Technical Memorandum:
Delta Risk Management Strategy (DRMS) Phase 1

Topical Area:

Impact to Ecosystem

Final

Prepared by:

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URS

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Subject: **Delta Risk Management Strategy**
Final Phase 1 Technical Memorandum – Impact to Ecosystem

Dear Mr. Bagheban:

We are providing the final Impact to Ecosystem Technical Memorandum (TM) (dated July 10, 2008) for Phase 1 of the Delta Risk Management Strategy (DRMS) project. Please see the foreword for a discussion of previous drafts of this TM.

This TM was prepared by Dr. Chuck Hanson, Hanson Environmental, Inc., Jon Rosenfield, d.b.a. Aquatic Restoration Consulting, and Dr. Jeannie Stamberger, Ms. Francesca Demgen, and Mr. David Halsing of URS. This TM was reviewed by Drs. Said Salah-Mars (URS) and Marty McCann (JBA). Internal peer review was provided in accordance with URS' quality assurance program, as outlined in the DRMS project management plan.

Sincerely,

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Topical Area: Ecosystem

Foreword

This Technical Memorandum was revised after the CALFED Science Program Independent Review Panel (IRP) provided its review comments on August 23, 2007. The review comments were particularly critical of the aquatic impact model. Specifically, the comments indicated that the model lacked clarity and robustness. The review panel recommended that the Delta Risk Management Strategy (DRMS) Ecosystem Team use a different approach and suggested the use of an expert elicitation process to develop the new aquatic impact model.

The new aquatic impact models presented in this technical memorandum was developed using input from experts. However, the model application and execution has not been completed because the experts had limited availability during the time frame required to complete the work. The other two models used in this technical memorandum (the vegetation and terrestrial species impact models) were not modified. The overall technical memorandum was edited and updated in accordance with the IRP comments.

The experts convened to help develop the aquatic ecosystem impact models were:

- Dr. Wim Kimmerer (UCSF, Romberg Tiburon Center for Environmental Studies)
- Dr. William Bennett (UC Davis)
- Dr. Peter Moyle (UC Davis)
- Dr. Chuck Hanson (Hanson Environmental, Inc.)

The development of the aquatic impact models relied on input and recommendations from these experts. The approach was phased. The experts developed the general elements of potential impact mechanisms to assess their relevance to the particular application in DRMS (ecosystem impacts as a result of levee failures). Then, each relevant mechanism or its subset was developed separately and presented to the experts for review and comments. Because of the limited availability of the experts to convene more frequently and the schedule constraint to complete the DRMS Phase 1 work, the aquatic model was not fully executed and implemented. Currently, the models have been developed and discussed with the experts and are presented in this TM. Model test runs and the implementation have not yet been performed.

Topical Area: Ecosystem

Preamble

In response to Assembly Bill (AB) 1200 (Laird, chaptered, September 2005), the California Department of Water Resources (DWR) authorized the Delta Risk Management Strategy (DRMS) project to perform a Risk Analysis of the Sacramento–San Joaquin Delta (Delta) and Suisun Marsh (Phase 1) and to develop a set of improvement strategies to manage those risks (Phase 2).

AB 1200 amends Section 139.2 of the Water Code to read: "The department shall evaluate the potential impacts on water supplies derived from the Sacramento–San Joaquin Delta based on 50-, 100-, and 200-year projections for each of the following possible impacts on the Delta:

1. Subsidence
2. Earthquakes
3. Floods
4. Changes in precipitation, temperature, and ocean levels
5. A combination of the impacts specified in paragraphs (1) to (4) inclusive."

AB 1200 also amended Section 139.4 to read: "(a) The Department and the Department of Fish and Game shall determine the principal options for the Delta. (b) The Department shall evaluate and comparatively rate each option determined in subdivision (a) for its ability to do the following:

1. Prevent the disruption of water supplies derived from the Sacramento–San Joaquin Delta.
2. Improve the quality of drinking water supplies derived from the Delta.
3. Reduce the amount of salts contained in Delta water and delivered to, and often retained in, our agricultural areas.
4. Maintain Delta water quality for Delta users.
5. Assist in preserving Delta lands.
6. Protect water rights of the "area of origin" and protect the environments of the Sacramento–San Joaquin river systems.
7. Protect highways, utility facilities, and other infrastructure located within the Delta.
8. Preserve, protect, and improve Delta levees.…"

To meet the requirements of AB 1200, the DRMS project has been divided into two parts. Phase 1 involves the development and implementation of a Risk Analysis to evaluate the impacts of various stressing events on the Delta. Phase 2 evaluates the risk reduction potential of alternative options and develops risk management strategies for the long-term management of the Delta.

As part of the Phase 1 work, 12 technical memoranda (TMs), which address individual topical areas, and one risk report have been prepared. This TM addresses the ecosystem issues that are considered in Phase 1. The TMs and the topical areas covered in the Phase 1 Risk Analysis are as follows:

1. Geomorphology of the Delta and Suisun Marsh
2. Subsidence of the Delta and Suisun Marsh
3. Seismology of the Delta and Suisun Marsh
4. Climate Change in the Delta and Suisun Marsh
5. Flood Hazard of the Delta and Suisun Marsh
6. Wind-Wave Hazard of the Delta and Suisun Marsh
7. Levee Vulnerability of the Delta and Suisun Marsh
8. Emergency Response and Repair of the Delta and Suisun Marsh Levees
9. Hydrodynamics, Water Quality, and Management and Operation of the Delta and Suisun Marsh (Water Analysis Module)*
10. Ecosystem Impacts to the Delta and Suisun Marsh
11. Impact to Infrastructure of the Delta and Suisun Marsh
12. Economic Consequences to the Delta and Suisun Marsh

*Two separate topical areas—the Hydrodynamics topical area and the Water Management topical area—were combined into one TM because of the strong interaction between them. The resulting TM is referred to as the Water Analysis Module (WAM).

The work products described in all of the TMs are integrated in the DRMS Risk Analysis. The results of the Risk Analysis are presented in a technical report referred to as:

13. Risk Analysis Report

Taken together, the Phase 1 TMs and the Risk Analysis Report constitute the full documentation of the DRMS Risk Analysis.

The Business-as-Usual Delta and Suisun Marsh: Assumptions and Definitions

To carry out the DRMS Phase 1 analysis, it was important to establish some assumptions about the future "look" of the Delta. To address the challenge of predicting the impacts of stressing events on the Delta and Suisun Marsh under changing future conditions, DRMS adopted the approach of evaluating impacts absent major future changes in the Delta as a baseline. Thus, the Phase 1 work did not incorporate or examine proposals for Delta improvements. Rather, Phase 1 identified the characteristics and problems of the current Delta (as of 2005), with its practices and uses. This approach, which allows for consideration of pre-existing agreements, policies, funded projects, and practices, is referred to as the "business-as-usual" (BAU) scenario. Defining a BAU Delta is necessary because one of the objectives of this project is to estimate whether the current practices of managing the Delta (i.e., BAU) are sustainable for the foreseeable future. The results of the Phase 1 Risk Analysis based on the BAU assumption not only maintained continuity with the existing Delta, but also served as the baseline for evaluating the risk reduction measures considered in Phase 2.

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The existing procedures and policies developed to address “standard” emergencies in the Delta, as covered in the BAU scenario, do not cover some of the major (unprecedented) events in the Delta that are evaluated in the Risk Analysis. In these instances, prioritization of actions is based on (1) existing and expected future response resources and (2) the highest value of recovery/restoration given available resources.

This study relied solely on available data. In other words, the effects of stressing events (changing future earthquake frequencies, future rates of subsidence given continued farming practices, the change in the magnitude and frequency of storm events, and the potential effects of global warming) on the Delta and Suisun Marsh levees were estimated using readily available engineering and scientific tools or based on a broad and current consensus among practitioners. Using the current state of knowledge, the DRMS project team made estimates of the future magnitude and frequency of occurrence of the stressing events 50, 100, and 200 years from now to evaluate the change in Delta risks into the future.

Because of the limited time available to complete this work, no investigation or research was conducted to supplement the current state of knowledge.

Perspective

The analysis results presented in this TM do not represent the full estimate of risk for the Delta and Suisun Marsh. The full estimate of risk is the probable outcome of the hazards (earthquake, floods, climate change, subsidence, wind waves, and sunny day failures) combined with the conditional probability of the subject outcome (levee failures, emergency response, water management, hydrodynamic response of the Delta and Suisun Marsh, ecosystem response, and economic consequences) given the stressing events. A full characterization of risk is presented in the Risk Analysis Report. In that report, the integration of the initiating (stressing) events, the conditional probable response of the Delta levee system, and the expected probable consequences are integrated to develop a complete assessment of risk to the Delta and Suisun Marsh. In this context, the subject of this TM is one element of the Risk Analysis.

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Acronyms and Abbreviations

^{o}C	degrees centigrade
%o	mean salinity
µm	micrometer(s)
AB	Assembly Bill
AIC	Akaikes Information Criteria
BAU	business-as-usual
BOD	biological oxygen demand
CALFED	CalFed Bay-Delta Program, administered by California Resources Agency; a consortium of California and federal government activities and interests
CCWD	Contra Costa Water District
CDFG	California Department of Fish and Game
CESA	California Endangered Species Acts
cfs	cubic feet per second
cm	centimeter(s)
cm/s	centimeter(s) per second
CNDDB	California Natural Diversity Data Base
CNPS	California Native Plant Society
CO	concentration
CPUE	Catch Per Unit Effort
CSTR	continuously stirred reactor
CVP	Central Valley Project
CVRWQCB	Central Valley Regional Water Quality Control Board
dS/m	decisiemens per meter
DO	dissolved oxygen
DRMS	Delta Risk Management Study
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
DWR	(California) Department of Water Resources
EHW	extreme high water
ERP	Ecosystem Restoration Program
ESA	Endangered Species Acts
ESU	evolutionarily significant unit
FMWT	fall mid-water trawl
GIS	geographic information system
g/l	gram(s) per liter
IEP	Interagency Ecological Program
IFSAR	Interferometric Synthetic Aperture Radar

km/day	kilometer(s) per day
LSZ	low salinity zone
mg/L	milligram(s) per liter
MHHW	mean higher high water
MHW	mean high water
MLHW	mean lower high water
mm	millimeter(s)
mph	miles per hour
MRT	mean residence time
MSCS	Multi-Species Conservation Strategy
MSL	mean sea level
MSR	mean square residuals
NRCS	Natural Resources Conservation Service
OMR	Old and Middle Rivers
ppt	parts per thousand
POD	pelagic organism decline
RMA	Resource Management Associates, Inc.
SAV	submerged aquatic vegetation
SDFF	South Delta Fish Facilities Forum
SEW	Suisun Marsh Ecological Workgroup
STN	summer tow-net
SWP	state water project
TAF	thousand acre-foot
TM	technical memorandum
TNS	summer tow-net
UCD	University of California, Davis
USBR	U.S. Bureau of Reclamation
USGS	U.S. Geological Survey
USFWS	U.S. Fish and Wildlife Service
USNRC	United States Nuclear Regulatory Commission

1 Introduction

The Sacramento–San Joaquin Delta (Delta), which (for purposes of this Technical Memorandum) includes Suisun Bay, Suisun Marsh, and the network of tidally influenced channels to the east of these water bodies (see Figure 1-1) are part of the larger San Francisco Estuary (Estuary), which includes San Pablo Bay, San Francisco Bay, the South Bay, and their associated wetlands. The Delta provides habitat for a diverse estuarine community including fish, shrimp and crabs, zooplankton, aquatic and terrestrial plants, and wildlife. The estuarine ecosystem supports extensive recreational fishing, bird watching, boating, aesthetic enjoyment, commercial fisheries, and commercial shipping traffic.

Over the past 150 years, a number of factors have influenced the fish and wildlife communities inhabiting the Delta and Suisun Marsh, including the loss of access to upstream habitat through construction of dams and impoundments, land use changes, reclamation and channelization/levee construction, exotic species introductions, water diversions and changes in seasonal hydrologic patterns, and other changes. As a result of these and other factors, many of the species in this area have experienced substantial declines in abundance and geographic distribution, leading to the listing of several species under the California and federal Endangered Species Acts (ESA) and the identification of others as species of special concern.

1.1 Purpose and Need

Levee failures that lead to the flooding of islands within the Delta and Suisun Marsh have the potential to affect these at-risk species and other aquatic and terrestrial species not only directly but also indirectly, by changing the quality and availability of suitable habitat and by altering fundamental estuarine processes. Because species interact with and depend on each other, direct impacts of levee failures on one species may cascade throughout the ecosystem and affect other species indirectly. Impacts to commercially valuable species have economic consequences, while impacts to at-risk species have legal and social consequences in addition to economic ones.

The purpose of this technical memorandum is to describe the approach, analytical framework, assumptions, and criteria used for the development of the ecosystem impact model within the Delta and Suisun Marsh. Levee failure would contribute to changes in hydrodynamics within the Estuary, salinity intrusion into the Delta, localized increases in suspended sediment concentrations (resulting from resuspended material at the levee breach and associated with the scour hole), entrainment onto the flooded island, direct loss of vegetation and wildlife habitat as a result of island flooding, and a variety of other ecosystem attributes.

Flooding after levee failure would also alter human water management activities in ways that could impact the aquatic ecosystem. In addition, island flooding would create “new” aquatic habitat (at least temporarily) that could be successfully colonized by a variety of aquatic and wildlife species.

The development of a framework for evaluating the potential for adverse and beneficial effects of a wide range of levee failure scenarios requires the integration of information on anticipated changes in hydrology, water project operations, water quality (e.g., salinity), and physical characteristics (e.g., water depth) within a flooded island after the levee failure. Information on anticipated emergency levee repair scenarios and estimates of the anticipated time required to close breaches after levee failure are also required.

This document describes the existing state of the Delta ecosystem, lists the existing data resources that could be used to analyze the ecosystem impacts from levee failure, and presents analytical methods for combining those data with other types of data sets and the results of other parts of the Delta Risk Management Strategy (DRMS) analysis to assess impacts to the ecosystem.

The ecosystem impact model was designed to evaluate the potential environmental effects on selected species over a wide range of levee failure scenarios at both the individual and regional population levels. For many of the potential effects or biological responses to levee failure, scientific and technical information is insufficient to support quantitative analysis. The emphasis of this Phase 1 report is therefore on developing the methods that might be used with existing data sets, or those that could reasonably be developed, to assess aquatic impacts. Analysis of impacts to terrestrial vegetation and wildlife proceeded further than the assessment of impacts to the aquatic ecosystem. As a result, for several hypothetical levee failures, this document presents preliminary results of impacts to terrestrial vegetation and wildlife but not impacts to the aquatic ecosystem.

The following sections describe the basic objectives of the ecosystem impact model, the evaluation process, identification of information needed to conduct the analysis, methodology, and, for terrestrial vegetation and wildlife, results of the ecosystem impact model for three levee breach scenarios. The analytical framework for the ecosystem impact model presented in this report will be applied to the more comprehensive DRMS analysis of levee failures.

1.2 Function of the Ecosystem Impact Model in the Overall DRMS Risk Analysis Context

The overall objective of the DRMS project is to develop a model that provides a quantitative measure of the risks to the Delta and California that may result from levee failures. With respect to the focus of the overall DRMS project, the ecosystem impact model is narrowly focused. The analysis will include an assessment of the effects (both adverse and beneficial) that levee failures could have on aquatic and terrestrial species. For instance, the question “Could levee failures result in a species’ extinction or contribute to an increase in its population?” will be asked.

2 Objective and Scope

The objective of the ecosystem impact model is to estimate the ecological impacts resulting from levee breaches in the Delta and Suisun Marsh and the uncertainties surrounding these estimates. Variables considered in the evaluation of levee failures (sequences) are shown in Table 2-1.

A comprehensive description of ecosystem response to perturbations that may result from a levee failure scenario is not possible for the following reasons:

- "ecosystems" are open systems with arbitrarily defined boundaries; as a result they are ecological abstractions (i.e. there are always inputs from "outside" the system that are not modeled)
- natural ecosystems are far more complex than current scientific understanding
- ecological outcomes are highly sensitive to initial conditions (Brown 1995)
- initial conditions are rarely knowable in general and are not known for the San Francisco Estuary or the Delta in particular.

Ecosystems contain literally thousands of *types* of actors (e.g., species, landscape features), each with its own population of independent components (individuals), responding on different time and geographic scales to a wide variety of physical parameters. Furthermore, many of these components interact with each other in ways that are poorly understood and defined by chaotic or non-linear dynamics. For example, animal distributions are affected by the distribution of physical habitat structure provided by vegetation as they simultaneously modify that physical habitat structure (e.g., by grazing).

With the recognition that the models would not be able to represent the full complexity of Delta ecosystems, the ecosystem impact model objectives were defined narrowly so that they could provide an analytical basis for developing management guidance. To the extent practical, the quantitative models were developed to allow the evaluation of impacts to the terrestrial and aquatic ecosystems of the Delta arising from levee failures. The models also include methods for quantifying the epistemic uncertainty in the effects that are estimated. The models do not present a comprehensive image of all impacts to the Delta ecosystem that may arise from levee failure; instead they provide "first order" estimates of certain major impacts that are (a) anticipated and (b) amenable to modeling.

To support the DRMS risk analysis, ecosystem impact model were designed to be applicable to a wide range of levee failures. Results produced from these models will allow decision-makers to understand the implications of different levee failure scenarios, patterns of impact shared across groups of scenarios, and the effects of impact reduction efforts (DRMS risk analysis, Phase 2).

The ecosystem impact models were developed to address two critical questions:

- Given the occurrence of a defined scenario of levee breaches and island flooding events, what is the impact to different species or community types?
- How likely are the estimated impacts to occur for a given scenario?

Time and resources were not sufficient to address a third critical question: What is the epistemic uncertainty in the estimate of the impacts and their likelihood? This question requires an assessment of epistemic uncertainties derived from an evaluation of the scientific uncertainties in the models.

2.1 Approach

The development of the DRMS ecosystem impacts model was divided into three parts, each of which covered a distinct part of the larger ecosystem: terrestrial vegetation, terrestrial wildlife (including amphibians, wading, and water birds), and aquatic organisms. Each part of the ecosystem impact model, which was developed independently, was designed to be:

- Applicable to multiple/diverse levee failure scenarios
- Applicable for multiple species
- Repeatable (clear approach, rules, and criteria)
- Quantifiable and interpretable (i.e., results are in the form of simple, meaningful numerics or categorical metrics) with respect to both best estimates and "epistemic uncertainty"
- Limited to areas of primary effects

2.1.1 Levee Failure Scenarios

A particular combination of events involving levee failures is referred to as a scenario. When an event such as a flood or earthquake occurs, a large part of the Delta's 1100+ miles of levee may be challenged, potentially leading to multiple levee breaches and flooded islands. Given the number of islands that could be affected by a single event, there are numerous combinations of islands that may be flooded. The timing of an event that results in levee failures is random for earthquakes, which can occur at any time of the year, but somewhat bounded for floods, which usually occur in winter or spring.

Table 2-1 summarizes the events and factors that are defined in a levee failure scenario in the impact analysis. These events and factors are inputs into the ecosystem impact models and determine the geographic scope, intensity, and, to some extent, the duration of impacts.

In addition, factors that define a levee failure scenario also determine physical changes in the Delta and Suisun Marsh; these physical changes, in turn, affect the subsequent biotic response modeled by the ecosystem impact models. For example, the number and collective volume of islands that flood during a levee failure scenario determines (a) the amount of flooded habitat, and (b) the extent to which the salt/brackish water cline moves eastward into the Delta. Thus, the ecosystem impact models use the outputs of other DRMS models as inputs.

2.1.2 Focal Species

Focal species were selected because they were considered proxies for a certain component (guild) of the biota or because the individual species was of particular economic or legal importance (e.g., protected by the ESA). Use of focal species simplifies analysis of levee failure impacts by reducing the number of species under consideration. In addition, in many cases, information is available for focal species that is not available for other species in the system—thus it is more likely that impact models can be applied to focal species than to other species in the ecosystem.

2.1.3 Repeatability

Given a description of the physical attributes that would persist after a levee failure scenario, biologists could construct hypotheses about the impacts of that scenario on particular components of the biota. This approach, however, would be unsuitable for the DRMS project. DRMS' models must account for any number and configuration of levee failures defined in a scenario. Levee failure scenarios themselves are possibilities that have certain likelihoods associated with them; many (perhaps thousands) different scenarios will be analyzed to gain an understanding of the spectrum and distribution of possible outcomes. Creating a separate "story" for each of these scenarios is untenable from a manpower perspective and would lend itself to assessment methodologies and assumptions that were neither consistent nor explicit. Despite the limitations and certain artificialities of quantitative models, they have the advantage of being transparent and repeatable. DRMS ecosystem impact models are designed to produce repeatable results.

2.1.4 Quantifiability and Interpretability

DRMS ecosystem impact models are intended to produce quantifiable results that are interpretable in terms of their real-world consequences. The results include the "best" estimate of the likely effects of a given levee-failure scenario. "Best" in this context means that the model reflects the scientific community's understanding of relationships associated with the impact; it does not imply that the estimate is good or accurate, only that no other estimate is more likely to be correct.

Ecosystem impact models also produce explicit, quantifiable estimates of the epistemic uncertainty associated with the best estimate, which is perhaps more important than the quantifiable best estimates. DRMS risk analysis, a taxonomy of uncertainties is used that distinguishes between those that are inherently random and those that are knowledge-based. Inherently random uncertainty, also referred to as aleatory uncertainty, is irreducible and associated with events or factors that occur on scales that cannot be explained by a model. Knowledge-based uncertainty, also referred to as epistemic uncertainty, is attributed to a lack of knowledge (e.g., information, scientific understanding, and data) (USNRC 1996). In principle, epistemic uncertainty can be reduced with improved knowledge and/or the collection of additional information. Epistemic uncertainty manifests itself in the uncertainty in models (e.g., alternative models) and the estimate of model parameters.

2.1.5 Geographic Limits of Analysis

The scope of the DRMS risk analysis is limited to areas of primary effect in the Delta and Suisun Marsh (see Figure 1-1); the limitation was applied with the full understanding that there could be numerous difficult-to-define effects on upstream and downstream environments. Levee failures in the Delta and Suisun Marsh would have effects outside this limited geographic area.

For the most part, effects in areas such as Suisun Bay, San Pablo Bay, and South San Francisco Bay were not evaluated in the ecosystem risk analysis. The magnitude of such a broad-based analysis would have been daunting. Also, the effects of levee failure could be less dramatic outside of the Delta and Suisun Marsh because of the dominance of tidal influences in the bays. Similarly, levee failure effects on freshwater environments north and south of the Delta would be difficult to assess, with the possible exception of those related to hydrodynamic effects of changed reservoir operations.

One potential exception to these geographical limits would occur in levee failure scenarios that had the immediate effect of drawing water from Suisun and San Pablo Bays onto flooding islands. Such events would also lead to fish from Suisun and San Pablo Bays being entrained on flooding islands and potentially suffering adverse impacts from that entrainment. Thus, fish species distributions in the northern San Francisco Estuary may be employed in calculations of the immediate impacts of flooding on fish species populations. See Section 6.3.1 for a discussion of the entrainment of fish on flooded islands.

2.2 Definition of Impacts

Impacts were defined as part of each impact model component (e.g. vegetation, aquatic fauna, terrestrial wildlife) and sub-model (e.g., for aquatics: immediate entrainment, future habitat development) as dictated by available data sources and scientific understanding of the different impact mechanisms and their implications.

2.2.1 Terrestrial Vegetation

Vegetation impacts were assessed by combining factors such as the size of the impacted area in a given flooding scenario, the reduction in population size due to loss of mature plants (as compared to seedling loss) from immediate impact of the flood, and the time for recovery of original vegetation types after the end of flooded island pump-out.

To evaluate the effect of levee breaches on vegetation types, metrics were created to independently assess (1) survival of the flood by mature plants, and (2) time to recovery of mature vegetation. The immediate impact and time to recovery of vegetation types was inferred from the response of focal species typical of the vegetation type. The impact of levee breaches on sensitive plant species was assessed by calculating the number of occurrences of sensitive species lost due to a levee breach, relative to the number of occurrences of the species in the Delta and Suisun Marsh and in the region (12 counties in the Bay Area and Delta). The aggregate (combined) response of the focal species for a vegetation type was used to predict the response of the vegetation community, supplementing with information on response of vegetation communities when it was available. The responses of vegetation to stressors associated with levee failure, but not explicitly output from the hydrologic models, were described with a qualitative level of analysis.

2.2.2 Aquatic Community

Levee failure in the Delta is expected to impact the aquatic ecosystem through numerous mechanisms. As part of, the aquatic ecosystem impacts analysis, three temporally distinct subcomponent models were developed. The subcomponent models reflect the fact that, after the initiation of levee breaches, events and processes (mechanisms) will occur over different time scales ranging from hours and days to months and possibly years. Mechanisms operating on one temporal and spatial scale may affect or be overwhelmed by mechanisms operating on another temporal and spatial scale. However, the mechanistic linkages between these processes are not well understood, especially under the conditions that will exist after catastrophic levee collapse. Therefore, the aquatic impact sub-models represent independent assessments of the potential impacts to aquatic fauna.

The following time periods have been identified for analysis and are shown in Figure 2-1:

- Short-term (immediate) impacts from entrainment on flooded islands
- Intermediate/long-term impacts resulting from avoided entrainment at export pumps
- Long-term impacts associated with development of new habitat on flooded islands

One subcomponent estimates the proportion of a focal species' population that may be immediately entrained on flooding islands and killed by elevated suspended sediment conditions on those islands. A second subcomponent estimates the proportion of focal species' populations that are *not* entrained at the state and federal water pumps when water export activities are halted after a levee-collapse. The third subcomponent model provides a coarse estimate of the habitat space "created" for aquatic species over the mid-long term by flooding of islands.

The first two subcomponents calculate proportional decrease or increase in population expected to occur from their respective impact mechanisms. In each case, the proportional impact estimates are then input into a model (the "Dennis Model," see below) that calculates a resulting change in the probability of extinction (or time to extinction). Although these two model subcomponents produce results in the same units (proportion of population impacted and relative effect on time to extinction), no effort is made to combine these impacts into one estimate of population-level impact. This is because the impact mechanisms operate on different time scales, use different input data sets, and employ different assumptions to convert sample data into population-wide estimates. Outputs of these model subcomponents can be viewed as independent estimates of the relative impacts for different levee failure scenarios; comparisons between the results of the two subcomponents would involve numerous assumptions, most of which are faulty or unsubstantiated.

The third model subcomponent does not produce a population level metric because additional potential habitat space does not necessarily or neatly correspond to increased population size or stability. Instead, this model estimates change in the available habitat space. This output could be expressed in terms of habitat surface area in acres, volume of habitat, or proportion of habitat compared to current (pre-flooding) conditions. This impact can be positive or negative because the methodology estimates the volume of new “habitat” that is likely to become anoxic (due to eutrophication) during some part of the year (the model can also estimate the likelihood of anoxic events). Islands that become anoxic are likely to kill many of the aquatic macroinvertebrates and fishes that occupy an island; thus, an island with otherwise excellent habitat characteristics might actually count as “negative habitat” if it is likely to become anoxic periodically.

2.2.3 Terrestrial Wildlife

Impacts to terrestrial wildlife arose from three sources: direct mortality at time of levee breach resulting from flooding (drowning), inundation of habitat until island pump-out, and permanent conversion of island habitat to a vegetative cover type that does not represent suitable habitat. Impacts are assessed based on knowledge of current distribution of terrestrial species and projected changes in terrestrial vegetation communities derived from the assessment of impacts to terrestrial vegetation communities performed here.

2.3 Use of This Technical Memorandum

The models presented here are in different stages of development and thus differ in their current utility to the DRMS risk analysis.

The impacts of levee failure on terrestrial wildlife and vegetation are expected to derive from mechanisms that are relatively straightforward – water will inundate and scour certain terrestrial habitats and, if the floodwaters are saline, they may alter the chemistry of soils on flooded islands. The duration and depth of flooding and salinity of floodwaters will affect the ability of different plants and wildlife species to recolonize after flooded islands are reclaimed. Because the impact mechanisms are relatively simple and easy to understand, the models that describe (to a first order) the impacts to these communities were completed and demonstrated in three different hypothetical levee breach scenarios.

The aquatic ecosystem impact models have been developed to the level of a preliminary description of the methodologies and data sets that would be used to develop first order estimates of the effects of levee failure. Aquatic ecosystem impact model components operate on different time scales and, although it is acknowledged that impacts at one time step affect those at other time steps, no effort has been made to link together the outputs of these different subcomponents to produce a single estimate of impacts. The aquatic ecosystem impacts modeling team believes that efforts to link these models together would not be scientifically credible as such a linkage would require numerous untested assumptions about other impact mechanisms that cannot be modeled and because ecosystem response to perturbations are often subject to non-linear dynamics that are highly sensitive to initial conditions which would not be well-characterized.

The Delta's aquatic ecosystem is a highly dynamic environment. Physical conditions fluctuate with the tides and on weekly, seasonal, and annual timesteps that correspond with changes in freshwater inflow and Delta water export operations. Fish and macroinvertebrate species move throughout the system in response to seasonal migration needs and developmental changes in physical tolerances and prey availability. There is also a random component to the spatial and temporal distribution of these organisms. Furthermore, invasive species represent a large portion of the Delta's biota (Moyle 2002) and these species continue to perturb the ecosystem causing directional changes in historic patterns of the abundance and distribution of native species (Carlton 1979; Carlton et al. 1990; Alpine and Cloern 1992; Sommer et al. 2007).

The impact of effect mechanisms on aquatic organisms is not as straightforward as it is for terrestrial organisms – flooding does not necessarily produce a change in habitat suitability for aquatic organisms the way it does for most terrestrial organisms. In addition, the pelagic macro-biota of the Delta aquatic ecosystem are currently in decline and the forces driving this decline are not well understood (Sommer et al. 2007); in other words, current scientific models do not capture the dynamics of this ecosystem prior to levee collapse. This suggests that current scientific understanding of the important drivers in this ecosystem is tenuous. Also, some of the direct impacts of levee-collapse will occur through mechanisms at temporal and spatial scales that are not typically studied by aquatic biologists. For example, studies of the tolerance of different aquatic organisms to elevated suspended sediment levels are generally lacking and our knowledge of the geographic distribution of aquatic organisms is temporally coarse (seasonal or monthly at best) relative to the time-step of certain impact mechanisms.

These limitations make identifying and describing the major driving forces producing impacts in the Delta aquatic ecosystem difficult. The models are considered to be representative of the likely impacts of levee collapse but are computationally more complex than those applied to terrestrial ecosystems. In some cases, data sets that are required to make the models operational are not available, although these data could be developed with targeted research on species of concern.

3 Aquatic Fauna and Terrestrial Plant and Wildlife Communities in the Delta and Suisun Marsh

The Delta and Suisun Marsh are part of a complex estuarine ecosystem that represents a transition zone between inland sources of freshwater and saltwater from the ocean. Upstream dams have trapped sediment and reduced sediment transport to the system, and channelization using riprap reinforced levees has isolated the peat-soil islands in the system. Both measures have increased the rate of organic soils decomposition by agricultural activities that dominate the area. This has led to dramatic decreases in the surface elevation of most Delta islands, most of which are now well below mean sea level (MSL) (see Figure 3-1). The levees protecting these islands may fail under a number of circumstances, and failure would cause widespread flooding of these below-sea-level islands. Subsidence within leveed sections of Suisun Marsh has not been as severe, but has occurred, and levee failure could result in shallow flooding and variable salinity conditions pending levee repair.

Because the Delta and Suisun Marsh are important habitats and it has been necessary to evaluate the potential effects of water project operations and other factors affecting species and habitats within the Estuary, extensive fishery and terrestrial monitoring has been conducted within the area over the past several decades. Results of these investigations provide insight into regional hydrodynamics, water quality, habitat, species composition, seasonal and geographic distribution, and factors affecting aquatic and terrestrial species. Forming the scientific foundation for this ecosystem impact model, the data considered in this analysis include, but are not limited to:

- The species that inhabit the Delta and Suisun Marsh
- The following characteristics of the species that inhabit the Delta and Suisun Marsh:
  - Geographic and seasonal distributions
  - Life-history characteristics, habitat requirements, and apparent preferences
  - Interactions with prey, predatory, and competing species, to the extent known

The following sections provide a brief introduction to the aquatic community, vegetation, and wildlife of the Delta and Suisun Marsh that would potentially be affected by levee failures.

3.1 Aquatic Community

Freshwater enters the Delta via the Sacramento River, the San Joaquin River, and various tributaries such as the Mokelumne and Cosumnes Rivers (see Figure 1-1). Suisun Marsh, to the west of the Delta, is a brackish tidal marsh where salinity varies seasonally and annually depending on freshwater flow from the Delta and local tributaries and tidal influence. Saltwater enters the Delta and Suisun Marsh from Suisun Bay and, ultimately, from the Pacific Ocean via the Golden Gate. Along the salinity gradient extending from the Golden Gate upstream into the Delta, the aquatic biological community changes dramatically in response to the salinity preferences and tolerances of various aquatic species inhabiting the Estuary (see Figure 3-2).

Impacts to the aquatic ecosystem propagate through the food web; thus, understanding the linkages between trophic levels in the aquatic ecosystem can inform interpretation of the ecosystem impacts of levee failures. Energy inputs into the Delta include solar radiation and exogenous organic matter transported into the Delta and Suisun Marsh from upstream. Energy sources and nutrients are used by primary producers and microbial decomposers to produce organic matter that forms the base of the aquatic food web. Primary producers (aquatic plants, photosynthetic bacteria, and protists) and microbial decomposers are preyed upon by primary consumers. Most consumers of primary productivity are zooplankton, such as copepods and cladocerans, in addition to filter feeding species such as clams. The primary consumers are, in turn, preyed upon by secondary consumers, consisting mainly of a variety of native and introduced invertebrates (polychaete worms, snails, copepods, shrimp, clams, and crabs), and fishes such as northern anchovy, Pacific herring, top smelt, delta and longfin smelt, white croaker, flatfish, gobies, sculpin, threadfin shad, juvenile salmonids, sturgeon, and a variety of other resident and migratory fish species (see Table 3-1). Tertiary consumers (predators), including fish (e.g., striped bass, largemouth bass, inland silverside, and catfish); marine mammals, birds, and humans prey on these secondary consumers. All species in the system also contribute to the formation of detritus, which is decomposed by microbes and consumed by detritivores (e.g., polychaete worms, amphipods, cladocerans, and a diverse group of other fish and macroinvertebrates).

Colonization by exotic species have contributed to a substantial change in the composition, trophic dynamics, and competitive interactions of the Delta’s aquatic ecosystem, affecting the population dynamics of native species. Going forward, the population dynamics of these non-native species (e.g., increasing populations and continued range expansion) and the likelihood of continued introductions of new non-native species represent significant sources of uncertainty for predicting the future state or ecological dynamics of the Delta ecosystem.

Over the past several years many of the pelagic fish species inhabiting the Delta and Suisun Marsh, such as Delta smelt and longfin smelt, have experienced a significant decline in abundance referred to locally by regulatory agencies, scientists, and stakeholders as the pelagic organism decline (POD; Sommer et al. 2007). The forces contributing to the POD are hypothesized to include: changes in seasonal hydrology (due to long-term climatic changes and water export project operational changes), competition from or predation by introduced species, exposure to toxic substances (especially pesticides), and other factors (Sommer et al. 2007). California and federal resource agencies are actively investigating the significance of these and other factors affecting pelagic fish species, their population dynamics, habitat suitability, and the overall condition of the Delta and Suisun Marsh. To date, the relative importance of each of these factors on populations of pelagic species has not been determined. Discriminating direct impacts and interactions among the multiple potential drivers of the POD is difficult and contributes to the uncertainty surrounding predictions of future states of the estuaries aquatic ecosystems.

3.1.1 Primary Producers and Primary Production: Status and Trends

Organisms that convert inorganic energy sources (e.g., sunlight) into organic energy storage compounds form the basis of ecosystem food webs and are referred to as "primary producers." These organisms include grasses and trees (in the terrestrial environment) and phytoplankton (in the aquatic environment) are consumed by other organisms. Primary production within the aquatic communities of the Delta and Suisun marshes consists of aquatic vegetation, macroalgae, phytoplankton, and bacteria. In addition to serving as a source of food, aquatic vegetation can serve as shelter or cover for aquatic organisms. Also at the base of the food web are organisms that decompose wastes and release nutrients into forms that can be used by primary producers. These decomposers feed on a combination of exogenous (imported) and enogenous organic carbon sources. Within the Estuary, bacteria, benthic macro-invertebrates, and zooplankton are primary decomposers of organic matter.

Aquatic plants and macroalgae are common aquatic producers in areas where there is a stable substrate for growth within well-lit waters. The rocky shores in a moderately protected western Central Bay support about 90 species of macroalgae (large plant-like organisms). The more protected habitats (mudflats, marshes, boat harbors) in eastern Central Bay support only about 30 species (Silva 1979). In San Pablo Bay, and upstream within Suisun Bay and the Delta, the abundance and diversity of macroalgae decreases sharply. Within the freshwater and low-salinity areas of the Delta and Suisun Marsh, aquatic plants are more prevalent, including invasive species, such as water hyacinth and the pondweeds *Elodea* spp. and *Egeria densa.* Within the lower-salinity regions of the Estuary, aquatic and floating plants may form dense growths along the edges of many sloughs and channels within the Delta and achieve extremely high densities during the summer months.

Vascular emergent plants, such as pickleweed, cord grasses, and tules, are very important to the aquatic ecology of the Estuary, as they stabilize sediments and create a diversity of habitats. Vascular plants are habitat for a variety of fish, invertebrates, birds, and animals; and contribute to the production of phytoplankton by providing a substrate for attached forms. Unlike phytoplankton and macroalgae, however, few aquatic organisms feed upon vascular plants. Rather, the aquatic vascular plants provide the main inflow of detritus into the system and act as a biological filter.

Phytoplankton consists of small organisms that live within the water column and collect solar energy from the sun through the process of photosynthesis, the same process used by plants. Major groups of phytoplankton in the Estuary include diatoms, dinoflagellates, and cryptomonads (Herbold et al. 1992). Seasonal patterns in physical factors such as temperature, freshwater flow, and isolation have a large impact on the distribution and abundance of phytoplankton. Turbidity, suspended sediments, and water depth also affect availability of sunlight and the abundance of phytoplankton within different areas of the Estuary.

In the high-salinity areas of the Estuary, including the Central Bay, dominant phytoplankton are diatoms and dinoflagellates. Diatom abundance is usually highest in the spring when coastal upwelling enriches coastal and bay waters with nutrients stored in offshore waters, and when sunlight duration and strength is nearing a seasonal maximum, and when water temperatures are rising in the shallow waters of Suisun and San Pablo bays and elsewhere within the Estuary. Diatom blooms are common within the Estuary during spring. In the low-salinity and freshwater areas of the Estuary, including the lower Sacramento and San Joaquin rivers, diatoms are the dominant phytoplankton. Green algae are abundant during winter and spring and may constitute as much as 60 to 70 percent of the phytoplankton populations of the Delta and Suisun Bay, especially in the dead-end sloughs. Silva (1979) and Kimmerer (2004) estimated that perhaps 30 percent of the primary productivity of Suisun/San Pablo bays may be attributable to microalgae. Green algae are generally less abundant in the more saline regions of the Estuary, but may be common in the fresh, slowly flowing waters of the interior Delta. The highest abundance of phytoplankton within the Estuary typically occurs within the Suisun Bay freshwater and saltwater mixing zone (Kimmerer 2004; Jassby 2005). Additionally, phytoplankton productivity in Suisun Bay and many Delta channels is highest in shallow water areas, were these organisms have better access to warm, sunlight waters.

As primary producers and decomposers form the prey base for all other organisms within the Estuary, changes in the density and distribution of primary producers will cause changes in the abundance and distribution of organisms at higher trophic levels. Water and land use practices have affected the composition and abundance of primary producers within the Estuary. The invasion of non-native aquatic plants, for example, has caused changes in both the structure of habitat and of the productive food base. Phytoplankton are susceptible to changes in water quality due to diversion and pollutants in runoff. In particular, turbidity decreases the penetration of sunlight into the water, reducing the energy available for primary producers.

Decreases in the abundance of phytoplankton within the Delta is largely correlated with the corresponding variability in Delta outflow (Jassby et al. 1995; Kimmerer 2004; Lehman 2004; Jassby 2005). Downstream transport, particularly at ebb tide, is an important mechanism for transporting chlorophyll in estuaries, and Delta outflow therefore is a major factor in controlling variability of phytoplankton productivity. Another major driver of phytoplankton abundance appears to be consumption by benthic herbivores, especially during low-flow periods where benthic invertebrates can become established in high enough densities to filter large quantities of water, affecting phytoplankton biomass (Alpine and Cloern 1992). Since the early 1980s, chlorophyll concentrations and shifts in species composition have occurred throughout the Estuary. A tenfold decrease in chlorophyll concentrations in Suisun Bay has occurred since 1986; this decrease is associated with, and may be the result of, the introduction of the Amur clam (Kimmerer 2004; Jassby 2005). These recent trends have raised questions about the ability of phytoplankton production in the low salinity region of the Estuary to support zooplankton production.

3.1.2 Secondary Production: Zooplankton, Mollusks, and Benthic Invertebrates —Status and Trends

The main consumers of primary production in this Estuary include a variety of native and introduced invertebrates (polychaete worms, snails, copepods, shrimp, clams, and crabs), and fishes. Tertiary consumers (predators), including fish (e.g., striped bass, largemouth bass, inland silverside, catfish), marine mammals, birds, and humans prey on these secondary consumers. Biomass associated with these organisms is referred to as "secondary production." The creation of levees, water diversions, and the introduction of non-native species has profoundly altered the composition and abundance of all trophic levels within the Estuary. Table 3-1 provides a list of the common and scientific names of fish and macroinvertebrates that inhabit the Delta and Suisun Marsh.

Zooplankton are microscopic and macroscopic animals. They are free-floating or weak swimmers and are largely transported by currents. As major consumers of primary production within the Estuary, they are important to the rest of the estuarine food web including lower trophic levels upon which they feed (phytoplankton, detritus) and also to the higher trophic levels (fish and macroinvertebrates) that rely on them for food. The abundance and distribution of zooplankton varies substantially within the Estuary in response to seasonal cycles and environmental factors such as salinity gradients (Kimmerer 2004). In the high-salinity portions of Central Bay the primary zooplankton include calanoid copepods (*Acartia clausi, A. tonsa*, and *Paracalanus parvus*). In the low-salinity regions of Suisun Bay and the Delta the primary zooplankton are calanoid copepods (*Eurytemora affinis* and *A. clausi*) and the opossum shrimp (*Neomysis mercedis*). The cladocerans (*Daphnia pulex* and *D. parvula*), and calanoid copepods (*Diaptomus* spp. and *Limnocalanus macrurus*) are the primary zooplankton species occurring within the freshwater portions of the Delta. The distribution and abundance of zooplankton is also related to the availability of food. Physical and chemical conditions that promote phytoplankton productivity (e.g., warm temperatures, high solar radiation, high nutrients, and slow-moving water) indirectly promote the productivity of zooplankton. Water body configuration and depth also affect phytoplankton productivity and therefore, zooplankton productivity.

The location of the saltwater and freshwater mixing zone (also referred to as the "Low Salinity Zone" (LSZ) and measured by the position of the 2 parts per thousand (ppt) isohaline ("X_2") during the spring influences the abundance of both phytoplankton and zooplankton within the Estuary (Kimmerer 2002; Jassby 2005). When the mixing zone is located in the shallow portions of Suisun Bay, the abundance of both phytoplankton and zooplankton increases. When the mixing zone is upstream in the deeper channels of the lower Sacramento and lower San Joaquin Rivers (in response to reduced freshwater inflow or increased water exports), productivity and abundance of both phytoplankton and zooplankton is reduced. A number of zooplankton species have been introduced into the Estuary (Cohen and Carlton 1995, 1998; Kimmerer 1998) through ballast water discharges from commercial shipping and have impacted native species inhabiting the Estuary.

Mollusks (clams, snails, etc.), are another major source of secondary production in the Estuary. Most of these organisms are filter feeders (e.g., clams and mussels) or benthic grazers (e.g., snails and limpets). The introduction of non-native mollusks has caused major changes to plankton populations within the Estuary system. The most dramatic change occurred with the introduction of the Amur ("overbite") clam (*Corbula amurensis*) in 1986 (Kimmerer and Orsi 1996). A tenfold decrease in chlorophyll concentrations in Suisun Bay has occurred since 1986; this decrease may be the direct result of phytoplankton consumption by the Amur clam (Kimmerer 2004; Jassby 2005). Similarly, the freshwater portions of the Delta have been impacted by the introduction of another invasive clam, (*Corbicula fluminea*). This freshwater invasive clam plays a significant role in grazing of zooplankton. These recent trends have raised questions about the zooplankton carrying capacity of the Delta.

Large populations of invasive filter feeders have caused changes in aquatic habitat as well. By removing plankton from the water, light penetration to the substrate is improved, increasing the abundance of aquatic plants and macroalgae. The role of these introduced species in the estuarine ecosystem of the Delta and Suisun Marsh is a factor contributing to uncertainty in the response of aquatic species to future levee failures.

A variety of benthic macro-invertebrates inhabit this Estuary, including both primary and secondary consumers. Within the Delta, major macroinvertebrate taxa include bay shrimp, opossum shrimp, amphipods, polychaetes, oligochaetes, crabs, and clams (see Table 3-1). Many of the more common benthic species that inhabit the Estuary are not native to the region but have been transported and introduced into the Estuary through the discharge of ballast water from commercial ships, or on the shells of live oysters brought from the East Coast for commercial farming in the late 19th century (Carlton 1979). Today, over 40 percent of the individuals comprising the benthic community in a given area of the Estuary can be non-indigenous species (Cohen 2000). Many of these introduced species may serve ecological functions similar to native species that they may have displaced; however, some species may be detrimental to native species in the aquatic ecosystem of the Estuary (Matern et al. 2002; Moyle 2002).

Characteristics of the macroinvertebrate communities are influenced by a variety of physical and water quality conditions that occur within the Estuary, the most important being flow velocities, substrate characteristics, and salinity gradients (Thompson et al. 2000). The factors most affecting the abundance, composition, and health of the benthic community from year-to-year are outflow from the Delta, local runoff, and pollution (Nichols and Pamatmat 1988; Herbold et al. 1992). Benthic invertebrate populations are generally most abundant in areas having reduced water velocities, fine-grained sediments, and relatively stable benthic environments (little sediment movement or disturbance, slow rates of accretion or depletion of sediments). Deeper water, channel, and high velocity areas are typically characterized by sand and coarse substrate. Benthic communities characteristically have reduced species diversity in these areas, as they exhibit substantial daily, seasonal, or interannual substrate movement (both accretions and depletions).

3.1.3 Fish Species: Status, Trends, Habitat Requirements, and Delta/Suisun Occupancy

Fish assemblage sampling programs within the Estuary have shown that it supports a diverse fish and macroinvertebrate community (Baxter et al. 1999). In total the Estuary supports more than 100 fish species, about 50 of which commonly occur in fishery sampling programs. About one-half of these are non-native, including some species that were purposefully introduced to provide recreational and commercial fishing opportunities (e.g., striped bass and American shad). Approximately, 68 fish species have been recorded from the Delta (Moyle pers. comm. 2007).

In recent years, several other fish species (e.g., yellowfin, chameleon gobies) and a wide variety of invertebrates have been accidentally introduced into the Estuary, primarily from Asia, through ballast water discharges resulting from commercial cargo shipping. An estimated 100 macroinvertebrates (e.g., overbite clam, New Zealand mudsnail, Chinese mitten crab) have also been introduced into the Estuary primarily through ballast water discharge and the aquarium trade (Carlton 1979; Cohen 1998). Many of these introduced fish and macroinvertebrates have colonized and now inhabit portions of the Delta and Suisun Marsh.

There has been a general and as yet unexplained decline in many pelagic fish species in the Delta (Sommer et al. 2007). This decline has affected both native species and introduced species. Numerous endangered species (e.g., Delta smelt, winter-run Chinook salmon) are now at greater risk of extinction due to recent population declines and other species have recently been listed as endangered (e.g., Green sturgeon) or are proposed for listing (e.g., longfin smelt). Whereas the cause of this decline (and even whether the decline has a single cause) is uncertain, leading hypotheses include: increased freshwater exports from the Delta, introduced species, and decreased water quality (especially with regard to new classes of potentially toxic compounds), or the cumulative impacts of some combination of these factors.

Fish species utilize the Delta for differing segments and durations of their life cycle. Delta smelt are an example of one species that spends nearly its entire life cycle in the Delta (because it is endemic, this means nearly the entire species' population is found in the Delta). Many fish species found in the Delta use this area for only part of their life history (see Figure 3-3). For some species, the Delta is a migratory pathway between different ecosystems used during their life history. For example, Chinook salmon use the Delta to migrate between spawning and rearing areas upstream and marine environments where they spend most of their lives; the Delta is used again by adults that return to spawn. Other species use the Delta opportunistically for parts of their life cycle such as rearing (e.g., sturgeon) or occasional spawning (e.g., splittail). Individuals of still other species use the Delta year-round but the Delta is only a small part of their geographic range (e.g., introduced Centrarchid bass). As a result of the transitory nature of most fish in the Delta, the magnitude of impacts to fish populations from catastrophic levee failure depend in large part on when, during the year, the environmental effects of levee failure are present.

Life history strategy is another factor that determines (in part) the effect of levee failure on fish species populations. For example, green sturgeon have a very long life span and, at any given time, most of their population is out of the Delta in marine environments. By contrast, the impacts of levee collapse are likely to produce dramatic population swings (both positive and negative) among species with short life spans; again, Delta smelt exemplify species that are most susceptible to the impacts of levee failure because of their short life span.

3.1.4 Sources of Data for Aquatic Ecosystem

Year-round fishery surveys have been conducted in the San Francisco Bay–Delta Estuary to characterize the abundance and geographic distribution of various lifestages of fish and macroinvertebrate species (see Figure 3-4 and Table 3-2). Specifically, the California Department of Fish and Game (CDFG) has undertaken in-Delta sampling, and the University of California, Davis (UCD) has undertaken Suisun Marsh sampling at a number of locations (see Figure 3-5). Data from 1995 to 2005 have been analyzed for each of the fishery surveys for Delta smelt, Chinook salmon, green sturgeon, striped bass, threadfin shad, longfin smelt, steelhead, and inland silverside. CDFG density data have been used from various year-round surveys to estimate the relative abundance and geographic distribution of the lifestages of the selected species for quantitative use in this assessment.

3.1.4.1 Fall Mid-Water Trawl Survey: 1967 to Present

Originally initiated to evaluate the effects of state water project (SWP) and Central Valley Project (CVP) operations on striped bass, the fall mid-water trawl survey is conducted by CDFG from September through December or March (varies by year). At present, CDFG uses the information it collects in this survey to estimate the relative abundance and geographic distribution of many adult and/or late juvenile species of fish. In 1980, the survey period was shortened from September to December due to variability in abundance indices associated with winter storm events (CDFG 2006b). The fall mid-water trawl survey also measures habitat parameters such as salinity, electrical conductivity, and Sechi depth to record water clarity.

3.1.4.2 Summer Townet Survey: 1959 to Present

CDFG conducts the summer townet survey from July through August or September. The survey targets juvenile striped bass that are roughly 38 millimeters (mm) in length but captures other species as well. The survey has proven useful in examining the relative densities of other fish species such as juvenile Delta smelt. Survey station locations are primarily the same as for the 20-mm survey (see Figure 3-5). The summer townet survey also measures habitat parameters such as salinity, electrical conductivity, and Sechi depth (to record water clarity).

3.1.4.3 20-mm Survey: 1995 to Present

CDFG conducts the 20-mm survey during the spring and early summer to monitor post-larval and juvenile Delta smelt distribution throughout their historical spring range (see Figure 3-5). These surveys are intended to provide near real-time data on distribution and relative abundance of Delta smelt for use in deciding whether the flows are sufficient to maintain Delta smelt rearing habitat away from the south and central Delta. The 20-mm survey also measures habitat parameters such as salinity, electrical conductivity, and Sechi depth (to record water clarity).

