of channel barrier installation was based on assumed material availability, placement rates, and approximate volume of rock needed to close the various channels. Table 4 lists the nine barriers and their assumed placement time.

Table 4: Channel Barrier Installation Times

Channel Barrier Name	Installation Time* (days after event)
Sutter Slough	17
Steamboat Slough	17
Sacramento River	20
Old River at Highway 4	26
Woodward Canal	32
Railroad Cut	18
Connection Slough	27
Empire Cut	21
San Joaquin River at Old River	16

* Includes initial 2-week delay prior to mobilization

There are some limitations that are inherent to the Delta ERT. These include its simplification of the Delta geometry- not all channels are modeled, islands are approximated as one-dimensional (1D) channels, and it's a tidally-averaged model. These simplifications result in the loss of some detailed resolution for channels that are tidally-driven (e.g., some of the western Delta channels) (RMA, 2016). Also, since it is a 1D model, detailed mixing is not explicitly computed. Instead, dispersion coefficients are used to approximate the mixing between channels, previously flooded islands (e.g., Franks Tract), and newly breached islands. The calibration effort was used to adjust these coefficients (RMA, 2016).

One of the key assumptions is that environmental permitting will not be a constraint. It is anticipated that regulatory agencies will be reluctant to authorize the construction of several channel barriers without substantial analysis of their potential impacts. The construction of the West False River Barrier in 2015 proved that even during a statewide emergency (in this case, the drought), permitting is still a lengthy process that requires detailed analysis. Also, releases of large volumes of freshwater will likely be heavily scrutinized by regulatory agencies and water users throughout the State (especially if previous years have been dry). Some of the mitigation efforts employed to successfully implement the West False River Barrier Project are outlined in the *Emergency Drought Barriers Project - Initial Study/Proposed Mitigated Negative Declaration* (AECOM, 2015a), and can be referred to for additional guidance on satisfying regulatory constraints.

The following are additional considerations for each of the response actions:

a. **Manage Reservoir Releases and Exports for Delta Water Quality (only used for scenarios 2 - 11)** – These response actions were developed as default constraints built into the WAM (RMA, 2018a). These were developed to be feasible responses to the given event, but would likely require deviations from *Water Right Decision 1641* (D-1641) water quality standards [State Water Resources Control Board (SWRCB), Revised 2000].

b. **Open DCC Gates** – This would likely require deviation from the D-1641 regulations for operating the DCC gates (SWRCB, 2000). Operation of the gates will require coordination with the United States Bureau of Reclamation (USBR).

c. **Freshwater Pulse Flows** – These pulse flows would require coordination with reservoir operators, water users, and permitting agencies. The pulse flows used for this analysis are substantial volumes that need to be weighed against the benefit of maintaining the water quality in the Delta and restarting exports sooner. The feasibility and volume of potential pulse flows would be based on several factors, including: north of Delta (NOD) reservoir storage, south of Delta (SOD) reservoir storage, carryover storage, snowpack conditions, in-stream flow requirements, cold-water pool conditions, time of the year, and any other special restrictions in place. The cost of water and power generation losses are not included in the total response costs listed in the results tables and figures in this Supplement. Additionally, if ramp down rates for reservoir releases are to be obeyed, a significant volume of water beyond the volume needed to achieve a targeted flowrate and duration, would need to be released and should be considered.

d. **Sutter and Steamboat Slough Channel Barriers** – These barriers are the northernmost barriers along the Sacramento River that would keep more water in the Sacramento River and through the DCC (when opened). These barriers could cause water quality and operational impacts to water users downstream of the barriers. The cost of these barriers and incremental impacts to other water users would have to be weighed against the benefit of maintaining the water quality in the Delta and restarting exports sooner.

e. **Closure of Channels adjacent to the Middle River Corridor and Changed Restart Criteria** – This effort would be a large undertaking to mobilize resources to acquire, transport, stockpile, and construct six additional barriers in the south Delta (and later remove). These barriers would likely have water quality impacts for in-Delta water users to the west of the barriers. The cost of these barriers and impacts to other water users would have to be weighed against the benefits of restoring the water exports to the water projects. Additionally, changing the restart criteria would likely require a deviation from the D-1641 water quality standards for operation of the water projects (SWRCB, 2000).

f. **San Joaquin River at Lathrop Barrier** – This barrier could have impacts to downstream water quality in the Delta. This barrier would likely be in place for a short time - prior to the pumps being restarted when the Middle River Corridor is needed to be flushed.

g. **San Joaquin River Pulse Flows** – There aren't any reservoirs in the San Joaquin River basin with Delta water quality management designated uses. Therefore, this response action would require negotiation with the reservoir operators to make these unplanned releases.

h. **Sacramento River Barrier** – This barrier would be located on the Sacramento River just downstream of the DCC gates and would force additional flow through the DCC (when opened). This barrier could cause water quality impacts to water users downstream of the barrier. The cost of this barrier and impacts to other water users would have to be weighed against the benefit of maintaining the water quality in the Delta and restarting exports sooner.

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10 Results

The results displayed in this section are based on the various combinations of levee breaches, hydrologic start times, and response strategies, which resulted in 760 model simulations. The results compare Export Disruption, Delta Recovery, and Repair time for each of the simulations.

The results for the scenarios tested are included in Table 5 and Table 6, and Figure 7 and Figure 8. Table 5 and Table 6 include the export disruption time, Delta recovery time, and response cost. Delta recovery is defined as the time for the Delta water quality to recover to the level it would have been had the breaches not occurred. Export quality is included for comparison and to verify that the quality of the exported water is sufficient. Minimum, maximum, and average values are taken from the 20 hydrologic start times run for each scenario and iteration. Figure 7 is a plot of the average export disruption time versus flooded island volumes for each response strategy under scenarios 2 - 11. A more-detailed breakdown of the results for scenarios 2 - 11 is included in Appendix 1. Figure 8 shows the Scenario 1 results for each iteration as "box and whisker" plots of export disruption time.

As expected, larger flooded island volumes generally resulted in larger disruption times. Also, for every scenario, the Middle River Corridor strategy results in a lower disruption time than the Basic strategy. The Cumulative strategy results in the shortest disruption time and the highest cost. Many costs associated with this strategy are not included, including: the cost of water, power generation losses, and mitigation activities. The cost difference between the Middle River Corridor strategy and Basic strategy is significant for the smaller events but not as significant for the larger events because of the relatively large costs for the breach repairs. The results show the wide range of disruption times for a given scenario based on the hydrology chosen. The minimum values for each scenario are less than one week (i.e., the time it takes for all islands to fill and exports to resume immediately thereafter) and the maximum values are up to 630 days. These results are as expected, because the initial and future hydrologic conditions have the greatest effect on the water quality impacts.

The results were also compared with previous studies described in Section 3, where applicable. Scenario 1 was compared with the *Seismic Risk Study* and scenarios 2 - 4 were compared with the *Corroboration Report*. The *Seismic Risk Study* ran only one hydrologic start time and had different criteria for restarting exports than were used for this study and did not use any response actions other than breach repairs. That study found that partial pumping could be restarted after 11.5 months following the event. This disruption time falls within the range of average export disruption times from Scenario 1's results. The *Corroboration Report* only used one hydrologic start time, and therefore is not directly comparable to scenarios 2 - 4 (which used 20 hydrologic start times). However, the *Corroboration Report's* export disruption times and Delta recovery times were within the range of results for scenarios 2 - 4. For additional discussion of the results and their implications, see Section 15.

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Table 5: Basic, Middle River, and Cumulative Strategy Results for Breach Scenarios 2 -11

Breach Scenario	Description	No. of Flooded Islands	Flooded Volume (TAF)	Recovery Strategy	Export Disruption (days)			Delta Recovery (days)			Time to Repair (Days)	Cost ($ Millions)			
					Min	Max	Avg.	Min	Max	Avg.		Breach Repair	Island Dewatering	Barriers	Total Response[1]
2	Case 1 from Corroboration Report	5	142	Basic	5	48	16	6	51	29	246	$27.8	$3.8	$0	$31.6
				Middle River	5	42	15	6	47	24	246	$27.8	$3.8	$30.4	$62.0
				Cumulative	5	13	7	6	64	17	247	$27.8	$3.8	$30.6	$62.2
3	Case 2 from Corroboration Report	15	1071	Basic	6	331	120	10	332	148	292	$107.4	$28.9	$0	$136.3
				Middle River	6	248	108	10	292	143	293	$107.4	$28.9	$30.4	$166.7
				Cumulative	6	146	66	9	244	104	293	$107.4	$28.9	$30.6	$166.9
4	Case 3 from Corroboration Report	20	1072	Basic	6	331	129	13	332	160	296	$122.8	$28.9	$0	$151.7
				Middle River	6	251	117	13	252	150	296	$122.9	$28.9	$30.4	$182.2
				Cumulative	6	160	74	11	306	121	298	$122.9	$28.9	$30.6	$182.4
5	Western Group	7	302	Basic	5	67	26	6	86	46	246	$42.6	$8.2	$0	$50.8
				Middle River	5	65	24	6	93	38	249	$42.7	$8.1	$30.4	$81.2
				Cumulative	5	12	6	6	64	17	247	$42.7	$8.1	$30.6	$81.4
6	Central Group	5	308	Basic	5	304	44	6	304	71	233	$37.4	$8.3	$0	$45.7
				Middle River	5	245	37	6	246	51	233	$37.4	$8.3	$30.4	$76.1
				Cumulative	5	27	10	6	64	23	234	$37.4	$8.3	$30.6	$76.3
7	Old River Group	4	206	Basic	5	72	27	6	97	46	268	$25.5	$5.5	$0	$31.0
				Middle River	5	72	23	6	98	34	269	$25.5	$5.5	$30.4	$61.4
				Cumulative	5	18	7	6	64	18	269	$25.5	$5.6	$30.6	$61.7
8	Middle River Group	4	371	Basic	8	304	53	7	304	73	215	$26.1	$10.0	$0	$36.1
				Middle River	6	245	45	7	246	60	218	$26.1	$10.0	$30.4	$66.5
				Cumulative	5	38	13	6	64	26	216	$26.1	$10.0	$30.6	$66.8
9	Western + Central Groups	12	610	Basic	5	326	71	7	327	99	268	$80.6	$16.4	$0	$97.0
				Middle River	5	244	59	7	245	90	273	$80.6	$16.5	$30.4	$127.5
				Cumulative	5	95	24	7	106	56	268	$80.6	$16.5	$30.6	$127.7
10	Western + Central + Old River Groups	16	816	Basic	5	328	101	9	329	130	310	$106.7	$22.0	$0	$128.7
				Middle River	5	246	87	9	291	120	311	$106.8	$22.0	$30.4	$159.1
				Cumulative	5	130	49	8	307	100	311	$106.8	$22.0	$30.6	$159.4
11	Western + Central + Old River + Middle River Groups	20	1187	Basic	6	333	143	10	334	175	332	$133.7	$32.0	$0	$165.7
				Middle River	6	257	136	10	258	167	333	$133.8	$32.0	$30.4	$196.2
				Cumulative	6	164	94	9	307	132	333	$133.8	$32.8	$30.6	$196.4

[1] Middle River strategy includes eight barriers at an estimated cost of $30.4 million. Cumulative strategy includes one additional barrier for a total barrier cost of $30.6 million.

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Figure 7: Relationship between Flooded Island Volume and Export Disruption Time

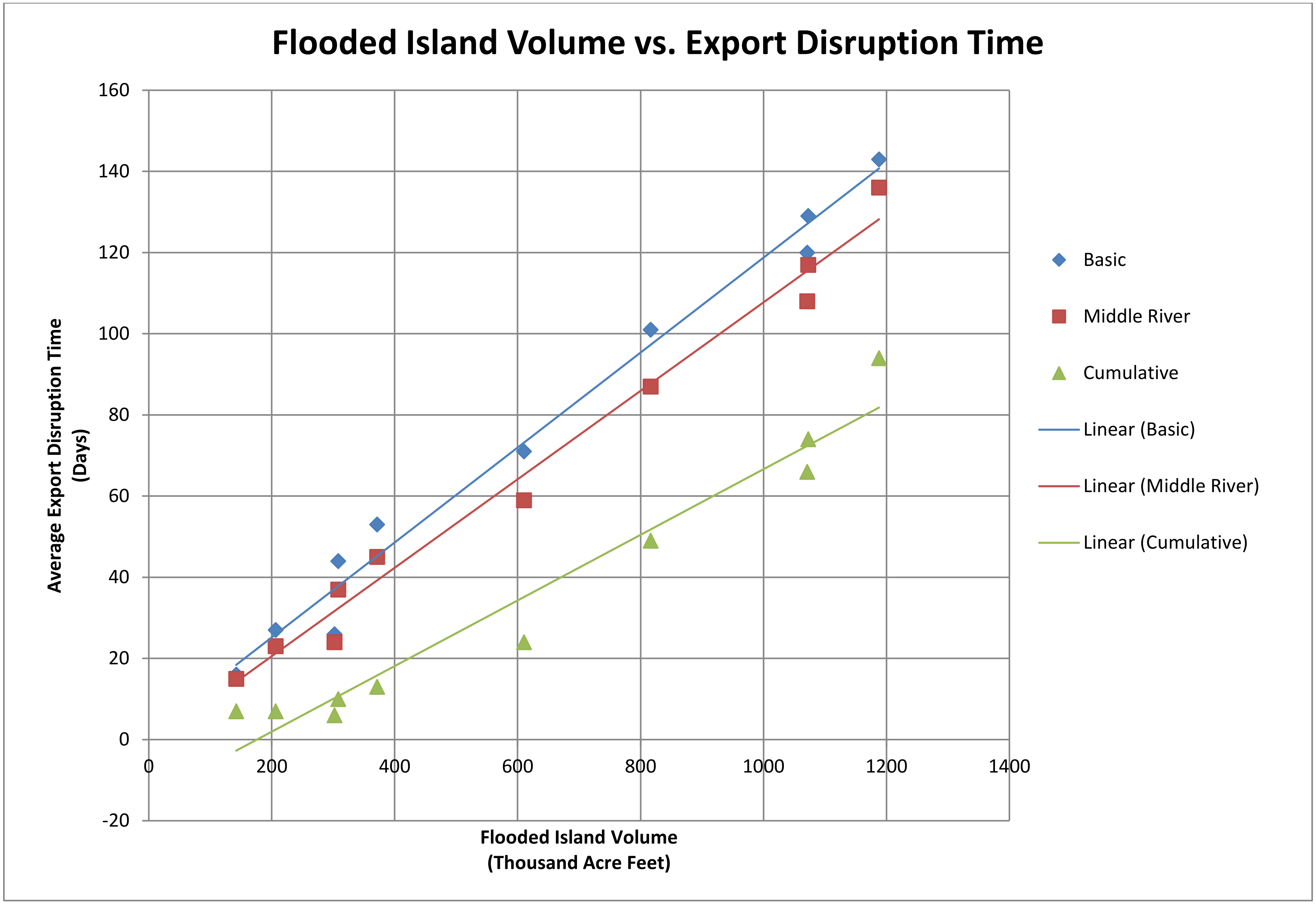

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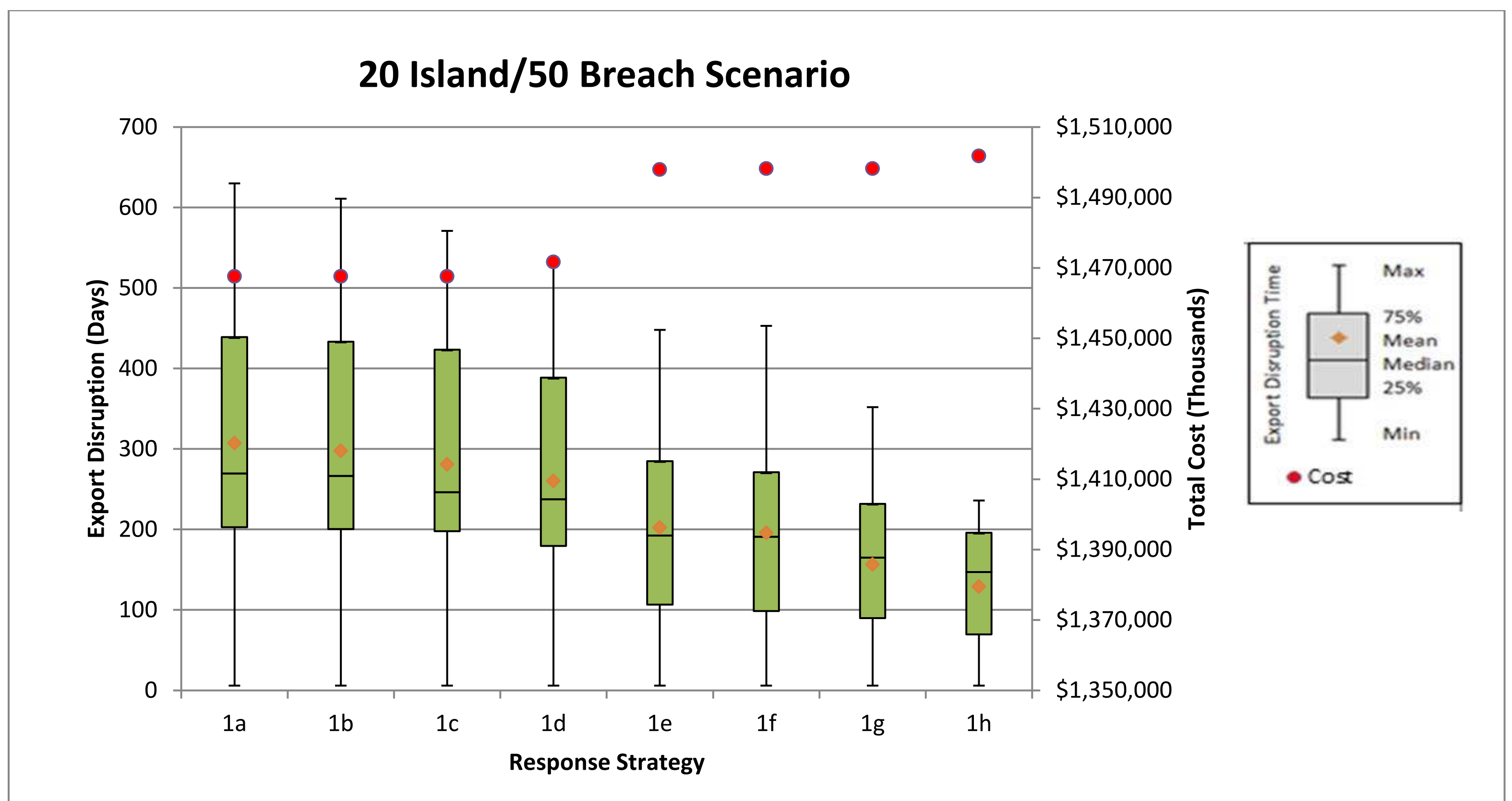
Table 6: Response Strategy Iterations Results for Scenario 1

Response Strategy Iterations	Incrementally Added Response Actions	Export Disruption (days)			Delta Recovery (days)			Max Export Quality (µS/cm)[1]			Time to Repair (days)	Cost ($ Millions)			
		Min	Max	Avg.	Min	Max	Avg.	Min	Max	Avg.		Levee Repair	Island Dewatering	Barriers	Total Response
1a	Basic Response Strategy	6	630	307	11	995	429	362	1489	1016	1188	$1,433	$35	-	$1,468
1b	Open DCC Gates	6	611	298	11	769	401	362	1334	1000	1188	$1,433	$35	-	$1,468
1c	Freshwater Pulse Flows	6	571	281	11	765	385	362	1351	988	1188	$1,433	$35	-	$1,468
1d	Sutter and Steamboat Slough Channel Barriers	6	529	260	11	608	340	362	1553	1010	1188	$1,433	$35	$4	$1,472
1e	Middle River Barriers & Head of Middle River Criteria	6	448	203	11	498	306	362	2342	1522	1188	$1,433	$35	$30	$1,498
1f	San Joaquin River at Old River Barrier	6	453	196	11	457	238	276	1710	881	1188	$1,433	$35	$31	$1,498
1g[2]	San Joaquin River Pulse Flows	6	352	157	9	410	213	276	1575	954	1188	$1,433	$35	$31	$1,498
1h[2]	Sacramento River Barrier	6	236	129	9	399	189	276	1689	1133	1188	$1,433	$35	$34	$1,502

[1] Represents the lowest quality water exported between the time that exports restart and the Delta recovers.
[2] This response strategy only uses 19 of the 20 CalSIM start times due to stability issues with the Jan 1977 CalSIM start time.

Figure 8: Scenario 1 Results



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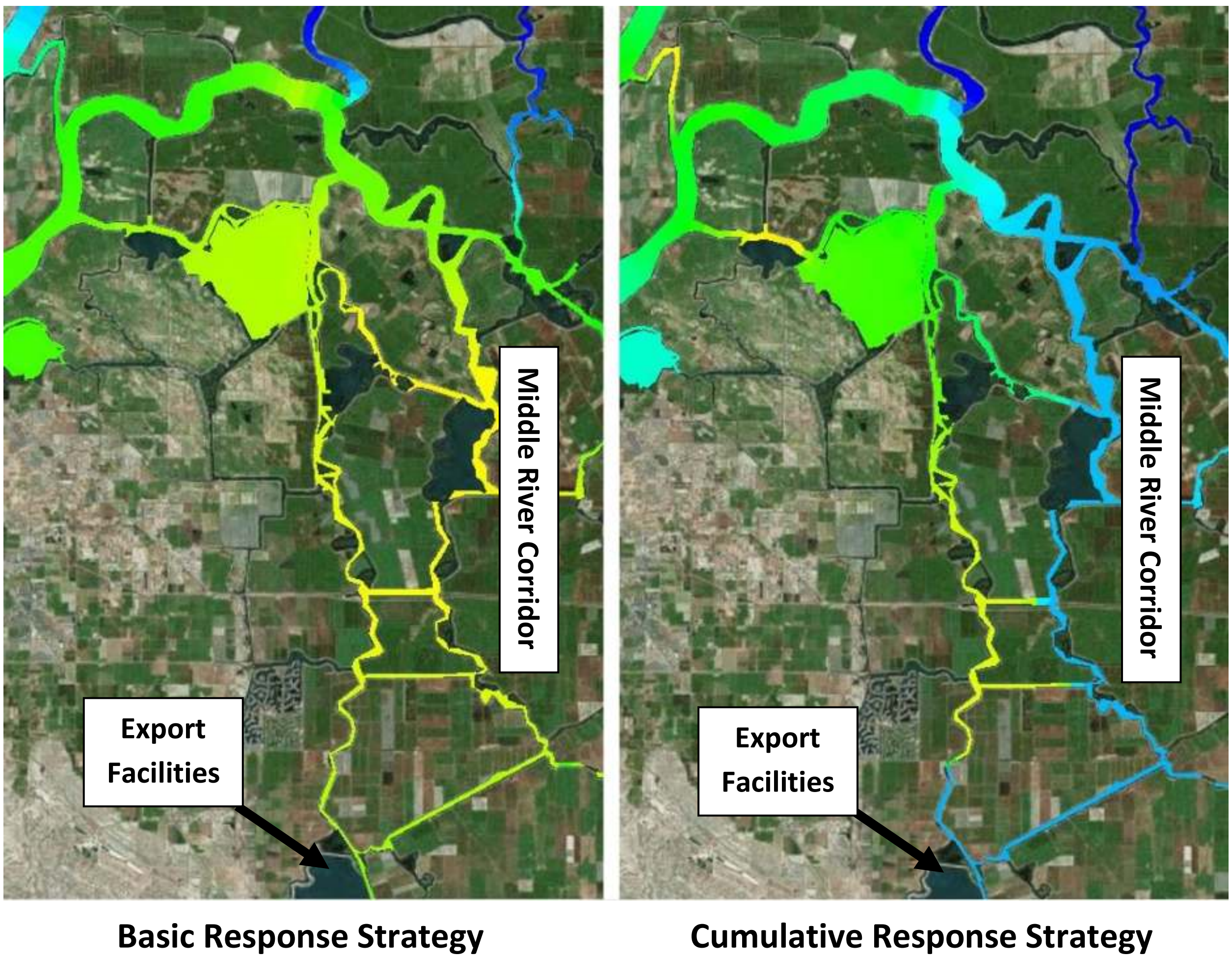
To provide visual context to the numerical results of Table 6, Figure 9 compares the salinity gradients from the Basic and Cumulative Response Strategies (i.e., scenarios 1a and 1h from Table 6). The figure shows the salinity distribution 90 days after the event occurred, which is the time when exports resumed under the Cumulative Response Strategy. The stark contrast in salinity along the Middle River is evidence of the insulating and freshening effect the combination of response actions have on the corridor, essentally creating a link between the NOD water supply and the export facilities.

Figure 9: Delta Salinity Distributions 90 Days After Event



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11 Restart Criteria Sensitivity Analysis

Based on the results found in the previous section, additional analysis was performed to determine the model's sensitivity to the water quality restart criteria parameter. This analysis was performed for Scenario 1 with the Middle River Corridor strategy (response iteration 1e) implemented.

Water quality restart criteria ranging from 200 µS/cm to 800 µS/cm, at 100 µS/cm increments were tested. All criteria were enforced at the head of Middle River, which is the same location used in iteration 1e. Using the 20 CalSIM hydrologic start times displayed in Table 3, export disruption times and water quality exported between export resumption and Delta recovery were computed.

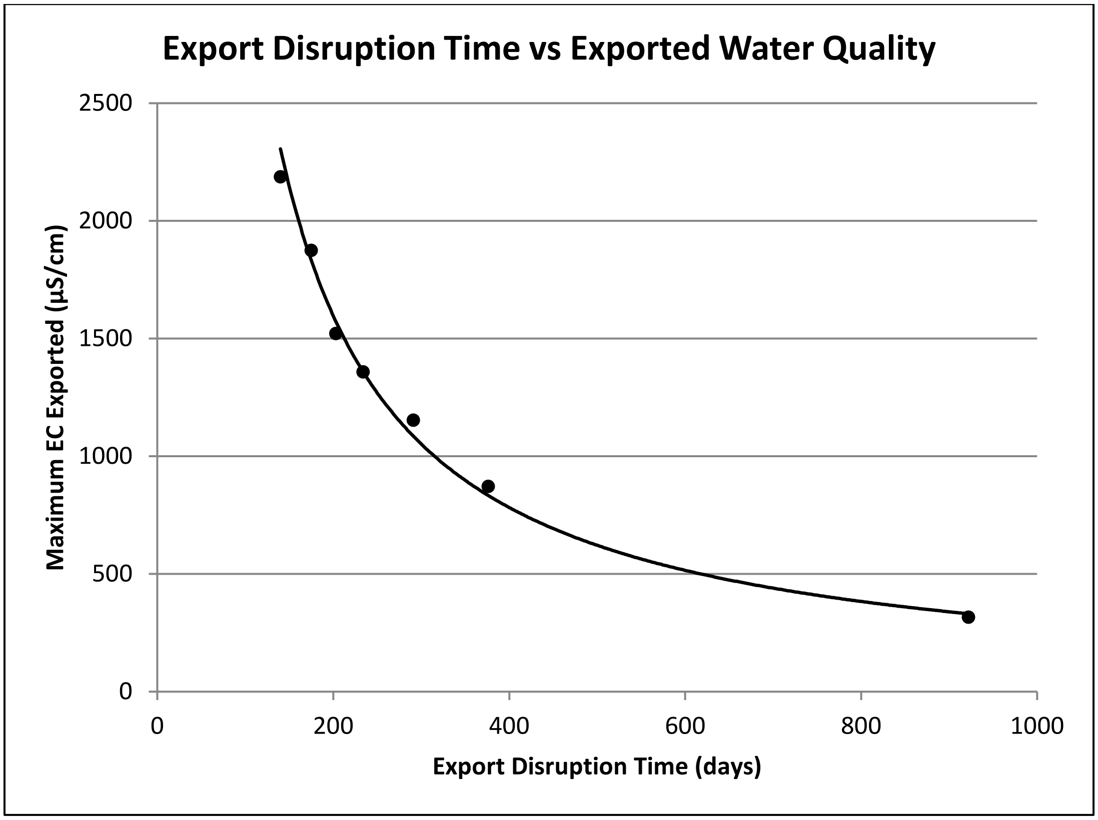
As expected, by enforcing more stringent restart criteria, export disruption time increased, and the quality of water exported improved. Relaxing the restart criteria resulted in the opposite effect - reduced disruption time and reduced quality of exports. Table 7 displays the results from the model runs.

Table 7: Restart Criteria Sensitivity Analysis Results

EC Threshold for Restarting Exports (µS/cm)	Export Disruption (days)			Max Export EC (µS/cm)		
	Min	Max	Avg.	Min	Max	Avg.
800	6	323	140	362	4263	2188
700	6	364	175	362	4091	1875
600	6	448	203	362	2342	1522
500	6	606	234	362	2235	1359
400	6	794	291	349	2197	1154
300	6	953	376	272	1929	872
200	158	1461	922	-	1123	317

It should also be noted that while lowering the EC threshold resulted in improved export water quality, the increase in export disruption time was not proportional. As the EC threshold approached the natural baseline for the channel, the export disruption time increased exponentially. This finding suggests that near the natural baseline, accepting slightly lower water quality (i.e., higher EC) could result in a relatively large reduction in export disruption time. The relationship between maximum EC exported and export disruption time is illustrated in Figure 10.

Figure 10: Relationship between Export Disruption Time and Exported Water Quality



12 Reservoir Release Timing Sensitivity Analysis

The simulation results clearly illustrate the effectiveness of using reservoir releases as a mechanism to flush saline water out of the Delta. However, the resulting improvement to Delta water quality comes at the potential cost of long-term water storage in our reservoirs. Since the most severe impacts typically occur during dry or critical water years — when reservoir storage is low — the need to maximize the benefit of this vital resource is critical. With this challenge in mind, the objective of this section is to determine the optimal timing of reservoir releases that minimize export disruption time and maximize water quality of exports once resumed.

Test Setup

For this analysis, the levee damage from Scenario 1 was used with breach widths set to default lengths. Additionally, all non-breach levee damage was assumed not to limit the conveyance capacity of any channels. This damage scenario was then paired with hydrologic start times 16 through 20 from Table 3, which were the most severe hydrologic conditions used in the study.

For the test setup, all the response actions listed under the Cumulative strategy were applied. The Cumulative strategy is an augmentation of the Middle River Corridor strategy that attempts to aggressively freshen up the Middle River Corridor through the addition of channel barriers along the Sacramento and San Joaquin River, as well as reservoir releases. The releases were simulated over a 7-day period and were 30,000 cfs and 10,000 cfs from NOD and SOD sources, respectively. All other ERR and WAM options were set to match the values used under the Cumulative strategy. The Basic Response strategy was also run to provide a baseline comparison for the tests.

Results

Table 8 contains the test matrix and results of the analysis. Combinations of the two independent test parameters, *Reservoir Release Condition* and *Export Resumption Condition*, were paired with the scenario and recovery strategy described above. The metrics used to gauge the effectiveness of the pairings were *Export Disruption* and *Average Exported EC*, which are defined as:

- *Export Disruption* – The duration, measured in days, from the start of the event until the listed export resumption condition is met.
- *Average Exported EC* – The average concentration of salinity in the exported water, measured in microsiemens per centimeter, from the time exports resume until Delta recovery (see the footnote on p. 8 for the definition of “Delta recovery”).

The minimum, maximum, and average *Export Disruption* and *Average Exported EC* for the five different hydrologic conditions modeled are displayed in Table 8.

Table 8: Reservoir Release Timing Sensitivity

Case	Response Strategy	Export Resumption Condition	Reservoir Release Condition	Export Disruption (days)			Average EC Exported (µS/cm)		
				Min	Max	Avg	Min	Max	Avg
1	Basic	Middle River & Old River EC = 1000	No Release	187	351	284	456	814	678
2	Cummulative	Head of Middle River EC = 600	No Release	71	105	88	732	842	769
3	Cummulative	Head of Middle River EC = 600	Immediate	68	92	81	605	852	737
4	Cummulative	Head of Middle River EC = 600	Corridor Repaired	67	106	85	690	850	757
5	Cummulative	Corridor Repaired	No Release	N/A	69	N/A	731	1013	829
6	Cummulative	Corridor Repaired	Immediate	N/A	69	N/A	591	926	751
7	Cummulative	Corridor Repaired	Corridor Repaired	N/A	69	N/A	683	852	756

*The export resumption condition based on when the corridor is repaired is constant, therefore, a value of "N/A" was assigned to the Min and Avg columns in the results matrix

The results can be generally organized into two groupings based on the *Export Resumption Condition**. The first condition simulates exports resuming once the salinity at the head of Middle River drops below an EC of 600 µS/cm. The second condition simulates exports resuming once all breaches along Middle River have been closed and all channel barriers have been installed (i.e., "Corridor Repaired"). Based on the levee damage scenario and default material placement rates, this occurs at approximately 69 days after the start of the event.

For both groupings, three different reservoir release conditions were simulated:

- *No Release* – No reservoir releases simulated.
- *Immediate* – Reservoir releases simulated at the start of the event, prior to any repairs.
- *Corridor Repaired* – Reservoir releases simulated after the Middle River Corridor has been repaired (day 69).

Discussion of Results and Conclusions

As previously mentioned, the Basic Response strategy (Case 1) is intended to provide a baseline of impacts for the test set. The average observed export disruption time was 284 days, which fell within the expected range based on the levee damage and hydrologic conditions simulated.

For export resumptions based on the EC at the head of Middle River, all five hydrologic scenarios showed that an immediate release was most effective at restoring water quality to the 600 EC threshold. By releasing immediately rather than after establishing the corridor, a reduction in disruption time ranging from 0 days to 14 days was observed across the five hydrologic start times. Water quality of the exports for both cases was very similar, varying on average by only a few µS/cm in the 750 EC range. This finding is consistent with previous studies that have shown holding reservoir releases until repairs are made is generally not as effective as an immediate release (JBA et al., 2005).

For the second set of tests, exports were set to turn on once the corridor was repaired rather than based on water quality levels in the Delta. Under this condition, export disruption time will be the same for all release times (69 days). Therefore, water quality, rather than export disruption, will be used as the metric to gauge the relative effectiveness of varying release times.

Similar to the first set of tests, an immediate release resulted in more favorable export water quality, on average. However, the average EC exported for both the immediate and delayed release were very close (751 μS/cm vs. 756 μS/cm). For the delayed releases, only one of the five hydrologic start times resulted in improved export water quality.

The findings from the test cases show that immediate reservoir releases generally provide greater benefit than delaying releases until the corridor is established. However, the difference in disruption time and exported water quality between the two release times appears to be minimal. Furthermore, it is also important to note that regardless of the release timing, the *No Release* condition produced export disruption times and water quality levels very close to both the immediate and delayed release. This suggests that the contribution from the release itself is not as significant as the suite of other response actions that makeup the Cumulative Response strategy, with the largest contributor being the barriers on the Sacramento and San Joaquin rivers. This should not be surprising considering that the volume of water diverted by these barriers, from the time of installation until export resumption, is about three times the volume used for the combined flushing releases.

Another significant finding of this analysis is that resuming exports once the Middle River Corridor has been established can reduce outage time while still maintaining a reasonable level of export water quality. By evaluating the results from Case 4 and Case 7, the delay in exports after the corridor is established provides essentially no additional benefit to export water quality. This would suggest that using the EC at the head of Middle River as an indicator for export resumption may not be the best approach.

Finally, while immediate releases generally were more effective than delayed releases, there were certain hydrologic start times where a delayed release had greater benefit. Therefore, for real-world events, the model should be run to determine the appropriate response.

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13 Reservoir Release Volume Sensitivity Analysis

In addition to reservoir release timing, it is also important to evaluate the Delta's sensitivity to various release volumes. The following analysis considers a range of release volumes from both north and SOD reservoirs, and evaluates their coupled effectiveness at restoring exports.

Test Setup

This analysis uses the same hydrologic start times and levee damage scenario described in Section 12. In addition, the Cumulative response strategy was also applied, however, the release volumes were altered as part of the sensitivity analysis.

The NOD releases were simulated to occur immediately following the event at a flowrate of 30,000 cfs. The SOD releases were simulated to occur at a flowrate of 14,000 cfs after all breaches along the Middle River Corridor were closed and the San Joaquin barrier was installed. The 14,000 cfs flowrate for the SOD release was selected based on approximate channel capacity. The duration of the releases varied from 0 to 10 days to represent the range of reservoir volumes being tested.

Results

Table 9 displays the simulation results in "export disruption time" for various combinations of release volumes from NOD and SOD reservoirs.

Table 9: Export Disruption Times for Varying Combinations of Reservoir Release Volumes

			South of Delta Reservoirs				
	Duration		0	1	3	7	10
		Volume	0	28	83	194	278
North of Delta Reservoirs	0	0	91	89	84	84	85
	1	60	91	87	83	83	84
	3	179	89	86	82	82	77
	7	417	87	84	80	80	76
	10	595	86	84	79	79	76

Reservoir Release Duration (days)

Export disruption time (days)

Reservoir Release Volume (1000 ac-ft)

Discussion of Results and Conclusions

Export disruption time ranged from 76 days, with a total release volume 873,000 ac-ft, to 91 days when no reservoir releases were made. Similar to the findings in Section 12, the results indicate that although reservoir releases can expedite export resumption, their influence is limited. A combined release volume of 873,000 ac-ft was only able to reduce disruption time by 15 days.

The results also indicate that increasing release volumes beyond a certain threshold did not always improve export resumptions. A release volume of approximately 80,000 ac-ft from SOD reservoirs was sufficient to flush the saline water from the Middle River Corridor. Release volumes beyond this threshold had negligible impact on export resumption time, regardless of NOD release volumes.