3.1.4.4 CVP and SWP Salvage: Late 1950s and 1960s to Present, Respectively

The fish salvage data collected at the Tracy (CVP) and Skinner (SWP) fish facilities have been used to characterize the juvenile and adult fish populations in the south Delta. Varying types of sampling gear, and sampling efficiency and methodology, between the salvage programs and the CDFG fishery survey data collected makes a direct comparison between these two data sets difficult. Salvage efficiencies are known to be highly variable among different species and size-classes of fish (SDFF 2003). The CVP and SWP fish facilities do not identify or enumerate larval fish that are less than 20 mm long and can only be considered appropriate sources of data for estimating seasonal trends in the abundance (density) of larger juvenile and adult lifestages.

3.1.4.5 Suisun Marsh Survey: 1980 to Present

Under a Department of Water Resources (DWR) contract, UCD monitors fish populations and selected aquatic invertebrates in Suisun Marsh (Meng and Moyle 1993, 1995; Meng et al. 1994; Meng and Matern 2001; Matern et al. 2002). The sampling was expanded after the construction of the Suisun Marsh salinity control gates to study the effects of the gates and other proposed changes in water circulation on fish populations. Data have been collected to quantify trends in diversity and abundance and to determine the habitat requirements of marsh fishes. Fishery sampling within Suisun Marsh occurs monthly year-round with an otter trawl at 17 stations located throughout Suisun Marsh (see Figure 3-5). Fifteen of the stations are in the western marsh and two are in the eastern marsh, both downstream of the salinity control gates. To provide more representative sampling of marsh species, in March 1994 researchers added two otter trawling sites in Nurse Slough and two otter trawling sites and one seining site in Denverton Slough. Seining was done with a beach seine.

Since 1994, UCD has also conducted a larval fish survey in Suisun Marsh. The larval fish sampling has been made using a 505-micrometer (μm) mesh plankton net mounted on a metal frame and sled that is similar to the larval fish sampling that CDFG conducts within the Delta. Typically, three replicate tows are made in the middle of the channel just under the water surface in First Mallard Branch and Suisun, Nurse, Denverton, and Cordelia sloughs.

3.2 Terrestrial Plant Communities

Terrestrial and wetland vegetation and wildlife are expected to be impacted by levee-failure events in the Delta and Suisun Marsh. Suisun Marsh is the largest contiguous brackish water marsh remaining on the west coast of North America; it is composed of 52,000 acres of non-tidal (managed) wetlands, 6,300 acres of tidal wetlands, 27,700 acres of upland grassland, and 30,000 acres of bays and sloughs. Suisun Marsh contains 10 to 12 percent of the seasonal and tidally influenced wetlands remaining in California. Prior to reclamation, the Delta was estimated to support about 400,000 acres of tidal marsh, with extensive riparian forests distributed along the floodplains of its tributaries.

The active tidal wetland communities, which are still prevalent in Suisun Marsh, provide societal values that include flood storage and retention, nutrient production and transport, hunting, and recreation. Both tidal and seasonal wetlands also provide a buffer and filter, improving water quality.

The Delta and Suisun Marsh support a diverse community of submerged aquatic vegetation (SAV), emergent wetlands, managed wetlands, riparian plants, agricultural crops, and upland communities and associated wildlife communities. Thirty-eight plant species in the region are considered special-status species, including seven listed as threatened or endangered under the Federal ESA, six listed under the California ESA, two considered "rare" by the California Department of Fish and Game, and 29 with special status under the California Native Plant Society (CNPS) ranking system (see Table 3-3). In addition, the Delta and Suisun Marsh support about 15 major non-native plant species, some of which have colonized large areas of the available habitat.

Vegetation communities within the Delta and Suisun Marsh occur in a patchy mosaic consisting of broad zones that are generally limited by abiotic gradients, principally salinity and water depth. Variation in salinity results in plant communities ranging from halophyte-dominated areas to freshwater and terrestrial communities that cannot tolerate salts.

Variation in depth and duration of flooding results in plant communities ranging from aquatic submerged vegetation to a wide array of wetlands and uplands. Distributions of, and variation among, plant communities are further influenced by the presence or absence of tidal action (such as the differences between diked and tidal marshes) and human impacts (such as agricultural history or levee construction). The Delta and Suisun Marsh plant communities include both herbaceous and woody species. Figure 3-6 shows a profile of the land and accompanying vegetation types.

In the Delta, the interior of diked islands has been converted primarily to agriculture but also contain patches of upland grasses and trees, riparian habitat, and freshwater marsh (see Figure 3-7). Decades of agriculture may have eradicated the original tidal marsh seed bank in many Delta islands. The channel sides of Delta levees are often steep and heavily reinforced with riprap (rock) and may support ruderal upland vegetation (see Figures 3-8 and 3-9), with fringing tidal marsh in narrow bands at the exterior (channel side) base of levees. The majority of sensitive species in the Delta are found in the fringing tidal marshes, interstitial islands within the channels, and in woody vegetation along the channels (see Figures 3-10 and 3-11).

As these figures indicate, there are substantial differences in levee configuration, levee maintenance, and aquatic, emergent, and riparian vegetation communities on Delta levees, in many cases reflecting the level of levee maintenance. Higher levees tend to be located in the west and central Delta and along the main river channels.

In contrast, Suisun Marsh is primarily managed diked wetlands consisting of a very patchy mosaic of tidal and freshwater marsh interspersed with upland communities. The diked wetlands are managed to allow for freshwater flooding for waterfowl, followed by a dry period to allow for crops and/or native vegetation growth to provide forage for the next season's waterfowl migration. The channel side of exterior levees has shallow slopes that support upland vegetation (see Figure 3-12). The majority of sensitive species in Suisun Marsh occur in marsh and upland habitats on the interior of dikes (see Figure 3-12). Suisun Marsh has a relatively large area of halophytic vegetation (i.e., alkali marsh), thus soils are already salt affected, and impacts of saline floodwaters on vegetation are expected to be lower than in the Delta.

Given these differences in levee function and configuration, the primary effects of levee-failure in the Delta versus that in Suisun Marsh would vary greatly in magnitude and duration. For example, flooding of several large islands in the west Delta would have a substantial effect on the tidal prism because of the size and depth of these islands and the projected longer period for repair of a multi-island breach. Breaching of numerous levees within Suisun Marsh would have a lower level of effect on the tidal prism because land elevations are higher relative to MSL and because levees could probably be repaired more rapidly. In addition, the effects of levee failure would vary between the Delta and Suisun Marsh because of the substantially different aquatic and wetland habitats in these areas. In either case, levee breaches and island flooding would have consequences for sensitive vegetation growing in the vicinity (see Table 3-4).

3.2.1 Occurrences of Sensitive Species at Risk from Delta Levee Breaches

CNDDB identified occurrences of 278 sensitive species in the region (the "region" includes the following Bay Area and Delta counties: Napa, Marin, Sonoma, Solano, Contra Costa, Alameda, Santa Clara, San Mateo, San Francisco, Yolo, Sacramento, and San Joaquin). CNDDB also identified 565 occurrences of 32 sensitive species in the Delta and Suisun Marsh (see Table 3-4). Occurrences of 14 sensitive species were recorded as being located on Delta levee slopes of Delta levees and within 200 feet of the levee centroid). About 27 percent of all sensitive species occurrences in the Delta and Suisun Marsh are located on Delta levee slopes (see Table 3-4). For 8 species, a substantial portion of all the observed occurrences of that species in the region (21 to 100 percent) occur on Delta levee slopes. The eight species with 21 to 100 percent of their regional occurrences on levee walls are *Carex vulpinoidea, Scutellaria lateriflora, Cirsium crassicaule, Hibiscus lasiocarpus, Aster lentus, Scutellaria galericulata, Lilaeopsis masonii,* and *Limnosella subulata* (see

Table 3-4). Several of these species were rarely observed in the Region 1 *(Carex vulpinoidea, Scutellaria lateriflora, Cirsium carssicaule,* and *Scutellaria galericulata)* but have a large proportion of their occurrences on Delta levee slopes. For the six other species with occurrences on Delta levee slopes, the number of occurrences on Delta levee slopes constituted only a small fraction (1.6 percent to 12.5 percent) of the total occurrences of those species in the region (see Table 3-4).

In the whole Delta, ten occurrences of sensitive species occurred on the landside of levee walls and therefore would be susceptible to flooding on the interior of the levee:

- Middle Roberts (1 occurrence)
- Rough and Ready (1 occurrence)
- Shin Kee (1 occurrence)
- Canal Ranch (1 occurrence)
- Area north of New Hope (2 occurrences)
- Area north of Hastings Tract (1 occurrence)
- Webb Tract (2 occurrences)
- Bouldin Island (1 occurrence)

This area was not flooded in January 2006 and is located on the northern side of the Roaring River Facility, in the southern end of Grizzly Island, Suisun Marsh. The Roaring River facility functioned as an exterior levee, preventing this area from being flooded in January 2006, unlike its counterparts to the south, which include Van Sickle Island and sections 902 and 903 (URS 2006).

3.3 Wildlife – Current Conditions, Threats, and Trends

The Delta and Suisun Marsh ecosystems support a high diversity of resident and migratory wildlife, including birds, mammals, reptiles, and amphibians. Current species composition, distribution, and abundance of wildlife in the Bay-Delta are determined primarily by the distribution and extent of the vegetative communities that support their habitats. The major change in Delta and Suisun Marsh habitats from historical conditions has been the loss of tidal influence with construction of levees and dikes and the conversion of marsh and riparian communities to agricultural uses. Consequently, the distribution and abundance of resident marsh- and riparian-associated species has declined (e.g., California black rail, salt marsh harvest mouse, western yellow-billed cuckoo). The distribution and abundance of species for which agricultural lands provide habitat have been less severely affected or benefited (e.g., wintering waterfowl, raptors). In addition to resident wildlife, the Bay-Delta serves as a wintering and migration stopover habitat for a large proportion of waterfowl, sandhill cranes, and shorebirds of the Pacific Flyway. Bay-Delta habitats (e.g., marshes, tideflats, agricultural lands) provide these species with the food resources needed to sustain their populations during winter and the energy reserves necessary to sustain migration and initiate breeding on their nesting grounds.

The primary ongoing threats to wildlife habitats in the Delta and Suisun Marsh are those related to loss and degradation of habitat. These include changes in salinity or other water quality parameters that could effect a change in vegetation communities that support existing habitats; the potential for conversion of agricultural and managed wetland habitats that support large numbers of wintering waterfowl and other birds that winter or migrate through the Delta to habitats that provide lower forage production or to other uses (e.g., development); and the permanent loss of these habitats to catastrophic levee failures.

3.3.1 Species of Concern

Species of concern in the Delta include species listed under the federal Endangered Species Act (ESA) and the California Endangered Species Act (CESA). Listed species that could occur in the Delta and/or Suisun Marsh are presented in Table 3-5. Other species of concern are those for which a large proportion of their occupied habitats are within the Delta and for which levee failures could result in substantial reductions in their distribution and abundance. These species include the Suisun ornate shrew (*Sorex ornatus sinuosus*) and saltmarsh common yellowthroat (*Geothlypis trichas sinuosa*), both designated by CDFG as California species of special concern.

3.3.1.1 Recreational and Economically Important Species

The primary recreational and economic uses of wildlife of the Delta include hunting and wildlife viewing (e.g., bird watching). Important hunted species include ducks, geese, and upland game (e.g., pheasant, dove, quail). Most hunting activity occurs on State refuges and private lands operated as hunting clubs. Important species of wildlife for viewing include the large numbers of waterfowl, sandhill cranes, and shorebirds that annually winter in and migrate through the Delta.

4 Species Selected for Analysis

A large number of aquatic and terrestrial species inhabit the Delta and Suisun Marsh that would potentially be affected by a sequence of levee failures. For purposes of quantifying the effect of levee failures on the ecosystem, it is not necessary for the risk analysis to address every species. Rather, a set of species can be selected that represents the diversity of the ecosystem and which could provide relevant metrics for future decision making. Therefore, representative taxa were selected for inclusion in the framework for analysis. Taxa were selected by considering factors that included:

- Life history and habitat requirements
- Vulnerability to significant impacts from levee failure
- Risk of extinction (ESA listed/species of concern)
- Trophic level
- Ability to structure/alter habitats
- Recreational or commercial importance

4.1 Aquatic Fauna

As part of the species selection process information on the life-history characteristics, temporal and geographic distribution of a species within the Estuary, and their vulnerability to population level impacts or benefits associated with the various impact mechanisms described in Section 6 were considered. Specifically, the following questions were used to guide selection of focal species for the aquatic ecosystem impact analysis:

- Is the species protected under the California or federal ESA and therefore potentially at risk of extinction in response to an environmental perturbation associated with a levee failure?
- Is the species identified in the CALFED Bay-Delta Program Multi-Species Conservation Strategy (MSCS) as an “R” or “r” to be addressed as part of the CALFED Ecosystem Restoration Program (ERP)? This criterion was selected to build on the work already completed by CALFED in identifying species/species groups of concern to the fish and wildlife management agencies. The species/species groups were identified in these documents because they were considered to be at risk of further population declines and/or were considered to be of high public interest.
- Is the Delta or Suisun Marsh included within designated critical habitat for listed species or as essential fish habitat for managed species?
- Is the species identified as a sensitive species, species of concern, or identified for recovery within the Estuary?
- Is the species representative of an assemblage of other species inhabiting the Estuary?

- Is information available on habitat suitability in response to factors such as salinity, water depth, and other environmental conditions that may change in response to one or more levee failures?
- Is the species representative of different life history characteristics and/or habitat uses within the Delta or Suisun Marsh (e.g., dependent on the Estuary year-round to support different life stages, anadromous species that use the Estuary as a migration corridor, etc.)? and
- Is the species an important recreational or commercial resource?

Based on consideration of these general criteria, aquatic species selected for inclusion in the risk analysis framework are presented in Table 4-1.

In addition, two other questions were considered in determining what organisms to focus on in the DRMS aquatic ecosystem impact analysis. They are:

- Is the species an important prey item and/or major component in community biomass?
- Is the species an important keystone species affecting habitat conditions or energy dynamics within the Estuary?

These questions led to consideration of taxa such as:

- *Corbula fluminea* – the "Asian clam"
- *Corbula amurensis* – the "Amur clam"
- Bass and sunfish from the family Centrarchidae
- Phytoplankton

Analysis of the impacts on these organisms will produce a binary outcome—good or bad — for the focal species above. Invasive predators such as bass and sunfish in the family Centrarchidae are major impediments to aquatic restoration programs because their presence excludes their native fish prey. Thus, if levee failure on a particular island creates excellent habitat for predatory centrarchids, that habitat would not be considered good habitat for focal prey species (e.g., Delta smelt)— indeed the "additional" habitat colonized by these predators would be counted as a negative impact (a population "sink"). The requirements of primary and secondary producers will, as a class, be taken into account as modification to the aquatic environment (e.g., surface area and/or residence time) that may affect overall productivity of the ecosystem. Whereas phytoplankton production is expected on all flooded islands (generally a positive for this potentially "food limited" ecosystem), habitat conditions that produce phytoplankton blooms which lead to eutrophic conditions would be considered a negative impact on fish species that might occupy the habitat prior to eutrophication.

Descriptions of the focal species are presented below.

4.1.1 Special Status Fish Species

Delta smelt – Delta smelt (*Hypomesus transpacificus*) are a federally endangered fish species endemic to the San Francisco Estuary (see Table 4-2). The entire population of this fish lives its entire life cycle in the zone that could be impacted by Delta levee failures (see Figure 3-3). This species is semelparous (dies after spawning), and most individuals reproduce after just one year of life (Bennett 2005). This life history and their narrow geographic range make them extremely susceptible to the impacts of levee failure.

Delta smelt spawn hatch and rear as larvae in freshwater. By July, they have moved into the brackish water zone of the Estuary which is usually located in the eastern part of Suisun Bay. Salinity tolerances and depth distributions are shown in Figures 4-1 and 4-2.

Longfin smelt – Longfin smelt (*Spirinchus thaleichthys*) are a species of special concern in the San Francisco Estuary and have recently been listed as protected under the state Endangered Species Act (see Table 4-2). Small isolated populations of this fish exist along the Pacific Coast of North America, from the San Francisco Estuary and to the north. Longfin smelt generally live for about two years and adults are believed to be semelparous (Moyle 2002)**.**

The Estuary's population of longfin smelt is believed to be declining rapidly (Rosenfield and Baxter 2007; Sommer et al. 2007). Recently, a petition was submitted to the U.S. Fish and Wildlife Service to list as threatened the longfin smelt population in the San Francisco Estuary. The State of determined that longfin smelt in the San Francisco Estuary were a candidate for listing under the state Endangered Species Act on February 7, 2008. Candidate species have all the legal protections of listed species during the candidacy period.

Sub-adults of this species are widely distributed throughout the Estuary throughout the year although, during summer, most of the population may be in the deep waters of the central San Francisco Bay or just off the coast (Rosenfield and Baxter 2007). One year old (pre-spawning) and mature longfin smelt migrate into the Delta and eastern Suisun Bay during the late-fall and early-winter. Most spawning occurs in the Delta over a protracted period that appears to last from late-fall through winter. The exact parameters (geographic and physico-chemical) of their spawning habitats are unknown. The location of collection of each year's first larvae suggest that most spawning takes place just downstream of Rio Vista in the Sacramento River and below Medford Island on the San Joaquin River (Wang 1986). Eggs attach to bottom substrates and so are unlikely to be entrained in either water diversions or flooding islands. However, larvae are abundant in the western Delta (including Suisun Bay and Marsh; Baxter 1999); thus, direct effects of levee failure may impact both spawning adult and larval life stages.

Chinook salmon – Four temporally and legally distinct runs of Chinook salmon (*Oncorhynchus tshwaytscha*) spawn in the Sacramento, San Joaquin, and Mokelumne Rivers and their tributaries. Two of these runs, winter and spring-run are protected under federal and state ESAs (see Table 4-2) and other runs are of special-management concern. Chinook salmon are semelparous.

These fish spawn upstream of the Delta and live most of their lives in the marine environment. Chinook salmon pass through the Delta as juveniles when they migrate between the ocean and freshwater and when they return to spawn as adults. The physiological requirements of Chinook salmon change dramatically as they move through the Delta and metamorphose from freshwater to marine fish.

Adult spawning migrations happen in temporally distinct pulses (discriminating between the different runs). The timing of juvenile migration through the Delta is also believed to be run-specific (and even sub-population-specific), but there is a good deal of overlap in the timing of these migrations. Juveniles begin to enter the Delta in late fall and are almost completely absent from the Delta by July (Williams 2006). Juveniles of the endangered winter-run are believed to pass through the Delta earlier in the year than the fall or spring runs. The residence time of individual juvenile salmon in the Delta is believed to be short, on the order of weeks, meaning that rearing in the Delta is minimal but the exact rate and timing of migration requires additional study (MacFarlane and Norton 2002; Williams 2006). Whether the current pattern reflects the historical (pre-levee) patter of Delta residence and migration is unknown.

Because of the Chinook salmon's migratory life history, the magnitude of immediate impacts of catastrophic levee failures on populations are expected to be greater for levee failure events that occur in the winter and spring than those that occur in the summer and fall. Also, because these fish mature at between 2-5 years of age, there are several year classes in the ocean at any given time..

Steelhead – Steelhead are a specific life-history strategy of the larger *O. mykiss* population. Anadromous (ocean-going) *O. mykiss* are called steelhead; non-migratory *O. mykiss* are called rainbow trout. The two life history strategies may breed with each other and each may produce offspring that follow the other life history strategy (McEwan 2001; Williams 2006).

Central Valley steelhead (*O. mykiss irideus*) are listed as threatened under the federal endangered species act (see Table 4-2). The range of this legally protected species (evolutionarily significant unit; ESU) contacts that of another ESU, the California Coastal steelhead, within the San Francisco Estuary. The Central Valley ESU's critical habitat includes the Delta as defined here.

Steelhead life history strategies are extremely variable and complex (McEwan 2001; Quinn 2005; Williams 2006). Their life-history patterns in the Central Valley are not well documented. Adults may migrate through the Delta to their upstream spawning grounds at any time during the year, although most spawners return between August and November (McEwan 2001; Williams 2006). Unlike Chinook salmon, steelhead adults can survive spawning and migrate back to the marine environment again; this behavior is believed to be quite rare in the Central Valley (McEwan 2001).

Juvenile steelhead rear in freshwater habitats for between several months and several years. They tend to migrate through the Delta as much bigger and more aggressive fish than the

Chinook salmon fry and smolts that pass through the Delta. This migration begins in January in some years and ends by July (McEwan 2001). There may be separate pulses of steelhead juveniles that pass through the Delta; hatchery-produced steelhead are believed to migrate earlier in the year than wild fish (Williams 2006).

Green sturgeon – Green sturgeon (*Acipenser medirostrus*) are a federally threatened fish species (see Table 4-2). They have been recorded in North American rivers from British Columbia in the North to the Sacramento River in the south. This enigmatic fish is naturally rare (made more so by human habitat modifications) and, as a result, sampling data are not abundant and do not necessarily capture population dynamics or spatial distribution of this species in the Delta. Green sturgeon grow very large (2.7 m) over a very long life-cycle (up to 70 years; Moyle 2002). They do not reproduce until they are at least 3 years old, but some females do not reproduce until they have spent over 10 years in marine waters (Moyle 2002). Like all sturgeon, these fish are anadromous and iteroparous (spawn and return to the ocean repeatedly in their life cycle). At any one time, most of the population is located outside of the Delta. Because they live so long and have the ability to delay reproduction until suitable conditions return, they may not be impacted much by the direct and immediate effects of levee collapse.

4.1.2 Other Representative Fish Species

4.1.2.1 Striped Bass

Striped bass (*Morone saxatalis*) were intentionally introduced to the San Francisco Estuary in 1879 (Moyle 2002). In recent years, their numbers have declined along with those of other populations of pelagic fish in the Estuary to record lows (Sommer et al. 2007). These fish represent the top predators in this ecosystem and, because they remain in the Estuary for most of their lives, their population trends reflect the status of the estuarine food web to some extent. Striped bass are major predators on native fish species and their ecological requirements are somewhat similar to those of native species; thus, there is a delicate balance between forces that favor striped bass populations and those that favor their prey base. A central problem in Delta fish habitat restoration is how to create conditions that favor native species while simultaneously excluding these non-native predators.

Striped bass are iteroparous spawners that require cool, large rivers for spawning. In the San Francisco Estuary, striped bass migrate to the Sacramento River (between Isleton and Butte City) or the San Joaquin River (from Venice Island to Antioch) to spawn (Moyle 2002). Striped bass live for up to 10 years old and do not reproduce for the first few years of life. These fish produce floating eggs that are carried down into the Delta; successful larvae are those that are transported near the mixing zone of fresh and saltwater (X_2). The period between spawning and metamorphosis from larval fish to juvenile fish requires about 10 days (Moyle 2002); during that time, stripes bass are vulnerable to entrainment.

Striped bass move between fresh and saline waters throughout their life cycle (i.e., they are catadromous). At any one time, the spatial distribution of the population includes the lower parts of major rivers, the Delta, the major embayments of the Estuary, and the nearshore ocean. As a result of their behavioral flexibility, they tolerate a wide range of water quality conditions including relatively high temperatures (up to ~30^{o}C), a wide range of salinities, high turbidities, and low dissolved oxygen concentrations (Moyle 2002).

4.1.2.2 Sacramento Splittail

Sacramento splittail (*Pogonichthys macrolepidotus*) are endemic to the Central Valley. Their conservation status is heavily scrutinized as they have been listed as threatened under the federal ESA until that listing was reversed after the initial listing was determined to be unwarranted (68 Fed. Reg. 55139-55166, September 22, 2003). Still, their populations have declined in recent years. Sacramento splittail reproduce on floodplains in the lower parts of major rivers and in some flooded environments in the Delta and Suisun Marsh. After they migrate to brackish waters, they remain in the northern Estuary for most or all of their life cycle. Their geographic restriction makes them susceptible to the immediate and long-term effects on the aquatic ecosystem of levee collapse.

These fish are iteroparous and long-lived for their size (Moyle 2002). They reproduce only when river flow conditions produce freshwater flooded spawning and larval rearing habitat. Thus, the loss of one year of reproduction is not catastrophic for this species as it would be for shorter-lived, semelparous estuarine endemics like Delta smelt or the local Longfin smelt population.

Salinity and other environmental tolerances of Sacramento splittail are summarized by Moyle (2002) and by Sommer et al. (2002).

4.1.2.3 Centrarchid Bass

Many members of the sunfish and bass family (Centrachidae) have been introduced to the Delta. These species are largely piscivorous. Their presence in slow moving warm-water habitats may prevent colonization of those habitats by native species. A central problem in Delta wetland restoration is how to create conditions that favor native species while simultaneously excluding these non-native predators. Generally speaking, habitats that support introduced bass and sunfish will be bad for native fish species.

These fish, including largemouth bass (*Micropterus salmoides*), warmouth, green sunfish and others, are year round residents of the freshwater parts of the delta. Some of these species are also tolerant of low salinity concentrations. They are generally iteroparous and long-lived.

4.1.2.4 Inland Silverside

Inland silverside (*Menidia beryllina*) are another introduced fish in the San Francisco Estuary. Their numbers are not believed to have declined during the recent period when other fish populations have declined. Indeed, some believe that silverside may have hastened the decline of native fish species because their high densities and high feeding rates can divert large amounts of primary productivity from other food chains (e.g., those that would be used by native species). Also, these fish are voracious predators and may consume large numbers of native species larvae. Habitats created by levee collapse that support large numbers of inland silverside will not support native fish species; such habitats may actually serve as population sinks for native species.

Inland silverside prefer shallow areas with little vegetation. Thus, they differ from other non-native predators in this system (striped bass and members of the family centrarchidae) that prefer vegetated habitats.

4.2 Plant Communities

4.2.1 Development of Vegetation Types

The fourteen vegetation types analyzed in this report were developed from vegetation data collected during extensive surveys of vegetation in the Suisun Marsh and Delta conducted by the Vegetation Classification Mapping Program of the California Department of Fish and Game. From these surveys, vegetation maps were created (Delta Vegetation Map unpublished, see Figure 4-3a and 4-3b; Suisun Marsh Vegetation Map 2003, see Figure 4-4), which provide plant community data described by the dominant species mapped in vegetation stands (or polygons). The Suisun Marsh vegetation map included 125 plant communities, and the Delta vegetation map included 133 plant communities. Each of these plant communities were assigned to one of 13 categories.

The wetland vegetation types generally follow the plant community definitions from Holland and Keil (1995; found in Goals Project 2000).

The vegetation types were developed by evaluating four ecological characteristics of the mapped plant communities:

- ***Physical structure and morphology:*** Are the dominant species floating or aquatic plants? Are the dominant species herbaceous, shrubs or trees?
- ***Hydrologic conditions:*** Are the dominant species in the plant community hydrophytes, i.e., are the species indicative of wetlands? Are the dominant species likely to occur in seasonal wetlands, or wetlands with perennial inundation? If the source of hydrologic inputs is tidal, are the species typical of a marsh zone (e.g., low marsh, middle marsh, or high marsh)?
- ***Salinity:*** Are the dominant species halophytes? Are they likely to occur only in areas with tidal influences, or a history of tidal influences?
- ***Native vs. non-native*:** Are the dominant species non-native? Are the dominant species ruderal (weedy or opportunistic)?

Based on the characteristics of the dominant species, each of the plant communities was assigned to one of fourteen vegetation types:

- Aquatic vegetation
- Alkali low marsh
- Alkali middle marsh
- Alkali high marsh
- Herbaceous upland
- Herbaceous upland ruderal
- Herbaceous wetland, perennially inundated
- Herbaceous wetland, seasonally inundated
- Herbaceous wetland, seasonally inundated, ruderal
- Shrub upland
- Shrub wetland (riparian)
- Tree wetland (riparian)
- Tree upland, native
- Tree upland, non-native

4.2.2 Vegetation Focal Species Selection Criteria

Focal species for each vegetation type are used to obtain detailed information on the response of the community to levee breach, because information on community-level response was lacking. Focal species were selected using the following criteria:

- The species is listed in the Delta and Suisun Marsh as one of the dominant cover species in originally mapped plant communities.
- A reasonable amount of scientific literature is available on the response of the species to the effect mechanisms of flooding and exposure to a range of salinity.
- The species is found in single vegetation type or does not exist in many other vegetation types.

A list of sensitive species observed in the Delta and Suisun Bay was also obtained from the California Natural Diversity Data Base (CNDDB) (2006). The CNDDB list includes all federal- and state-listed plants, all species that are candidates for listing, all species of special concern, and those species that are considered "sensitive" by government agencies and the conservation community. Special-status plant species within the Delta and Suisun Marsh are listed in Table 3-3.

The thirteen vegetation types are described below. The species that were examined in this analysis are listed in Tables 4-3a and 4-3b. Figure 3-6 shows a profile of the land in the Delta and Suisun Marsh with the accompanying vegetation types.

4.2.2.1 Aquatic Vegetation

Focal species: *Potamogeton pectinatus (native), Egeria densa (non-native)*
The aquatic vegetation type is defined by presence of floating or submerged aquatic obligate species, such as pondweed (*Potamogeton pectinatus*), Brazilian waterweed (*Egeria densa*), floating primrose willow (*Ludwigia peploides),* water hyacinth (*Eichornia crassipes*), and floating marsh pennywort (*Hydrocotyle racunculoides*). These areas are characterized by perennial inundation with freshwater.

4.2.2.2 Alkali Marsh Vegetation

Alkali marsh includes tidal marsh, which occurs along coastlines, and diked marsh, which is historical tidal marsh that has been blocked from tidal inputs by levees. More than 95 percent of tidal marshes in the San Francisco Bay have been diked or filled. In Suisun Marsh, tidal marsh (6,684 acres) occupies about 10 percent of the total area (69,000 acres), and the remainder is predominately diked managed marsh (Vaghti and Keeler-Wolf 2004). Alkali marsh occupies the ecotone between coastal waters and uplands. This ecotone includes three major transition zones (further defined below): low, middle, and high marsh, which are designated by tidal extent.

Diked marsh differs from tidal marsh in that diked marsh has a reduced tidal prism and virtually no transition zone between high marsh and uplands. Diked and tidal marshes also differ in overall species composition and physical stature of vegetation stands. It is noteworthy that the available information on dominant species in the plant communities is insufficient to confidently distinguish between tidal marsh and diked marsh, and their respective low, middle, and high marsh zones. For this reason, the vegetation types used in this report define alkali marsh in broad zones. The presence or absence of tidal inputs was determined not by dominant vegetation, but rather by landscape position. That is, small, linear patches of alkali marsh located on the channel side of levee walls are defined as fringing tidal marsh. Fringing tidal marshes do not maintain the complex food web and complete ecosystem function of historic tidal marsh, but they do support native tidal marsh plant communities and provide some habitat value for rare plants and wildlife. Fringing marsh, some evidence suggests, is tolerant to a wide range of channel water salinity (SEW 2001).

4.2.2.3 Alkali Low Marsh Vegetation

Focal species: ***Scirpus californicus, Scirpus acutus, Scirpus maritimus, Typha angustifolia***

In tidal areas, the low marsh vegetation occurs between the mean lower high water (MLHW) and mean high water (MHW) (Josselyn 1983). In diked areas, alkali low marsh occurs in areas of longer and deeper inundation (compared to middle and high marsh zones). Alkali low marsh vegetation is dominated by perennial, emergent, herbaceous, monocots up to 2 meters tall. The dominant species are tolerant of extended periods of tidal submergence. The dominant plant species in Alkali Low Marsh are hardstem bulrush (*Scirpus acutus*) and California bulrush (*Scirpus californicus*), which tend to occur in monotypic stands. Most Plants in this zone are inundated once or two times daily, thus species that occur in this zone can tolerant tidal submergence for a long duration. Soil salinity is more constant than in the middle and high marsh zones (SEW 2001).

4.2.2.4 Alkali Middle Marsh Vegetation

Focal species: ***Salicornia virginica, Sesuvium verrocosum, Lilaeopsis masonii***

In tidal areas, the alkali middle marsh vegetation type occurs between MHW and mean higher high water (MHHW) (Josselyn 1983). In diked areas, alkali middle marsh occurs in areas of long duration and depth that is intermediate to low and high marsh zones. Alkali middle marsh vegetation is dominated by perennial, fleshy halophytes. The dominant species are pickleweed (*Salicornia virginica*), American bulrush (*Scirpus americanus*), and saltgrass (*Distichlis spicata*). Plants in this zone are inundated once daily, and salinity is less extreme than in the high marsh zone (SEW 2001).

4.2.2.5 Alkali High Marsh Vegetation (and upland transition zone)

Focal species: ***Frankenia salina, Grindelia stricta***

In tidal areas, the alkali high marsh vegetation type occurs between MHHW and extreme high water (EHW) (Josselyn 1983). In diked areas, alkali high marsh occurs in areas with lower depth and duration of inundation. Alkali high marsh vegetation is generally dominated by pickleweed (*Salicornia virginica*) and saltgrass (*Distichlis spicata*), although this marsh zone may support non-native ruderal species such as rabbitsfoot grass (*Polypogon maritimus*) and Italian wildrye (*Lolium perenne*), especially in diked areas. Plants in this zone are inundated seasonally. The intermittent hydrology creates a cycle of tidal fluctuations and evaporation, allowing salts to accumulate in the soil (SEW 2001).

The upland transition zone is the area between mean high water and adjacent uplands; the upland transition zone is used as refugia for many animals use to escape extreme high tides or winter floods. This habitat has been greatly impacted by diking, which results in a sharper boundary between tidal marshes and the upland (Josselyn 1983).

The herbaceous upland vegetation type is dominated by herbaceous plants (as distinguished from woody plants) that die back in winter. The soils that support this vegetation type do not become saturated long enough to create anaerobic conditions, and standing water is usually absent. The vegetation is dominated by species native to the region. Due to the highly modified landscape, and the abundance of non-native species, this vegetation type occurs infrequently in the region.

4.2.2.6 Herbaceous Upland Ruderal Vegetation

Focal species: *Avena fatua, Bromus hordeaceous, Lolium multiflorum* var. *multiflorum, Hordeum murinum*

The herbaceous upland ruderal vegetation type is similar to the herbaceous upland vegetation type except that the dominant species are ruderal, or opportunistic, species. Typically the plant species are non-native (that is, indigenous to areas outside the region, often indigenous to areas outside North America). The herbaceous upland ruderal vegetation type includes non-native grasslands dominated by European annual grass species. The vegetation type may include invasive species such as yellow star-thistle (*Centaurea solstitialis*). This vegetation type is widespread, and often occurs in areas utilized for rangeland.

4.2.2.7 Herbaceous Wetland Vegetation, Perennially Inundated

Focal species: *Polygonum amphibium, Typha latifolia, Scirpus americanus*

The herbaceous wetland vegetation type is dominated by herbaceous, hydrophytic, emergent plant species. The dominant species are often graminoids or monocots, and are not usually halophytes. This vegetation type includes both native and ruderal dominated areas. The soils that support this vegetation type are usually saturated or inundated throughout most of the year, and the inundation creates anaerobic conditions. The hydrogic regime consists of inundation by freshwater, usually runoff, and salt-water inputs are absent.

4.2.2.8 Herbaceous Wetland Vegetation, Seasonally Inundated

Focal species: *Juncus balticus, Juncus effuses*

This herbaceous wetland vegetation type is characterized by seasonal inundation. The dominant plant species are herbaceous, hydrophytic, non-halophytic that are native to the region and include a mix of grasses, graminoids and forbs (broad leaf plants). The soils are inundated with anaerobic conditions for part of the year. The source of hydrologic inputs may be runoff or groundwater, with no tidal or salt-water inputs.

4.2.2.9 Herbaceous Wetland Vegetation, Seasonally Inundated, Ruderal

Focal species: *Lepidium latifolium, Lolium multiflorum* var. *perenne*

The herbaceous wetland seasonal ruderal vegetation type is similar to the herbaceous wetland seasonally inundated vegetation type except that the dominant species are ruderal. The dominant plant species are herbaceous, hydrophytic, and non-native to the region. The ruderal, or opportunistic, species include a mix of grasses, graminoids, and forbs. Some of the species in this vegetation type, because they are opportunists, can tolerate a range of hydrologic and saline conditions (e.g., broadleaved pepperweed [*Lepidium latifolium*]). The soils that support this vegetation type are inundated with anaerobic conditions for part of the year. The hydrologic inputs may come from a range of sources, including runoff and groundwater.

4.2.2.10 Shrub Upland Vegetation

Focal species: *Baccharis pilularis, Rosa californica*

The shrub upland vegetation type is dominated by woody shrubs (as distinguished from trees). The distinction between trees and shrubs is a poorly defined concept, but for the purposes of this report shrubs lack a uniform trunk and are generally less than four meters tall. The dominant species are native, and are upland species (i.e., not hydrophytes) that lack affinity for alkali soils (i.e., not halophytes). The plant community may include an understory of herbaceous upland species similar in composition to the herbaceous upland vegetation type or the herbaceous upland ruderal vegetation type. The soils that support this vegetation type do not become saturated long enough to create anaerobic conditions, and standing water is usually absent.

4.2.2.11 Shrub Wetland (Riparian) Vegetation

Focal species: *Rubus discolor, Salix exigua, Salix laevigata*

The shrub wetland vegetation type is dominated by woody, hydrophytic shrubs. The dominant species include native and ruderal plants, and this vegetation type may include an understory of herbaceous hydrophytes similar in plant species composition to the herbaceous wetland seasonal vegetation type or the herbaceous wetland seasonal ruderal vegetation type. The locations that support this plant community are characterized by seasonal inundation associated with a stream corridor (i.e., riparian areas), and may be subject to frequent flooding by freshwater.

4.2.2.12 Tree Wetland (Riparian) Vegetation

Focal species: *Fraxinus latifolia, Alnus rhombifolia*

The tree wetland vegetation type is dominated by woody, hydrophytic trees. The dominant species include primarily native plants, and this vegetation type may include an understory of riparian shrubs or herbaceous hydrophytes similar in plant species composition to the herbaceous wetland seasonal vegetation type or the herbaceous wetland seasonal ruderal vegetation type. The locations that support this plant community are characterized by seasonal inundation associated with a stream corridor (i.e., riparian areas), and may be subject to frequent flooding by freshwater.

4.2.2.13 Tree Upland Vegetation, Native

Focal species: *Quercus agrifolia, Quercus lobata*

The tree upland native vegetation type is dominated by woody trees that are native to the region. This vegetation type may support an understory with a range of upland herbaceous or upland shrub species. The soils that support this vegetation type are not inundated frequently enough to create anaerobic conditions and salt-water inundation is absent.

4.2.2.14 Tree Upland Vegetation, Non-native

Focal species: *Ailanthus altissima, Eucalyptus globata*

The tree upland non-native vegetation type is dominated by woody trees that are non-native to the region (the dominant species are usually indigenous to a continent outside North America). The dominant trees are ruderal, or opportunistic, species which may include invasive species. The dominant species usually grow quickly (compared to native trees), have seeds that disperse easily, may reproduce clonally, and may possess a broad range of tolerance to salts and/or inundation. The tree-of-heaven (*Ailanthus altissima*) is a rapid colonizer and is frequently observed growing in heavily disturbed or waste areas. Eucalyptus (*Eucalyptus globata*) often grows in monotypic stands, such that other species cannot survive or colonize a eucalyptus grove. The soils that support this vegetation type are not inundated frequently enough to create anaerobic conditions and salt-water inundation is usually (but not always) absent.

4.3 Terrestrial Wildlife

The following criteria were developed to screen and select the wildlife species/species groups that would be appropriate for use in the environmental risk analysis. The criteria were designed to focus the scope of the analysis to a manageable number of species/species groups, while representing the range of the types of possible consequences on wildlife that could be associated with levee failures.

The following two criteria were applied to assemble a list of species/species groups that were included in the analysis.

- The species/species group is identified in the CALFED Bay-Delta Program (CALFED) Multi-Species Conservation Strategy (MSCS) (CALFED 2000a) as an “R” or “r”[1] The

[1] “R” species are species for which the MSCS goal is to recover the species’ population within the MSCS focus area to levels that ensure the species’ long-term survival in nature. “r” species are species for which the MSCS

species is a species assemblage addressed by the CALFED Ecosystem Restoration Program (ERP) Plan (CALFED 2000b). This criterion was selected to build on the work already completed by CALFED in identifying species/species groups of concern to the Wildlife Agencies. The species/species groups were identified in these documents because they were considered to be at risk of further population declines and/or were considered to be of high public interest.

- The species/species groups identified via Criterion 1 must inhabit portions of Suisun Marsh or the Delta that could be affected by levee failures. The CALFED process included species throughout the CALFED solution area, an area much larger than the DRMS Study Area. This criterion was selected to ensure that the species/species groups selected would include only those whose habitats include those portions of the Delta or Suisun Marsh that would be affected by levee failures. The determination of whether or not a species/species group could be substantially affected by levee failures was determined based on a qualitative assessment of the proportion of occupied species/species group habitats that could be inundated by levee failures.

Species/species groups meeting both Criteria 1 and 2 were next screened based on the following criterion.

- Current knowledge is sufficient to allow the estimation (either directly or indirectly) of the response of each species/species group to levee failures. This criterion was selected to ensure that sufficient information about the species distribution, habitat requirements, and behaviors is available to conduct a meaningful analysis.

The results of applying the criteria to the wildlife species/species groups are presented in Table 4-4. The species selected for analysis are:

- Mammals: Suisun ornate shrew, salt marsh harvest mouse
- Insects: valley elderberry longhorn beetle
- Birds: California clapper rail, black rail, saltmarsh common yellowthroat, greater sandhill crane, Swainson’s hawk

goal is to implement some of the actions deemed necessary to recover the species’ population within the MSCS focus area (CALFED 2000a).

5 Assessing Sources of Uncertainty and Limits of Knowledge

The purpose of the DRMS risk analysis is to estimate likelihood of consequences (positive and negative) that may occur as a result of levee failures. This analysis includes the effects of levee failures on the ecosystem. For each type of consequence that is evaluated, all sources of uncertainty (aleatory and epistemic (see URS/JBA 2008)) that affect the estimate of consequences, conditional on the occurrence of levee failures, can in principal be estimated.

Ecological science is not well-suited to developing predictions of ecosystem dynamics over any but the shortest time scales because ecological systems are unreplicated, complex, and stochastic (e.g., Mayr 1961; May 1974). These “complex adaptive systems” (Brown 1995) respond to many, often subtle, and often non-linear forces and their structure and dynamics are not accurately characterized by a reductionist modeling approach (Brown 1995). Because of this complexity and because ecological outcomes are highly dependent on initial conditions (which often are not known or well understood), ecologists are ill-equipped to predict the outcomes of perturbations to ecosystems. As a result, comprehensive quantitative models that predict future population levels of any species after large-scale perturbations are generally unavailable. These limitations are particularly apparent because all but artificial, experimental “ecosystems” are open systems (they are nested entities with arbitrarily defined boundaries) where the composition of interacting entities changes continuously. For example, in the Delta aquatic ecosystem, species composition and the forces affecting species’ interactions are constantly changing (e.g., Alpine and Cloern 1992; Matern et al. 2002). Indeed, the Delta aquatic ecosystem is in the midst of a rapid shift in biological diversity (commonly referred to as “pelagic organism decline”); the forces driving this shift are not well-understood (Sommer et al. 2007).

The DRMS Ecosystem Impact Modeling methodology team was tasked with answering a very broad question: What will happen to the Delta after levee failure? Modern ecology cannot address such a broad question quantitatively because there are too many complex interactions, some dominated by non-linear dynamics and interactions that are not well understood even in “isolated” ecosystems (e.g., Werner 1992; Brown 1995). Instead, DRMS Ecosystem Impact Modeling team identified different mechanisms that were expected to produce relatively large impacts to their focal ecosystems (aquatic or terrestrial) as a result of levee failure and island flooding. For each of these mechanisms, the team identified models to estimate the impact to the relevant ecosystems. These models provide “first-order” estimates of major impacts to selected focal organisms in the ecosystems of the Delta. They are based on relationships of focal species to physical characteristics of their environment. Possible biological interactions are innumerable, context-dependent, and poorly-understood; thus, modeling of these (potentially important) effects was severely limited.

The ability to estimate the environmental effects of levee failures is limited by our current state-of-knowledge of ecological processes in general, and the impact that significant stressing events such as levee failures may have in particular. Although substantial effort has been made to study and collect data on the species, habitats, and ecological processes in the Delta and Suisun Marsh, the state of knowledge on some subjects is quite limited. Our understanding of critical attributes of species, habitats, and processes in the estuarine ecosystem is patchy. Although some species have been extensively studied, others are lacking significant and or current information.

As described above, the Delta provides habitat to a diverse assemblage of resident and migratory estuarine organisms. A wide range of habitats, created by the interaction of physical forces (e.g., flow rates, tidal influence, water depth, salinity intrusion, temperature) with different primary producers (that influence both the local energy supply for other trophic levels and the physical structure of the habitat), and human activities (e.g., agriculture, suburban housing, managed diked-wetlands) leads to a geographically complex pattern of species assemblages. Furthermore, many species use the Delta as a migration corridor, while other species are year-round residents that use different habitats throughout their life cycle. This physical, biological, geographical, and temporal complexity makes analysis of biological sampling data challenging. For example, even intensive sampling efforts may fail to capture important associations between species and habitats that happen seasonally or in a particular environment whose location changes seasonally or annually (e.g., based on freshwater outflow). Despite these limitations, valuable data from long-term and intensive fish and wildlife sampling programs conducted by state and federal agencies and academic institutions are available for the study of biological trends and relationships within the Delta and the larger San Francisco Estuary.

In the Delta, key unknowns that contribute to our epistemic uncertainty for many of the species include (but are by no means limited to):

- Current or historical population abundance and relationships (e.g., linear, logarithmic) between population indices and actual population abundance
- Basic life history data (e.g., fecundity and mortality rates)
- Physical habitat tolerances and preferences (salinity, temperature, dissolved oxygen, turbidity, pollutants)
- The strength, extent, and natural variability in biological interactions including predator-prey dynamics, diseases and their epidemiology, and competitive interactions
- Ecosystem carrying capacity, the trends in carrying capacity, and the drivers that produce those limits and trends

The risk analysis of environmental effects resulting from a wide range of potential levee failure events is characterized by a large amount of uncertainty. Uncertainty is associated with interpretation of existing data for a species, the range of individual responses and tolerances, variations in habitat preferences, and other factors related to developing a single response curve that is representative of the species. Other sources of uncertainty include lack of data regarding:

- The manner in which individual effects on species life stages compound or interact to produce overall changes in individuals
- The manner in which changes in individuals lead to changes in population levels of the species
- The manner in which changes in individual species lead to changes in ecosystem-level effects

In general, these and other knowledge gaps extend across species, habitats, and trophic guilds. Uncertainty regarding these factors is less for some species than for others. Further, factors such as population abundance and the strength of density-dependent limits on population growth can only rarely be determined precisely (May 1974).

In addition to the epistemic uncertainty surrounding predictions of ecosystem response to environmental perturbations, predictions of this sort in biological systems are also subject to significant aleatory uncertainty. Chance (aleatory) events play an important role in population dynamics, interactions among species, and other environmental processes. The forces that produce aleatory uncertainty become increasingly important as population abundance decreases ("Allee effects," Stephens and Sutherland 1999) or the geographic extent of a critical habitat declines (e.g., Rosenfield 2002). Many of the species and habitats included in the environmental risk analysis component of the DRMS project are small, geographically limited, and endemic or extremely isolated. Thus, aleatory uncertainty is expected to have a relatively large impact on the predictions that will result from this analysis.

In contrast to the state of knowledge regarding the Delta's aquatic ecosystem, the relationships between the availability of terrestrial species habitats (i.e., extent, connectivity, patch sizes, and quality) and the distribution and abundance of wildlife in the Delta and Suisun Marsh are generally well understood. However, the data necessary to quantify these relationships is often lacking (e.g., the likely effects of a change in food availability on a species distribution, behavior, or abundance).

6 Risk Analysis Methodology

This chapter describes the risk analysis methodology for aquatic fauna, vegetation and terrestrial wildlife. Three impact mechanisms are explored: the immediate effects of levee breaching, the impacts from flooding delta islands and changes related to altered hydrology and salinity. These mechanisms are described in Section 6.1 for aquatic fauna and their associated impact methodologies. Section 6.2 presents vegetation impact mechanisms and associated uncertainties. Section 6.3 briefly describes the impact mechanisms to terrestrial wildlife.

6.1 Impact Mechanisms for Aquatic Fauna

Levee failure in the Sacramento-San Joaquin Delta is expected to alter the aquatic ecosystem in several ways. When levees fail and water enters an island, sediments are suspended in the water higher than normal concentrations. Suspended sediments may impact pelagic organisms, and settling sediments may impact benthic organisms such as mollusks and aquatic plants. When several islands flood, freshwater in the Delta will be displaced by brackish water, drawn from the Bay, producing a measurable movement of the salinity field to the east. Movement of the salt field will modify habitat availability for a number of organisms because aquatic organisms are generally sensitive to salinity conditions. The flooded islands themselves will become new aquatic habitats. Some of the islands may develop into habitat suitable for fish species. All of the islands will increase the habitat available for primary producers, at least in parts of the year. Finally, levee failure and island flooding will alter human activities in the Delta, including (most importantly) the operation of the state water project (SWP) and federal Central Valley Project (CVP) export pumping facilities.

Several factors will determine the magnitude of impacts to the aquatic ecosystem after a levee failure. For example, the number and cumulative volume of islands that flood will determine the degree of salt field displacement. The spatial distribution and proportion of a species' population in the Delta varies somewhat predictably by season for many aquatic species; thus, the timing of levee failures is a critical factor in determining immediate impacts to aquatic species (see Figure 3-3). For example, because some species use the Delta mainly as a migratory corridor, the season in which levee failure occurs will determine whether a large or negligible proportion of a given species will experience immediate impacts. The location and physical measure of islands whose levees fail may also determine the effect on aquatic organisms because some islands are near migration corridors.

Levee failures within the Delta or Suisun Marsh have the potential to affect fish and wildlife species directly (e.g., mortality to fish entrained onto a flooded island, removal of vegetation during a levee break or as a result of levee reconstruction) or indirectly (e.g., changes in the amount or quality of habitat, water quality, or changes in upstream water releases and diversions from the Delta). Changes in habitat conditions may be detrimental to some species or lifestages and beneficial to others. Also, changes may have different effects depending on the geographic location and extent of the change and the timing and duration of the occurrence; some effects may occur over a relatively short period (days to months), while others may occur over longer periods (years to decades).

The models developed in this study operate on different time scales after levee failure and island flooding (see Table 6-1). Clearly, the results of forces operating on one time scale affect the inputs and outcomes of mechanisms operating on other time scales. No effort has been made to link outputs of one model component to those of other model components. Furthermore, outputs are not directly comparable across components and should therefore be evaluated independently.

6.1.1 Impact 1: Entrainment of Fish on Flooding Islands

6.1.1.1 Conceptual Underpinning

After a levee failure, water will flow onto islands, and fish will likely be drawn onto islands in the floodwaters. The flooding will also lead to high levels of suspended sediments as water scours the collapsed levee, levee foundation, and island floor. The suspended sediments may stress or kill fish entrained on flooding islands.

Exposure to suspended sediment has the potential to result in lethal and sublethal conditions depending on the sensitivity of the species and lifestage, the concentration of suspended sediment, and the duration of exposure (Davis and Hidu 1969; Minello et al. 1987; Grant and Thorpe 1991; Newcombe and MacDonald 1991; Newcombe and Jenson 1996; Hanson et al. 2004). Although larger sediment particles would settle out of the water column over a relatively short period of time, turbulence and resuspension of sediments may result in exposure durations of hours or days, and possibly longer depending on the particle size and hydraulic characteristics of a flooding island.

Other sources of mortality resulting from flooding (including that due to shear-stress, increased predation due to disorientation, stranding, etc.) are not modeled.

The chance of entrainment onto a flooded island is a function of the location of a fish species in the Delta at the time of the levee failure, and the volume of water initially drawn onto the island. The potential mortality of fish that are entrained will depend on the suspended sediment concentrations found on flooded islands, the duration of elevated suspended sediment concentrations, and the species-specific tolerances for suspended sediment concentrations. Fish species' densities and the proportion of a species' population represented in the Delta vary according to seasonal behaviors and annual hydrological conditions (see Figure 3-3). The volume of water drawn onto flooding islands depends on the number, area, and depth of flooding islands (Table 6-2). Suspended sediment concentrations on flooding islands will vary over the time course of flooding and according to the soil composition on the flooding island (see Figures 6-1a and 6-1b). The duration of exposure to different suspended sediment conditions results from the interaction of the time course of fish entrainment and the time course of sediment suspension and settling. Finally, suspended sediment tolerances vary by species and life-stage – tolerances for some species have been studied (e.g., Newcombe and Jenson 1996), but most species/life-stage tolerances are poorly documented.

Each of these inputs is subject to variability and uncertainty. For example, there is natural variability in the individual reaction of fish to suspended sediment concentrations. Also, many of these inputs are random and not well understood. For example, the time course of suspended sediment concentrations on flooding islands in the Delta have not been documented and must be estimated from limited knowledge. As a result, modeling of the impact associated with entrainment on flooding islands is subject to uncertainty.

Estimating population level impact from entrainment on flooding islands

The entrainment model can be used to estimate the *proportion* of a species' population that may be killed by elevated suspended sediment levels on flooding islands. The impact of the projected mortality is evaluated by assessing their effect on the estimated time to extinction for a species (Dennis et al. 1991). The "Dennis Model" uses population abundance measurements to empirically estimate the growth rate or decline of a species over time. Coupled with an estimate of the variance in population abundance, the Dennis Model can be used to estimate the time to extinction (assuming a population quasi-extinction level) of a species and its uncertainty (due to the limited data and the uncertainty in the model parameters). An example of this result is illustrated in **Figure 6-2**. The reduction in population size resulting from mortality on flooding islands is expected to decrease a species' time to extinction. The decrease in population size estimated to result from each levee failure scenario can be expressed as a proportion of the present day population. Indeed, this proportion can be calculated without knowledge of the present population size as long as the proportion of fish entrained on flooding islands (as estimated from spatial distribution data) and the proportion of entrained fish that suffer mortality can be estimated.

This estimate of a reduction in population size can be input to the Dennis Model framework using techniques described by Bennett (2005) for species of the San Francisco Estuary. The "impact" of entrainment and exposure to elevated suspended sediments will be measured as the change in time to extinction or change in probability of extinction for each species. **Figure 6-3** is a heuristic example of this technique. The figure plots the mean population abundance (diagonal black line) and its associated variation (blue bell curve) over time. In this example, the population is decreasing over time prior to the levee breach event. At that point (vertical dashed line), the population experiences an immediate impact after which it resumes its previous rate of decline. A population would go extinct when it crossed below the population viability threshold (red dotted line). The red-shaded area under the population viability threshold portrays the probability of extinction. Note that for this example species population, the levee breach reduces the time to extinction and increases the immediate probability of extinction. This is not necessarily the case for all species; some would be unaffected by or even benefit from a levee breach.

This approach assumes the species of interest does not experience density dependent mortality. This may be true for the severely reduced Delta smelt population but is not likely to be true for Chinook salmon, which are known to experience compensatory survival and growth in response to mortality at early life stages (Quinn 2005). The presence of density-dependent survival and growth (reproduction) means that use of the Dennis Model on some species will produce an overestimate of the "impact" of entrainment on species extinction probabilities.

6.1.2 Methodology: Mortality Due to Entrainment on Flooding Islands

6.1.2.1 Framework

The impact to aquatic species in waters subject to entrainment on flooded islands can be measured in terms of the proportion of the population that is killed as a result of a levee failure event. This impact, which is conditional on the levee failure scenario (i.e., conditional on the events and variables that define a scenario), can be expressed as:

$$I_M(i,m) = \phi_P(x,m) \quad \phi_E(i) \quad S(i) \quad \phi_M(S(i)) \tag{1}$$

where:

$I_M(i,m) =$ fraction of the fish species population that is killed as a result of the levee failure scenario that occurs in month m and on an island *i*

$\phi_P(\underline{x},m) =$ spatial distribution of a fish species population in the Delta for a month, *m*

$\phi_E(i) =$ proportion of a fish species' population in the Delta that is entrained on an island *i*

$S(i) =$ suspended sediment concentration in the water column on the flooding island as a result of levee failure.

$\phi_M(S(i)) =$ fraction of the fish entrained on island *i* that are killed. (The dependence of fish mortality on islands reflects the variation of suspended sediment concentrations that may exist from one island to another, if this is the case.) Fish mortality will be defined for each species and each life stage. Therefore, as necessary, multiple mortality models may be required for a species to reflect their vulnerability during different life stages. (Note that indices denoting the dependence on species and life stage are not included in the notation).

The total proportion of fish killed on all islands that are flooded during a levee failure scenario is given by:

$$I_M(m) = \sum_i I_M(i,m) \tag{2}$$

Different approaches can be considered to estimate the spatial distribution of a species in the Delta. Alternative estimates of the temporal and spatial distribution of a species may be required because of differences in their life histories and behaviors. Below, several approaches to estimating $\phi_P(\underline{x}, m)$ are explained. One set of approaches would be applicable to Delta smelt and other species whose migration through the Estuary is relatively slow (such that monthly sampling programs may characterize their spatial and temporal distribution). The other approach (which incorporates estimates of migration rates and flux through the Delta) is more appropriate for species whose migration through the Delta is relatively rapid (i.e., salmonids).

Estimating spatial distribution of fish in the Estuary

Entrainment onto a flooding island is calculated as a function of the month when a levee failure occurs, the spatial distribution (e.g., density) of a fish species in the area of the levee failure, and the volume of water initially drawn onto the island.

- **Calculating the proportion of a population susceptible to entrainment on flooding islands—Delta smelt.** Several aquatic community sampling programs (see Table 3-2, Figures 3-4 and 3-5) determine the density of fish and other taxa throughout the Estuary, including the Delta and Suisun Marsh. Sampling localities throughout this area are traditionally grouped into "sampling regions" that are believed to represent relatively homogenous habitats for fish. By multiplying density in these regions by the size of the regions (e.g., surface area or volume), one can estimate the "number" of fish in each region and, by summing, the total number of fish in the Delta (Armor and Herrgessell 1985). Similarly, if one can project the region from which floodwaters will enter a flooding island, the proportion of a given species total population that is entrained on an island can be calculated by multiplying island volume by the local fish density.

  This approach is applied across most of the aquatic community sampling programs in this Estuary to develop "abundance indices" However, it is not considered to be highly accurate because the density of sampling localities (and the size of "sampling regions") is probably insufficient to characterize an "average density" for most of the species sampled (Rosenfield and Baxter 2007). Also, absolute numbers of fish entrained or killed are not entirely relevant for the DRMS analysis of levee failures in the future because a declining trend has been established for many of the Delta's aquatic species (Sommer et al. 2007). Thus, for purposes of estimating mortality due to entrainment on flooding islands, it is more valuable to characterize a population's spatial distribution in terms of the *proportion* of the population that is present at the time of a levee failure and therefore exposed to possible entrainment as opposed to the exact number of fish that are entrained. The density-volume approach can provide a reasonably accurate estimate of this proportion that will be useful for relative comparisons of impact across different levee failure scenarios.

  – **Approach 1:** The entire area of the Delta can be divided into sampling regions based on simple geographic proximity to major habitat features. Figure 6-4 displays one effort to divide the Estuary into 13 regions using a subjective discrimination of sampling localities into areas of "homogenous" habitat types. This approach is similar to that commonly used by management agencies and researchers in this Estuary to delineate sampling regions for aquatic community sampling programs (e.g., Armor and Herrgessell 1985; Baxter et al. 1999).

Within each of the 13 “sampling regions,” monthly average fish densities (calculated from counts at the CDFG sampling stations in each analysis region) as weighted by GIS-based estimates of total water volume are used to determine the proportional distribution of fish in different regions of the Delta.

– **Approach 2:** Kimmerer divided the entire Estuary, including Suisun Marsh, into 11 zones representing different hydrological, geomorphological, and biological conditions. These sampling zones are thus based on the physical similarity between water bodies as experienced by aquatic organisms – not just geographic proximity (Kimmerer pers. comm.).

– **Approach 3**: A third approach to estimating the distribution of individuals of a species in space and time employs a statistical technique called hierarchical cluster analysis to group adjacent portions of the Estuary that share similar trends in fish CPUE (Aldenderfer et al. 1984; Romesburg 2004). This method is distinct from the other approaches described here in that it relies on objective, statistical correlations of distributions of fish presence to determine clusters rather than on indirect correlations of fish presence, such as geographical, hydrological, or biological conditions. Another advantage of this approach is that it can be applied separately for each species to determine whether “homogenous” habitat zones differ among species.

A hierarchical cluster analysis produces dendrograms where the “branches” and “leaves” of the tree-like diagram are the station numbers where the trends in the CPUE data are similar over a given number of samples (see Figure 6-5). Several commonly-used criteria for calculating distance (dissimilarity) between clusters may be employed. Ward’s criterion is reasonable for this application because it measures the increase in variance that would accompany adding another station to the cluster (Romesburg 2004). The result is that sampling localities may be grouped into regions of similar fish density. Non-adjacent sampling localities that cluster together (i.e., show similar patterns in fish density dynamics) are placed in separate sampling regions. Hierarchical clustering (where clusters are determined successively) is preferable to partitional clustering (where all clusters are determined simultaneously using an initial random assignment of stations) in this application because it produces repeatable results (Romesburg 2004).

The dataset cannot contain missing cells; data for each sampling period must be recorded for each sampling station (i.e., the data set must be complete). In datasets from the San Francisco Estuary, this requirement will reduce the total length of the time because of occasional gaps in the data set (e.g., Rosenfield and Baxter 2007).

Finally, a criterion must be defined to determine the number of clusters to be generated. Akaikes Information Criteria (AIC) can be used to determine an appropriate number of clusters. A cluster analysis reports how much more information is gained by dividing the data into smaller and smaller clusters. AIC is used to establish a cut-off of the number of clusters to use by determining when the information gained from adding clusters drops off sharply (Romesburg 2004).

This approach enables an understanding of the spatial zones in the Delta of similar densities for a given fish species. An example of this approach, using data for Delta smelt catches, is presented in Figure 6-6. Note that clusters do not necessarily indicate large or equivalent portions of the population; rather, they represent stations with correlated measurements of fish densities.

- **Calculating the proportion of a population susceptible to entrainment on flooding islands—Chinook salmon and steelhead.** Chinook salmon and steelhead smolts pass through the Delta only once during their juvenile life stage. Their susceptibility to entrainment on flooding islands is a function of the duration of their residence in the Delta. Data are available for the number of tagged, hatchery-raised (from the Livingstone Stone National Fish Hatchery on the Upper Sacramento River and the Coleman National Fish Hatchery) smolts passing Chipps Island each day. Corresponding release date data are also available. These data can be used in conjunction with an estimate of migration speed in the upper Sacramento River.

  The USFWS Chipps Island trawl survey data can be used to develop fish passage curves for "Delta departure." Combining these data with the above release dates, and factoring in the migration speed and distance to the delta from the release point, it is possible to develop a "mean residence time" (MRT) and estimates for daily "Delta arrivals."

  These smolts departure-day counts and arrival-day estimates are converted into percentages of the population leaving and arriving in the delta on each day. This assumes that survival and migration rates of hatchery fish are not significantly different from those of wild fish. From the daily arrival and departure percentages, cumulative percentages arriving and departing can be calculated. The difference between these is the net percentage of population in the delta on a given day. If islands fill in a single day after a breach, then this is also the percent at risk of island entrainment. If, however, islands require more than one day to fill, then the percent arrival estimates for the additional day(s) should are added to the percent of population at risk. The percentage departing is not subtracted out because those smolts do not depart; they are already entrained.

  Although, smolts that are west of Chipps Island are considered "out" of the Delta and, thus, comparatively safe from entrainment at the CVP and SWP pumps, large levee failure events could pull water and fish from as far west as San Pablo Bay. The calculations below can be modified to take into account fish that would be entrained from west of the Delta. Smolts that have not yet arrived in the Delta may also avoid entrainment during a levee failure scenario depending on how long it takes for flooding islands to fill. The proportion of the population at risk from island entrainment is limited to those in the Delta on the day of the breach plus those arriving in the Delta during the time the islands are filling.

Because this approach operates on percentages of the population, no assumptions about rates of other sources of mortality are necessary. The population proportion at risk of island entrainment is the proportion of the *surviving* population in or about to enter the Delta on a given day. It is not the percent of the original or final population.

Table 6-3 shows an example of the derivation of these basic and cumulative percentage curves by Julian day. Figure 6-7 is a plot of the curves representing all the percent passage data and calculations against Julian day for this *entirely fictitious* data set. In this example, "% Dep Day" represents the Chipps Island survey data showing that all Chinook smolts leave the Delta between Julian Day 31 and 45, in a normal distribution centered at Day 38. The "Cum Dep %" column shows the accumulated departure of smolts that are now "safe" from entrainment; adjustments can be made to these calculations to reflect susceptibility of salmonid smolts that have recently migrated past Chipps Island.

Brandes (pers. comm. 2008) calculated Delta residence times over a set of different migration periods for smolts of different runs, races, origins (wild vs. hatchery-raised) that had been marked using a variety of tagging protocols. These calculations produced a wide range of Delta residence time estimates. She found that hatchery and wild spring run and fall run hatchery smolts released in the Delta resided in the Delta on average 8 to 10 days. For this example, we used the implicit mean residence time of 9 days. For purposes of this illustration, we assumed standard deviation of ±3 days.

Brandes also found that the peak of fall/mainstem spring-run emigration from the Delta occurred in April and May. As a result, in this example outmigration is normally distributed around Julian Day 120 (April 30). Finally, for this example, the emigration period is artificially compressed into a 13-day period.

In Table 6-3, the central columns show the percent arrival by Julian Day. Daily arrival percentage is calculated for each day. Then, the daily columns are summed to develop the "% Am/Day" metric (in yellow). The "Cum Arr %" column shows the cumulative percent of the population that has arrived in the Delta by day.

The "Net % in Delta" column is simply the difference between the cumulative arrival and departure percentages. If the islands were to fill in a single day, this column would be equivalent to the "% at Risk" of entrainment. However, this example assumes that islands take two days to fill, and so the "% at Risk" on any given day is equal to the "Net % in Delta" plus the percent arriving in the next two days ("% Arr/Day").

The numbers and passage/population dynamics in this example are simplified from estimates by Brandes (personal communication 2008) to illustrate the conceptual process of this approach. For these runs, residence time in the Delta of 9 +/- 3 days were used. Passage through the Delta is assumed to be normal and centered around Day 120 (April 30).

Applying the results of these calculations would assume that all Chinook smolts present in the Delta during island filling are at risk of being entrained, regardless of the number or location of breached levees.

Curves are based on values in Table 6-3 to illustrate the conceptual process of this approach. The percent at risk is shown to be the percent in the Delta on the day of levee breach, plus the percentages arriving over an assumed two-day island-filling period. This could be modified to include that had recently departed the Delta for levee failure scenarios that resulted in inflows of water from embayments to the west.

Estimating the entrainment of fish

For this impact mechanism, it is assumed that all fish in water destined to flow onto a flooding island will be entrained. In other words, during the initial flooding of islands, fish behave like particles. This assumption is likely to be true for small fish as the velocity of water flowing on to flooding islands is expected to be quite high. Fish with greater swimming abilities (i.e. those that are larger) may be able to adjust their position so as to avoid entrainment, but (a) there are no data to estimate the net effect of such behavioral responses and (b) this analysis focuses on smaller fish (i.e. those in earlier life-stages), which are more common.

To determine the density of fish flowing onto a flooding island, the origin of the water flowing onto the island (e.g., its location in the Delta at the moment of levee failure) must be determined. The spatial distribution of water flowing onto flooding islands is a function of which islands flood, where levee breaches are located, and the number of islands flooding simultaneously. Advanced analyses such as particle tracking can provide insight into the origin of floodwaters; however, for computational reasons, particle tracking cannot be employed for every levee failure scenario. Therefore, simple algorithms must be developed to determine how (from where) floodwater flow onto an island. These algorithms may then be tested by a small set of particle tracking experiments to determine their accuracy. Different water movement algorithms are more likely to produce different results when the number of flooding islands is small; when large numbers of islands flood, floodwaters (and entrained fish) may originate from as far away as San Pablo Bay.

Estimating suspended sediment concentrations on flooding islands

Fish that are entrained on flooding islands may encounter suspended sediment conditions that stress or kill them. The suspended sediment concentration is a function of the levee cross-sectional area, number of levee breaches on an island, the levee/foundation soil type, the island's surface area and volume, and time elapsed since initial breach and since the flooding was complete. A method for estimating $S(i)$ and the time course of suspended sediment concentrations on each island is presented in the form of an example.

Representative breach sizes for Delta levees were determined by reviewing data contained in the Table 6-4 (from the Levee Vulnerability TM) shows the island (or tract), date and width of the breaches utilized in the analysis. The mean value of the widths shown in Table 6-4 was utilized as a representative breach width in the sedimentation analyses.

Figure 6-8 is an aerial picture of Webb Tract, highlighting a breach on the right side of the image. Dimensions of this breach were used as the 'mean' values calculations; upper and lower bounds were calculated using the mean ± 1 standard deviation. Breach lengths were scaled linearly from the widths. The mean volume of the breach is then calculated as $446 \times 1700 \times 35$: 2.8×10^7 ft^3. An additional volume corresponding to the eroded levee embankment and approximate erosion on the waterside channel was added to this value.

The calculated area for the tract is 8.4 square miles, tract surface elevation –20 feet, and mean high water elevation +3 feet (NAVD88). The volume of water in the flooded island is $5.4x10^9$ ft^3. The total volume of suspended sediment was assumed to be in suspension prior to the completion of island filling; thus, the maximum suspended sediment concentration is greater than the value (suspended sediment mass ÷ total island volume).

From available laboratory analyses of samples collected at different locations in the area, it was determined that a sandy clay (CL) is likely to be found as the foundation soil for that island. Peat particles were not considered due to their low density (they are expected to float) and assumption that this material in suspension would not challenge or injure fish species.

Table 6-5 shows the percentages by weight of each particle size considered in the calculations. Sediment concentrations are expressed as the weight of suspended soil particles in relation to the volume of water in the island. Initial concentration (Co) values for each particle are calculated by dividing the weight of each material type by the volume of water present inside the island at the time settling begins.

Table 6-5 shows the calculated initial concentrations for each particle type. The total initial sediment concentration is determined by adding the initial concentration values for each particle type. Figures 6-1a and 6-1b show the relative concentration of each grain size category as a function of time since levee failure. The values in the upper right corner of the plots show the values of 'mean' initial concentration, as well as the upper and lower bounds calculated from the available information.

After suspended sediment levels reach their maximum, settling will reduce their concentrations gradually over time. Water and fish will still be flowing onto the island. Thus, the suspended sediment concentrations that the first fish entrained on an island encounter will be different from those encountered by fish entrained later during the course of flooding.

The breach initiates at time "zero." Four hours later, the breach was assumed to be fully developed, and sedimentation of the medium sand particles begins. Fine sand particles are assumed to begin sedimentation two hours later (time: 6 hours). For this example, it was assumed that flooding would be complete after two days (time: 48 hours); turbulence would be minimized at this point, allowing silts and clays to begin settling.

Stoke's formula was used to compute the rate of sedimentation in water for different particle sizes. The model assumes vertical movement of particles without interaction or turbulence forces. The governing equation is described as follows:

$$V = \frac{\left[D^2 * g * (\rho_s - \rho_w)\right]}{18 * \eta} \qquad (3)$$

where:

η = fluid viscosity (dynamic)

ρ_w = water density

g = acceleration of gravity

ρ_s = soil particle density

V = settling velocity

Sedimentation velocities were then calculated for several particle sizes, as shown in Tables 6-6 and 6-7. These results are depicted graphically in Figures 6-1a and 6-1b.

Mortality of entrained fish

During the initial phase of island flooding, fish and other aquatic organisms within the area affected by the breach will be subjected to increased suspended sediment concentrations. It has been well documented that suspended sediment affects fish species (Wilber and Clarke 2001). Certain species are adapted to and prefer turbid environments over clear water (Gradall and Swensen 1992, Cyrus and Blaber 1982; as described in Wilber and Clarke 2001). However, high concentrations of suspended sediment are known to negatively affect many species of fish, including salmonids.

The effect of suspended sediment on anadromous salmonids has been documented (Wilber and Clarke 2001). The impacts of suspended sediment levels on other species of concern in the Delta are not as well documented. For example, no data on Delta smelt or other members of the family Osmeridae were available for incorporation into this report. In addition, the existing studies of suspended sediment level impacts on fishes are not standardized in terms of exposure duration, size/age of organisms, and critical particle size distributions. Development of relevant and consistent metrics of suspended sediment tolerance for potentially impacted life stages of all fish species in the Delta is a critical data need for implementing this model subcomponent.

Table 6-8 summarizes studies of behavioral reactions and mortality rates resulting from increased suspended sediment concentrations. Only juvenile and adults of Chinook salmon and steelhead were considered. Because salmonid spawning habitat does not occur in the Delta, effects of suspended sediments on salmonid eggs and larvae were not considered. To limit the analysis to exposure times that might reasonably occur during an initial levee failure event, only studies with sediment exposure times of 96 hours or less were considered.

Results from previous studies of salmonid tolerance to elevated suspended sediment levels show a range of impacts across three orders of magnitude. Elevated suspended sediment tolerances of for fish species in the Delta will need to be elicited from experts in this area of study. Clearly, targeted research into these tolerances for life stages and soil types relevant to the Delta could improve such estimates. Still, the estimates of suspended sediment concentrations produced in the hypothetical exercise above (see Table 6-5) suggest that suspended sediment concentrations on flooded islands may be in the tens of thousands of mg/L for some period of time – this is clearly in the range where impacts to survival of salmonid juveniles may be detectable (Table 6-8).

Assessing the impact of entrainment mortality to population viability using the Dennis Model

Recall that the total proportion of fish killed on all islands that are flooded during a levee failure scenario is given by:

$$I_M(m) = \sum_i I_M(i,m) \qquad (4)$$

The prior sections outlined several key steps in various approaches to developing estimates for $I_M(m)$. This section explains how these estimated values would be used in the Dennis Model to generate measures of "impact" to aquatic species of mortality resulting from entrainment on flooding islands.

The main output of the Dennis Model is the probability of extinction and its rate of change over time. This mean probability is bracketed by bootstrapped confidence intervals around the central projection. The Dennis Model assumes density independence, an assumption that is almost certainly violated for salmonids (e.g., Zabel et al. 2006) and other species in the Delta; in its current depressed state, Delta smelt population dynamics may operate in a manner approaching density independence. Nonetheless, the estimated changes in extinction probabilities and time to extinction, with associated estimates of uncertainty can provide a measure of the relative magnitude of different levee failure scenario parameters.

The key element of the Dennis Model as employed by Bennett (2005) involves the estimate of μ, the average rate of population change and σ^2 variance around μ. These parameters are calculated from regressions of observations of fish population index data at different time periods. The values for quasi-extinction threshold (N_x), time horizon of interest (t_{max}) are based on knowledge and/or assumptions about the biology and population in question. Using bootstrapping (Efron, 1982) the uncertainty in μ and σ^2 are obtained. Inputs into this sub-component will be the expected proportion of a species' population killed via entrainment (and associated uncertainty around that estimate). The Dennis Model can incorporate population proportions instead of raw numbers. Each of the above approaches to determining the temporal-spatial distribution of species at the time of breach will produce this proportional value without the need to estimate total population size. These are suitable for adjusting the population size parameter after the levee breach. The regression estimating the population decline rate (and its associated error) before the levee failure event can be extended from the new population level after levee failure to provide a new estimate of time to extinction and uncertainty in that estimate. The quasi-extinction threshold must also be expressed as proportion this value is relatively subjective and accounts for the approximate size of the current population relative to an "original" or "baseline" population. Determinations of an appropriate threshold may be elicited from experts on the species in question and those with special expertise in population/extinction processes. Finally, to adapt the Dennis Model to run on population percentages instead of population sizes, the raw count data will need to be converted into percentages and then regressed to produce values for μ and σ^2.

Bennett (2005) describes μ as the slope of a regression line plotted from *x* and *y* coordinates calculated as below:

x for the regressions = $(t_{i+1} - t_i)$^$^{0.5}$

y for the regressions = ln (N_2/N_1) / $(t_{i+1} - t_i)$^$^{0.5}$

where:

N_1 = number of fish at time i, and N_2 = number of fish at time i + 1

The σ^2 is estimated from the mean square residuals of the regression.

Delta smelt live their entire life cycle in the area that would be impacted by levee failures. Therefore, in each year, almost the entire population is at risk. The model configurations discussed above are appropriate for this species. However, for species with multiple age classes where part of the total population is outside of the area that will be impacted by entrainment on flooding islands, modifications to the approach above are required with regard to estimation of current population size, *Nc*. For example, Chinook salmon may spend 1 to 3 years in the ocean; thus, in any single year, only one-third of the total juvenile population passes through the Delta and is thus exposed to these risks. Whatever the entrainment losses are in the wake of a levee failure, the impacts of those losses are only brought to bear on about one-third of the actual total population.

6.1.3 Impact 2: Avoided entrainment at SWP/CVP pumps resulting from altered pumping rates and schedules

6.1.3.1 Conceptual Underpinning

Water exported by the SWP and CVP from the Delta supplies municipal and agricultural users south and west of the Delta. Current export practices at the SWP and CVP diversions result in entrainment and direct mortality to numerous species of fish and macroinvertebrates. Tables 6-9a and 6-9b list the number of salvaged Delta smelt individuals at the SWP and CVP, respectively, for 1995 to 2005. If brackish water intrudes easterly into the Delta as a result of levee failure (as is anticipated under certain levee failure scenarios; see Figures 6-9a and b), Delta export facilities operations may be curtailed or halted to avoid exporting brackish water. Curtailment of export pumping at the SWP/CVP pumps would produce concomitant reduction in the proportion of fish entrained under business-as-usual export operations. Contrary to the impact of entrainment on flooding islands (described above), reduction in export pumping from CVP/SWP facilities in the south delta would have a positive impact on fish species' populations.

In addition to the direct mortality of fish entrained at the pumps, current water diversion practices (by the SWP, CVP, and others) are expected to produce indirect mortality (or reduction in productivity) to a variety of aquatic organisms. For example, water diversions have a significant effect on hydrodynamics in the Delta. In particular, by altering currents in the Delta, SWP/CVP exports operations may cause migratory fish to follow migration paths that lead to higher mortality or reduce reproductive success (e.g., salmonids; Brandes and McLain 2001). Also, by removing freshwater from the Delta, operation of these export facilities shifts the freshwater/saltwater interface to the east (and closer to the pumps themselves). These indirect effects are poorly understood and are not modeled here; curtailment of pumping is expected to produce positive impacts to fish populations through reduction in both direct and indirect impacts of business-as-usual operations.

Many other water diversions in the Delta probably also entrain and kill aquatic organisms under business-as-usual operating procedures. Increased salinity (and the direct flooding of some irrigated islands) will reduce operations of these diversions as well and, as a result, the mortality caused by these diversions is expected to decrease as well. The mortality caused by the thousands of other water diversions in the Delta is poorly understood and poorly documented (Moyle and Israel 2005; but see Hanson 2001). As a result, the impact of curtailed water exports from in-delta diversions is not modeled here, although this mechanism is expected to produce positive impacts to fish populations.

The impact of fish entrainment resulting from CVP/SWP exports is difficult to estimate. The screening mechanisms at the CVP/SWP pumping facilities have species and life-stage specific efficiencies that are poorly characterized and not known with much certainty (Kimmerer in press). Similarly, pre- and post-screening mortalities are likely to differ across life stages. Below, two methods are described for estimating current entrainment-related mortality at the CVP/SWP facilities.

Estimating population level impact from curtailed pumping-related entrainment at water export facilities

The CVP/SWP entrainment sub-component will project the proportion of a species' population that may not be killed as a result of curtailed export pumping at the CVP and SWP facilities. Entrainment mortality is believed to be considerable for some species when the pumps are operating (Kimmerer in press; Sommer et al. 2008). However, the methods for measuring and estimating entrainment mortality are complicated and rely on numerous untested assumptions. Also, no estimate of mortality can be made for species and life stages that are not "filtered" out by the behavioral louvers (screens) at these facilities. Similarly, there is no way of estimating indirect mortality due to the hydrodynamic impacts of pumping although these may be large impacts for some species.

The impact of estimates of averted mortality will be evaluated by assessing their effect on estimated time to extinction for each species. The "Dennis Model" (described above) estimates time to extinction based on empirical data about a species' current rate of decline and the variance in that rate of decline. The projected increase in population size resulting from averted mortality at the CVP/SWP pumps is expected to increase a species' time to extinction. The proportional increase in population size estimated to result from each levee failure scenario will be input into the Dennis Model framework in the manner described above.

6.1.4 Methodology: Averted mortality due to curtailment of export pumping at the CVP and SWP south-delta pumping facilities

6.1.4.1 Framework

The beneficial impact of pump shutdown for a species can be measured in terms of the proportion of the population that would otherwise be killed each day during pumping and summed over the duration of the shutdown. This impact, which is conditional on the levee failure scenario (i.e., conditional on the events and variables that define a scenario) can be expressed as:

$$I_{M,P}(i,m) = \quad \phi_E \quad \phi_{M,P} \quad T_{P,i} \tag{5}$$

where:

$I_{M,P}(i,m) =$ proportion of the fish species population that would be killed as a result of entrainment at the pumps that occurs in month *m* and for a period of shutdown *i*

$\phi_E =$ proportion of a fish species population in the Delta that is entrained at the pumps

$\phi_{M,P} =$ fraction of the fish entrained at the pumps that are killed per day

$T_{P,i} =$ duration in days of the pumping interruption

During a given levee failure scenario, the pumps may be shut down and intermittently returned to service, depending on the water quality, time of year, etc. As a result, the fish mortality benefit will involve a sum over those periods when the pumps are actually shutdown. The total proportion of fish killed during the periods when the pumps are shutdown during a levee breach scenario is given by:

$$I_{M,P}(m) = \sum_i I_{M,P}(m) \tag{6}$$

where the sum is carried out over the number of periods when the pumps are shut down for a given levee breach scenario.

Two approaches are presented for estimating entrainment at the South Delta pumping facilities. In the DRMS Risk Assessment framework, both of these approaches could be modeled and run to develop simultaneous estimates of the impacts of different levee failure scenarios. In addition, the relative merits and likely accuracy of each model could be formally elicited from a team of qualified experts. After presenting the two techniques, we discuss how each could be modeled to account for the important effects of seasonality and hydrologic conditions that among years. These two temporal factors produce wide variations in the distribution of fish populations and the species-specific entrainment rates.

6.1.4.2 Estimating Species-Specific Entrainment Rates at the CVP And SWP South Delta Pumping Facilities — Approach 1

Losses due to entrainment into SWP/CVP pumping facilities are calculated by multiplying average monthly diversions (i.e., volume of exported water) by the average monthly densities of fish in (1) the 20 mm+ tow-net surveys conducted by CDFG at several south Delta sampling stations, and (2) fish salvage data collected by DWR & USBR at the SWP/CVP pumping stations.

The average monthly values for fish density and export volume are assumed to be constant from year to year, regardless of Delta outflow, total precipitation, snowpack, or timing of peak snowmelt. Salvage survival is assumed to be zero. Every fish entrained is assumed to be a loss. Data to evaluate this assumption are limited and would be methodologically difficult to develop.

Results of these calculations are expressed as estimates of the *number* of fish lost rather than in the *proportion* of the population lost. The DRMS model functions on population proportions; however, further adjustments would need to be made to use those results. These adjustments are discussed in the following sections.

6.1.4.3 Estimating Species-Specific Entrainment Rates at the CVP And SWP South Delta Pumping Facilities -- Approach 2

The second approach to SWP/CVP losses is described in Kimmerer (in press), who estimated proportional losses from export pumping of (1) juvenile Chinook salmon, (2) adult Delta smelt, and (3) juvenile Delta smelt. Because of different data availability and life histories, these fish categories are treated somewhat differently. Kimmerer's analysis is mechanistic rather than correlative. It does not use statistical correlations to estimate export losses but instead uses salvage data and other empirically-based estimates of mortalities or other population dynamics to estimate proportional losses. A brief summary of this approach's methods follows.

- Daily fish salvage at the pumps is estimated from data recorded during all sampling periods and locations on each day (DWR, USBR). Entrainment is back-calculated from estimates of pre-salvage mortality and behavioral louver efficiency. Live salvaged fish (Chinook salmon only) are returned to the Delta near its western edge.

- Daily total loss is the difference between daily entrainment and daily releases of fish surviving the salvage process. Since Delta smelt are not believed to survive the salvage and transportation process, daily losses for both life stages are equal to daily entrainment.
- Proportional losses must be calculated differently for each species or life stage because of differences in behavior relative to the pumps. Salmon smolts face a one-time risk of export pump entrainment as they migrate through the Delta until they pass Chipps Island. Delta smelt, however are Delta residents, and they face entrainment risk through much of their life cycle whenever the pumps are in operation.
- Kimmerer (in press) used recapture rates of tagged hatchery Chinook salmon smolts to calculate rates of salvage and loss at fish facilities. He used data on smolts released from the Livingstone Stone National Fish Hatchery on the Upper Sacramento River and the Coleman National Fish Hatchery. Flux (passage) of fish past Chipps Island and out of the Delta was estimated using the Chipps Island trawl survey (USFWS). These rates were accumulated over the season and then used to calculate proportional salvage and loss.
- For adult Delta smelt, Kimmerer divided estimates of daily entrainment by the monthly estimated population size (as calculated by the CDFG spring Kodiak trawl) to get a daily proportional loss rate, which was then accumulated over each day in the month and over each month in the season.
- For juvenile Delta smelt, Kimmerer modified his adult Delta smelt approach in two significant ways: 1) he did not use reported salvage data, which can underestimate the abundance of small fish; 2) his extrapolation from daily to seasonal losses was more complicated for juveniles, primarily to account for different hatch dates.

Kimmerer (in press) reported:

- The proportion of Chinook salvaged increased with export flow, with a mean value around 10 percent at the highest export flows recorded. Mortality was around 10 percent if pre-salvage (i.e., after entrainment but before salvage counts) losses were about 80 percent. A lower pre-salvage loss rate would increase the mortality estimate.
- Adult Delta smelt losses ranged between 1 percent and 50 percent, with a median at 15 percent.
- Daily losses of juvenile Delta smelt were 0 to 8 percent, and accumulated seasonal losses were 0 to 25 percent, with a median of 13 percent.

Kimmerer does not address the role of “indirect” losses from altered hydrodynamic conditions or migration cues. These losses are potentially significant (NMFS 1997) but currently unquantifiable based on existing data.

6.1.4.4 Modifying Entrainment Rates to Account for Seasonality and Hydrologic Conditions

This section describes how the two different approaches above for estimating $I_{M,P}(i,m)$, or one of the factors leading to its calculation, could be adapted for use in the DRMS modeling system.

The DRMS model Aquatic Ecosystem Impact models will account for impacts related to month, season, and, "water-year" (hydrologic conditions) to assess the population-level impacts of stopping the SWP/CVP pumps. Water-years have five classifications (wet, above normal, normal, dry, and critically dry) that convey information about the total amount of precipitation in an area. The pattern of total precipitation is irrelevant to the classification of a water-year: snow and rain are treated equally, and the timing of precipitation's arrival is irrelevant.

Months and water-year type are both relevant because those are two major determinants of fresh water flow into and through the Delta, and they influence the abundance and distribution (proportion susceptible to entrainment) of all species in the Delta. Since there are 12 months and five water-year types, there are 60 different estimates needed to achieve the goal of simulating export entrainment avoided for any breach event timing. Either of the approaches below could achieve this standard.

6.1.4.5 Adapting Approach #1 to Estimating Export Entrainment Avoided

Approach 1 (above) estimates an average export entrainment for each month of the calendar year. The monthly estimates (as described above) are species-specific but they are not water-year-specific. The source data for monthly fish densities in the south delta and volume of water exported can be parsed into the five different types of water-years and then developed into monthly averages. Calculations of export entrainment based on this data modification would create monthly averages that were water-year-specific.

If monthly increments of export pump curtailment are adequate, then these estimates could be used as they are. If daily or weekly estimates are needed, the estimated export entrainment can be interpolated on the appropriate time scale. Since the monthly estimates do not come from constant fish counts but instead of intermittent samples, the monthly averages themselves are an up-scaling from daily data.

Three factors limit the feasibility of this approach. The first is that current SWP/CVP operational criteria have only been in place since 1995, but all five types of water-years may not have occurred since 1995; using pre-1995 data on entrainment might produce misleading results. Another confounding factor is that parsing just 10 years of data into even three or four water-year types (instead of all five) means that the averages will be based on a very low number of observations with correspondingly large error bars (or missing variance estimates if only one observation of a hydrologic condition occurred).

This approach does not actually estimate $I_{M,P}(i,m)$, the proportion of a fish population that is lost as a result of export entrainment; it assumes that all entrained fish are lost (i.e., there is no successful salvage). This assumption is probably true for Delta smelt – additional study is required for Chinook salmon and other species. As a result, estimates from Approach 1, come closer to estimating ϕ_E, the proportion of a population that is entrained, which is equal to $I_{M,P}(i,m)$ under the no-salvage assumption. However, as discussed earlier, this approach does not produce *proportions* of the population that are entrained in the pumps; rather, it produces *numbers* of fish entrained.

Nevertheless, this approach is simple and entrainment results can be converted into proportions of the population relatively easily. One of the "zonation approaches" described in Section 6.3.3 would be used to estimate a total population and the proportion of the total population in the South Delta when the pumps would normally be operated.

6.1.4.6 Adapting Approach #2 to Estimating Export Entrainment Avoided

The previous approach estimated export entrainment and assumed complete mortality of all entrained fish. In this approach, Kimmerer (in press) directly estimates the proportion of the population that would be killed as a result of entrainment, $I_{M,P}(i,m)$, with proportional entrainment, ϕ_E, and proportional mortality of entrained fish, $\phi_{M,P}$, estimated as intermediate steps. This is a far more detailed and computationally intense approach than the alternative.

Kimmerer's approach was to use daily salvage counts to estimate daily losses that are then aggregated over time to produce proportional losses over the course of the season. It is possible to modify this approach and aggregate for specific time intervals of interest. Adjustments would be needed – primarily to the days and/or months over which the losses are summed or multiplied, which would be changed to fit the user-defined breach scenarios —but the analysis remains unchanged.

Further, since Kimmerer used data from ten years of Delta sampling programs, salvage counts, hydrological flows, and estimations of fish populations, a parsing of data into wet, normal, or dry water-year types, similar to that discussed for Approach 1, would be possible. Proportional loss rates for a particular month in a specific type of water-year of interest could be calculated and used in the larger DRMS model. However, the same small sample size limitations discussed above would apply.

6.1.4.7 Delta Smelt

A general formula for aggregating daily survival over a time interval is:

$$(1-x)^n \tag{7}$$

where *x* = daily mortality rate, and *n* = number of days in the interval

If *x* is small, this is an estimate that will yield results not much different than compiling the actual measured daily mortalities. This is valid only if there is no density-dependence in the population dynamics and if proportional losses have equal effect on the total population regardless of the life stage in which they occur. These conditions are not likely to be true for most focal species in the Delta; however, these estimates present a measure of the *relative impacts* of different levee failure scenarios.

For fish such as adult Delta smelt, the daily salvage data for each combination of calendar month and water-year type available will be collected. Next, those figures will be adjusted for pre-salvage losses to estimate entrainment. Dividing salvage figures by a net efficiency for federal and state efficiencies to yield total entrainment. Net efficiency is a combined efficiency for behavioral louvers and screens at both CVP and SWP facilities; Kimmerer (in press) approximated net efficiency at 13 percent, though more detailed estimations are possible.

For juvenile Delta smelt, the approach is modified as follows. Abundance calculations are derived from CDFG trawl-derived CPUE data in the six south delta sampling stations and the volume of water in a trawl (as described earlier). Then, day-specific abundance calculations are estimated by linear interpolation between survey dates and those are multiplied by daily exported water volume to estimate daily entrainments.

For either adults or juveniles, these daily entrainments are then used to derive an average daily entrainment for time periods of interest. Simple arithmetic averaging would be an adequate approximation. The period-specific average daily entrainment totals are then converted into entrained *proportions* of the Delta population for that interval.

Dividing the daily entrainment by the monthly estimated delta population size from the CDFG Kodiak trawl (or by a linearly interpolated value between monthly averages for a briefer period) produces an average proportional daily entrainment rate for the desired period. For either life stage, the interval's average daily entrainment rate is the mortality rate, *x*, in Eq. 6 and the interval duration is *n* in Eq. 6.

One advantage of this approach is that natural and other sources of mortality need not be calculated specifically because their effect on surviving population proportions in both the pre- and post-entrainment periods should be equal.

Currently, data to apply this method to adult and juvenile Delta smelt are available. However, while the data for Chinook salmon are available from the same sources (CDFG 20-mm trawl and DWR/USBR salvage data for SWP/CVP pumps, in particular), the approach is somewhat different for salmon.

6.1.4.8 Chinook Salmon

For salmon, the daily salvage counts are divided by pre-screen loss rates and estimates of louvre efficiency to derive entrainment estimates. Louvre efficiencies were originally estimated at 90 percent (Skinner 1973), but more recent estimates from Karp et al. (1995) and Bower et al. (2004) places federal facility louver efficiency estimates for the federal facility at 50 percent and 85 percent, respectively; mean pre-screen survival at the state facility was 85 percent with a range of 66 percent to 99 percent. The regulatory value currently in use is 75 percent. Pre-screen losses at the federal facility are said to be only 15 percent, in large part because of a smaller forebay. Trucking and handling survival rates through the salvage-and-return process are about 96 percent (Kimmerer in press), so the losses to the export process are somewhat larger than the salvage counts. From the difference between these estimates of total entrainment and successful salvage, daily loss rates can be derived.

Tagged fish captured by the USFWS Chipps Island trawl survey could be used to extrapolate a daily fish passage from mean catch per volume and migration speed past Chipps Island (6 km/day average). Performing these calculations for each day the Chipps Island trawl was operated, and then linearly interpolating between these to form daily estimates would be the next step. The proportional export loss for a period is the total export loss divided by the sum of export loss and outmigration past Chipps Island, each of which needs to be aggregated for the days, week, or month of interest.

While feasible, the results of this approach will have large error bars around them. One reason is the large uncertainty around pre-screen mortality rates for salmon smolts. Because the pre-screen mortality of Chinook smolts is such a large unknown, it is impossible to know how much of the mortality seen during those flow periods is actually due to pumping loss or some other source of mortality. If pre-screen mortality is high, then shutting the pumps off would have little effect because the pre-screen mortality is essentially unchanged. If pre-screen mortality is low, then pumping mortality is high, and shutting the SWP/CVP pumps off would be beneficial to the salmon. This does not appear to be a resolvable question at the present time, which is a weakness of this approach for this species.

6.1.4.9 Alternative Approach to Estimating Export Entrainment Avoided

Kimmerer notes (pers. comm. 2008) that this level of computational detail and specificity is probably not warranted within the DRMS project. He instead offers a suggestion to approximate his larger results in fewer steps and with less data.

Month and water-year estimates of export entrainment are partly dependent on flow. Flow is particularly important in the Old and Middle Rivers (OMR), the nearest large waterways to the Clifton Court Forebay, where the intakes for the pumps are located. A regression analysis showed that southward flow is highly correlated with large amount of export entrainment (Kimmerer in press). A weak northward flow has very little export entrainment, and strong northward flows eliminated it almost entirely.

Therefore, the original goal of developing estimates of export entrainment for 60 combinations of months (12) and water-year type (5) was quite rational. However, it is possible, for example to have a dry or very dry March in a wet water-year. It is also possible to have a very wet April in a normal or dry water-year. A better predictor of export entrainment is what might be called a “water-month.” Months and water-year types are good estimators of export entrainment, but water-month types would be better. That is, it would be more useful to know the OMR flow in a dry March than in March of a dry year.

Data on monthly OMR flows (as well as associated San Joaquin River and export flows) are available from the USGS. Strong correlations exist between these OMR flows and export entrainment (Kimmerer pers. comm. 2008). This approach would use OMR flows to estimate export losses under very specific conditions. Instead of estimating export losses in March of a dry year, this approach would enable the superior estimate of export losses in a dry March.

The process would begin by characterizing each actual month of OMR flows as wet, above normal, normal, dry, or critically dry. Next, the regression-based estimates for export losses would be derived for each type of each calendar month. Repeating this for adult and juvenile Delta smelt and juvenile Chinook salmon would complete Figure 6-10 with population proportions for each water-month type. Figure 6-10 shows only three of the five types as examples. The table could be a data file that provides input from the DRMS modeling system. When the user sets the input parameters for a desired water-month type, the model would draw the appropriate value(s) from that Figure 6-10 to use as proportional export losses avoided for one or more species.

For juvenile Delta smelt, regression equations and data presented in Kimmerer (in press) would suffice to derive these estimates of proportional losses to export entrainment. For adult Delta smelt, minimal additional data gathering would be necessary as these data are available from Kimmerer (pers. comm. 2008).

For juvenile Chinook salmon, however, there are other steps and uncertainties in the process. In general, the approach is the same: relate OMR flow regimes in the various scenarios of interest to the percent loss of the smolts population. However, the uncertainty around pre-screen mortality (discussed above) of Chinook smolts is again a problem. This method may not be suitable for this species if that uncertainty cannot be reduced.

6.1.4.10 Using these Approaches for Estimating Export Entrainment Avoided in the Dennis Model

As in Aquatic Impact Model Component 1 (mortality due to entrainment on flooded islands), the Dennis Model would be used to estimate changes in the probability of extinction after a levee breach. In this case, however, these probability changes come from the reductions in SWP/CVP operations associated with the increased salinity. This change is expected to be positive because of the cessation of exports. That is to say, the value of

$I_{M,P}(i,m)$, the population proportion normally entrained in export pumps, should change outputs of the Dennis Model in a way that decreases the extinction probability.

6.1.5 Impact 3: Estimating Impacts from Habitat Development on Flooded Islands

Aquatic habitats on flooded islands may support increased fish populations directly and indirectly. Creation of additional habitats suitable for fish species in the Delta can increase the likelihood of population persistence directly in two ways. First, creation of new habitat may alleviate density-dependent interactions (e.g., competition). It is not known which species' in the Delta are currently limited by density-dependent interactions. Second, by increasing the space available for fish, new habitats on flooded islands may allow for greater spatial distribution of fish populations; increased spatial distribution may insulate populations from the effect of localized catastrophic events (e.g., chemical spills). Flooded islands are expected to support production of phytoplankton and zooplankton populations, a potential indirect benefit to those fish species in this Estuary that are believed to be food-limited (Kimmerer 2004).

The population-level impact of these different habitat-related mechanisms is not estimated here. The population response to increased potential habitat volume is highly complex and not well understood for any species in the San Francisco Estuary. Also, the impact of increased habitat space almost certainly varies across and within years for each species.

A simple metric of the potential impact of new aquatic habitat can be calculated as potential habitat for a species (i.e., that which meets its requirements for salinity, depth, temperature, and turbidity) minus the area of potential habitat that may become anoxic due to eutrophication. Thus, the value of newly-created aquatic habitat can be either positive or negative depending on whether the area of breached islands with bathymetric and breach dimensions supportive of eutrophication exceeds the area of breached islands with good habitat where periodic eutrophication is unlikely. Again, determining which islands are potential population sinks (e.g., those that become eutrophic or those likely to support a high density of predator species) for species-of-concern will help determine priorities for island restoration.

6.1.6 Impact 3: Changes in Habitat Quantity – Characteristics of Flooded Islands and Potential for Eutrophication

Flooded islands may provide additional habitat for certain aquatic species. The value of flooded islands depends on the physical and chemical attributes of the habitat they contain and requirements of different species. Important habitat characteristics for fish species include, among others, salinity, turbidity, temperature, depth, and substrate type (vegetated or not). Depth, volume, and substrate of flooded islands are easy to determine from their known topography, elevation, land use, and soil types. Local temperature and local turbidity are not expected to change over the long-term in the Delta as a result of island flooding after levee failures. Salinity concentrations for the Delta will be output from water quality modeling associated with DRMS.

Although restoration of breached levees and pumping of flooded islands is expected, islands may serve as habitat while they are inundated. During this period they may export primary producers and fish to the rest of the Estuary. Furthermore, an understanding of which islands are likely to support fish species (and sensitive species in particular) will assist in the planning an implementation of island recovery efforts.

The benefits of flooded islands will be realized by those organisms that are currently limited by density-dependent factors (e.g., competition for food or other habitat attributes). Another benefit of flooded islands habitat would come from the potential for increased spatial distribution of the population – the more places a species' exists, the less likely it is to be eliminated by a localized catastrophic event.

The impact of flooded island "habitat" may not always be positive for fish species. Whereas all flooded islands are expected to produce phytoplankton, some islands may develop anoxic conditions if the local biological oxygen demand (BOD) is high relative to the exchange rate of oxygenated water with the surrounding environment (i.e., high residence times). Factors affecting the potential for low dissolved oxygen concentrations resulting from eutrophication include the volume and retention time of water on the island. Retention time is a function of island volume, shape, and breach size. Turbidity is an important factor in controlling phytoplankton population growth; turbidity is related to the ambient turbidity of water entering the island on flood cycles and the amount of endogenous, wind-wave suspended turbidity generated on flooded islands. This second factor is a function of local wind speed, the depth and area of the island, and the soil composition of the island surface. These factors can be modeled or estimated from existing datasets (e.g., wind and soil composition maps) to project the potential for eutrophication and anoxia on flooded islands.

Islands that become eutrophic will not represent long-term habitat for most aquatic organisms. Indeed, islands that become periodically eutrophic will act as population sinks, killing fish and other organisms that previously colonized the aquatic habitats. Predictions regarding the likelihood of island eutrophication may thus help to determine the priority for island recovery.

Similarly, some flooded islands will support high populations of invasive predators (such as striped bass, true bass and sunfish of the family Centrarchidae, or inland silverside); these islands could represent population sinks for native prey species, such as Delta smelt. Because many of these predators are also sportfish, their habitat requirements have been well-studied and their potential use of different flooded islands can be modeled.

The habitat value of flooded islands is also somewhat time dependent. Different organisms will realize the potential benefits of flooded habitat as the duration of inundation approaches time-scales that are relevant to their life history. Species at the base of the food web such as phytoplankton and zooplankton may increase on newly-flooded islands as soon as the initial spike in turbidity declines. Because they have longer generation lengths than phytoplankton, organisms such as fish, plants, and macroinvertebrates will require longer island inundation periods to experience increased population growth as a result of island flooding. Population growth rates of fish species with short life-spans (e.g., Delta smelt, inland silversides) may display increase if flooded islands with beneficial habitat characteristics remain flooded throughout one spring. Species with longer life-spans (e.g., Centrarchid bass species) may only benefit from new habitats that remain flooded for a full year or more.

6.1.7 Methodology: Development of Habitat on Newly Flooded Islands

6.1.7.1 Framework

To evaluate the potential changes in habitat availability for a species and lifestage, habitat suitability relationships are developed from the scientific literature and analysis of survey data collected by CDFG and UCD. Factors such as salinity and temperature tolerance and depth and turbidity preferences are important considerations. Also, the seasonal usage of the Delta is critically important to projections of flooded island use by different species and their life-stages (see Figure 3-3).

Temperature

Temperature is an important water quality characteristic that constrains habitat availability for aquatic species. Temperature tolerances for most of the focal species are also readily available. Temperatures patterns across the Delta are not expected to change dramatically as a result of levee failures; thus, current temperature maps (assembled from CDFG and UCD sampling programs) can be used to project future temperature conditions on flooded islands.

Salinity

Salinity also determines habitat suitability for many aquatic species and life-stages. Results of water quality monitoring within the Delta during levee failures (DWR unpublished data; URS 2005) and hydrodynamic modeling (see Figure 6-9) demonstrate an increase in salinity intrusion from San Francisco and San Pablo bays upstream into Suisun Bay and the Delta in response to levee failures. The extent and magnitude of increased salinity varies in response to a number of factors such as the location, size, and number of levee failures, tidal currents, the magnitude of freshwater flow into and through the Delta and Suisun Bay, SWP and CVP export operations, and other factors (RMA 2005). The increase in salinity at a specific location in response to levee failure may result in habitat conditions that are more or less suitable for a given species. Other components of the overall DRMS Risk assessment model will produce estimates of salinity in the region of flooded islands and these may be used to determine whether salinity conditions on particular flooded islands will permit usage by populations of focal species.

Depth

Habitat suitability for many fish also varies in response to water depth. A number of fish species and lifestages inhabiting the Delta and Suisun Marsh preferentially inhabit shallow water areas along channel margins. Depth characteristics of flooded islands can be calculated from known depth profiles (e.g., LIDAR data) of these islands and GIS.