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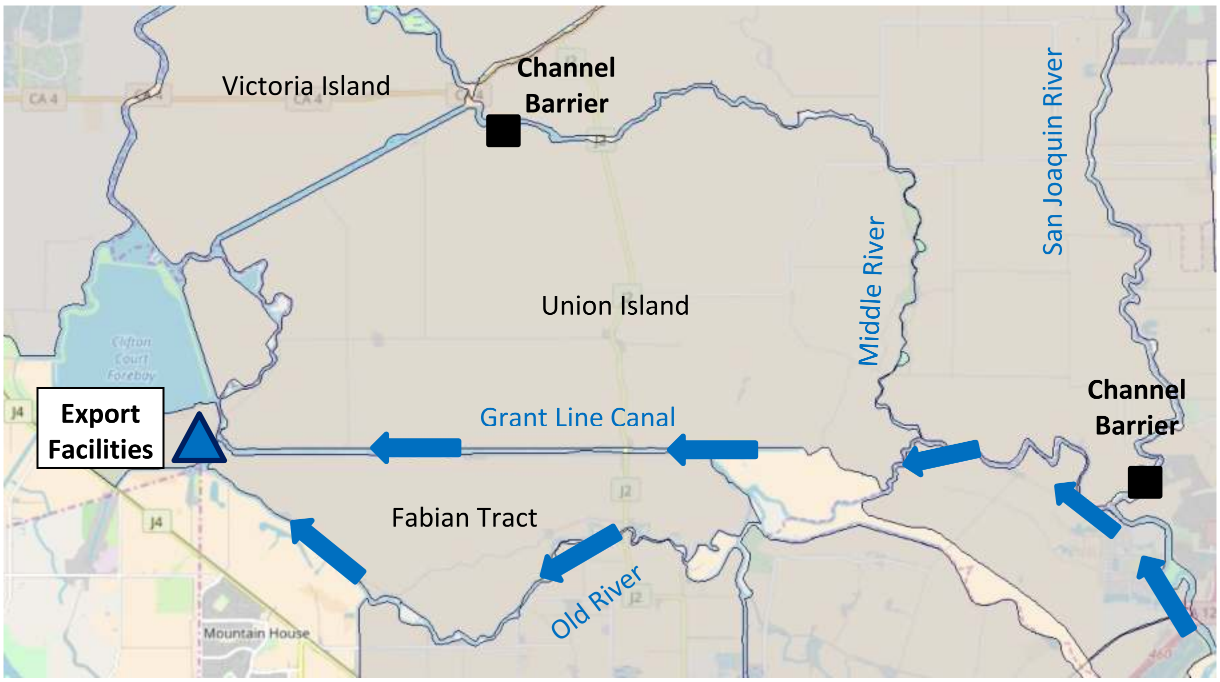
14 Rapid Restart Strategy for Limited Exports

The intent of this analysis is to identify if limited export capacity can be established shortly after a large event. This would be advantageous because some water contractors along the South Bay aqueduct have limited storage which could runout within weeks following an outage.

The general strategy to accomplish this is to divert the San Joaquin River directly toward the export facilities by installing barriers on the San Joaquin River and Middle River. Figure 11 shows the proposed barrier locations.

Figure 11: San Joaquin River Diverted Toward Export Facilities



With the barriers in place, flows from the San Joaquin River would be forced down Grant Line Canal and Old River toward the export facilities. Once installation is complete, exports should be able to resume at a limited flowrate without drawing on the highly saline water to the north. The test setup described below will attempt to identify export flowrates that result in reasonable water quality by establishing a relationship between flowrate and salinity.

Test Setup

The levee damage for this analysis is based on Scenario 1. Breach widths were adjusted to default lengths and all non-breach levee damage was assumed not to limit the conveyance capacities of any channel. Hydrologic start times 16 through 20 from Table 3 were used as the initial conditions and inflows for the simulation.

The test matrix pairs reservoir release conditions with a range of export flowrates. The three release conditions analyzed were:

- *No Release* – No reservoir releases simulated.
- *Immediate* – Reservoir releases simulated at the start of the event.
- *Barriers Installed* – Reservoir releases simulated after the San Joaquin and Middle River barriers have been installed (day 21).

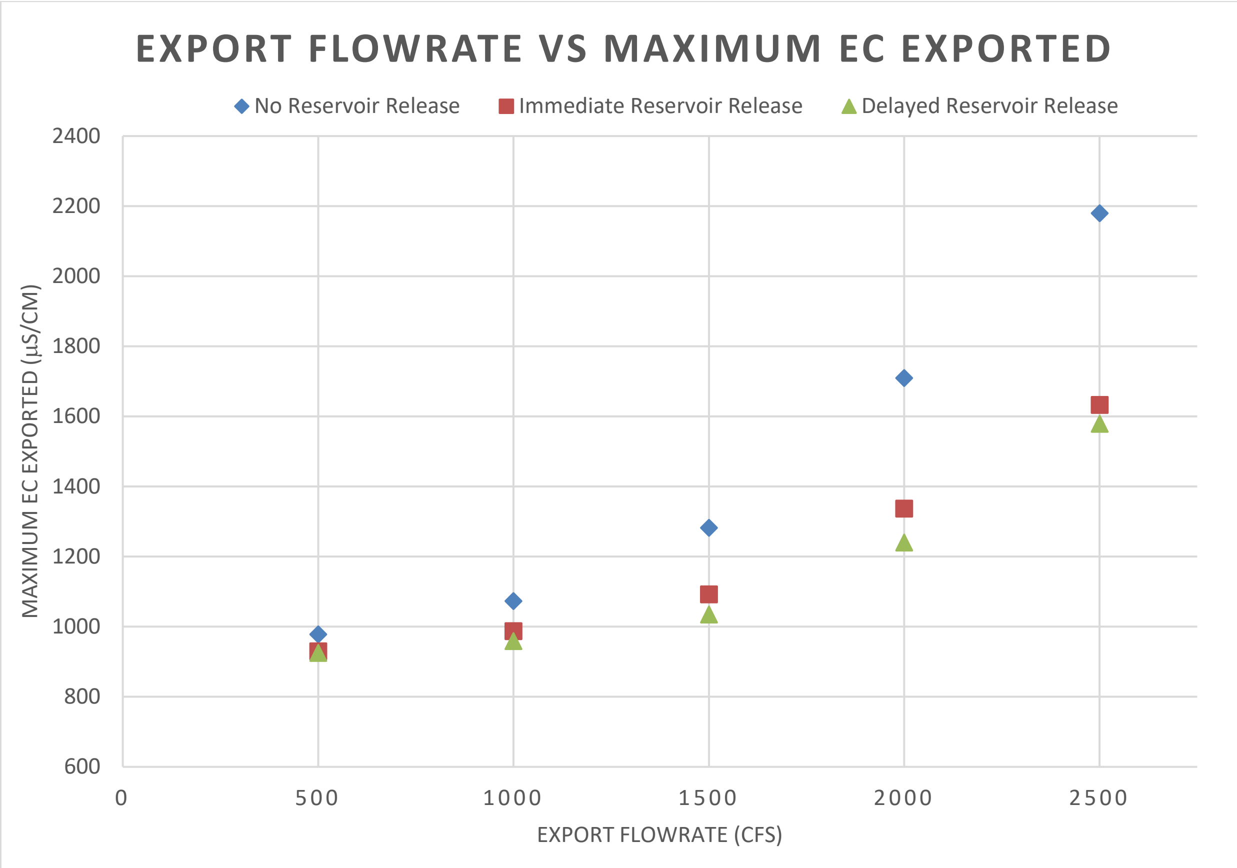
Release rates were 30,000 cfs from NOD sources and 10,000 cfs from SOD sources, over a 7-day period. The resulting maximum EC* of the exported water for each of these combinations is displayed in Table 10 and plotted in Figure 12 .

Table 10: Maximum EC for Varying Export Flowrates and Reservoir Release Conditions

Reservoir Release Condition	Exports (cfs)	Maximum EC Exported (µS/cm)		
		Min	Max	Avg
No Release	500	939	1052	978
	1000	940	1274	1073
	1500	951	1745	1282
	2000	1005	2522	1710
	2500	1150	3445	2180
Immediate	500	823	988	930
	1000	939	1113	987
	1500	944	1354	1092
	2000	969	1953	1337
	2500	1042	2563	1633
Barriers Installed	500	807	978	925
	1000	878	1078	959
	1500	944	1301	1035
	2000	934	1901	1240
	2500	1047	2547	1579

*Red shading indicates an EC value that is likely too high for exporting through SWP and CVP

Figure 12: Relationship between Export Flowrate and Average EC Exported



Discussion of Results and Conclusions

The results from Table 10 indicate that it would be possible to resume exports at a limited flowrate once the barriers on San Joaquin and Middle River are installed. As export rates increase, water quality of exports decrease. However, so long as export rates approximately matched San Joaquin River inflow rates, water quality remained within manageable levels. At an export rate of 1000 cfs, the average peak EC of exports ranged from 878 µS/cm to 1274 µS/cm.

Delaying reservoir releases until the barriers were in place proved more beneficial than an immediate release. However, the improvements were marginal. Additionally, the *No Release* condition resulted in EC values only slightly higher than when reservoir releases were made (approx. 100 µS/cm higher). This effect is largely due to the open breaches north of the exports facilities. Once the reservoir pulse passes the export facilities, it begins mixing with the highly saline water within the flooded islands immediately to the north. The large volume of these highly saline islands quickly defuses any "flushing" effect that the pulse would have had if the breaches on these islands were closed. The benefit from the pulse is primarily seen during the seven days as it passes the export facilities and provides improved water quality during that period. Because of this, a more effective way to utilize reservoir storage for a *rapid restart strategy* would be to attempt to match release rates to export rate. This would allow the majority of the fresh water released to be exported, rather than used as a flushing mechanism for the Delta.

Similar to the findings in Section 12, the most important element of this strategy is the channel barriers.

Figure 14 and 14 show salinity in the channels surrounding the export facilities just prior to and after barrier installation.

Figure 13: Channel Salinity Prior to Barrier Installation (day 16)

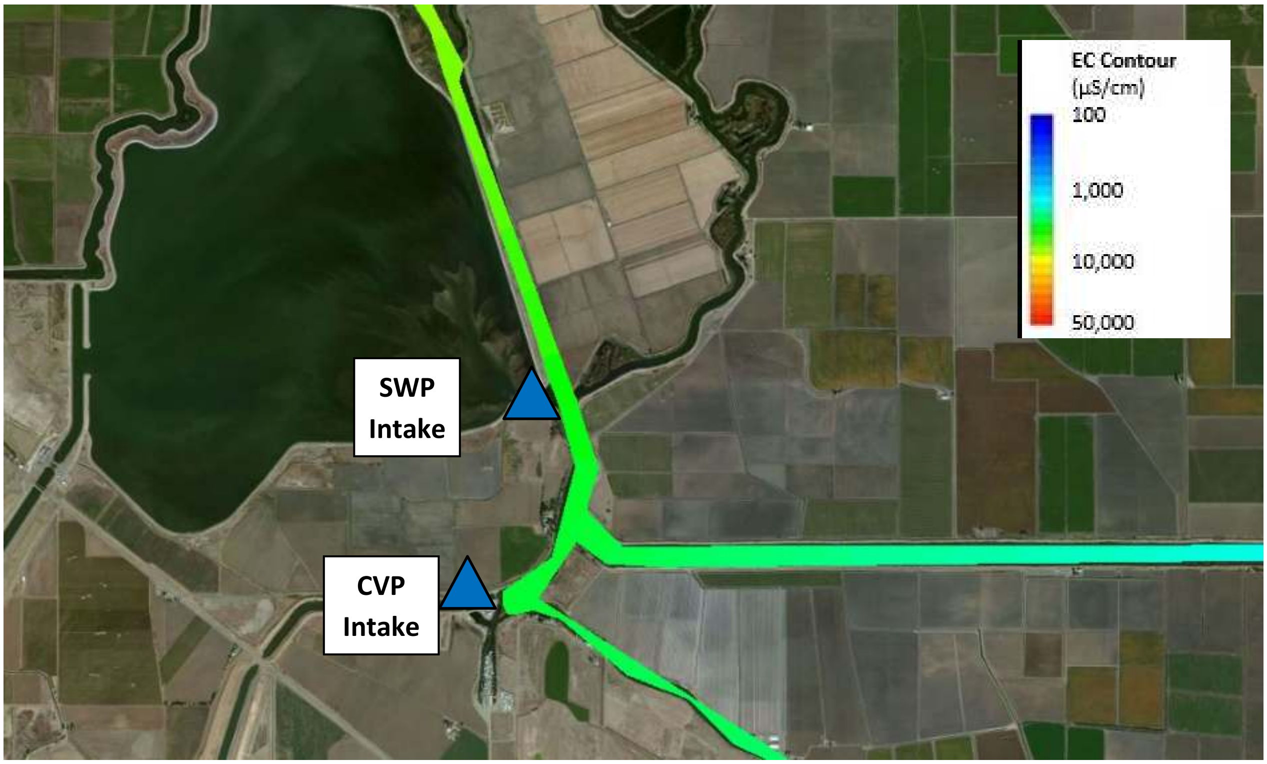
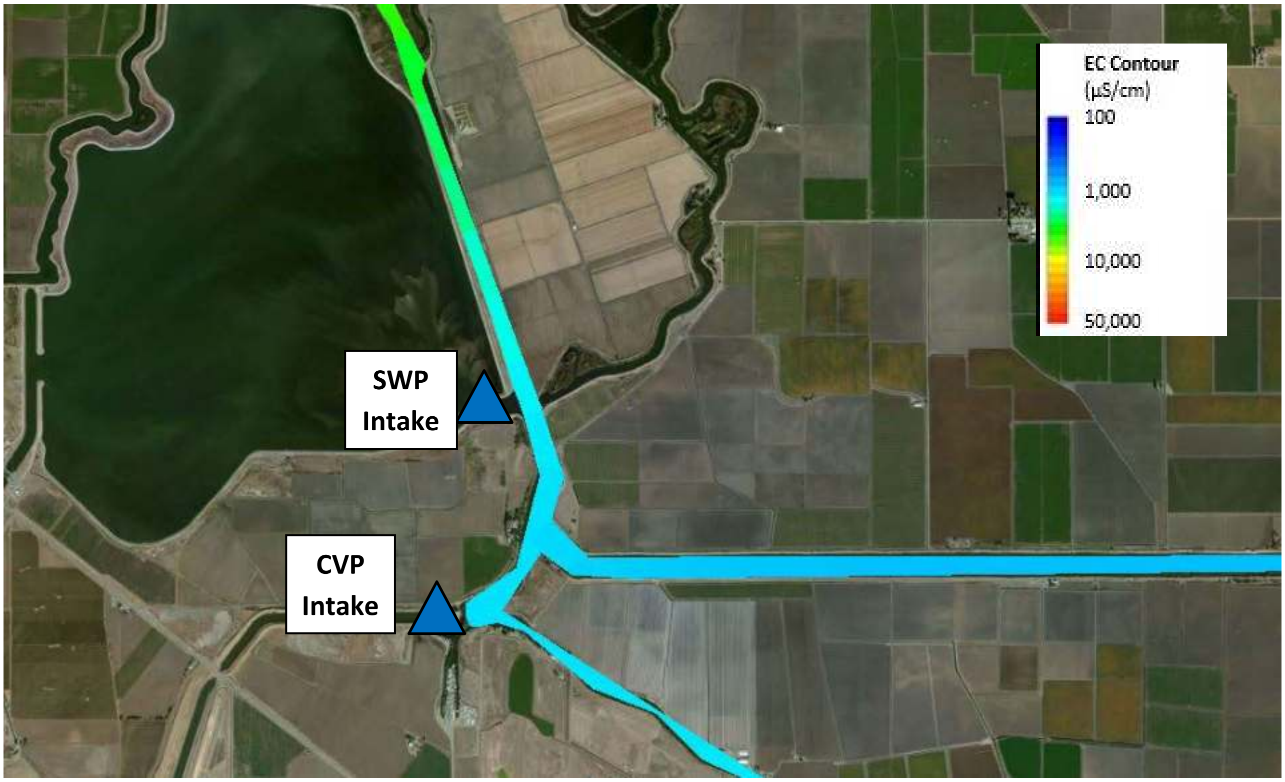


Figure 14: Channel Salinity After Barrier Installation and Limited Export Resumption (day 21)



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15 Conclusions

Based on the results of the 760 model simulations and additional sensitivity analyses, the following inferences regarding the duration of export disruption due to various conditions and response actions can be made:

- Disruption times can vary widely based on initial conditions, future conditions, and response actions.
- Not only the volume, but also the location of breached islands can have a significant impact on disruption time.
- Aggressive strategies for small events had minimal impacts on disruption times and may not be worth implementing.
- Accepting slightly lower water quality can, in some cases, significantly decrease disruption times.
- A small volume of water released from SOD sources can have a significant impact on export disruption times, relative to NOD sources.
- In general, reservoir releases were shown to be most beneficial when made immediately following a levee failure event.
- The effectiveness of reservoir releases can vary based on the timing relative to other response actions, such as breach repairs and barrier placement.
- It is possible to resume exports at a limited capacity shortly after a catastrophic event by diverting San Joaquin flows directly toward Clifton Court.

The wide range of disruption times for different scenarios is attributable to the sensitive nature of the Delta water quality response to different initial and future conditions. The implementation of the various response actions would likely only be cost-effective for events that occur during periods of poor water quality that cause substantial disruptions. For events occurring during times of poor water quality, the results show that the response actions are very effective at reducing disruption times. The cost and impacts of these response actions would need to be weighed against the benefit of maintaining the water quality in the Delta and restarting exports sooner. The range of disruption times for each scenario reinforces the importance of the Delta ERT for emergency responders and decision makers to model the sensitive nature of the initial and forecasted conditions.

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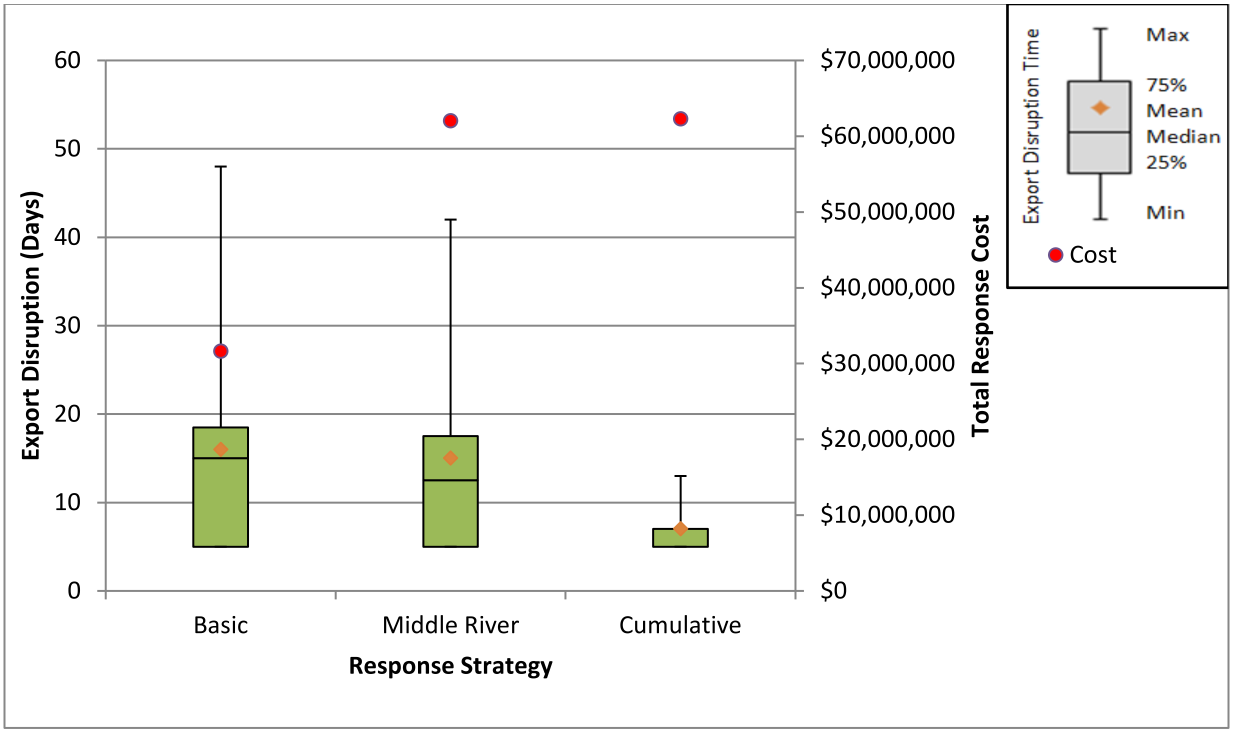
Appendix 1 – Detailed Results

Figure 15 through Figure 24 include box and whisker plots showing the mean, median, quartiles, minimum, and maximum values for export disruption for scenarios 2 - 11. * Exceptions noted on figures 15 and 18. The plots show that most of the results are closer to the minimum values, which leads us to expect that most events would not have significant disruption times unless the water quality conditions were unusually poor.

Figure 15: Scenario 2 - 5 Island Breach from Corroboration Report



*Note: Bottom whiskers missing due to 25% quartile being the same as the minimum value

Figure 16: Scenario 3 - 15 Island Breach from Corroboration Report

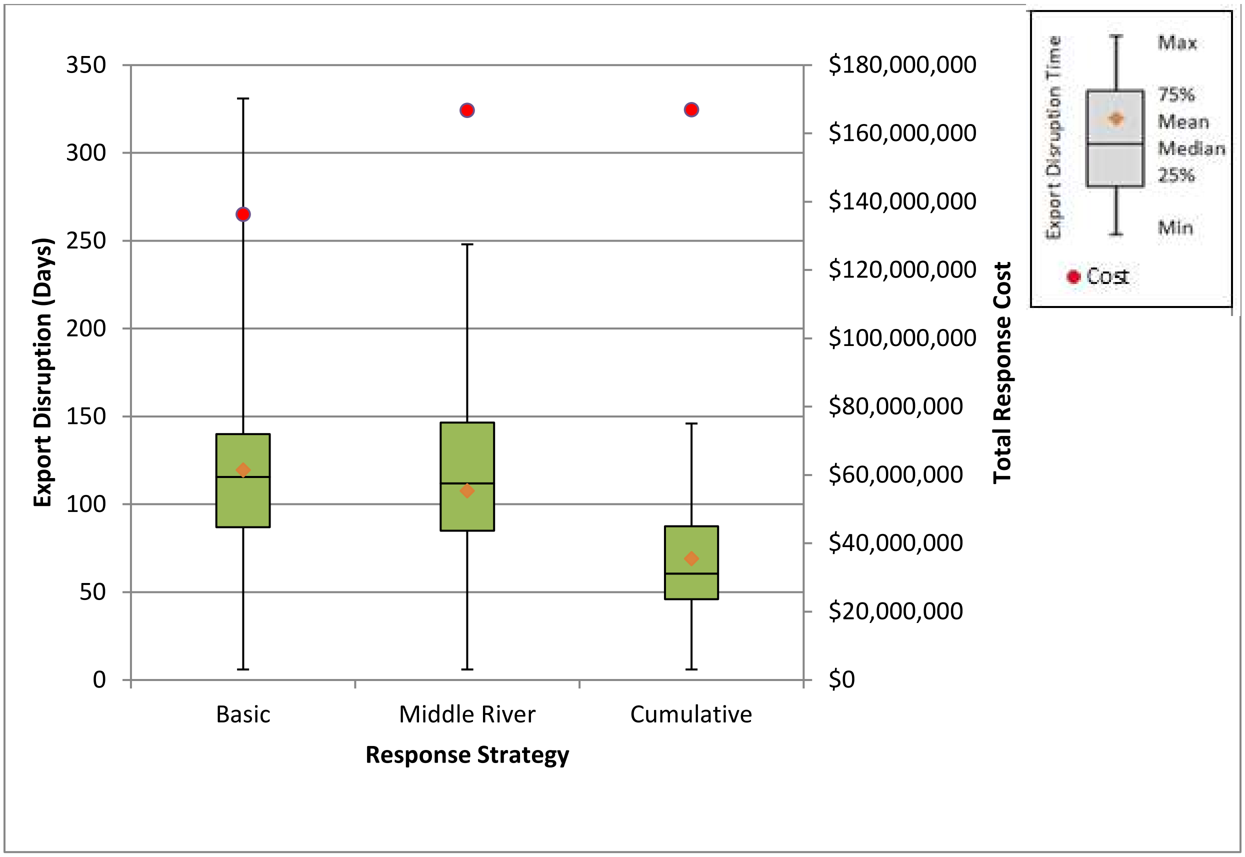


Figure 17: Scenario 4 - 20 Island Breach from Corroboration Report

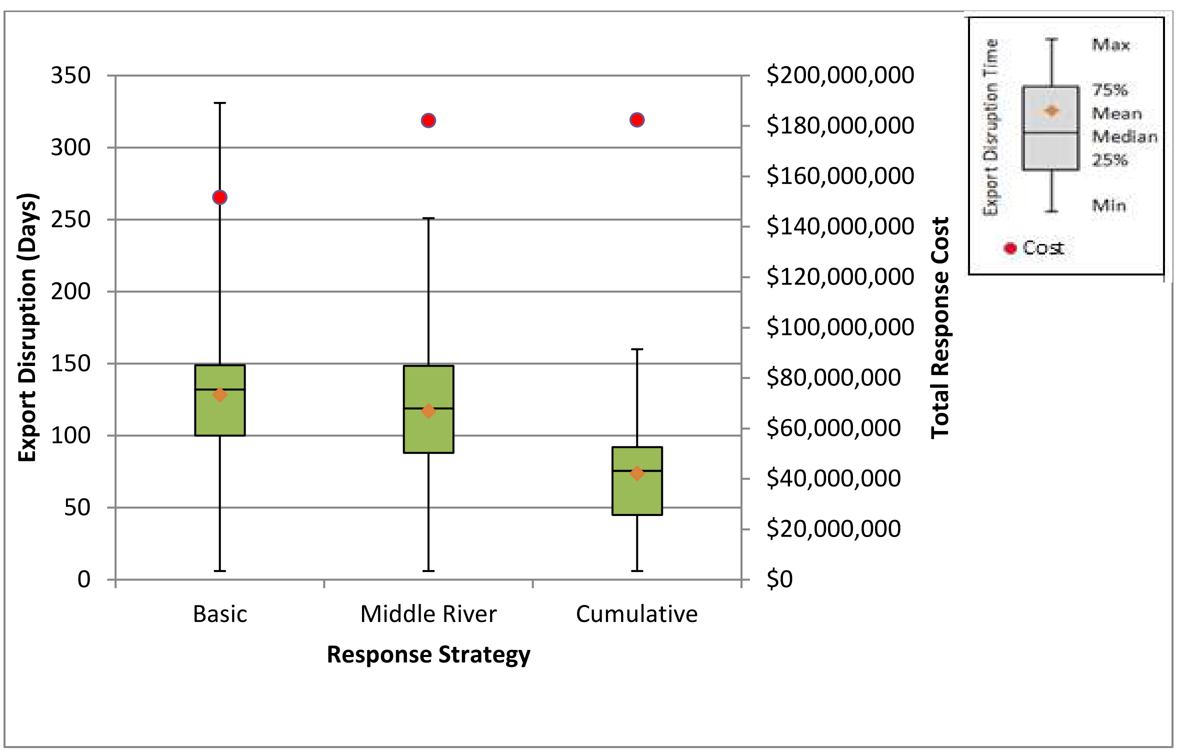
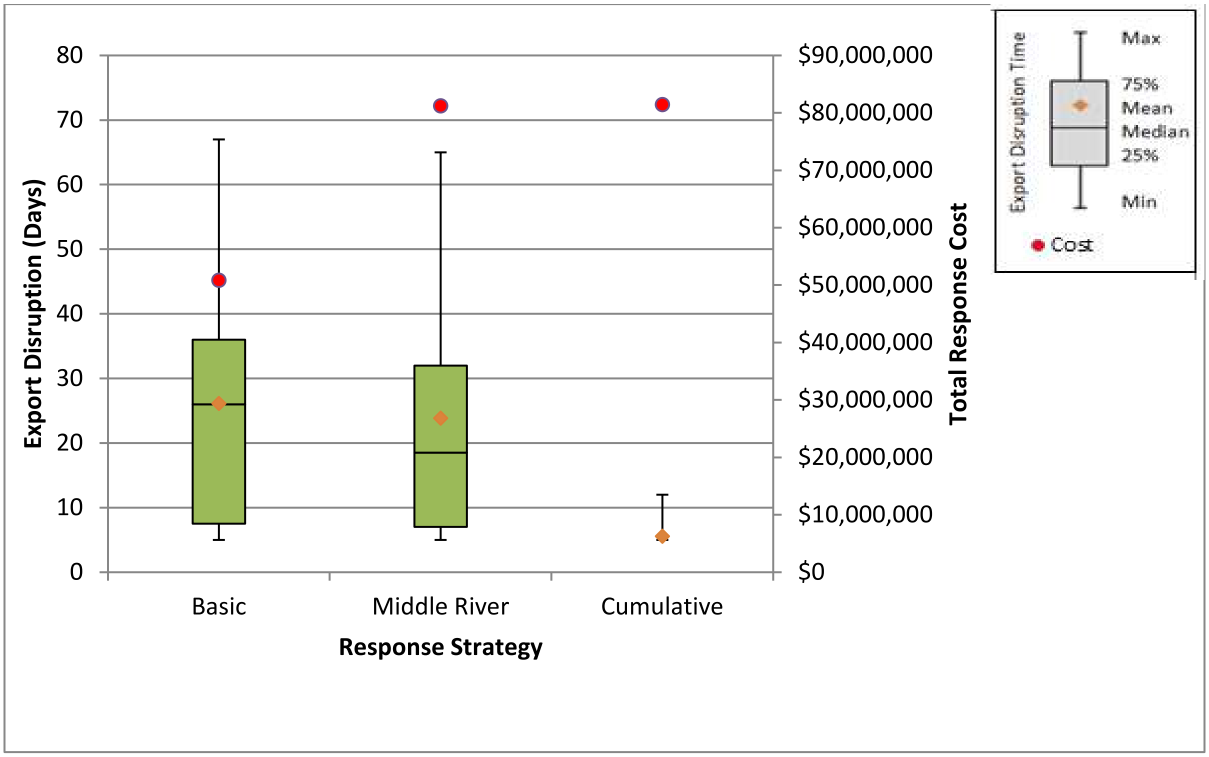


Figure 18: Scenario 5 - 7 Breaches of Western Group Islands



*Note: Boxes not shown because minimum, 25%, median, and 75% quartiles are all the same value

Figure 19: Scenario 6 - 5 Breaches of Central Group Islands

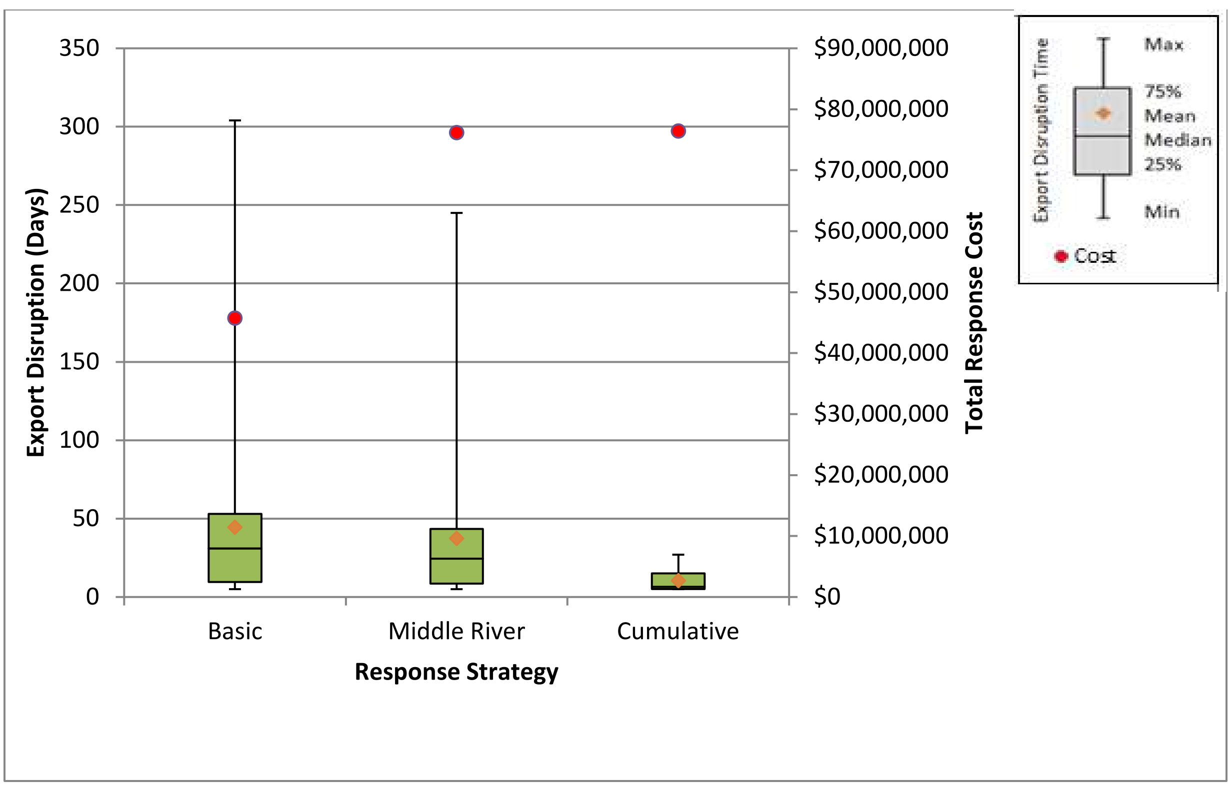


Figure 20: Scenario 7 - 4 Breaches of Old River Islands

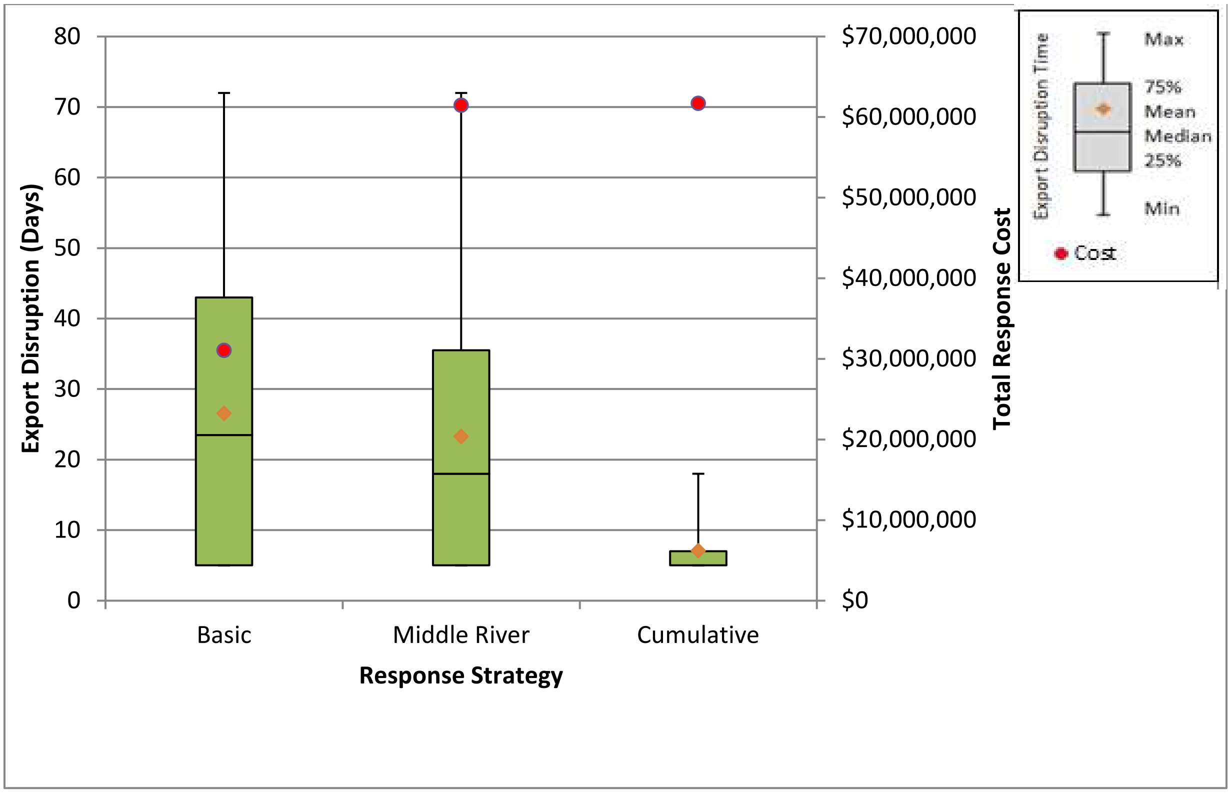


Figure 21: Scenario 8 - 4 Breaches of Middle River Islands

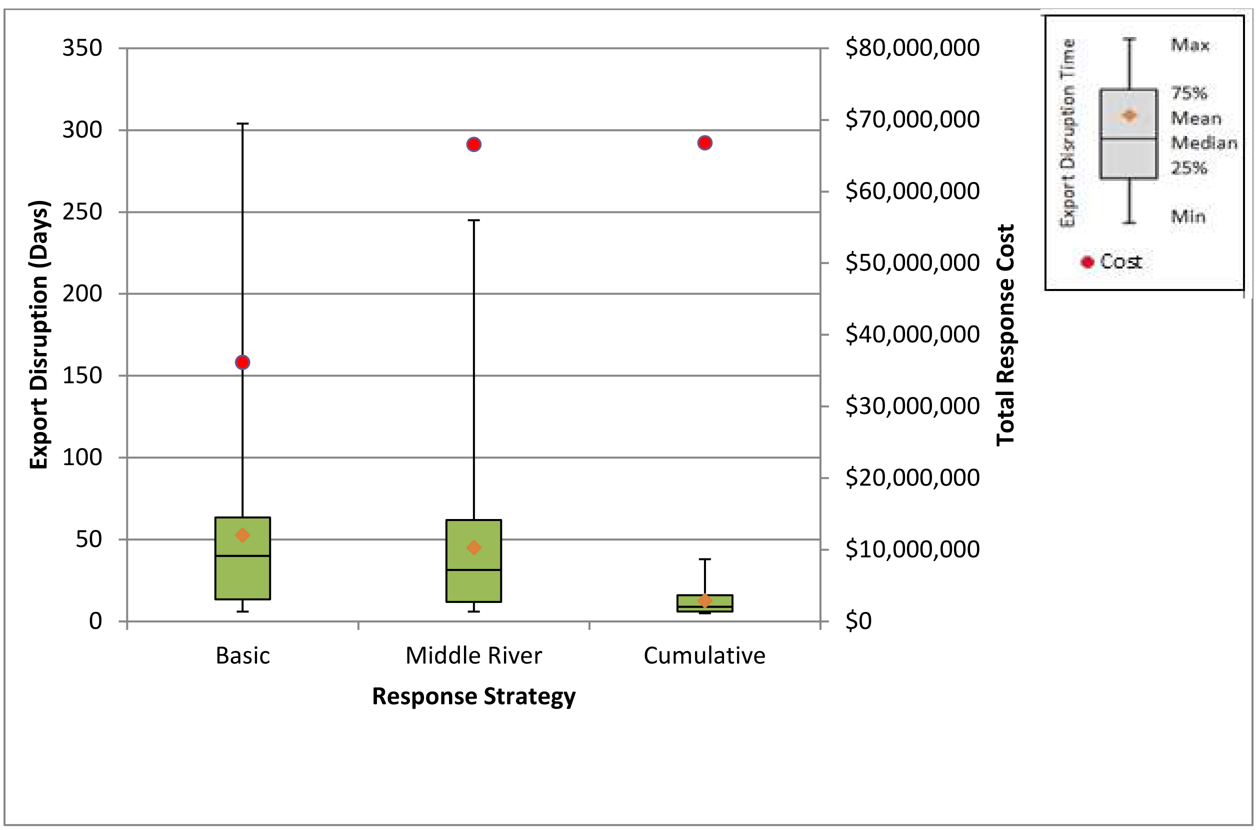


Figure 22: Scenario 9 - 12 Breaches of Western and Central Islands

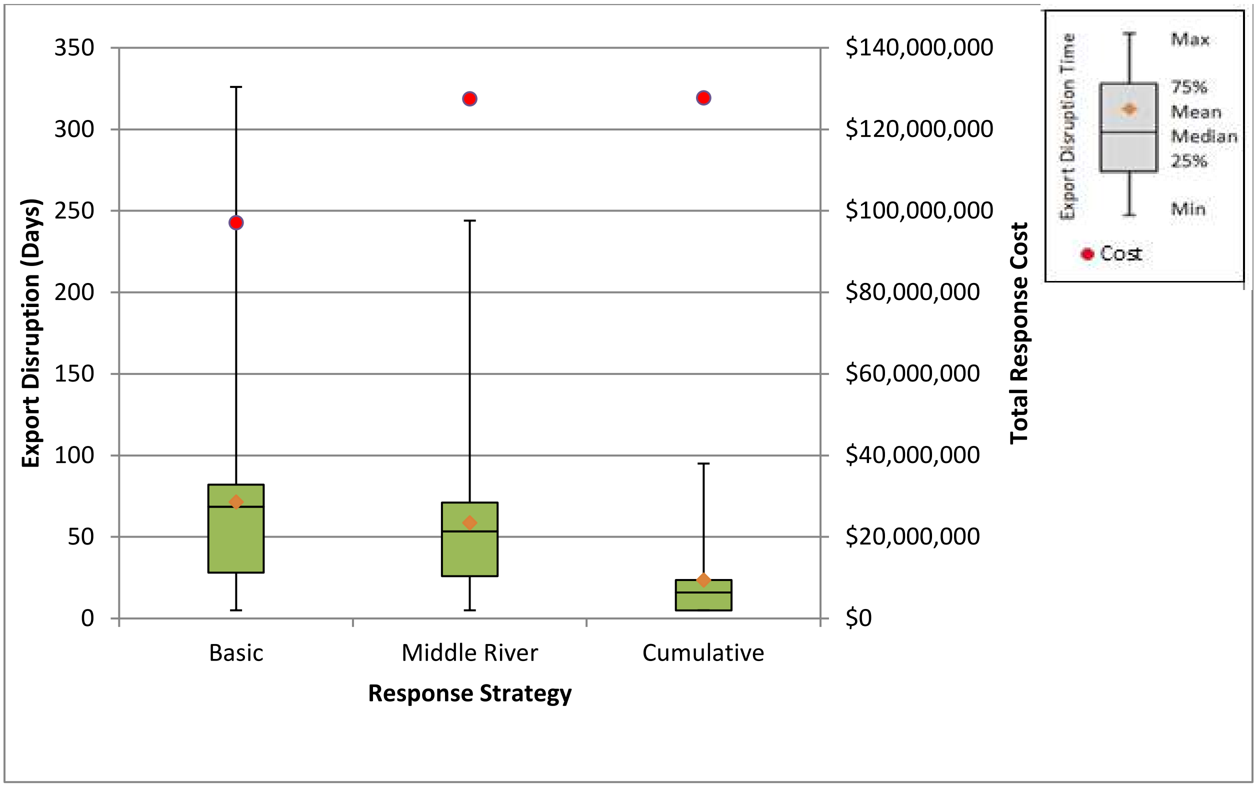


Figure 23: Scenario 10 - 16 Breaches of Western, Central, and Old River Islands

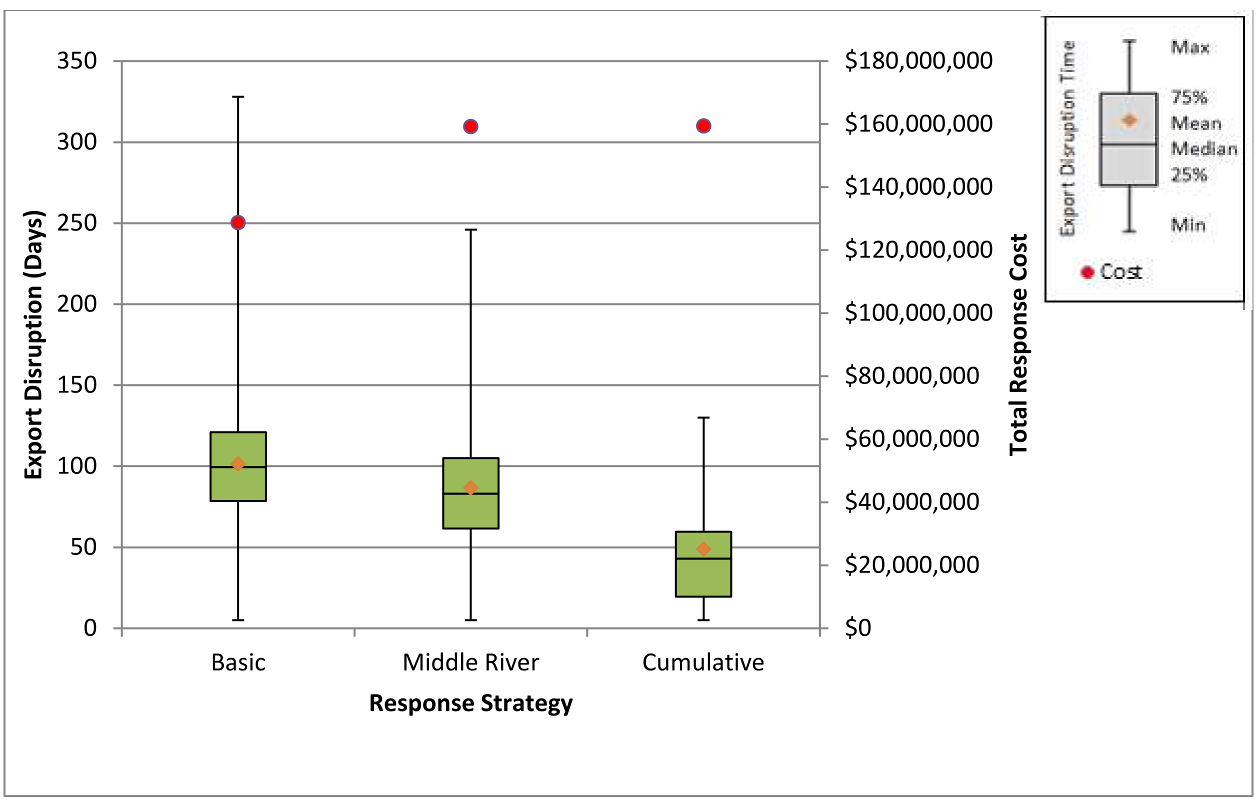
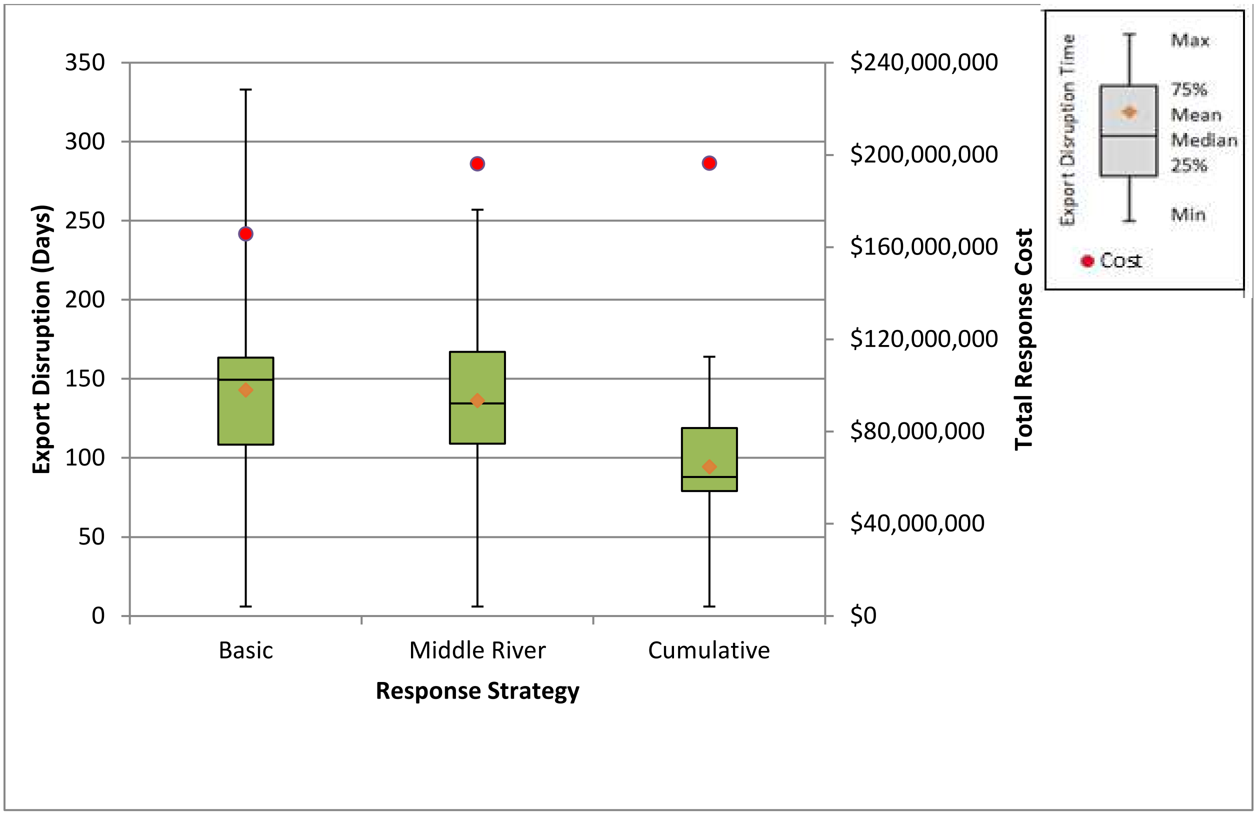


Figure 24: Scenario 11 - 20 Breaches of Western, Central, Old River, and Middle River Islands



Appendix 2 – Model Output Formats

The Delta ERT has been developed with a variety of output formats to aid the user in communicating model results to a wide audience. The three primary output formats include summary reports, time-series data, and salinity contour animations. Each of the three formats provides a unique perspective of the model results and can be tailored as appropriate for a specific audience.

Reports

Reports are commonly the first tool used to view model results and are readily accessible through the Delta ERT GUI. There is a suite of pre-generated report templates built into the program that provide a high-level summary of simulation results. These reports include the total time and cost to complete repairs as well as the duration of export disruption, among other metrics.

When reports are generated, they are saved as PDF files on the local hard drive. The compact and organized format of the report PDFs make them excellent tools for briefing management and can easily be disseminated to partner agencies.

Figure 25 is an example of a simulation summary report created by the Delta ERT report generator. The figure shows the first two pages of the WAM Summary report for a given scenario.

Figure 25: WAM Summary Report Example

Delta-ERT
Water Analysis WAM Results Summary

Event: Slump_ResOpsOff_Rock
01Jul2002
Earthquake
Plan: SJ_Barrier

Simulation Performed on: 1/24/17 8:34 AM
Report Produced by: Isanati

Number of Islands Damaged but not Breached: 1
Number of Islands Breached: 19
Total Volume of Breached Islands (TAF): 1,296,145.00

WAM Start Times: 20
7/1923, 8/1968, 7/1959, 6/1989, 8/1949, 9/1971, 9/1973, 6/1957, 5/1976, 10/1970, 8/1994, 12/1927, 12/1977, 11/1929, 10/1969, 1/1977,

Duration (Days after Event)

	Start of Export	Delta Recovery	Repair Complete	NOD Recovery	SOD Recovery	End of Simulation
Ref (7/1923)	243	244	1352	609	1339	1370
Maximum	453	457	1352	609	1430	1430
Minimum	6	11	1352	30	91	1369
Average	196	236	1352	242	878	1377

Export Deficit (acre-ft)

	Start of Export	Delta Recovery	Repair Complete	NOD Recovery	SOD Recovery	End of Simulation
Ref (7/1923)	4,208,180.	4,208,180.	5,935,242.	5,444,932.	6,069,024.	5,935,242.1
Maximum	4,395,463.	4,804,069.	5,935,242.	5,485,905.	6,069,024.	5,935,242.1
Minimum	113,422.7	113,422.7	653,042.3	5,485,905.	80,162.4	653,042.3
Average	2,470,214.	2,650,554.	3,236,122.	2,283,616.	3,003,405.	3,241,727.0

Slump_ResOpsOffSJ_Barrier, 06/16/2017 8:18 AM Page 1 of 3

Delta-ERT WAM Results Summary Report

Delivery Deficit (acre-ft)

	Start of Export	Delta Recovery	Repair Complete	NOD Recovery	SOD Recovery	End of Simulation
Ref (7/1923)	2,040,075.1	2,040,075.1	5,566,708.2	3,966,757.5	5,565,805.1	5,566,708.2
Maximum	2,524,560.5	3,802,180.8	5,566,708.2	3,966,757.5	5,565,805.1	5,566,708.2
Minimum	312.0	312.0	326,134.9	0.0	4,213.1	326,134.9
Average	1,097,014.0	1,362,192.1	2,701,785.8	1,293,700.4	2,523,374.9	2,701,824.6

Export Quality Summary between Start of Exports and Delta Recovery

	Avg EC (uS/cm)	Min EC (uS/cm)	Max EC (uS/cm)	Avg Cl (mg/l)	Avg Br (ug/l)
Ref (7/1923)	994.0	994.0	994.0	216.0	822.0
Maximum	1,161.0	994.0	1,710.0	258.0	960.0
Minimum	276.0	275.0	276.0	35.0	228.0
Average	700.5	492.0	881.4	142.0	579.2

Salt Exported between Start of Exports and Delta Recovery

	Mass of Salt Exported (1000 kg)			Salt Export Rate (1000 kg/d)		
	Base Run	Breach Run	Brch - Base	Base Run	Breach Run	Brch/Base
Ref (7/1923)	4,900	8,259	3,359	4,900	8,259	1.69
Maximum	512,014	892,762	530,745	5,141	9,600	2.47
Minimum	646	892,762	-104,795	646	325	0.19
Average	152,259	8,259	42,275	3,536	4,133	1.13

Water Volume Exported between Start of Export and Delta Recovery (acre-ft)

	Base Run	Breach Run
Ref (7/1923)	8,626.0	13,884.0
Maximum	1,979,431.	1,305,462.
Minimum	2,476.0	1,587.0
Average	589,249.7	413,774.8

Controlling Water Quality Criteria for Delta Recovery

	Export EC	Old River EC	Middle River EC	x2 Position	Dispersion	End of Simulation
Ref (7/1923)	0	0	0	1	0	0

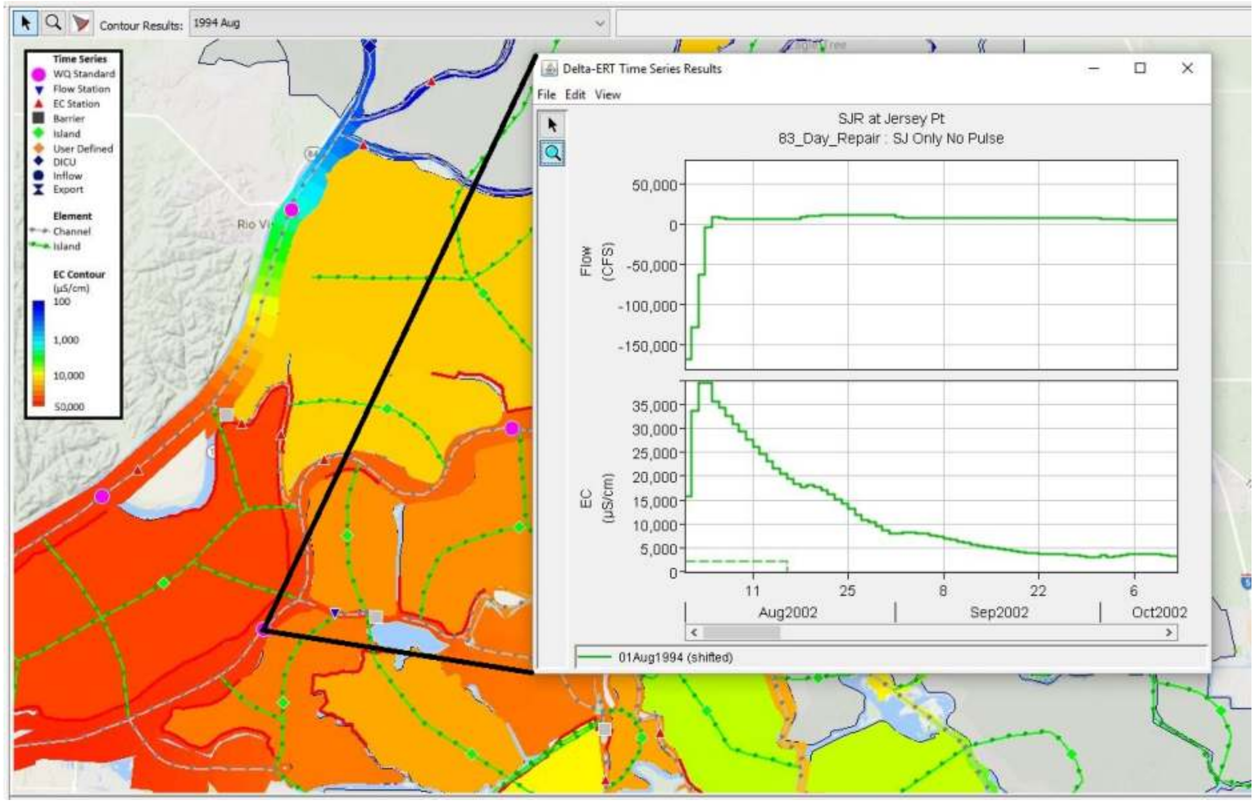
Slump_ResOpsOffSJ_Barrier, 06/16/2017 8:22 AM Page 2 of 3

In addition to the pre-generated report templates that are built into the program, custom reports can be created using third party report writing software. Using Structured Query Language (SQL) commands, these custom reports can pull data from an H2 database which is populated with simulation results once the model has run. There is an extensive array of model data that can be accessed, ranging from detailed water quality data, to high level export disruption times and water deliver deficit data. Additionally, time-series plots can be included as graphics imbedded within the reports, which will be discussed further in the following section.

Time-Series Plots

Another useful way to view model results is by accessing the flow and salinity time-series plots through the main interface of the Delta ERT. This output format is a convenient way to view results at specific locations, since the model nodes are georeferenced to a base map. The user can select different nodes on a map of the Delta and pull up plots of both water quality and flowrates at that location. This output feature improves the transparency of the model and can help the user better understand how response efforts impact various locations throughout the Delta. Figure 26 shows an example of a time-series plot accessed through the main interface.

Figure 26: Delta ERT Main Interface Displaying Time-Series Data at Jersey Point

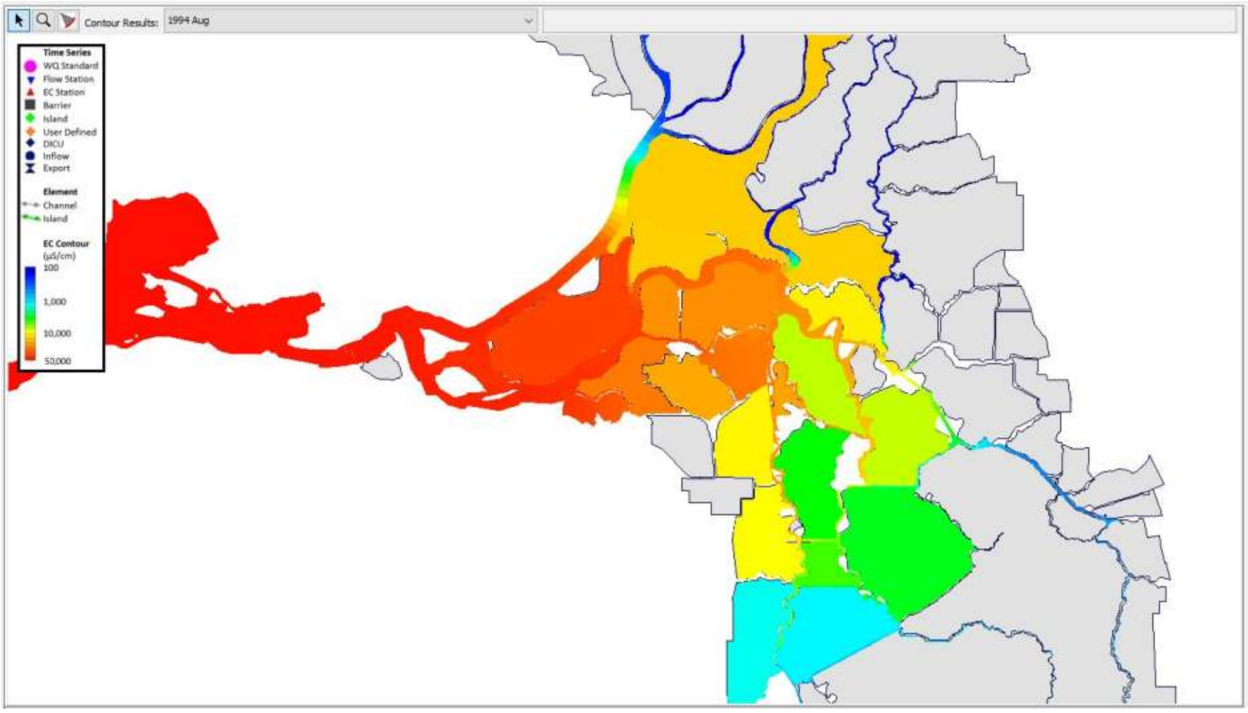


Salinity Animations

The third form of output available within the Delta ERT is salinity contour animations. These animations provide insight on how the salinity gradient across the Delta changes over time. The animations start out showing the initial gradient just prior to the breach event. As the animation plays, the viewer can observe the abrupt influx of saline water from the San Francisco Bay as breached islands begin to fill, and then the eventual subsidence of the salinity gradient as Delta inflows and various operational response efforts help restore the Delta to equilibrium.

The animations are the most visual form of model output available and are an excellent tool for demonstrating model results to both technical and nontechnical audiences alike. Figure 27 shows a snapshot of an animation for a multi-island breach scenario.

Figure 27: Snapshot of Animation for a Multi-Island Breach Scenario



Appendix 3 – Table of Flooded Island and Tract Volumes

NAME	VOLUME (AF)
Bacon Island	92,107
Bethel Island	30,886
Bishop Tract	9,207
Bouldin Island	101,042
Brack Tract	38,366
Bradford Island	28,761
Brannon-Andrus	208,998
Byron Tract	36,351
Canal Ranch	22,673
Coney Island	8,077
Dead Horse Island	929
Egbert Tract	10,341
Empire Tract	63,451
Fabian Tract	8,331
Fay Island	696
Glanville Tract	2,051
Grand Island	156,299
Hastings Tract	4,276
Holland Tract	52,030
Hotchkiss Tract	13,846
Jersey Island	41,671
Jones Tract	145,579
King Island	36,892
Little Egbert Tract	18,181
Mandeville Island	97,076
McCormack-Williamson Tract	2,097
McDonald Island	108,348
Medford Island	15,949

NAME	VOLUME (AF)
Merritt Island	7,201
Netherlands	43,290
New Hope Tract	13,452
Palm-Orwood Tract	53,983
Pearson District	44,963
Quimby Island	10,350
Rindge Tract	95,261
Rio Blanco Tract	1,976
Roberts Island	148,640
Rough and Ready Island	2,764
Ryer Island	97,792
Sargent-Barnhart Tract	5,543
Sherman Island	143,056
Shima Tract	7,875
Shin Kee Tract	3,809
Smith Tract	1,457
Staten Island	130,724
Sutter Island	7,711
Terminous Tract	114,431
Twitchell Island	57,547
Tyler Island	105,589
Union Island	91,573
Veale Tract	8,256
Venice Island	57,812
Victoria Island	85,036
Webb Tract	97,825
Woodward Island	23,947
Wright-Elmwood Tract	16,986

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Abbreviations and Acronyms

1D	One-dimensional
2D	Two-dimensional
AB	Assembly Bill
ac-ft	acre-feet
CCFB	Clifton Court Forebay
CFS	Cubic Feet Per Second
CVP	Central Valley Project
D-1641	Water Right Decision 1641
Delta	Sacramento-San Joaquin Delta
DCC	Delta Cross Channel
DFEMP	Delta Flood Emergency Management Plan
DFERP	Delta Flood Emergency Recovery Plan
DRMS	Delta Risk Management Strategy
DSM2	Delta Simulation Model 2
DWR	Department of Water Resources
EC	Electrical Conductivity
ERR	Emergency Response and Recovery
ERT	Emergency Response Tool
FIBC	Flexible Intermediate Bulk Container
FOC	Flood Operations Center
GUI	Graphical User Interface
JBA	Jack Benjamin & Associates
km	Kilometer
MWD	Metropolitan Water District of Southern California
NOD	North of Delta
RMA	Resource Management Associates
SOD	South of Delta
SQL	Structured Query Language
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	Thousand Acre Feet
USBR	United States Bureau of Reclamation
WAM	Water Analysis Module
WY	Water Year

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State of California

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California Natural Resources Agency

Karla Nemeth
Director
Department of Water Resources

For additional information, contact
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Or, visit us on the Web at:
https://water.ca.gov/What-We-Do/Flood-Preparedness

Prepared by GEI Consultants, Inc. for The California Department of Water Resources
Naser Bateni, Program Manager (PE 36128)

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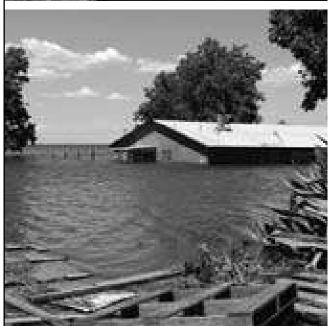
EXHIBIT F TO BRADNER DECLARATION






EXECUTIVE SUMMARY

PHASE 1

Delta Risk Management Strategy

FEBRUARY 2009

Prepared by the California Department of Water Resources from documents developed by URS Corporation/Jack R. Benjamin & Associates, Inc., as listed below.

Phase 1 Risk Analysis Report Technical Memoranda

- Seismology
- Flood Hazard
- Climate Change
- Levee Vulnerability
- Wind-Wave Hazard
- Geomorphology
- Subsidence
- Emergency Response and Repair
- Water Analysis Module
- Impact to Ecosystem
- Impact to Infrastructure
- Economic Consequences

These documents are available electronically on the compact disc attached to the back cover of this Executive Summary. They are also available online at http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp.

Pictured on cover [upper left to bottom, then right]:
Earthquake damage – Sylmar [February 9, 1971]
Source: DWR

Upper Jones Tract failure – Delta [June 4, 2004]
Source: DWR

Flood damage – Delta [June 7, 2004]
Source: DWR

Delta islands protected by levees from flooding
Source: DWR

FOREWORD

The Sacramento-San Joaquin River Delta, including the Suisun Marsh, is one of California's most important natural resources. An extensive levee system maintains the waterways and islands that define the Delta and Suisun Marsh.

Levees in the Delta and Suisun Marsh are at risk of failing due to a variety of factors, including earthquakes and winter storms. Levee failures and the flooding that follows can cause fatalities, destruction of property and infrastructure, interruption of a large portion of California's water supply, environmental damage and statewide economic impacts.

The Department of Water Resources engaged a team of experts to complete an evaluation of levee failure risks in the Delta and Suisun Marsh. This evaluation is divided into two phases. Phase 1 analyzes various risks to levees and the local and statewide consequences of levee failure. Phase 2 identifies and analyzes measures to reduce the risks and consequences of levee failure. The results of Phase 1 are summarized in this report.

The successful completion of Phase 1 is a major milestone in the ongoing effort to understand the Delta and Suisun Marsh. The results of Phase 1, and the results of Phase 2 to follow, are necessary for informing the decisions that must be made to maintain and improve levees and protect the Delta and Suisun Marsh.

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Pictured facing page: Overlooking the Delta. Source: DWR

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A complex system of over 1330 miles of levees in the Delta Region protects property, infrastructure and people. Levees also protect the region's water supply and ecosystem functions.

The Sacramento-San Joaquin River Delta [Delta] and Suisun Marsh, collectively referred to as the Delta Region, is the largest estuary in the western United States. The Delta Region is home to numerous plant and animal species, some of which are found nowhere else. The Delta Region is also the hub of California's water supply system. Diversions from the Delta provide water for about 25 million people and about 3 million acres of farm land. Key transportation, transmission and communication lines cross the region. The region is also important to recreation and tourism. The rich soils of the Delta islands support a highly productive farming industry. Figure 1 is a map of the Delta Region.

Delta Region levees and the areas and resources they protect are not sustainable under business-as-usual practices.

Phase 1 of the Delta Risk Management Strategy [DRMS] Project analyzes the risks and consequences of levee failure in the Delta Region. The Phase 1 analysis considers current and future risks of levee failures from earthquakes, high water conditions [storms and tides], climate change, subsidence, dry-weather events and a combination of these factors. The analysis also estimates the consequences of levee failures to the local and state economy, public health and safety and the environment.

Various scenarios to reduce the risks and consequences of levee failure are considered in Phase 2 of the DRMS Project. Phase 2 is due to be completed in 2009.

One of the objectives of Phase 1 is to determine whether current [business-as-usual] management practices can sustain the Delta Region through the next 100 years. Business-as-usual practices include current management practices and regulatory requirements.

Pictured above: Delta islands protected by levees from flooding. Source: DWR

Phase 1 of the DRMS analysis concludes that under business-as-usual practices, the Delta Region as it exists today is unsustainable. Seismic risk, high water conditions, sea level rise and land subsidence threaten levee integrity. A seismic event is the single greatest risk to levee integrity in the Delta Region. If a major earthquake occurs, levees would fail and as many as 20 islands could be flooded simultaneously. This would result in economic costs and impacts of $15 billion or more. All economic costs and impacts presented in this summary are expressed in 2005 dollars.

While earthquakes pose the greatest risk to Delta Region levees, winter storms and related high water conditions are the most common cause of levee failures in the region. Under business-as-usual practices, high water conditions could cause about 140 levee failures in the Delta over the next 100 years. Multiple island failures caused by high water would likely be less severe than failures from a major earthquake, but could still be extensive and could cause approximately $8 billion or more in economic costs and impacts.

Dry-weather levee failures [also called "sunny-day" events] unrelated to earthquakes, such as from slumping or seepage, will continue to occur in the Delta about once every seven years. Costs to repair a single island flooded as the result of a dry-weather levee failure are expected to exceed $50 million.

The risk of flooding in the Delta Region will only increase with time if current management practices are not changed. By the year 2100, Delta levee failure risks due to high water conditions will increase by 800 percent. The risk of levee failure from a major earthquake is projected to increase by 93 percent during the same period.

A major earthquake of magnitude 6.7 or greater in the vicinity of the Delta Region has a 62 percent probability of occurring sometime between 2003 and 2032. This could cause multiple levee failures, fatalities, extensive property destruction and adverse economic impacts of $15 billion or more.

Upper Jones Tract levee repair 2004. Source: DWR

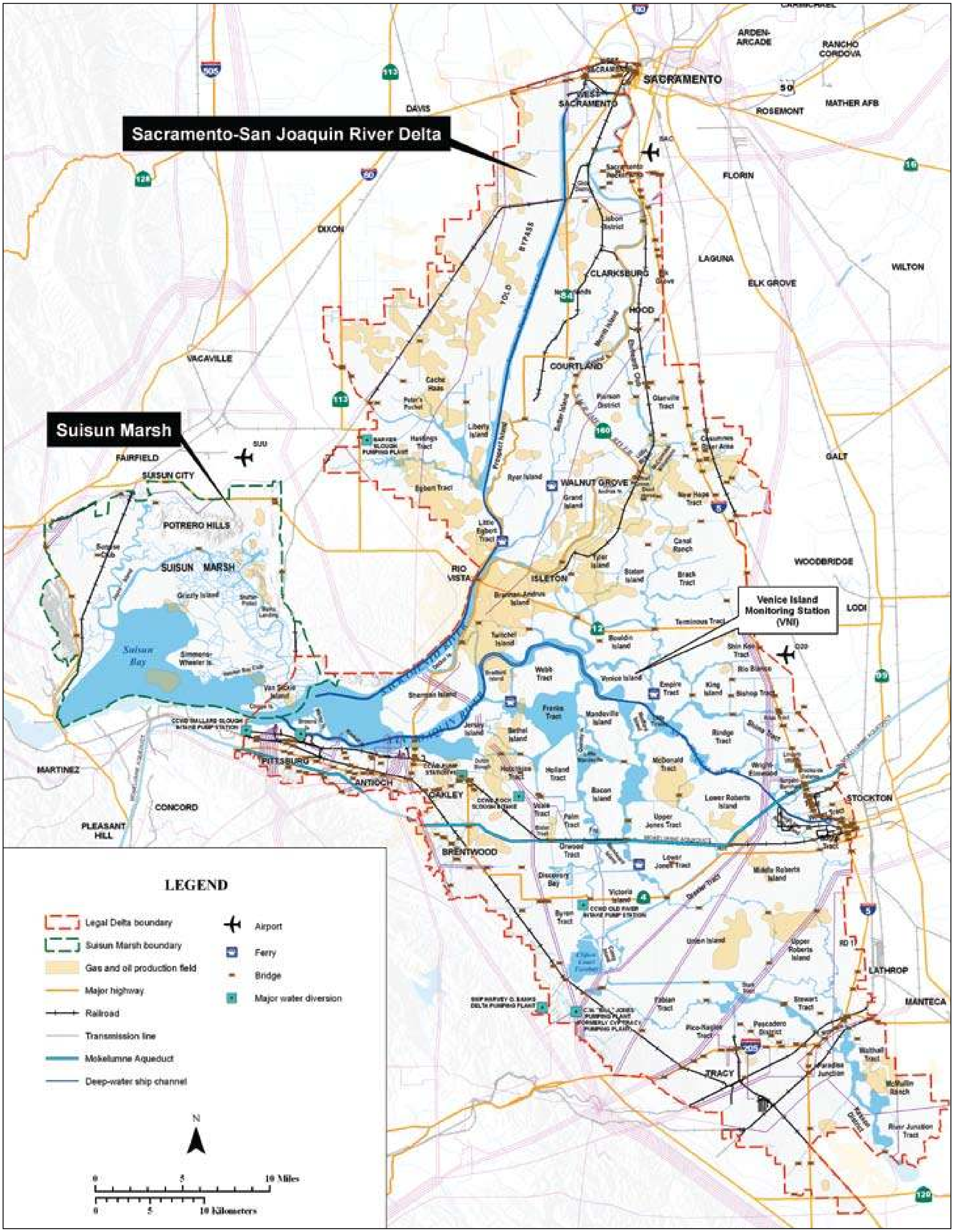


Figure 1 The Sacramento–San Joaquin River Delta and Suisun Marsh [the Delta Region]

Source: Adapted from Status and Trends Report [URS 2007]

INTRODUCTION

The Delta Region is a unique and valuable resource and is an integral part of California's water system.

The Delta Region is vital to California's economy and environment. The region contains highly fertile agricultural land and provides a unique estuarine habitat for many resident and migratory fish and birds, some of which are threatened or endangered. The Delta Region contains critical infrastructure including pipelines, state highways and power and communication lines. The region is the hub of the state's water supply system, which is critical to the state's economy.

Pictured above: Overlooking the Delta at dusk. Source: DWR

Earthquake damage – Sylmar [February 9, 1971]. Source: DWR

Much of the land in the Delta Region is below sea level and is protected by a fragile system of levees. Many of the region's 1330 miles of levees were built in the late 1800s and early 1900s without using modern engineering practices. The Delta Region's levees are critical for protecting the various assets, resources, uses and services that Californians obtain from the region.

A unique feature of the Delta Region is that much of its land is made up of highly organic soils, commonly referred to as "peat soils". Peat soils are very fertile and support an abundant agricultural harvest. Over time, agricultural practices have caused the land surface of Delta islands to subside. During the past century, subsidence has lowered the land surface of some Delta islands to as much as 25 feet below sea level, as shown in Figure 2. Land that is below sea level requires levees to hold back water 365 days a year.

Since 1900, levee failures during high water and during dry weather have caused Delta islands to be flooded a total of 158 times. Some islands have been flooded and recovered multiple times. A few islands, such as Franks Tract, have never been recovered. Franks Tract is located in the central Delta, as shown in Figure 1.