Non-native species

Generally speaking, invasive species are able to colonize new habitats rapidly; thus, the spread of these species into newly flooded islands is considered likely. Several studies have identified changes in habitat suitability for various fish species (both positive and negative changes) based on the colonization of a habitat by non-native (exotic) aquatic species (Simenstad et al. 2000; Grimaldo and Hymanson 1999). Three of the non-native species that have received attention within the Estuary are the pondweed (*Egeria densa*), the overbite or Amur clam (*Corbula amurensis*), and the Asian clam (*Corbicula fluminea*). *Egeria* colonization of a habitat may affect water velocities, sedimentation rates, and provide habitat for other non-native predatory fish (Simenstad et al. 2000; Grimaldo and Hymanson 1999). Invasion by clams is expected to reduce the amount of primary productivity generated on an island that becomes available for fish species. In addition, colonization of flooded islands by fish species in the family Centrarchidae (basses and sunfish) would represent a negative impact to many native fish species as non-native bass and sunfish are voracious fish predators. Colonization by these predators could result in flooded island habitats acting as population sinks for some native species (e.g., Delta smelt).

The colonization of a flooded island by these non-native species would be viewed as an adverse environmental affect on habitat quality for native species. The presence or absence of the non-native mollusks used as a binary indictor in the (a) eutrophication model (below); the presence/absence of *Egeria* is used as a binary indicator of habitat suitability for each of the focal species based on whether they are known to occupy habitats with dense aquatic vegetation. For example, habitats colonized by *Egeria* are not considered to be habitat for Inland silverside, but they would create good habitat for largemouth bass (Moyle 2002).

For purposes of this assessment, water depth and salinity were assumed to be the two primary factors that would affect habitat suitability for colonization by these non-native species. Habitat suitability relationships were compiled for *Egeria* (Figure 6-11), *Corbula* (Figure 6-12, and *Corbicula* (Figure 6-13). Water depth within a new flooded island was estimated as described above (see Table 6-2). Salinities are obviously a key discriminator between *Corbicula* and *Corbula* habitat. As stated above, salinity will be estimated for each flooded island one month after the levee failure using results of the RMA water quality model.

6.1.7.2 Dissolved Oxygen and the Potential for Eutrophication

Aquatic animals rely on dissolved oxygen to perform all metabolic functions. Without adequate dissolved oxygen concentrations, these organisms will die. Dissolved oxygen concentrations on flooded islands will reflect (1) oxygenation of water entering the island, (2) oxygenation that occurs on the island at the surface of the water column, and (3) net biological oxygen demand on the island (BOD). Water entering a flooded island through a levee breach is likely to be relatively well-oxygenated because it is coming from a somewhat turbulent environment (good for oxygenation). Oxygenation on the island is a function of the surface area: volume ratio of the island (higher numbers being better for oxygenation) and the residence time of water on the former island. Lower residence times indicate faster exchange of water; faster water exchange reduces the amount of time required for oxygen depleting mechanisms (BOD) to remove oxygen from any single unit of water.

Evaluation of the impact of dissolved oxygen conditions is based on the dissolved oxygen requirements of focal species, but these are only known for some of the focal species (e.g., splittail (Young and Cech 1996); sturgeon (Cech et al. 1984, 1990; Cech and Crocker 2002).

Another metric for impact would be to classify islands where dissolved oxygen drops below a certain threshold (e.g., 5 or 6 mg/L, depending on the season, a limit set by regulation for this ecosystem by the Central Valley Regional Water Quality Control Board (CVRWQCB 1998) as potential population sinks for focal animals. The volume of these islands would then be classified as "negative" habitat for aquatic species as it would represent a "sink" habitat.

To predict how the growth of phytoplankton biomass could affect the level of DO (and therefore the value of any new habitat) a simple mathematical model was developed to calculate the concentration of phytoplankton chlorophyll. The discussion that follows provides a method for determining the quality of habitat on flooded islands based on dissolved oxygen conditions. An example application of the method is also described. A detailed analysis requires that the calculations be expanded to cover a wider range of conditions that exist in the Delta.

Phytoplankton growth and contribution to low dissolved oxygen conditions

To calculate the phytoplankton biomass (as the concentration of chlorophyll *a* in mg/m^3), a mass balance is performed. The mass balance includes the following assumptions:

- Photosynthetic efficiency at low irradiance is constant
- Light attenuation is affected by suspended sediment and biotic self-shading.
- The maximum instantaneous photosynthetic rate is constant
- Photosynthetic rate is not limited by nutrient availability
- Photosynthetic rate is not a function of temperature
- Phytoplankton consumption by zooplankton is included using a constant rate constant but benthic grazing of phytoplankton was assumed to be negligible because of the depth of water on the flooded islands.

- The photosynthetic rate was only averaged over the depth of the photic zone, assumed to be 3 meters, rather than calculating an average over the entire depth.

The simulated biomass concentrations may be calculated on an hourly time-step using Equation 8.

$$B_{i+1} = B_i + \left(\frac{P_{ave}}{\theta} \cdot B_i \cdot \Delta t \right) - \left(ZP \cdot B_i \cdot \Delta t \right) + \frac{Q_{in} B_{in} \Delta t}{V} - \frac{Q_{out} B_i \Delta t}{V} \quad (8)$$

where:

B_{i+1}	Phytoplankton biomass as concentration of chlorophyll at current time step, not to fall below or exceed set minimum and maximum concentrations		$(mg\ chl_a)(m^3)^{-1}$
B_i	Phytoplankton biomass as concentration of chlorophyll at previous time step		$(mg\ chl_a)(m^3)^{-1}$
B_{in}	Chlorophyll *a* concentration in the inflowing water	From measured date for Rio Vista Gauge	
P_{ave}	Depth-averaged photosynthetic rate adjusted for respiration		$(mg\ C)(mg\ chl_a)^{-1}(day)^{-1}$
θ	Ratio of carbon (C) to chlorophyll *a* (chl_a)	50	$(mg\ C)(mg\ chl_a)^{-1}$
Δt	Time step	1	(hr)
ZP	Grazing rate of zooplankton	0.1	$(day)^{-1}$
Q_{in}, Q_{out}	Flow into or out of the flooded island due to the tides	Calculated from the residence time calculations	ft^3/s
V	Average volume of flooded island	Surface area of island times the depth, for example application a depth of 15 feet was assumed	ft^3

In this example, initial chlorophyll concentration (B_0) was set equal to 1.5 mg chl *a* m^{-3}. The chlorophyll concentration was limited to a minimum of 0.5 mg chl *a* m^{-3}. and a maximum of 500 mg chl *a* m^{-3}. The minimum value is consistent with the minimum chlorophyll concentrations measured at Rio Vista on the Sacramento River during April 2008. The maximum value was set much higher than expected peak concentrations so that the peak would not actually be limited.

The light attenuation coefficient due to suspended sediment (k_t) was calculated using Equation 9:

k_t = SSC (0.056) + 0.71 (9)

where:

SSC is the suspended sediment concentration.

Equation 9 is based on a linear regression between U.S. Geological Survey calculated suspended particulate matter and measured extinction coefficients in San Francisco Bay in the spring of 1993. This relationship is similar to one proposed by Cloern (1987) [k_t = SSC (0.06)+ 0.77] developed in 1980. The light attenuation coefficient due to biotic self-shading (k_b) was calculated as shown as Equation 10 below (Lucas 1997):

$$k_b = 0.016 \frac{A}{\text{chl}\, a} B_i \quad (10)$$

B_i = Phytoplankton biomass as concentration of chl *a* at previous time step *i* in units of mg chl *a* m^{-3}

A = area m^2

chl *a* = mass of chl *a* in mg

The irradiance at a given depth is calculated using Equation 11, shown below.

$$I(z) = I_o \exp\left[-\left(k_t + k_b\right) z\right] \quad (11)$$

where:

I(z) = Irradiance at depth z, in units of Einsteins m^{-2} day^{-1}

I_O = Surface irradiance in units of Einsteins m^{-2} day^{-1}. Surface Irradiance data were obtained from measurements from The California Irrigation Management Information System (CIMIS) gauge on Twitchell Island.

k_t = Abiotic light attenuation coefficient in units of m^{-1}

k_b = Biotic light attenuation coefficient in units of m^{-1}

z = Water depth in units of m

The photosynthetic rate was calculated using Equation 12 from Lucas (1997), shown below.

$$\mathrm{P(z)} = \mathrm{P}_{max}\{\tanh[\alpha \cdot \mathrm{I(z)}] - \mathrm{r}\} \quad (12)$$

where:

P(z)	Photosynthetic rate at depth z		(mg C)(mg $chl_a)^{-1}(day)^{-1}$
P_{max}	Maximum photosynthetic rate	100	(mg C)(mg $chl_a)^{-1}(day)^{-1}$
α	Photosynthetic efficiency at low irradiation	0.1	(m^2)(day)$(Einsteins)^{-1}$
r	Respiration rate as % of P_{max}	0.05	

The values of P_{max}, α, and r shown above were taken from Lucas (1997).

The depth-averaged rate of photosynthesis was calculated using Equation 13.

$$P_{avg} = \left(\frac{1}{H_{max}}\right)\int_0^{H_{max}} P(z)dz$$

$$P_{avg} = \left(\frac{1}{H_{max}}\right)\int_0^{H_{max}} P_{max}\{\tanh[\alpha I(z)] - r\}dz \qquad (13)$$

where H_{max} is water depth in m, not to exceed specified depth of photic zone

The results of the simulated phytoplankton growth are shown in Figure 6-14. It should be noted that the modeled chl *a* concentrations of the phytoplankton biomass were quite sensitive to a number of input parameters. Therefore, this simulation is provided as an example of the results that the method produces. The chl *a* concentration is sensitive to shading coefficient and the zooplankton grazing rate.

The mass balance relationship for dissolved oxygen in the water column was calculated using Equation 14:

$$c_{i+1} = c_i + K_a(c_s - c_i)\Delta t + a_{op}\left(\frac{P_{avg}}{\theta}B_i\Delta t\right) - a_{op}rB_i \qquad (14)$$

where:

c = concentration of dissolved oxygen

K_a = reaeration coefficient

c_s = saturated dissolved oxygen concentration

a_{op} = ratio of oxygen to chl *a* produced, assumed equal to 133 mg O_2 /mg chl *a* (Thomann and Mueller 1987)

r = plankton respiration rate, assumed to equal 0.05.

The re-aeration coefficient (K_a) represents the transfer of oxygen across the air-water interface. It was assumed to be a function of wind speed only since current speeds in the flooded island are assumed to be small. The re-aeration coefficient can be calculated using Equation 15 below (Thomann and Mueller 1987):

$$K_a = K_o z \qquad (15)$$

where:

K_o = the oxygen transfer coefficient

z = water depth

The impact of residence time in island eutrophication and the development of flooded island "habitat"

Residence time (or flushing time) is an important component in Equation 8 that determines the potential for phytoplankton to deplete dissolved oxygen on a flooded island. In addition, residence time may be used as a rough estimate of the potential for a flooded island to serve as a migratory trap for fish species and early life stages in particular. Fish that are weak swimmers (for example, larval and juvenile fish of some species) may behave more or less like simple particles in a flow field. Thus, these organisms may be washed into an island on a flood tide and not be able to find their way out through the breach. In this case, residence time for water approximates residence times for fish. Being trapped on an island in this manner can increase predation exposure and may also interrupt time-sensitive migration requirements. High residence times on flooded islands will impact migratory aquatic species negatively.

Residence time can be described in several ways. Monsen et al. (2002) describe several methods for estimating residence time and provide an example using Mildred Island in the Delta. They estimated the residence time using a multidimensional hydrodynamic model of the Delta. The preliminary habitat evaluation for DRMS does not require this level of analysis. The residence time ("flushing time" as defined in Monsen et al. (2002)) is estimated using Equation 16:

$$T_f = 0.504 * \frac{V}{Q} \qquad (16)$$

where:

T_f = flushing the time (days)

V = volume of flood island (acre-feet)

Q = exchange rate between island and adjacent river (ft^3/s)

The constant 0.504 converts units of acre-feet to ft^3 and seconds to days.

Applying Equation 16 to estimate the residence time of a flooded island involves the following assumptions:

- water and constituents that enter the island are instantaneously fully mixed (i.e., the concentration is always spatially constant)
- the island has a constant volume
- the exchange rate is constant

- water that leaves the island does not return

For the case of reservoir in which water flows through the water body, the residence time can be calculated directly from Equation 16 and provides a reasonable estimate. However, for a flooded island where water does not flow through the island but enters and exits from the same opening, assuming the water body behaves like a continuously stirred reactor (CSTR) will provide a better estimate. In this case, the concentration in the island is the mixed concentration of water entering the island and the concentration in the water in the island. With the assumption the concentration in the island (*C)* is equal to (Thomann and Mueller 1987):

$$\frac{C(t)}{C_o} = e^{-(Q/V)T_f} = e^{-t/T_f} \qquad (17)$$

where *t* is time and *Co* is the initial concentration

Figure 6-15 shows an example of the result using Equation 15. In this example, the original water in the flooded island is never completely replaced. After one residence time, about 37 percent of the original water remains. Ninety-five percent of the original water is replaced after a period equivalent to about 3 residence times.

To use Equation 17, it is necessary to estimate the exchange rate between the flooded island and the adjacent river. The flow between island and the adjacent river through the breach is calculated as:

$$Q = CA\sqrt{2g\Delta H} \qquad (18)$$

where:

Q = exchange rate between the island and river

C = loss coefficient through the breach assumed to equal 0.80

A = area of the breach which equals the width of the breach times its depth. For the example analysis presented in this report the depth of the breach is assumed to be equal to 15 feet. For any given breach the actual invert of the breach would be somewhere between the invert of the channel feeding the breach and the bottom of the island and the depth would vary with the tide.

g = gravitational acceleration 32.2 fts^{-2}

ΔH_i = difference between the tidal height (from a measured tide gauge) and the water surface elevation (h) measured at time *i*. For the river, the water surface elevation was taken from measured water surface elevations in the Delta.

The water surface elevation on the island was calculated as:

$$h_{i+1} = h_i + \frac{Q}{As}\Delta t \quad (19)$$

where:

h_i = water surface elevation on the island at time i

hi_{+1} = water surface elevation on the island at time $i + \Delta t$

As = surface area of the island

Q = exchange rate between the island and river

Δt = time step used in calculation. A 1-hour time step was used consistent with the measured water surface elevation data.

The average residence time using the above relationships for different island sizes and breach width is shown in Figure 6-16. The majority of islands in the Delta are less than 5,000 acres in size. For these islands the residence time is predicted to be less than 5 days. The above estimates likely underestimate the residence time for islands with large breaches. The analysis assumed that there is no restriction on the ability of the river to transport water to a breach. In reality, especially for large breaches, the exchange between the flooded island and the adjacent river may not be restricted by the breach size but by the ability of the adjacent rivers to transport water to the breach. In addition, the exchange between the island and the river will decrease away from the breach such that residence times will be short near the breach and long far from the breach. An example of this is shown in Figure 6-17.

Table 6-10 provides the results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches, assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range. Table 6-10 provides a preliminary estimate of the relative differences among residence times by island and breach sizes.

Observations from the Jones Tract failure provide information that can be used to check the validity of the calculation described above. The flooded area for Jones Tract covered about 12,000 acres, had a depth of between 12 and 16 feet and a breach size of 300 feet (DWR 2005). Tidal flows in and out of the breach were on the order of 30,000 cfs according to observations by DWR. DWR staff observed about a one foot change in stage on Jones Tract which corresponds to about a 12 thousand acre-foot (TAF) change in volume. To remove and replace this volume of water would require tidal flows of about 36,000 cfs (DWR 2005).

Figure 6-18 shows results from the calculation described above for a 12,000-acre island, 15 feet deep with a 300-foot-wide breach. The results indicate that under those conditions the peak tidal flows would vary from about 30,000 to almost 40,000 cfs and the stage would vary by from about 0.9 feet to 1.8 feet depending upon the driving tidal range. Although these results may not be sufficient to validate of the model, they provide support that the analysis is providing a reasonable estimate of the exchange between a flooded island and the surrounding rivers.

Modeling dissolved oxygen on flooded islands: Example

Factors determining phytoplankton growth and exchange rates on flooded islands are described above. These can be applied to model dissolved oxygen dynamics in response to phytoplankton population growth. The above model was applied to an arbitrary flooded island to illustrate how the model would be applied to determine the potential habitat value of the island relative to dissolved oxygen. The important physical parameters affecting DO concentration are the exchange rate between the island and the surrounding river and the wind speed blowing over the flooded island. The exchange will remove plankton from the island on an outgoing tide possibly limiting the buildup of plankton on the island. Wind driven re-aeration is the major factor replenishing oxygen that is used by the plankton.

Figure 6-19 shows the calculated concentration of dissolved oxygen on a flooded island for different relative amounts of exchange for normal and low wind conditions. Under worst-case conditions of no exchange and low wind, the dissolved oxygen concentration eventually plummets as the concentration of plankton increases beyond a critical concentration. The model does not have a feedback mechanism between dissolved oxygen and plankton concentration so once the DO concentration drops to zero it does not recover. The point at which this limit is met is sensitive to the respiration rate of the plankton; with minimal re-aeration, low values of DO would eventually occur on the flooded island.

Where there is exchange between the island and the adjacent channel, the analysis indicates that there is a limit to the concentration of plankton that can occur on the island. This is shown in Figure 6-14. During an outgoing tide plankton mass is removed from the island and the analysis assumes that there was no return of the plankton on the next incoming tide. Eventually a quasi-steady-state is achieved where the mass of plankton removed equals the mass produced during the daily growth cycle. If this concentration is below the critical value where eutrophication leads to anoxia, a quasi-steady-state will be achieved for DO also.

Although this example indicates that the quasi-steady-state value for DO is above 6 mg/L for even a low exchange rate, the value could be higher or lower depending upon the growth and respiration parameters used in the analysis. Values were selected for this example to demonstrate in-concept how the analysis of DO would proceed and the types of answers that could be obtained. More detailed calibration and verification studies to determine likely range of parameters that are applicable to the Delta are required.

6.2 Impact Mechanisms for Vegetation

This section assesses the response of macrophytes, i.e. higher order vascular plants (phytoplankton is discussed above in the aquatic community section) in the Delta and Suisun Marsh to potential breach scenarios. The following topics are presented and discussed:

- The impacts of catastrophic breaching on vegetation were assessed by classifying impacts associated with the breach, the associated scour hole, the flooding prior to breach repair, the recovery period (defined as until when the vegetation returns to pre-breach conditions), the impacts to special status species and the probability of extinction, the aggregation of responses by vegetation community, and assigning response impacts are discussed in Section 6.2.1.
- Section 6.2.2 discusses the sources of uncertainty affecting vegetation responses to the scenarios. Uncertainty results from temporal and spatial variability associated with the continuum of flooding/inundation and salinity conditions and due to data gaps.
- The variability of potential responses related to salinity and inundation among the mapped vegetation communities is presented in Section 6.2.3.

6.2.1 Impact of Breach on Vegetation

Levee breaches would have immediate and long-term impacts on species abundance (population size) and distribution (see Figures 6-20a and 6-20b) because of loss of surface area and habitat conversion by inundation. Metrics were created to independently assess the effect of levee breaches on vegetation types.

- size of immediately impacted area - comprised of the levee breach footprint and the associated scour hole that forms at breach
- survival or reduction in population size due to loss of adults from immediate impact of the flood
- time to recovery of mature vegetation after pump-out was inferred from the predicted response of focal species designated for each vegetation type.

The immediate impact ranges from 0, the designator for a large reduction in population size, to 1, which designates no reduction in population size. The immediate impact metric was calculated by multiplying the suitability (adult survival) of focal species of a vegetation type to salinity level, flood depth and duration, and tolerance/sensitivity to flooding dependent on plant life stage(seed, seedling, sapling, mature reproductive), plant phenology (dormant, reproductive, active growth), and time of year breach occurs. Weather conditions, particularly precipitation (e.g., wet years and dry years), can shift the phenology of plants several weeks. This analysis does not account for shifts in the phenology or life history stage of plants due to weather.

The focus on flooding and salinity was because they are primary factors structuring marsh communities (Traut 2005), and there was a lack of information on the vegetation response to other factors associated with flooding, such as sedimentation and scour. The effects of salinity on vegetation will depend on salinity tolerance of focal species, and the magnitude of aquatic salinity change which is affected by the breach scenario and the time of year.

An example of calculating an impact metric is presented here for pondweed (*Potamogeton pectinatus*); see Figure 6-21. If the flood depth were 10 feet, the flood duration 20 months, and the salinity 10 ppt, the impact would be 0.75 × 1.0 ×1.0 = 0.75. Alternatively, if the flood depth were 20 feet, the flood duration 20 months, and the salinity 10 ppt, the impact would be 0.05 × 1.0 × 1.0 = 0.05.

The immediate impacts of levee breaches, repair and recovery are described in further detail below beginning with levee breach impacts in Suisun Marsh, the Delta and to special status species.

6.2.1.1 Impact of a Levee Breach in Suisun Marsh: In Suisun Marsh the sensitivity of vegetation types to flooding caused by a seismic event was assessed by calculating the area of flooded sensitive vegetation.[2]. Areas considered sensitive to flooding due to seismic events were island interiors underlain by thickness of 30 feet or more of organic material. Suisun Marsh islands have both exterior and interior levees. Thus levee breaching could take several weeks to flood the entire area, as interior levees breached in a domino effect subsequent to exterior levees. Due to the current Suisun Marsh water management practices, most vegetation would tolerate high salinity associated with floodwaters; however, the vegetation would be damaged by the atypical flood duration and depth associated with flooding due to an exterior levee breach.

In Suisun Marsh, Grizzly Island has flooded frequently (1998, 2006), and images of the marsh before, during, and after flooding were used to assess the resilience of the marsh community to flooding of different durations (see Photos 14 – 17). The southern part of Grizzly Island, in particular areas to the south of the Roaring River facility which functioned as an exterior levee preventing flooding of the northern part of the island, experienced flooding on January 1, 2006, due to a combination of high tides, storm conditions with 50 mph winds, and large freshwater outflows from snow melt (S. Chappell, pers. comm. 2006). Exterior levees breached in several areas, most were overtopped, and in one area the core of the exterior levee was destroyed. The DWR Roaring River Road acted as an exterior levee, preventing flooding of the rest of Grizzly Island. Photo 13 shows the area north of the Roaring River Road, and the managed wetlands that represented the pre-flooding baseline vegetation. The baseline vegetation is complex (many different species), dense and tall. Photos 14 and 15 show Van Sickle Island during flood conditions (October 16, 2006) and several months after floodwaters were removed (July 15, 2006, i.e., after a 6-month flood duration). Barren patches of soil were visible; green vegetation was germinating seedlings which probably would not be able to complete development and set seed before winter (S. Chappell, pers. comm. 2006). Photo 17 shows parcels 933 and 905 which were flooded due to the breach that broke out the core of the levee (Photo 16) and therefore required more extensive repair. At the time the image was taken, repairs were not complete (flood duration > 6 months). Tule stands (*Scirpus* spp.) increased in size, and dead pickleweed (*Salicornia virginica*) is visible on a berm in the middle of the flooded area. These images were taken at

[2] The hydrologic modeling to predict flooding did not produce detailed levee failure scenarios for Suisun Marsh.

low tide when tidal flux is about 6 feet, and the dead pickleweed is therefore submerged by about 4 feet of water on a daily basis.

***6.2.1.2 Impact of a Levee Breach in the Delta*:** Detailed Delta levee breach scenarios were made to evaluate vegetation response. The factors evaluated included: breach date and location, approximations of flood depth, duration of vegetation inundation, and salinity. The duration of flooding was estimated as the number of months from the levee breach to the end of pump-out. Salinity was estimated as the maximum salinity level of the floodwaters in the interior of the flooded island at the time of breach closure. Flood depth was estimated as the average elevation of the interior of the island, from island elevations from both topographic (IFSAR) and bathymetric elevation data. Derived values include: average depth of flooding, maximum salinity level exposure, and salinity level of soil water after the end of pump-out. No information was provided on management response to flood scenario, and the influence of management responses on the time to recovery of mature vegetation was not assessed in this report.

Vegetation growing on the channel-side of the breached levee and in the associated scour hole is lost during breaching. These locations can include critical habitat including fringing tidal wetlands and endangered species. During breach repair operations the channel-side of the levee is also impacted by construction equipment about 1.5X the breach width, to either side of the breach. Observations reported regarding the Jones Tract breach suggest that vegetation growing on the exterior levee slopes of adjacent interstitial islands was not washed away (S. Salah-Mars, pers. comm. 2006); therefore, we assume that habitat on interstitial islands are not affected by proximal levee breaks.

***6.2.1.3 Impacts of a Levee Breach to Sensitive Vegetation Species*:**

Levee destruction could result in lost habitat for sensitive species. Sensitive species on interstitial islands may be indirectly impacted by levee breach through short-duration change in water levels as water rapidly fills breached islands. The impact of levee breaches on sensitive species was assessed by calculating the number of mapped CNDDB[3] occurrences of sensitive species lost due to a levee breach, relative to the number of occurrences of the species in the Delta, Suisun Marsh, and in the 12 counties in the Bay Area and Delta. Levee repair operations could destroy sensitive species on the channel side levee proximal to the breach (within 1.5 times the width of the breach [S. Salah-Mars, pers. comm. 2006], as shown in Figure 6-22). Occurrences of sensitive species on the channel side of Delta levees were considered lost if they were within the breach area or the part of the levee that would be impacted by repair operations (see Table 6-11). Similarly, occurrences within breached islands were considered lost. Sensitive species on interstitial islands proximal to the breach may be impacted through sediment deposition due to levee repair operations, regional

[3] CNDDB reports known occurrences of rare species, and includes both errors of commission (species occurrences that once existed but no longer occur) and errors of omission (species occurrences that have not been observed and recorded).

changes in salinity levels, and dampening of tidal range, but those losses are not evaluated here.

6.2.1.4 Assessing Probability of Extinction

Suisun Marsh and the Delta contain many threatened and endangered species, some endemic to the area. Formerly abundant species now have reduced populations and smaller geographic range and are at an increased risk of extinction due to stochastic variation (Shaffer 1981). Levee failure and sea level rise may further reduce habitat area and population size. Population size has a significant inverse relationship with population survival (Matthies et al. 2004). For annual species, reduction of reproductive potential can have a large impact on population size of the subsequent generation. Increasing population size variability for small populations of annuals increases probability of population extinction. Reduction of a reproductive potential for a single year for biennials and perennials will have little long term impact on the population size, if the adults are able to survive flooded conditions and reproduce in the following years.

It is difficult to quantify the number of individuals required to result in a high probability of population survival ("minimum viable population size") because the number of individuals varies widely among species (Matthies et al. 2004), and can be related to environmental variation of the habitat (Brook et al. 2006). For endemic and endangered species in the Delta and Suisun Marsh, the realistic assumption is made that, in general, reduction in population size of rare species due to levee failures is exponentially related to the increase in the probability of population extinction. Furthermore, probability of re-colonization of sensitive species once pre-flood conditions are re-established is reduced in small populations due to a low number of reproductive propagules.

Amount of island subsidence and Delta position (affecting tidal amplitude) will define flood depths and duration until the levee breach is repaired and the island pumped out. Pump-out duration is related to the total volume of water contained within the island. Water flowing into breached areas can dampen the Delta's tidal range. For example, in the 20-island scenario there was a 45 percent reduction in tidal range from the 50-breach scenario. The tidal range recovers over the duration of the levee repair operations. Tidal range and bathymetry defines suitable habitat for mid, low, and high marsh communities and wither the area will be reduced or increased.

6.2.1.6 Time to Recover Mature Vegetation: The time until recovery of mature vegetation after pump-out is influenced by a number of factors associated with flood conditions: the number of surviving adults and their post-flood reproductive potential, the number of surviving vegetative propagules, the size of the seed bank, and rate of import of propagules from elsewhere (seeds and vegetative propagules). Recovery time can vary widely over species because the predicted time until mature (reproductive) vegetation develops ranges over two orders of magnitude between annual grasses and trees. Salinity level of floodwater on the island at the time of breach closure as well as the depth of sediment that settles out of floodwater would influence species composition of germinating seeds. The time of year when pumping is completed influences time to the start of vegetation recovery. For example, if pump-out ends in late spring, vegetation that germinates in early spring would not appear until 9 to 11 months later. This difference is significant for herbaceous species that grow to maturity in a year but not as significant for riparian trees because of the longer amount of time for individuals to reach maturity.

Floodwater can affect the ability of soils to support upland vegetation, possibly affecting long-term survival of adults that survive flood duration. The time until recovery of mature vegetation was calculated from the shortest time until mature vegetation of surviving adults develops from vegetative propagules[4] and seedlings. The survival of vegetative propagules depends on the tolerance of vegetative propagules to duration of anoxic conditions that result from flooding. Time until mature vegetation developed from seeds is influenced by salinity affects on germination and growth.

Levee failure scenarios modeled in the risk analysis assume that initial conditions are restored at some period after the levee breach and that original vegetation types are recovered. If mature adults survive flooding, the recovery time (i.e., the time from pump-out to occurrence of mature vegetation) was 0 years. If adults die and vegetative propagules survive, then recovery time is based on the time it takes the propagule to mature.

If both adults and vegetative propagules die, vegetation would re-establish from seeds. The time from seed germination to mature vegetation varies widely among vegetation types and species, ranging <1 year for annual grasses, 3 to 5 years for some emergent coastal marsh vegetation (e.g., tules), to upwards of several decades for long-lived plants such as *Fraxinus latifolia,* which takes 30 years to mature. Because plant species grow on a seasonal basis, we also include in the estimate of time to recover mature vegetation the number of months after the first occurrence of suitable habitat until the month when new propagules begin growing.

Sediment settling out of flood waters can affect the ability of plants to recover post-inundation. Suspended sediment increases turbidity, reducing light penetration and photosynthetic depths, inhibiting seed germination (Mitsch and Gosselink 1993) and has also been implicated in decreasing the daily temperature amplitude (van der Valk 1986). Sediment deposition of 2 cm significantly reduced taxa density and seedling emergence in tidal wetland vegetation (Peterson and Baldwin 2004). In freshwater to brackish wetlands (Canada) seedling emergence is significantly reduced at sedimentation coverage of as little as 1 cm, and larger seeds (e.g., *Hordeum* tolerates 5-cm sediment) can emerge from greater soil depth than small seeded vegetation (e.g., *Typha* spp. tolerates 1 cm sediment) (Galinato and Van der Valk 1986).

6.2.1.7 Qualitative Analysis

The aggregate (combined) response of the focal species for a vegetation type was used to predict the response of the vegetation community, supplementing with information on

[4]Propagules include: stolons, bulbs, cuttings (pieces of a plant), sprigs, rhizomes, or tubers.

response of vegetation communities when it was available (see Section 6.2.3). The responses of vegetation to stressors associated with levee failure, but not explicitly output from the hydrologic models, are described with a qualitative level of analysis. Similarly, the non-linear impact of an aggregate of stressors on vegetation was described with a qualitative level of analysis.

Detailed responses of focal species to stressors were used to inform the response of the vegetation type. However, species within the same vegetation types can differ widely in their responses to flood conditions. For example salinity tolerance differs widely not only among species, but also among clonal strains, and populations of the same species. For example, in oligohaline marsh species in northern Gulf of Mexico coast, recovery from flooding with saline water of moderate salinity levels (6 to 12 g/l) varied within a species (Howard and Mendelssohn 1999b).

6.2.1.8 Assigning Response Impacts

Due to the highly species-specific response of vegetation to stressors, the general response to environmental disturbance of a larger number of species for each vegetation type is provided to aid in generalizing the response of the community to environmental disturbance. Species were grouped by life history strategies (r, K) and by their relative tolerance to change in the physical environment from the species optimum. The “r” life history strategy includes species with high reproductive output (high seed abundance, high vegetative propagule generation or spread by vegetative propagules), rapid growth rate, and short life span (e.g., annuals). The “K” life history strategy includes low reproductive output (low seed abundance, and no or low ability to spread vegetatively), low growth rate and long life span (e.g., perennials).

6.2.2 Uncertainty in the predictions of impacts and recovery of vegetation to levee breach scenarios

Uncertainty in predicting vegetation impacts and recovery for the levee breach scenarios is related to inundation/hydrology and salinity and the interaction between the two. Phenology of adults (blooming, seed maturation and seed set, fruits, dormant, active growth) influence the impact of the flood on adult survival and the contribution of reproductive propagules from which subsequent generations can re-colonize. For example, mid-summer flooding will have little impact on the seed production of annual grasses which have set seed and senesced in early summer, but may have a large impact on the number of seeds from plants which are blooming and setting seed during mid-summer. If flooding occurs when a species is flowering, then seed production may not occur. For many perennial marsh species flowering is intermittent and sexual reproduction through seed production is only favored in times of lowered salinity, and annual reproduction of these plants from seeds is not essential for their long-term survival (SEW report).

The time until recovery or reestablishment of mature vegetation does not take into account several critical processes including: inter-specific competition and succession, which influences seed germination and seedling success, species abundance (i.e., population size) and initial species composition of a community (that is, the floristic quality of patches of a community). These aspects were not included in the analysis because the required data were not available.

Seed persistence describes the duration of storage of viable seeds as well as the speed at which seeds in the seed bank germinate. Seed persistence varies among species, from short seed persistence (e.g., *Avena fatua* whose seeds do not stay in the seed bank long because they germinate rapidly) to other plant species in which viable seeds can be stored for upwards of 20 years; the upper limit of storage of viable seeds is unknown. Viability of seeds is influenced by storage conditions (e.g., levels of moisture and salinity), but little is known about the impact of flooding on seed viability for the range of communities found in the Delta and Suisun Marsh. About four times more seeds were found in the banks of fringing marsh than in a managed marsh; species composition of seeds in managed marsh were more diverse, and viability estimates of dominates in the two different marsh types were similar in Louisiana marshes (La Peyre et al. 2005). The ability of seedbanks to re-establish communities is impacted by soil characteristics, salinity and hydrology, which can impact the establishment of species from the seed bank (LePeyre et al. 2005).

Generally the seeds and seedlings of all plants are sensitive to flooding and high salinity levels. Even in halophytes, high salt concentrations can reduce seed germination and initial seedling growth (Callaway and Sabraw 1994; Callaway and Zedler 1998; Kuhn and Zedler 1997; Shumway and Bertness 1992; Ungar 1978; all in Zedler et al. 2003). For example, mature individuals of *Cordylanthus mollis* ssp. *mollis*, a high marsh halophyte, tolerate higher soil salinity than seeds will germinate at (Ungar 1991; Ruygt 1994).

Salinity

Vegetation in the Delta and Suisun Marsh occupies habitats with a wide range of salinity; from none to hypersaline conditions in panne features due to evaporation. Complex species-specific responses to short duration salt pulses may lead to changes in species dominance and structure of communities (Howard and Mendelssohn 1999b). Saline tolerant plants have adaptations physiologically to process high salt concentrations (e.g., through osmotic adjustment) or avoid salt (salt extrusion, salt exclusion or dilution) (Kozlowski 1997). Specialized tissues or organs are involved with avoiding salt, such as the inner cells of the cortex of roots of vascular plants and the passage cells of the steele, which are barriers to transport of salt into the plant. Some plants secrete salt through organs, such as salt glands, in which energy is used to selectively move ions from vascular tissue in the leaves (Mitsch and Gosselink 1993). The precise mechanisms through which salinity inhibits growth are complex (Kozlowski 1997). Plants which have adapted to high salinity conditions can survive in low salinity environments, but due to the energy expended on adaptations for high salinity, are typically out-competed by non salt tolerant plants. Complex species-specific responses to short duration salt pulses may lead to changes in species dominance and structure of communities (Howard and Mendelssohn 1999b).

The following benchmarks provide a framework for understanding the range of salinities in the Delta and Suisun Marsh:

- The upper limits for salinity of human drinking water are 2 or 5 dS/m
- Water in Suisun marsh ranges from 7.8 to 18 dS/m (Suisun Marsh Monitoring Data, DWR 2001, Table I-4)
- Seawater is 46 dS/m (32-36 ppt)

In this report, salinity tolerance is defined as a <10 percent reduction in growth, and described using the following categories (NRCS 2007):

- none 0 – 2 dS/m
- low 2.1– 4.0 dS/m
- medium 4.1 – 8 dS/m
- high > 8.dS/m

These categories may not fully address the breadth of salinities found in the Delta and Suisun Marsh. Tolerance is often assigned based on the *in situ* salinity, rather than a response curve that describes plant mortality at a range of salinities. There is little empirical information, therefore, on the upper salinity tolerance of plants. This report does not predict shifts in species composition due to salinity.

Flooding

Flooding blocks oxygen supply to submerged plant parts. Respiration shifts from aerobic to anaerobic, impairing the energy status of cells, and reducing all metabolic activities. In particular, the low energy produced by anaerobic glycolysis in flooded upland plants causes a reduction in nutrient uptake. The toxic end-products of anaerobic glycolysis (fermentation) cause cytoplasmic acidosis and eventually death (Roberts 1988 in Mitsch and Gosselink 1993). Flooding also causes decreased water uptake, resulting in drought-like symptoms of closed stomata and wilting. Flooding cuts not only cuts off the oxygen supply to submerged vegetative tissue, but cuts off oxygen supply to the soil, as well. These anaerobic soil conditions result in an accumulation of substances that have a toxic effect on roots, including by products of anaerobic bacteria, and soluble reducing minerals such as iron, manganese, and sulfur (Kozlowski 1997; Ernst 1990 in Mitsch and Gosselink 1993). Furthermore, infrequent flooding alters the soil structure and capacity of the soil to support plant growth of non-flood tolerant species (Mitsch and Gosselink 1993).

At the cellular level, flood-tolerant and flood-intolerant vascular plants have similar adaptations to flooding. Flood-tolerant species adapt to flooding by expending energy, either from the reduced operating efficiency of oxygen deprived cells or energy expended to protect cells from stressors. Physiological changes include adaptations to reduce oxygen demand. Structural adaptations to flooding include increasing pore spaces in cortical tissue to supply oxygen from aerial parts to submerged roots. Structural changes also occur in response to flooding, including rapid stem elongation in some aquatic and semi-aquatic plants; development of adventitious roots above the anoxic zone in both flood-tolerant and in-tolerant plants; and an increase aerenchyma (air spaces) in plant tissues (Burdick and Mendelssohn 1990 in Mitsch and Gosselink 1993).

There is evidence that plants have a non-linear response to combinations of the multiple factors involved in flooding (flood depth, duration, salinity, and scour). For example, flooding upland trees with high salinity water has a much greater impact than flooding by low salinity water (Kozlowski 1997). For four species common to oligohaline marshes of the northern Gulf of Mexico, the magnitude of growth suppression in response to salinity increased for all species as the duration of exposure increased (Howard and Mendelssohn 1999a). Increased salinity and duration of exposure impaired recovery of some species but not others, e.g., American bulrush (*Scirpus americanus*) (Howard and Mendelssohn 1999b). However, due to data limitations, the response of vegetation in this analysis is modeled in a linear fashion; due to the potential for interaction effects between stressors, the impact of levee breaches on vegetation may be underestimated.

Flooding with high salinity floodwater and accompanying sediment deposition can alter the soil structure such that it poorly supports upland species (Kozlowski 1997). This analysis does not take into account the effect of altered soil conditions after pump out. Altered soil conditions could result in mortality of adult plants or could affect re-colonization of plant species. The impact of flooding on vegetation varies with the depth and duration of inundation. Breaching of levees in the Delta will result in up to several meters of flooding and 0.3 to 1 m in Suisun Marsh. Duration of scenarios ranges from a little over a month to 2.5 years. Increasing depth reduces light penetration affecting photosynthesis. Increasing duration increases the exposure of plants to anoxic conditions, resulting in higher concentrations of toxic byproducts which accumulate over time from anaerobic respiration and hypoxic soils.

6.2.3 Flooding (Inundation) and Salinity Effects and Variability by Mapped Vegetation Community

The following sections provide information on species-specific or community-level response to stressors such as salinity, flood depth and duration by mapped vegetation types.

6.2.3.1 Aquatic vegetation (permanently flooded)

Inundation: Aquatic vegetation, including floating and submerged plant species, has a range of adaptations to live in permanently flooded conditions. Aquatic plants may have air pockets or leaf structures which allow them to float on the top of the water, avoiding the oxygen limitations of anaerobic conditions. Some species are rooted in the substrate while others float. However, there are limits to the depth of open water at which colonization can occur. Photosynthesis is typically inhibited at depths greater than 6 feet due to limited light penetration of the water, and high turbidity decreases the photosynthetic depth. For some plants (e.g., *Egeria*) which can disperse by division, the scour associated with flooding creates vegetative propagules and spreads them with flood waters.

Salinity: Aquatic plants found in Suisun Marsh and Delta tolerate a wide salinity range. Salinity may limit some species such as *Egeria densa* and *Eichornia crassipes*.

6.2.3.2 Marsh vegetation (including seasonal alkali low marsh, seasonal alkali middle marsh, and seasonal alkali high marsh)

Inundation: Depth and duration of flooding are primary factors in structuring low, middle, and high marsh vegetation communities (Marsh 1969; Josselyn et al. 1990). Tidal range (and river run-off in brackish marshes) influences depth, duration and frequency of flooding. Tidal range is dampened in diked marshes, and major episodes of flooding or prolonged drought are part of the normal variability experienced by these systems (Zedler et al. 1986 in SEW 2001 report). Marsh plants possess structural and biochemical adaptations to survive flooding and salts. Other vegetative structures, such as underground tubers of *Typha* can survive flooding only if the aerial vegetative structures which are used for respiration in the winter dormancy period are not flooded (overtopped). For many aquatic and marsh species, reproduction by vegetative propagules has a much larger contribution to population size than seeds; clonal marsh plants including tules or bulrushes (*Scirpus* spp.) have a low rate of establishment from seed, but populations are maintained and spread by clonal rhizomes (Adam 1990, Cook 1985). Regeneration of *Scirpus* spp., propagules from pump-out to fully grown takes 1 year, while from seed mature vegetation occurs after 3 to 5 years; (S. Chappell pers. comm. 2006). In coastal salt marshes, disturbances associated with high salinity and flooding result in changes in the recovered communities and the species comprising them (Baldwin and Mendelssohn 1998).

Salinity: Suisun Marsh is characterized by wide annual and seasonal swings in salinity, and has an east-west estuarine salinity gradient over some 30 kilometers of land (Malamud-Roam et al. 1995). The major vascular plant species of the tidal marshlands are ordered along a salinity gradient (Collins and Foin 1993), but recent research has suggested that the structuring of marsh communities has less to do with salinity tolerance than inter-specific competition (SEW 2001). Salt tolerance of marsh plants is generally high. Wide ranges in channel salinity in recent years have been tolerated by low marsh plants (SEW 2001). Salinity affects the establishment, growth, survival, and reproduction of halophytes (Waisel 1972 in Zedler et al. 2003). After a disturbance event such as flooding in coastal marsh communities, there is a rapid succession of dominant species, shifting the species composition and the species dominance within the community.

6.2.3.3 Freshwater, herbaceous, wetland vegetation (seasonally flooded, including herbaceous wetland perennial, herbaceous wetland seasonal, and herbaceous wetland seasonal ruderal vegetation types)

Inundation: Freshwater wetland vegetation occurs in areas characterized by seasonally fluctuating water levels from ground water, precipitation, seasonal flooding. Water depths vary within a season and between years. Wetland plants require moist soils or inundated conditions to grow, but extreme depths (i.e., sufficient to overtop the plants, which varies by species) may result in mortality. Prolonged, deep, flooding may kill vegetative propagules, such rhizomes and stolons, eliminating vegetative growth.

Salinity: Some species of freshwater wetland vegetation tolerate brackish conditions, e.g. salt concentrations of less than 5 ppt, however freshwater wetland plant communities generally lack physiologic mechanisms to process or exclude higher salt concentrations.

6.2.3.4 Vernal pools (seasonally flooded; mapped as seasonal herbaceous wetlands)

Inundation: Vernal pools are created by microtopographic variations in areas underlain by hardpan soils and have a seasonal hydrologic cycle: filling with precipitation during the rainy season, remaining inundated until the water evaporates, followed by 4-8 months of desiccated soils (Keeley and Zedler 1998). The period of extreme desiccation precludes other species from colonizing vernal pools (Keeley and Zedler 1998). There is little information on response of vernal pools to catastrophic flooding, but several vernal pool communities have been extirpated by changing the hydraulic regime: channeling a vernal pool for mosquito abatement, runoff from irrigated agriculture into vernal pool habitat, and inundation resulting from construction of a livestock pond (Federal Register 1993).

Salinity: Some vernal pools have high concentrations of soil salinity/alkalinity such that a salt crust forms on the soil. There is very little information available about response of vernal pool species to high salinity level.

6.2.3.5 Riparian Vegetation (Temporarily Flooded; Shrub Riparian and Tree Riparian Vegetation Types)

Riparian areas are those influenced by an adjacent stream. The hydrologic regime consists of either perrenial or ephemeral channel flow and seasonal overbanking as a flash- or pulse-flooding after heavy winter and spring rains. Most riparian species are phreatophytic, extracting water from the stream and are adapted to seasonal, short-duration, freshwater, flooding, e.g. cottonwood, alder, willow. Adaptations to flood conditions may include root systems that can withstand high velocity, or adventitious roots that rise above the flood zone and translocate oxygen during flood conditions (Mitsch and Gosselink 1993). In riparian habitats, summer flooding caused greater disturbance for vegetation because vegetation development was at a maximum in comparison with winter flooding (Barrat-Segretain and Amoros 1995). Seedlings of riparian willows, which as adults tolerate seasonal catastrophic flooding, are sensitive to flooding.

6.2.3.6 Non-flood tolerant, upland vegetation (Not flooded; Herbaceous Upland, Herbaceous Upland Ruderal, shrub upland, tree native, tree non-native vegetation types)

Inundation: Flooding of upland trees can inhibit seed germination, create physical injury to plants, cause early plant senescence and mortality, and alter forest composition and distribution (Kozlowski 2000). Flooding has adverse effects on all development stages of flood intolerant plants, but generally less effect on trees during the dormant stages (Kozlowski 1997). Flooding during a dormant period, however, can impede regeneration, increase mortality of overstory trees, induce windthrow and crown dieback, and alter species composition from less to more water tolerant species (Kozlowski 2000). There is relatively little detailed information on flood tolerance (duration or depth) of species in herbaceous upland, herbaceous upland ruderal, shrub upland vegetation categories.

Salinity: High salinity affects upland trees by inhibiting seed germination, reducing growth (through changing osmotic absorption of minerals, ability to photosynthesize, altering balance between water, hormones, minerals, and carbohydrate) and inhibiting flowering, seed set, and cone formation etc. (Kozlowski 2000). Salt on leaf tissue as well as within water in the root zone causes tree damage (Kozlowski 2000). Rising sea level and increase in salinity of ground and soil water has resulted in reducing population of *Pinus ellioti* trees in Florida, and remaining trees exhibit salinity stress (Kozlowski 2000).

6.3 Impact Mechanisms for Terrestrial Wildlife

The primary effect of levee failures on wildlife will result from loss of foraging and breeding habitats as a result of the direct loss of habitats present on failed levee sections and the subsequent loss of habitat from inundation. In addition to the loss of habitat, the rapid loss of levee sections could cause direct mortality of individuals that cannot escape the failing levee or habitat inundation area (e.g., small mammals, eggs) as a result of physical trauma and drowning. Secondary impacts could result if displacement of wildlife from inundated habitats to other habitat areas occupied by the species results in increased mortality associated with disease or malnutrition/starvation as a result of insufficient food resources.

6.3.1 Direct Loss of Levee Habitat Due to Failures

Levees support linear habitats that include riparian scrub and woodland in locations where such vegetation is not periodically removed for levee maintenance, herbaceous vegetation, and emergent vegetation that may be present along the interior and exterior toes of levees. Levee failures would result in the direct and immediate loss of these habitats at the point of failure. Additional loss could occur as a result of ongoing erosion of the levee breach.

6.3.2 Direct Loss of Habitat as a Result of Flooding

Levee breaches on Delta islands could result in loss of agricultural habitats, marsh and riparian habitats associated with drains and ditches, and herbaceous habitats located at elevations below the water surface elevations in adjacent channels as a result of inundation. These effects would be temporary on islands that are drained and reclaimed to their former uses. Breaches of dikes in Suisun Marsh would also result in loss of these habitats as a result of the initial inundation after the breach and subsequent tidal inundation.

6.3.3 Loss of Habitat as a Result of Changed Hydrology and Salinity

Change in the extent and quality of habitat could result from changes in patterns of hydrology and salinity that result from levee breaches if such changes are of sufficient magnitude to convert vegetation communities to other communities that do not support habitat for a species.

6.3.4 Model Parameters

The parameters used to conduct the analysis for each selected wildlife species/species group are presented in Table 6-12.

7 Results by Breach Scenario

7.1 Selected Levee Failure Scenarios

To test the performance of the analysis framework in developing environmental indicators that are representative of the conditions and response of a species experiencing a levee failure, a range of three modeled levee breach scenarios were selected for initial analysis. The three levee breach scenarios are (1) a single breach on each of three islands, (2) 30 breaches on 20 islands, and (3) 50 breaches on 21 islands. The three levee breach scenarios selected for use in testing the environmental analysis framework were intended to represent a wide range of potential environmental conditions within the Estuary. Results of the initial test of the analytical framework, which included the range of indicators developed for various species, were compiled and used to refine the biological response functions, assumptions, and analyses to improve the performance and reliability of the approach for providing meaningful results on the potential environmental effects associated with levee failures. The revised framework and biological response functions, including estimates of uncertainty where appropriate, are presented in this section for the three levee breach scenarios that were tested. The risk assessment framework and assumptions/criteria were provided by the experts for integration into the larger scenario-based levee failure risk assessment.

7.2 Information Requirements

To evaluate the potential environmental effects of the three levee breach scenarios described above, information was compiled from a variety of sources. The primary sources of information were data collected by the Interagency Ecological Program (IEP) and resource agencies regarding the seasonal and geographic distribution and relative abundance of selected species within the Delta and Suisun Marsh. The California Natural Diversity Database (CNDDB) provided information on the location of wildlife species populations, and recent vegetation surveys conducted by CDFG provided information on the habitat types associated with each island within the Delta and Suisun Marsh. Information collected by agencies after the recent Jones Tract flooding event in 2004, as well as information from levee breaches (both managed and unmanaged) from within the Delta and elsewhere was used to determine the types of data on environmental conditions and biological responses that were available and helpful in building and validating the framework of assessing environmental risks and benefits of levee failure and island flooding.

In addition, biological and physical information about each island within the Delta and areas within Suisun Marsh was compiled using GIS data collected by various resource agencies and other sources, and results of hydrodynamic and water quality modeling. Information of particular importance included:

- The volume of water on each island when flooded
- The maximum and average depth of water of each island when flooded

- The acreage on each island in various water depth classes when flooded
- Changes in the magnitude and geographic distribution of salinity in response to levee breaches
- A vegetation map of the Suisun Marsh from CDFG
- A vegetation map of the Sacramento and San Joaquin Delta from CDFG
- The California Natural Diversity Database
- Data or reports from the Jones Tract levee failure describing island use by wildlife before and after flooding, including recolonization after pumping, as well as assessments of direct and indirect effects on wildlife, water quality, hydrodynamics, emergency response etc.
- Winter distribution and abundance of waterfowl, shorebirds, and sand hill cranes by island or sub-areas of the Delta and Suisun Marsh (e.g., mid-winter count data)
- Habitat distribution and occurrence maps for special-status species in the Delta and Suisun Marsh
- Information compiled from the scientific literature, technical reports, and available datasets on the habitat preferences, tolerance, and biological responses of the selected species to environmental conditions within the Delta and Suisun Marsh that may change as a result of levee failure.

Using the models and inputs described above, vegetation and wildlife impacts were assessed for three levee breach scenarios. The scenarios were:

- Three levee breaches on three Delta islands (Sherman Island, Brannan-Andrus Island, and Bacon Island) (hereafter referred to as the “three-breach scenario”)
- Thirty levee breaches on 20 Delta islands (Byron Tract, Brannan-Andrus Island, Bouldin Island, Bacon Island, Bethel Island, Bradford Island, Twitchell Island, Webb Tract, Jersey Island, Woodward Island, Palm Tract, Orwood Tract, Venice Island, Mandeville Island, Victoria Island, Upper and Lower Jones Tract, McDonald Tract, Quimby Island, and Holland Tract) (hereafter referred to as the “thirty-breach scenario”)
- Fifty levee breaches on 21 Delta islands (same islands as the thirty-breach scenario with the addition of Sherman Island, which is breached 20 times) (hereafter referred to as the “fifty-breach scenario”)

Due to limitations on time and resources, the aquatics impact submodels were not developed to a point where they could be used to assess these test scenarios. No impact results are therefore presented for the aquatic ecosystem.