Levee failures have caused the flooding of Delta islands 158 times since 1900

Levee breaches at Tyler Island [1986].
Source: DWR

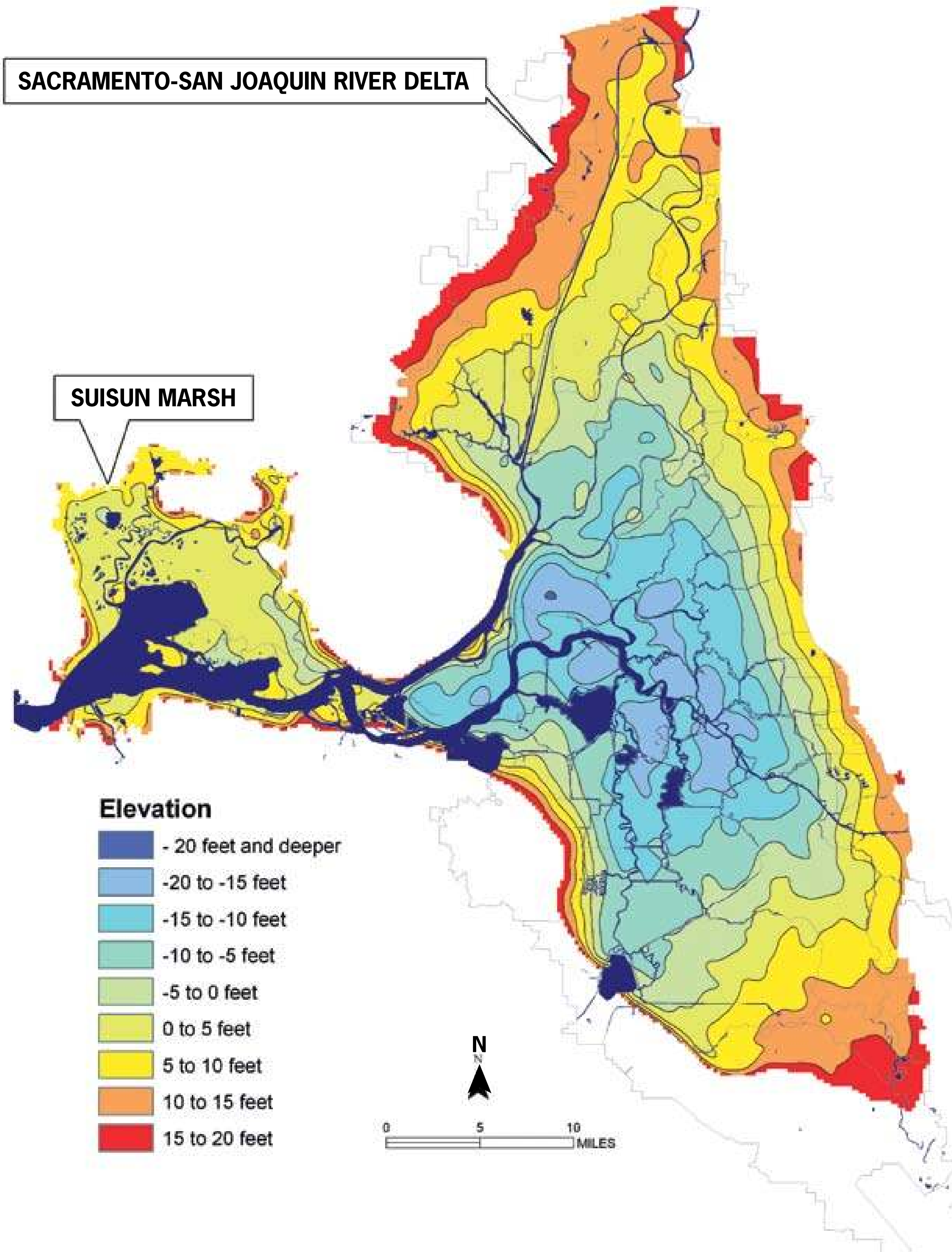


Figure 2 Surface elevation map of the Delta Region

Source: DRMS Risk Report [URS/JBA 2008c], Figure 5-14

Delta Region levees, in their current state and configuration, have not yet experienced a damaging earthquake. The risk of a major earthquake in the Delta Region is high. A major earthquake could cause multiple levee failures and several islands to be flooded simultaneously. If such an event occurs during a time of low-to-moderate fresh water inflow to the Delta from rivers and streams, saline water would move upstream into the Delta from Suisun Bay. Delta waters would then become salty and could not be used for in-Delta irrigation, local urban supplies [such as for the Contra Costa Water District] or State and federal water project exports. The Delta's ecosystem would also be impacted.

The following summary of the Phase 1 DRMS analysis provides estimates of the risks and consequences of levee failures.

The Delta Region has highly fertile agricultural land and provides a unique estuarine habitat for many resident and migratory fish and birds…

Great Blue Heron. Source: DWR

RISKS & CONSEQUENCES

Earthquakes, high water events, continued land subsidence and climate change pose risks to the Delta Region's levee system.

A massive failure of the Delta Region's levee system would have significant adverse effects on the Delta Region and California's economy. Levee failure risks evaluated in the DRMS analysis include seismic, high water and dry-weather levee failures.

Pictured above: Upper Jones Tract Failure [June 4, 2004].
Source: DWR

SEISMIC RISKS

Seismic risk in the Delta Region is characterized as moderate-to-high because of many active faults in the San Francisco Bay Area. Figure 3 illustrates the locations of faults in and near the San Francisco Bay Area and the Delta Region. As shown in Figure 4, area seismic activity during the last 100 years is significantly less than what was experienced during the 1800s and the first part of the 1900s. Seismic experts predict increased seismic activity in the future similar to that which occurred up to the first part of the 1900s.

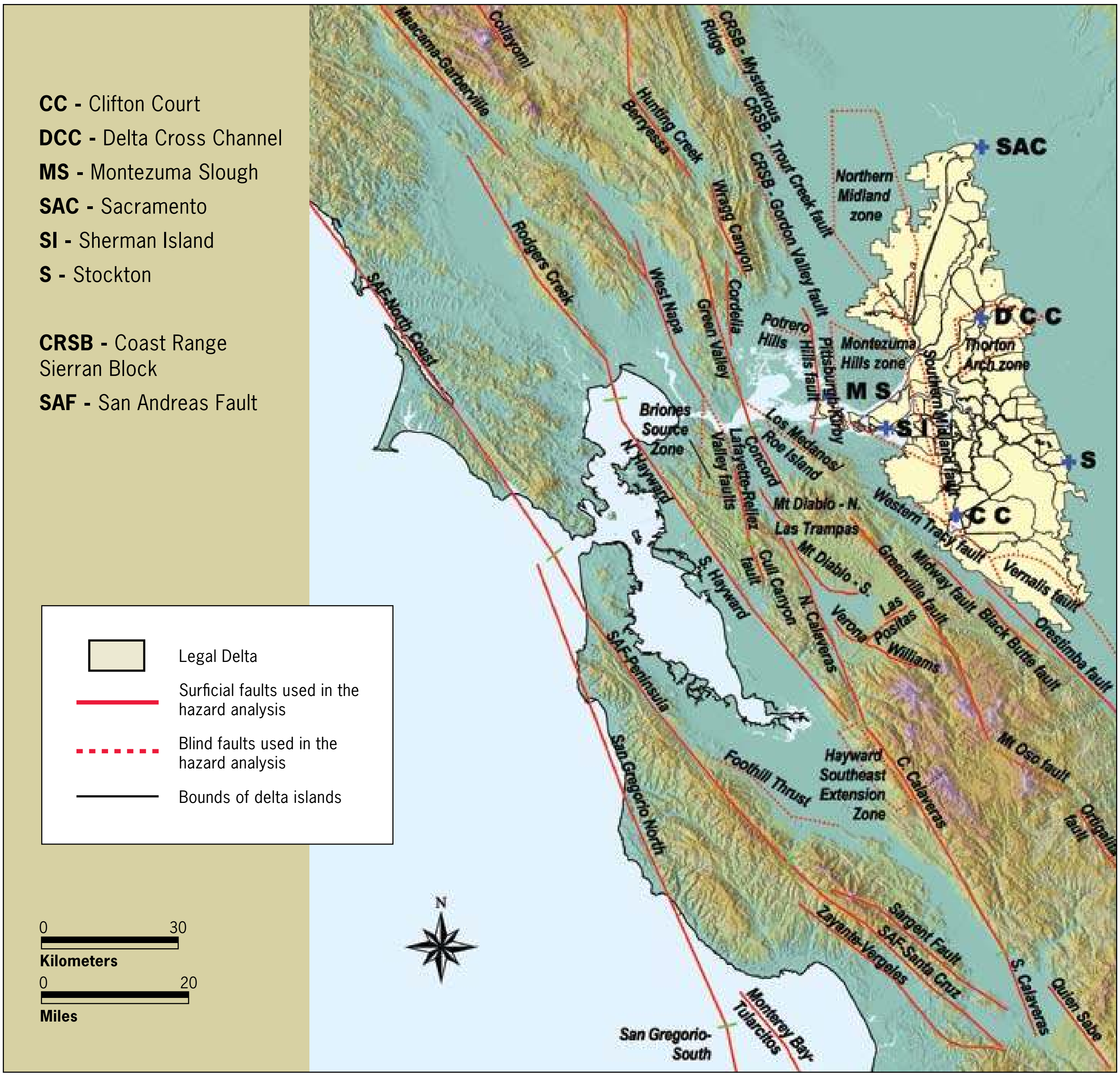


Figure 3 Faults and seismic sources in the vicinity of the Delta Region

Source: DRMS Risk Report [URS/JBA 2008c], Figure 6-1

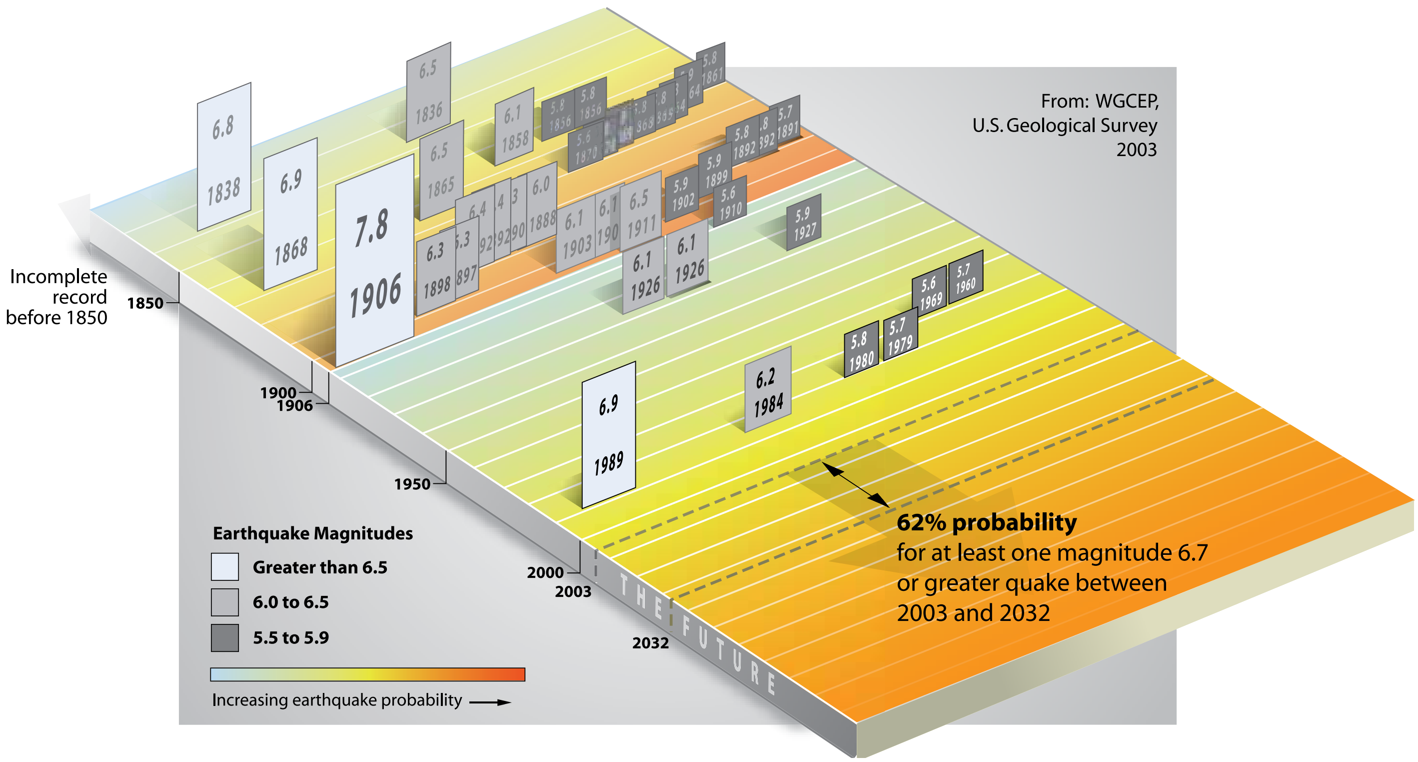


Figure 4 Past and future earthquakes in the San Francisco Bay Area and the Delta Region

Source: DRMS Risk Report [URS/JBA 2008c], Figure 13-8

The U.S. Geological Survey estimates that an earthquake of magnitude 6.7 or greater has a 62 percent probability of occurring in the San Francisco Bay Area between 2003 and 2032 [Figure 4]. Such an earthquake is capable of causing multiple levee failures in the Delta Region which could result in fatalities, extensive property damage and the interruption of water exports from the Delta for an extended period of time. Potential earthquakes on the Hayward, Calaveras or San Andreas faults pose the highest risk to Delta Region levees.

Probability of Multiple Levee Failures

A major earthquake can cause extensive damage to large sections of levees on multiple islands at the same time. As a result, many islands could be flooded simultaneously. For example, there is a 40 percent probability of a major earthquake causing 27 or more islands to flood at the same time in the 25-year period from 2005 to 2030, as shown in Figure 5.

Emergency Response and Levee Repair

The duration and cost of levee repairs increases with the number of islands that are flooded due to an earthquake, as shown in Table 1. This is not only due to the extensive amount of repairs required, but also to the availability of labor and materials to make the repairs.

Table 1 – DURATION AND COST OF REPAIRS
for earthquake-induced levee failures

Number of flooded islands	Estimated range of cost of repair and dewatering [$million]	Estimated range of time to repair breaches and dewater [days]
1	43 – 240	136 – 276
3	204 – 490	270 – 466
10	620 – 1,260	460 – 700
20	1,400 – 2,300	750 – 1,020
30	3,000 – 4,200	1,240 – 1,660

Source: DRMS Risk Report [URS/JBA 2008c], Table 13-9

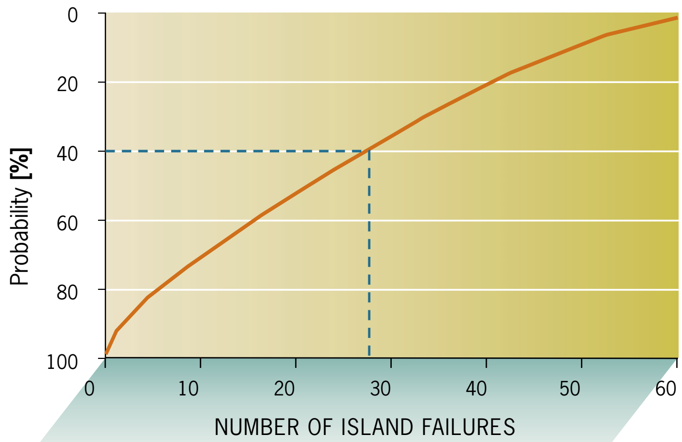


Figure 5 Probability of exceeding a number of simultaneous islands flooding due to earthquake events over a 25-year period [2005-2030]

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figure 13-4

Export Disruption

Earthquake damage to levees and to the islands they protect could take years to repair following a major earthquake. One significant impact of levee failures would be to the state's water supply. For example, if 20 islands were flooded as a result of a major earthquake, the export of fresh water from the Delta could be interrupted for about a year and a half. Water supply losses of up to 8 million acre-feet would be incurred by State and federal water contractors and local water districts. The area served by the Contra Costa Water District, an urban water supply agency in the vicinity of the Delta, is an example of an area at high economic risk from water supply disruption. The district's service area is particularly vulnerable to the loss of its Delta water supply since other sources of water are not readily available.

...emergency repairs for 20 flooded islands could cost up to

$2.3 billion

and take about three years.

North Walnut Grove Rd. Bridge between Tyler and Staten Islands [larger bridge]. Source: DWR

Economic Consequences

The total economic cost and impact of multiple levee failures due to a major earthquake in the Delta Region could be tens of billions of dollars. Figures 6a and 6b show the probability of economic costs and impacts from potential earthquakes during the 25-year period from 2005 through 2030. For example, there is a 40 percent probability of incurring $22 billion or more in costs [Figure 6a] and $3 billion or more in impacts [Figure 6b] in the period from 2005 through 2030.

Impacts to Water Quality

Though not specifically analyzed in the DRMS Project, it is reasonable to conclude that, if subsided Delta islands are flooded due to levee breaches, significant amounts of dissolved organic carbon [DOC] would be released into Delta waters from the highly organic peat soils on these islands. Disinfectants used during the drinking water treatment process react with DOC to produce disinfection byproducts in treated water. Many of these chemical byproducts can increase cancer risks or cause other health effects.

Other water quality problems resulting from island flooding include increased algae blooms. Algae blooms can complicate drinking water treatment processes and can adversely affect some aquatic species.

Some soils in the Delta Region contain moderate levels of mercury due, among other things, to historical gold mining activities that occurred upstream of the Delta during the Gold Rush. Mercury in soils can, under certain circumstances, be converted to the highly toxic methylated form when islands are flooded. Methylated mercury can accumulate in the food chain

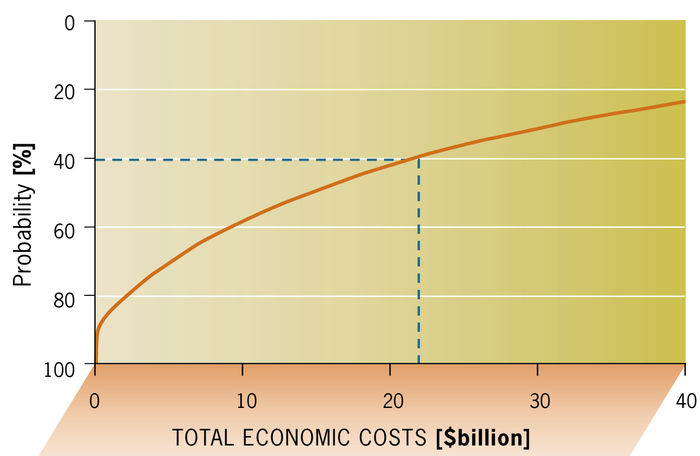


Figure 6a Probability of exceeding an amount in total economic costs due to earthquake events over a 25-year period [2005-2030]

Economic Costs *include the direct economic losses associated with the repair of levees, tracts, islands, and infrastructure; the replacement of lost homes and the payment of living expenses for displaced persons; agricultural losses; and the lost water supply to State and federal water contractors and local water districts.*

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figures 13-19a [costs] and 13-19b [impacts]

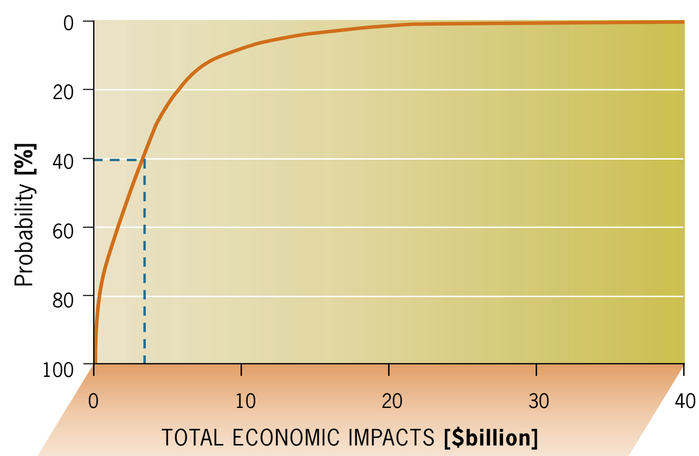


Figure 6b Probability of exceeding an amount in total economic impacts due to earthquake events over a 25-year period [2005-2030]

Economic Impacts *include the indirect economic losses associated with the loss of potential revenues because of services not provided. These include the loss of revenue that customers of Pacific Gas and Electric Company, Metropolitan Water District of Southern California, railroads and other service providers suffer because they lose the services these companies provide, combined with lost wages and jobs that result because consumers lose these services.*

Decker Island Habitat Restoration Project. Source: DWR

potentially affecting fish. Humans and animals that consume fish contaminated with methylated mercury are at risk of poisoning.

Ecosystem Consequences

Ecosystem impacts and consequences due to levee failure were not fully quantified in the DRMS Project. The main factors that influence ecosystem effects are the location and number of levee failures, time of year and water conditions. Potential ecosystem effects due to levee failures from high water, seismic or dry-weather levee failure events are expected to be similar.

IMPACTS TO AQUATIC SPECIES: Impacts to aquatic species were not quantified in the DRMS Project and require further study.

IMPACTS TO EXISTING VEGETATION: Most of the land in the Delta is used for agricultural purposes. However, areas of vegetation exist where land has not been cleared for agriculture or other uses. Riparian vegetation exists along many waterways in the Delta Region. Wetland vegetation occurs in areas where shallow water often exists, including areas where wetting occurs through tidal action. Upland vegetation is found in areas that remain dry most of the time.

Great Blue Heron. Source: DWR

The results of the DRMS Project suggest that large-scale levee breaches in the Suisun Marsh will cause substantial losses of available habitat, food shortages and the displacement of birds and other species.

In all seismic levee failure scenarios, the area of vegetation impacted increases with the area flooded. The degree of impact depends on the type of vegetation flooded. Results of the DRMS Project indicate potential losses of up to 39 percent of herbaceous wetland, seasonal grasses and low-lying vegetation, 29 percent of non-native trees, and 24 percent of shrub wetland due to an event where multiple islands are flooded.

IMPACTS TO TERRESTRIAL SPECIES: The failure of levees in Suisun Marsh could result in impacts on several terrestrial wildlife species of concern, including the federally-endangered saltmarsh harvest mouse and the California clapper rail. The results of the DRMS Project suggest that large-scale levee breaches will cause substantial losses of available habitat, food shortages and the displacement of birds and other species. However, ecosystem benefits could also result from increases in tidal water habitat.

Public Health and Safety Consequences

The Delta levees most likely to fail due to earthquakes are generally located in the central-west area of the Delta. Their failure will cause rapid flooding and leave little time for evacuation.

The greatest immediate public safety concern is for the people working and living on Delta islands, and for people traveling through the Delta on various roads and highways. Figure 7 shows the estimated loss of life resulting from an earthquake affecting the Delta Region. For example, there is a 40 percent probability of 90 or more fatalities in the Delta from levee failures due to a seismic event in the 25-year period from 2005 through 2030. The expected fatalities from earthquake-related island flooding is high due to the lack of warning for earthquakes and because of the rapid rate of flooding likely to occur after an earthquake.

Future Seismic Risk

Assuming a major earthquake does not occur in the Delta Region before 2050, the probability of earthquakes and the seismic vulnerability of levees in the Delta Region will continue to increase. The risk of levee failure in the Delta due to an earthquake will increase by 35 percent over the next 50 years and by 93 percent over the next 100 years. The risk of levee failure will increase even more significantly if a major earthquake does not occur by 2100.

The consequences of a major earthquake in the Delta Region will also increase with time. Because of increasing water demand and the state's growing population and economy, the economic consequences of an interruption in Delta water supply operations due to an earthquake will increase. Consequences to the Delta Region will also increase due to additional development. Total expected economic losses are anticipated to increase by about 200 percent by 2050 and by about 500 percent by 2100. The risk of fatalities is expected to increase, on average, by about 250 percent from 2005 to 2050.

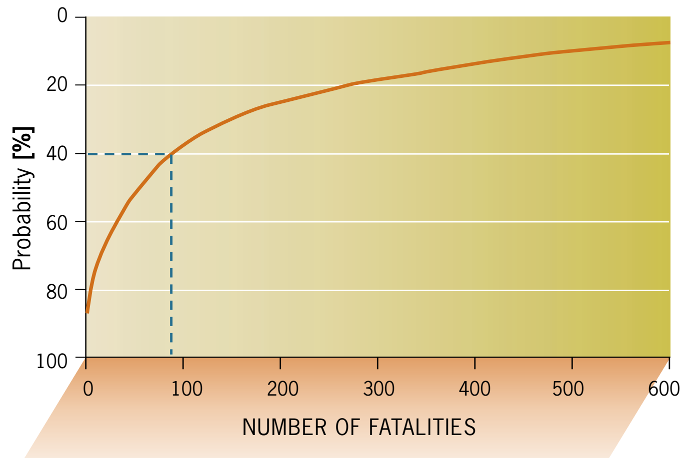
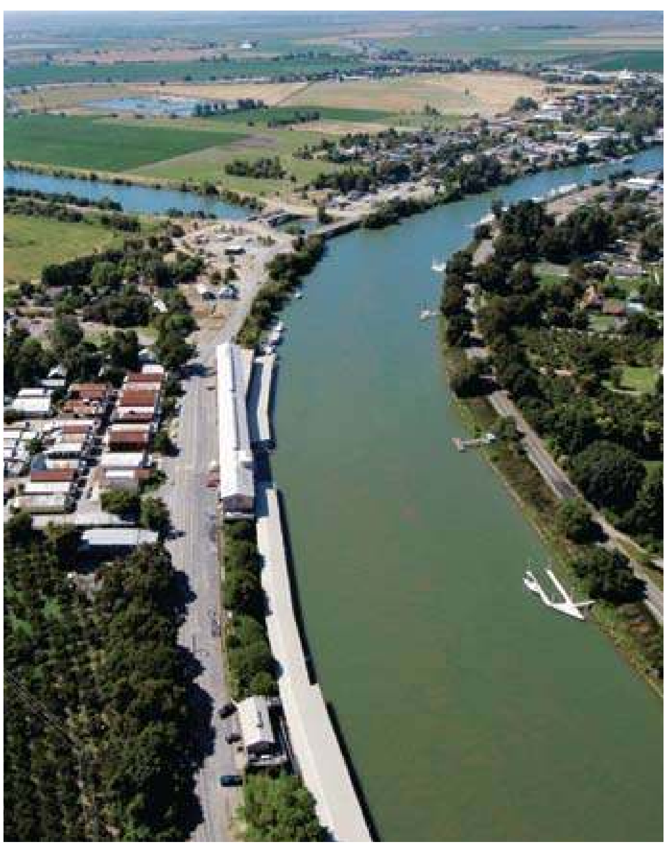


Figure 7 Probability of exceeding a number of fatalities due to earthquake-related levee failures over a 25-year period [2005-2030]

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figure 13-20



Sacramento River and Delta Cross Channel. Source: DWR

The risk of levee failure in the Delta due to an earthquake will increase by 35 percent over the next 50 years and by 93 percent over the next 100 years.

HIGH WATER RISKS

Although earthquakes pose the greatest single risk to Delta Region levees, winter storms and related high water conditions are also a serious risk. High water in the Delta Region can overtop levees. High water also increases the hydrostatic pressure on levees and their foundations, causing instability. The risk of through-levee and under-levee seepage failures increases as well.

Most levee failures in the Delta Region have occurred during winter storms and related high water conditions, often in conjunction with high tides and strong winds. Figure 8 shows measured and modeled [predicted] water surface elevations and ranges as a function of return periods at the Venice Island Monitoring Station. The location of the monitoring station is shown on Figure 1.

Considering the probability of all high water-related levee failures under current conditions and existing levee maintenance programs, about 140 levee failures are expected to occur in the Delta over the next 100 years [compared with 158 during the past 100 years]. This corresponds to an average rate of 1.4 levee failures per year.

Probability of Multiple Levee Failures

Depending on the severity of the high water conditions, tides, wind and other factors, multiple levees could fail during a single high water event. Figure 9 illustrates the probability of multiple islands being flooded due to high water conditions for the 25-year period from 2005 through 2030.

Flood damage – Delta [June 7, 2004]. Source: DWR

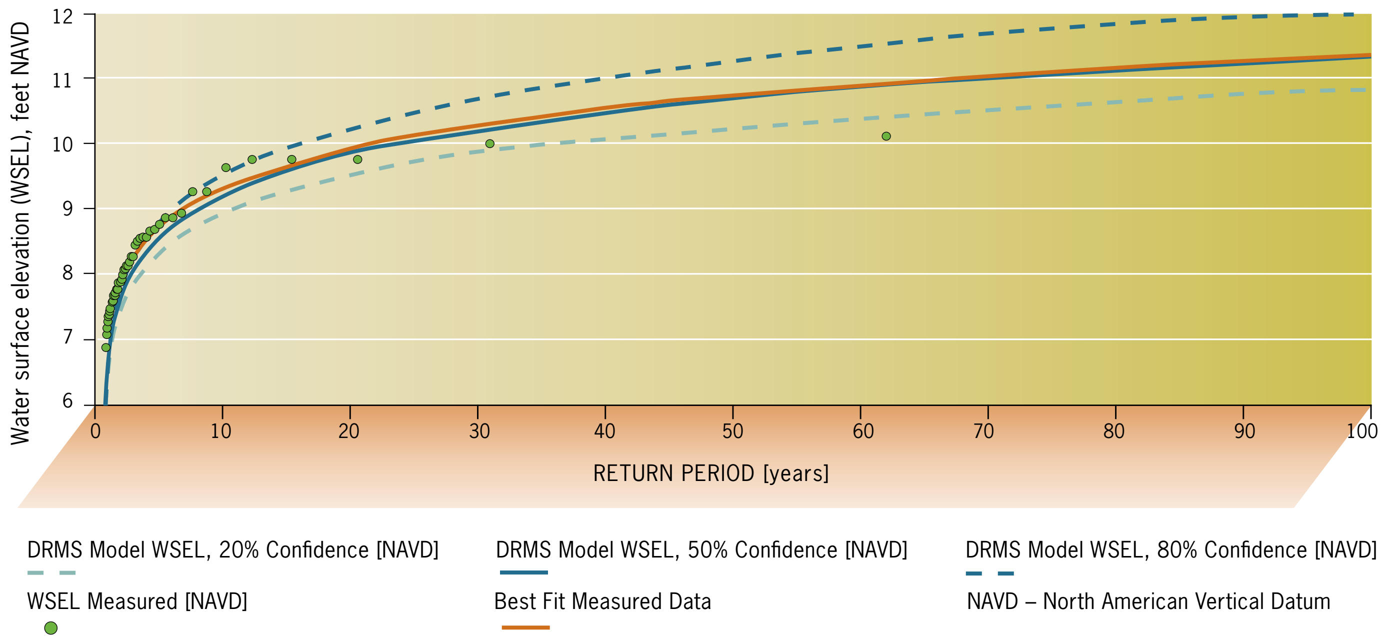


Figure 8 DRMS model predictions versus measured water-surface elevation – Venice Island Monitoring Station

Source: DRMS Flood Hazard TM [URS/JBA 2008a], Figure 7-1

Emergency Response and Levee Repair

The duration and cost of repairs due to high water-related levee failures is listed in Table 2. The cost of levee repairs is generally less for high water conditions than that predicted for earthquakes. This is because high water-related levee failures tend to be more localized and much smaller than those expected for seismically-related failures. The duration of island repair and dewatering efforts for high water-related levee failures are generally similar to earthquake-related failures for a given number of flooded islands.

Export Disruption

High water-related levee failures pose less risk to water supplies than failures from earthquakes. The Delta would likely be receiving large volumes of fresh water inflow from upstream when high water-related levee failures occur. As long as levee breaches are managed appropriately, and repairs are completed when fresh water inflows into the Delta are still relatively high, no long-term water supply export disruptions should occur. Also, the size and number of levee failures due to high water events are expected to be less than earthquake-related failures. With fewer and smaller failures, repairs would take less time.

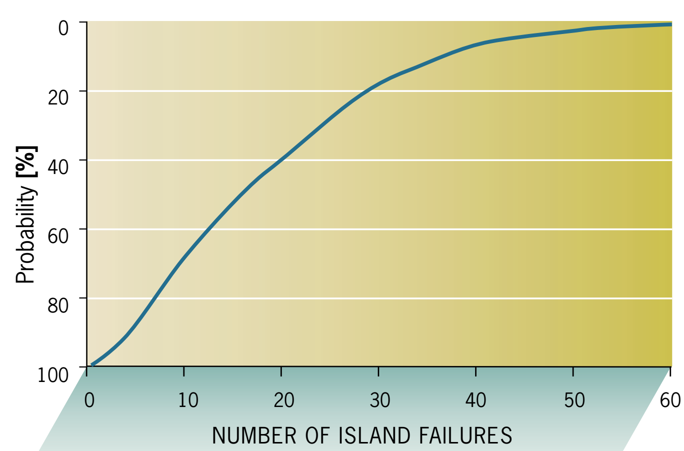


Figure 9 Probability of exceeding a number of simultaneous islands flooding due to high water conditions over a 25-year period [2005-2030]

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figure 13-11

Table 2 – DURATION AND COST OF REPAIRS for high water-related levee failures		
Number of flooded islands	Estimated range of cost of repair and dewatering [$million]	Estimated range of time to repair breaches and dewater [days]
1	30 – 110	47 – 170
3	140 – 260	240 – 450
10	490 – 680	590 – 1,060
20	990 – 1,200	930 – 1,110
30	1,500 – 1,800	1,380 – 1,580

Source: DRMS Risk Report [URS/JBA 2008c], Table 13-26

Economic Consequences

Figures 10a and 10b show the probability of economic costs and impacts due to high water-related levee failures over the next 25 years from 2005 though 2030. Levee failures from high water events are generally predicted to result in lower economic **costs** than levee failures from seismic events. In the case of economic **impacts**, levee failures from either high water events or seismic events carry similar impacts for exceedance probabilities greater than about 40%. However, when exceedance probabilities are less than 40%, these economic impacts tend to be larger for failures from high water events.

Impacts to Water Quality

Impacts to water quality from high water-related levee failures are expected to be less than from a major earthquake. Salt, DOC and methylated mercury concentrations during and after high water-related levee failures are expected to be lower because of greater freshwater inflows.

Ecosystem Consequences

Impacts to aquatic species, vegetation and terrestrial species from multiple high water-related levee failures are expected to be similar to impacts that would be experienced from a major earthquake.

Public Health and Safety Consequences

The primary public safety concern from high water-related levee failures is for the people living and working on Delta islands, and for people traveling through the Delta on roads and highways. Figure 11 presents estimates of the probability of fatalities due to high water-related levee failures. For example, there is about a 40 percent probability of 80 fatalities or more in the Delta Region from levee failures due to a high water event during the 25-year period from 2005 to 2030.

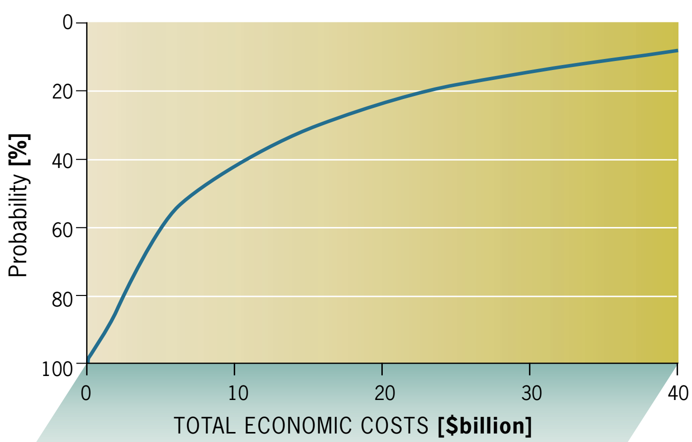


Figure 10a Probability of exceeding an amount in total economic costs due to high water-related levee failures over a 25-year period [2005-2030]

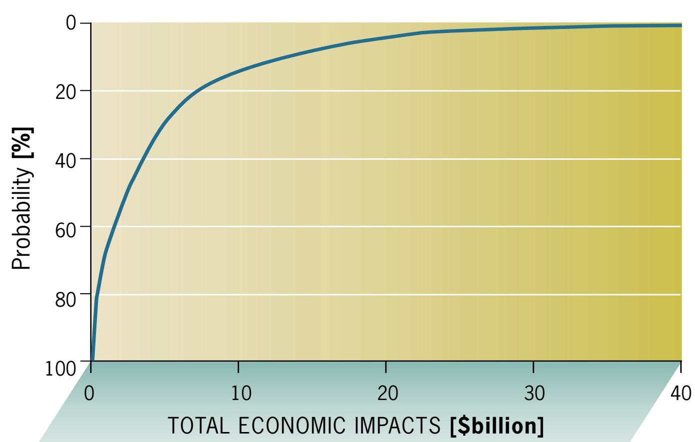


Figure 10b Probability of exceeding an amount in total economic impacts due to high water-related levee failures over a 25-year period [2005-2030]

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figures 13-21a [costs] and 13-21b [impacts]

Some densely populated areas, such as the Sacramento Pocket Area and West Sacramento, are especially at risk of fatalities.

Future High Water Risks

Under business-as-usual practices, climate change will cause more frequent high water conditions in the Delta [and increase the risk of related levee failure] due to more winter precipitation falling as rain rather than snow. Sea level rise will also increase the probability of levee failure. The continued deterioration of the Delta's levees further increases levee failure risk.

The consequences of high water-related levee failure in the Delta Region will increase with time due to increased population and development.

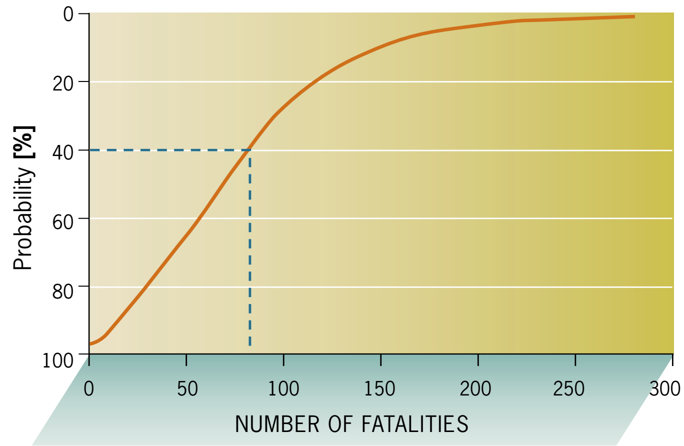


Figure 11 Probability of exceeding a number of fatalities due to high water-related levee failures over a 25-year period [2005-2030]

Source: Adapted from DRMS Risk Report [URS/JBA 2008c], Figure 13-22

Pictured above: Protecting the land side of a levee on a flooded island [Upper Jones Tract, 2004].
Source: DWR

Sandbags temporarily control a sand boil on Staten Island on June 18, 2007. The muddy water indicates that material in the levee or its foundation is being washed away. Unnoticed, sand boils can lead to a failure of the levee.
Source: DWR

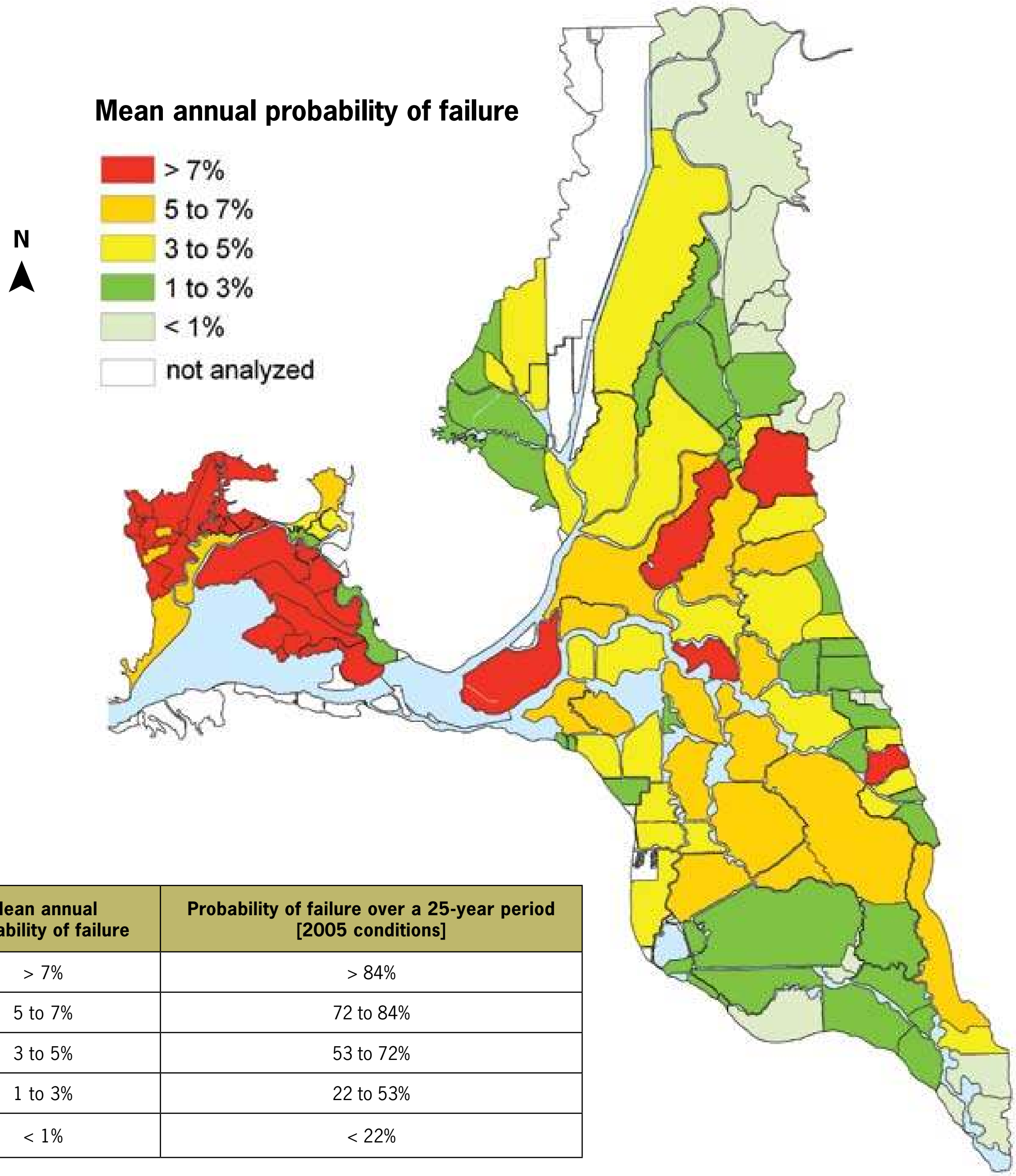
DRY-WEATHER RISKS

Dry-weather levee failures, also known as sunny-day events, occur occasionally in the Delta Region. Individual failures can be attributed to factors such as burrowing animals, pre-existing weaknesses in levees and their foundations, slow deterioration of levees over time and other circumstances. High astronomical tides can also be a factor in dry-weather levee failures. The most recent example of a dry-weather failure is the June 2004 Upper Jones Tract levee breach. The total cost of damages and island recovery efforts was well over $50 million.

Historical levee failures were used as the model to estimate the future rate of dry-weather levee failures in the Delta Region. Under business-as-usual practices, the Delta is expected to have about 10 dry-weather levee failures during a 100-year period. The Suisun Marsh is expected to have approximately four dry-weather levee failures during the same period.

COMBINED RISKS

The combined risk of an individual island being flooded due to earthquakes, high water and dry-weather events can be estimated. Considering the probability of levee failures from all hazards under business-as-usual practices, the expected annual probability of island flooding is illustrated in Figure 12. This figure shows that islands in Suisun Marsh and the western and central Delta are the most vulnerable.



Mean annual probability of failure	Probability of failure over a 25-year period [2005 conditions]
> 7%	> 84%
5 to 7%	72 to 84%
3 to 5%	53 to 72%
1 to 3%	22 to 53%
< 1%	< 22%

Figure 12 Mean annual probability of levee failure in the Delta Region from the combined risk of earthquakes, high water and dry-weather failures [2005 conditions]

Source: DRMS Risk Report [URS/JBA 2008c], Figure 13-16

NEXT STEP

Phase 2 of the DRMS Project will evaluate long-term risk-reduction options for Delta and Suisun Marsh levees. It will not propose a new plan for the Delta Region; rather, Phase 2 will describe a discrete set of actions that can be taken to reduce the risks and consequences of levee failures. Phase 2 is expected to be available for public review in 2009.

More information on the DRMS Project can be found on the DRMS Web portal, http://www.water.ca.gov/floodmgmt/dsmo/sab/drmsp, part of the California Department of Water Resources' Web site.

Pictured above: Bridge on the Sacramento River, near Courtland. Source: DWR

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EXHIBIT G
TO BRADNER
DECLARATION

Benefit-Cost Analysis of the Delta Conveyance Project

Prepared by David Sunding, Ph.D.

and Oliver Browne, Ph.D.

May 16, 2024

BRG
Berkeley Research Group

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Executive Summary

This report presents the results of a benefit-cost analysis for the Delta Conveyance Project (DCP), a plan to modernize the State Water Project (SWP)'s conveyance infrastructure in the Sacramento-San Joaquin River Delta (Delta). The SWP plays a crucial role in supplying water resources to 27 million Californians. Businesses in the area served by the SWP produce $2.3 trillion in goods and services annually, making it the world's eighth-largest economy. The SWP delivers an average of 2.56 million acre-feet of water annually to urban and agricultural customers in the Bay Area, Central Valley, Central Coast, and Southern California. However, by 2070, climate change and sea-level rise are expected to reduce SWP deliveries by approximately 22%, or 546 thousand acre-feet per year (TAF/yr). In addition, the SWP faces an ongoing risk of service disruptions following seismic events near the Delta; these events could cause outages and reduce the quality of water exports from the SWP south of the Delta.

The DCP's intended purposes are to mitigate climate and seismic risks for the SWP and provide water managers with additional operational flexibility in the Delta. The DCP would add new intake facilities in the North Delta to divert water from the Sacramento River and a tunnel to convey water to the South Delta for export to the SWP's urban and agricultural customers. The DCP would increase SWP deliveries by approximately 17%, or 403 TAF/yr, largely offsetting the anticipated reduction in water deliveries due to climate change. The DCP would also be less vulnerable to earthquakes near the Delta, meaning that SWP supplies could continue largely uninterrupted following seismic events.

A benefit-cost analysis is a rigorous method for evaluating the economic viability of a project—specifically, by forecasting a project's expected future benefits and costs. The present value of future benefits and future costs is calculated relative to a no-project alternative. Present values are calculated using real discount rates that reflect the time-value of money. As detailed in recent federal guidance (OMB Circular A-94), we adopt a real discount rate that starts at 2% in 2020, reflecting current inflation-adjusted Treasury bond rates, and gradually decreases to 1.4% by 2140 to reflect long-run uncertainties. The benefit-cost ratio is calculated by dividing the present value of future benefits by the present value of future costs. As discussed later in this report, for the DCP, we calculate a benefit-cost ratio of 2.20 and show that this ratio is robust with respect to a number of alternative assumptions regarding climate change, sea-level rise, SWP operations, and project costs. The approach to benefit-cost analysis taken in this report is consistent with the approaches described in the Department of Water Resources (DWR) Economic Analysis Guidebook and with State of California and federal guidelines for economic analysis of water resource–related investments.

The benefits and costs of the DCP are estimated in the context of forecast changes in water supply and demand. Climate change and sea-level rise are expected to significantly reduce future SWP deliveries. Future precipitation and runoff are forecast using an ensemble of climate scenarios selected by DWR's Climate Change Technical Advisory Group. Then, project deliveries are simulated using CalSim 3, a resource planning model that simulates operations of the SWP and Central Valley Project (CVP) under different hydrologic conditions. The project timeline, based on DWR's most recent expectations, involves preconstruction from 2026 to 2028, construction from 2029 to 2044, and an evaluation of economic benefits for a century of operations from 2045 to 2145.

Benefits of the DCP

This report quantifies the benefits of the DCP in four areas: urban water supply reliability, agricultural water supply, water quality, and seismic reliability.

1) ***Urban water supply reliability***

The primary benefit of the DCP is that it would reduce the anticipated increase in the frequency of water supply shortages for SWP's urban contractors caused by climate change and sea-level rise. The frequency and size of future water supply shortages are assessed using information provided by State Water Contractors, as described in their respective urban water management plans (UWMPs) or, for the Metropolitan Water District, in the Integrated Resource Plan (IRP). These models are used to estimate the frequency and magnitude of shortages for each contractor, with and without the project and under various future climate assumptions. This approach to estimating water supply reliability is consistent with the Delta Independent Science Board's 2020 review of approaches to water supply reliability estimation.[1]

The economic impact of future water shortages for urban customers is estimated using economic models that measure consumer welfare, a measure of well-being for urban water customers resulting from the reliability of their urban water supply loss. The estimates of consumer welfare loss use a standard model from the academic literature.[2] Calibration of this model is based on retail water rates and utility-specific estimates of customer demand sensitivity. Over the project's lifetime, the present value of improved water supply reliability (i.e., the DCP's ability to mitigate the effects of forecast climate change and sea-level rise) is estimated to be worth more than $33.3 billion in 2023 dollars.

---

[1] Delta Independent Science Board. 2016. *Review of Water Supply Reliability Estimation Related to the Sacramento-San Joaquin Delta*. Report to the Delta Stewardship Council. June. Sacramento, CA. Available: https://deltacouncil.ca.gov/pdf/isb/products/2022-06-16-isb-water-supply-reliability-review.pdf.

[2] See, for example, Brozovic et al. 2007, Buck et al. 2016, or Buck et al. 2023 for examples of this approach.

Buck, S., M. Auffhammer, S. Hamilton, and D. Sunding. 2016. Measuring Welfare Losses from Urban Water Supply Disruptions. In *Journal of the Association of Environmental and Resource Economists*, 3(3), 743–778.

Buck, Steven, Mehdi Nemati, and David Sunding. Consumer Welfare Consequences of the California Drought Conservation Mandate. In *Applied Economic Perspectives and Policy,* 45, No. 1 (2023):510–533.

2) Agricultural water supply

The benefits of improved agricultural water supply reliability are estimated using two approaches. First, a willingness-to-pay approach is used, based on the Statewide Agricultural Production (SWAP) model, a regional model of irrigated agricultural production in California's Central Valley developed by researchers at the University of California, Davis that simulates the economic decisions of farmers. This estimate reflects the long-term value of water to agricultural customers in the Central Valley. Second, we use a market-based approach, valuing the incremental water supplies produced by the DCP at average market prices, as measured by the Nasdaq Veles California Water Index. This estimate reflects the ability of farmers to extract additional value by selling water to other urban or agricultural users during short-term periods of scarcity. Averaging estimated benefits across these two approaches, the present value of the DCP's future agricultural water supply benefits is $2.3 billion in 2023 dollars.

3) Water quality

The DCP is expected to lead to a modest improvement in the average quality of water exported south of the Delta. The benefits of improved water quality in the urban sector are estimated using the Salinity Economic Impact Model (SEIM) developed by the U.S. Geological Survey (USGS). The present value of benefits from improved urban water quality in Southern California is worth $1.33 billion in 2023 dollars. The benefits of improved water quality in the agricultural sector of the San Joaquin Valley and Southern California are estimated using models that calculate the value of a reduced yield impact and irrigation water requirements due to reduced salinity in the agricultural water supply. The present value of improved agricultural water quality is expected to be around $0.09 billion in 2023 dollars.

Anticipated operation of the DCP would lead to changes in salinity in the Delta; the impacts of these changes are assessed as being "less than significant" in the project's environmental impact report (EIR); however, costs associated with potential increased Delta salinity are accounted for under the costs of remaining environmental impacts after mitigation. Overall, the benefits of improved salinity for downstream agricultural water contractors significantly outweigh the cost of the small increase in salinity in the Delta region. The project would also provide additional operational flexibility to help SWP operations adapt to water regulations in the Delta, the benefits of which are not explicitly quantified in this report.

4) Seismic reliability

The project would also provide significant economic benefits by acting as an insurance policy against the risk of water supply interruptions during a major seismic event in the San Francisco Bay or Delta region. The DCP's benefits in terms of improved seismic reliability are estimated using a seismic scenario described in the Delta Flood Emergency Management Plan (DFEMP). This scenario describes a 500-year seismic event that causes up to 50 levee breaches in the Delta, flooding 20 islands. Under the recovery scenario that we consider for such an event, exports from the Delta are expected to cease for between six and 448 days. After that period, exports resume but with impaired water quality for between five to 103 additional days. The DCP is engineered to withstand such an event and remain operational. The benefits of continued water deliveries during such an event are estimated by assuming that either the DCP operates at capacity for the duration of the seismic impacts or that it operates at a minimum level to meet health and safety requirements. Depending on the specific scenario, the benefits of DCP operations during the seismic event range from $60 million to $53 billion. Averaging across the scenarios considered and accounting for the annual likelihood of such an event, we estimate the present value of seismic benefits from DCP operations to be around $1 billion in 2023 dollars.

We estimate total benefits with a present value of $33.8 billion. Some benefits of the DCP are not explicitly quantified in this report. For example, this report does not quantify the project's benefits in terms of increased operational flexibility in the Delta or the benefits associated with the Community Benefits Program, which will invest in local communities. The DCP is also expected to relieve pressure on groundwater supplies in the Central Valley and increase the average storage levels of the state's major reservoirs, the impacts of which are not quantified in this report.

Costs of the DCP

In addition to considering benefits, this report quantifies the costs associated with construction of the DCP. Three types of costs are considered in this report: the project costs associated with development and construction of the project, the operations and maintenance (O&M) costs associated with operating the project over its 100-year lifespan, and the costs associated with any remaining environmental impacts after mitigation.

1) Construction costs and related expenditures

The Delta Conveyance Design and Construction Authority (DCA) produced two cost estimates for the DCP. The primary cost estimate reflects the project's current specifications, as detailed in the EIR, estimated at $20.1 billion before discounting. In addition, a secondary estimate, referred to as the "project-wide innovations and savings estimate," evaluates the financial impact of potential design modifications and construction innovations. These innovations aim to enhance cost efficiency and feasibility without changing core project specifications, potentially reducing costs and construction timelines while minimizing environmental impacts. Before discounting, the secondary estimate stands at $18.9 billion.

After applying discount rates, the present value of the primary and secondary estimates is $15.4 billion and $14.5 billion, respectively. These figures are based on 2023 dollars and include various cost components:

- **Construction costs** for the intakes, tunnels, pumping plants, and other infrastructure, including a 30% contingency, worth $11.5 billion or $10.7 billion in present-value terms for the primary and secondary estimates, respectively.
- **Other project costs** include those associated with planning, design, construction management, land acquisition, and power use as well as the cost of a settlement agreement with the Contra Costa Water District, worth $3.0 billion or $2.9 billion in present-value terms for the primary and secondary estimates, respectively.

- **Costs for** a **community benefits program,** worth $200 million undiscounted or $153 million in present-value terms.
- **Costs for the mitigation of environmental impacts** identified in the EIR, worth $960 million undiscounted or $735 million in present-value terms. Expected environmental impacts and approaches to mitigation are identified in the project's EIR.

2) Operations and maintenance costs

Projected O&M costs for the DCP are detailed in a memorandum authored by the DWR and the DCA.[3] This cost forecast included facility O&M, materials, power, capital equipment replacement and refurbishment, and the management of project restoration sites. In 2023 dollars, estimated annual O&M costs are $52.6 million, amounting to a present value of $1.7 billion over the project's 100-year operational span from 2040 to 2140.

3) Remaining environmental impacts after mitigation.

Most environmental impacts identified as significant in the EIR can be mitigated to levels where they are considered less than significant after mitigation. However, some environmental impacts identified in the EIR are anticipated to have significant and unavoidable impacts after the implementation of proposed mitigation measures. In an appendix to this report, each significant and unavoidable impact is considered, and where appropriate, economic tools are used to estimate the economic costs associated with these impacts. Our assessment also estimates costs associated with an increase in Delta salinity, included despite being "less-than-significant" impacts in the EIR, in order to provide a complete account of all salinity-related impacts alongside the previously discussed water quality benefits. The costs of environmental impacts that remain significant after mitigation are calculated in the following areas:

- Lost agricultural land
- Air quality impacts
- Noise impacts
- Transportation impacts
- Reduced water quality in the Delta

The costs of other impacts—specifically, in terms of aesthetic and visual resources, paleontological resources, and tribal cultural resources—are not estimated because there is no appropriate economic methodology to do so. For the impacts that are quantified, the present value of future costs is $167 million in 2023 dollars. These impacts may disproportionately affect specific populations adjacent to the construction project.

[3] California Department of Water Resources. 2024. *O&M Annual Cost Estimate Basis for Bethany Reservoir Alternative*. April.

Benefit-Cost Ratios and Sensitivity Analyses

Table 1 summarizes the primary DCP benefit-cost estimate. We estimate the present value of the benefits of the DCP to be $37.96 billion in 2023 dollars, and we estimate the present value of the costs of constructing and operating the DCP to be $17.26 billion in 2023 dollars. Based on these estimates, we find the proposed DCP project has a benefit-cost ratio of 2.20. Under the cost estimate with project-wide innovations and savings, the benefit-cost ratio is higher, at 2.33.

Table 1 also shows estimates per acre-foot of the benefits and costs of the DCP. These estimates per acre-foot are calculated using a levelized cost-of-water approach that accounts for the timing of future SWP deliveries.[4] Based on this approach, we estimate levelized benefits of $2,918 per acre-foot, along with levelized costs of $1,327 per acre-foot and $1,255 per acre-foot, respectively, in the primary and secondary cost estimates.

The primary benefit-cost analysis shown in Table 1 is referred to as the 2070 median scenario with 1.8 feet of sea-level rise. This scenario considers changes in precipitation and runoff from a median climate change projection, based on an ensemble of global climate models for the period 2056–2085.[5] The primary scenario assumes 1.8 feet of sea-level rise by 2070, based on guidance from the California Ocean Protection Council for the likely range of sea-level rise under a high emissions scenario.[6] To test the robustness of the estimated benefit-cost ratio to these assumptions, a number of sensitivity analyses are also considered that make alternative assumptions in terms of future precipitation and runoff, sea-level rise, and adaptation measures to reduce operational risks associated with climate change. Across all the sensitivity analyses considered, the incremental deliveries of the proposed project are at least 395 TAF/yr on average, highlighting that the proposed project is robust to different assumptions about climate change and sea-level rise. In each of these sensitivity scenarios, the benefits of the project significantly exceed costs with benefit-cost ratios between 1.54 and 2.69.

---

4 Levelized cost of water is calculated with the formula $LCOW = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+r_t)^t}}{\sum_{t=1}^{n} \frac{Q_t}{(1+r_t)^t}}$ where C_t is the cost associated with the DCP at time t, Q_t is the volume of additional SWP deliveries as a result of the DCP at time t, and r_t is the discount rate at time t. This methodology is described in more detail here:
Fane, Simon, J. Robinson, and S. White. The Use of Levelized Cost in Comparing Supply and Demand-Side Options. In *Water Science and Technology: Water Supply,* 3, No. 3 (2003):185–192.

5 See California Department of Water Resources "CalSim 3 Results for 2070 Climate Change and Sea-Level Projections and Sensitivity Analysis."

6 See California Ocean Protection Council. 2018. *State of California Sea-Level Rise Guidance: 2018 Update*. Sacramento: CA.

Table 1: Summary of Benefits and Costs

	Main Scenario	
	Primary Cost Estimate	**Costs w. Project-wide Innovations & Savings**
	Present Value of Future Benefits	
	$ Millions, 2023	$ Millions, 2023
Urban Water Supply and Reliability	$33,300	$33,300
Agricultural Water Supply and Reliability	$2,268	$2,268
Urban Water Quality	$1,330	$1,330
Agricultural Water Quality	$90	$90
Seismic Reliability Benefits (Water Supply)	$969	$969
Seismic Reliability Benefits (Water Quality)	$2	$2
Total Benefits	**$37,960**	**$37,960**
	Present Value of Future Costs	
	$ Millions, 2023	$ Millions, 2023
Construction Costs	$11,486	$10,723
Other Project Costs	$3,021	$2,852
Community Benefit Program	$153	$153
Environmental Mitigation	$735	$735
O&M Costs	$1,697	$1,697
Environmental Impacts after Mitigation	$167	$167
Total Costs	**$17,259**	**$16,327**
Levelized cost per AF	*$1,327*	*$1,255*
Benefit-Cost Ratio	**2.20**	**2.33**

Sources and Notes:

- Construction Costs include 30% contingency.
- Other Project Costs include project design, management, oversite, land, power, and Contra Costa Water District Settlement Agreement cost shares.
- Benefits and costs evaluated under the 2070 median climate scenario with 1.8 feet of sea-level rise. All benefits and costs are net present values in millions of 2023 dollars.
- A declining discount rate of 2% (2023–2079), 1.9% (2080–2094), 1.8% (2095–2105), 1.7% (2106–2115), 1.6% (2116–2125), 1.5% (2127–2134), 1.4% (2135–2140) is used in accordance with Office of Management and Budget guidance.

1. Introduction

1.1. BACKGROUND ON DELTA CONVEYANCE

The Sacramento-San Joaquin River Delta (Delta) is an expansive network of waterways in Northern California at the confluence of the Sacramento and San Joaquin Rivers. The Delta serves as a critical junction for the distribution of water from the wetter northern and eastern parts of the state to the drier coastal and southern regions through two major water conveyance projects: the State Water Project (SWP) and the Central Valley Project (CVP).[7] Water conveyed south through the SWP is used to supply residential, agricultural, commercial, and industrial customers in California, including in the South of the San Francisco Bay Area, in the Central Valley, in the Central Coast, and in Southern California. The SWP supports a service area that includes 27 million people with a gross domestic product (GDP) equivalent to the world's eighth-largest economy ($2.3 trillion). Within this service area, the SWP currently deliveries approximately 2.56 million acre-feet of water annually to urban and agricultural customers. However, the SWP infrastructure that moves this water through the Delta is outdated and at risk due to climate change, sea-level rise, and seismic activity. Climate change and sea-level rise are expected to reduce SWP water deliveries by about 22% by 2070. Rising sea levels threaten to increase saltwater intrusion, which can compromise local ecosystems and the quality of water available for export. Furthermore, climate change is expected to bring more extreme weather patterns, including both severe droughts and intense storms. This unpredictability adds stress to existing ecological constraints on storage and conveyance, potentially reducing future deliveries and making their timing more uncertain. Furthermore, the Delta's systems of aging levees, some of which date back to the gold rush era, are vulnerable to failure. A major seismic event in the Delta could lead to numerous levee failures, significantly compromising the conveyance system in the area. This would pose a direct risk to water supply and water quality throughout the region.

The construction of additional conveyance infrastructure in the Delta has been extensively studied in a number of different proposals over several decades. The Department of Water Resources' (DWR's) 1957 California Water Plan suggested a "Trans-Delta System" to convey water; a peripheral canal was part of the original proposal for the SWP. During the 1980s, Governor Brown passed legislation providing for the addition of a peripheral canal in the Delta as part of the CVP. This proposal was extensively studied; however, the legislation was subsequently repealed in a voter referendum in 1982.

[7] The SWP is a complex system of reservoirs, aqueducts, power plants, and pumping stations. It supplies water to more than 27 million people and irrigates about 750,000 acres of farmland. Planned, built, operated, and maintained by DWR, the SWP is the nation's largest State-owned water and power generator and user-financed water system.
The CVP, managed by the Federal Bureau of Reclamation, serves primarily agricultural users in California's Central Valley. It includes 20 dams and reservoirs, 11 power plants, and 500 miles of major canals, playing a critical role in the region's agricultural productivity.

In 2009, the Bay Delta Conservation Plan proposed by Governor Schwarzenegger studied alternative Delta conveyance facilities, including twin tunnels with a capacity of 9,000 cubic feet per second. A modified version of this proposal, called Cal WaterFix, was proposed in 2015 during Governor Brown's third term. The current Delta Conveyance Project (DCP) proposal considers a single tunnel with a capacity of 6,000 cubic feet per second, along with a new route close to Interstate 5 and a connection to Bethany Reservoir on the California Aqueduct. Authors of this report have been involved in economic analyses for each of these proposals since 2009. Each analysis has used similar methodologies and has consistently found that the benefits of the proposed project exceed its costs, with comparable results in terms of estimated economic benefits.[8]

1.2. THE PURPOSE OF THE DELTA CONVEYANCE PROJECT

The purpose and objectives of the proposed DCP are described in Chapter 2 of the project's environmental impact report (EIR).[9] The purpose of the DCP is to develop new diversion and conveyance facilities in the Delta to protect the reliability of SWP deliveries, in light of anticipated future climate change and sea-level rise. Operation of these conveyance facilities will help achieve several related objectives by addressing sea-level rise, minimizing the impact of major earthquake events on SWP and potentially CVP deliveries, and protecting the ability of the SWP to deliver water and provide further operational flexibility. If approved, these updates would improve climate resiliency and the reliability of the state's largest source of safe, affordable, and clean water for 27 million Californians and 750,000 acres of farmland, with continued support for local water supply projects, such as local storage, recycling, groundwater recharge, and water quality management projects.

1.3. THE DELTA CONVEYANCE PROJECT

The DCP would modernize the water transport infrastructure in the Delta by adding new facilities in the North Delta to divert water and a tunnel to convey water to the South Delta. The proposed project is described in Chapter 3 of the project's EIR. This analyzes the costs and benefits associated with the preferred project alternative proposed in the EIR—specifically, Alternative 5. Other alternatives outlined in the EIR and additional planning documents are not included in this evaluation.

Key components of the DCP entail upgrading existing SWP infrastructure and establishing two intakes on the Sacramento River, alongside a 45-mile-long tunnel and a pumping station to channel water into Bethany Reservoir on the California Aqueduct. The tunnel, designed with launch, reception, and maintenance shafts, runs

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[8] Sunding, David L. 2018. *Economic Analysis of Stage I of the California WaterFix*. Prepared for the California Department of Water Resources. September 20, 2018.

Hecht, Jonathan, and David Sunding. 2013. *Bay Delta Conservation Plan Statewide Economic Impact Report*. August 2013.

[9] Delta Conveyance Project. 2023. *Certified Final Environmental Impact Report*. Permits and Regulatory Compliance. Available: https://www.deltaconveyanceproject.com/planning-processes/california-environmental-quality-act/final-eir/final-eir-document. Accessed: April 2024. Hereinafter "DCP EIR."

along the eastern perimeter of the Delta, strategically avoiding the central Delta region. The proposed conveyance facilities would have a capacity of 6,000 cubic feet per second. Figure 1 presents a map of the infrastructure that would be built for conveyance in the preferred alternative.

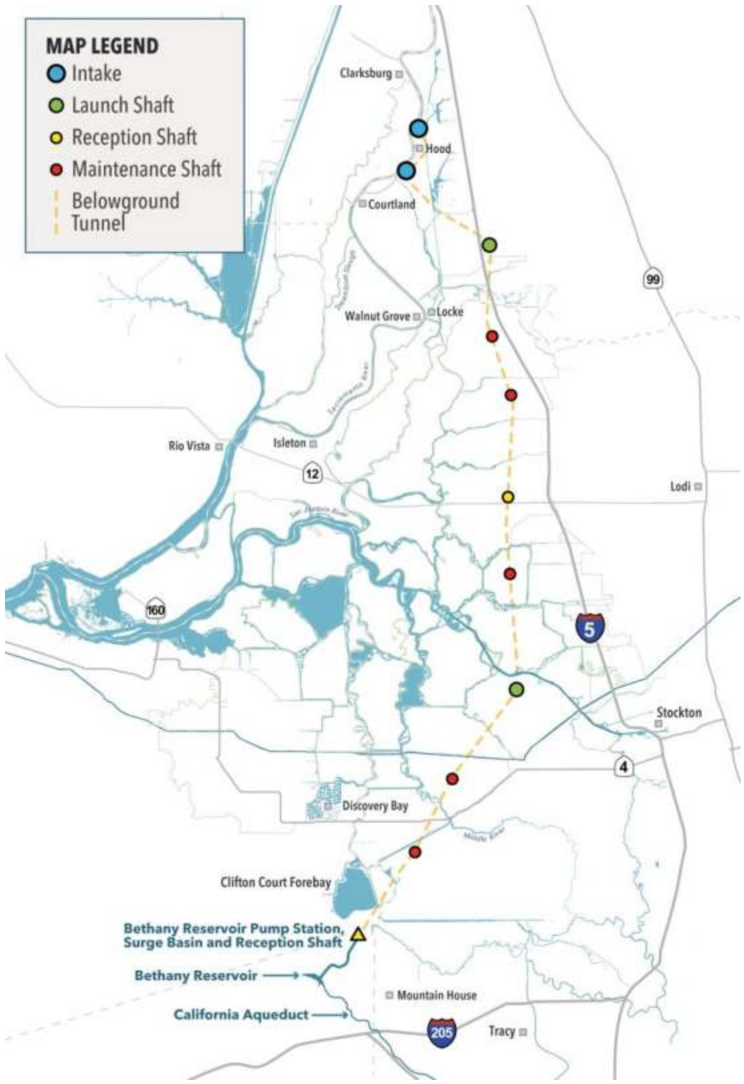
Once the water reaches existing aqueducts and water facilities in the South Delta, it can be conveyed through existing infrastructure to SWP contractors in the Bay Area, Central Coast, Central Valley, and Southern California. These infrastructure enhancements would provide DWR with the flexibility to capture, transport, and store water in accordance with regulatory standards, ensuring its availability during periods of limited supply.

The DCP's increased conveyance capacity will enable increased deliveries of project water to State Water Contractors south of the Delta. The increase in deliveries from the DCP will partially offset the expected reduction in deliveries caused by future climate change and sea-level rise.

The seismic reliability of the DCP ensures the continuous conveyance of water, even during seismic events that might otherwise cause significant disruptions to conveyance operations throughout the Delta. The seismic design criteria adopted for the 45-mile DCP tunnel is based on what is designated as the Maximum Design Earthquake (MDE), an extreme seismic event estimated to happen once every 2,475 years.

Following DWRs currently timeline, in our analysis, preconstruction activities take place between 2026 and 2028. Construction is expected to occur between 2029 and 2044, with subsequent economic benefits estimated over the 100-year operational period from 2045 to 2145.

Figure 1: Map of the Proposed Delta Conveyance Project



Sources: Map of the Delta Conveyance Project, January 2024

2. Framework for Benefit-Cost Analysis

2.1. INFLATION, DISCOUNT RATES, AND RISK

In benefit-cost analysis, as well as in other economic and financial analyses, it is standard to analyze all benefits and costs using "real prices." For the purposes of this report, all figures are expressed in 2023 dollars. This means that, regardless of the year in which a cost or benefit occurs, the value of the cost or benefit is assessed as if it were occurring in 2023. This is done to account for inflation, the general increase in the price of goods and services over time. Because the upfront investment and benefit streams occur in different years, it is important to measure costs and benefits at different times in comparable units. Using 2023 prices removes the distorting effects of inflation, allowing present-day expenditures to be directly comparable to future benefits and providing a clear basis for evaluating a project's economic viability.

Unexpected inflation should not significantly change the outcome of our benefit-cost analysis. If inflation affects future costs and benefits similarly, changes in the inflation rate will not affect the conclusions of the benefit-cost analysis. Unexpected inflation could skew the project's benefit-cost ratio but only if the inflation experienced disproportionately affects costs relative benefits, or vice versa. This is unlikely for the DCP because the benefits are largely tied to water rates, and costs are associated with construction expenses, whose prices generally move in tandem.

In addition to inflation, benefit-cost analyses must also account for the time-value of money, which recognizes that money available today is worth more than the same amount in the future because it can be used immediately (e.g., to pay for things or to invest and earn more money). This concept is crucial, especially in long-term projects like the DCP, which assumes a 15-year construction and commissioning period starting in 2029 followed by a 100-year operational project life.

To account for the time-value of money, future benefits and costs are discounted at a rate called the "real discount rate." This is standard in benefit-cost analysis and other infrastructure benefit-cost planning and regulatory analyses. [10] The benefits of money invested at the beginning of the project unfold over 100 years, and the discounting factor incorporates the forgone opportunity cost of the money had it not been invested into the DCP but rather received the risk-free rate of return on savings in a heavily traded market.[11]

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[10] The White House. 2023. *Biden-Harris Administration Releases Final Guidance to Improve Regulatory Analysis*. November 9, 2023. Available: https://www.whitehouse.gov/omb/briefing-room/2023/11/09/biden-harris-administration-releases-final-guidance-to-improve-regulatory-analysis/. Hereinafter "OMB Circular A-94."

[11] OMB Circular A-94.

Office of Management and Budget (OMB) Circular A-94 recently updated the guidance on the use of discount rates in benefit-cost analysis. Circular A-94 identifies the real, inflation-adjusted return on long-term government debt is a good measure of the discount rate. The updated long-run discount rate starts at 2% from 2023 to 2079 and gradually falls to 1.4% from 2064 to 2172, reflecting both the social rate of time preference and the expected growth of capital.[12]

It is important to separately account for uncertainty and risk when performing benefit-cost analysis. To account for uncertain but positively correlated discount rates, economists recommend assigning probabilities to future discount rates, resulting in declining certainty-equivalent discount rates.[13] Because the discount rate captures only the risk-free interest rate, other risks are explicitly accounted for in the benefit-cost analysis (e.g., by simulating a distribution of hydrologic outcomes when assessing the project's water supply benefits, based on historic rainfall patterns and climate change).

The outcome of a benefit-cost analysis is an estimated benefit-cost ratio, the ratio of the discounted present value of benefits to the discounted present value of costs. In this analysis, a project should be considered economically viable if the benefit-cost ratio exceeds some hurdle rate, which is set above one. This hurdle rate is a policy decision that reflects social expectations for the required return on investment. A benefit-cost ratio greater than one does not necessarily mean that the benefits exceed the costs for all parties affected by the project. A more detailed analysis is required to assess the distribution of impacts across different groups because the benefits and costs may not be uniformly distributed.

2.2. DWR AND OTHER AGENCY GUIDANCE

The approach for this benefit-cost analysis is guided by DWR's Economic Analysis Guidebook. The DWR published the guidebook in 2008 as a resource to help DWR economists perform economic analyses through its discussion of economic analysis guidelines, methods, and models, among other topics. [14] In the guidebook, it is preferred that analyses be performed in a manner that is also consistent with the federal Principles, Requirements, and Guidelines (PR&Gs), except where State of California (State) interests might differ from federal interests or where the PR&Gs are considered outdated. As such, the approaches in this report have been made consistent with the federal PR&Gs, despite the fact there is no federal component to this project.

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[12] OMB Circular A-94.

[13] Arrow, Kenneth J., Maureen L. Cropper, Christian Gollier, Ben Groom, Geoffrey M. Heal, Richard G. Newell, William D. Nordhaus, Robert S. Pindyck, William A. Pizer, Paul R. Portney, Thomas Sterner, Richard S. J. Tol, and Martin L. Weitzman. 2014. Should Governments Use a Declining Discount Rate in Project Analysis? In *Review of Environmental Economics and Policy,* Volume 8, No. 2. Available: https://www.journals.uchicago.edu/doi/full/10.1093/reep/reu008. Accessed: December 6, 2023.

[14] California Department of Water Resources. 2008. *Department of Water Resources Economic Analysis Guidebook*. January 2008, pp. vii–viii. Hereinafter "CADWR Guidebook."

The guidebook advocates for an economic evaluation “of all economic costs for structural and non-structural alternatives. These costs include capital, operations, maintenance, and mitigation. Non-monetary costs and benefits must also be taken into account. In addition, identifying how the costs and benefits are allocated among involved parties is an important component of any plan.” [15]

The DWR guidebook identifies three common economic analysis methods:

1. **Cost-effectiveness analysis** is used to compare multiple alternatives for achieving an identical set of objectives and identify which alternative achieves those objectives at the lowest cost.
2. **Benefit-cost analysis** estimates all the benefits and costs of a proposed project and compares them to a no-project alternative. In a benefit-cost analysis, a project is considered economically viable if the ratio of a project’s benefits to its costs is larger than some proposed hurdle rate that is greater than one.
3. **Socioeconomic impact analysis** considers the distribution of benefits and costs of a proposed project among different parties.

This report contains only a benefit-cost analysis. It does not determine which of the proposed project alternatives is least costly, and it does not consider the distributional impacts of the proposed project.

The DWR guidebook also emphasizes the importance of incorporating risk and uncertainty into any economic analysis. In this context, risk describes situations where the probability of various outcomes can be measured or estimated, whereas uncertainty arises in scenarios where these probabilities are unknown or unquantifiable. For example, estimating the future distribution of precipitation and hydrologic inflows is a key part of our analysis. In this context, risk is described by our estimates of the probability of a future dry year, with low precipitation and inflows based on historical years. There is remaining uncertainty about the extent of future climate change, which we model by simulating a range of different climate scenarios and examining the robustness of our estimates to different climate assumptions.