7.3 Three-Breach Scenario

7.3.1 Scenario Description

This scenario models single breaches on three Delta islands (see Figure 7-1). Table 7-1 shows key physical parameter outputs from the model. Levee breaches, based on 1992 hydrology, were modeled to occur over 24 hours beginning on July 1. The last breach was assumed to be closed on September 3. The total breach duration was 2 months, 3 days. The size of the levee breaches increased over the initial failure conditions from 350 to 750 feet wide with a depth of about –25 to –35 feet MSL. SWP and CVP export operations were curtailed for a period of 6 months in response to salinity intrusion into the Delta.

Pump-out duration, which was not modeled in the scenario, was estimated to occur over 10 days, resulting in flood durations of 43 days (Sherman Island), 58 days (Brannan-Andrus Island), and 75 days (Bacon Island). The average flood depths for the three islands were 6 to 12 feet and the maximum salinity levels are about 2.1 to 4.0 ppt.

Island flooding under the three-breach scenario resulted in an increase in the area of surface water within the Delta of about 10 percent for 24 hours, one week, one month, and two months after the breach.

The low salinity zone has been defined as the location where bottom salinity is less than 2 ppt (also referred to as "X_2"). The X_2 location at the time of the three-breach scenario was examined using the RMA hydrologic and water quality simulation models. RMA is developing other information on the location of X_2 for use in the more comprehensive DRMS analysis.

Modeling of changes in average monthly salinity within the interior of each of the three islands breached in this case (RMA hydrodynamic model) suggested that once levee failure occurs and salinity conditions have been established within a flooded island, relatively little variation in average monthly salinity occurs from one month to the next. In the three-breach scenario, a single levee was breached on each of the islands (see Figure 7-1) and this affected residence time and water movement patterns onto and off of the flooded island.

Results of the three-breach scenario showed that salinity intrusion into the Delta would occur as shown in Figures 7-2, 7-3, and 7-4. Under the three-breach scenario, increased salinity would persist for a period of about 2 months. Increased salinity would affect habitat conditions within the marsh sloughs and channels; however, these changes are predicted to be relatively small, localized, and temporary. The potential effects of increased salinity within the Marsh on marsh vegetation and wildlife in response to the three-breach scenario are discussed below. The island pump-out schedule is shown in Table 7-1.

7.3.2 Results for Vegetation

7.3.2.1 Vegetation

If Sherman, Bacon, and Brannan-Andrus islands breached under conditions equivalent to those on July 1, 1992, sensitive species on the channel-side of the levees would be lost if they were in close proximity to the breach. The modeling assumes that while a breach is open, the breach width increases from 350 to 750 feet, creating a total area of impacted habitat on the channel-side of each island of 3,000 feet, given a distance of 1.5 times the length of the breach, which was impacted by repair operations to either side of the breach Thirty-five occurrences of 7 sensitive species were impacted on the levee's channel-side of the breach (see Table 7-2). For six of these species, the percentage of total occurrences on the "channel-side" was a small portion (<6 percent) of the total occurrences in the Delta and Suisun Marsh. The exception was *Carex vulpinoidea* (a CNPS 2.2 listed species), which had only one occurrence in the Delta and Suisun Marsh, on the channel-side of Bacon Island. One of the occurrences of a sensitive species on Sherman Island was a federally endangered species, *Cordylanthus mollis* ssp. *mollis*; this occurrence was 1 of 17 occurrences of this species in the Delta. No occurrences of sensitive species were listed in the interior of the flooded islands. In the three-breach scenario, 9 percent (30,690 acres) of the Delta[5] floods (Table 7-3). The vast majority of flooded land is agricultural (88 percent), but flooded agricultural land comprises only a small portion (10 percent) of all agricultural land in the Delta. Some 91 percent of the flooded land is habitat unsuitable for wild vegetation, including agricultural land, open water (less than 1 percent), developed land (less than 2 percent), no information (<0.00 percent, but 4,252 square feet occur on Brannan-Andrus Island), and non-vegetated land (less than 1 percent). The remaining vegetation types occupy 8.88 percent of the flooded area; most of that area (7 percent) is occupied by upland vegetation types, primarily herbaceous upland ruderal (6 percent). The flooded upland area includes a sizeable amount of the total shrub upland and tree upland non-native areas found in the Delta (20 percent and 14 percent, respectively). A very small amount of the total breached area is alkali low marsh (less than 1 percent), however, this area constitutes a large percentage (43 percent, or 143 acres) of that vegetation type found in the Delta. The remaining area consists of small percentages of breached area (<0.05 percent of breached area) and small percentages (<7 percent) of the total area of the vegetation type in the Delta for the following vegetation types: aquatic, alkali marsh high, herbaceous wetland (perennial, seasonal, and seasonal ruderal), freshwater wetland, and riparian vegetation types (shrub, tree).

7.3.2.2 Time to Recover to Mature Vegetation

The time from start of breach until recovery to mature vegetation in the three-breach scenario ranges from 0 (i.e., mature vegetation survives flooding) in the case of the native

[5] The "total area of the Delta" refers to legal boundary of the Delta and the primary boundary of Suisun Marsh, which were the areas surveyed for vegetation. The legal boundary does not exactly follow the 100-year floodplain and excludes some areas in the floodplain, particularly in the northern part of the Delta.

and non-native aquatic species *Egeria densa*, *Eichornia crassipes,* and *Potamogeton pectinatus* to the times to recover for trees, including the non-native *Eucalyptus globulus* (75 months, or 6 years), the native *Quercus lobata* (249 months, or 21 years), and the native riparian tree *Fraxinus latifolia* (369 months, or about 31 years) (see Table 7-4). Brackish marsh species *(Typha angustifolia, Salicornia virginica,* and *Frankenia salina)* took 14 to 18 months to recover, and on two breached islands adult *Typha angustifolia* adults survived flooding. However, these data do not incorporate survival of vegetative propagules, which may occur in short-term flooding in the three-breach scenario and would speed the time for recovery of emergent marsh plants. Species in freshwater wetland, including *Juncus balticus, Lolium multiflorum,* and *Scirpus americanus*, recover in 18 to 21 months. In the upland habitat, non-tree upland recovers in 8 to 21 months, with wide variation (< 1 year) in recovery times among islands, with the greatest duration on Bacon Island. Shrub wetland riparian (*Rubus discolor*) recovers in 32 to 33 months (about 2.75 years).

7.3.3 Results for Terrestrial Wildlife

Because the extent of habitat on breached portions of levees is extremely small relative to the total extent of the affected habitats elsewhere in the Study Area, the direct loss of levee habitats is expected to have no measurable effect on the distribution and abundance of the evaluated species. However, the loss of these habitats could result in direct mortality of evaluated wildlife that cannot escape the breach site (e.g., valley elderberry longhorn beetle, eggs present in nests) at the time of breaching. Direct losses of evaluated species are not expected to measurably affect the distribution or abundance of these species.

Table 7-5 summarizes the extent of wildlife habitat affected under the three-breach scenario. This scenario would result in the loss of about 10 percent of the agricultural lands in the Delta that could support foraging habitat for winter waterfowl and foraging habitat for greater sandhill cranes. Losses of this quantity of foraging habitat would result in the movement of individuals that would otherwise forage on these islands to other habitat areas. If the abundance of forage is sufficiently reduced, the rate of over-winter and spring migration mortality typically associated with these species could be increased above pre-breach conditions. The assessment of effects assumes that the affected islands will be restored to pre-breach agricultural uses (thus restoring the affected habitat areas) by the first or second winter after the loss of habitat. Given this assumption, the effects of the three-breach scenario are not expected to result in a long-term decline in the abundance of wintering waterfowl or greater sandhill cranes or their distribution within the Study Area. The effects of the loss of Swainson’s hawk agricultural foraging habitats are expected to be the same as described for wintering waterfowl and greater sandhill cranes.

Approximately 220 acres of woody riparian and upland habitats, representing about 5.5 percent of these habitats in the Delta, could be lost as a result of inundation. These losses could affect the distribution and local abundance of neotropical migrant birds in the Study Area, but because these losses represent a minimal amount of the total habitat present throughout the range of this species group, the losses would not be expected to affect the total population abundance of these species. After repair of the breaches and restoration of the inundated islands to their former conditions and uses, the riparian habitats these species use will gradually reestablish themselves over an estimated period of 3 to 33 years.

As shown in Table 7-5, loss of California black rail habitat would be minimal and would not affect the distribution or abundance of the species.

Habitats that are created during the reclamation period of breached islands could benefit shorebirds and wading birds by creating mudflat conditions along the receding margins of the island inundation pools that would develop as water is removed from breached islands. These mudflat conditions would be expected to provide large temporary patches of foraging and resting habitat for this species group.

7.4 Thirty-Breach Scenario

7.4.1 Scenario Description

Model test configurations were developed to represent a scenario in which 30 levees are breached on 20 Delta islands, as shown in Table 7-6 and Figure 7-5. Levee breaches were modeled to occur over 24 hours, beginning on July 1, 2002. The size of the levee breaches increase in length over the initial failure conditions from 350 to 750 feet and in depth from approximately –25 to –35 feet MSL. The last breach is assumed to be closed on October 13, 2003, representing a total breach duration of 15 months. SWP and CVP exports are curtailed as a result of salinity intrusion throughout the entire period that levee breaches remain open.

The hydrologic and water quality models for the thirty- and fifty-breach scenarios assume historical Delta inflow data for the end of the 2002 water year and part of the 2003 water year. These hydrologic data were selected to represent normal year hydrology within the Delta and Suisun Marsh. The 2003 water year hydrologic data were used repeatedly until the repairs were completed. The model assumes that all breaches would be repaired over a period of approximately 1 year for the thirty-breach scenario. Table 7-7 shows the pump-out schedule for the thirty-breach scenario.

In the thirty-breach scenario, 20 islands in the central Delta are flooded in July 2002, and levees are repaired over time, with pump-out durations averaging 30 days (the maximum pump-out duration is 98 days, for Brannan-Andrus Island) (Table 7-7). Islands are flooded from between 2.2 to 16.2 months (1.4 years), with flood depths ranging from 2.4 to 14.0 feet, with the exception of Byron Tract, For Byron Tract, the average elevation is well above sea level (+24.96 feet MSL), which is a poor representation of the minimum elevation on the island (–16.43 feet MSL). Salinity at time of breach closure ranges from 0.6 to 5.1 ppt for islands in the thirty-breach scenario, with the majority of the islands at salinity levels of <1.0 ppt. After levee repair, island pump-out would range from 4 to 98 days (Table 7-7).

The assumption that 30 levee breaches could be repaired and all islands pumped dry in less than 2 years may be optimistic; other repair and pump-out scenarios should be included in the actual risk analysis. In this analysis, estimates of pump out time and other response characteristics are standardized to match those elsewhere in the Phase 1 DRMS analysis. Nonetheless, given the social and economic consequences of a thirty-breach scenario, the situation would likely be considered an emergency and repair and pump-out of at least some of the islands would be accomplished rapidly. Based on the assumption of relatively rapid repair and pump-out under emergency conditions, the ecosystem risk model does not at this time address issues of community succession. For scenarios involving an extended period of breached-levee conditions, a general model of succession and colonization would be developed.

The position of the low salinity zone, X_2, at the time of the thirty-breach scenario was examined using the RMA hydrologic and water quality simulation models. Changes in average monthly salinity within the interior of each of the three islands breached in this case are presented in Figures 7-6 through 7-9 (RMA hydrodynamic model). Under the thirty-breach scenario, increased salinity would develop in the southern Delta and might persist in the far southern Delta for up to one year. Increased salinity would affect habitat conditions within the marsh sloughs and channels. The potential effects of increased salinity within the Marsh on marsh vegetation and wildlife in response to the three-breach scenario are discussed below.

7.4.2 Results for Vegetation

In the thirty-breach scenario, 73 occurrences of 8 sensitive species were located on the channel-side of breached levees: *Aster lentus* (26), *Carex vulpioidea* (1), *Hibiscus lasiocarpus* (12), *Lathyrus jepsonii* var. *jepsonii* (9), *Lilaeopsis masonii* (20), *Limosella subulata* (3), *Scutellaria galericulata* (1), and *Tropidocarpum capparideum* (1). All of these species were CNPS listed; none were federal or state listed. In the thirty-breach scenario, three occurrences of sensitive species occurred on the interior of breached islands and were considered lost during the flood (two on Webb Tract; one on Bouldin Island).

Twenty islands were breached in the thirty-breach scenario, inundating 94,785 acres and 28.03 percent of the area of the Delta. The majority of the inundated area (79 percent) was occupied by low-quality or non-native vegetation types (agricultural [76 percent], open water [<0.45 percent], non-vegetated [0.77 percent], developed [2 percent], no information [<0.001 percent]), including a quarter (26 percent) of all the agricultural land in the Delta (see Table 7-6). The remaining 21 percent of the flooded area consisted of very large (>40 percent) fractions of the total area of the vegetation types in the Delta (aquatic: 41 percent; marsh: 55 percent; freshwater wetland: 50 percent; upland: 54 percent; and riparian: 46 percent). Breaking this down by vegetation category, the vegetation type constituting the next largest area was herbaceous ruderal upland, occupying 13 percent of the flooded area. The rest of the flooded area (8 percent) included 11 vegetation types, excluding herbaceous upland non-native, which does not occur in the breached area. The 11 vegetation types each occupied a small percentage of the total breach area (less than 4 percent, most types less than 1 percent), yet this inundated land accounted for between 20 percent and 88 percent of the entire area of the vegetation type in the Delta:

- Alkali low marsh: 30 percent
- Alkali mid-marsh: 64 percent
- Alkali high marsh: 62 percent
- Herbaceous wetland, seasonal: 88 percent
- Herbaceous wetland, seasonal and ruderal: 67 percent
- Shrub upland: 42 percent
- Tree upland non-native: 27 percent
- Shrub upland riparian: 48 percent
- Tree riparian: 43 percent

In contrast, the inundated area of native upland trees (0.06 percent) was only a small percentage (7 percent) of the total native upland tree habitat in the Delta. The entire area of flooded alkali mid-marsh and herbaceous wetland seasonal vegetation occurred on single islands (Byron and Bradford tracts, respectively), and the areas of the rest of the vegetation types were distributed among many islands.

7.4.2.1 Time to Recover to Mature Vegetation

The time from start of breach until recovery to mature vegetation in the thirty-breach scenario ranges from 0 (i.e., mature vegetation survives flooding) in the case of native and non-native aquatic species *Egeria densa, Eichornia crassipes,* and *Potamogeton pectinatus* to the times to recover for trees, including the non-native *Eucalyptus globulus* (87 months, or about 7 years), the native *Quercus lobata* (260 months, or about 22 years), and the native riparian tree *Fraxinus latifolia* (381 months, or about 32 years) (Table 7-8).

7.4.3 Results for Terrestrial Wildlife

Table 7-9 summarizes the extent of evaluated species/group habitats removed under the thirty-breach scenario. This scenario would result in the loss of about 22 percent of agricultural lands that could support foraging habitat for winter waterfowl in the Delta and foraging habitat for greater sandhill cranes. Loss of this quantity of foraging habitat would likely measurably change the wintering distribution and abundance of these species in the Study Area. The abundance of forage may be sufficiently reduced that over-winter and spring migration mortality increases relative to pre-breach conditions. The assessment of effects assumes that the affected islands will be restored to pre-breach agricultural uses (thus restoring the affected habitat areas) by the first or second winter after the loss of habitat. Based on this assumption, the effects of the thirty-breach condition are not expected to result in a long-term decline in the abundance of wintering waterfowl or greater sandhill cranes or their distribution within the Study Area. Effects of the loss of Swainson's hawk agricultural foraging habitats are expected to be the same as described for wintering waterfowl and greater sandhill cranes.

As indicated in Table 7-10, a substantial portion of woody riparian and upland habitats in the Delta could be lost as a result of inundation. These losses would affect the distribution and local abundance of neotropical migrant birds in the study, but, because these losses represent a minimal amount of the total habitat present throughout the range of this species group, they would not be expected to affect the total population abundance of these species. After repair of the breaches and restoration of the inundated islands to their former conditions and uses, riparian habitats used by these species will gradually re-establish over a number of years.

As indicated in Table 7-9, about 1,200 acres of California black rail habitat would be lost, representing about 32 percent of habitat present in the Delta. This loss would be expected to affect the local distribution and abundance of black rail in the Delta, but effects on the entire population of black rail are expected to be minimal because the Delta does not support core populations of the species.

Benefits of the thirty-breach condition for shorebirds and wading birds would be the same as described for the three-breach condition except that extent of created temporary mudflat habitats would be substantially greater.

7.5 Fifty-Breach Scenario

7.5.1 Scenario Description

Model configurations were developed to represent 50 levee breaches on 21 Delta islands, as shown in Tables 7-11 and 7-12 and Figure 7-10, with assumptions regarding island depth, topography, breach timing, and size of each breach the same as for the other breach scenarios. In this scenario, SWP and CVP exports are curtailed as a result of salinity intrusion throughout the entire period that levee breaches remain open. The schedule for levee repair is presented in Table 7-11. The primary differences between the thirty-breach scenario and the fifty-breach scenario are the addition of Sherman Island to the fifty-breach scenario, the more rapid filling of Delta islands due to a greater number of breached areas, and the extended repair and pump-out time. Impacts are similar to the thirty-breach scenario, but their magnitude is marginally greater than those of the thirty-breach scenario.

In the fifty-breach scenario, 1.2 million acre-feet of water rush into the Delta from Suisun and San Francisco bays and flood 21 islands with an area of 104,968 acres. Water stage within the adjacent channels is predicted to fall to 10 feet below sea level at the SWP and CVP export facilities, to 6 feet below sea level at Franks Tract, and to approximately 5 feet below sea level in the lower Sacramento and San Joaquin rivers as the nearby water in these channels is entrained into the flooding islands. These conditions would also result in salinity intrusion farther upstream into the Delta.

The hydrologic and water quality models for the fifty-breach scenario assume historical Delta inflow data for the end of the 2002 water year and part of the 2003 water year. These hydrologic data were selected to represent normal year hydrology within the Delta and Suisun Marsh. The 2003 water year hydrologic data are used repeatedly until the repairs are completed. The model assumes that all breaches are repaired over a period of approximately 2 years for the fifty-breach scenario.

In the fifty-breach scenario, 20 islands in the central Delta area are breached in July 2002, repaired over time, and pumped out (average duration of pump-out is 28 days, standard deviation ± 21 days; maximum duration is 98 days [Brannan-Andrus Island]; minimum duration is 4 days [Quimby Island]) (Table 7-11). This scenario results in flood durations ranging from 3.1 months (Bethel Tract) to 28.3 months (2.4 years) (Woodward Island), with 11 islands flooded for more than 1.5 years. Island flood depths range from 2.4 to 13.9 feet with the exception of Byron Tract, where the average elevation is well above sea level (+24.96 feet MSL), which is a poor representation of the minimum elevation on the island (-16.43 feet MSL). Salinity levels at the time of breach closure range from 0.2–5.1 ppt, with the majority of floodwaters on islands at the time of breach closure below 1.0 ppt. Average water depths in channels next to Sherman, Brannan-Andrus, and Bacon islands are shown in Table 7-1.

7.5.1.1 X_2 Location

The fifty-breach scenario would have virtually the same impacts on salinity distribution in the Delta (Figures 7-11 through 7-14) as the thirty-breach scenario, except that (a) the initial rush of salinity into the Delta would be more rapid, giving animal species that are intolerant of high salinities less time to avoid the intrusion, and (b) the duration of the altered salinity regime would be greater.

7.5.2 Results for Vegetation

7.5.2.1 Vegetation

In the fifty-breach scenario, 92 occurrences of nine sensitive species were located on the channel-side of levee walls that are breached in this scenario. The nine sensitive species are *Aster lentus* (33 occurrences); *Cordylanthus mollis* ssp. *mollis* (1 occurrence); *Carex vulpioidea* (1 occurrence); *Hibiscus lasiocarpus* (12 occurrences); *Lathyrus jepsonii* var. *jepsonii* (10 occurrences); *Lilaeopsis masonii* (28 occurrences); *Limosella subulata* (5 occurrences); *Scutellaria galericulata* (1 occurrence); and *Tropidocarpum capparideum* (1 occurrence). Nineteen occurrences of sensitive species were listed on Sherman island: *Aster lentus* (7 occurrences); *Cordylanthus mollis* ssp. *mollis* (1 occurrence); *Lathyrus jepsonii* var. *jepsonii* (1 occurrence); *Lilaeopsis masonii* (8 occurrences); and *Limosella subulata* (2 occurrences). *Cordylanthus mollis* ssp. *mollis* (a federal endangered species) was the only species to be impacted in the fifty-breach scenario that was not impacted in the thirty-breach scenario. This occurrence of *Cordylanthus mollis* ssp. *mollis* was one of 17 occurrences of the species in the Delta and Suisun Marsh. As in the thirty-breach scenario, three occurrences of sensitive species were located on the interior of breached islands in the fifty-breach scenario, and these three occurrences were considered lost during the levee breach. Two occurrences were on Webb Tract, and one occurrence was on Bouldin Island.

Although the fifty-breach scenario results in a large increase in the number of breaches relative to the thirty-breach scenario, the fifty-breach scenario resulted in a comparatively small increase in the flooded area. The fifty-breach scenario included all of the islands in the thirty-breach scenario (94,785 acres) as well as Sherman Island (10,183 acres), increasing the breached area from 28 percent to 31 percent of the Delta (Table 7-13). As in the thirty-breach scenario, a disproportionately high amount of natural vegetation in the Delta is located in the flooded area in the fifty-breach scenario. Thus, even though only 31 percent of the Delta is impacted, more than 40 percent of the total area of groups of wild vegetation in the Delta are flooded (aquatic: 41.36 percent; marsh: 65.17 percent; freshwater wetland: 52 percent; upland: 57 percent; riparian: 48 percent; see Table 7-14). If the impacted area is broken down by vegetation type, 21 to 90 percent of the area of natural vegetation types in the Delta was flooded:

- Aquatic, 41 percent
- Alkali marsh low, 73 percent
- Alkali marsh mid, 64 percent
- Alkali marsh high, 62 percent
- Herbaceous wetland perennial, 21 percent
- Herbaceous wetland seasonal non ruderal, 88 percent
- Herbaceous wetland seasonal ruderal, 70 percent
- Herbaceous upland ruderal, 61 percent
- Shrub upland, 49 percent
- Tree upland non-native, 28 percent
- Shrub riparian, 50 percent
- Tree riparian, 45 percent

Exceptions include upland native trees, for which a small percentage (7 percent) of area in the Delta is flooded, and herbaceous upland non-ruderal, which did not occur in the flooded area. The addition of Sherman Island in the fifty-breach scenario dramatically increases the total area of flooded alkali low marsh—from 30 to 73 percent due to the 143.09 acres occurring on Sherman Island. However, for the other vegetation types, the addition of Sherman Island results in a small (0 to 8 percent) increase in percentage of the total area of the vegetation type in the Delta. The following list shows vegetation types and the percent increase in impacted habitat in the fifty-breach scenario over the thirty-breach scenario:

- Aquatic: 0 percent

- Alkali marsh mid: 0 percent
- Alkali marsh high: 0.07 percent
- Herbaceous wetland perennial: 1 percent
- Herbaceous wetland seasonal non ruderal: 0 percent
- Herbaceous wetland seasonal ruderal: 2 percent
- Herbaceous Upland ruderal: 4 percent
- Shrub upland: 7 percent
- Tree upland non-native: 1 percent
- Shrub riparian: 2 percent
- Tree riparian: 1 percent

7.5.2.2 Time to Recover to Mature Vegetation

The time from start of breach until recovery to mature vegetation in the fifty-breach scenario ranges from 0 (i.e., mature vegetation survives flooding) in the case of native and non-native aquatic species *(Egeria densa, Eichornia crassipes,* and *Potamogeton pectinatus)* to the times to recover for trees, including the non-native *Eucalyptus globulus* (99 months, or about 8.25 years), the native *Quercus lobata* (273 months, or about 23 years), and the native riparian tree *Fraxinus latifolia* (393 months, or about 33 years) (see Table 7-15).

7.5.3 Results for Terrestrial Wildlife

The potential effects of the fifty-breach scenario on evaluated wildlife are the same as described for the thirty-breach scenario.

Table 7-16 summarizes the extent of evaluated species/group habitats removed under the fifty-breach scenario. This case results in the loss of up to about 26 percent of agricultural lands in the Delta that could support foraging habitat for wintering waterfowl and foraging habitat for greater sandhill cranes. The effects of these habitat losses would be the same as described under the thirty-breach scenario.

As indicated in Table 7-16, the loss of California black rail habitat would be about 1,200 acres, representing about 32 percent of habitat present in the Delta. The effects of these habitat losses would be the same as described under the thirty-breach scenario.

The benefits of the fifty-breach scenario for shorebirds and wading birds would be the same as described for the three-breach scenario except that the extent of created temporary mudflat habitats would be substantially greater under the fifty-breach scenario.

7.6 Suisun Marsh Levee Breach

In Suisun Marsh, a failure scenario was developed in which levees overlaying 30 feet of organic sediments are breached (Figure 7-15). Exterior levees are defined as levees circumscribing areas that would flood if that levee failed. Exterior levees do not necessarily correspond with (a) levees as determined from IFSAR topography data and over-flight photographs (because interior levees and exterior levees were difficult to distinguish), (b) property boundaries, or (c) URS analysis zones. Areas that would fail an extreme seismic event were defined as areas in which exterior levees overlay organic material thicker than 30 feet. Finally, the vegetation maps (see Figures 4-3 and 4-4) were compared through GIS overlay with areas at risk from flooding due to a seismic event.

7.6.1 Suisun Marsh Levee Breach

In Suisun Marsh, the area of vegetation that would be impacted by flooding from a seismic event was determined in the following manner. First, exterior levees were delineated (Chappell pers. comm. 2007) (see Figure 7-15). Exterior levees were defined as those levees circumscribing areas that would flood if that levee were to fail. Exterior levees do not necessarily correspond with (a) levees as determined from IFSAR topography data and over-flight photographs (because interior levees and exterior levees were difficult to distinguish), (b) property boundaries, or (c) URS analysis zones. Second, areas that would fail in response to an extreme seismic event were defined as those areas in which exterior levees overlay organic material thicker than 30 feet. Third, the vegetation maps (see Figures 4-3 and 4-4) were compared through GIS overlay with areas at risk from flooding due to a seismic event. The area of each vegetation type that would be impacted by flooding is presented in Table 7-17.

7.6.2 Vegetation Impacted

In the scenario in which Suisun Marsh floods as a result of a seismic event, only small percentages of low-quality habitat is inundated, but large amounts of natural and native vegetation would be impacted:

- A small area of agricultural land would be as lost (263 acres; 0.6 percent of the breached area, 0.1 percent of the agricultural area in the Delta and Suisun Marsh).
- The total area of non-wild vegetation impacted by seismic breaches in the Suisun Marsh would be only 0.8 percent of the area in the entire Delta and Suisun Marsh (non-wild vegetation types included no information, agriculture, developed, non-vegetated, and open water). Only small amounts of herbaceous upland ruderal would be inundated.
- The total area of marsh habitat inundated would be 54.4 percent of the total marsh habitat, 81.2 percent of alkali mid marsh vegetation, and 30.8 percent of freshwater wetland in the Suisun Marsh and the Delta combined.
- A large percentage of the native herbaceous upland vegetation (67.0 percent) and native shrub upland vegetation (48.3 percent) found in the Delta and Suisun Marsh would be inundated.

- However, impacts to riparian vegetation (shrub wetland and tree wetland) and upland trees would be very small, with impacts to only 1.1 percent of shrub wetland, 0.0 percent of tree wetland, 0.0 percent of upland native trees, and 3.1 percent of upland non-native trees in the Delta and Suisun Marsh.

8 Model Integration/Linkages/Interfaces

The environmental risk analysis has been based on information provided on environmental changes within the Delta and Suisun Marsh that would be expected to occur in response to levee failure. Information developed from complementary modeling elements of the project, such as the levee fragility modeling, hydrodynamic modeling, water quality modeling, and emergency response and repair all provided input that was used in various aspects of the environmental analysis. Similarly, information developed from the environmental risk analysis was provided as one factor in evaluating the potential economic effects associated with a levee failure scenario. Information developed through GIS analysis of current conditions within the Delta and Suisun Marsh was also be used as input to the environmental risk analysis. Examples of the model integration, information transfer, and linkages to the environmental risk analysis are presented below:

- Date of the levee breach (levee fragility)
- Length of the levee breach (levee fragility)
- Location of the levee breach (levee fragility)
- Occurrence of multiple levee breaches (levee fragility)
- Volume of water entrained onto the flooded island (GIS mapping)
- Changes in SWP and CVP export operations in response to levee failure (hydrodynamics)
- Changes in upstream reservoir operations and instream releases (hydrodynamics)
- Changes in on-island water diversions for irrigation (GIS mapping)
- Area of the island that is flooded (GIS mapping)
- Water depth within the flooded island (GIS mapping)
- Duration that the breach remains open (emergency response)
- Duration that the island remains flooded (emergency response)
- Changes in salinity for each scenario within the flooded island and adjacent channels (hydrodynamics, water quality)
- Changes in water temperature, salinity, dissolved oxygen, and suspended sediments within and next to each flooded island (hydrodynamics, water quality)
- Changes in low salinity areas within the Estuary (X_2 location) and Suisun Marsh (hydrodynamics, water quality)
- Changes in local water velocity patterns within the channels next to a levee breach and within the flooded island (hydrodynamics)
- Hydraulic residence time within a flooded island (hydrodynamics)
- Particle entrainment onto the flooded island (hydrodynamics)
- Potential exposure to toxic contaminants within a flooded island (GIS mapping)

Information developed through modeling and other analytical tools used to characterize changes in environmental conditions in response to a levee failure scenario was integrated with information on the seasonal and geographic distribution of selected species developed from surveys conducted by CDFG, USFWS, UCD, and other investigators, and the anticipated biological response of a species and life stage to environmental conditions formed the foundation for the environmental risk assessment.

In addition to the limited number of selected breach scenarios that were examined in greater detail in this technical report, probabilistic modeling has also been used to assess the anticipated response of selected aquatic and terrestrial species to a large number of modeled levee failure scenarios. This conditional risk assessment incorporates both epistemic and aleatory uncertainty into model outputs to help provide insight into the degree of uncertainty in the predicted response of a species to levee failure. As part of developing the functional relationships associated with the species-specific models, the level of uncertainty in predicted outcomes was also documented. This documentation facilitated both (a) identification of key knowledge gaps that, if filled, would reduce model uncertainty, and (b) updates to the model as parameter/response estimates or their associated uncertainties change.

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Source for Figure 6-2a: http://www.npwrc.usgs.gov/resource/plants/pondweed/table5.htm; C.J. Stewman, pers. comm., 2007

Source for Figure 6-2b: http://www.npwrc.usgs.gov/resource/plants/pondweed/develop.htm

Source for Figure 6-2c: http://www.npwrc.usgs.gov/resource/plants/pondweed/table5.htm

Table 2-1. Events and variables defined in the levee breach sequences.

No.	Event or Variable	Description
1	Hydrologic year	Establishes the Delta inflows and upstream storage
2	Initiating event	The type event that initiates (causes) levee failures
3	Month	Month during the year when the levee breaches occur
4	Flooded islands	Specific islands in the Delta that are breached and flooded during the event
5	Levee breaches	Number and location of levee breaches that occur on each island during an event
6	Levee repair and island de-watering	Order and timing of breach closures and island de-watering

Table 3-1. Fish and major shrimp, crab, and mollusk species inhabiting the Delta and Suisun Marsh.

	Common Name	**Latin Name**
FISH	Pacific lamprey*	*Lampetra tridentate*
	River lamprey*	*Lampetra ayersi*
	White sturgeon*	*Acipenser transmontanus*
	Green sturgeon*	*Acipenser medirostris*
	American shad	*Alosa sapidissima*
	Threadfin shad	*Dorosoma petenense*
	Central Valley steelhead*	*Oncorhynchus mykiss*
	Chum salmon	*Oncorhynchus keta*
	Chinook salmon (all four runs)*	*Oncorhynchus tshawytscha*
	Longfin smelt*	*Spirinchus thaleichthys*
	Delta smelt*	*Hypomesus transpacificus*
	Wakasagi	*Hypomesus nipponensis*
	Northern anchovy*	*Engraulis mordax*
	Pacific sardine*	*Sardinops sagax*
	Starry flounder*	*Platichthys stellatus*
	Hitch*	*Lavinia exilicauda*
	Sacramento blackfish*	*Orthodon microlepidotus*
	Sacramento splittail*	*Pogonichthys macrolepidotus*
	Hardhead*	*Mylopharodon conocephalus*
	Sacramento pikeminnow*	*Ptychocheilus grandis*
	Fathead minnow	*Pimephales promelas*
	Golden shiner	*Notemigonus chrysoleucas*
	Common carp	*Cyprinus carpio*
	Goldfish	*Carassius auratus*
	Sacramento sucker*	*Catostomus occidentalis*
	Black bullhead	*Ameiurus melas*
	Brown bullhead	*Ameiurus nebulosus*
	Yellow bullhead	*Ameiurus natalis*
	White catfish	*Ameiurus catus*
	Channel catfish	*Ictalurus punctatus*
	Western mosquitofish	*Gambusia affinis*
	Rainwater killfish	*Lucania parva*
	Striped bass	*Morone saxatilis*
	Inland silverside	*Menidia beryllina*
	Bigscale logperch	*Percina macrolepida*
	Bluegill	*Lepomis macrochirus*
	Redear sunfish	*Lepomis microlophus*
	Green sunfish	*Lepomis cyanellus*
	Warmouth	*Lepomis gluosus*
	White crappie	*Pomoxis annularis*
	Black crappie	*Pomoxis nigromaculatus*
	Largemouth bass	*Micorpterus salmoides*
	Smallmouth bass	*Micropterus dolomieui*

Table 3-1. Fish and major shrimp, crab, and mollusk species inhabiting the Delta and Suisun Marsh.

	Common Name	**Latin Name**
FISH (cont.)	Bigscale logperch	*Percina macrolepida*
	Tule perch*	*Hysterocarpus traski*
	Threespine stickleback*	*Gasterosteus aculeatus*
	Yellowfin goby	*Acanthogobius flavimanus*
	Chameleon goby	*Tridentiger trigonocephalus*
	Prickly sculpin*	*Cottus asper*
SHRIMP	California Bay shrimp*	*Crangon franciscorum*
	Blacktail Bay shrimp*	*Crangon nigricauda*
	Blackspotted Bay shrimp*	*Crangon nigromaculata*
	Opossum shrimp*	*Neomysis mercedis*
	Oriental shrimp	*Paleomon macrodactylus*
	Siberian prawn	*Exopaleomon modestus*
CRABS	Dungeness crab*	*Cancer magister*
	Brown rock crab*	*Cancer antennarius*
	Red rock crab*	*Cancer productis*
	Graceful rock crab*	*Cancer gracilis*
	Chinese mitten crab	*Eriocheir sinensis*
MOLLUSKS	Bay mussel*	*Mytilis edulis*
	Softshell clam*	*Mya arenaria*
	Amur clam	*Corbula amurensis*
	Asian clam	*Corbicula fluminea*
	Japanese littleneck clam	*Tapes japonica*
	New Zealand mudsnail	*Potamopyrgus antipodarum*

* native species
Source: DFG (unpublished data)

Table 3-2. Year-round fishery surveys conducted by the California Department of Fish and Game showing seasonal timing.

Survey/ Gear Type	Institution	Year	Months (Frequency)	Locations (Stations)	Life Stages
Fall Midwater Trawl	CDFG	1967 to present	September – March (monthly)	San Pablo Bay – Delta (53-113)	Juvenile – adult
Summer Tow-Net	CDFG	1959 to present	June – August (biweekly)	Suisun Bay – Delta (30)	Juvenile – adult
20-mm Tow-Net	CDFG	1995 to present	March – June (biweekly)	Napa River – Delta (30)	Larvae – juvenile
Spring Kodiak Trawl	CDFG	2002 to present	March – May (biweekly)	Suisun Bay – Delta (30-40)	Maturing – spawning
Bay Study Midwater Trawl	CDFG	1980 to present	January – December (monthly)	South San Francisco Bay – Suisun Bay (42)	Juvenile – adult
Otter Trawl	UCD	1979 to present	January – December (monthly)	Suisun Marsh (18)	Juvenile – adult
SWP/CVP Water Projects	DWR; USBR	1979 to present	January – December (daily)	South Delta near Tracy (2)	20-mm post-larvae – adult
Midwater Trawl	USFWS	1976 to present	April – June (daily)	Chipps Island (1)	Juvenile – adult
Beach Seine	USFWS	1977 to present	January – June (biweekly)	Delta – Sacramento River (23)	Juvenile – adult

CDFG = California Department of Fish and Game
CVP = Central Valley Project
DWR = (California) Department of Water Resources
SWP = state water project
UCD - = University of California, Davis
USBR = U.S. Bureau of Reclamation
USFWS = U.S. Fish and Wildlife Service
Sources: Bennett 2005; CDFG 2006b

Table 3-3. Special-status plant species occurring in the legal Delta and Suisun Marsh.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Nativity
Suisun Marsh aster	*Aster lentus*	*Symphyotrichum lentum (Greene) Nesom; A. chilensis Nees* vars. *l. (Greene) Jeps. and sonomensis (Greene) Jeps.*	perennial herb (composite)	—	—	1B.2	native and endemic
Ferris's milk vetch	*Astragalus tener* var. *ferrisiae*	—	annual herb	—	—	1B.1	native and endemic
Alkali milk-vetch	*Astragalus tener* var. *tener*	—	annual herb (legume)	—	—	1B.2	native and endemic
heartscale	*Atriplex cordulata*	*Atriplex cordulata* ssp. *cordulata*	annual herb	—	—	1B.2	native and endemic
brittlescale	*Atriplex depressa*	*Atriplex parishii* var. *depressa*	annual herb	—	—	1B.2	native and endemic
San Joaquin spearscale	*Atriplex joaquiniana*	*Atriplex patula* ssp. *spicata*	annual herb	—	—	1B.2	native and endemic
Bristly sage; Longhair sedge	*Carex comosa*	—	perennial herb (rhizomatous), sedge	—	—	2.1	native
fox sedge	*Carex vulpinoidea*	*Carex vulpinoidea* var. *vulpinoidea*	perennial sedge (herb)	—	—	2.2	native
Congdon's tarplant	*Centromadia parryi* ssp. *Congdonii*	*Hemizonia parryi* ssp. *congdonii*	annual herb	—	—	1B.2	native
pappose tarplant	*Centromadia parryi* ssp. *Parryi*	*Hemizonia parryi* ssp. *parryi; Hemizonia parryi*	annual herb	—	—	1B.2	native
slough thistle	*Cirsium crassicaule*	—	annual, perennial herb	—	—	1B.1	native and endemic
Suisun thistle	*Cirsium hydrophilum* var. *hydrophilum*	*Cirsium vaseyi* var. *hydrophilum*	perennial herb	E	—	1B.1	native and endemic

Table 3-3. Special-status plant species occurring in the legal Delta and Suisun Marsh.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Nativity
Soft bird's-beak	*Cordylanthus mollis* ssp. *Mollis*	—	annual herb (hemiparasitic)	E	R	1B.2	native and endemic
Recurved larkspur	*Delphinium recurvatum*	—	perennial herb	—	—	1B.2	native and endemic
dwarf downingia	*Downingia pusilla*	*Downingia humilis; Bilelia humilis*	annual herb	—	—	2.2	native
Mt. Diablo buckwheat	*Eriogonum truncatum*	—	annual herb	—	—	1B.1	native
Delta coyote thistle (Delta button-celery)	*Eryngium racemosum*	—	annual, perennial herb	—	E	1B.1	native and endemic
Contra Costa Wallflower	*Erysimum capitatum ssp. angustatum*	—	perennial herb	E	E	1B.1	native and endemic
Boggs Lake hedge-hyssop	*Gratiola heterosepala*	—	annual herb (vernal pool obligate)	—	E	1B.2	native
rose-mallow	*Hibiscus lasiocarpus*	*Hibiscus californicus; Hibiscus moscheutos* ssp. *lasiocarpus, Hibiscus moscheutos* var. *occidentalis, Hibiscus moscheutos* ssp. *lasiocarpos, Hibiscus moscheutos*	perennial herb (rhizomatous)	—	—	2.2	native
Northern California black walnut	*Juglans californica* var. *hindsii*	—	tree	—	—	1B.1	native and endemic
Contra Costa Goldfields	*Lasthenia conjugens*	—	annual herb (vernal pool obligate)	E	—	1B	native and endemic
Delta tule pea	*Lathyrus jepsonii* var. *jepsonii*	—	perennial herb (legume)	—	—	1B.2	native and endemic

Table 3-3. Special-status plant species occurring in the legal Delta and Suisun Marsh.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Nativity
legenere	*Legenere limosa*	*Howellia limosa*	annual herb	—	—	1B.1	native and endemic
Heckard's pepper grass	*Lepidium latipes* var. *heckardii*	*Lepidium latipes*	annual herb	—	—	1B.2	native and endemic
Mason's lilaeopsis	*Lilaeopsis masonii*	—	perennial herb	—	R	1B.1	native and endemic
Delta mudwort	*Limosella subulata*	—	perennial herb	—	—	2.1	non-native
Baker's navarretia	*Navarretia leucocephala* ssp. *Bakeri*	*Navarretia bakeri*	annual herb	—	—	1B.1	native and endemic
Colusa grass	*Neostapfia colusana*	—	annual grass (vernal pool obligate)	T	E	1B.1	native
Antioch Dunes evening primrose	*Oenothera deltoides* ssp. *Howellii*	—	perennial herb	E	E	1B.1	native and endemic
bearded popcorn-flower	*Plagiobothrys hystriculus*	*Allocarya hystricula*	annual herb	—	—	1B.1	native
Eel-grass pondweed	*Potamogeton zosteriformis*	—	annual herb (aquatic)	—	—	2.2	native
Sanford's arrowhead	*Sagittaria sanfordii*	—	perennial herb (rhizomatous)	—	—	1B.2	native and endemic
marsh skullcap	*Scutellaria galericulata*	*Scutellaria epilobifolia; Scutellaria galericulata* ssp. *pubescens; Scutellaria galericulata* var. *epilobifolia, Scutellaria galericulata* var. *pubescens*	perennial herb (rhizomatous)	—	—	2.2	native

Table 3-3. Special-status plant species occurring in the legal Delta and Suisun Marsh.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Nativity
blue skullcap	*Scutellaria lateriflora*	*Scutellaria lateriflora* var. *lateriflora*	perennial herb (rhizomatous)	—	—	2.2	native
Wright's trichocoronis	*Trichocoronis wrightii* var. *wrightii*	—	annual herb	—	—	2.1	non-native
caper-fruited tropidocarpum	*Tropidocarpum capparideum*	—	annual herb	—	—	1B.1	native
Crampton's tuctoria	*Tuctoria mucronata*	—	annual grass (vernal pool obligate)	E	E	1B.1	native and endemic

Federal Status
E = Endangered
T = Threatened

State (California) Status
E = Endangered
R = Rare

California Native Plant Society (CNPS) Status
1B = Rare, threatened, or endangered in California and elsewhere
1B.1 = Rare, threatened, or endangered in California and elsewhere, seriously endangered in California
1B.2 = Rare, threatened, or endangered in California and elsewhere, fairly endangered in California
2.1 = Rare, threatened or endangered in California, but more common elsewhere; seriously threatened in California
2.2 = Rare, threatened, or endangered in California, but more common elsewhere, fairly endangered in California

Source: CNDDB 2007

Table 3-4. Number of occurrences of sensitive vegetation species in the Delta, Delta levee slopes, and region.

Common Name	Latin Name	Number of Occurrences			Percent in Delta on Levee Slopes[1]	Percent in Region[2] on Levee Slopes[1]
		Delta	Levee Slopes[1]	Region[2]		
Ferris's milk vetch	*Astragalus tener* var. *ferrisiae*	2	0	4	0.0	0.0
Heartscale	*Atriplex cordulata*	1	0	10	0.0	0.0
Brittlescale	*Atriplex depressa*	1	0	27	0.0	0.0
Bristly sage; Longhair sedge	*Carex comosa*	3	0	6	0.0	0.0
Congdon's tarplant	*Centromadia parryi* ssp. *Congdonii*	1	0	41	0.0	0.0
Pappose tarplant	*Centromadia parryi* ssp. *Parryi*	3	0	16	0.0	0.0
Suisun thistle	*Cirsium hydrophilum* var. *hydrophilum*	3	0	3	0.0	0.0
Dwarf downingia	*Downingia pusilla*	3	0	54	0.0	0.0
Mt. Diablo buckwheat	*Eriogonum truncatum*	1	0	6	0.0	0.0
Delta coyote thistle (Delta button-celery)	*Eryngium racemosum*	2	0	5	0.0	0.0
Northern California black walnut	*Juglans californica* var. *hindsii*	1	0	4	0.0	0.0
Legenere	*Legenere limosa*	3	0	43	0.0	0.0
Baker's navarretia	*Navarretia leucocephala* ssp. *Bakeri*	1	0	28	0.0	0.0
Antioch Dunes evening primrose	*Oenothera deltoides* ssp. *Howellii*	5	0	9	0.0	0.0
Bearded popcorn-flower	*Plagiobothrys hystriculus*	1	0	9	0.0	0.0
Eel-grass pondweed	*Potamogeton zosteriformis*	1	0	1	0.0	0.0
Sanford's arrowhead	*Sagittaria sanfordii*	7	0	31	0.0	0.0
San Joaquin spearscale	*Atriplex joaquiniana*	4	1	64	25.0	1.6

Table 3-4. Number of occurrences of sensitive vegetation species in the Delta, Delta levee slopes, and region.

Common Name	Latin Name	Number of Occurrences			Percent in Delta on Levee Slopes[1]	Percent in Region[2] on Levee Slopes[1]
		Delta	Levee Slopes[1]	Region[2]		
Alkali milk-vetch	*Astragalus tener* var. *tener*	6	1	55	16.7	1.8
Soft bird's-beak	*Cordylanthus mollis* ssp. *Mollis*	17	1	27	5.9	3.7
Caper-fruited tropidocarpum	*Tropidocarpum capparideum*	1	1	13	100.0	7.7
Delta tule pea	*Lathyrus jepsonii* var. *jepsonii*	113	16	128	14.2	12.5
Heckard's pepper grass	*Lepidium latipes* var. *heckardii*	3	1	8	33.3	12.5
Delta mudwort	*Limosella subulata*	38	9	42	23.7	21.4
Mason's lilaeopsis	*Lilaeopsis masonii*	133	45	146	33.8	30.8
Marsh skullcap	*Scutellaria galericulata*	3	1	3	33.3	33.3
Suisun marsh aster	*Aster lentus*	122	47	139	38.5	33.8
rose-mallow	*Hibiscus lasiocarpus*	80	29	82	36.3	35.4
Slough thistle	*Cirsium crassicaule*	2	1	2	50.0	50.0
Blue skullcap	*Scutellaria lateriflora*	2	1	2	50.0	50.0
fox sedge	*Carex vulpinoidea*	1	1	1	100.0	100.0
Wright's trichocoronis	*Trichocoronis wrightii* var. *wrightii*	1	0	N/A	0.0	N/A
	Totals	565	155	1,009	27.4	15.4

[1]An occurrence was determined to be on the levee wall if it was both on the channel-side of the Delta and within 200 feet of the levee centroid.

[2] "Region" includes the following Bay Area and Delta counties: Napa, Marin, Sonoma, Solano, Contra Costa, Alameda, Santa Clara, San Mateo, San Francisco, Yolo, Sacramento, and San Joaquin.

Source: CNDDB 2007

Table 3-5. Listed terrestrial and vernal pool wildlife species that could occur in the Delta and Suisun Marsh.

	Common Name	Latin Name	Federal Status	State Status
MAMMALS	Salt marsh harvest mouse	*Reithrodontomys raviventris*	E	E
	Riparian brush rabbit	*Sylvilagus bachmani riparius*	E	E
BIRDS	American peregrine falcon	*Falco peregrinus anatum*	—	E
	Bald eagle	*Halieeatus leucocephalus*	T	E
	California black rail	*Laterallus jamaicensis coturniculus*	—	T
	California clapper rail	*Rallus longirostris osoletus*	E	E
	California brown pelican	*Pelecanus occidentalis californicus*	E	E
	Greater sandhill crane	*Grus canadensis tabida*	—	T
	Swainson's hawk	*Buteo swainsoni*	—	T
REPTILES	Giant garter snake	*Thamnophis gigas*	T	T
AMPHIBIANS	California tiger salamander	*Ambystoma californiense*	T	—
INVERTEBRATES	Conservancy fairy shrimp	*Branchinecta conservatio*	E	—
	Delta green ground beetle	*Elaphris viridus*	T	—
	Valley elderberry longhorn beetle	*Desmocerus californicus dimorphus*	T	—
	Vernal pool fairy shrimp	*Branchinecta lynchi*	T	—

Federal Status
E = Endangered
T = Threatened

State (California) Status
E = Endangered
T = Threatened

Table 4-1. Selected focal aquatic species to be analyzed in the aquatic ecosystem impact analysis.

Common Name	Latin Name	Listed under California or Federal ESA	DRERIP	Ecosystem Architect	Important Prey Species	Important Predatory Species	Commercially/ Recreationally Important	Geographically Restricted Delta Habitat
Delta smelt	*Hypomesus transpacificus*	√	R	—	—	—	—	√
Longfin smelt	*Spirinchus thaleichthys*	a	R	—	√	—	—	—
Chinook salmon (all species)	*Oncorhynchus tschawystcha*	√	R	—	√	—	√	—
Steelhead	*Oncorhynchus mykiss*	√	R	—	—	—	√	—
Green sturgeon	*Acipenser medirostris*	√	R	—	—	—	—	—
Threadfin shad	*Dorosome petenense*	—	—	√	√	—	—	—
Striped bass	*Morone saxitilis*	—	H	√	—	√	√	—
Sacramento splittail	*Pogonichthys macrolepidotus*	—	R	—	—	—	—	—
Inland silverside	*Menidia beryllina*	—	—	√	√	√	—	—

[a] At the time of this writing, longfin smelt in the San Francisco Estuary were designated as a candidate for listing under both the federal and state ESAs. Under the state ESA, candidate species receive full protection. Under the federal ESA, candidate species receive no special legal protection until formally listed as threatened or endangered.

ESA = Endangered Species Act

DRERIP = Delta Regional Ecosystem Restoration Implementation Plan
H = Harvestable
R = Recovery

Table 4-2. Fish species with special legal status found in the Delta or Suisun Marsh.

Common Name	**Latin Name**	**Federal Status**	**State Status**
Green sturgeon	*Acipenser medirostris*	FT	CSC
Sacramento splittail	*Pogonichthys macrolepidotus*	FSC	CSC
Sacramento perch	*Archoplites interruptus*	—	CSC
Delta smelt	*Hypomesus transpacificus*	FT	ST
Longfin smelt	*Spirinchus thaleichthys*	FSC	State Candidate
Fall-run Chinook salmon	*Oncorhynchus tschawystcha*	Federal Candidate	CSC
Spring-run Chinook salmon	*Oncorhynchus tschawystcha*	FT	ST
Winter-run Chinook salmon	*Oncorhynchus tschawystcha*	FE	SE
Central Valley steelhead	*Oncorhynchus mykiss*	FT	CSC
River lamprey	*Lampetra ayresii*	FSC	CSC
Pacific lamprey	*Lampetra tridentata*	FSC	—

Federal Status (U.S. Fish and Wildlife Service and National Marine Fisheries Service)
FE = Listed as Endangered
FSC = Federal Species of Special Concern
FT = Listed as Threatened

State Status (California Department of Fish and Game)
CSC = California Species of Special Concern
SE = State-listed as Endangered
ST = State-listed as Threatened

Table 4-3a. Species selected as focal species for the vegetation categories for the ecosystem impact model. Impact on a vegetation category was defined from existing data on phenology and tolerance of the focal species. The species were selected as focal because of their dominant presence in the Delta and because their characteristics typify their vegetation category.