2.3. CLIMATE ASSUMPTIONS

This report analyzes a range of possible future climate scenarios to give a full picture of the robustness and uncertainty in estimated benefits and costs. The primary benefit-cost analysis scenario considers changes in precipitation and runoff using a median climate change projection, based on an ensemble of global climate models for the period 2056–2085. The primary scenario assumes 1.8 feet of sea-level rise by 2070, based on guidance from the California Ocean Protection Council for the likely range of sea-level rise under a high emissions scenario. In separate sensitivity analyses, we also consider lesser degrees of climate change, either under existing conditions or 2040 climate conditions. We also consider scenarios with greater and lesser degrees

[15] CADWR Guidebook, p. 3.

of sea-level rise. For a comparison across climate scenarios, refer to the Sensitivity Analyses section of the report.

To simulate the 2070 climate scenarios, meteorologic and hydrologic boundary conditions were developed with 10 Coupled Model Intercomparison Project 5 global climate projections. Historical meteorological data perturbed with the differences observed in the ensemble of selected global climate projections are used to estimate future climate conditions, including runoff, surface water evaporation, and evapotranspiration. Ten hydrologic scenarios are used, each representing one General Circulation Model (GCM). The 10 projections were selected from the 64 datasets of Locally Constructed Analogs, based on three metrics of projected change: the mean annual streamflow, a coefficient of variation of streamflow, and the average annual temperature. The inclusion of projected variability in annual streamflow served as an important factor because it is identified as an important driver affecting California's water supply.[16]

Because much of the land in the Delta is below sea level and it relies on more than 1,000 miles of levees for protection against flooding, taking into consideration future sea-level rise scenarios is crucial for analysis.[17] The projections for sea-level rise in the San Francisco Bay considered for this analysis are based on the California Ocean Protection Council's guidance as of 2018.[18] The modeling takes a probabilistic approach, assigning likelihoods of occurrence for potential sea-level rise heights and rates tied to a range of emissions scenarios. The median scenario of sea-level rise is estimated to be 1.8 feet by 2070. The model also produces estimates under extreme scenarios. A 3.5-foot sea-level rise with a probability of occurrence being less than 0.5% is considered in the Sensitivity Analyses section, corresponding to a medium-high risk aversion scenario. Sea-level rise estimates are trained on the Delta hydrodynamic model, then inputted into CalSim 3 through the Artificial Neural Network to simulate the delivery and salinity outputs considered for this analysis. [19]

2.4. PROJECT DELIVERIES

The future deliveries under both the project alternative and no-project baseline are simulated with the CalSim 3 model. The climate models discussed in the previous section simulate future precipitation and runoff. The results are then inputted into the CalSim 3 model to simulate future water supply scenarios, water quality estimates, reservoir levels, groundwater levels, and more. CalSim 3's modeled output with the DCP operations, given environmental and regulatory constraints and demand forecasts, compared to the no-project future

[16] DCP EIR, Appendix 30A.

[17] DCP EIR, Appendix 5A, Section B.

[18] California Ocean Protection Council, 2018. *State of California Sea-Level Rise Guidance: 2018 Update*. Sacramento: CA.

[19] DCP EIR, Appendix 30A.

baseline serve as the basis of the benefit analysis. The allocation of deliveries is based on the existing Table A allocations among contractors that joined the Agreement in Principle.

CalSim 3 is a resource planning model that simulates operations of the SWP and CVP under different hydrologic conditions. The model was developed jointly by DWR and U.S. Bureau of Reclamation.

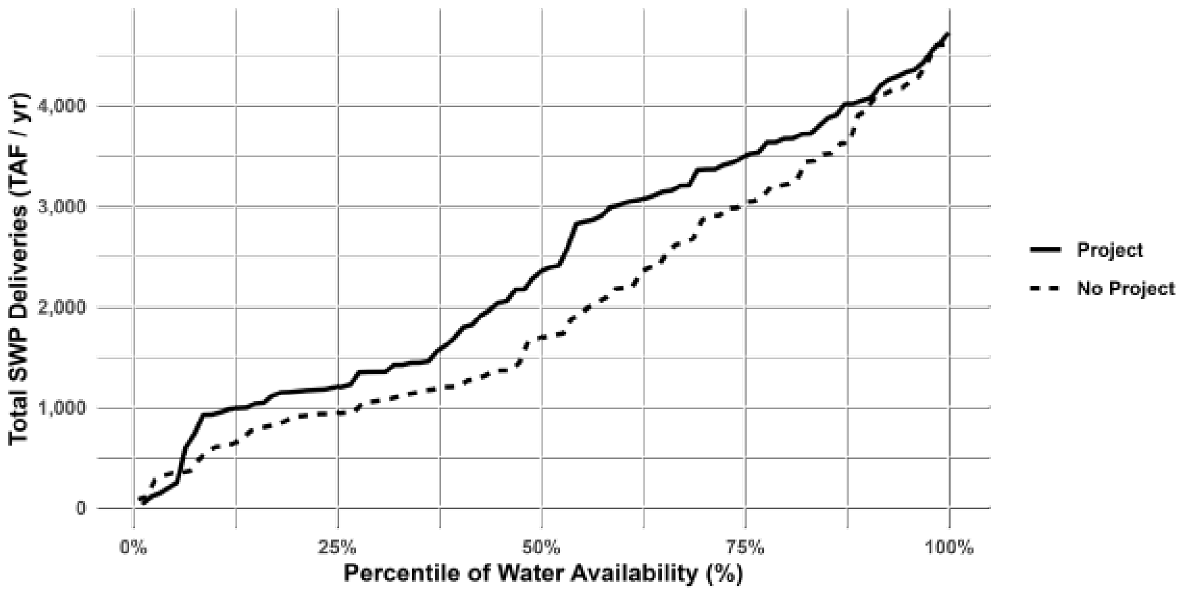
CalSim 3 uses linear programming on monthly timesteps to make water allocation and management decisions.[20] The 94 years of historical hydrology from 1921 to 2015, including unimpaired inflows and rainfall runoff, water demands, return flows, and groundwater recharge from precipitation and irrigation, are used to simulate a distribution of outputs, including river and streamflows, reservoir storage, Delta channel flows, exports, and project deliveries. The water supply and quality measures for Delta exports are of particular interest in analyzing the benefits of DCP.

The simulation of future SWP deliveries under both no-project and with project conditions is shown in Figure 2, below. Without DCP, the SWP deliveries range from 150 thousand acre-feet (TAF) to more than 4,000 TAF. The highly variable deliveries are a result of the variable climate conditions of California, characterized by interchanging drought and wet years. The average delivery under the 2070 median climate scenario, with 1.8 feet of sea-level rise without DCP, is 1,990 TAF.

With DCP, the average additional deliveries would be around 403 TAF per year (TAF/yr) compared to a no-project scenario. The additional water deliveries would be substantial during below normal and above-normal water years. However, during extreme drought and the wettest water years, DCP would not substantially increase SWP deliveries. As shown in Figure 2, in the bottom 10th percentile and above the 95th percentile, project deliveries are almost identical to no-project baseline scenarios.

[20] DCP EIR, Appendix 5B.

Figure 2: Total State Water Project Deliveries with and without DCP



Sources and Notes: Based on CalSim 3 simulations of SWP deliveries to all contractors under the 2070 median climate change scenario, with 1.8 feet of sea-level rise and 94 simulations of historical hydrology.

2.5. FRAMEWORK FOR ESTIMATION OF WELFARE BENEFITS

Two approaches are commonly used to estimate benefits: those based on market prices and those based on estimating consumers' willingness to pay (WTP). The DWR Economic Analysis Guidebook and the federal PR&Gs identify both approaches as appropriate methodologies for economic analysis, depending on the context.

In a market-based approach, estimates of benefits are based on market prices; this is frequently considered the gold standard in economics because the estimates are a straightforward way to measure and reflect actual market activity. However, markets may not exist or prices might not be observable for benefits in many settings. For example, during droughts and seismic events, utilities typically do not increase prices to ration the water supply, instead relying on unpriced conservation programs and rationing. Furthermore, because extreme droughts and major earthquakes are rare, data may not be available to identify market prices in such contexts. Furthermore, WTP is typically highest during extreme shortages resulting from such rare events. Similarly, water quality is typically not priced in the market but has significant implications for consumer welfare. Finally, many environmental impacts, such as reduced air quality or increased noise and traffic impacts, are not explicitly priced in the market. In these cases, instead of adopting a market approach, benefits are estimated by calculating a consumer's hypothetical WTP, the maximum price the consumer would be willing to pay for a good or service. In these situations, WTP can be estimated by observing behavior in adjacent markets or estimating an economic model of consumer demand.

2.6. SENSITIVITY ANALYSES

To evaluate the robustness of the DCP's economic benefits provided by the DCP under uncertain climate trajectories, a sensitivity analysis is performed under different assumptions of future climate scenarios. Three time periods are considered: 2040 median, 2040 central tendency (CT), and 2070 median.

The two 2040 climate assumptions differ mainly in the ensemble of general circulation models that were used to represent climate change in 2040.[21] For the 2040 CT scenario, 20 GCM projections are selected by the DWR Climate Change Technical Advisory Group, consisting of 10 GCMs that each consider two future emission scenarios, or Representative Concentration Pathways (RCPs). The 2040 median scenario consists of 10 GCM projections selected by the DWR Climate Change Program. Both 2040 climate scenarios show similar flow patterns, as flow in December–March increases and in April–July decreases consistently. Both 2040 scenarios also assume 1.8 feet of sea-level rise, which has a probability of occurrence of less than 0.5%.

Because DCP becomes operational only after 2040, and benefits unfold for the next 100 years, the 2070 climate scenarios are more relevant for analyzing the benefits. For 2070, the analysis considers both the median climate scenario of 1.8 feet, which has a probability of occurrence of 66%, and the extreme scenario of 3.5 feet, which has a probability of occurrence of less than 0.5%. In addition, further operational assumptions and scenarios with adaptation measures are included to avoid operational constraints associated with conveyance and the operation of the system's major reservoirs.[22]

Table 2 compares the deliveries across all seven scenarios considered. The incremental deliveries from the DCP are robust to a wide range of climate assumptions, showing that the project is robust to differing degrees of assumed climate change. Furthermore, deliveries in the 2070 project scenario are similar to non-project deliveries in 2020. As such, the project can be viewed as mitigating 50 years of future climate change by bringing future levels of water supply reliability closer to current levels.

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[21] DCP EIR, Appendix 30A.

[22] California Department of Water Resources. n.d. *CalSim 3 Results for 2070 Climate Change and Sea Level Projections and Sensitivity Analysis.*

Table 2: Scenarios Considered in Sensitivity Analyses

Scenario	Main Scenario	Sensitivity Analyses 1	Sensitivity Analyses 2	Sensitivity Analyses 3	Sensitivity Analyses 4	Sensitivity Analyses 5	Existing Conditions
	2070 Median w. 1.8' SLR	2070 Median w. 1.8' SLR & Adaptation	2070 Median w. 3.5' SLR	2070 Median w. 3.5' SLR & Adaptation	2040 Median w. 1.8' SLR	2040 Central Tendency w. 1.8' SLR	2020 EC
	[TAF / Yr]						
No Project	1,990	2,019	1,876	1,920	2,098	2,314	2,560
Project	2,393	2,416	2,281	2,315	2,505	2,751	3,014
Difference	403	397	404	395	406	437	454

Sources and Notes: All modeled deliveries are measured in thousand acre-feet and averaged over 94 simulations with historical hydrology. In 2070, analysis is conducted under the median climate scenario along with multiple sea-level rise scenarios and whether adaptation measures are adopted. In 2040, both the median climate scenario and central tendency are considered for analysis. The 2020 EC scenario represents estimated deliveries under existing climate conditions.

3. Urban Water Supply Benefits

A key benefit of the DCP is the increase in water supply reliability for the SWP's urban customers. The SWP supplies water to urban customers in Southern California, the Central Coast, the Central Valley, and the Bay Area.[23] The reliability of the urban water supply has critical implications for public health and safety in urban areas, ensuring consistent access to clean water for drinking, cooking, and sanitation. Water is also critical for daily business operations in the state's commercial and industrial sectors; water supplied south of the Delta by the SWP services an area that accounts for more than half of California's GDP. Business interruptions from disruptions in water supply, if significantly large and sustained, can affect the growth and stability of the local economy.[24]

The DCP will provide additional water supply that will increase reliability by reducing the frequency and magnitude of shortages during dry periods. This section gives an overview of our approach to estimating the economic benefits of reduced water shortage welfare losses for urban customers resulting from the construction of the DCP. Further details on our approach are provided in Appendix B. For each SWP contractor with urban customers, we estimate urban water supply reliability benefits using the following steps:

1. The level of demand and price sensitivity are forecast for different types of urban water supply customers, including residential, commercial, and industrial customers.
2. Future shortages are forecast for each type of urban customers with and without the DCP.
3. The economic cost of future shortages is estimated for each type of urban customers with and without the DCP.
4. The reliability benefits of the DCP are based on the difference in the economic cost of future shortages with and without the project.

3.1. DEMAND FORECASTS FOR URBAN CUSTOMERS

Our estimates of the benefits of improved urban water supply reliability are based on forecasts of water demand and water conservation for each State Water Contractor. These forecasts are based on each contractor's Urban Water Management Plan (UWMP) or, in the case of Metropolitan Water District (MWD), its Integrated Resource Plan (IRP). Agencies are required to produce these plans every five years to ensure

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[23] There are currently 17 participants in the Agreement in Principle: Alameda Zone 7, Alameda County WD, Santa Clara Valley, Empire West Side ID, Kern County WA, SLO FCWCD, Antelope Valley-East Kern, Santa Clarita Valley, Coachella Valley, Crestline Lake Arrowhead, Desert WA, MWDSC, Mojave, Palmdale, San Bernadino Valley, San Gabriel, San Gorgonio Pass, Ventura County.

[24] Boarnet, Marlon, Wallace Walrod, David L. Sunding, Oliver R. Browne. 2022. *The Economic Impacts of Water Shortages in Orange County.* July 2022.

adequate water supplies are available to meet existing and future water needs under California's 2009 Water Conservation Act (SB X7-7). Demand and conservation forecasts are based on various economic, demographic, and climatic characteristics and produced following best management practices under consultation with local communities. Different agencies take different approaches to forecasting future demand; however, these approaches cover the full spectrum of urban water use, including residential, commercial, industrial, institutional, and unmetered water uses.[25]

In the 2020 UWMPs and MWD's 2020 IRP, agencies project water demands out to 2045. For our analysis, we use these agency-produced forecasts for 2045 and assume no growth in demand during the period for which we simulate DCP operations, 2045 to 2145.

3.2. SHORTAGE ESTIMATES FOR URBAN CUSTOMERS

For urban customers, we define water shortages as the difference between a baseline level of demand, as forecast in urban water management plans, and the actual volume of water made available to customers, based on the realized hydrology in a particular year. In this sense, any reductions in demand relative to the forecast baseline are considered a shortage. The term "shortage" is used to include reductions in consumer demand during drought conditions, including voluntary reductions in response to media campaigns, along with savings from management policies that restrict the scope of when and how water can be used; responses to drought surcharges; and other forms of demand curtailment.

Shortages are estimated using reliability models provided by State Water Contractors, principally an extended version of MWD's IRP Simulation Model (IRPSIM), a supply-and-demand mass balance simulation model that was developed for MWD as a basis for its IRP. IRPSIM forecasts demand using a sales model and simulates supply according to local supplies and imports, SWP supplies, Colorado River Aqueduct supplies, and MWD's storage portfolio. Outputs from the CalSim 3 model are used as inputs in IRPSIM to forecast SWP deliveries. The model accounts for climate change by adjusting inflows from other imported supplies. IRMSIM simulates MWD's

[25] Most agencies consider only a single demand scenario in forecasting their future water supply reliability; however, MWD considers four scenarios in its IRP that consider different future demand and supply assumptions. The four scenarios assume different levels of demand and imported water supply, ranging from a scenario with falling demand and stable imports to a scenario with growing demands and reduced imports. The key differences between these scenarios are assumed climate change, regulatory requirements, and economic conditions For further details, see "2020 IRP – Regional Needs Assessment," The Metropolitan Water District of Southern California, April 2022.
In this analysis, we consider the IRP's Scenario D, which is characterized by growing demand and reduced imports. This scenario most closely comports with our other assumptions pertaining to climate change and population growth. It is described in the IRP as follows: "This scenario is driven by severe climate change impacts to both imported and local supplies during a period of population and economic growth. Demands on Metropolitan are increasing due to rapidly increasing demands and diminishing yield from local supplies. Efforts to develop new local supplies to mitigate losses underperform. Losses of regional imported supplies are equally dramatic."

storage portfolio by considering operational constraints, put-and-take capacities, contractual arrangements, and other operational considerations. [26]

For each year of demand, IRPSIM simulates supply, based on each year of the historic hydrologic trace, adjusted for climate change. This results in 96 trials, based on historical hydrologic data, beginning in 1922. IRPSIM then calculates a distribution of outcomes, allowing MWD to evaluate probabilities of surpluses and shortages and further forecast the magnitude and frequency of shortages. This report uses an extended version of IRPSIM that simulates supply and shortages for most urban State Water Contractors, except the Santa Clara Valley Water District, which provided separate hydrologic modeling for this report that follows a similar methodology, as described in its UWMP.[27] Shortages are forecast with and without the DCP, based on demand levels in 2045. Levels of reliability are assumed to remain constant for the duration of the DCPs operating life between 2045 and 2145.

Based on this modeling, the frequency and magnitude of shortages are estimated for 2070 under the median climate change scenario, with 1.8 feet of sea-level rise. Figure 3 summarizes the results. The vertical axis shows the shortages as a percentage of total demand, ranging from 0% to 32%. The horizontal axis shows the frequency of shortages by arranging simulated hydrologic years from the driest (0%) to the wettest (100%). In the no-project scenario, by 2070, there are demand shortages in 61% of all years. Construction of the DCP increases the water supply such that there are shortages in only 44% of all years. In the no-project scenario, there is an average shortage of 9% of total demand. Construction of the DCP reduces the size of the average shortage to only 5% of total demand.

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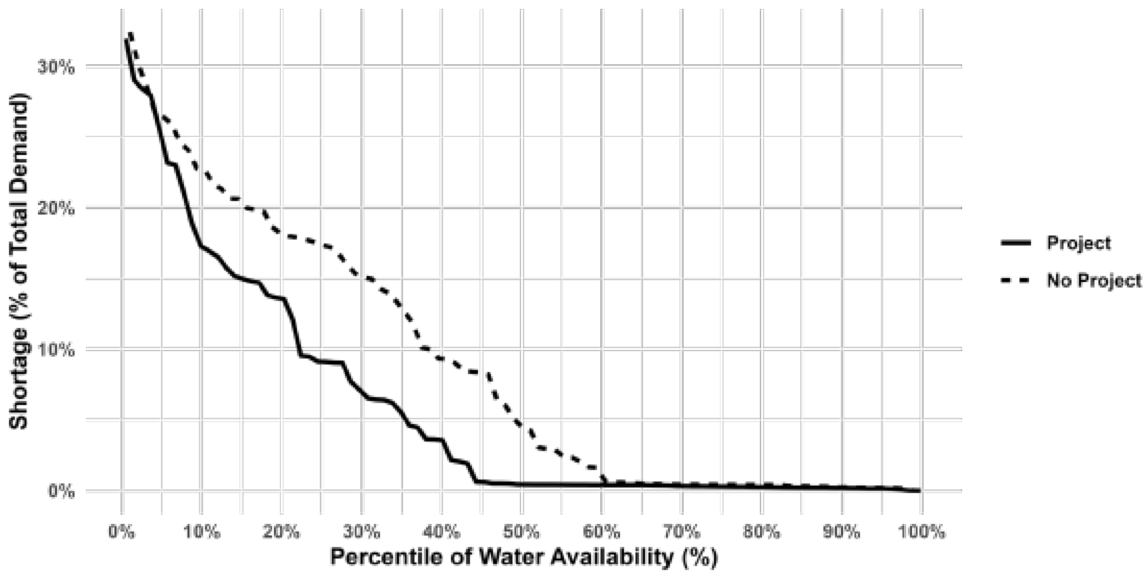
[26] MWD 2020 IRP.

[27] Santa Clara Valley Water. 2021. *2020 Urban Water Management Plan*. June 2021.

Figure 3: Shortage as a Percentage of Total Urban Water Demand



Sources and Notes: Based on MWD's IRPSIM modeling. The distribution represents 96 simulated shortages under a wide range of historical hydrology and the 2070 median climate scenario with 1.8 feet of sea-level rise.

3.3. ECONOMIC COSTS OF URBAN WATER SHORTAGES

Estimates of the economic costs of urban water shortages are based on an economic model of consumers' WTP to avoid water supply interruptions. Water supply reliability benefits are estimated using a WTP-based approach rather than a market-based approach. Utilities usually rely on non-price mechanisms such as conservation campaigns and water use restrictions to manage demand rather than charging elevated drought rates during droughts. As a result, a market-based approach that estimates water supply reliability benefits only, based on customer rates, would understate the water supply benefits during droughts, which are expected to become frequent due to future climate change and significantly mitigated by construction of the proposed DCP.

To estimate district-specific price elasticities of demand, we rely on econometric models that are estimated in Buck et al. (2016).[28] This paper constructs a panel dataset of average monthly water consumption and average rates over five years that covers 75 urban water utilities, including State Water Contractors in the South Bay and

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[28] Buck, Steven, Maximilian Auffhammer, Stephen Hamilton, and David Sunding. 2016. Measuring Welfare Losses from Urban Water Supply Disruptions. In *Journal of the Association of Environmental and Resource Economists,* 3, No. 3 (2016): 743–778.

Southern California. The authors then perform a log-log panel regression of average monthly water use on water rates and household income. This regression also controlled for weather fluctuations, seasonal effects, and utility-specific and secular trends. The result is an estimate of how changes in price and income affect demand for water, based on relative changes across utilities over time. The paper finds that water demand is less elastic for lower-income consumers. For example, across all State Water Contractors, the average price elasticity of demand is -0.18, meaning that a 10% increase in rates would induce only about a 1.8% reduction in water use. This average estimate varies, based on income; customers in higher-income communities typically have more discretionary water uses, such as larger yards with more landscape irrigation, and so can reduce consumption in a less costly manner during drought. In contrast, lower-income consumers who depend heavily on water for basic needs such as drinking and sanitation experience larger welfare losses to reduce their consumption by a similar amount.

Based on the econometric relationships estimated in this paper, we construct an estimate of the price elasticity of demand for each urban State Water Contractor participating in the DCP and for each member agency of the MWD. The estimates presented in this paper have been updated with current water rates and household income data for each water agency.

Using an economic model described further in Appendix B, we apply a formula that estimates welfare losses based on the size of the shortage, the marginal cost of SWP deliveries, and the estimated price elasticity of demand. The derived welfare loss function exhibits a declining marginal utility of water, meaning the larger the welfare loss per unit of shortage, the larger the magnitude of the shortage. This behavior implicitly captures complexities in water consumption behavior; for example, when shortages are small, customers can reduce water use relatively cheaply by reducing outdoor irrigation, leading to relatively small unit welfare losses. However, as shortages become more severe, consumers must reduce water use in more costly ways that might directly affect daily household activities or business operations, leading to much larger unit welfare losses. This behavior is also consistent with drought management plans that utilities are required to put in place to identify the least costly way to meet different levels of conservation.

For each year we simulate, we calculate welfare losses for 96 trials, based on the historical hydrologic trace between 1922 and 2018. Average welfare losses across all simulations are then calculated separately for each district participating in the DCP using customer-specific elasticity estimates and retail water rates.[29] Significant costs are associated with forecast shortages due to forecast reductions in supply as a result of climate change; in the no-project scenario, more than 61% of all years are expected to have water shortages, leading to annual welfare losses of more than $1.1 billion.

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[29] Note that currently the reliability estimates are calculated only for Metropolitan Water District and Santa Clara Valley Water. Estimates of welfare losses are then extrapolated to all other agencies. However, the final economic analysis will incorporate water district–specific estimates that will be produced once modeling of district specific shortages becomes available.

3.4. WATER SUPPLY RELIABILITY BENEFITS

The quantified economic benefits of the DCP in terms of improved water supply reliability are based on the change in the frequency and size of water shortages between the project and no-project scenarios. As previously discussed, the costs of shortages are calculated for each State Water Contractor and MWD customer using an economic model that estimates customer welfare losses from shortages, based on the frequency and size of shortages in each district and district-specific rates and demand elasticities. The economic benefits of the DCP for urban customers are estimated as the difference in the welfare losses from shortages between the project and no-project scenarios. Using this approach, the present value of improved water supply reliability is estimated to be worth, on average, more than $33.3 billion in 2023 dollars over the project's lifetime. These benefits amount to an average value of $2,560 for every additional acre-foot of water supplied to urban customers from the DCP's operations. However, there is significant variability in the benefits of these deliveries, depending on the prevailing hydrologic conditions. In the driest 5% of years, additional deliveries from the DCP have an average value of between $6,000 and $9,000 per acre-foot.

4. Agricultural Water Supply Benefits

The DCP is estimated to deliver, on average, an additional 148.5 TAF/yr of water to agricultural contractors. Agricultural State Water Contractors may use the additional water supplied by the DCP to grow crops, to recharge or otherwise offset deficits in groundwater extraction, or to sell to other customers in urban sectors.

We take two approaches to estimating water supply benefits to agricultural users. The first approach is a demand-based approach that uses a planning model to estimate the shadow value of water in the Central Valley, based on unmet demands for water of agricultural activity in the Central Valley. The second approach is a market-based approach, based on an index of the prices for water transfers in the Central Valley.

4.1. VALUATION OF WATER USE IN AGRICULTURE – SWAP MODEL

The benefits of agricultural water supply are estimated using a WTP approach that identifies the "shadow price" of water, based on a model of agricultural production in the Central Valley. The SWAP is a multi-region, multi-input and output economic optimization model that simulates agricultural production in California.[30] The model is widely used for policy analysis and planning purposes by the state and federal agencies.

SWAP simulates the behavior and decisions of farmers under the assumption of profit maximization in a static competitive market subject to resource, technical, and market constraints. With 37 regions in the model, 27 of which are in the Central Valley, SWAP provides detailed data coverage and production estimates for agricultural water supply and cost changes. The SWAP model takes account of water supplies (SWP and CVP, other local supplies, and groundwater) into production cost-effectiveness optimization by adjusting the crop mix, water resource availability, and land fallowing.[31]

The SWAP model is widely used in recent studies. It is considered an appropriate and conservative approach for estimating DCP's agricultural water supply benefits. Based on the SWAP model, the marginal value of agricultural water is $301 per acre-foot in 2023 dollars.

[30] UC Davis Center for Watershed Sciences. n.d. *SWAP Model*. Available: https://watershed.ucdavis.edu/project/swap-model.

[31] UC Davis Center for Watershed Sciences. n.d. *A Brief Overview of the SWAP Model*. Available: https://watershed.ucdavis.edu/doc/water-economics-and-management-group/brief-overview-swap-model.

4.2. VALUATION OF WATER USE IN AGRICULTURE – MARKET APPROACH

In addition to a WTP based approach for estimating the benefits of the SWP for the agricultural sector, we also adopt a market-based approach. To provide a comprehensive valuation of marginal agricultural water value, we estimate the water supply benefits of the DCP. The water transfer includes voluntary buying and selling of a quantifiable allocation between a willing seller and buyer; the price of water set in the water bidding process reflects people's perceived marginal value of water.

This analysis relied on the empirical Nasdaq Veles California Water Index. Developed in conjunction with Westwater Research and Veles Water, the index reflects the commodity value of water at the source, not accounting for transportation costs or losses.[32] The price data are aggregated from the five largest and most actively traded markets in California, with Southern California being the most active market.[33] The water is priced weekly and on a per-acre-foot basis, reflecting the prevailing market price for water transactions. The Nasdaq Water Index price is a spot price that reflects the short-term value of water; to estimate a long-run value for agricultural water, we average the historical weekly prices over the entire history of the water index from September 2019 to April 2024. Using this approach, the marginal value of water use in agriculture is $646 per acre-foot in 2023 dollars.

In the benefit-cost analysis, we assess the value of additional SWP deliveries in the agricultural sector, based on the average of the prices estimated using the WTP and the market-based approaches, a value of $474 per acre-foot in 2023 dollars. With an average additional delivery of 148.5 TAF/yr to the agricultural water users, the estimated total benefit is $68.5 million per year.

[32] Nasdaq. 2024. *Nasdaq Veles California Water Index*. Available: https://www.nasdaq.com/solutions/nasdaq-veles-water-index. Accessed: December 8, 2023.

[33] Ibid.

5. Water Quality Benefits

Construction of the DCP will reduce the salinity of water supplies exported south of the Delta to customers in both the urban and agricultural sectors. This improvement in water quality will be a result of some SWP deliveries being conveyed through the proposed tunnels directly to the Banks Pumping Plant where they will be exported through the California Aqueduct rather than being conveyed through more saline parts of the Bay Delta.

Chapter 9 of the EIR quantifies the impacts of the operations of the DCP on a number of different water quality dimensions in the Delta and the Delta's export service area. Water quality is evaluated under project and no-project scenarios using Delta Simulation Model II (DSM2). Based on this modeling, construction of the DCP would reduce the average salinity of Delta exports by 22 milligrams per liter (mg/l), from 237 mg/l under the project scenario to 215 mg/l under the no-project scenario. Note that this average conceals the significant variability of the change in water quality, which is highly correlated with the volume of export volumes and seasonal flows.

The DCP's operations will improve water quality for SWP contractors on two dimensions. First, the DCP will improve the water quality of exports themselves. Secondly, it will lead to a substitution toward relatively higher-quality SWP water and away from lower-quality sources such as groundwater or water imported from the Colorado River.

5.1. WATER QUALITY FOR URBAN WATER CUSTOMERS

The benefits of improved water quality due to the DCP are estimated in the SWP's Southern California service area and evaluated using the Salinity Economic Impact Model (SEIM).[34] The SEIM, a product of a collaborative effort between the Bureau of Reclamation and MWD, is designed to evaluate the economic impact of salinity changes in Southern California and the broader Lower Colorado River service area.

Within Southern California, the SEIM model estimates economic impacts for each of the 15 subregions, accounting for region-specific water supply conditions and economic variables. For each subregion, estimates of salinity costs are based on demographic data, water deliveries, total dissolved solids (TDS) concentrations, and sector-specific cost relationships. To simulate the overall salinity of urban water, SEIM explicitly accounts for the distribution and blending of different water sources within each region, including local surface water and groundwater, desalinated seawater, and the water from the Colorado Aqueduct, along with water delivered through the Delta to the East and West Branch Aqueducts of the SWP. The weighted average salinity in terms of

[34] Metropolitan Water District of Southern California and Bureau of Reclamation. 1999. *Salinity Management Study, Final Report.*

TDS is estimated in terms of mg/l for each region. Economic impacts are calculated for different end uses of water, including residential, commercial, industrial, utilities, groundwater, recycling, and wastewater, based on region-specific demand estimates for each end use.

In the residential sector, the SEIM assesses the damage caused by salinity through its reduction in the useful life of household appliances like water heaters, faucets, and washing machines. It also models the costs of avoidance strategies, such as the installation of water softeners and the purchase of bottled water. In the commercial sector, the SEIM estimates the share of regional water use in sanitary, cooling, landscape irrigation, kitchen, laundry, and other uses; estimates of economic impacts are based on a unit price in each use category. Similarly, in the industrial sector, estimates of economic impacts are based on the total volume of water used in each sector and sector-specific estimates for the cost of demineralization and softening as well as for specific industrial applications such as cooling towers and boiler feed.

To estimate the salinity benefits from the construction of the DCP, estimates of the salinity of project water exported from the Banks Pumping Plant into the California Aqueduct from the DSM2 model are inputted into the SEIM under the project and no-project scenarios. The SEIM then estimates the salinity deliveries on the West Brach Aqueduct and East Branch Aqueduct of the SWP in Southern California.

Table 3 summarizes the annual urban water quality benefits estimated by the SEIM model. Based on this modeling, improvements in water quality as a result of DCP operations lead to an annual benefit of more than $41 million in terms of reduced economic impacts as a result of improved water quality. These benefits are accounted for primarily by benefits to residential customers, improved quality for recycled water, and reduced impacts on groundwater resources. Note that this estimate does not include estimates of the benefits to agricultural customers, which are accounted for separately in the next section. This estimate also does not include benefits to urban customers outside of Southern California, who are not accounted for in this model.

5.2. WATER QUALITY FOR AGRICULTURAL WATER CUSTOMERS

The analysis of water quality benefits to agriculture also focuses primarily on the impact of reduced salinity on water treatment costs and yield losses. Crop production and yield are greatly affected by the salinity of the crop's root zone. High salinity in the crop's root zone creates unfavorable osmotic pressure for the plants to absorb water.[35] This hindered water absorption induces physiological drought within the plant, even if the soil contains abundant water.[36] The salinity threshold for yield losses is below 10 decisiemens per meter (dS/m) for most crops grown in the region. Some sensitive crops such as alfalfa, beans, and maize start to experience yield

[35] University of California Salinity Management. 2024. Crop Salinity Tolerance and Yield Function. Available: https://ucanr.edu/sites/Salinity/Salinity_Management/Effect_of_soil_salinity_on_crop_growth/Crop_salinity_tolerance_and_yield_function/.

[36]Ibid.

losses below two dS/m.[37] Salt-tolerant crops such as cotton and barley also start to experience declining yields when the soil's electrical conductivity reaches eight dS/m.

Irrigation using river or groundwater that contains salts is the primary man-made cause of soil salination. After irrigation water is applied to the soil, the water gradually evaporates or absorbed by a plant, leaving the dissolved salts in the soil. To reduce the salinity level in the soil, farmers adopt a common practice of applying excess irrigation water that drains the salt downward past the root zone, called leaching. The more saline the irrigation water is, the more excess water is required for leaching the salt away from the plant's root zone.

For the salinity benefit to agricultural water users, we calculated the amount of irrigation water savings from leaching due to reduced salinity with the DCP project alternative. Detailed crop coverage data are obtained from the U.S. Department of Agriculture (USDA). For each crop, the irrigation requirements and leaching fractions to lower the salinity level below yield loss thresholds are used to calculate the annual leaching savings in each water district benefiting from the DCP. Overall agricultural irrigation water use would be reduced by nearly 6,000 acre-feet annually. Along with the agricultural water cost estimates produced by the SWAP model and the water transfer market, the annual savings on irrigation water amounts to more than $3 million. The breakdown of agricultural water quality benefits is summarized in Table 3, below. The San Joaquin Valley benefits the most from agricultural water quality improvement, at nearly $2.9 million annually, while Southern California's annual benefit is nearly $300,000.

Because the EIR assessment predicted a slight increase in salinity in the Delta, we also estimate the costs of increased salinity on agricultural water users in the Delta. The CalSim 3 model predicts an increase in electrical conductivity of 0.008 dS/m on average across the Delta. Although deemed "less than significant" in the EIR, we still quantified the costs of increased Delta salinity and incorporated them in the analysis of remaining environmental impacts after mitigation. Overall, the benefits of improved salinity to downstream agricultural water contractors significantly outweigh the cost of the small increase in salinity in the Delta region.

Similar to the urban water quality analysis, this water quality analysis provides a conservative estimate of total DCP water quality benefits. Because this analysis focuses only on salinity improvement, it does not explicitly price many other measures of water quality improvements, such as reductions in pollutants, pathogens, and man-made chemicals that pose health risks.

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[37]Ibid.

Table 3: Water Quality Benefits

Urban Water Quality Benefits	Millions of 2023 $
Residential	$12.0
Commercial	$4.3
Industrial	$0.6
Utilities	$0.1
Groundwater	$15.8
Recycled Water	$8.4
Total	$41.2
Agricultural Water Quality Benefits	
Southern California	$0.3
San Joaquin Valley	$2.9
Total	$3.2
Total Annual Water Quality Benefits	$44.4

Sources and Notes: Urban water quality benefits based on SEIM model simulations.
Agricultural water quality benefits based on soil leaching water savings analysis.

5.3. WATER QUALITY IN THE DELTA

The EIR evaluates construction and operation of the project on a number of dimensions of water quality, including on boron, mercury, nutrients, organic carbon, dissolved oxygen, selenium, pesticides, trace metals, and total suspended solids and turbidity relative to existing conditions and concludes that the impact on water quality from construction of the project alternatives would be less than significant.[38] Operation of the proposed project facilities has the potential to affect water quality through differences in Delta inflows from the Sacramento River, relative to existing conditions, resulting in increased proportions of the other Delta inflow waters (such as eastside tributaries, the San Francisco Bay, and the San Joaquin River) in some regions of the Delta.[39] The EIR concludes that changes in bromide, chloride, and electrical conductivity (EC) would be less than significant.

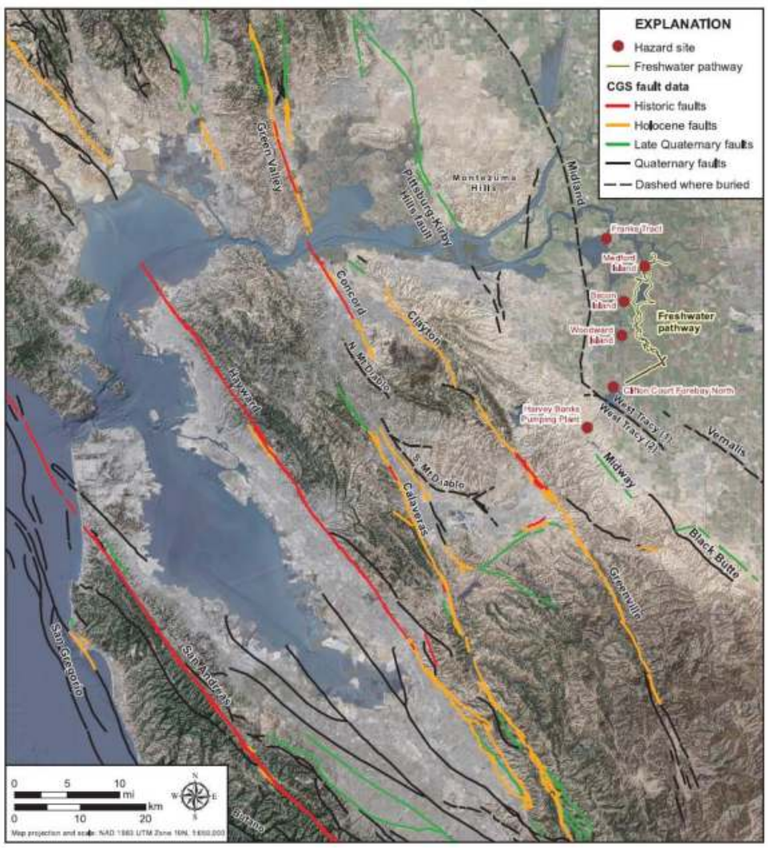
[38] DCP EIR, Chapter 9.

[39] Ibid.

6. Improvements to the Seismic Reliability of the SWP

A key objective of the DCP is to mitigate the impact of seismic events on the Delta's water conveyance infrastructure. By adding redundancy to the current conveyance infrastructure, DCP will help mitigate the impact of seismic events on the quantity and quality of water delivered south of the Delta. Therefore, it would minimize the potential for adverse public health and safety impacts from a major earthquake.

Figure 4: Major Fault Lines near the Delta



Sources and Notes: "Delta Flood Emergency Management Plan – Supplement C, " California Department of Water Resources, October 2018.

There are many active faults surrounding the Delta. Figure 4 displays active faults and historical seismicity near the Delta. The USGS analyzed the earthquake potential of the faults in the Bay Area. The Hayward-Rodgers Creek fault poses the highest probability of generating an earthquake of magnitude 6.7 or greater in the following 30 years, at 27%. The estimates of maximum magnitude range from 6.5 to 7.3. Other than the Hayward-Rodgers Creek fault, there are a couple of smaller faults adjacent to or below the Delta. The West Tracy fault, passing beneath the Clifton Court Forebay at the southwestern part of the Delta, is estimated to have a maximum magnitude of 6.25 to 6.75. The Midland fault that passes beneath the western margin of the Delta has the potential to produce an earthquake of magnitude 7.1. The Greenville fault, the easternmost part of the San Andreas fault system and located southwest of the Banks Pumping Plant, has the potential to generate earthquakes ranging from 6.6 to 7.2.[40]

Active faults, along with land subsidence and poor, highly organic soils that are subject to liquefaction and settlement, make earthquakes the greatest risk associated with flooding. A large earthquake in the San Francisco Bay Area could cause levees in the Delta to breach, leading to an inundation of brackish water in areas where existing SWP and CVP pumping plants operate in the southern Delta. Historically, levee failure and breaches have occurred for various reasons. In the past century, there were 161 breaches of Delta levees. Despite there being few breaches since the 2000s, the Upper Jones Tract levee failure in 2004 demonstrated that there are still significant breach risks.[41]

In any major seismic event with significant brackish water invasion, conveyance through the Delta will most likely be impossible for an extended period. A major seismic event could also damage the SWP and CVP conveyance infrastructure in the Delta. Cessation of conveyance through the Delta for any extended period of time would pose major reliability challenges to State Water Contractors south of the Delta. This could lead to shortages significantly more severe than those posed by dry-year events.

DCP project facilities are designed to withstand at least a 500-year return-period earthquake while maintaining system operational capability. For some more complex or difficult-to-repair facilities, a much higher return period event is assumed for design. Building the DCP serves as an insurance policy that would allow at least some water to continue to be delivered south of the Delta in the event of a major earthquake.

It is difficult to precisely quantify the likelihood and water supply impacts of different seismic events that may occur. These impacts will depend on the location, magnitude, and nature of the seismic event; the number and location of levee failures; and the response to repairing failed levees. Furthermore, the economic costs of water supply interruptions from a major seismic event will also depend on other factors, including the hydrologic and economic conditions that influence the water demand. Rather than attempting to provide a comprehensive analysis of the likelihood and impacts of the full range of hypothetical seismic events that could occur in the Delta region, we instead describe a hypothetical seismic scenario and estimate the impacts and economic costs associated with this scenario.

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[40] Wong, Ivan G., Patricia Thomas, Nora Lewandowski, and Dennis Majors. 2021. Seismic Hazard Analyses of the Metropolitan Water District Emergency Freshwater Pathway, California. In *Earthquake Spectra,* Volume 38(2), 981–1020, 2022, DOI: 10.1177/87552930211047608.

[41] California Department of Water Resources. 2018. *Supplement C – Water Project Export Disruptions for Multiple-Island Breach Scenarios Using the Delta Emergency Response Tool.* May 2018.

The Delta Emergency Response Tool (ERT) is used to simulate Delta levee failures and help forecast impacts and develop response mitigation strategies. The ERT allows a user to test various response strategies to each simulated scenario and helps support decision-making. The ERT simulated 11 base scenarios, ranging from four to 20 breached islands, of which Scenario 1 represents a 500-year earthquake. Scenario 1 simulated a 20 island/ 50 breach event, with a total flooded volume of 1,296 TAF.[42] Figure 5 shows the specific breach locations. Export disruption and water quality are modeled under a range of hydrologic conditions, including specific scenarios involving severe flood and drought conditions. Eight different response strategies were simulated in an incremental approach, and for each strategy, ERT modeled the distribution of export disruption time, Delta recovery time, and response cost across 20 hydrologic simulations for each response strategy. Out of the eight responses, the Middle River Corridor Strategy results in a shorter disruption time than the basic strategy and a lower cost compared to the cumulative strategy.[43] The cost of restoring the seismic damage consists of three parts: breach repair cost, island dewatering cost, and barrier repair cost. For the Middle River Corridor Strategy, the costs are $1.4 billion, $35 million, and $31 million, respectively.[44]

The Middle River Corridor Strategy attempts to construct a freshwater pathway from the northern Delta to the pumps in the southern Delta. It accomplishes this by prioritizing the repair of levees along the Middle River and installing channel barriers to isolate the corridor from the rest of the Delta. Without the DCP, under the Middle River Corridor Strategy, the export disruption ranges from six days to 448 days, with an average of 203 days. The Delta recovery time, defined as the time required for the Delta water quality to recover to the level with no breach, ranges from 11 days to 498 days, with an average of 306 days. Under the DCP alternative, we considered two scenarios for analysis: DCP operating at 6,000 cubic feet per second (cfs) capacity and DCP operating at 500 cfs health and safety levels. These scenarios reflect the maximum and minimum balance at which DCP might be able to operate under the seismic event; however, the exact operation is uncertain and affected by other infrastructure.

Table 4 outlines benefits under the DCP alternative for different disruption and DCP operation scenarios. Assuming the DCP operating at the minimum health and safety levels, the average avoided water supply disruption benefits amount to $2.36 billion, and the improved water quality benefits amount to $2.65 million. Assuming the DCP operating at capacity during an earthquake event, the average avoided water supply disruption benefits amount to $28.4 billion, and improved water quality benefits amount to $31.6 million. Assuming a 500-year return period, the net present value of the DCP is estimated to be $1.8 billion when it operates at capacity and $152 million when it operates at health and safety levels. The overall seismic benefit

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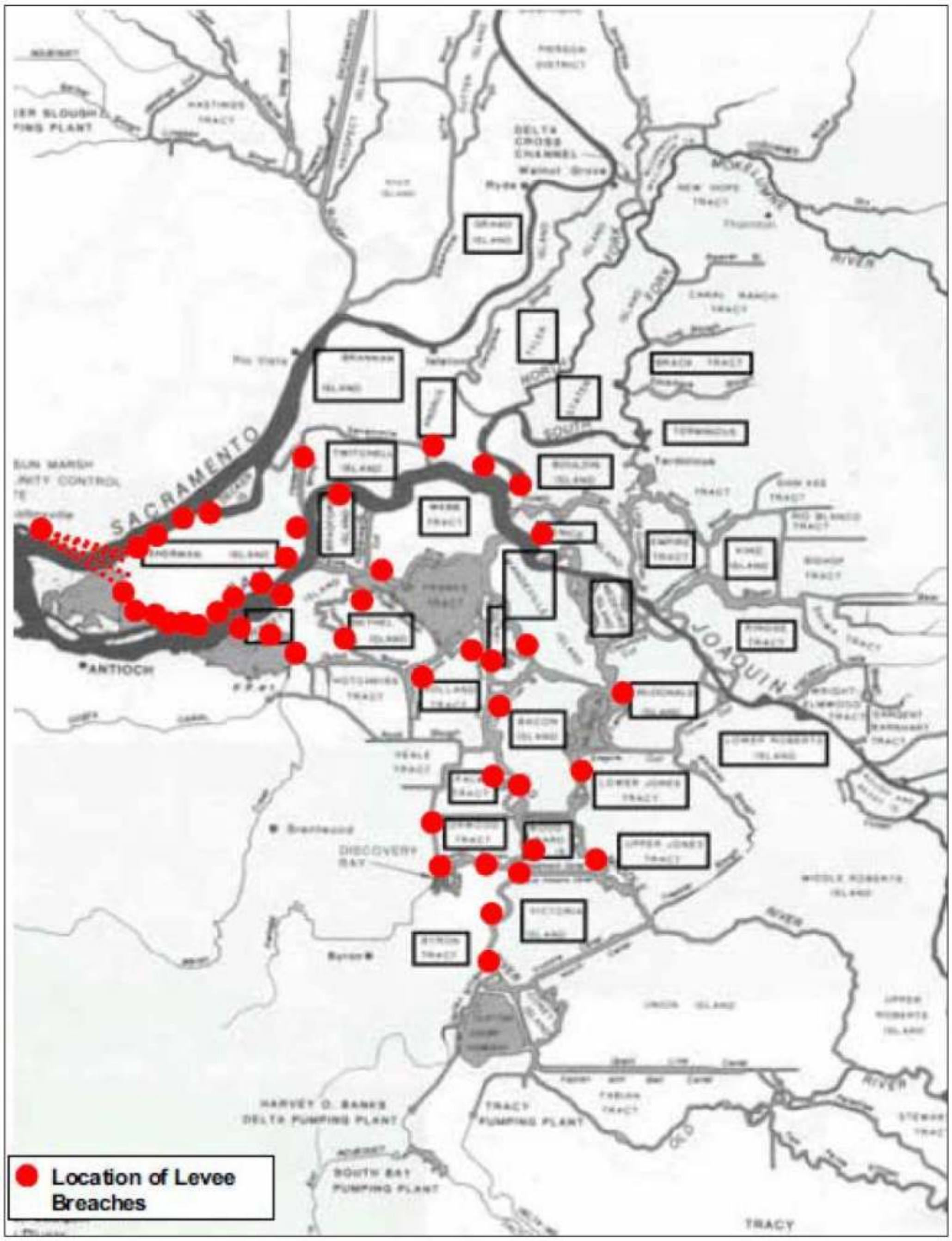
[42] Ibid.

[43] The assumptions of the seismic analysis, based on the ERT, is significantly more conservative compared to an economic analysis this team previously produced for the WaterFix project. The previous analysis assumed more breaches and islands flooded and a significantly more probable earthquake event with a 100-year return period.

[44] Ibid.

estimate takes into account the full range of scenarios by averaging the net present-value estimates under various export disruption, Delta recovery duration, and DCP operating scenarios.

Figure 5: Seismic Scenario Levee Locations



Sources and Notes: Seismic scenario with 50 levee breaches and 20 flooded islands. "Delta Flood Emergency Management Plan – Supplement C, "California Department of Water Resources, October 2018.

Table 4: Benefit Summary under Seismic Disruption Scenarios

			Benefits during Seismic Event		Net Present Value w. 500-year Return Period	
	Export	Delta	$ millions, 2023		$ millions, 2023	
	Disruption	Recovery	Water Supply	Water Quality	Water Supply	Water Quality
Scenario	Days	Days	**Benefits**	**Benefits**	**Benefits**	**Benefits**
DCP Operates at Health & Saftey Levels (500 CFS)						
Minimum Disruption	6	11	$63.3	$0.5	$4.1	$0.2
Average Disruption	203	306	$2,141.3	$5.3	$138.1	$0.3
Maximum Disruption	448	498	$4,725.6	$10.9	$304.9	$0.7
Average			**$2,310.1**	**$5.6**	**$149.0**	**$0.4**
DCP Operates at Capacity (6,000 CFS)						
Minimum Disruption	6	11	$759.5	$6.3	$49.0	$0.4
Average Disruption	203	306	$25,695.7	$63.3	$1,657.8	$4.1
Maximum Disruption	448	498	$56,707.7	$130.4	$3,658.5	$8.4
Average			**$27,721.0**	**$66.7**	**$1,788.4**	**$4.3**

Sources and Notes: Benefits calculated under the 20 island / 50 breach scenario with the Middle River Corridor response strategy.

All benefits valued in millions of 2023 dollars.

7. Other Benefits not Explicitly Valued

The analysis of benefits in the previous four sections concentrates solely on those that can be reliably measured and quantified. However, the DCP is expected to yield additional benefits that are not included in this analysis, primarily because the necessary data to quantify them are unavailable.

- The DCP creates **redundancy in the Delta conveyance** that will enhance short-term operational flexibility in the Delta. At certain times, this additional flexibility may allow short-term actions to be undertaken to either increase SWP deliveries (e.g., Article 21 water) or improve water quality. However, this benefit-cost analysis relies on CalSim 3 modeling that has a monthly time step and therefore lacks the granularity to quantify these short-term operational benefits. Therefore, these benefits are underestimated in our current modeling analysis. For example, if the DCP had been operational between January 1 and March 9, 2024, DWR estimates that an additional 909 TAF of water could have been captured by the DCP due to fishery-related regulatory constraints in the South Delta. These constraints are not reflected in our current modeling, resulting in an understatement of program benefits.[45]
- The costs estimate for the DCP includes a **Community Benefits Program,**[46] which is anticipated to fund a variety of specific local projects such as enhancing public safety, improving water and air quality, and developing educational programs and recreational facilities like parks and walking trails. However, this analysis has not attempted to quantify any benefits arising from these investments.
- The DCP could play a role in the **conservation of groundwater resources** in the Central Valley and other parts of California. The increase in SWP deliveries will be a substitute for groundwater in the SWP service area. To the extent that the DCP leads to a reduction in groundwater demand, it will help agencies achieve the goals under the Sustainable Groundwater Management Act (SGMA). A reduction in groundwater demand could also lead to higher groundwater levels and consequently reduced pumping costs. These benefits have not been quantified in this analysis.

[45] See California Department of Water Resources. 2024. *Missed Opportunity*. March 2024. Available: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/Delta-Conveyance/Public-Information/DCP_Missed-Opportunity.pdf.

[46] California Department of Water Resources. 2022. *Community Benefits Program Overview*. June 2022.

8. Project Costs

The DCA has produced two cost estimates for the DCP. The primary cost estimate, based on the project's specifications outlined in the EIR, projects the total design and construction cost at approximately $20.1 billion in undiscounted 2023 dollars. A secondary estimate, referred to as the “project-wide innovations and savings estimate,” considers potential cost reductions through design, construction, and management innovations that do not alter the core project specifications. These innovations lower construction costs by $1.2 billion, bringing the estimate to $18.9 billion. These cost estimates are broken down in Table 5, below.[47]

The cost estimates cover various phases and components of the project. Construction costs, which include major works on tunnels, aqueducts, intakes, and a pumping plant, are detailed in both estimates. For example, in the primary estimate, construction costs include $1.7 billion for two 3,000 cfs intakes, $6.4 billion for tunnels and shafts, and $3.2 billion for the pumping plant and related structures, with a 30% contingency adding another $3.5 billion. The secondary estimate slightly reduces these costs due to the anticipated innovations.

In addition to construction costs, other significant expenses include design, planning, and management, which total $3.3 billion in the primary estimate and $3.1 billion in the secondary cost estimate with project-wide innovations.

Other costs, totaling $1.78 billion, are the same in both the primary and secondary cost estimates. These expenses cover land acquisition, environmental mitigation, power, a settlement agreement with the Contra Costa Water District, and a community benefits program. Further details on the environmental mitigation and community benefits programs are provided in the sections below.

Construction is scheduled to take place between 2029 and 2044, with the highest rate of spending focusing on the tunnels and aqueducts occurring between 2035 and 2040. Before 2029, expenditures are mainly for project design, planning, and land acquisitions. The project's cumulative cost trajectory is displayed in Figure 6 below.

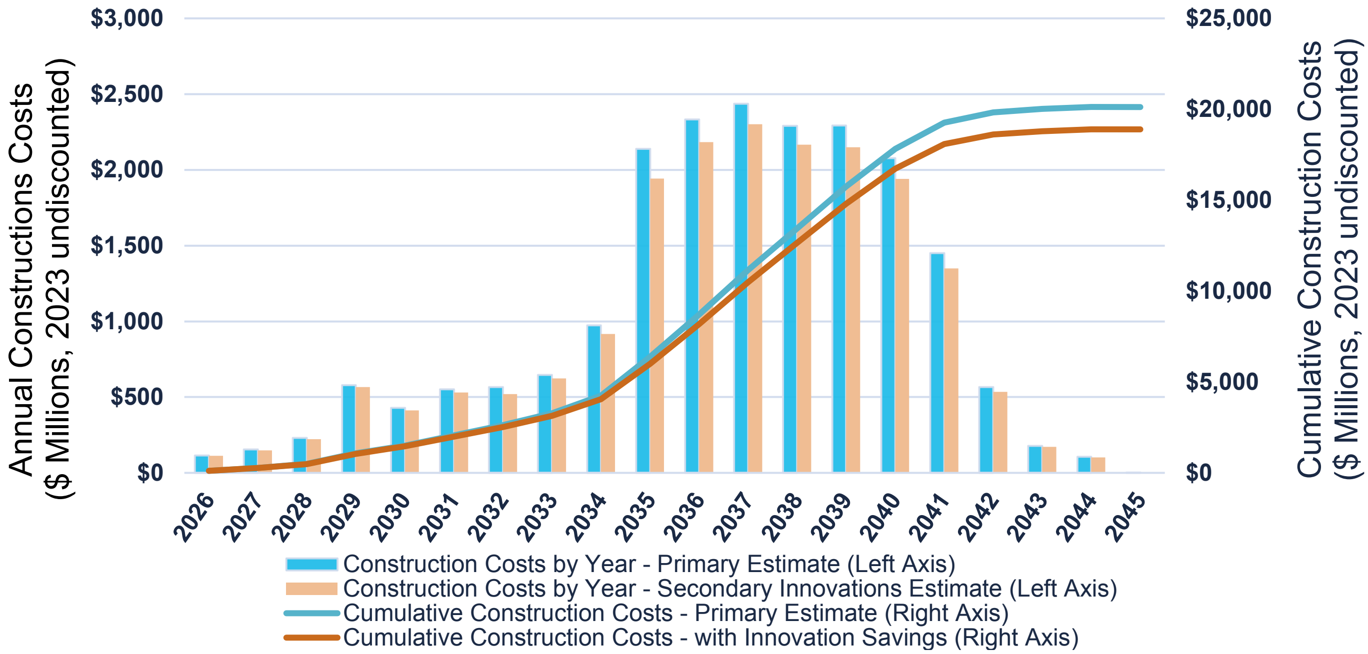
[47] Note that these are undiscounted and not directly comparable to the costs presented in Table 1 and Table 8.

Table 5: Project Construction Costs

Cost Category	Primary Cost Estimate	Costs w. Project-wide Innovations & Savings
Construction	$ Millions, 2023	
Intakes	$1,714	$1,678
Main Tunnels	$6,353	$6,130
Pumping Plant & Surge Basin	$2,536	$2,160
Aqueduct Pipe & Tunnels	$563	$485
Discharge Structure	$99	$58
Access Logistics & Early Works	$253	$234
Communication	$13	$13
Restoration	$17	$17
Construction Subtotal	**$11,548**	**$10,775**
Contingency (30%)	$3,464	$3,233
Total Construction Cost	**$15,012**	**$14,008**
Other Project Costs		
DCO Oversite	$426	$398
Program Management Office	668	$623
Engineering/ Design /Construction Management	$2,167	$2,022
Permitting and Agency Coordination	$67	$63
Total Planning/Design/Construction Management	**$3,328**	**$3,106**
Land	$158	$158
DWR Mitigation	$960	$960
Power	$415	$415
CCWD Settlement Agreement	$ 47	$47
Community Benefits Program	$200	$200
Total Other Costs	**$1,780**	**$1,780**
Grand Total	**$20,120**	**$18,894**

Sources and Notes: Costs measured in millions of undiscounted 2023 dollars and not escalated to the time of construction. For the secondary cost estimate, the planning, design, and construction management costs are assumed to be the same percentage of construction as the primary cost estimate. Cost estimate provided by the DCA.

Figure 6: Construction Costs by Year



Sources and Notes: DCA Cost Estimate, March 2024

8.1 ENVIRONMENTAL MITIGATION COSTS

The design and construction of the DCP incorporate environmental commitments and best management practices to minimize the environmental impacts of the project's construction and operation, as required under the California Environmental Quality Act (CEQA). The project's EIR evaluates its environmental and socio-economic impacts on more than 20 different areas. The report proposes mitigation measures to meet requirements under CEQA (i.e., the project adopts feasible mitigation measures where available to reduce significant impacts to a "less-than-significant" level). The DCA budgets $960 million for proposed mitigation measures to meet these requirements. These costs include items for tribal monitoring, mitigation plan development, habitat mitigation (including compensatory mitigation), and other significant mitigation, as described in the EIR.

For some environmental impacts identified in the EIR, it is not feasible to mitigate impacts to less-than-significant levels. In these cases, compensatory measures and resource specific mitigation are considered.[48] The

[48] DCP EIR.

costs associated with remaining environmental impacts that cannot be mitigated to less-than-significant levels are estimated in Section 10 and Appendix C and incorporated into the benefit-cost analysis.

8.2 COMMUNITY BENEFITS PROGRAM

The proposed DCP includes a $200 million Community Benefits Program to support local communities affected by the project, beyond what's required by CEQA and other laws. This program will collaboratively provide resources to those most affected, including tribal groups, local residents, government agencies, non-governmental organizations, and other Delta stakeholders.[49]

The program consists of two main parts:

- The **Delta Community Fund** aims to finance projects that preserve and enhance the Delta's cultural, historical, recreational, agricultural, and economic aspects through community-led initiatives. It will support projects related to water and air quality, public safety, recreation, habitat conservation, cultural celebrations, economic growth, transport and communication infrastructure, agriculture, education, and levee maintenance.
- The **Economic Development and Integrated Benefits Program** will focus on economic growth by hiring locally and involving businesses in construction of the DCP. It also includes plans to build or repurpose construction features for community use.

[49] EIR, Appendix 3G, California Department of Water Resources.

9. Operation and Maintenance Costs

The DCP's annual operations and maintenance (O&M) costs were estimated by the DCA and DWR to be approximately $52.6 million per year in undiscounted 2023 dollars. This estimate includes DWR's O&M labor, materials, equipment refurbishments and replacements, power, and restoration sites during the first 100-year lifespan of the proposed project.[50] Table 6 breaks down the annual DCP O&M costs for each component listed in the formula above.

The facility O&M cost is calculated with the labor rates of relevant civil engineers, mechanical engineers, electrical engineers, and hydroelectric plant technicians and contractors. The material costs include periodic activities such as sediment removal and disposal, repaving, and sealing roadways and parking lots. The power cost associated with moving water through the DCP system is estimated using CalSim 3 monthly modeling, averaging over all water year types, including critical and dry years. The O&M costs associated with restoration sites, including farmland, levee, channel margin, tidal, and other habitats, consist of ground and vegetation management, access work, monitoring, and other restoration needs.

Table 6: Operation and Maintenance Costs

	Annual O&M Costs
Category	$ Millions, 2023
Water Facility Costs	
Facility O&M	$17.5
Material Cost	$0.5
Power Cost	$2.7
Capital Equipment Refurbishment	$4.8
Capital Equipment Replacement	$18.7
Restoration sites Costs	
Restoration sites O&M Cost	$84
Total Annual O&M Costs	**$52.6**

Sources and Notes: Average annual power cost only includes the energy needed to convey 621,266 AF of water through the tunnel from the North Delta Intake to an average South Delta elevation. It does not include the energy needed to move additional water through the entire SWP system. From DWR's O&M annual cost estimate basis for Bethany reservoir alternative memorandum.

[50] California Department of Water Resources. 2024. *O&M Annual Cost Estimate Basis for Bethany Reservoir Alternative*. April 2024.

10. Remaining Environmental Impacts after Mitigation

This section provides a brief overview of the estimation of the costs associated with environmental impacts identified as being "significant" or "significant and unavoidable" after mitigation in the project's EIR. Additional details on these impacts and the process for estimating the associated costs is provided in Appendix C. Of the 223 areas for environmental and socio-economic impacts reviewed in the EIR, impacts on eight of these areas are identified as being "significant and unavoidable" after proposed mitigation measures. For four of these areas, aesthetic, cultural, paleontological, and tribal impacts, we do not attempt to assign any costs to the remaining economic impacts because there is not a generally accepted economic best practice for valuing costs of those nature. In four remaining areas, we estimate the costs of remaining environmental impacts following best practices form the economics literature:

- Lost agricultural land in the Delta
- Construction-related air quality impacts
- Construction-related noise impacts
- Construction-related transportation impacts

To ensure our assessment considers all salinity impacts of the DCP, including both benefits and costs, this section also quantifies the costs related to increased salinity for agricultural water users in the Delta, even though the EIR found this increase to be insignificant.

In terms of lost agricultural land, the construction of the DCP will result in both permanent and temporary effects on certain land parcels in the Delta. To value the loss of farmland, we rely on average market or rental prices by county and crop type. In present-value terms, the total cost of the farmland conversion is estimated to be $22.6 million, of which $2.9 million is associated with temporary farmland conversion and the remaining $19.7 million is associated with permanent farmland conversion. Of the permanent impacts, the crop types with the highest value of converted land are alfalfa, grapes, and almonds.

Project construction will increase airborne emissions across three California air districts: Sacramento Metropolitan Air Quality Management District (SMAQMD), San Joaquin Valley Air Pollution Control District (SJVAPCD), and the Bay Area Air Quality Management District (BAAQMD). These increased emissions will impose social costs to affected areas, which we quantify using estimates published by the U.S. Environmental Protection Agency (EPA). Applying these social cost metrics to total estimated pollution emissions attributable to the DCP, we estimate a total social cost of $48.7 million in present-value terms. Note that this section does not estimate the impacts of greenhouse gas emissions associated with construction and operation of the DCP because these emissions will be offset by a proposed mitigation program that is included in the project's costs.

DCP construction is also expected to create noise nuisance in the local areas surrounding construction sites. The impact of construction noise on residents can best be quantified using the hedonic pricing method. Based on a review of relevant literature, we assume a temporary 14% drop in residential home prices for approximately 800 homes affected by project noise for the duration of the noise impacts.[51] This temporary price drop is applied to average housing values in the relevant property and rental markets. In present-value terms, we estimate a total of $6 million in remaining noise impacts across the construction period after mitigation measures are undertaken. This estimate does not include the cost of the mitigation measures, such as window replacement and temporary relocation, whose costs are accounted for as part of the project's environmental mitigation costs.

Finally, DCP construction will most likely affect 120 road segments. To calculate the economic impact of the travel delays on these road segments, we consider historical traffic data and each roadway's speed limit. Then, by approximating the average speed of travel on a congested roadway, we obtain the increased travel time resulting from DCP construction. Multiplying this by a range of opportunity costs for time lost due to traffic, we estimate the social cost to be $78.8 to $105.3 million, with a midpoint of $84.7 million in present-value terms.

The estimated impact of increased salinity on Delta yields, calculated in present-value terms, is $68.53 million due to the higher demand for irrigation water. Modeling from the EIR indicates this increase to be an average change in EC of 0.008 dS/m across the Delta. Although this change in salinity is deemed "less than significant" in the EIR, these costs are still incorporated into our analysis. Similar to cost discussion in Section 5.2, the costs of increased salinity are based on the additional water requirements to leach soils and manage salinity levels. Using detailed crop coverage data from the USDA, the calculation included the irrigation requirements and leaching fractions necessary to maintain salinity below the thresholds that cause yield loss.

Table 7, below, summarizes the total cost of the remaining environmental costs after mitigation quantified in this report. The total cost of these impacts after mitigation is $248 million in present-value terms, or $167 million in discounted terms.

Table 7: Costs of Remaining Environmental Impacts after Mitigation

Total Costs	$ Millions, 2023
Agriculture	$25.9
Air Quality	$61.3
Noise	$7.7
Transportation	$84.7
Delta Salinity	$68.5
Total	**$248.1**

Sources and Notes: All costs measured in millions of 2023 undiscounted dollars. See Appendix C for cost breakdown within each category.

[51] We use the low end of the 14% to 18% range estimated by a 2016 study on housing price impacts from railroad noise.

11. Benefit-Cost Ratio and Sensitivity Analysis

11.1. BENEFIT-COST RATIO ESTIMATE

Table 1, shown in the executive summary, presents the results from our main benefit-cost scenario. The primary estimate, based on a 2070 median climate scenario with 1.8 feet of sea-level rise, shows an overall benefit of $38.0 billion, measured in discounted 2023 dollars. The majority of this benefit comes from urban water supply, valued at $33.3 billion (87%). Agricultural water supply benefits, the second-largest component, are valued at $2.3 billion. The DCP also significantly enhances water quality, providing $1.3 billion in benefits for urban customers and $90 million for agricultural customers. In addition, by adding redundancy to the existing water supply infrastructure, the expected benefits for a 500-year earthquake include $969 million for reduced water supply disruption and $2 million for improved water quality.

On the cost side, two scenarios are considered: the primary scenario, based on the costs of building the project as currently described in the EIR, and a secondary scenario, incorporating project-wide innovations and savings. When discounted to present values, the total costs in the primary scenario, including construction, other project costs, the Community Benefit Program, environmental mitigation, O&M costs, and the costs of remaining environmental impacts, amount to $17.3 billion. The secondary scenario, with project-wide innovations and savings, the total costs amount to $16.3 billion. The levelized cost of water from the DCP is calculated by discounting the total costs of the project over its lifetime and then dividing this by the discounted total volume of water deliveries. In the primary scenario, this results in a cost of $1,327 per acre-foot, while in the secondary scenario, which includes project-wide innovations and savings, the cost is $1,255 per acre-foot.[52]

The benefit-cost ratio is calculated by dividing the present value of total benefits by the present value of total costs. In the primary scenario, we find a benefit-cost ratio of 2.20, and in the secondary scenario, the ratio is 2.33. This means that for every dollar spent on the DCP, the expected benefits are worth $2.20 in the primary scenario and $2.33 in the secondary scenario. Under either cost estimate, the benefits of the project significantly exceed the costs.

[52] Levelized cost of water is calculated with the formula $LCOW = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+r_t)^t}}{\sum_{t=1}^{n} \frac{Q_t}{(1+r_t)^t}}$ where C_t is the cost associated with the DCP at time t, Q_t is the volume of additional SWP deliveries as a result of the DCP at time t, and r_t is the discount rate at time t.

This methodology is described in more detail here:
Fane, Simon, J. Robinson, and S. White. 2003. The Use of Levelized Cost in Comparing Supply and Demand Side Options. In *Water Science and Technology: Water Supply* 3, No. 3 (2003):185–192.

11.2. SENSITIVITY ANALYSES

Table 8 compares the results from the main benefit-cost scenario to five sensitivity scenarios. The primary estimate, as discussed in Section 2.3, is based on a 2070 median climate scenario with 1.8 feet of sea-level rise. The sensitivity analyses compare benefits of the project under various climate, sea-level rise, and adaptation scenarios.

Sensitivity analysis 1, which incorporates adaptation measures into the main scenario, estimates total benefits and a benefit-cost ratio of $38.0 billion and 2.20, respectively. The adaptation assumptions in Scenario 1 include improved SWP operations. However, their impact on contractors is mixed (i.e., relaxed water quality standards and the fallowing policy enhance water supply reliability, while Delta export restrictions diminish it). Overall, benefits still exceed costs, and the net impact of the adaptation assumptions is nearly zero.

Sensitivity analyses 2 and 3 assume an extreme sea-level rise of 3.5 feet and find higher benefits due to the low DCP deliveries and water supply reliability in the no-project scenario. Scenario 2 has benefits of $45.4 billion and a benefit-cost ratio of 2.63. Scenario 3, which adds the adaptation assumptions, has benefits of $42.3 billion and a benefit-cost ratio of 2.45.

Sensitivity analyses 4 and 5 are based on 2040 climate scenarios and therefore reflect less severe climate change and water scarcity. Analysis 4, using a median ensemble of climate models, finds benefits of $30.6 billion and a benefit-cost ratio of 1.78, while Analysis 5, using a CT ensemble, finds benefits of $26.6 billion and a benefit-cost ratio of 1.54.

Across all scenarios, the benefits of the DCP range from $26.5 billion to $45.4 billion, consistently exceeding costs and passing the benefit-cost ratio test. The DCP is economically viable and robust under various future climate scenarios, with the greatest benefits seen in the extreme 2070 median scenario, with a 3.5-foot sea-level rise. Even in the 2040 scenarios, the benefits still outweigh the costs.

Table 8: Sensitivity Analysis

	Main Scenario	Sensitivity Analyses				
		1	2	3	4	5
	2070 Median w. 1.8' SLR	2070 Median w. 1.8' SLR & Adaptation	2070 Median w. 3.5' SLR	2070 Median w. 3.5' SLR & Adaptation	2040 Median w. 1.8' SLR	2040 Central Tendency w. 1.8' SLR
$ Millions, 2023	**Benefits**					
Urban Water Supply and Reliability	$33,300	$33,395	$40,847	$37,729	$25,940	$21,642
Agricultural Water Supply and Reliability	$ 2,268	$ 2,221	$2,211	$2,165	$2,317	$2,520
Urban Water Quality	$ 1,330	$ 1,330	$1,330	$1,330	$1,330	$1,330
Agricultural Water Quality	$ 90	$ 90	$90	$90	$90	$90
Seismic Reliability Benefits (Water Supply)	$969	$969	$969	$969	$969	$969
Seismic Reliability Benefits (Water Quality)	$ 2	$ 2	$2	$2	$2	$2
Total Benefits	$37,960	$38,008	$45,449	$42,285	$30,648	$26,553
	Costs					
Construction Costs	$11,486	$11,486	$11,486	$11,486	$11,486	$11,486
Other Project Costs	$ 3,021	$ 3,021	$3,021	$3,021	$3,021	$3,021
Community Benefit Program	$153	$153	$153	$153	$153	$153
Environmental Mitigation	$735	$735	$735	$735	$735	$735
O&M Costs	$ 1,697	$ 1,697	$1,697	$1,697	$1,697	$1,697
Environmental Impacts after Mitigation	$167	$167	$167	$167	$167	$167
Total Costs	$17,259	$17,259	$17,259	$17,259	$17,259	$17,259
Benefit-Cost Ratio	**2.20**	**2.20**	**2.63**	**2.45**	**1.78**	**1.54**

Sources and Notes: All benefits and costs are measured in millions of discounted 2023 $. A declining discount rate is used from 2% to 1.4%, consistent with guidance from OMB. The primary estimate considers the 2070 median climate with 1.8 feet of sea-level rise. The sensitivity analyses vary in terms of climate assumptions, sea-level rise, adaptation measures introduced to reduce operational risks for the State Water Project

12. Conclusions

This report has conducted a benefit-cost analysis of the proposed DCP. The project’s benefits are estimated in terms of water supply reliability and water quality, in light of anticipated climate change, future sea-level rise, and seismic risks. The project’s costs are estimated in terms of capital and O&M costs as well as the costs of mitigated and unavoidable environmental impacts. We consider the difference in the total benefits and costs between a scenario in which the proposed project is built and a no-project scenario. We estimate a benefit-cost ratio of 2.20.

In addition to the primary estimate of the benefit-cost ratio, a number of sensitivity analyses are conducted that consider various scenarios for climate and sea-level rise. The additional deliveries under the project scenario relative to the no-project scenario are similar across all sensitivity analyses, and consequently, the benefit-cost ratio remains above 1.5 in all scenarios. The DCP's benefits tend to increase in scenarios with more extreme climate change, assuming the project continues to deliver similar incremental water supplies.

Appendix A: Works Cited

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Appendix B: Additional Details on Estimation of Urban Water Supply Reliability Benefits

This appendix provides additional details on the methodology that is used to estimate the urban water supply reliability benefits. These benefits are estimated using a framework that is described in several peer-reviewed academic papers including Brozovic et al. (2007), Buck et al. (2016), and Buck et al. (2023) and the text in this appendix has been closely adapted from those works.[53]

B.1. FRAMEWORK FOR CONSUMER WELFARE LOSS ANALYSIS

Urban consumers are evaluated using a measure of willingness to pay to avoid observed water supply reductions. This same approach is adopted in other works in the recent peer-reviewed literature including Brozovic et al. (2007), Buck et al. (2016), and Buck et al. (2023). Under this approach, welfare losses are measured as the area under an estimated demand curve and above estimated marginal costs. Figure B-1 shows a visual illustration of this area representing the consumer welfare losses experienced in response to water supply disruptions. The demand curve in Figure B - 1 depicts a constant-elasticity demand curve, a curve in which a one percentage change in water prices leads to a constant percentage change in consumption of water at any baseline level of consumption. In this figure the welfare loss from a reduction in water supply from Q^* to Q^R is equal to the area shaded in grey. This welfare loss has two components: 1) a consumer welfare loss equal to the triangle that is shown with an arrow on the figure and 2) a loss in revenue for the utility that is equal to the square below the triangle or $P^*(Q^* - Q^R)$. The remainder of this sub-section uses economic theory to formalize this approach to estimating consumer welfare losses.

[53] Brozović, Nicholas, David L. Sunding, and David Zilberman. 2007. Estimating Business and Residential Water Supply Interruption Losses from Catastrophic Events. In *Water Resources Research,* 43, No. 8 (2007).