Vegetation Type	Common Name	Latin Name	Synonym(s)	Description	Native/ non-native
A	Brazilian waterweed	*Egeria densa*	—	perennial herb	non-native
A	Water hyacinth	*Eichornia crassipes*	—	creeping aquatic	non-native
A	Floating primrose-willow	*Ludwigia peploides*	—	perennial herb	native and non-native subspecies
A	Sago pondweed	*Potamogeton pectinatus*	*Stuckenia pectinata (L.) Böerner*	perennial herb (aquatic)	native
HU	Beardless wildrye	*Leymus triticoides*	—	perennial herb (grass)	native
HU,r	Wild oat	*Avena fatua*	—	annual herb (grass)	non-native
HU,r	Soft brome	*Bromus hordeaceus*	—	annual herb (grass)	non-native
HU,r	Italian rye	*Lolium multiflorum* var. *multiflorum*	—	annual, biennial herb (grass)	non-native
HU,r	Mouse barley	*Hordeum murinum*	—	annual herb (grass)	non-native
HW,p	American tule	*Scirpus americanus*	*Schoenoplectus pungens (Vahl) Palla* var. *badius (J.& K. Presl) S.G. Sm.*	perennial herb (rush)	native
HW,p	Water knotweed	*Polygonum amphibium*	—	perennial herb	native
HW,p	Broadleaf cattail	*Typha latifolia*	—	perennial herb (aquatic)	native
HW,s	Baltic rush	*Juncus balticus*	—	perennial herb (rush)	native
HW,s	Common rush	*Juncus effusus*	—	perennial herb (rush)	native
HW,s,r	Broadleaved pepperweed	*Lepidium latifolium*	—	perennial herb	non-native
HW,s,r	Perennial ryegrass	*Lolium multiflorum* var. *perenne*	—	perennial herb (grass)	non-native
HW,s,r	Poison hemlock	*Conium maculatum*	—	perennial herb	non-native
HW,s,r	Swamp pricklegrass	*Crypsis schoenoides*	—	annual herb	non-native

Table 4-3a. Species selected as focal species for the vegetation categories for the ecosystem impact model. Impact on a vegetation category was defined from existing data on phenology and tolerance of the focal species. The species were selected as focal because of their dominant presence in the Delta and because their characteristics typify their vegetation category.

Vegetation Type	Common Name	Latin Name	Synonym(s)	Description	Native/ non-native
MH	Thinleaf orach, fat-hen	*Atriplex triangularis*	*Atriplex hastata sensu Aellen, non L. ATLA3 Atriplex latifolia Wahlenb. ATPAH3 Atriplex patula L.* ssp. *hastata sensu Hall & Clements 1923, non (L.) Hall & Clements ATPAH2 Atriplex patula L.* var. *hastata auct. non (L.) Gray [misapplied] ATPAT A*	annual herb	native
MH	Saltgrass	*Distichlis spicata*	—	perennial herb (grass)	native
MH	Alkali heath	*Frankenia salina*	—	perennial herb	native
MH	Oregon gumweed	*Grindelia stricta*	—	perennial herb	native
ML	common tule	*Scirpus acutus*	*Schoenoplectus acutus (Muhl. ex Bigelow) A.& D. Löve* var. *acutus*	perennial herb (rush)	native
ML	California bulrush	*Scirpus californicus*	*Schoenoplectus californicus (C.A. Mey.) Palla*	perennial herb (rush)	native
ML	prairie bulrush	*Scirpus maritimus*	*Schoenoplectus maritimus (L.) Lye*	perennial herb (rush)	native
ML	Narrowleaf cattail	*Typha angustifolia*	—	perennial herb (aquatic)	native
MM	Common reed	*Phragmites australis*	—	perennial herb (reed grass)	native
MM	Pickleweed	*Salicornia virginica*	*Salicornia depressa (IT IS Standard report); Salicornia pacifica (FWS/OBS-83/23, 1983)*	perennial herb	native
SU	Coyotebrush	*Baccharis pilularis*	—	shrub	native
SU	California wild rose	*Rosa californica*	—	shrub	native

Table 4-3a. Species selected as focal species for the vegetation categories for the ecosystem impact model. Impact on a vegetation category was defined from existing data on phenology and tolerance of the focal species. The species were selected as focal because of their dominant presence in the Delta and because their characteristics typify their vegetation category.

Vegetation Type	Common Name	Latin Name	Synonym(s)	Description	Native/ non-native
SU	Common elderberry	*Sambucus mexicana*	*Sambucus nigra L. ssp. canadensis (L.) R. Bolli; Sambucus nigra L.* ssp. *caerulea (Raf.) R. Bolli*	tree, shrub	native
SW,r	Himalayan blackberry	*Rubus discolor*	*Rubus armeniacus Focke*	shrub	non-native
SW	Narrowleaf willow	*Salix exigua*	—	tree, shrub	native
SW	Red willow, Polished Willow	*Salix laevigata*	—	tree	native
SW	Arroyo willow	*Salix lasiolepis*	—	tree, shrub	native
TR	White alder	*Alnus rhombifolia*	—	tree	native
TR	Oregon ash	*Fraxinus latifolia*	—	tree	native
TU	California live oak	*Quercus agrifolia*	—	tree	native
TU	Valley Oak	*Quercus lobata*	—	tree	native and endemic
TU,nn	Tree of Heaven	*Ailanthus altissima*	—	tree	non-native
TU,nn	Blue gum	*Eucalyptus globulus*	—	tree	non-native

Vegetation Types

A = aquatic
HU = herbaceous upland
HW = herbaceous wetland
MH = alkali marsh, high
ML = alkali marsh, low
MM = alkali marsh, mid
nn = non-native
p = perennial
r = ruderal
s = seasonal
SU = shrub upland
SW = shrub wetland
TR = transitional riparian
TU = transitional upland

Table 4-3b. Special-status plant species examined in the ecosystem impact model. An impact occurred to a special-status species if the location of a special-status species described in the California Natural Diversity Database (CNDDB) database was altered (e.g., flooded) due to a sequence.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Native/ non-native
Suisun Marsh aster	*Aster lentus*	*Symphyotrichum lentum (Greene) Nesom ; A. chilensis Nees vars. l. (Greene) Jeps. and sonomensis (Greene) Jeps*	perennial herb (composite)	—	—	1B.2	native and endemic
Ferris's milk vetch	*Astragalus tener* var. *ferrisiae*	—	annual herb	—	—	1B.1	native and endemic
Alkali milkvetch	*Astragalus tener* var. *tener*	—	annual herb (legume)	—	—	1B.2	native and endemic
heartscale	*Atriplex cordulata*	*Atriplex cordulata* ssp. *cordulata*	annual herb	—	—	1B.2	native and endemic
brittlescale	*Atriplex depressa*	*Atriplex parishii* var. *depressa*	annual herb	—	—	1B.2	native and endemic
San Joaquin spearscale	*Atriplex joaquiniana*	*Atriplex patula* ssp. *spicata*	annual herb	—	—	1B.2	native and endemic
Bristly sage; Longhair sedge	*Carex comosa*	—	perennial herb (rhizomatous), sedge	—	—	2.1	native
fox sedge	*Carex vulpinoidea*	*Carex vulpinoidea* var. *vulpinoidea*	perennial sedge (herb)	—	—	2.2	native
Congdon's tarplant	*Centromadia parryi* ssp. *congdonii*	*Hemizonia parryi* ssp. *congdonii*	annual herb	—	—	1B.2	native
pappose tarplant	*Centromadia parryi* ssp. *parryi*	*Hemizonia parryi* ssp. *parryi; Hemizonia parryi*	annual herb	—	—	1B.2	native
slough thistle	*Cirsium crassicaule*	—	annual, perennial herb	—	—	1B.1	native and endemic
Suisun thistle	*Cirsium hydrophilum var. hydrophilum*	*Cirsium vaseyi* var. *hydrophilum*	perennial herb	E	—	1B.1	native and endemic

Table 4-3b. Special-status plant species examined in the ecosystem impact model. An impact occurred to a special-status species if the location of a special-status species described in the California Natural Diversity Database (CNDDB) database was altered (e.g., flooded) due to a sequence.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Native/ non-native
Soft bird's-beak	*Cordylanthus mollis* ssp. *mollis*	—	annual herb (hemiparasitic)	E	R	1B.2	native and endemic
Recurved larkspur	*Delphinium recurvatum*	—	perennial herb	—	—	1B.2	native and endemic
dwarf downingia	*Downingia pusilla*	*Downingia humilis; Bilelia humilis*	annual herb	—	—	2.2	native
Mt. Diablo buckwheat	*Eriogonum truncatum*	—	annual herb	—	—	1B.1	native
Delta coyote thistle (Delta button-celery)	*Eryngium racemosum*	—	annual, perennial herb	—	E	1B.1	native and endemic
Contra Costa Wallflower	*Erysimum capitatum* ssp. *angustatum*	—	perennial herb	E	E	1B.1	native and endemic
Boggs Lake hedge-hyssop	*Gratiola heterosepala*	—	annual herb	—	E	1B.2	native
rose-mallow	*Hibiscus lasiocarpus*	*Hibiscus californicus; Hibiscus moscheutos* ssp. *lasiocarpus, Hibiscus moscheutos* var. *occidentalis, Hibiscus moscheutos* ssp. *lasiocarpos, Hibiscus moscheutos*	perennial herb (rhizomatous)	—	—	2.2	native
Northern California black walnut	*Juglans californica* var. *hindsii*	—	tree	—	—	1B.1	native and endemic
Contra Costa Goldfields	*Lasthenia conjugens*	—	annual herb	E	—	1B	native and endemic
Delta tule pea	*Lathyrus jepsonii* var. *jepsonii*	—	perennial herb (legume)	—	—	1B.2	native and endemic
legenere	*Legenere limosa*	*Howellia limosa*	annual herb	—	—	1B.1	native and endemic

Table 4-3b. Special-status plant species examined in the ecosystem impact model. An impact occurred to a special-status species if the location of a special-status species described in the California Natural Diversity Database (CNDDB) database was altered (e.g., flooded) due to a sequence.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Native/ non-native
Heckard's pepper grass	*Lepidium latipes* var. *heckardii*	*Lepidium latipes*	annual herb	—	—	1B.2	native and endemic
Mason's lilaeopsis	*Lilaeopsis masonii*	—	perennial herb	—	R	1B.1	native and endemic
Delta mudwort	*Limosella subulata*	—	perennial herb	—	—	2.1	non-native
Baker's navarretia	*Navarretia leucocephala* ssp. *bakeri*	*Navarretia bakeri*	annual herb	—	—	1B.1	native and endemic
Colusa grass	*Neostapfia colusana*	—	annual grass	T	E	1B.1	native
Antioch Dunes evening primrose	*Oenothera deltoides* ssp. *howellii*	—	perennial herb	E	E	1B.1	native and endemic
bearded popcorn-flower	*Plagiobothrys hystriculus*	*Allocarya hystricula*	annual herb	—	—	1B.1	native
Eel-grass pondweed	*Potamogeton zosteriformis*	—	annual herb (aquatic)	—	—	2.2	native
Sanford's arrowhead	*Sagittaria sanfordii*	—	perennial herb (rhizomatous)	—	—	1B.2	native and endemic
marsh skullcap	*Scutellaria galericulata*	*Scutellaria epilobifolia; Scutellaria galericulata* ssp. *pubescens; Scutellaria galericulata* var. *epilobifolia, Scutellaria galericulata* var. *pubescens*	perennial herb (rhizomatous)	—	—	2.2	native
blue skullcap	*Scutellaria lateriflora*	*Scutellaria lateriflora* var. *lateriflora*	perennial herb (rhizomatous)	—	—	2.2	native

Table 4-3b. Special-status plant species examined in the ecosystem impact model. An impact occurred to a special-status species if the location of a special-status species described in the California Natural Diversity Database (CNDDB) database was altered (e.g., flooded) due to a sequence.

Common Name	Latin Name	Synonym(s)	Description	Federal Status	State Status	CNPS Status	Native/ non-native
Wright's trichocoronis	*Trichocoronis wrightii* var. *wrightii*	—	annual herb	—	—	2.1	non-native
caper-fruited tropidocarpum	*Tropidocarpum capparideum*	—	annual herb	—	—	1B.1	native
Crampton's tuctoria	*Tuctoria mucronata*	—	annual herb (grass)	E	E	1B.1	native and endemic

Federal Status
E = Endangered
T – Threatened

State (California) Status
E = Endangered
R = Rare

California Native Plant Society (CNPS) Status
1B.1 = Rare, threatened, or endangered in California and elsewhere; seriously endangered in California
1B.2 = Rare, threatened, or endangered in California and elsewhere; fairly endangered in California
2.1 = Rare, threatened or endangered in California, but more common elsewhere; seriously threatened in California
2.2 = Rare, threatened, or endangered in California, but more common elsewhere; fairly threatened in California

Table 4-4. Application of the selection criteria to wildlife species/species groups.

Species/Species Group	Meets Criterion 1	Meets Criterion 2	Meets Criterion 3	Selected for Analysis
MSCS "R" Species				
Suisun ornate shrew	Yes	Yes	Yes	Yes
Valley elderberry longhorn beetle	Yes	Yes	Yes	Yes
Lange's metalmark	Yes	No	—	No
MSCS "r" Species				
Salt marsh harvest mouse	Yes	Yes	Yes	Yes
Bank swallow	Yes	No	—	No
California clapper rail	Yes	Yes	Yes	Yes
California black rail	Yes	Yes	Yes	Yes
California yellow warbler	Yes	No	—	No
Saltmarsh common yellowthroat	Yes	Yes	Yes	Yes
Greater sandhill crane	Yes	Yes	Yes	Yes
Least Bell's vireo	Yes	No	—	No
Little willow flycatcher	Yes	No	—	No
Swainson's hawk (foraging habitat)	Yes	Yes	Yes	Yes
Western yellow-billed cuckoo	Yes	No	—	No
Delta green ground beetle	Yes	No	—	No
Riparian brush rabbit	Yes	No	Yes	No
Giant garter snake	Yes	Yes	No	No
ERP Species Assemblage				
Geese, swans, and dabbling ducks	Yes	Yes	Yes	Yes
Diving ducks	Yes	No	—	No
Shorebirds	Yes	Yes	Yes	Yes
Wading birds	Yes	Yes	Yes	Yes
Neotropical migratory bird	Yes	Yes	Yes	Yes

ERP = Ecosystem Restoration Program
MSCS = CalFed Bay-Delta Program (CALFED) Multi-Species Conservation Strategy
MSCS "R" = MSCS species goal of recover species
MSCS "r" = MSCS species goal of contribute to recovery of species

Table 6-1. Relative time frames for three impacts of levee failure on the Delta's aquatic ecosystem.

No.	Period	Time Frame			Description
		Start	**End**	**Duration**	
1	Immediate impact due to entrainment on flooded islands	Levee breach	Slightly before or when islands complete flooding (or when suspended sediment concentrations on flooding islands drop below species-specific tolerances)	Days to weeks	When a levee breaches, flows will enter an island while eroding the levee embankment and scouring the levee foundation as well as a section of the island. As water rushes onto the island, sediments from the breach and scoured foundation are suspended in the flood waters, as are surface sediments as the flood waves passes. Mortality of fish due to entrainment will occur during the period when suspended sediment conditions on islands exceed their species-specific tolerances.
2	Intermediate–long term	When salt-field re-establishes seasonal equilibrium and, for islands, when island is not eutrophic	For islands – when islands become eutrophic, breaches are closed, or the island becomes dominated by invasive plants and invertebrates. For pre-existing aquatic habitats – when all levee breaches are restored	Months to years	Flooded islands represent new aquatic habitats in the Delta. As islands stabilize geomorphically, ambient water quality conditions will determine their suitability for different fish species.
3	Export pumping disruption	Levee breach	When water quality returns to acceptable levels and pumping resumes	Days to years	During an event, the export pumps may be shutdown for a considerable period of time due to the salinity intrusion that has taken place. The pumps may be shut down for extended periods, restarted and shutdown again during different times of the year. When the pumps are shutdown, there is a benefit to fish since they will not be entrained and potentially killed which would be the case during normal operations.

Table 6-2. Physical dimensions of the Delta islands.

Island/Tract	Perimeter (ft)	Area (sq ft)	Acres	Elevation Data (ft)					Water Area (sq ft) NGVD + 0	Volume (Acre-ft) NGVD + 0
				MIN	MAX	RANGE	MEAN	STD		
Bacon Island	75,820	245,344,518	5,632	–22.46	49.79	72.25	–11.66	4.64	235,800,000	70,756
Bethel Island	61,030	154,149,405	3,539	–21.86	51.9	73.77	–2.36	5.62	121,600,000	14,953
Bishop Island	64,011	174,958,851	4,017	–18.14	139.39	157.53	2.9	6.89	81,160,000	6,246
Bouldin Island	94,389	264,407,232	6,070	–25.35	42.91	68.26	–13.13	4.77	253,400,000	85,291
Bradford Island	39,578	95,980,326	2,203	–26.74	47.07	73.81	–5.67	7.27	79,200,000	16,596
Brannan-Andrus Island	230,336	677,651,208	15,557	–27.25	94.4	121.66	–8.1	11.15	556,120,000	165,409
Byron Island	357,586	672,315,602	15,434	–16.43	368.46	384.9	24.96	37.97	168,880,000	23,821
Holland Island	58,397	186,764,230	4,288	–20.57	64.12	84.7	–6.69	5.21	172,920,000	33,709
Jersey Island	84,050	156,318,819	3,589	–38.18	194.54	232.72	–6.28	6.42	140,480,000	27,463
Jones Tract	98,295	537,746,037	12,345	–20.19	65.17	85.36	–7.62	4.25	514,680,000	105,265
Mandeville Island	121,380	226,571,990	5,201	–24.86	39.16	64.02	–13.47	5.9	216,360,000	75,041
McDonald Island	73,889	269,957,043	6,197	–36.49	55.03	91.52	–12.95	5.73	257,960,000	86,360
Palm Tract	55,317	113,560,705	2,607	–17.32	52.99	70.31	–7.43	5.2	105,360,000	22,238
Orowood Tract	44,911	102,792,931	2,360	–22.78	74.11	96.89	–5.62	6	87,560,000	16,237
Quimby Island	37,461	35,480,014	815	–22.95	34.94	57.89	–7.64	5.8	31,280,000	7,343
Sherman Island	135,185	457,369,861	10,500	–37.31	366.37	403.69	–8.42	6.92	409,840,000	102,582
Twitchell Island	63,558	161,224,814	3,701	–26.63	47.16	73.79	–10.21	6.72	148,200,000	42,140
Venice Island	78,256	142,373,903	3,268	–23.65	44.76	68.42	–13.86	7.4	128,560,000	49,248
Victoria Island	79,695	316,937,383	7,276	–34.83	102.09	136.92	–7.2	3.54	306,960,000	59,028
Webb Tract	82,435	237,997,347	5,464	–34.46	37.77	72.23	–12.22	6.18	225,800,000	72,447
Woodward Island	47,227	81,462,947	1,870	–19.26	35.31	54.57	–8.85	4.87	75,440,000	18,429

NGVD = National Geodetic Vertical Datum
Source: URS/DWR 2006

Table 6-3. Simulated arrivals to and departures from the Delta of percentages of the Chinook salmon smolts population.

	Julian Day	% Dep/Day	Cum Dep %	% Arrival on Day, calculated from % Departures by Day & MRT																				% Arr/Day	Cum Arr %	Net % in Delta	% at Risk
				102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	121				
0.00	102	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03	0.03	0.03	0.98
0.00	103	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.30	0.33	0.33	2.33
0.00	104	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.65	0.98	0.98	4.43
0.00	105	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1.35	2.33	2.33	8.58
0.00	106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.10	4.43	4.43	15.00
0.00	107	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.15	8.58	8.58	23.20
0.00	108	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.43	15.00	15.00	34.75
0.00	109	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8.20	23.20	23.20	50.25
0.00	110	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11.55	34.75	34.75	65.65
0.00	111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15.50	50.25	50.25	78.65
0.00	112	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15.40	65.65	65.65	87.95
0.00	113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13.00	78.65	78.65	93.60
1.00	114	1	1	0.03	0.15	0.20	0.40	0.15	0.05	0.03	0	0	0	0	0	0	0	0	0	0	0	0	0	9.30	87.95	86.95	96.00
2.00	115	2	3	0	0.15	0.25	0.35	0.60	0.35	0.25	0.05	0	0	0	0	0	0	0	0	0	0	0	0	5.65	93.60	90.60	95.80
3.00	116	3	6	0	0	0.20	0.35	0.60	1.25	0.40	0.15	0.05	0	0	0	0	0	0	0	0	0	0	0	3.40	97.00	91.00	93.70
6.00	117	6	12	0	0	0	0.25	0.50	1.00	2.50	1.25	0.25	0.25	0	0	0	0	0	0	0	0	0	0	1.80	98.80	86.80	87.95
10.00	118	10	22	0	0	0	0	0.25	1.00	1.25	3.00	2.25	1.75	0.50	0	0	0	0	0	0	0	0	0	0.90	99.70	77.70	78.00
15.00	119	15	37	0	0	0	0	0	0.50	1.50	2.00	4.50	3.25	1.75	1.50	0	0	0	0	0	0	0	0	0.25	99.95	62.95	63.00
18.00	120	18	55	0	0	0	0	0	0	0.50	1.50	3.00	6.00	4.00	2.50	0.50	0	0	0	0	0	0	0	0.05	100.00	45.00	45.00
14.00	121	14	69	0	0	0	0	0	0	0	0.25	1.25	3.25	5.00	2.75	1.25	0.25	0	0	0	0	0	0	0.00	100.00	31.00	31.00
12.00	122	12	81	0	0	0	0	0	0	0	0	0.25	0.75	2.75	3.75	3.25	1.00	0.25	0	0	0	0	0	0.00	100.00	19.00	19.00
9.00	123	9	90	0	0	0	0	0	0	0	0	0	0.25	1.25	2.00	3.25	1.25	0.75	0.25	0	0	0	0	0.00	100.00	10.00	10.00
6.00	124	6	96	0	0	0	0	0	0	0	0	0	0	0.15	0.35	0.75	2.75	1.25	0.50	0.25	0	0	0	0.00	100.00	4.00	4.00
3.00	125	3	99	0	0	0	0	0	0	0	0	0	0	0	0.15	0.25	0.30	1.00	0.75	0.40	0.15	0	0	0.00	100.00	1.00	1.00
1.00	126	1	100	0	0	0	0	0	0	0	0	0	0	0	0	0.05	0.10	0.15	0.30	0.25	0.10	0.05	0	0.00	100.00	0.00	0.00
0.00	127	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	100.00	0.00	0.00
0.00	128	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	100.00	0.00	0.00
0.00	129	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00	100.00	0.00	0.00
	MRT = 9 Days, +/- 3 days.			0.03	0.30	0.65	1.35	2.10	4.15	6.43	8.20	11.55	15.50	15.40	13.00	9.30	5.65	3.40	1.80	0.90	0.25	0.05	0.00				

At Risk = Net % in Delta + Arrivals over next 2 days.

Table 6-4. Historical Delta levee breach widths and years of occurrence.

Island/Tract	Width of Breach (ft)	Year
Bouldin Island	355	1909
Bradford Island	450	1983
Empire Tract	860	1955
Franks Tract	520	1936
Franks Tract	390	1938
Holland Island	250	1980
Lower Jones Tract	275	1980
Little Franks Tract, wl	40	1981
Little Franks Tract, wr	60	1982
Little Franks Tract, s	174	1983
Little Mandeville Island	263	1986/1994
Mandeville Island	930	1938
McCormack-Williamson Tract	871	1997
Mildred Island	473	1983
Mildred Island	330	1969
New Hope Island	170	1986
Quimby Island	260	1955
Sherman Island	260	1969
Sherman Island	1150	1904
Staten Island	311	1907
Tylor Island	300	1986
Upper Jones Tract	432	2004
Venice Island	500	1982
Webb Tract	690	1950
Webb Tract	825	1980
Mean	446	
Standard deviation	288	
Mean + 1 std. dev.	723	
Mean – 1 std. dev.	157	

wl = west left
wr = west right
s = south

Table 6-5. Sample calculations of initial concentration of suspended sediment of various particle sizes on flooding islands.

Particle Type	Diameter Range (mm)	Average Diameter (mm)	Percent by Weight	Initial (max) Concentration, Co (mg/lt)
Medium sand	0.6 – 0.2	0.4	15	9,883
Fine sand	0.2 – 0.075	0.1	20	8,433
Coarse silt	0.075 – 0.008	0.02	20	1,054
Fine silt	0.008 – 0.002	0.004	25	1,318
Coarse clay	0.002 – 0.0006	0.001	10	527
Fine clay	0.0006 – 0.0002	0.0004	10	527
		Totals	100	21,692

Table 6-6. Particle sizes of medium and fine sand, coarse and fine silt, and coarse and fine clay.

Particle Type	Range (mm)	Value for Calculations (mm)
Medium sand	0.6 – 0.2	0.4
Fine sand	0.2 – 0.075	0.1
Coarse silt	0.075 – 0.008	0.02
Fine silt	0.008 – 0.002	0.004
Coarse clay	0.002 – 0.0006	0.001
Fine clay	0.0006 – 0.0002	0.0004

Source: ASTM D 2487

Table 6-7. Settling velocities of medium and fine sand, coarse and fine silt, and coarse and fine clay.

Particle size, velocity, and time	Medium Sand	Fine Sand	Coarse Silt	Fine Silt	Coarse Clay	Fine Clay
Particle size (mm)	0.4	0.1	0.02	0.004	0.001	0.0004
Velocity (cm/s)	14.5	0.9	3.64×10^{-2}	1.45×10^{-3}	9.09×10^{-5}	1.45×10^{-5}
Settling time (hr)	0.01	0.21	5.35	133.9	2,141.8	13,386

Table 6-8. Mortality and behavioral changes of salmonids associated with elevated suspended sediment conditions.

Common Name (Latin Name)	Life Stage	Percent Mortality or Behavior Changes	Concentration (mg/l)	Time Period (hours)	Substrate Type/Median Particle Size	Reference
Chinook salmon (*O. tshawytscha*)	Juvenile	Reaction distance to planktonic prey decreases logarithmically/linearly to increased turbidity	N/A	N/A	—	Gregory and Northcote (1993)
		Increased turbidity decreases bird and fish avoidance response	N/A	N/A	—	Gregory (1993)
		50%	1400	36	Probably volcanic ash/ 15 µm (reference unclear)	Newcomb and Flagg (1983)
		50%	9400	36	Probably volcanic ash/ 15 µm (reference unclear)	Newcomb and Flagg (1983)
		90%	39,400	36	Volcanic ash	Newcomb and Flagg (1983)
	Smolts	Tolerance to stress reduced	943	72	Volcanic ash	Stober et al. (1981)
	Adult	0%	39,300	24	Volcanic ash /15 µm	Newcomb and Flagg (1983)
		60%	82,400	6	Volcanic ash /15 µm	Newcomb and Flagg (1983)
		100%	207,000	1	Volcanic ash /15 µm	Newcomb and Flagg 1983
Steelhead (*O. mykiss*)	Juvenile	Reduced growth rate	102	336	Fire clay, bentonite clay	Sigler et al. (1984)
	Adult	Sub-lethal stress, blood cell count and chemistry change	500	3	Volcanic ash	Redding and Shreck (1982)
"Rainbow trout" (*O. mykiss)*	Adult	Mortality (percent unknown)	200	24	Wood fiber	Herbert and Richards (1963)
		50%	49,838	96	Drilling mud	Lawrence and Sherer (1974)
	Juvenile	100%	4315	57	180 to 740 µm	Newcombe et al. (1995)

Table 6-9a. Number of Delta smelt individuals salvaged at the State Water Project (SWP) export facility by month from 1995 to 2005.

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1995	1937	457	4	0	0	0	0	0	0	0	0	0
1996	3109	846	131	9	19,361	8445	76	0	0	0	0	6
1997	0	32	146	139	16,760	6140	216	0	0	0	0	257
1998	118	0	8	0	4	30	100	0	0	0	0	16
1999	4	110	124	176	38,258	49,332	19498	36	0	0	0	66
2000	238	5491	1690	282	35,721	40,352	1249	6	26	27	70	36
2001	25	1662	2740	244	6756	1005	6	0	0	0	0	781
2002	3983	112	141	0	35,637	7942	0	0	0	0	0	2008
2003	7413	951	15	0	4819	8044	0	0	0	0	0	6
2004	3405	681	1415	0	2407	5768	18	0	0	0	0	0
2005	1107	263	0	0	467	1085	0	0	0	0	0	0
Average	1940	964	583	77	14,563	11,649	1924	4	2	2	6	289

Source: CDFG 2006 unpublished data

Table 6-9b. Number of Delta smelt individuals salvaged at the Central Valley Project (CVP) export facility by months from 1995 to 2005.

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1995	120	24	12	24	0	0	0	0	0	0	0	0
1996	1080	444	24	102	11,038	996	72	0	0	0	12	12
1997	0	48	1584	1020	16,068	1,736	12	0	0	0	0	24
1998	12	24	584	48	0	36	24	0	0	0	0	0
1999	24	1356	440	234	20,671	24,036	324	12	0	0	24	60
2000	564	2328	1056	1464	13,680	8772	264	0	0	0	240	156
2001	156	2208	1008	276	6378	1320	0	0	0	0	0	348
2002	1248	168	84	372	11,724	3984	24	0	0	0	0	792
2003	2136	540	468	492	11,358	1536	12	0	0	0	0	120
2004	1189	480	852	276	3,348	624	0	0	0	0	0	0
2005	540	108	0	0	74	108	0	0	0	0	0	0
Average	643	703	556	392	8,576	3923	67	1	0	0	25	137

Source: CDFG 2006 unpublished data

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
1016	Lincoln_Village_Tract	1395	1.26	0.70	0.28
1015	Sherman_Island	10,299	9.27	5.15	2.06
1014	McMullin_Ranch-River_Junction Tract	3495	3.15	1.75	0.70
1013	Bishop_Tract	3708	3.34	1.85	0.74
1012	Atlas Tract	318	0.29	0.16	0.06
1010	Byron_Tract 2	810	0.73	0.40	0.16
1009	Mossdale_R_D_NO_2107	1044	0.94	0.52	0.21
1008	Stewart_Tract	3965	3.57	1.98	0.79
1007	Upper Andrus Island	12,690	11.42	6.35	2.54
1006	Brannan-Andrus Island	2356	2.12	1.18	0.47
1005	Elk Grove	11,135	10.02	5.57	2.23
1004	West Sacramento South	6831	6.15	3.42	1.37
1003	Middle_Roberts_Island	25,243	22.72	12.62	5.05
1002	Drexler Tract	3132	2.82	1.57	0.63
1001	Hastings Tract	7185	6.47	3.59	1.44
1000	Netherlands	32,523	29.27	16.26	6.50
218	Discovery_Bay	1156	1.04	0.58	0.23
216	Zone 216	138	0.12	0.07	0.03
212	Clifton Court Forebay Water	2175	1.96	1.09	0.43
210	Ryer Island	11,793	10.61	5.90	2.36
205	Chipps_Island	842	0.76	0.42	0.17
204	SM-204	234	0.21	0.12	0.05
203	Simmons-Wheeler_Island	2222	2.00	1.11	0.44
202	SM-202	869	0.78	0.43	0.17
201	Honker_Bay_Club	827	0.74	0.41	0.17
200	Van_Sickle_Island	2453	2.21	1.23	0.49
199	SM-199	161	0.14	0.08	0.03
198	SM-198	2845	2.56	1.42	0.57

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
197	Zone 197	2346	2.11	1.17	0.47
196	Sacramento_Pocket_Area	27,222	24.50	13.61	5.44
191	Sargent_Barnhart_Tract 2	2101	1.89	1.05	0.42
190	Wright-Elmwood_Tract	2159	1.94	1.08	0.43
187	Shima_Tract	2684	2.42	1.34	0.54
185	Zone 185	586	0.53	0.29	0.12
183	Rio_Blanco_Tract	1500	1.35	0.75	0.30
182	Shin_Kee_Tract	2140	1.93	1.07	0.43
179	Twitchell_Island	3583	3.22	1.79	0.72
177	Bouldin_Island	6042	5.44	3.02	1.21
176	Brack_Tract	5354	4.82	2.68	1.07
175	Canal Ranch	5269	4.74	2.63	1.05
174	Staten_Island	9094	8.18	4.55	1.82
173	Deadhorse Island	210	0.19	0.11	0.04
172	New_Hope_Tract	8132	7.32	4.07	1.63
171	Zone 171	4360	3.92	2.18	0.87
170	Glanville_Tract	7409	6.67	3.70	1.48
169	McCormack_Williamson_Tract	1615	1.45	0.81	0.32
168	Libby_McNeil_Tract 1	397	0.36	0.20	0.08
167	Libby_McNeil_Tract 2	377	0.34	0.19	0.08
166	RD 17 (Mossdale)	9790	8.81	4.90	1.96
165	Walthal_Tract	2827	2.54	1.41	0.57
163	Fabian_Tract	6544	5.89	3.27	1.31
162	Zone 162	529	0.48	0.26	0.11
160	Zone 160	64	0.06	0.03	0.01
159	Boggs_Tract	2161	1.95	1.08	0.43
158	Zone 158	644	0.58	0.32	0.13
157	Smith_Tract	1498	1.35	0.75	0.30

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
156	Sargent_Barnhart_Tract 1	83	0.07	0.04	0.02
153	Rough_and_Ready_Island	1428	1.29	0.71	0.29
152	Medford_Island	1176	1.06	0.59	0.24
150	Venice_Island	3156	2.84	1.58	0.63
149	Pierson_Tract	9256	8.33	4.63	1.85
148	Zone 148	2351	2.12	1.18	0.47
147	Grand Island	16,797	15.12	8.40	3.36
146	Sutter Island	2548	2.29	1.27	0.51
144	Mandeville_Island	5246	4.72	2.62	1.05
143	Rindge_Tract	6852	6.17	3.43	1.37
141	Merritt Island	4774	4.30	2.39	0.95
135	West Sacramento North	6005	5.40	3.00	1.20
134	SM-134	559	0.50	0.28	0.11
133	SM-133	491	0.44	0.25	0.10
132	SM-132	611	0.55	0.31	0.12
131	Schafter-Pintail Tract	1805	1.62	0.90	0.36
129	Veale_Tract 1	1753	1.58	0.88	0.35
127	Byron_Tract 1	5327	4.79	2.66	1.07
126	Pico_Naglee_Tract	6600	5.94	3.30	1.32
124	SM-124	3000	2.70	1.50	0.60
123	SM-123	3114	2.80	1.56	0.62
121	Kassou_District	1179	1.06	0.59	0.24
120	Zone 120	4463	4.02	2.23	0.89
119	Paradise Junction	3529	3.18	1.76	0.71
118	Pescadero	7563	6.81	3.78	1.51
117	Union_Island 1	23,774	21.40	11.89	4.75
115	Upper_Roberts_Island	7511	6.76	3.76	1.50
114	Stark_Tract	710	0.64	0.36	0.14

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
113	Union_Island 3	758	0.68	0.38	0.15
112	Union_Island 2	160	0.14	0.08	0.03
109	Hotchkiss_Tract 2	233	0.21	0.12	0.05
108	Hotchkiss_Tract 1	2857	2.57	1.43	0.57
89	Cache_Haas_Tract 2	1622	1.46	0.81	0.32
88	Cache_Haas_Tract 1	8582	7.72	4.29	1.72
87	Terminous_Tract 2	10,387	9.35	5.19	2.08
86	Terminous_Tract 1	2083	1.88	1.04	0.42
85	SM-85-Grizzly_Island	4293	3.86	2.15	0.86
84	SM-84	7410	6.67	3.71	1.48
82	Zone 82	966	0.87	0.48	0.19
80	Zone 80	1797	1.62	0.90	0.36
79	Zone 79	2050	1.85	1.03	0.41
78	Zone 78	2926	2.63	1.46	0.59
77	Zone 77	381	0.34	0.19	0.08
75	Zone 75	2750	2.48	1.38	0.55
72	Peter Pocket	1382	1.24	0.69	0.28
70	Egbert_Tract	5907	5.32	2.95	1.18
69	Zone 69	438	0.39	0.22	0.09
68	Little_Egbert_Tract	3248	2.92	1.62	0.65
63	Tyler_Island 2	8987	8.09	4.49	1.80
62	Walnut_Grove	481	0.43	0.24	0.10
60	SM-60	1316	1.18	0.66	0.26
59	SM-59	1922	1.73	0.96	0.38
58	SM-58	390	0.35	0.20	0.08
57	SM-57	1867	1.68	0.93	0.37
56	SM-56	3391	3.05	1.70	0.68
55	SM-55	1737	1.56	0.87	0.35

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
54	SM-54	3851	3.47	1.93	0.77
51	SM-51	580	0.52	0.29	0.12
50	SM-50	2358	2.12	1.18	0.47
49	SM-49	1787	1.61	0.89	0.36
48	SM-48	2063	1.86	1.03	0.41
47	SM-47	565	0.51	0.28	0.11
46	SM-46	449	0.40	0.22	0.09
45	SM-45	298	0.27	0.15	0.06
44	SM-44	630	0.57	0.31	0.13
43	SM-43	730	0.66	0.37	0.15
42	SM-42	71	0.06	0.04	0.01
41	SM-41	184	0.17	0.09	0.04
40	SM-40	856	0.77	0.43	0.17
39	SM-39	910	0.82	0.46	0.18
33	Zone 33	35	0.03	0.02	0.01
32	Coney_Island	976	0.88	0.49	0.20
21	Victoria_Island	7213	6.49	3.61	1.44
20	Orwood_Tract	2425	2.18	1.21	0.48
19	Woodward_Island	1870	1.68	0.93	0.37
17	Jones_Tract-Upper_and_Lower	12,205	10.98	6.10	2.44
16	Palm_Tract	2520	2.27	1.26	0.50
15	Bacon_Island	5586	5.03	2.79	1.12
14	Zone 14	258	0.23	0.13	0.05
13	Holland_Tract	4286	3.86	2.14	0.86
12	McDonald_Tract	6173	5.56	3.09	1.23
11	Quimby_Island	783	0.70	0.39	0.16
10	Bethel_Island	3460	3.11	1.73	0.69
9	Jersey_Island	3499	3.15	1.75	0.70

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
7	King_Island	3252	2.93	1.63	0.65
6	Bradford_Island	2153	1.94	1.08	0.43
5	Empire_Tract	3677	3.31	1.84	0.74
4	Webb_Tract	5519	4.97	2.76	1.10
2	SM-2	393	0.35	0.20	0.08
1	SM-1	486	0.44	0.24	0.10
0	Water Body	157	0.14	0.08	0.03
0	Water Zone 3	6063	5.46	3.03	1.21
0	Water Zone 4	8626	7.76	4.31	1.73
0	Water Zone 5	8921	8.03	4.46	1.78
0	Water Zone 1	30,296	27.27	15.15	6.06
0	Water Zone 2	51,206	46.09	25.60	10.24
-1	Decker_Island	625	0.56	0.31	0.13
-1	Fay Island	94	0.08	0.05	0.02
-1	Zone 36	210	0.19	0.10	0.04
-1	Zone 37	234	0.21	0.12	0.05
-1	Zone 38	611	0.55	0.31	0.12
-1	SM-52	1356	1.22	0.68	0.27
-1	SM-53	299	0.27	0.15	0.06
-1	Zone 65	51	0.05	0.03	0.01
-1	Hastings_Tract 1	152	0.14	0.08	0.03
-1	Zone 90	1724	1.55	0.86	0.34
-1	Browns_Island	694	0.62	0.35	0.14
-1	Bixler_Tract	223	0.20	0.11	0.04
-1	Veale_Tract 2	75	0.07	0.04	0.02
-1	Liberte Island	4566	4.11	2.28	0.91
-1	Yolo_Bypass	37,647	33.88	18.82	7.53
-1	Zone 206	3099	2.79	1.55	0.62

Table 6-10. Results of a simple calculation of the residence time for Delta islands included in the ecosystem impact model with different lengths of breaches (100 feet, 200 feet, and 400 feet), assuming that flow into the breach is not restricted by channel size of neighboring channels for a single tidal range.

URS ID Phase 1a	URS Name Phase 1a	Area (acres)	Estimated Residence Time (days)		
			100-ft Breach	200-ft Breach	400-ft Breach
-1	Zone 207	1049	0.94	0.52	0.21
-1	Kimball Island	101	0.09	0.05	0.02
-1	Pittsburg	1716	1.54	0.86	0.34
-1	Prospect_Island	2210	1.99	1.10	0.44
-1	Zone 64	175	0.16	0.09	0.04
-1	Winter Island	423	0.38	0.21	0.08
-1	Zone 31	56	0.05	0.03	0.01
-1	Union_Island 4	73	0.07	0.04	0.01
-1	Byron_Tract 3	112	0.10	0.06	0.02
-1	Zone 74	5002	4.50	2.50	1.00
-1	Zone 214	328	0.29	0.16	0.07
-1	Water Canal	124	0.11	0.06	0.02
-1	Little Holland Tract	1456	1.31	0.73	0.29
-1	Terminous_Tract 3	9	0.01	0.00	0.00
-1	Byron_Tract 2	519	0.47	0.26	0.10

RD = Reclamation District
SM = Suisun Marsh

Table 6-11. Sensitive species observations on the channel side and within 200 feet of Delta levees.

Analysis Zone (URS_ID)	Island Name/ URS_Name	100-Foot Marker	Latin Name	Observation ID (EONDX)
3	Decker_Island	20800	*Lilaeopsis masonii*	32742
4	Webb_Tract	34500	*Hibiscus lasiocarpus*	50151
5	Empire_Tract	23800	*Aster lentus*	32572
5	Empire_Tract	36600	*Lilaeopsis masonii*	20543
5	Empire_Tract	36800	*Limosella subulata*	17064
9	Jersey_Island	57900	*Aster lentus*	46560
9	Jersey_Island	22500	*Aster lentus*	15150
10	Bethel Island	10700	*Lilaeopsis masonii*	9423
10	Bethel Island	34100	*Aster lentus*	22286
11	Quimby Island	30600	*Lilaeopsis masonii*	9078
12	McDonald Tract	18600	*Aster lentus*	32575
12	McDonald Tract	24600	*Aster lentus*	32576
12	McDonald Tract	66800	*Aster lentus*	32578
12	McDonald Tract	27200	*Aster lentus*	32577
14	Zone 14	2400	*Lilaeopsis masonii*	7668
15	Bacon Island	2100	*Lilaeopsis masonii*	46368
15	Bacon Island	1900	*Hibiscus lasiocarpus*	50130
15	Bacon Island	33400	*Carex vulpinoidea*	66575
15	Bacon Island	33400	*Lilaeopsis masonii*	66951
15	Bacon Island	25700	*Hibiscus lasiocarpus*	6218
17	Jones Tract	40400	*Lathyrus jepsonii* var. *jepsonii*	6206
17	Jones Tract	38100	*Lathyrus jepsonii* var. *jepsonii*	6205
19	Woodward Island	34700	*Hibiscus lasiocarpus*	6209
19	Woodward Island	11500	*Lilaeopsis masonii*	8003
19	Woodward Island	2500	*Lilaeopsis masonii*	19962
19	Woodward Island	2400	*Limosella subulata*	50166
20	Palm-Orwood South	33700	*Hibiscus lasiocarpus*	6199
21	Victoria Island	45400	*Hibiscus lasiocarpus*	50124
21	Victoria Island	17000	*Hibiscus lasiocarpus*	66187
21	Victoria Island	21900	*Hibiscus lasiocarpus*	66315
21	Victoria Island	13100	*Lilaeopsis masonii*	6202

Table 6-11. Sensitive species observations on the channel side and within 200 feet of Delta levees.

Analysis Zone (URS_ID)	Island Name/ URS_Name	100-Foot Marker	Latin Name	Observation ID (EONDX)
21	Victoria Island	2700	*Hibiscus lasiocarpus*	50128
21	Victoria Island	36900	*Scutellaria galericulata*	18943
21	Victoria Island	73000	*Lilaeopsis masonii*	9895
32	Coney Island	24300	*Lilaeopsis masonii*	9896
32	Coney Island	23800	*Hibiscus lasiocarpus*	20793
62	Tyler Island 1	5200	*Aster lentus*	46575
72	Peter Pocket	27600	*Lathyrus jepsonii* var. *jepsonii*	6305
72	Peter Pocket	16500	*Lathyrus jepsonii* var. *jepsonii*	6306
72	Peter Pocket	26000	*Lilaeopsis masonii*	16464
72	Peter Pocket	33100	*Atriplex joaquiniana*	16735
72	Peter Pocket	9100	*Hibiscus lasiocarpus*	63416
72	Peter Pocket	12600	*Lepidium latipes* var. *heckardii*	30160
76	Zone 76	66500	*Sagittaria sanfordii*	19286
81	Zone 81	37400	*Lilaeopsis masonii*	22268
81	Zone 81	36900	*Aster lentus*	6309
87	Terminous Tract 2	20000	*Aster lentus*	46552
87	Terminous Tract 2	82900	*Hibiscus lasiocarpus*	50159
87	Terminous Tract 2	24400	*Aster lentus*	46548
87	Terminous Tract 2	41400	*Aster lentus*	46546
87	Terminous Tract 2	66400	*Hibiscus lasiocarpus*	50158
108	Hotchkiss_Tract 1	28500	*Hibiscus lasiocarpus*	50129
108	Hotchkiss_Tract 1	5500	*Lilaeopsis masonii*	7667
117	Union_Island 1	109300	*Hibiscus lasiocarpus*	14129
117	Union_Island 2	42200	*Hibiscus lasiocarpus*	20792
117	Union_Island 3	38500	*Hibiscus lasiocarpus*	20790
117	Union_Island 4	42200	*Lilaeopsis masonii*	5883
117	Union_Island 5	38300	*Lilaeopsis masonii*	5884
117	Union_Island 6	55200	*Hibiscus lasiocarpus*	20791
125	Veale_Tract 1	8100	*Hibiscus lasiocarpus*	6211
127	Byron_Tract 1	25300	*Lilaeopsis masonii*	66953

Table 6-11. Sensitive species observations on the channel side and within 200 feet of Delta levees.

Analysis Zone (URS_ID)	Island Name/ URS_Name	100-Foot Marker	Latin Name	Observation ID (EONDX)
127	Byron_Tract 1	21000	*Hibiscus lasiocarpus*	6201
127	Byron_Tract 1	40100	*Lilaeopsis masonii*	19964
127	Byron_Tract 1	21100	*Tropidocarpum capparideum*	20439
127	Byron_Tract 1	17700	*Hibiscus lasiocarpus*	50141
143	Rindge_Tract	76800	*Aster lentus*	32573
143	Rindge_Tract	56300	*Aster lentus*	46555
143	Rindge_Tract	53800	*Aster lentus*	46556
143	Rindge_Tract	51800	*Lilaeopsis masonii*	19977
143	Rindge_Tract	71800	*Aster lentus*	46554
144	Mandeville_Island	72600	*Aster lentus*	32584
144	Mandeville_Island	40500	*Lilaeopsis masonii*	2840
144	Mandeville_Island	47300	*Aster lentus*	32585
144	Mandeville_Island	51900	*Lilaeopsis masonii*	20349
144	Mandeville_Island	35200	*Lilaeopsis masonii*	2838
144	Mandeville_Island	74600	*Aster lentus*	32582
144	Mandeville_Island	45800	*Lilaeopsis masonii*	17086
144	Mandeville_Island	32200	*Lilaeopsis masonii*	14641
150	Venice_Island	53700	*Aster lentus*	46557
150	Venice_Island	42300	*Aster lentus*	32581
154	Roberts_Island 1	27200	*Hibiscus lasiocarpus*	14131
154	Roberts_Island 1	36200	*Hibiscus lasiocarpus*	20789
158	Zone 158	17200	*Astragalus tener* var. *tener*	6926
161	Zone 161	28800	*Cirsium crassicaule*	17117
162	Zone 162	1900	*Lilaeopsis masonii*	19966
162	Zone 162	7100	*Lilaeopsis masonii*	12765
163	Fabian_Tract	77700	*Lilaeopsis masonii*	30898
163	Fabian_Tract	88300	*Lilaeopsis masonii*	30911
169	McCormack_ Williamson_Tract	19000	*Limosella subulata*	50172
169	McCormack_Williamson_Tract	34500	*Hibiscus lasiocarpus*	21533
169	McCormack_Williamson_Tract	26600	*Scutellaria lateriflora*	66985

Table 6-11. Sensitive species observations on the channel side and within 200 feet of Delta levees.

Analysis Zone (URS_ID)	Island Name/ URS_Name	100-Foot Marker	Latin Name	Observation ID (EONDX)
170	Glanville_Tract	34500	*Hibiscus lasiocarpus*	6304
172	New_Hope_Tract	7800	*Lilaeopsis masonii*	46370
174	Staten_Island	47700	*Aster lentus*	60768
174	Staten_Island	70100	*Limosella subulata*	29532
174	Staten_Island	72100	*Limosella subulata*	29610
174	Staten_Island	72100	*Lathyrus jepsonii* var. *jepsonii*	29611
175	Canal Ranch	34800	*Lathyrus jepsonii* var. *jepsonii*	46487
176	Brack_Tract	31000	*Aster lentus*	46574
176	Brack_Tract	44300	*Hibiscus lasiocarpus*	19497
177	Bouldin_Island	12300	*Aster lentus*	60785
177	Bouldin_Island	79900	*Aster lentus*	60791
177	Bouldin_Island	14700	*Aster lentus*	60786
177	Bouldin_Island	55600	*Aster lentus*	60802
177	Bouldin_Island	23300	*Aster lentus*	60790
177	Bouldin_Island	47000	*Aster lentus*	60793
177	Bouldin_Island	64500	*Lathyrus jepsonii* var. *jepsonii*	32652
177	Bouldin_Island	56500	*Lathyrus jepsonii* var. *jepsonii*	32653
177	Bouldin_Island	60100	*Hibiscus lasiocarpus*	56935
177	Bouldin_Island	44900	*Aster lentus*	60792
177	Bouldin_Island	61700	*Aster lentus*	60806
177	Bouldin_Island	49200	*Lathyrus jepsonii* var. *jepsonii*	32655
177	Bouldin_Island	30600	*Aster lentus*	32580
177	Bouldin_Island	52700	*Aster lentus*	60797
177	Bouldin_Island	45200	*Lathyrus jepsonii* var. *jepsonii*	32656
177	Bouldin_Island	94400	*Aster lentus*	32571
177	Bouldin_Island	65700	*Aster lentus*	32579
177	Bouldin_Island	6200	*Aster lentus*	46547
178	Brannan-Andrus Island	172800	*Lathyrus jepsonii* var. *jepsonii*	6445
178	Brannan-Andrus Island	141100	*Lathyrus jepsonii var. jepsonii*	56175
178	Brannan-Andrus Island	2300	*Aster lentus*	30471

Table 6-11. Sensitive species observations on the channel side and within 200 feet of Delta levees.

Analysis Zone (URS_ID)	Island Name/ URS_Name	100-Foot Marker	Latin Name	Observation ID (EONDX)
178	Brannan-Andrus Island	173900	*Aster lentus*	14255
178	Brannan-Andrus Island	208600	*Lilaeopsis masonii*	14600
178	Brannan-Andrus Island	19900	*Lathyrus jepsonii* var. *jepsonii*	42511
178	Brannan-Andrus Island	5500	*Limosella subulata*	8578
178	Brannan-Andrus Island	12800	*Lilaeopsis masonii*	7763
178	Brannan-Andrus Island	23900	*Lilaeopsis masonii*	14257
178	Brannan-Andrus Island	23900	*Aster lentus*	14101
178	Brannan-Andrus Island	4800	*Lilaeopsis masonii*	14382
179	Twitchell_Island	62600	*Limosella subulata*	6040
179	Twitchell_Island	62600	*Lilaeopsis masonii*	6063
181	Sherman_Island	92900	*Lathyrus jepsonii* var. *jepsonii*	55743
181	Sherman_Island	119200	*Aster lentus*	46565
181	Sherman_Island	83100	*Lilaeopsis masonii*	9394
181	Sherman_Island	111700	*Lilaeopsis masonii*	9537
181	Sherman_Island	39400	*Limosella subulata*	43
181	Sherman_Island	39400	*Lilaeopsis masonii*	16149
181	Sherman_Island	39400	*Aster lentus*	20561
181	Sherman_Island	116600	*Aster lentus*	46566
181	Sherman_Island	93500	*Aster lentus*	15151
181	Sherman_Island	109400	*Lilaeopsis masonii*	9498
181	Sherman_Island	26800	*Aster lentus*	8569
181	Sherman_Island	103900	*Lilaeopsis masonii*	9486
181	Sherman_Island	97200	*Lilaeopsis masonii*	9450
181	Sherman_Island	78600	*Aster lentus*	30274
181	Sherman_Island	112000	*Cordylanthus mollis* ssp. *mollis*	6420
181	Sherman_Island	50500	*Aster lentus*	9363
181	Sherman_Island	50500	*Lilaeopsis masonii*	9385
181	Sherman_Island	88500	*Lilaeopsis masonii*	9424
181	Sherman_Island	109200	*Limosella subulata*	11880
184	Bishop_Tract	34800	*Hibiscus lasiocarpus*	50147

Table 6-11. Sensitive species observations on the channel side and within 200 feet of Delta levees.

Analysis Zone (URS_ID)	Island Name/ URS_Name	100-Foot Marker	Latin Name	Observation ID (EONDX)
187	Shima_Tract	8300	*Lilaeopsis masonii*	66954
190	Wright-Elmwood_Tract	32600	*Lilaeopsis masonii*	46367
191	Wright-Elmwood_Tract-Sargent Burnhart Tract	12700	*Hibiscus lasiocarpus*	6262
210	Ryer Island	53400	*Lathyrus jepsonii* var. *jepsonii*	15642
210	Ryer Island	28100	*Lathyrus jepsonii* var. *jepsonii*	19249

Source: CNDDB 2007

Table 6-12. Analysis parameters used in the terrestrial wildlife analysis.

Species/ Species Group	Mechanism			Area of Occurrence	Land Cover Types Composing Habitat	
		Habitat Loss				
	Direct Mortality	Temporary (not type converted)	Permanent (type converted)		Suisun Marsh	Delta
Suisun ornate shrew	**Level:** Category III **Timing:** Yearlong **Mechanism:** • Direct trauma at instant of breach • Drowning following breach • Increased susceptibility to predation/ starvation	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Inundation of habitat • Degradation of habitat resulting from siltation, loss of cover and food **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Conversion to a land cover type that does not support habitat **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	Suisun Marsh	Brackish marsh—Mid	NA
Salt marsh harvest mouse	**Level:** Category III **Timing:** Yearlong **Mechanism:** • Direct trauma at instant of breach • Drowning following breach • Increased susceptibility to predation/ starvation	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Inundation of habitat • Degradation of habitat resulting from siltation, loss of cover and food **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Conversion to a land cover type that does not support habitat **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	Suisun Marsh	Brackish marsh—Mid	NA
California clapper rail	**Level:** Category III **Timing:** • April-July (breeding season) • September-March **Mechanism:** • Direct trauma at instant of breach • Loss of eggs • Increased susceptibility to predation/ starvation	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Inundation of habitat • Degradation of habitat resulting from siltation, loss of cover and food **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Conversion to a land cover type that does not support habitat **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	Suisun Marsh	Brackish marsh—Mid Brackish marsh—High	NA

Table 6-12. Analysis parameters used in the terrestrial wildlife analysis.

Species/ Species Group	Mechanism			Area of Occurrence	Land Cover Types Composing Habitat	
		Habitat Loss				
	Direct Mortality	**Temporary (not type converted)**	**Permanent (type converted)**		**Suisun Marsh**	**Delta**
California black rail	**Level:** Category III **Timing:** • April-June (breeding season) • September-March **Mechanism:** • Direct trauma at instant of breach • Loss of eggs • Increased susceptibility to predation/ starvation	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Inundation of habitat • Degradation of habitat resulting from siltation, loss of cover and food **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	**Level:** Category II Timing: Yearlong **Mechanism:** • Conversion to a land cover type that does not support habitat **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	Suisun Marsh Delta	Brackish marsh—Mid Brackish marsh—High	Brackish marsh—Mid
Saltmarsh common yellowthroat	**Level:** Category III **Timing:** • April-July (breeding season) • September-March **Mechanism:** • Direct trauma at instant of breach • Loss of eggs • Increased susceptibility to predation/ starvation	**Level:** Category II **Timing:** Yearlong **Mechanism:** • Inundation of habitat • Degradation of habitat resulting from siltation, loss of cover and food **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	**Level:** Category II **Timing**: Yearlong **Mechanism:** • Conversion to a land cover type that does not support habitat **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of total habitat affected	Suisun Marsh	Brackish marsh—Mid Brackish marsh—High Herbaceous wet	NA
Sandhill crane	**Level:** Category III **Timing:** • September-March (wintering habitat) **Mechanism:** • Increased susceptibility to predation/starvation • Reduction in breeding success as result of poor condition following migration to breeding grounds	**Level:** Category II **Timing:** • September-March (wintering habitat) **Mechanism:** • Inundation of foraging habitat • Degradation of habitat resulting from siltation, loss of food or food availability **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of habitat affected	**Level:** Category II **Timing:** • September-March (wintering habitat) **Mechanism:** • Inundation by sea level rise **Metric:** • Acres of occupied islands • Percentage of habitat affected • Model Output: • Acres of habitat affected • Percentage of habitat affected	Islands in the North and Central Delta	Not applicable	Wheat and grain Corn Alfalfa Irrigated pasture

Table 6-12. Analysis parameters used in the terrestrial wildlife analysis.

Species/ Species Group	Mechanism			Area of Occurrence	Land Cover Types Composing Habitat	
		Habitat Loss				
	Direct Mortality	Temporary (not type converted)	Permanent (type converted)		Suisun Marsh	Delta
Goose, swan, and dabbling duck winter foraging habitat	**Level:** Category III **Timing:** • September-March (wintering habitat) **Mechanism:** • Increased susceptibility to predation/starvation • Reduction in breeding success as result of poor condition following migration to breeding grounds	**Level:** Category II **Timing:** • September-March (wintering habitat) **Mechanism:** • Inundation of foraging habitat • Degradation of habitat resulting from siltation, loss of food or food availability **Metric:** • Acres of habitat **Model Output:** • Acres of habitat affected • Percentage of habitat affected	**Level:** Category II **Timing:** • September-March (wintering habitat) **Mechanism:** • Inundation by sea level rise **Metric:** • Acres of occupied islands • Percentage of habitat affected **Model Output:** • Acres of habitat affected • Percentage of habitat affected	Delta islands and Suisun Marsh	Grain and hay crops Corn Alfalfa Irrigated pasture Herbaceous ruderal wet (non- invasive) Herbaceous wet	Grain and hay crops Corn Alfalfa Irrigated pasture Herbaceousruderal wet (non-invasive)

Table 7-1. Three-breach sequence: Characteristics.

Island	Flood Characteristics									
	Breaches per Island	Date of Breach Closure	Date of Completion of Pump-out	Flood Duration (Time from Breach to End of Pump-out)			Flood Depth[1]		Max Salinity Level of Floodwater at Breach Closure (ppt)[2]	Monthly Average Water Depth, July (feet)
				Days	~Months	Years	Average (ft)	Max (ft)		
Sherman Island	1	8/2/1992	8/12/1992	43	1.4	0.1	–11	–37	4.1	–8.0
Brannan-Andrus Island	1	8/15/1992	8/25/1992	58	1.9	0.2	–5	–27	2.1	–10.1
Bacon Island	1	9/3/1992	9/10/1992	75	2.5	0.2	–11	–22	2.1	–9.3

Number of islands breached	3
Breach start	7/1/1992
SWP/CVP shut-off duration	6 months

Source: RMA April 2007

Note: RMA did not model pump-out; a 10-day period to complete pump-out was assumed starting the day that the breach was fully closed.

[1] Approximated to nearest foot; IFSAR data accuracy is not known

[2] Reported from RMA in ppt

Table 7-2. Occurrences of sensitive species on the channel side of levees of islands in breach sequences.

Island/Tract	*Aster lentus* CNPS 1B.2	*Astragalus tener* var. *tener* CNPS 1B.2	*Atriplex joaquiniana* CNPS 1B.2	*Carex vulpinoidea* CNPS 2.2	*Cirsium crassicaule* CNPS 1B.1	*Cordylanthus mollis* ssp. *mollis* Fed_E, CA_R, CNPS 1B.2	*Hibiscus lasiocarpus* CNPS 2.2	*Lathyrus jepsonii* var. *jepsonii* CNPS 1B.2	*Lepidium latipes* var. *heckardii* CNPS 1B.2	*Lilaeopsis masonii* C_R	*Limosella subulata* CNPS 2.1	*Scutellaria galericulata* CNPS 2.2	*Scutellaria lateriflora* CNPS 2.2	*Tropidocarpum capparideum* CNPS 1B.1	Total	Percent of total CNDDB Occurrences in the Delta and Suisun Marsh
Bacon Island	—	—	—	1	—	—	2	—	—	2	—	—	—	—	5	0.9
Bethel Island	1	—	—	—	—	—	—	—	—	1	—	—	—	—	2	0.4
Bouldin Island	13	—	—	—	—	—	1	4	—	—	—	—	—	—	18	3.2
Bradford	—	—	—	—	—	—	—	—	—	—	— —	—	—	—	0	0.0
Brannan-Andrus Island	3	—	—	—	—	—	—	3	—	4	1	—	—	—	11	1.9
Byron Tract 1	—	—	—	—	—	—	2	—	—	2	—	—	—	1	5	0.9
Holland	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	0.0
Jersey	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0	0.0
Jones Tract	—	—	—	—	—	—	—	2	—	—	—	—	—	—	2	0.4
Mandeville Island	3	—	—	—	—	—	—	—	—	5	—	—	—	—	8	1.4
McDonald Tract	4	—	—	—	—	—	—	—	—	—	—	—	—	—	4	0.7
Palm-Orwood South	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	0.2
Quimby Island	—	—	—	—	—	—	—	—	—	1	—	—	—	—	1	0.2
Sherman Island	7	—	—	—	—	1	—	1	—	8	2	—	—	—	19	3.4
Twitchell Island	—	—	—	—	—	—	—	—	—	1	1	—	—	—	2	0.4
Venice Island	2	—	—	—	—	—	—	—	—	—	—	—	—	—	2	0.4
Victoria Island	—	—	—	—	—	—	4	—	—	2	—	1	—	—	7	1.2
Webb Tract	—	—	—	—	—	—	1	—	—	—	—	—	—	—	1	0.2
Woodward Island	—	—	—	—	—	—	1	—	—	2	1	—	—	—	4	0.7
Total three-breach	10	0	0	1	0	1	2	4	0	14	3	0	0	0	35	6.2
Percent Delta and Suisun	8.2	0.0	0.0	100.0	0.0	5.9	2.5	3.5	0.0	10.5	7.9	0.0	0.0	0.0	—	—
Total thirty-breach	26	0	0	1	0	0	12	9	0	20	3	1	0	1	73	12.9
Percent Delta and Suisun Marsh	21.3	0.0	0.0	100.0	0.0	0.0	15.0	8.0	0.0	15.0	7.9	33.3	0.0	100.0	—	—
Total fifty-breach	33	0	0	1	0	1	12	10	0	28	5	1	0	1	92	16.3

Table 7-2. Occurrences of sensitive species on the channel side of levees of islands in breach sequences.

Island/Tract	Species Name, Status														Total	Percent of total CNDDB Occurrences in the Delta and Suisun Marsh
	Aster lentus	*Astragalus tener* var. *tener*	*Atriplex joaquiniana*	*Carex vulpinoidea*	*Cirsium crassicaule*	*Cordylanthus mollis* ssp. *mollis*	*Hibiscus lasiocarpus*	*Lathyrus jepsonii* var. *jepsonii*	*Lepidium latipes* var. *heckardii*	*Lilaeopsis masonii*	*Limosella subulata*	*Scutellaria galericulata*	*Scutellaria lateriflora*	*Tropidocarpum capparideum*		
	CNPS 1B.2	**CNPS 1B.2**	**CNPS 1B.2**	**CNPS 2.2**	**CNPS 1B.1**	**Fed_E, CA_R, CNPS 1B.2**	**CNPS 2.2**	**CNPS 1B.2**	**CNPS 1B.2**	**C_R**	**CNPS 2.1**	**CNPS 2.2**	**CNPS 2.2**	**CNPS 1B.1**		
Percent Delta and Suisun Marsh	27.0	0.0	0.0	100.0	0.0	5.9	15.0	8.8	0.0	21.1	13.2	33.3	0.0	100.0	—	—
Total Delta, Suisun Marsh	122	6	4	1	2	17	80	113	3	133	38	3	2	1	565	—

Note: These data refer to the number of observed occurrences reported to the CNDDB before January 2006

CNDDB = California Natural Diversity Database

Federal Status
Fed_E = Endangered

State (California) Status
CA_R = Rare

California Native Plant Society (CNPS) Status
1B = Rare, threatened, or endangered in California and elsewhere
1B.1 = Rare, threatened, or endangered in California and elsewhere, seriously endangered in California
1B.2 = Rare, threatened, or endangered in California and elsewhere, fairly endangered in California
2.2 = Rare, threatened, or endangered in California, but more common elsewhere, fairly endangered in California

Table 7-3. Three-breach sequence: Area of vegetation types impacted.

			Vegetation Type Area (Acres)																				
			No Wild Vegetation					**Aquatic**	**Marsh**			**Freshwater Wetland**			**Upland**					**Riparian**			
Area	**Island/ Tract**	**Calculation**	No Information	Agriculture	Developed	Non-Vegetated	Open Water	Aquatic Vegetation	Alkali Marsh Low	Alkali Marsh Mid	Alkali Marsh High	Herbaceous Wetland, Perennial	Herbaceous Wetland, Seasonal	Herbaceous Wetland, Seasonal, Ruderal	Herbaceous Upland	Herbaceous Upland, Ruderal	Shrub Upland	Tree Upland	Tree Upland, Non-Native	Shrub Wetland (Riparian)	Tree Wet (Riparian)	**Total Area (Acres)**	**Percent**
Island	Bacon	—	0.00	5149.85	64.82	16.58	4.50	0.00	0.00	0.00	6.74	0.97	0.00	5.11	0.00	268.06	0.00	0.61	6.61	4.69	2.09	5530.63	—
	Brannan-Andrus	—	0.10	13237.69	379.73	77.44	15.09	9.40	0.00	0.00	0.00	12.36	0.00	26.63	0.00	724.74	10.13	47.61	292.56	96.88	45.43	14975.80	—
	Sherman	—	0.00	8796.22	71.51	99.36	50.75	0.00	143.09	0.00	0.63	13.94	0.00	114.60	0.00	793.70	5.49	0.00	23.78	47.74	22.34	10183.15	—
Breached area	—	Area (acres)	0.10	27183.76	516.06	193.38	70.34	9.40	143.09	0.00	7.38	27.27	0.00	146.33	0.00	1786.51	15.63	48.23	322.94	149.31	69.86	30689.58	—
	—	%	0.00	88.58	1.68	0.63	0.23	0.03	0.47	0.00	0.02	0.09	0.00	0.48	0.00	5.82	0.05	0.16	1.05	0.49	0.23	—	—
	—	%					91.12	0.03			0.49			0.57					7.08		0.71	—	—
Breached area vs. Delta	—	Total area in Delta (acres)	6.85	282502.73	8989.64	2171.95	6284.75	350.62	332.06	91.72	937.61	2729.48	12.45	4707.89	0.57	21928.07	77.61	774.13	2241.46	2207.78	1759.99	338107.38	—
	—	% of veg type in Delta	1.42	9.62	5.74	8.90	1.12	2.68	43.09	0.00	0.79	1.00	0.00	3.11	0.00	8.15	20.14	6.23	14.41	6.76	3.97	—	—
	—	% of veg group in Delta					0.10	0.00			11.05			2.33					8.69		5.52	—	—
	—	% of Delta					8.27	0.00			0.04			0.05					0.64		0.06	—	9.08

Table 7-4. Three-breach sequence: Time to recover to mature vegetation for vegetation-type focal species.

	Focal Species of Vegetation Types, Time Until Recovery Of Mature Vegetation (Months)															
	Aquatic			**Marsh**			**Freshwater Wetland**			**Upland**					**Riparian**	
	Aquatic Non-Native	**Aquatic Non-Native**	**Aquatic Native**	**Marsh Low**	**Marsh Mid**	**Marsh High**	**Herbaceous Wetland Seasonal**	**Herbaceous Wetland Seasonal Ruderal**	**Herbaceou s Wetland Perennial**	**Herbaceous Upland**	**Herbaceous Upland Ruderal**	**Shrub Upland**	**Tree Native**	**Tree Non-Native**	**Shrub Wetland (Riparian)**	**Tree Riparian**
Island Name	*Egeria densa*	*Eichornia crassipes*	*Potamogeton pectinatus*	*Typha angustifolia*	*Salicornia virginica*	*Frankeni a salina*	*Juncus balticus*	*Lolium multiflorum* var. *perenne*	*Scirpus americanus*	*Leymus triticoides*	*Avena fatua*	*Baccharis pilularis*	*Quercus lobata*	*Eucalyptus globulus*	*Rubus discolor*	*Fraxinus latifolia*
Bacon Island	0	0	0	18	15	15	18	21	21	21	24	24	249	75	33	369
Brannan-Andrus Island	0	0	0	0	15	15	18	21	21	9	12	12	249	63	33	369
Sherman Island	0	0	0	0	14	14	17	20	20	8	11	11	248	62	32	368

Table 7-5. Three-breach sequence: Extent of terrestrial wildlife habitat affected.

Selected Species/Species Group	Delta (acres)	Suisun Marsh	Total Extent of Habitat in the Study Area	Percent of Total Habitat Area Affected in the Study Area
Suisun ornate shrew	0	0	0	0
Salt marsh harvest mouse	0	0	0	0
California clapper rail	0	0	0	0
California black rail	<1	TBD	0	0
Saltmarsh common yellowthroat	0	TBD	0	0
Greater sandhill crane	18,387	0	0	TBD
Geese, swans, and dabbling ducks	27,184	TBD	0	TBD

Table 7-6. Thirty-breach sequence: Area of vegetation types affected.

Breach Sequence	Area	Island/Tract Name	Calculation	Vegetation Type Area (Acres)																			Total Area (Acres)	%
				No Wild Veg					Aquatic	Marsh			Freshwater Wetland			Upland					Riparian			
				No Information	Agriculture	Developed	Non-Vegetated	Open Water	Aquatic Vegetation	Alkali Marsh Low	Alkali Marsh Mid	Alkali Marsh High	Herbaceous Wetland, Perennial	Herbaceous Wetland, Seasonal	Herbaceous Wetland, Seasonal, Ruderal	Herbaceous Upland	Herbaceous Upland, Ruderal	Shrub Upland	Tree Upland	Tree Upland, Non-Native	Shrub Wetland (Riparian)	Tree Wet (Riparian)		
30, 50	Island	Bacon	—	0.00	5149.85	64.82	16.58	4.50	0.00	0.00	0.00	6.74	0.97	0.00	5.11	0.00	268.06	0.00	0.61	6.61	4.69	2.09	5530.63	—
		Bethel	—	0.00	477.06	429.75	25.25	2.30	3.07	0.00	0.00	0.00	1.27	0.00	122.28	0.00	1965.79	0.00	1.39	216.65	132.21	86.59	3463.62	—
		Bouldin	—	0.00	5330.78	12.47	2.26	5.73	0.42	22.62	0.00	0.00	19.21	0.00	7.14	0.00	508.31	0.00	0.00	5.09	18.12	5.14	5937.29	—
		Bradford Island	—	0.00	10.79	16.86	32.04	26.26	4.48	0.00	0.00	1.38	49.11	10.95	498.16	0.00	1145.80	0.00	0.00	5.33	183.93	152.40	2137.48	—
		Brannan-Andrus	—	0.10	13237.69	379.73	77.44	15.09	9.40	0.00	0.00	0.00	12.36	0.00	26.63	0.00	724.74	10.13	47.61	292.56	96.88	45.43	14975.80	—
		Byron	—	0.00	4351.30	114.13	1.27	6.78	0.00	0.00	59.06	35.76	0.27	0.00	0.00	0.00	337.80	0.00	0.00	2.22	0.00	0.00	4908.59	—
		Holland	—	0.00	1064.50	8.30	31.68	69.09	6.01	7.26	0.00	81.99	65.53	0.00	1292.36	0.00	1408.27	1.68	0.00	4.54	80.80	95.51	4217.51	—
		Jersey	—	0.00	471.67	5.71	36.31	1.75	0.00	0.00	0.00	0.00	41.08	0.00	212.53	0.00	2646.81	0.00	0.00	0.00	19.76	28.39	3464.00	—
		Mandeville	—	0.00	2314.63	4.85	24.63	88.70	74.57	63.50	0.00	403.56	241.51	0.00	642.64	0.00	1175.64	1.25	0.00	12.02	69.64	96.67	5213.81	—
		McDonald	—	0.00	4913.10	78.26	344.30	18.08	15.59	0.00	0.00	21.07	55.64	0.00	128.85	0.00	299.27	19.19	0.00	14.47	108.51	46.10	6062.45	—
		Orwood	—	0.00	2208.99	13.60	6.47	18.83	0.00	5.83	0.00	3.27	22.28	0.00	26.81	0.00	150.11	0.00	0.00	1.00	14.58	1.62	2473.39	—
		Palm	—	0.00	2160.75	84.52	18.28	0.00	0.00	0.00	0.00	0.00	5.34	0.00	2.77	0.00	86.30	0.00	0.77	12.33	10.97	2.27	2384.32	—
		Quimby	—	0.00	551.73	0.00	19.19	5.39	6.41	0.01	0.00	29.79	1.09	0.00	5.14	0.00	101.32	0.00	0.00	1.86	43.44	4.51	769.87	—
		Twitchell	—	0.00	3115.50	11.47	10.01	5.02	2.81	0.00	0.00	0.00	12.73	0.00	29.91	0.00	329.41	0.00	0.00	13.22	34.86	3.38	3568.33	—
		Upper, Lower Jones	—	0.00	11403.34	90.18	45.44	32.24	10.96	0.00	0.00	0.00	3.29	0.00	26.16	0.00	345.76	0.00	0.00	12.63	119.05	42.24	12131.29	—
		Venice	—	0.00	2758.93	4.02	3.13	18.79	9.58	0.00	0.00	1.70	7.31	0.00	24.37	0.00	160.88	0.00	0.00	3.64	29.49	73.57	3095.42	—
		Victoria	—	0.00	6678.25	205.67	17.77	25.19	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	262.66	0.00	0.87	4.48	0.01	0.00	7195.74	—
		Webb	—	0.00	4434.76	0.00	15.02	82.19	0.88	0.00	0.00	0.00	26.08	0.00	118.06	0.00	605.10	0.00	0.00	5.19	79.14	74.44	5440.86	—
		Woodward	—	0.00	1652.27	29.46	7.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	112.99	0.00	4.21	0.00	4.27	3.95	1814.92	—
30 (w/o Sherman Island)	Breached area	—	Total area (acres)	0.10	72285.88	1553.81	734.14	425.93	145.03	99.22	59.06	585.27	565.07	10.95	3169.62	0.00	12635.03	32.25	55.46	613.84	1050.35	764.30	94785.31	—
		—	% of breached area	0.00	76.26	1.64	0.77	0.45	0.15	0.10	0.06	0.62	0.60	0.01	3.34	0.00	13.33	0.03	0.06	0.65	1.11	0.81	—	—
		—	% of breached area	79.13					0.15	0.78			3.95			14.07					1.91		—	—
	Breached area vs Delta		Total area in Delta (acres)*	6.85	282502.73	8989.64	2171.95	6284.75	350.62	332.06	91.72	937.61	2729.48	12.45	4707.89	0.57	21928.07	77.61	774.13	2241.46	2207.78	1759.99	338107.38	—
			% of veg type in Delta*	1.42	25.59	17.28	33.80	6.78	41.36	29.88	64.38	62.42	20.70	87.95	67.33	0.00	57.62	41.55	7.16	27.39	47.58	43.43	—	—
			% of veg group in Delta*	25.00					41.36	54.62			50.28			53.30					45.73		—	—
		—	% of Delta	22.18					0.04	0.22			1.11			3.94					0.54		—	28.03

Table 7-7. Thirty-breach sequence: Duration of Breach and Island pump-out schedule.

Islands / Tracts Breached on July 1, 2002.						Total Flood Duration			Flood Depth		
Island / Tract	Number of Breaches	Date of Breach Closure / Pump-out Begins	Duration of Breach (days)	Pump-Out Duration (days)	Month of Year Pump-out Complete	Days	~Months	~Years	Average	Maximum	Maximum Salinity of Floodwater, at Breach Closure (ppt)
Bacon Island	2	10/13/2003	469	40	11	509	2.2	0.2	-12.22	-34.46	2.1
Bethel Tract	2	8/29/2002	59	13	9	72	2.4	0.2	-2.36	-21.86	3.3
Bouldin Island	1	1/22/2003	205	47	3	252	7.2	0.6	-6.28	-38.18	0.9
Bradford Island	1	1/22/2003	205	11	2	216	4.6	0.4	-13.13	-25.35	0.6
Brannan-Andrus Island	2	1/11/2003	194	98	4	292	4.1	0.3	-6.69	-20.57	0.9
Byron Tract	1	8/4/2002	34	32	9	66	5.9	0.5	-11.66	-22.46	0.6
Holland Tract	3	6/8/2003	342	22	6	364	9.7	0.8	-12.95	-36.49	0.6
Jersey Island	4	12/8/2002	160	17	12	177	8.4	0.7	24.96	-16.43	5.1
Lower and Upper Jones Tract[3]	2	4/11/2003	284	70	6	354	12.3	1.0	-7.64	-22.95	0.6
Mandeville Island	1	2/25/2003	239	8	3	247	8.2	0.7	-13.47	-24.86	0.9
McDonald Tract	1	10/24/2002	115	52	12	167	12.1	1.0	-10.21	-26.63	0.9
Orwood Tract	2	5/24/2003	327	11	6	338	13.6	1.1	-7.2	-34.83	0.9
Palm Tract	2	3/10/2003	252	14	3	266	14.1	1.2	-13.86	-23.65	0.9
Quimby Island	1	8/9/2003	404	4	8	408	11.8	1.0	-7.43	-17.32	0.6
Twitchell Island	1	10/24/2002	115	24	11	139	5.6	0.5	-5.67	-26.74	1.4
Venice Island	1	6/8/2003	342	28	7	370	8.9	0.7	-7.62	-20.19	0.9
Victoria Island	1	7/23/2003	387	37	8	424	11.3	0.9	-5.62	-22.78	0.6
Webb Tract	1	10/13/2002	104	19	11	123	16.2	1.3	-8.1	-27.25	0.9
Woodward Island	1	10/8/2003	464	11	10	475	15.8	1.3	-8.85	-19.26	0.6

Number of islands breached = 20

SWP/CVP shut-off duration = 1 year, 3.3 months

SWP/CVP shut-off duration under emergency repair schedule = 10.5 months

[1] Breach date is July 2002; average time to pump out an island is 30 days ±24 day, max = 98 (Brannan-Andrus), min = Quimby Island

[2] Parts per thousand (ppt) information converted from data reported as electrical conductivity (µmho/cm) by multiplying by 0.00064

[3] Note that Upper and Lower Jones Tract are one island separated by a roadway bridge making them function as two with regard to flooding

Table 7-8. Thirty-breach sequence: Time to recover to mature vegetation for vegetation-type focal species.

Island Name	Focal Species of Vegetation Types, Time Until Recovery of Mature Vegetation (Months)															
	Aquatic			Marsh			Freshwater Wetland			Upland					Riparian	
	Aquatic Non-Native	Aquatic Non-Native	Aquatic Native	Marsh Low	Marsh Mid	Marsh High	Herbaceous Wetland Seasonal	Herbaceous Wetland Seasonal Ruderal	Herbaceous Wetland Perennial	Herbaceous Upland	Herbaceous Upland Ruderal	Shrub Upland	Tree Native	Tree Non-Native	Shrub Wetland (Riparian)	Tree Riparian
	Egeria densa	*Eichornia crassipes*	*Potamogeton pectinatus*	*Typha angustifolia*	*Salicornia virginica*	*Frankenia salina*	*Juncus balticus*	*Lolium multiflorum var_ perenne*	*Scirpus americanus*	*Leymus triticoides*	*Avena fatua*	*Baccharis pilularis*	*Quercus lobata*	*Eucalyptus globulus*	*Rubus discolor*	*Fraxinus latifolia*
Bacon Island	0	0	0	30	27	27	30	33	33	33	36	36	261	87	45	381
Bethel Tract	0	14	0	0	14	14	17	20	0	0	23	23	248	74	0	368
Bouldin Island	0	0	0	29	26	26	29	32	32	20	23	23	260	74	44	380
Bradford Island	0	0	0	0	15	15	18	21	0	21	24	24	249	75	33	369
Brannan-Andrus Island	0	0	0	0	27	27	30	33	33	21	24	24	261	75	45	381
Byron Tract*	11	14	11	17	14	14	17	20	0	0	23	23	248	74	0	368
Holland Tract	0	0	0	0	26	26	29	32	32	20	23	23	260	74	44	380
Jersey Island	0	0	0	0	15	15	18	21	0	21	24	24	249	75	33	369
Lower and Upper Jones Tract	0	0	0	0	27	27	30	33	33	21	24	24	261	75	45	381
Mandeville Island	0	0	0	29	26	26	29	32	32	20	23	23	260	74	44	380
McDonald Tract	0	0	0	30	27	27	30	33	33	21	24	24	261	75	45	381
Orwood Tract	0	0	0	0	27	27	30	33	33	21	24	24	261	75	45	381
Palm Tract	0	0	0	0	26	26	29	32	32	20	23	23	260	74	44	380
Quimby Island	0	0	0	0	27	27	30	33	33	21	24	24	261	75	45	381
Twitchell Island	0	0	0	18	15	15	18	21	21	21	24	24	249	75	33	369
Venice Island	0	0	0	29	26	26	29	32	32	20	23	23	260	74	44	380
Victoria Island	0	0	0	0	27	27	30	33	33	21	24	24	261	75	45	381
Webb Tract	0	0	0	18	15	15	18	21	21	21	24	24	249	75	33	369
Woodward Island	0	0	0	0	27	27	30	33	33	33	36	36	261	87	45	381

Table 7-9. Thirty-breach sequence, extent of terrestrial wildlife habitat affected.

Selected Species/Species Group	Delta (acres)	Suisun Marsh	Total Extent of Habitat in the Study Area	Percent of Total Habitat Area Affected in the Study Area
Suisun ornate shrew	0	0	0	0
Salt marsh harvest mouse	0	0	0	0
California clapper rail	0	0	0	0
California black rail	1,195	0	0	0
Saltmarsh common yellowthroat	0	0	0	0
Greater sandhill crane	41,122	0	0	TBD
Geese, swans, and dabbling ducks	63,490	TBD	0	TBD

Table 7-10. Thirty-breach sequence: Adult survival of vegetation-type focal species.

	Vegetation Types and Focal Species (Adult Suitability)															
	Aquatic			**Marsh**			**Freshwater Wetland**			**Upland**					**Riparian**	
	Aquatic Non-Native	Aquatic Non-Native	Aquatic Native	Marsh Low	Marsh Mid	Marsh High	Herbaceous Wetland Seasonal	Herbaceous Wetland Seasonal Ruderal	Herbaceous Wetland Perennial	Herbaceous Upland	Herbaceous Upland Ruderal	Shrub Upland	Tree Native	Tree Non-Native	Shrub Wetland (Riparian)	Tree Riparian
Island name	*Egeria densa*	*Eichornia crassipes*	*Potamogeton pectinatus*	*Typha angustifolia*	*Salicornia virginica*	*Frankenia salina*	*Juncus balticus*	*Lolium multiflorum var_ perenne*	*Scirpus americanus*	*Leymus triticoides*	*Avena fatua*	*Baccharis pilularis*	*Quercus lobata*	*Eucalyptus globulus*	*Rubus discolor*	*Fraxinus latifolia*
Bacon Island	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bethel Tract	1.0	0.0	0.6	0.5	0.3	0.0	0.0	0.1	1.0	1.0	0.0	0.0	0.0	0.0	0.5	0.1
Bouldin Island	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bradford Island	1.0	0.8	0.8	1.0	0.0	0.0	0.1	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Brannan-Andrus Island	1.0	0.6	0.6	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Byron Tract	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.1	0.5	1.0	0.0	0.0	0.0	0.0	0.5	0.1
Holland Tract	1.0	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jersey Island	1.0	0.8	0.8	1.0	0.0	0.0	0.1	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lower and Upper Jones Tract	1.0	0.6	0.6	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mandeville Island	1.0	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
McDonald Tract	0.8	0.8	0.8	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Orwood Tract	0.8	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Palm Tract	0.8	1.0	1.0	1.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quimby Island	0.8	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Twitchell Island	1.0	0.6	0.6	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Venice Island	1.0	0.6	0.6		0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Victoria Island	1.0	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Webb Tract	1.0	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Woodward Island	0.5	0.6	0.6	0.5	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	**0.9**	**0.6**	**0.7**	**0.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.1**	**0.0**

Table 7-11. Fifty-breach sequence: Duration of Breach and Island pump-out schedule.

Islands / Tracts Breached on July 1, 2002.						Total Flood Duration			Flood Depth		
Island / Tract	Number of Breaches	Date of Breach Closure / Pump-out Begins	Duration of Breach (days)	Pump-Out Duration (days)	Month of Year Pump-out Complete	Days	~Months	~Years	Average	Maximum	Maximum Salinity of Floodwater, at Breach Closure (ppt)
Bacon Island	2	9/9/2004	801	40	10	841	28.0	2.3	-12.22	-22.46	0.6
Bethel Tract	2	9/19/2002	80	12	9	92	3.1	0.3	-2.36	-21.86	2.1
Bouldin Island	1	3/11/2003	253	47	4	300	10.0	0.8	-6.28	-25.35	0.4
Bradford Island	1	10/27/2002	118	11	11	129	4.3	0.4	-13.13	-26.74	0.9
Brannan-Andrus Island	2	2/20/2003	234	98	5	332	11.1	0.9	-6.69	-27.25	0.6
Byron Tract	1	8/4/2002	34	32	9	66	2.2	0.2	-11.66	-16.43	5.1
Holland Tract	3	3/18/2004	626	22	4	648	21.6	1.8	-7.43	-20.57	0.4
Jersey Island	4	1/12/2003	195	17	1	212	7.1	0.6	24.96	-38.18	0.9
Lower and Upper Jones Tract	2	5/16/2004	685	7	5	692	23.1	1.9	-8.42	-20.19	0.6
Mandeville Island	1	1/21/2004	569	43	3	612	20.4	1.7	12.95	-24.86	0.6
McDonald Tract	1	6/16/2004	716	52	8	768	25.6	2.1	-10.21	-36.49	0.6
Orwood Tract	2	7/31/2004	761	12	8	773	25.8	2.1	-7.2	-17.32	0.6
Palm Tract	2	7/13/2004	743	14	7	757	25.2	2.1	-13.86	-22.78	0.6
Quimby Island	1	1/20/2004	568	4	1	572	19.1	1.6	-5.62	-22.95	0.4
Sherman Island	20	1/20/2004	568	13	2	581	19.4	1.6	-13.47	-37.31	0.2
Twitchell Island	1	11/9/2002	131	24	12	155	5.2	0.4	-5.67	-26.63	0.9
Venice Island	1	5/16/2004	685	28	6	713	23.8	2.0	-7.62	-23.65	0.6
Victoria Island	1	4/26/2003	299	37	6	336	11.2	0.9	-7.64	-34.83	0.9
Webb Tract	1	5/2/2004	671	42	6	713	23.8	2.0	-8.1	-34.46	1.4
Woodward Island	1	10/16/2004	838	11	10	849	28.3	2.3	-8.85	-19.26	0.6

Number of islands breached = 21

SWP/CVP shut-off duration = 2 years, 3.5 months

SWP/CVP shut-off duration based on an emergency repair schedule = 11.5 months

[1] Breach date is July 2002; average time to pump out an island is 30 days ±24 day, max = 98 (Brannan-Andrus), min = Quimby Island.

[2] Parts per thousand (ppt) information converted from data reported as electrical conductivity (µmho/cm) by multiplying by 0.00064.

[3] Note that Upper and Lower Jones Tract are one island separated by a roadway bridge making them function as two with regard to flooding.

Table 7-12. Fifty-breach sequence: Duration of flooding on breached islands.

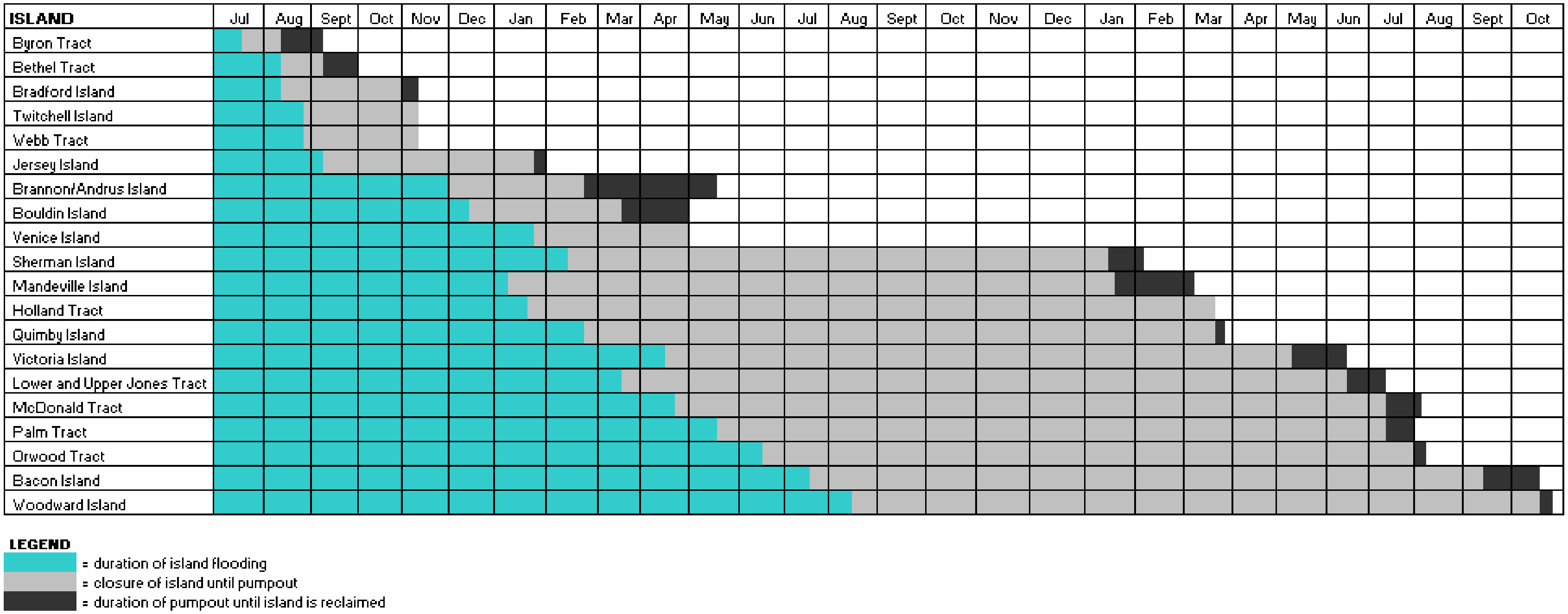


Table 7-13. Fifty-breach sequence: Area of vegetation types affected.

No. breaches	Area	Island/Tract Name	Calculation	Vegetation type area (acres)																			Total area (acres)	%
				No wild veg					Aquatic	Marsh			Freshwater wetland			Upland					Riparian			
				No Information	Agriculture	Developed	Non-Vegetated	Open Water	Aquatic Vegetation	Alkali Marsh Low	Alkali Marsh Mid	Alkali Marsh High	Herbaceous Wetland, Perennial	Herbaceous Wetland, Seasonal	Herbaceous Wetland, Seasonal, Ruderal	Herbaceous Upland	Herbaceous Upland, Ruderal	Shrub Upland	Tree Upland	Tree Upland, Non-Native	Shrub Wetland (riparian)	Tree Wet (riparian)		
50 (w/ Sherman Island)	Island	Bacon	—	0.00	5149.85	64.82	16.58	4.50	0.00	0.00	0.00	6.74	0.97	0.00	5.11	0.00	268.06	0.00	0.61	6.61	4.69	2.09	5530.63	—
		Bethel	—	0.00	477.06	429.75	25.25	2.30	3.07	0.00	0.00	0.00	1.27	0.00	122.28	0.00	1965.79	0.00	1.39	216.65	132.21	86.59	3463.62	—
		Bouldin	—	0.00	5330.78	12.47	2.26	5.73	0.42	22.62	0.00	0.00	19.21	0.00	7.14	0.00	508.31	0.00	0.00	5.09	18.12	5.14	5937.29	—
		Bradford Island	—	0.00	10.79	16.86	32.04	26.26	4.48	0.00	0.00	1.38	49.11	10.95	498.16	0.00	1145.80	0.00	0.00	5.33	183.93	152.40	2137.48	—
		Brannan-Andrus	—	0.10	13237.69	379.73	77.44	15.09	9.40	0.00	0.00	0.00	12.36	0.00	26.63	0.00	724.74	10.13	47.61	292.56	96.88	45.43	14975.80	—
		Byron	—	0.00	4351.30	114.13	1.27	6.78	0.00	0.00	59.06	35.76	0.27	0.00	0.00	0.00	337.80	0.00	0.00	2.22	0.00	0.00	4908.59	—
		Holland	—	0.00	1064.50	8.30	31.68	69.09	6.01	7.26	0.00	81.99	65.53	0.00	1292.36	0.00	1408.27	1.68	0.00	4.54	80.80	95.51	4217.51	—
		Jersey	—	0.00	471.67	5.71	36.31	1.75	0.00	0.00	0.00	0.00	41.08	0.00	212.53	0.00	2646.81	0.00	0.00	0.00	19.76	28.39	3464.00	—
		Mandeville	—	0.00	2314.63	4.85	24.63	88.70	74.57	63.50	0.00	403.56	241.51	0.00	642.64	0.00	1175.64	1.25	0.00	12.02	69.64	96.67	5213.81	—
		McDonald	—	0.00	4913.10	78.26	344.30	18.08	15.59	0.00	0.00	21.07	55.64	0.00	128.85	0.00	299.27	19.19	0.00	14.47	108.51	46.10	6062.45	—
		Orwood	—	0.00	2208.99	13.60	6.47	18.83	0.00	5.83	0.00	3.27	22.28	0.00	26.81	0.00	150.11	0.00	0.00	1.00	14.58	1.62	2473.39	—
		Palm	—	0.00	2160.75	84.52	18.28	0.00	0.00	0.00	0.00	0.00	5.34	0.00	2.77	0.00	86.30	0.00	0.77	12.33	10.97	2.27	2384.32	—
		Quimby	—	0.00	551.73	0.00	19.19	5.39	6.41	0.01	0.00	29.79	1.09	0.00	5.14	0.00	101.32	0.00	0.00	1.86	43.44	4.51	769.87	—
		Twitchell	—	0.00	3115.50	11.47	10.01	5.02	2.81	0.00	0.00	0.00	12.73	0.00	29.91	0.00	329.41	0.00	0.00	13.22	34.86	3.38	3568.33	—
		Upper, Lower Jones	—	0.00	11403.34	90.18	45.44	32.24	10.96	0.00	0.00	0.00	3.29	0.00	26.16	0.00	345.76	0.00	0.00	12.63	119.05	42.24	12131.29	—
		Venice	—	0.00	2758.93	4.02	3.13	18.79	9.58	0.00	0.00	1.70	7.31	0.00	24.37	0.00	160.88	0.00	0.00	3.64	29.49	73.57	3095.42	—
		Victoria	—	0.00	6678.25	205.67	17.77	25.19	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	262.66	0.00	0.87	4.48	0.01	0.00	7195.74	—
		Webb	—	0.00	4434.76	0.00	15.02	82.19	0.88	0.00	0.00	0.00	26.08	0.00	118.06	0.00	605.10	0.00	0.00	5.19	79.14	74.44	5440.86	—
		Woodward	—	0.00	1652.27	29.46	7.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.70	0.00	112.99	0.00	4.21	0.00	4.27	3.95	1814.92	—
		Sherman*	—	0.00	8796.22	71.51	99.36	50.75	0.00	143.09	0.00	0.63	13.94	0.00	114.60	0.00	793.70	5.49	0.00	23.78	47.74	22.34	10183.15	—
	Breached area	—	Total area (acres)	0.10	81082.11	1625.31	833.51	476.68	145.03	242.31	59.06	585.90	579.01	10.95	3284.22	0.00	13428.74	37.74	55.46	637.62	1098.09	786.64	104968.47	—
		—	% of breached area	0.00	77.24	1.55	0.79	0.45	0.14	0.23	0.06	0.56	0.55	0.01	3.13	0.00	12.79	0.04	0.05	0.61	1.05	0.75	—	—
		—	% of breached area	80.04					0.14	0.85			3.69			13.49					1.80		—	—
	Breached area vs Delta	—	Total area in Delta (acres)*	6.85	282502.73	8989.64	2171.95	6284.75	350.62	332.06	91.72	937.61	2729.48	12.45	4707.89	0.57	21928.07	77.61	774.13	2241.46	2207.78	1759.99	338107.38	—
		—	% of veg group in Delta*	1.42	28.70	18.08	38.38	7.58	41.36	72.97	64.38	62.49	21.21	87.95	69.76	0.00	61.24	48.63	7.16	28.45	49.74	44.70	—	—
		—	% of veg type in Delta*	28.01					41.36	65.17			52.00			56.59					47.50		—	—
		—	% of Delta	24.85					0.04	0.26			1.15			4.19					0.56		—	31.05
30 vs. 50	—	—	% difference 30 vs 50-breach sequence	0.00	3.11	0.80	4.57	0.81	0.00	43.09	0.00	0.07	0.51	0.00	2.43	0.00	3.62	7.08	0.00	1.06	2.16	1.27	—	

Table 7-14. Fifty-breach sequence: Adult survival of vegetation-type focal species.

Island Name	Vegetation Types and Focal Species (Adult Suitability)															
	Aquatic			Marsh			Freshwater wetland			Upland					Riparian	
	Aquatic Non-Native	Aquatic Non-Native	Aquatic Native	Marsh Low	Marsh Mid	Marsh High	Herbaceous Wetland Seasonal	Herbaceous Wetland Seasonal Ruderal	Herbaceous Wetland Perennial	Herbaceous Upland	Herbaceous Upland Ruderal	Shrub Upland	Tree Native	Tree Non-Native	Shrub Wetland (Riparian)	Tree Riparian
	Egeria densa	*Eichornia crassipes*	*Potamogeton pectinatus*	*Typha angustifolia*	*Salicornia virginica*	*Frankenia salina*	*Juncus balticus*	*Lolium multiflorum var_ perenne*	*Scirpus americanus*	*Leymus triticoides*	*Avena fatua*	*Baccharis pilularis*	*Quercus lobata*	*Eucalyptus globulus*	*Rubus discolor*	*Fraxinus latifolia*
Bacon Island	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bethel Tract	1.0	0.0	0.6	0.5	0.0	0.0	0.0	0.1	1.0	1.0	0.0	0.0	0.0	0.0	0.5	0.1
Bouldin Island	0.5	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bradford Island	1.0	0.6	0.6	0.1	0.0	0.0	0.1	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Brannan-Andrus Island	0.5	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Byron Tract	0.8	0.8	0.8	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Holland Tract	0.5	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Jersey Island	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.5	0.8	0.1	0.1	0.1	0.1	0.1	0.1
Lower and Upper Jones Tract	0.5	0.6	0.6	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mandeville Island	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
McDonald Tract	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Orwood Tract	0.5	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Palm Tract	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Quimby Island	0.5	0.8	0.8	1.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sherman Island	0.5	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Twitchell Island	1.0	0.8	0.8	1.0	0.0	0.0	0.1	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Venice Island	0.5	0.6	0.6	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Victoria Island	1.0	0.6	0.6	1.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Webb Tract	1.0	0.6	0.6	1.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Woodward Island	0.5	0.6	0.6	0.5	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	**0.6**	**0.6**	**0.6**	**0.6**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**0.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Table 7-15. Fifty-breach sequence: Time to recover to mature vegetation from breach for vegetation-type focal species.

	Focal species of Vegetation Types, Time Until Recovery of Mature Vegetation (Months)															
	Aquatic			Marsh			Freshwater Wetland			Upland					Riparian	
	Aquatic Non-Native	Aquatic Non-Native	Aquatic Native	Marsh Low	Marsh Mid	Marsh High	Herbaceous Wetland Seasonal	Herbaceous Wetland Seasonal Ruderal	Herbaceous Wetland Perennial	Herbaceous Upland	Herbaceous Upland Ruderal	Shrub Upland	Tree Native	Tree Non-Native	Shrub Wetland (Riparian)	Tree Riparian
Island Name	*Egeria densa*	*Eichornia crassipes*	*Potamogeton pectinatus*	*Typha angustifolia*	*Salicornia virginica*	*Frankenia salina*	*Juncus balticus*	*Lolium multiflorum var_ perenne*	*Scirpus americanus*	*Leymus triticoides*	*Avena fatua*	*Baccharis pilularis*	*Quercus lobata*	*Eucalyptus globulus*	*Rubus discolor*	*Fraxinus latifolia*
Bacon Island	0	0	0	42	39	39	42	45	45	45	48	48	273	99	57	393
Bethel Tract	0	14	0	0	14	14	17	20	0	0	23	23	248	74	0	368
Bouldin Island	0	0	0	30	27	27	30	33	33	21	24	24	261	75	45	381
Bradford Island	0	0	0	0	14	14	17	20	0	20	23	23	248	74	32	368
Brannan-Andrus Island	0	0	0	0	27	27	30	33	33	21	24	24	261	75	45	381
Byron Tract*	11	14	11	17	14	14	17	20	0	0	23	23	248	74	0	368
Holland Tract	0	0	0	0	39	39	42	45	45	33	36	36	273	87	57	393
Jersey Island	0	0	0	0	15	15	18	21	21	21	24	24	249	75	33	369
Lower and Upper Jones Tract	0	0	0	0	39	39	42	45	45	33	36	36	273	87	57	393
Mandeville Island	0	0	0	41	38	38	41	44	44	32	35	35	272	86	56	392
McDonald Tract	0	0	0	42	39	39	42	45	45	33	36	36	273	87	57	393
Orwood Tract	0	0	0	0	39	39	42	45	45	33	36	36	273	87	57	393
Palm Tract	0	0	0	0	39	39	42	45	45	33	36	36	273	87	57	393
Quimby Island	0	0	0	0	39	39	42	45	45	33	36	36	273	87	57	393
Sherman Island	0	0	0	0	26	26	29	32	32	32	35	35	260	86	44	380
Twitchell Island	0	0	0	17	14	14	17	20	20	20	23	23	248	74	32	368
Venice Island	0	0	0	30	27	27	30	33	33	21	24	24	261	75	45	381
Victoria Island	0	0	0	0	39	39	42	45	45	33	36	36	273	87	57	393
Webb Tract	0	0	0	18	15	15	18	21	21	21	24	24	249	75	33	369
Woodward Island	0	0	0	0	39	39	42	45	45	45	48	48	273	99	57	393

Table 7-16. Fifty-breach sequence: Extent of terrestrial wildlife habitat affected.

Selected Species/Species Group	Delta (acres)	Suisun Marsh	Total Extent of Habitat in the Study Area	Percent of Total Habitat Area Affected in the Study Area
Suisun ornate shrew	0	TBD	TBD	0
Salt marsh harvest mouse	0	TBD	TBD	0
California clapper rail	0	TBD	TBD	0
California black rail	1,210	TBD	TBD	0
Saltmarsh common yellowthroat	0	TBD	TBD	0
Greater sandhill crane	41,122	0	TBD	TBD
Geese, swans, and dabbling ducks	72,286	TBD	TBD	TBD

Table 7-17. Area of vegetation types impacted: Suisun Marsh.