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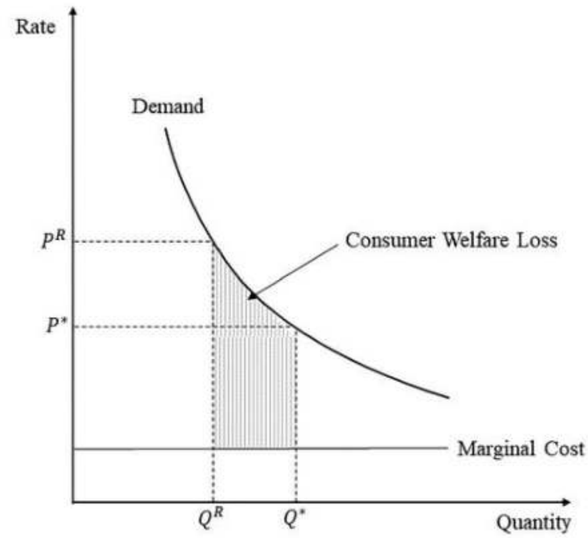
Figure B - 1: Depiction of Welfare Losses under Demand Curve



Source: Buck, Steven, Mehdi Nemati, and David Sunding. "Consumer Welfare Consequences of the California Drought Conservation Mandate." *Applied Economic Perspectives and Policy* 45, no. 1 (2023): 513.

The severity of the water supply disruption in region i at time t is denoted as $z_{it} \in [0;\ 1]$, where $z_{it} = 0$ corresponds to a complete outage and $z_{it} = 1$ corresponds to the baseline level of service. Let $f_{it}(z_{it})$ represent the probability density function of residential water disruption z_{it} in region i at time t and let $W_i(z_{it})$ denote consumer willingness to pay to avoid a supply disruption z_{it} in region i at time t. For a period of duration T until baseline water service is reestablished, consumer willingness to pay to avoid a cumulative service disruption across sectors I regions and T periods is given by:

$$W = \sum_{t=1}^{T} \sum_{i=1}^{I} \int_0^1 W_i(x) f_{it}(x) dx$$

with x as the variable denoting the values z_{it} can assume. For a given region and time, the computation of $W_i(z_{it})$ involves integrating the area under a demand curve for a supply disruption level of z_{it}. Specifically, willingness to pay to avoid a supply disruption of magnitude z_{it} in region i at time t can be defined as:

$$W_i(z_{it}) = \int_{Q_i(z_{it})}^{Q_i^*} P_i(x) dx,$$

where $P_i(Q_i)$ is the (inverse) demand function for residential water in region i, $Q_i^* = Q_i(z_{it} = 1)$ is the baseline quantity of water delivered to residences in region i prior to a supply disruption, and $Q_i(z_{it})$ is the quantity of supply available after a water supply disruption in region i at time t.

Consumer willingness to pay to avoid a (contemporaneous) water supply disruption of a given magnitude i is calculated for each region by constructing an aggregate demand curve to represent the residential water segment. For utilities with a uniform pricing structure, $P_i^* = P_i(Q_i^*)$ is the volumetric rate paid by residential homeowners under baseline conditions prior to the water supply disruption in region i. For regions with an increasing block pricing (IBP) structure, P_i is the marginal rate paid by a representative residential consumer in region i corresponding to the tier on which the last unit of household water consumption occurred.

Ratepayer welfare losses that result from water supply disruption in a given market are mitigated to the extent that delivering a smaller quantity of water reduces the system-wide cost of water service. The ratepayer welfare loss that occurs in region i following a water supply disruption is therefore the difference between the measure in the first equation and the avoided cost of service. If water service is characterized by constant unit cost at the prevailing baseline price level, P_i, then the avoided cost of service is $P_i^*\left(Q_i^* - Q(z_{it})\right)$, and the ratepayer welfare loss following a water supply disruption of a given magnitude reduces to the usual consumer surplus triangle.

Let $c_i(z_{it})$ denote the avoided unit cost of service in region i at time t. Accordingly, the contemporaneous ratepayer welfare loss in region i of a given magnitude water supply disruption is given by:

$$L_i(z_{it}) = \int_{Q_i(z_{it})}^{Q_i^*} P_i(x) - c_i(x)dx$$

Once again, notice that the contemporaneous welfare loss in this equation corresponds with a consumer surplus measure in the case where $c_i(z_{it}) = P_i^*$. In this case, the equation reduces to:

$$L_i(z_{it}) = \int_{Q_i(z_{it}}^{Q_i^*} P_i(x)dx - P_i^*(Q_i^* - Q(z_{it}))$$

The expression for losses in the above equation is a lower bound on the economic loss experienced by ratepayers and corresponds to the case of marginal cost pricing. For a period of duration T until baseline water service is reestablished, the ratepayer welfare loss in the residential (R) sector resulting from a cumulative service disruption across I regions and T periods is given by:

$$L^R = \sum_{t=1}^{T} \sum_{i=1}^{I} \int_0^1 L_i(x) f_{it}(x)dx$$

where $L_i(z_{it})$ is defined in the previous equation. We note that L^R represents aggregate expected losses across I regions between the current period and period T, which reflects the value of a perfectly reliable supply.

B.2. ECONOMETRIC MODEL OF WATER DEMAND

To operationalize the theory in Section B.1, we need to estimate the function $P_i(Q_i)$. A key parameter in estimating $P_i(Q_i)$ is the price-elasticity of demand. We rely on estimates of demand elasticity produced in Buck et al. (2016).[54] This paper estimates utility-specific demand elasticities from a panel of utility service area level water price and consumption data. The main challenge in this estimation is avoiding simultaneity bias, typically addressed by including year fixed effects and considering utility fixed effects to control for unobserved time-invariant characteristics. The study avoids the endogeneity issue, common with increasing block price schedules, by using the median tier price of each utility's tiered pricing schedule and instrumenting this price with lagged prices. Additionally, the research considers different pricing structures, like uniform pricing and increasing block pricing (IBP), as they may affect the estimated price elasticity of demand. The study addresses the complications introduced by increasing block pricing by using an instrumental variables approach where price tiers are used as instruments for the median price.

The authors estimate a regression consumer demand on water rates using the following equation:

$$\ln(q_{it}) = \beta_1 \widetilde{\ln(p_{it})} + \beta_2 \widetilde{\ln(p_{it})} \ln(y_{it}) + \mu_i + \tau_t + \xi_{it}$$

Where q_{it} is average consumption in utility i at time t. $\widetilde{\ln(p_{it})}$ is an instrumented measure of median rates, y_{it} is median household income within the utility service area, μ_i are utility fixed effects, τ_t are year and month fixed effects and ξ_{it} are controls for weather. Using this approach, the authors produce the regression estimates shown below in Table B - 1.

In the paper, these estimated coefficients are subjected to a number of robustness checks regarding impact of increasing block pricing, drought, and other omitted variables and found to be reliable. Since the data in this paper is dated, in the next section we recalculate utility-specific demand elasticity estimates based off of the most recent data on each utility's rates, income, and demand.

[54] Buck, S., M. Auffhammer, S. Hamilton, and D. Sunding. 2016. Measuring Welfare Losses from Urban Water Supply Disruptions. In *Journal of the Association of Environmental and Resource Economists*, 3(3), 743–778.

Table B - 1: Econometric Estimate of Water Demand from Buck et al. (2016)

	OLS (1)	OLS (2)	IV (3)	OLS (4)	IV (5)
ln(Price)	0.173	-0.100***	-0.143***	-0.591***	-0.637***
	(0.120)	(0.033)	(0.046)	(0.194)	(0.242)
ln(Price) x ln(Income)				0.110**	0.113**
				(0.041)	(0.050)
Observations	453	453	453	453	453
Weather controls	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
Utility fixed effects	No	Yes	Yes	Yes	Yes

Note.—Standard errors clustered at the water utility level reported in parentheses.
* p < .10.
** p < .05.
*** p < .01.

Source: Buck, S., Auffhammer, M., Hamilton, S., & Sunding, D. (2016). "Measuring Welfare Losses from Urban Water Supply Disruptions," *Journal of the Association of Environmental and Resource Economists*, 3(3), 743-778.

B.3. ESTIMATION OF WELFARE LOSSES

This subsection describes the derivation of the function that is used to estimate welfare losses from water shortages. This derivation is presented in more detail in Buck et al. (2016). We assume a constant elasticity of demand specification:

$$P_i = A_i Q_i^{1/\varepsilon_i}$$

for $i = 1 \ldots n$, where ε_i is the price elasticity of water demand in region i and A_i is a constant. Let P_i and Q_i, respectively, denote the retail water price and quantity of water consumed by residential households in region i under baseline conditions. For a given water supply disruption with an available level of water given by $Q_i(z_{it}) < Q_i^*$, it is helpful to define the relationship between these quantities in terms of the percentage of water rationed in region i at time t, r_{it}, as

$$Q_i(z_{it}) = (1 - r_{it})Q_i^*.$$

Based on the preceding equations, the welfare loss following a supply disruption of magnitude z_{it} in region i at time t can be calculated as:

$$L_i(z_{it}) = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* Q_i^* \left[1 - (1-r)^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] - \int_{Q_i(z_{it})}^{Q_i^*} c_i(x)dx.$$

Under the assumption of a flat marginal cost curve, we can rewrite this equation in terms of average loss per unit of shortage:

$$\frac{L_i}{Q_i^* r_{it}} = \frac{\varepsilon_i}{1+\varepsilon_i} P_i^* \left[1 - (1 - r_{it})^{\frac{1+\varepsilon_i}{\varepsilon_i}}\right] / \, r_{it} - c_i,$$

where c_i is a constant per unit marginal cost. This makes clear that conditioned on a supply disruption r_i, the welfare implications of a supply disruption in a particular region depends on heterogeneity in (i) price elasticities, (ii) initial prices, and (iii) the variable cost of water service, where ii and iii provide insight into the extent to which fixed costs are bundled into volumetric rates.

Using the above equations, we calculate welfare losses from shortages for State Water Contractors and Metropolitan Water District customers under both the project and no-project scenarios. In our calculations, P_i is each districts' median-tier water rate. Where possible we rely on forecast rates for the year 2045 that are produced as part of the district's planning process. Otherwise, current rates are used based on the most recent available data. It is assumed that there is no increase in real rates for the duration of our estimate. Where a State Water Contractor is a wholesaler that serves multiple retailers, a median rate is calculated across all retailers. Baseline Demand, Q_{it}^*, is based on each demand forecast produced by each district as part of their resource planning process. Shortages, r_{it}, are calculated based on district specific reliability modeling. Long-run variable costs for water deliveries, c_i, are calculated based on data reported in the State Water Project's Bulletin 132-19.[55]

Due to the constant elasticity of demand assumption, welfare losses in our model are unbounded as shortages become increasingly large. In the model, we have limited consumer welfare losses at a marginal value of $10,000 per acre-foot, which is approximately equal to the costs of providing emergency water supplies to residential and commercial customers via truck.[56]

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[55] California Department of Water Resources. n.d. *Bulletin 132, Management of the California State Water Project.*

[56] Brozović, Nicholas, David L. Sunding, and David Zilberman. 2007. Estimating Business and Residential Water Supply Interruption Losses from Catastrophic Events. In *Water Resources Research*, 43, No. 8 (2007).

Appendix C: Additional Details on Costs of Remaining Environmental Impacts after Mitigation

This appendix provides further details on the estimation of the costs of remaining environmental impacts after mitigation provided in Section 10 of the report. The Environmental Impact Report is a comprehensive study that identifies the significant environmental and social impacts associated with the construction of the Delta Conveyance Project. It assesses impacts in over twenty areas and identifies mitigation measures to offset them. After mitigation, remaining environmental impacts are quantified or identified as 'Less than Significant.' The proposed mitigation project will be financed by the environmental mitigation costs discussed in Section 0 and incorporated into the DCA's cost estimates. Several environmental impacts are still identified as being significant after mitigation efforts, particularly in terms of lost agricultural land in the delta region and construction-related air quality, noise, and transportation impacts.

C.1. LOST AGRICULTURAL LAND IN THE DELTA

The EIR identifies parcels of land that would be affected by construction of DCP and categorizes impacts to them as either permanent or temporary. Permanent impacts are described as "resulting from the physical footprint of project facilities" and as "land that cannot be returned to farmland."[57] Impacts that would last for the duration of construction, but for which there also exists post-construction uncertainty were additionally designated as permanent. Temporary impacts are those which would be "largely limited to the duration of construction activities at a given site but could be returned to active farmland after cessation of construction activities."[58]

To value permanent loss of farmland, we rely on the average market prices for farmland by county and crop type. Temporary loss of farmland is valued using the annual rental price by county and crop type. Non-agricultural land impacted by construction, such as seasonal wetlands and miscellaneous grasses, are excluded from the analysis. To value affected cropland, we rely on appraisal values calculated in the "Trend in Agricultural Land and Lease Values" report provided by the California chapter of the American Society of Farm Managers and Rural Appraiser, the largest professional association for rural property land experts. If an appraisal value was not available for an affected crop type and county, we rely on the average value of Delta farmland. In the case of almond croplands, we rely on the mean value per acre across irrigated and well-watered almond cropland. Appraisal values for relevant croplands are presented in Table C-1 below.

[57] DCP EIR, 15–25.

[58] Ibid.

Table C-1: Value of Cropland in Project Area

Crop Type	County	Low Value ($ per Acre)	High Value ($ per Acre)	Mid Value ($ per Acre)
[A]	[B]	[C]	[D]	[E]
Almonds	San Joaquin, Contra Costa, Sacramento	$19,145	$58,499	$38,822
Rangeland Grazing Only	San Joaquin, Contra Costa, Sacramento	$638	$ 3,191	$1,915
Rangeland (perm plant potential)	San Joaquin, Contra Costa, Sacramento	$5,318	$ 9,573	$7,445
Walnuts	San Joaquin, Contra Costa, Sacramento	$19,145	$37,227	$28,186
Wine Grapes	San Joaquin, Contra Costa, Sacramento	$23,400	$42,545	$32,972
Cherries	San Joaquin, Contra Costa, Sacramento	$26,591	$38,290	$32,440
Delta	San Joaquin, Contra Costa, Sacramento	$15,954	$19,145	$17,550
Row Crops	Santa Clara	$26,591	$63,817	$45,204

Sources and Notes:
[A]: These are the crop types with available information in the 2022 ASFMRA report, and values converted to 2023 dollars.
[B]: Note that ASFMRA combines counties into agricultural regions. San Joaquin, Contra Costa, and Sacramento fall into the Northern San Joaquin region, whereas Alameda County is placed in the Central Coast region.
[C] – [D]: The ASFMRA lists a high and a low value for each type of farmland.
[E]: The mid value is just the average of the high and low values listed in the 2022 ASFMRA report.

To value the cost of temporary impacts, we rely on rent values provided by the United States Department of Food and Agriculture's National Agricultural Statistics Service (NASS). NASS rent values are characterized as irrigated and non-irrigated; we calculate a mean across both types. Rental prices are presented below in Table C-2. We calculate the cost of temporary impacts as the product of rental value per acre and the total temporary affected acreage by county. We assume all temporarily affected fields are affected for the entire duration of construction, thereby potentially overestimating the cost of lost farmland.

Table C - 2: Summary of Rent by County for Irrigated and Non-Irrigated Farmland

County	Irrigated Land Rent ($ per Acre)	Non-Irrigated Land Rent ($ per Acre)	Average Land Rent ($ per Acre)
[A]	[B]	[C]	[D]
Alameda	1,414.62	21.27	717.94
Contra Costa	344.61	19.15	181.88
Sacramento	264.84	40.95	152.90
San Joaquin	447.78	36.69	242.24

Sources and Notes:
All rent measured in 2023 dollars.
[A]: Affected counties as described in DCP EIR.
[B],[C]: From the United States Department of Agriculture National Agricultural Statistics Service.
[D]: ([B] + [C]) / 2.

We assume all permanent impacts begin in the first year of construction. Due to discounting, this assumption yields a relatively high estimate of total costs. Acreage impacted is inclusive of the farmland that will be affected by construction of mitigation measures such as on Bouldin Island and within I-5 Ponds 6, 7, and 8.

Using the mean value for the appraisal of farmland and the average value between the rent prices of irrigated and non-irrigated farmland in the four counties, the total undiscounted cost of the farmland conversion is estimated to be $25.94 million, as shown in Table C-3. Of this total, $3.99 million is associated with temporary farmland conversion and $21.96 million are associated with permanent farmland conversion. Of the permanent impacts, the crop types with the highest value of converted land are alfalfa, grapes, and almonds.

Table C - 3: Summary of Costs Associated with Conversion of Farmland

Construction Year	Cost of Temporary Acres Impacted	Cost of Permanent Acres Impacted	Total Cost
($ millions, 2023)			
CY1	$0.249	$21.950	$22.199
CY2	$0.249	$0.000	$0.249
CY3	$0.249	$0.000	$0.249
CY4	$0.249	$0.000	$0.249
CY5	$0.249	$0.000	$0.249
CY6	$0.249	$0.000	$0.249
CY7	$0.249	$0.000	$0.249
CY8	$0.249	$0.000	$0.249
CY9	$0.249	$0.000	$0.249
CY10	$0.249	$0.000	$0.249
CY11	$0.249	$0.000	$0.249
CY12	$0.249	$0.000	$0.249
CY13	$0.249	$0.000	$0.249
CY14	$0.249	$0.000	$0.249
CY15	$0.249	$0.000	$0.249
CY16	$0.249	$0.000	$0.249
Total	**$3.991**	**$21.950**	**$25.941**

C.2. CONSTRUCTION-RELATED AIR QUALITY IMPACTS

This section evaluates the social cost of construction with respect to four pollutants: reactive organic gases (ROG), nitrogen oxides (NO_X), particulate matter less than 10 microns in diameter (PM_{10}), and particulate matter less than 2.5 microns in diameter ($PM_{2.5}$). Project construction will increase emissions across three districts: Sacramento Metropolitan Air Quality Management District (SMAQMD), San Joaquin Valley Air Pollution Control District (SJVAPCD), and the Bay Area Air Quality Management District (BAAQMD). In particular, construction will increase PM_{10} in excess of SMAQMD and SJVAPCD thresholds and increase NO_X emissions above thresholds set in all three districts. Note that this section does not estimate the impacts of greenhouse gas emissions associated with the construction and operation of the DCP because these emissions will be offset by a proposed mitigation programs that are included in the project's costs.

Both nitrogen oxides and particulate matter are associated with negative impacts on human health. Short-term NO_x exposure is associated with respiratory symptoms, especially in people with asthma. Longer-term exposure is associated with development of asthma.[59] In addition to its health effects, NO_x is associated with acid rain, global warming, and nutrient overload. Particulate matter refers to microscopic solids or liquid droplets which are small enough to be inhaled. Particulates less than 10 micrometers in diameter can be inhaled deep in the lungs and absorbed into the bloodstream.[60] Because smaller particulates can be absorbed more deeply into the lungs and bloodstream, $PM_{2.5}$ poses a greater health risk than PM_{10}.

Due to the health risks posed by air pollutants, the DCP incorporates mitigation plans to reduce the impact of project-related emissions. DWR will enter into agreements with the affected air districts to provide offset fees. DWR will establish programs to fund emissions reduction projects which include but are not limited to alternative fuel school busses and transit public vehicles, diesel engine retrofits, electric vehicle rebates, and video-teleconferencing systems and telecommuting start-up costs for local businesses. DWR will additionally fund compensatory mitigation plans which restore wetlands and tidal habitats on Bouldin Island and in the North Delta Arc. A more complete discussion of mitigation plans is found in Chapter 23 of the EIR.

Table C - 4 presents baseline levels of annual pollution and the expected increase across the four studied air quality districts. Project-related pollution constitutes less than a 1% increase in pollution levels in all pollutants and counties except for a 2.2% increase in NO_X emissions in SMAQMD. No significant changes in pollution levels are predicted in Yolo-Solano Air Quality Management District for any of the studied pollutants.

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[59] U.S. Environmental Protection Agency. n.d. *Basic Information about NO_2*. Available: https://www.epa.gov/no2-pollution/basic-information-about-no2#Effects. Accessed: December 6, 2023.

[60] U.S. Environmental Protection Agency. n.d. *Particulate Matter (PM) Basics.* Available: https://www.epa.gov/pm-pollution/particulate-matter-pm-basics#effects. Accessed: December 6, 2023.

Table C - 4: Annual Air Quality Changes between no project and project scenarios (Tons/Year)

		ROG	NOX	CO	PM 10 Total	PM2.5 Total	SO2
Sacramento Metropolitan Air Quality 1 Management District							
Baseline Emissions	[1]	18,849	12,676	75,887	11,779	3,927	303
Increased Emissions	[2]	21	278	603	108	24	0
Percent Increase	[3]	0.1%	2.2%	0.8%	0.9%	0.6%	0.0%
Yolo-Solano Air Quality Management District							
Baseline Emissions	[1]	8,329	6,453	21,864	12,136	2,508	164
Increased Emissions	[2]	0	0	4	0	0	0
Percent Increase	[3]	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Bay Area Air Quality Management District							
Baseline Emissions	[1]	89,976	81,997	331,062	32,730	13,600	8,424
Increased Emissions	[2]	14	147	505	220	34	0
Percent Increase	[3]	0.0%	0.2%	0.2%	0.7%	0.3%	0.0%
San Joaquin Valley Air Pollution Control District							
Baseline Emissions	[1]	117,136	83,384	248,244	97,495	25,130	2,347
Increased Emissions	[2]	15	153	255	120	22	0
Percent Increase	[3]	0.0%	0.2%	0.1%	0.1%	0.1%	0.0%
Total							
Baseline Emissions	**[1]**	**234,290**	**184,511**	**677,057**	**154,140**	**45,165**	**11,238**
Increased Emissions	**[2]**	**50**	**578**	**1,367**	**448**	**80**	**0**
Percent Increase	**[3]**	**0.0%**	**0.3%**	**0.2%**	**0.3%**	**0.2%**	**0.0%**

Sources and Notes:
[1]: California Air Resources Board, "Emissions by Air District," accessed September 2022.
[2]: Environmental Impact Report for the Delta Conveyance Project, Chapter 23B, Table 23-22.
[3]: [2] / [1].

To quantify the social cost of increased pollutants, we apply EPA estimates of social cost per ton. The EPA estimates the social costs of air pollution using BenMAP-CE. The BenMAP-CE model first estimates health impacts using inputs from the published epidemiological literature: air quality changes, population levels, baseline incidence rates, and health effect estimates. The model calculates economic values from these estimates using cost-of-illness and willingness-to-pay metrics. Cost-of-illness reflects expenses associated with pollution-related illness, while willingness-to-pay reflects the more comprehensive toll of pollution related illness, incorporating individuals' reduction in quality of life beyond medical expenses. This analysis relies specifically on BenMAP social cost estimates in the refineries sector: values in 2023 dollars per ton are presented in Table C - 5 below.

Table C - 5: Social Cost of Pollutants

		Social Cost ($ / ton)
ROG	[1]	$14,556
NOX	[2]	$102,016
PM 10	[3]	$12,315
PM2.5	[4]	$465,781
SO2	[5]	$64,425

Sources and Notes:
Social cost reported in 2023 $/ton.
[1], [2], [4], [5]: EPA BenMAP Emissions by Sector.
[3]: Regulatory Impact Analysis of the Proposed Reciprocating Internal Combustion Engines NESHAP.
[3], [4]: For PM10 and PM2.5, social costs are determined using values reported for exhaust.

Applying these social cost metrics to total estimated pollution emissions attributable to the DCP, we estimate a total social cost of $61.29 million.[61] Annual social costs are presented in Table C - 6 below. This estimate is likely an upper bound for two reasons. First, the DCP EIR evaluates its emissions estimates to be an upper bound on expected emissions; if actual increased emissions are lower, then the corresponding social cost will be closer to zero. Second, EPA BenMAP social cost estimates have increased in recent years to reflect a more comprehensive account of social costs. Past EPA estimates have been only looking at the social costs of $PM_{2.5}$ precursors, while the current estimates use both $PM_{2.5}$ precursors and ozone precursors. This causes an increase in social costs of NO_x and ROGs. In a comparable analysis conducted for an earlier version of the project in 2013, the social cost of NO_x was estimated to be $13,691; the current social cost is more than seven times this amount.[62] Because the total costs are driven primarily by increases in NO_x emissions, the change in estimated cost/ton explains 81% of the total social cost of increased air pollution; using the values in the 2013 report, we find a total social cost of $7.1 million.[63] This comparison is not intended to trivialize the impact of air pollutants in the project air districts, but rather to give context to the magnitude of the estimated social cost.

[61] Measured in undiscounted 2023 dollars and assuming preliminary field investigation year (PFIY 1) will begin 2 years from the time of this analysis.

[62] The original input was $11,000; the value in text is adjusted to 2023 dollars.

[63] The 2013 values for social cost are adjusted for inflation. As in the main analysis, we assume a 2% discount rate and that the preliminary field investigation year (PFIY 1) will begin 2 years from the time of this analysis.

Table C - 6: Total Annual Social Cost of Project-Related Air Pollution

Construction Year	Total Social Cost ($ Millions, 2023)
PFIY1	$0.64
PFIY2	$0.64
PFIY3	$0.64
CY1	$1.22
CY2	$0.73
CY3	$1.14
CY4	$4.23
CY5	$9.40
CY6	$10.59
CY7	$8.86
CY8	$6.60
CY9	$6.59
CY10	$6.38
CY11	$2.80
CY12	$0.61
CY13	$0.22
CY14	$0.00
Total	**$61.29**

Notes:
Costs are reported in millions of undiscounted 2023 $. PFIY 1 is assumed to begin two years from the time of this analysis.

C.3. CONSTRUCTION-RELATED NOISE IMPACTS

Construction of the Delta Conveyance Project is expected to increase noise in the local areas surrounding construction sites. The project will primarily impose noise nuisances during the construction of permanent project features over a period of 12 to 14 years. Heavy equipment noise will occur at project sites, and construction of levee improvements, bridges, and other project developments will also generate localized noise disruptions. A more complete description of expected noise impacts can be found in Chapter 24 of the EIR.

Excess noise is a nuisance to local residents. In addition to quality-of-life impacts, excess noise may incur economic costs if, for example, work from home is disrupted or outdoor recreation businesses are negatively affected. The economic value of this nuisance is challenging to quantify; two individuals may experience different burdens from the same level of noise, and the ultimate noise impact itself can depend on factors such as home insulation. To quantify the overall burden of excess noise on a locality, we depend on an econometric method called hedonic pricing. The hedonic pricing method uses the value of related market goods to estimate the value of non-market goods. More specifically, the hedonic pricing method uses statistical techniques to infer the value of environmental attributes, such as noise levels, by comparing values of properties that have a given environmental attribute and those that do not. If houses are comparable across characteristics other than the attribute of interest (in this case, noise), then differences in the market price can be attributed to differences across this attribute.

Common sources of disruptive noise levels include roadways, general construction, airports, railroads, and industrial activity. Roadways are not a close comparison point because they primarily impose ambient noise. Typical construction projects may also be an inappropriate comparison point because the longevity of the DCP construction imposes higher costs than would short-term construction projects. While a perfect comparison is elusive, noise from railroad activity is analogous to DCP construction-related noise because both impose irregular noise impacts and are long-term nuisances. For this analysis, we thus rely on hedonic values derived from a study of housing price differences attributable to railroad proximity. Walker (2016) finds a 14% to 18% decline in residential property values in Memphis, Tennessee, if the property is exposed to sixty-five decibels or greater of railroad noise.[64] The study finds no impact on commercial property values.

Relying on this study, we assume a 14% impact on housing values due to increased noise. We apply this cost metric to average California housing values in both the property and rental markets.[65] The duration of noise disruption varies by location. Of the seventeen locations discussed in the EIR, five experience disruptions lasting five hours to one week, and an additional three locations are not located near any residences. These eight locations are excluded from the social cost analysis. Of the remaining nine locations, five experience disruptions lasting one month to 3.5 years. For these locations, we apply the cost metric to an estimated average California monthly rental price for the duration of the disruption. For the four locations experiencing nine or more years of disruptions, we apply the cost metric to the full property value.

The results of the analysis are presented in Table C - 7 below. We estimate an undiscounted cost of $8.7 million in noise impacts. These estimates assume that disruptive noise begins in the first year of construction. Note that the EIR finds that if all eligible property owners participate in the proposed the Noise Control Plan proposed in the EIR, the impacts would be less than significant.

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[64] Walker, Jay. 2016. Silence is Golden: Railroad Noise Pollution and Property Values. In *The Review of Regional Studies*, 45 (2016), 75–89.

[65] Local housing prices in the affected areas are lower than average California housing values. To conduct a socially equitable analysis, we rely on statewide averages. We assume a home value of $788,679 and a rental value of $7,886.79, or 1% of a home's value.

Table C - 7: Social Cost of Project-Related Noise

Location/ Site	Construction Activity	Duration	Number of Residences Daytime	Damages with Local Average House Values ($ millions, 2023)
Intakes Construction	Pile Driving	42 Months	117	$3.21
	Nighttime concrete pours	2 Months	147	$0.19
	Heavy Equipment	12 years	9	$0.59
Tunnel Shaft Construction	Lower Roberts Island Levee Improvements	1 month	19	$0.01
	Lower Roberts Island RTM Stockpile	9 years	5	$0.33
	Upper Jones Tract Maintenance Shaft Buildout	9 years	1	$0.09
Bethany River Complex Construction	Bethany Reservoir Pumping Plant, Surge Basin and Aqueduct Buildout	13 years	12	$1.70
	Bethany Reservoir Pumping Plant, Surge Basin and Aqueduct night concrete pours	2 months	0	$0.07
Bridges, New Access Roads, Road Improvements, and Park-and-Ride Lots	Construction	1.5 months	450	$0.79
Total				**$6.97**

Notes:
Costs are reported in millions of undiscounted 2023$. The number of residences includes both daytime and nighttime residences. Twin cities complex is shown in this table as there are no adjacent residences that might experience noise impacts.

C.4. CONSTRUCTION-RELATED TRANSPORTATION IMPACTS

This section estimates the costs associated with construction induced traffic delays associated with the construction of the DCP. The costs as estimated based on total time delays estimated in the EIR and U.S. Department of Transportation (DOT) estimates of the opportunity cost of such delays to road users.

The EIR identifies 120 road segments, ranging from local roads to interstate highways, which are likely to be impacted by DCP construction based on the regional and local travel routes of construction workers and estimated truck traffic delivering project materials to and from project features.[66]

[66] Not all segments would be included in the adopted EIR project. For this project, construction access would not be allowed along SR 160 and River Road or along SR 4 between Old River and Middle River. See DCP, Appendix 20A 20A-1.

For each segment, baseline roadway traffic estimates from 6 AM to 7 PM for 2020 were developed using data collected from 2015 to 2019 and adjusted upward to estimate 2020 traffic absent Covid-19 impacts.[67] Within a road segment's range of traffic flows, we assume the upper end during rush hour (7AM to 10 AM and 4 PM to 7 PM) and the lower end during non-rush hour periods.

To estimate the economic impact of travel delays resulting from the construction of the Delta Conveyance Project, we first calculate the speed at which vehicles travel on a congested roadway using the following equation (Singh 1999):

$$Congested\ Speed = \frac{Free\ Flow\ Speed}{1 + 0.20[(\frac{Volume}{Capacity})^{10}]}$$

We assume free flow speed to be the roadway's speed limit. We assume capacity corresponds to a LOS E grade.[68] We estimate baseline volume using the EIR volume estimates discussed above. Average time to traverse the segment in each hour of the day is estimated using the congested speed and length of the segment.[69] Finally, the cumulative time spent across drivers on a given segment is calculated using average time to traverse and the total estimated volume of traffic on the segment during that hour.

The EIR identifies two segments that will deteriorate below acceptable LOS standards during morning and evening commute periods because of construction in listed years. For these segments during these hours, the traffic volume increases to the threshold of LOS E. This assumption constitutes an extreme upper bound, as we assign traffic impacts to the entire year, whereas the EIR expects the maximum volume to be reached only one to two weeks per year. To account for traffic increases which do not result in deterioration below LOS acceptable standards, remaining DCP-related trips are assumed to be distributed across road segments proportionally to the share of baseline traffic on each road segment.

Using the distribution of DCP-related trips across segments and hours, we calculate congested speed with project construction and compare this value to that under the baseline scenario to find the increased travel time resulting from the construction of the Delta Conveyance Project.

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[67] DCP, Appendix 20A 20A-16.

[68] The certified final EIR conducts a level-of-service (LOS) analysis to qualitatively evaluate the level of comfort and convenience associated with driving on a segment at a given time. Segments are assigned a letter grade, wherein LOS A reflects free-flow conditions and LOS F reflects stop-and-go conditions.

[69] To illustrate, if the congested speed is 60 mph and the segment is 60 miles long, then average time to traverse is one hour. This step implicitly assumes that each vehicle will be on the roadway segment for the entire length of the segment. Although this assumption might result in an overestimation of time spent on congested roadways, data are not available on how long each vehicle remains on each roadway segment. Because most segments are freeways and highways, and the average segment is relatively short (3.07 miles), this assumption is reasonable.

To estimate the economic value of increased local travel time under DCP construction, we rely on an opportunity cost methodology. The opportunity cost of a travel delay is the value of the time lost because of additional time spent in traffic. The value of this time differs depending on what the time would have been used for had it not been spent in traffic. As construction will affect both business and personal travel, the value chosen for the opportunity cost of time spent in traffic is representative of both leisure and work. The total delay time is multiplied by estimates of the opportunity cost of a traveler's time used by DOT to assign a monetary value to delay times in regulatory analyses. DOT develops and periodically updates the value of travel time to be used in analyses of proposed regulations. This value is widely used by transportation agencies to estimate the time burden of proposed regulations, including those promulgated by DOT, the Transportation Security Administration, and the U.S. Coast Guard. DOT's 'all purpose' estimate of the value of time is used in the calculation, which is a weighted average of the value of time for both business and leisure trips based on historical rates of each type of trip. DOT estimates an intercity low value of $26.52 and a high value of $35.45.[70]

Using a high and low price for the opportunity cost of time lost in traffic, we develop a range for the total cost associated with the traffic impacts of construction. These results are presented in Table C-8 below. The additional traffic caused by construction incurs an undiscounted social cost of $78.9 million to $105.4 million incurred between 2024 and 2035. Annual costs stemming from traffic delays peak during year six of construction and taper off afterward due to discounting and decreased construction activity.

The estimates presented here constitute an upper bound of total transportation costs. 86.5% of the total time lost in traffic because of construction occurs on the five segments which the EIR states will experience LOS E conditions because of the project during morning and evening commute periods. We assume that these segments will experience LOS E conditions on every construction day of the affected years, but segments are likely to only be affected for a few weeks of the year.

[70] California Department of Transportation. 2016. *Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis*. Values are converted from 2016 dollars to 2023 dollars.

Table C - 8: Costs Associated with Traffic Impacts

Construction Year	Traffic Impact, Day of Construction (hours / day)	Construction Time (days)	Yearly Traffic Impact (hours)	DOT Value of Travel Time Savings ($ / hour)			Yearly Traffic Impact ($ millions, 2023)		
				Low	**Mid**	**High**	**Low**	**Mid**	**High**
[A]	[B]	[C]	[D]	[E]	[F]	[G]	[H]	[I]	[J]
1	23.11	325	7,517.66	$26.52	$28.47	$35.45	$0.20	$0.21	$0.27
2	23.11	325	7,517.66	$26.52	$28.47	$35.45	$0.20	$0.21	$0.27
3	115.64	325	37,613.03	$26.52	$28.47	$35.45	$1.00	$1.07	$1.33
4	161.95	325	52,675.62	$26.52	$28.47	$35.45	$1.40	$1.50	$1.87
5	2,394.28	325	778,740.48	$26.52	$28.47	$35.45	$20.65	$22.17	$27.60
6	2,451.04	325	797,200.68	$26.52	$28.47	$35.45	$21.14	$22.70	$28.26
7	2,394.28	325	778,740.48	$26.52	$28.47	$35.45	$20.65	$22.17	$27.60
8	1,348.98	325	438,754.71	$26.52	$28.47	$35.45	$11.63	$12.49	$15.55
9	104.07	325	33,848.93	$26.52	$28.47	$35.45	$0.90	$0.96	$1.20
10	80.93	325	26,322.62	$26.52	$28.47	$35.45	$0.70	$0.75	$0.93
11	23.11	325	7,517.66	$26.52	$28.47	$35.45	$0.20	$0.21	$0.27
12	23.11	325	7,517.66	$26.52	$28.47	$35.45	$0.20	$0.21	$0.27
						Total	**$78.86**	**$84.67**	**$105.42**

Sources and Notes:
All Yearly Traffic Impact costs measured in millions of undiscounted 2023 $.
[A]: From DCP EIR Appendix 20A Figure 20A-11. Vehicle Trips per Day for DCP project alternative.
[B]: From Total Daily Time lost in Traffic by Year for each Impacted Segment.
[C]: From DCP EIR Appendix 20A, p. 30.
[D]: [B] x [C].
[E] – [G]: From Department of Transportation's 2016 Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis.
[H]: [D] x [E].
[I]: [D] x [F].
[J]: [D] x [G].
[K]: [H] / (1.02 ^ ([A] + 1)).
[L]: [I] / (1.02 ^ ([A] + 1)).
[M]: [J] / (1.02 ^ ([A] + 1)).

C.5. OTHER IMPACTS

The DCP's EIR provides a comprehensive assessment of the impacts of the construction and operation of the project on over twenty different resources. Some of these impacts are identified in the EIR as being less than significant without any mitigation measures.[71] Other resources are identified having impacts from the DCP; however, these impacts are less than significant after the adoption of mitigation measures.[72] Impacts on the following resources are identified in the EIR as being less than significant after the adoption of mitigation measures.[73]

The following impacts are identified in the EIR as being significant and unavoidable, however they are not quantified in this report because there are not appropriate economic tools to estimate a monetary value of their impacts:

- Aesthetic and Visual Resources (Chapter 16)
- Cultural Resources (Chapter 19)
- Paleontological Resources (Chapter 29)
- Tribal and Cultural Resources (Chapter 32)

[71] Specifically, these resources and their respective chapters in the EIR are:
Groundwater, Ch.8; Water Quality, Ch.9; Geology and Seismicity, Ch.10; Land Use, Ch.14; Recreation, Ch.16; Public Utilities and Services, Ch.21; Energy, Ch.22; Mineral Resources, Ch.27.

[72] Groundwater, Ch.8 ; Water Quality, Ch.9; Geology and Seismicity, Ch.10; Land Use, Ch.14; Recreation, Ch.16; Public Utilities and Services, Ch.21; Energy, Ch.22; Mineral Resources, Ch.27.

[73] Flood Protection, Ch.7; Soils, Ch.11; Fish and Aquatic Resources, Ch.12; Terrestrial Biological Resources, Ch.13; Hazards, Hazardous Materials, and Wildfire, Ch.25; Public Health, Ch.26.