Area	Area of Vegetation Type (acres, percent)																			Total
	No Wild Vegetation					**Aquatic**	**Marsh**			**Freshwater Wetland**			**Upland**					**Riparian**		
Area	No Info.	Agriculture	Developed	Non-Vegetated	Open Water	Aquatic	Alkali Marsh Low	Alkali Marsh Mid	Alkali Marsh High	Herbaceous Wetland, Perennial	Herbaceous Wetland, Seasonal	Herbaceous Wetland, Seasonal, Ruderal	Herbaceous Upland	Herbaceous Upland, Ruderal	Shrub Upland	Tree Upland, Native	Tree Upland, Non-Native	Shrub Wetland (Riparian)	Tree Wetland (Riparian)	**Total**
Suisun marsh, interior of leveed areas over 30 ft of organic material	0	263.0	864.8	1687.5	2026.8	5.8	6143.2	13311.4	3073.6	5524.8	2279.7	1741.1	341.6	6721.6	236.7	0.8	192.6	73.0	1.7	44489.6
Percent of breached area	0	0.6	1.9	3.8	4.6	0.0	13.8	29.9	6.9	12.4	5.1	3.9	0.8	15.1	0.5	0.0	0.4	0.2	0.0	—
Delta and Suisun Marsh (acres)[2]	107	478201	61278	10974	66412	4485	16649	16391	8370	17258	3390	10355	510	78169	490	2202	6126	6650	7106	795124
Percent of Delta and Suisun Marsh	0	0.1	1.4	15.4	3.1	0.1	36.9	81.2	36.7	32.0	67.3	16.8	67.0	8.6	48.3	0.0	3.1	1.1	0.0	—
	0.8					**0.1**	**54.4**			**30.8**			**8.6**					**0.5**		—

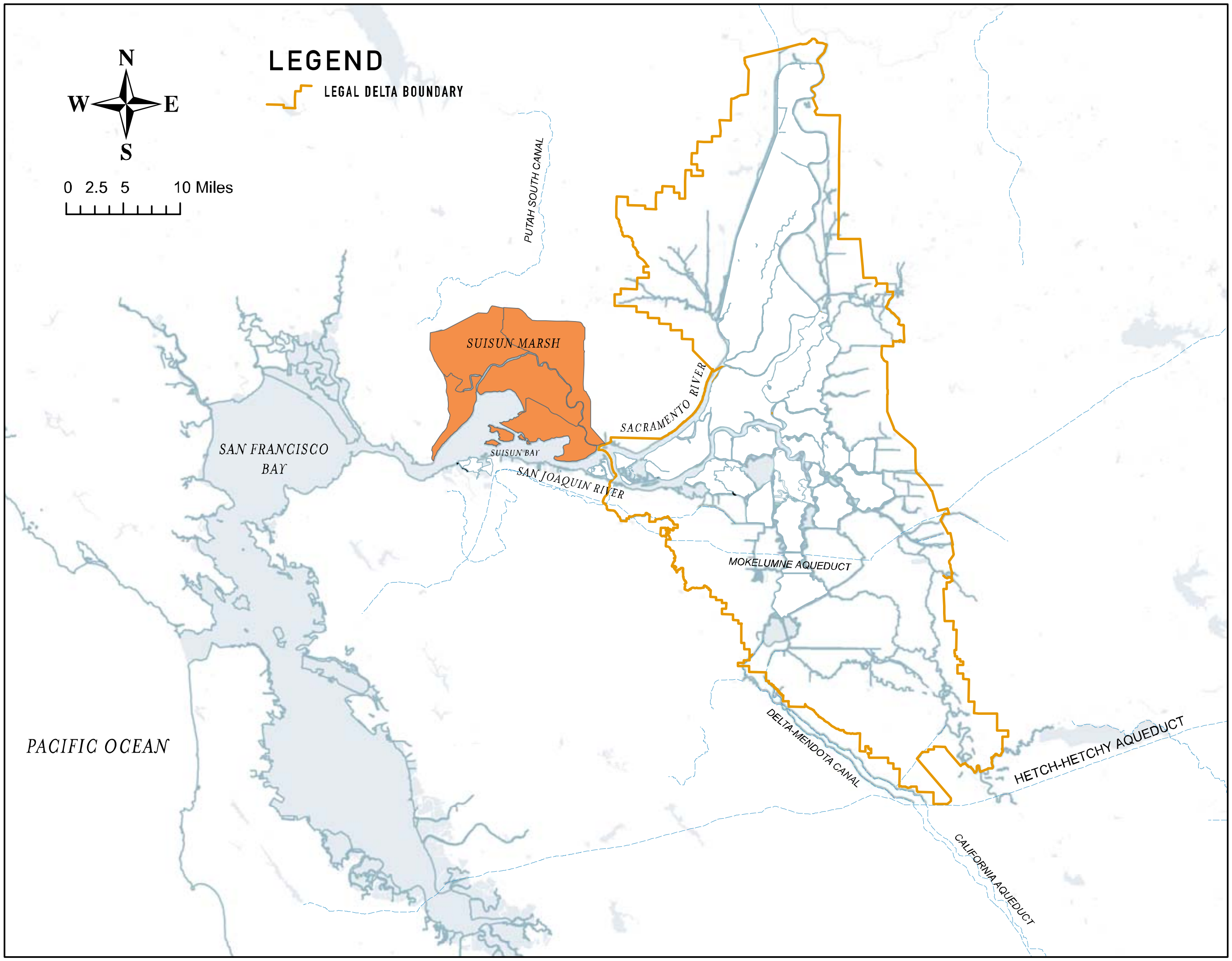


Figure 1-1 Map of the Sacramento–San Joaquin Delta and Suisun Marsh.

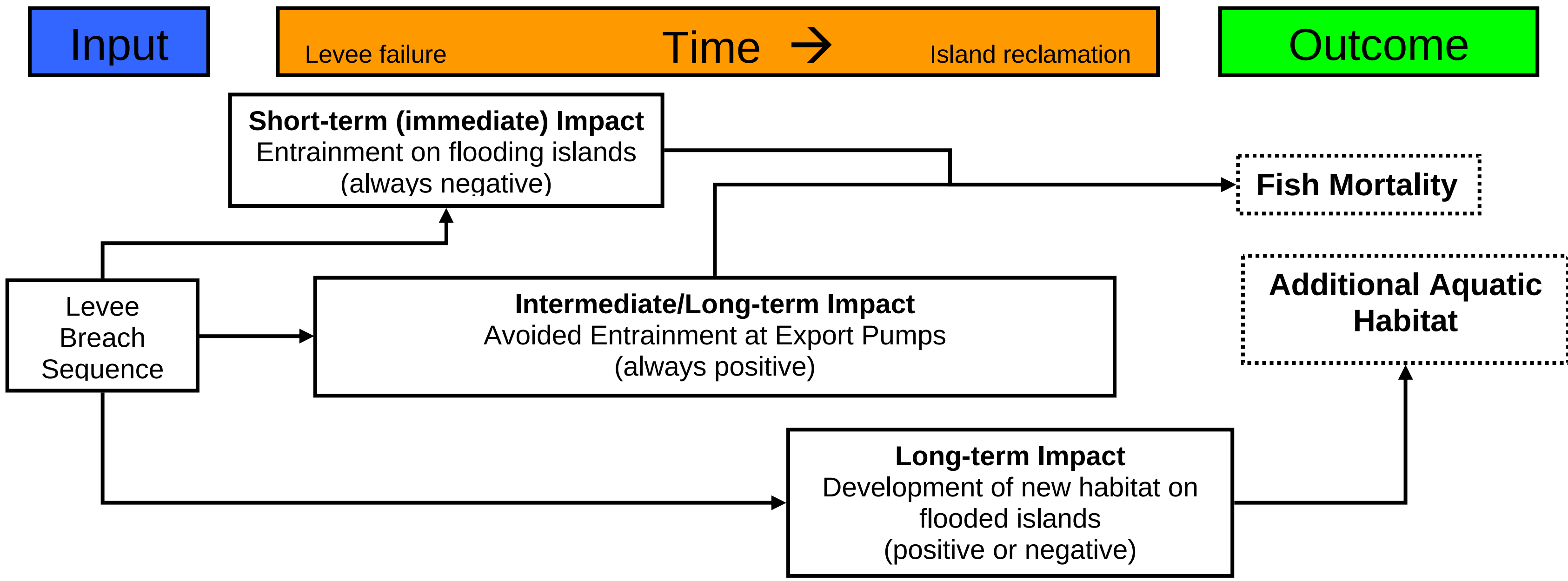


Figure 2-1 Schematic illustration of the aquatics impact model showing three effect mechanisms operating on different time scales

Figure 3-1 Subsidence on Delta Islands (USGS 2000)

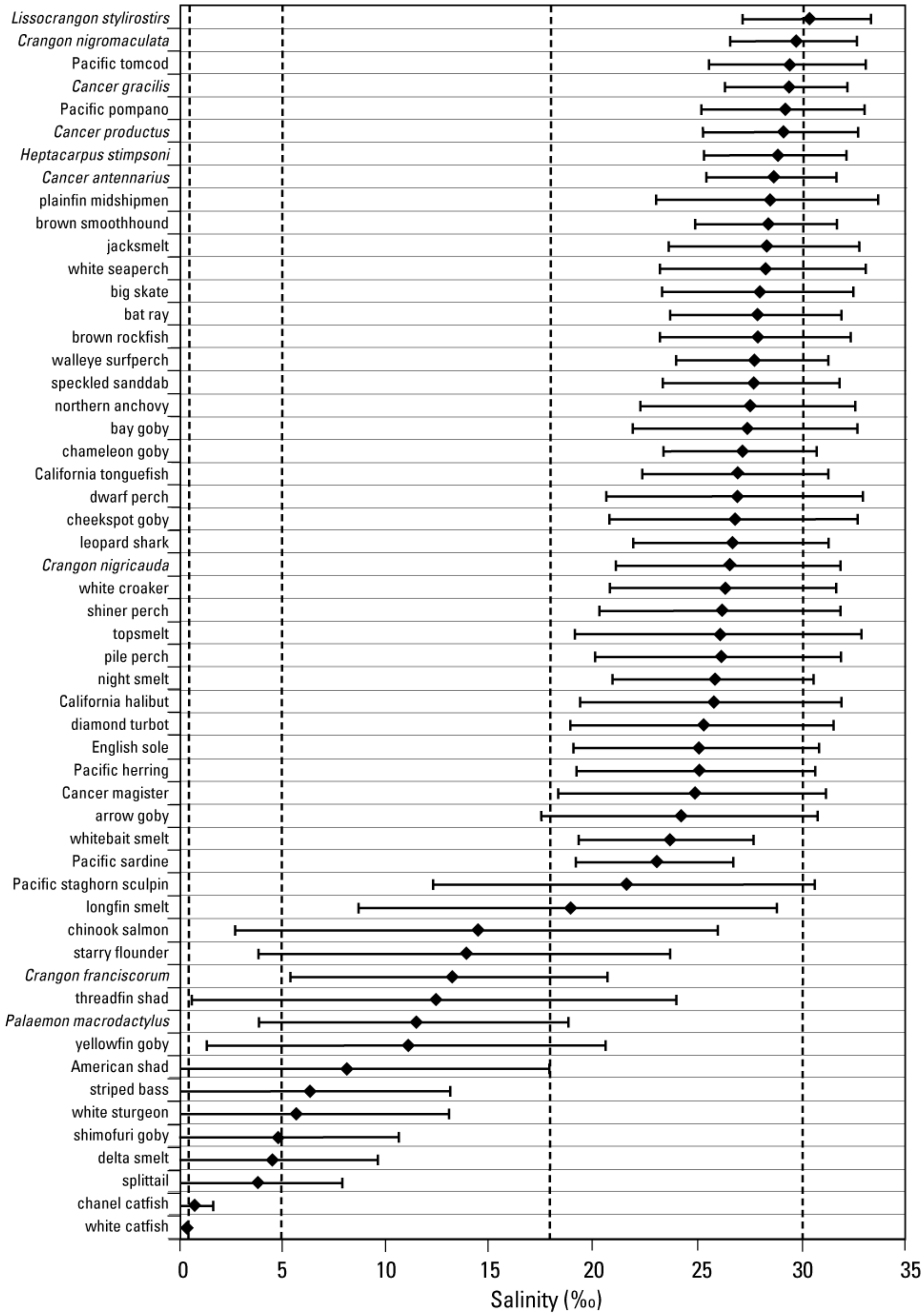


Figure 3-2 Mean salinity (%o) +/- standard deviation for the 54 most commonly collected species of fishes, shrimps, and crabs during the Bay Study, 1980 to 1995 (survey continues through present) (Baxter et al. 1999)

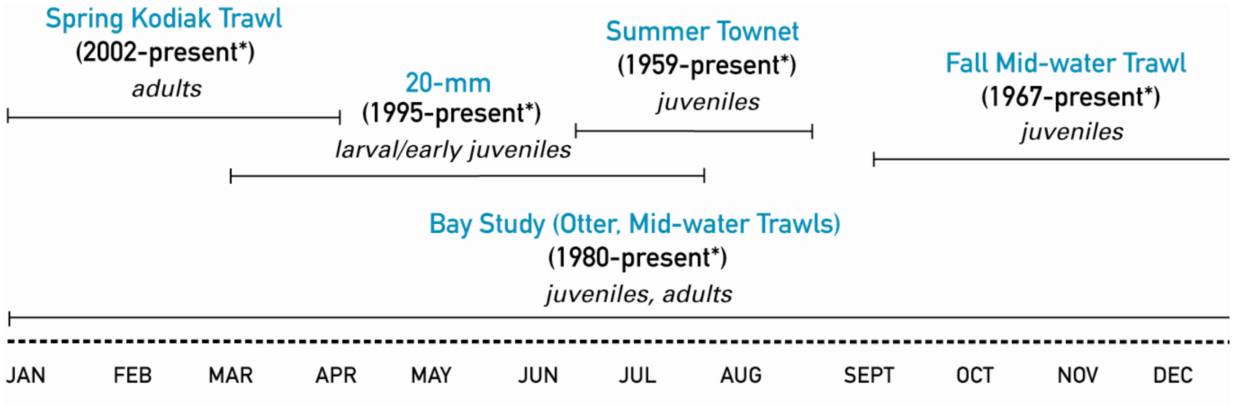


Figure 3-3 Seasonal periods when fishery sampling is conducted within the Delta and Suisun Marsh using various collection methods.

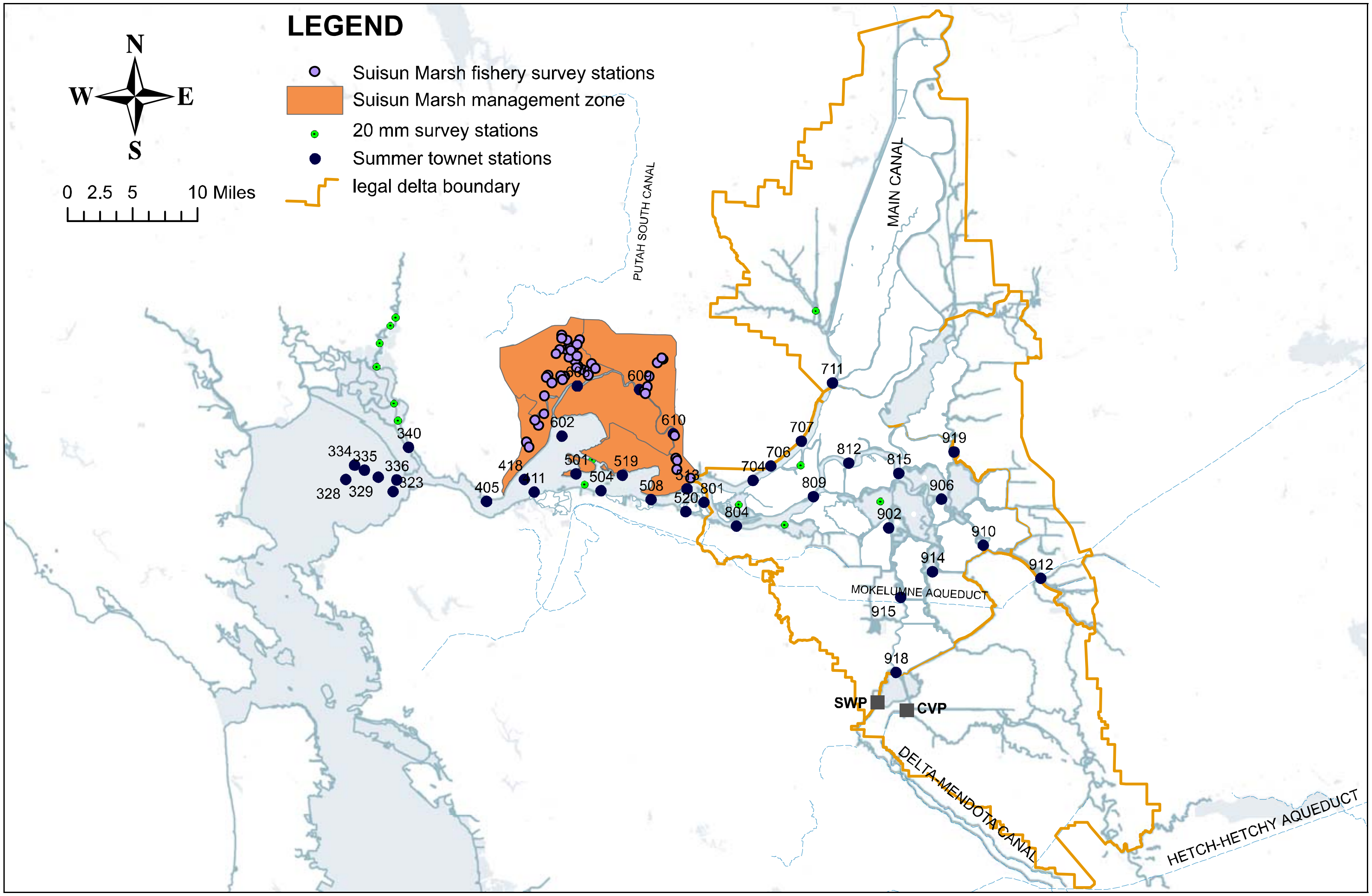


Figure 3-4 Survey sites for three aquatic ecosystem sampling programs throughout the Delta and Suisun Marsh. In the Fall Mid-water Trawl (not pictured), more than 81 sites in the northern estuary are sampled between September and December. In the Bay Study (not pictured), more than 50 sites throughout the estuary, including San Francisco Bay and the South Bay, are sampled (CDFG 2006b).

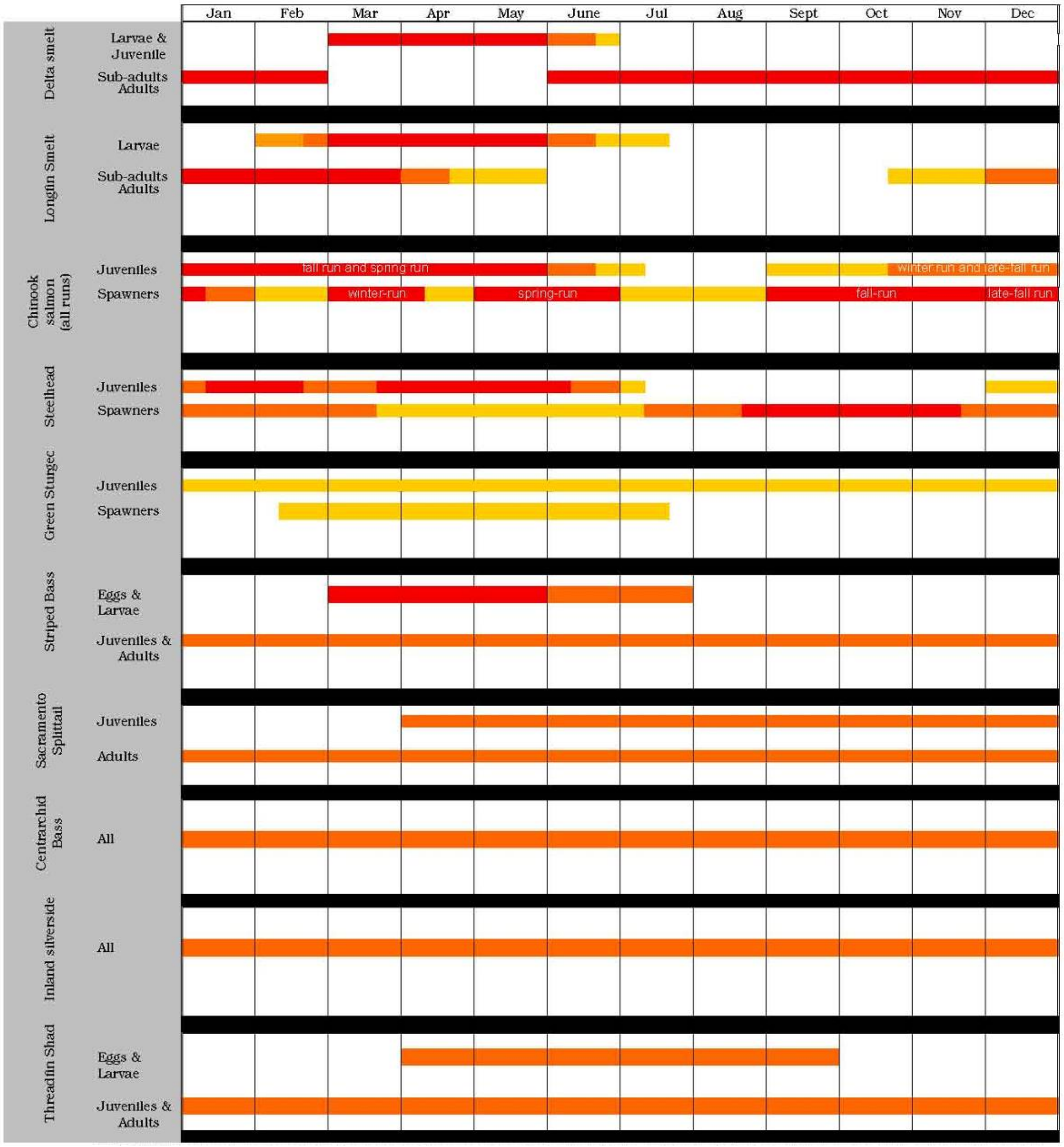


Figure 3-5 Periods of residence in the Northern San Francisco Estuary, including Suisun Marsh and San Pablo Bay, of selected representative taxa considered in the DRMS aquatic ecosystem analysis. Coloration and shading indicate relative temporal distribution of population in the northern estuary. Red hatched cells indicate months of peak occurrence, orange cells indicate moderate occurrence, yellow cells indicate infrequent or rare occurrence. Little is known about the temporal and spatial distribution of green sturgeon; thus, the time periods presented here for that species are estimates.

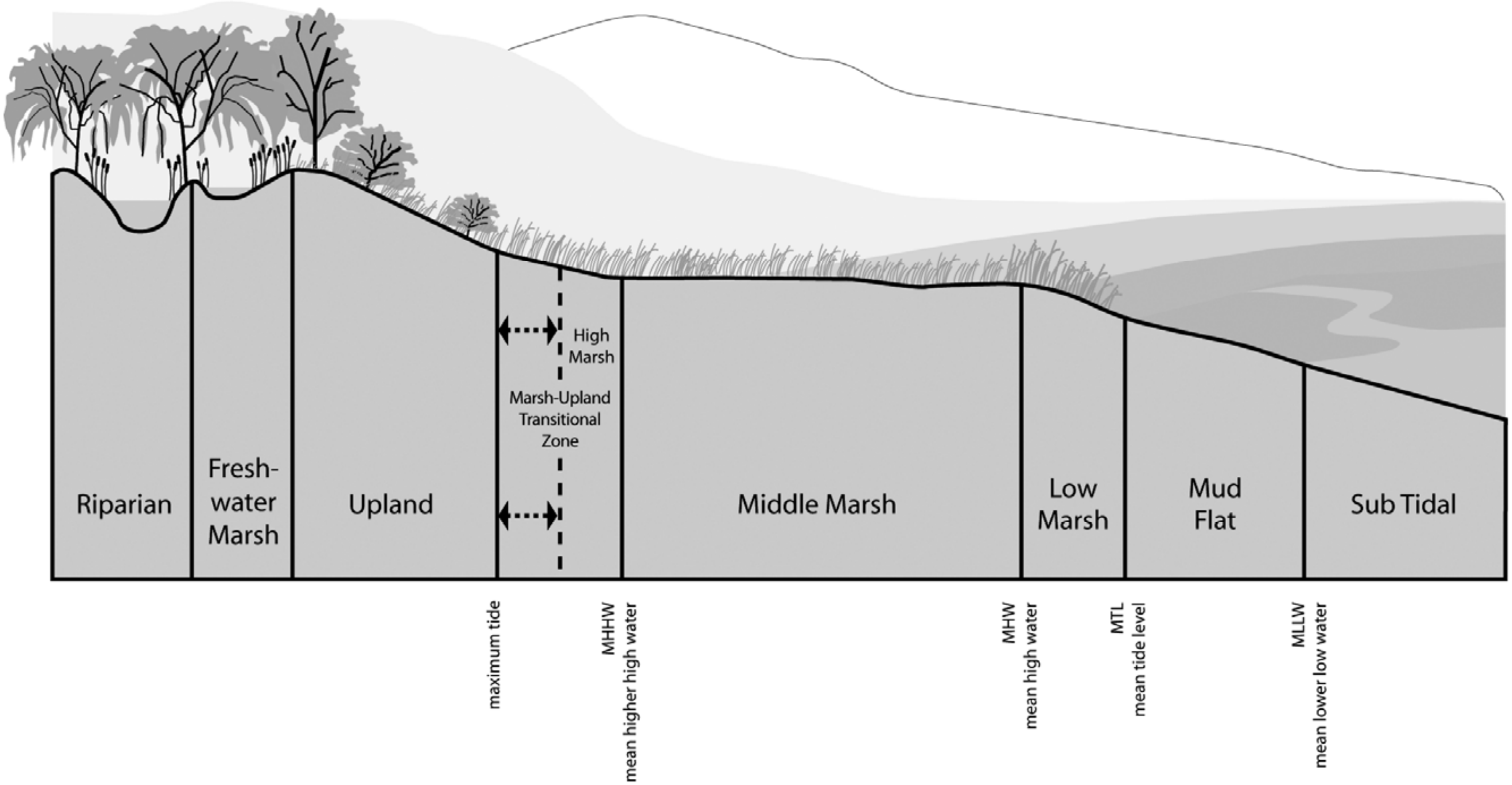


Figure 3-6. Profile of land in the Delta and Suisun Marsh and accompanying vegetation types.

Figure 3-7 Old River near Route 4 (CCWD et al. 2003). Channel side of Delta levees of different heights with range of densities vegetation.

Figure 3-8 Channel side of Delta levee, Old River near Route 4; no vegetation (CCWD et al. 2003).

Figure 3-9 Channel side of Delta levee Old River between Orowood Bridge; upland but no marsh habitat (CCWD et al. 2003).

Figure 3-10 Channel side of Delta levee, Old River Orowood Bridge area; extensive vegetation, in vegetation categories including trees (CCWD et al. 2003).

Figure 3-11 Channel side of Suisun marsh exterior levee (URS 2006)

Figure 3-12 Interior of Suisun Marsh exterior levees. Managed diked tidal marsh "base case" on October 18, 2006.

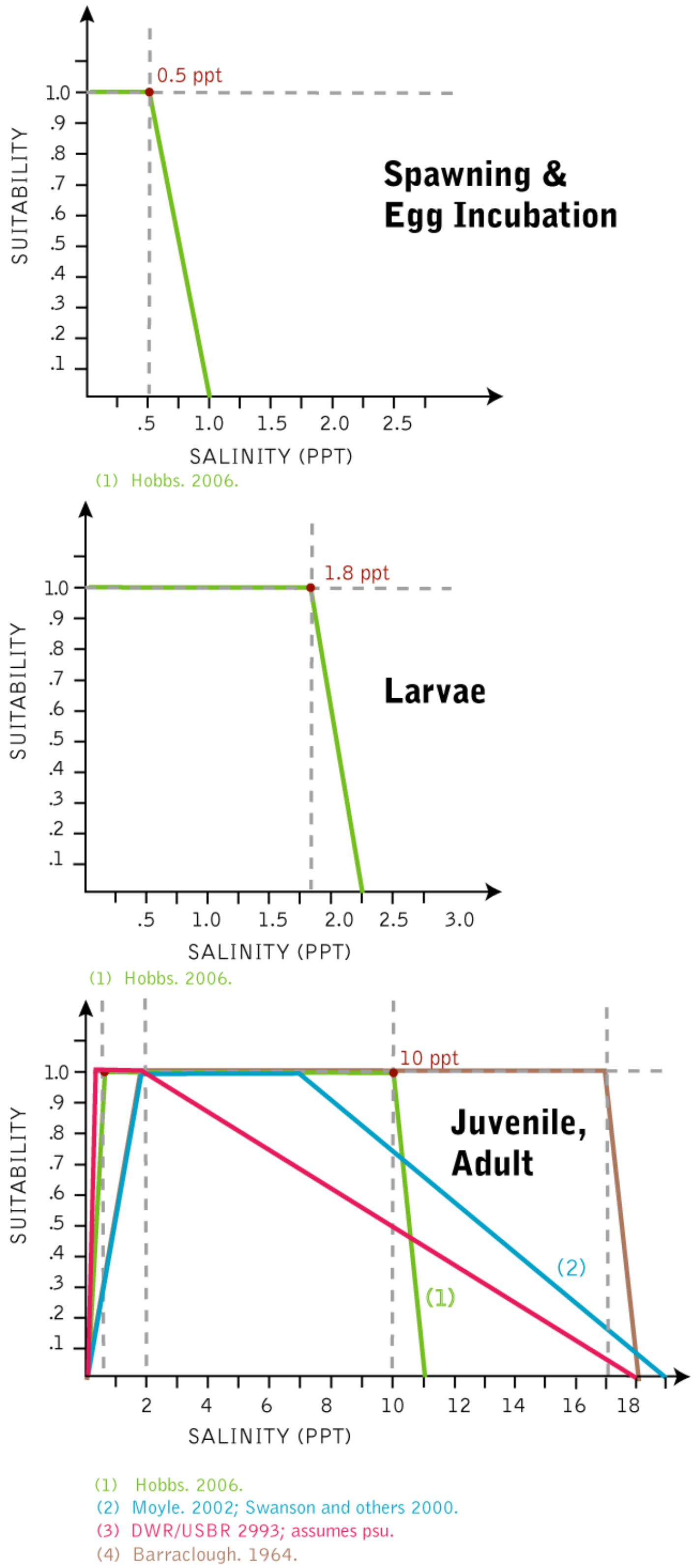
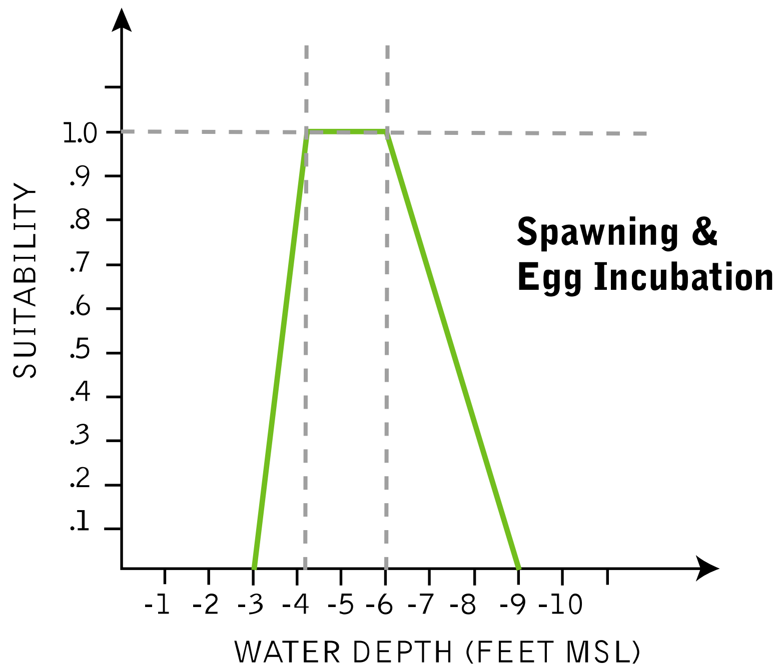


Figure 4-1 Delta smelt salinity suitability curves.



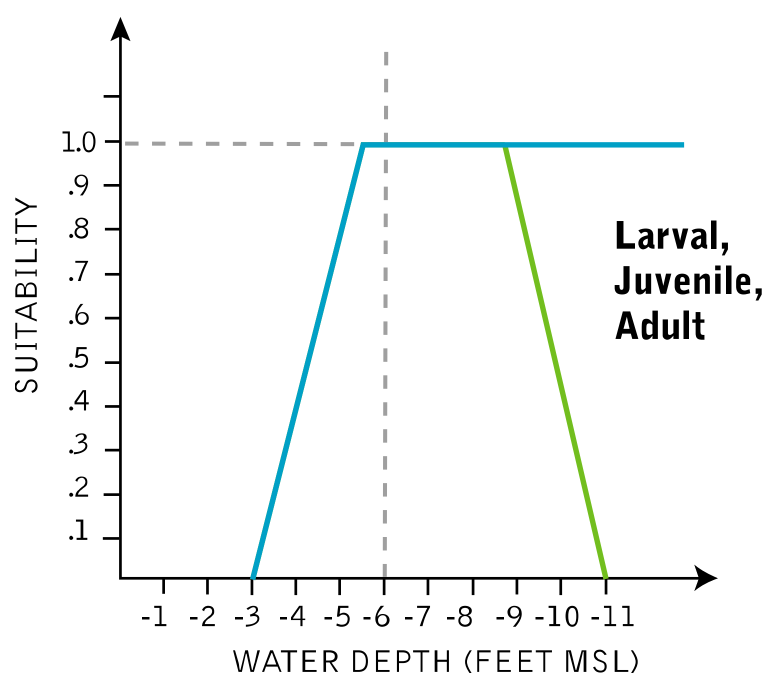


Figure 4-2 Delta smelt depth suitability curves

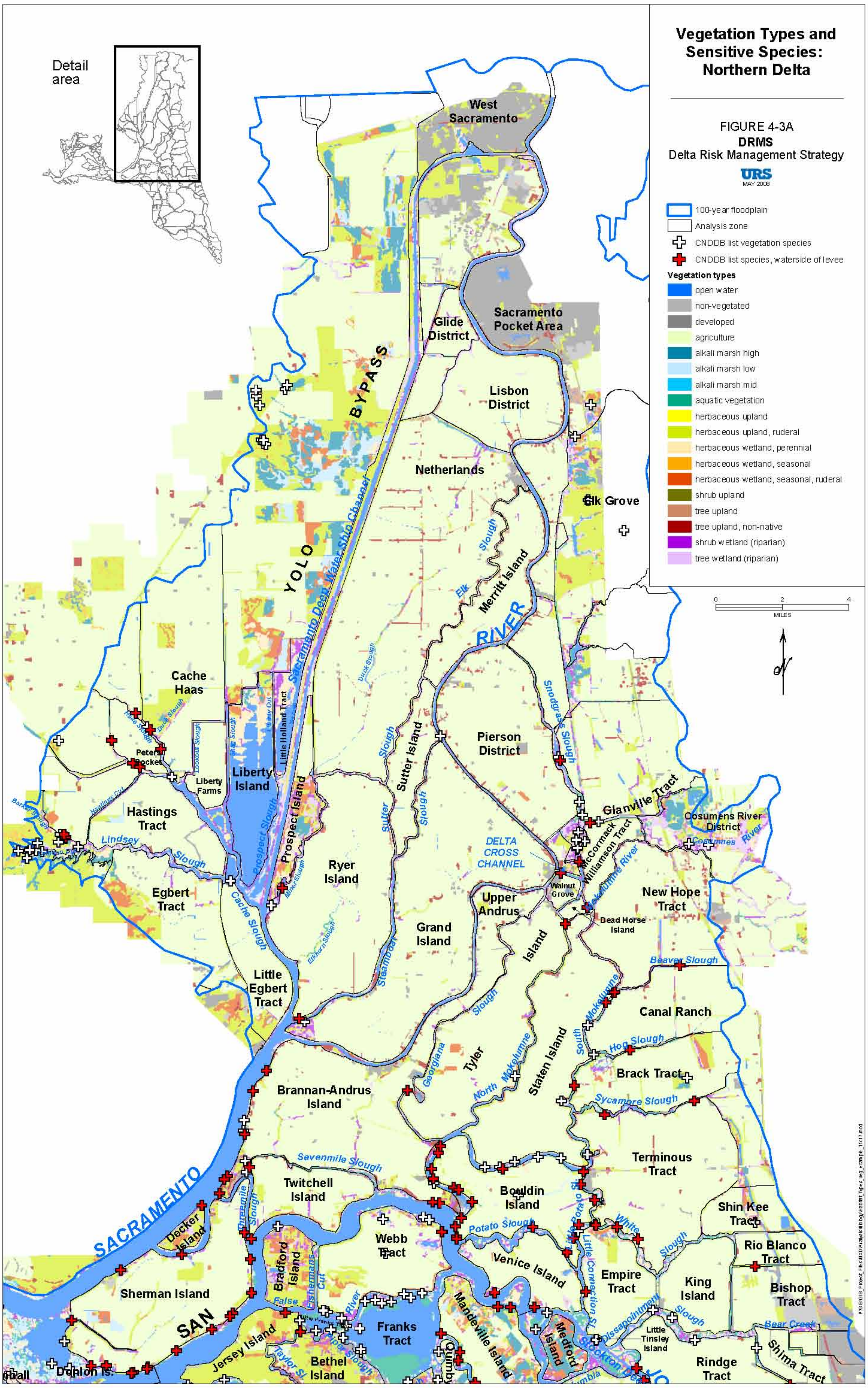


Figure 4-3a Vegetation Types and Sensitive Species: Northern Delta

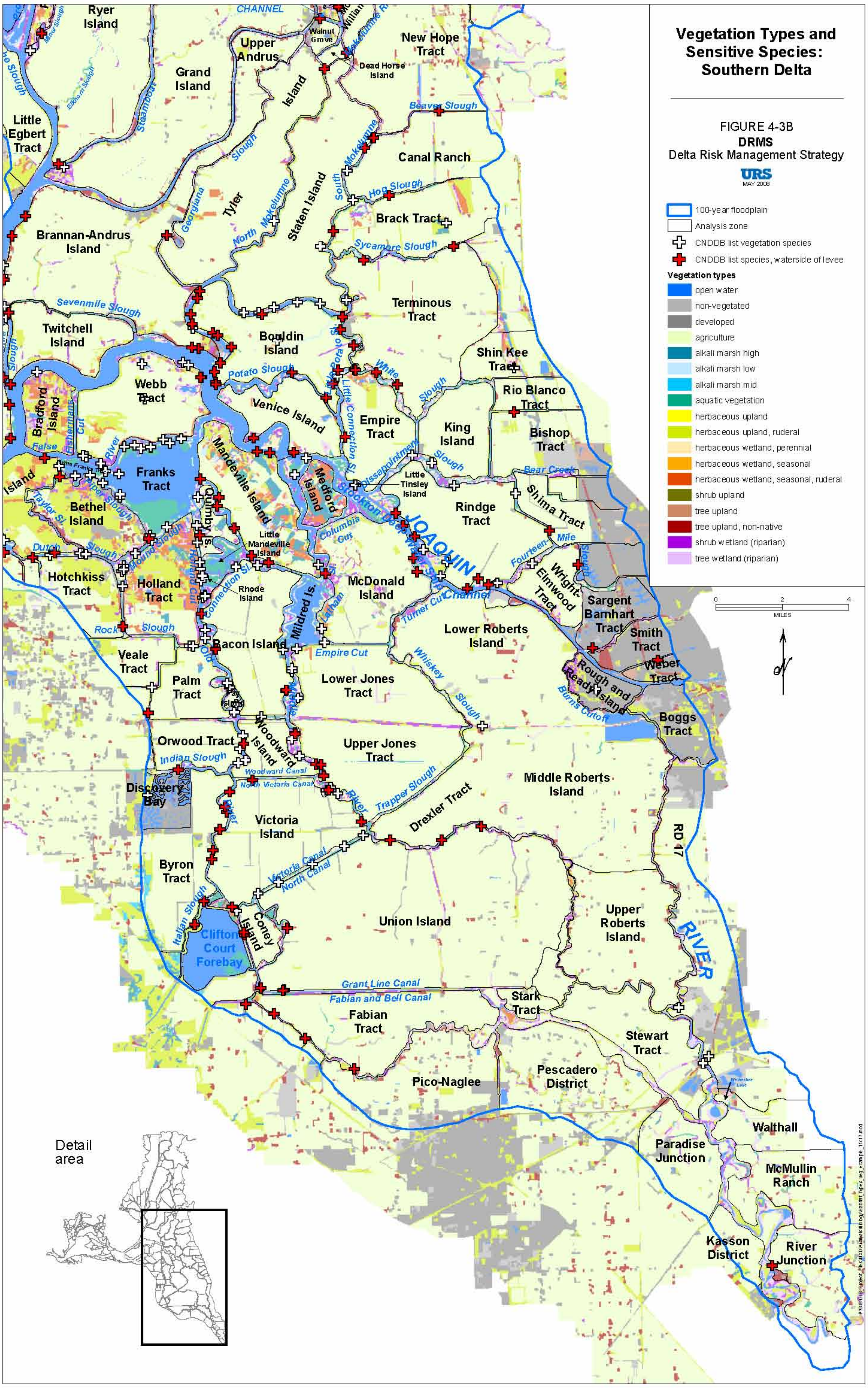


Figure 4-3b Vegetation Types and Sensitive Species: Southern Delta

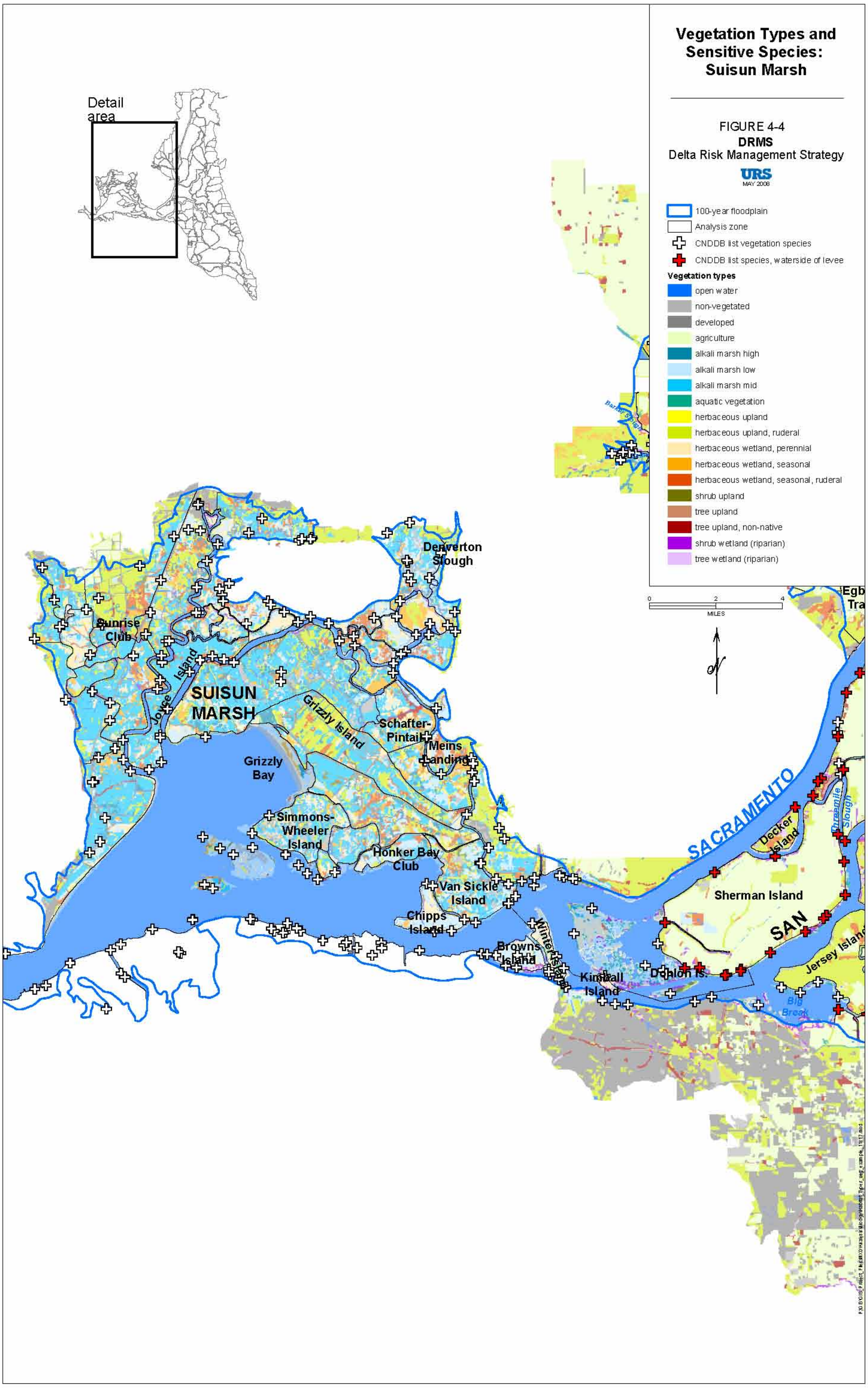


Figure 4-4 Vegetation Types and Sensitive Species: Suisun Marsh

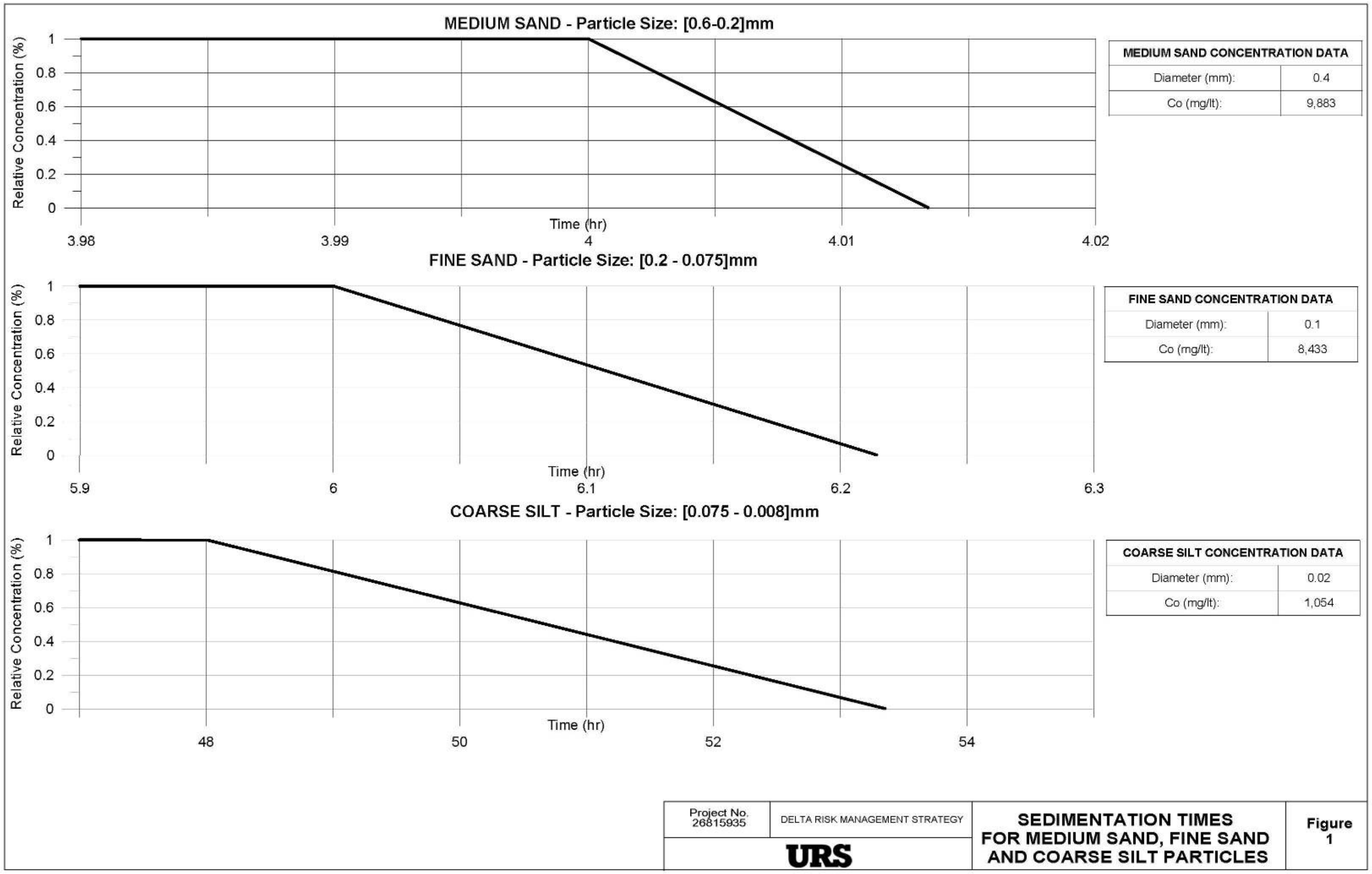


Figure 6-1a Settling times of coarse fraction of sediments suspended as a result of island flooding. Settling is assumed to begin when the island completed flooding (hr = 0).

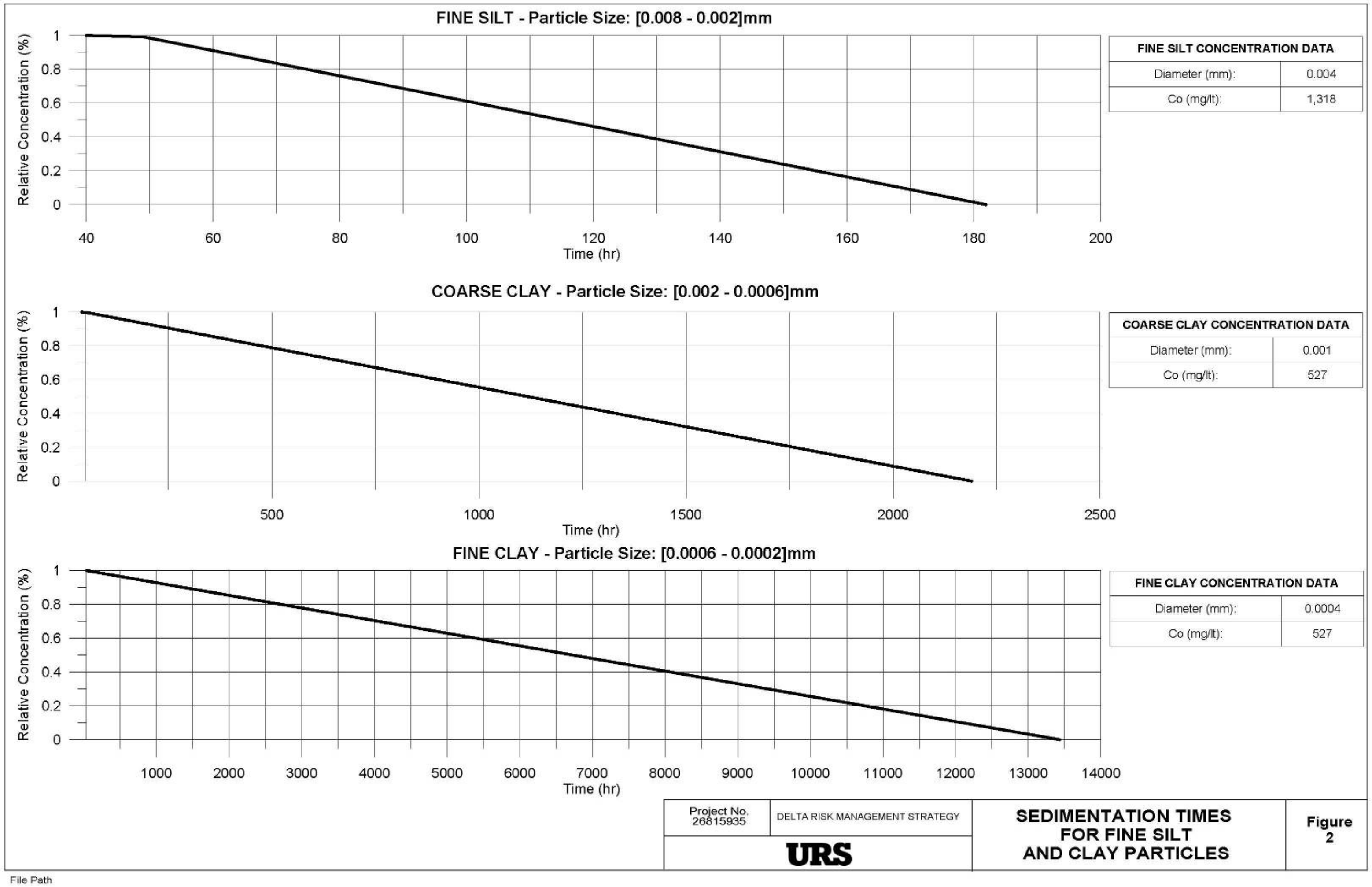


Figure 6-1b. Settling times of fine fractions of sediments suspended as a result of island flooding. Settling is assumed to begin when the island completed flooding (hr = 0).

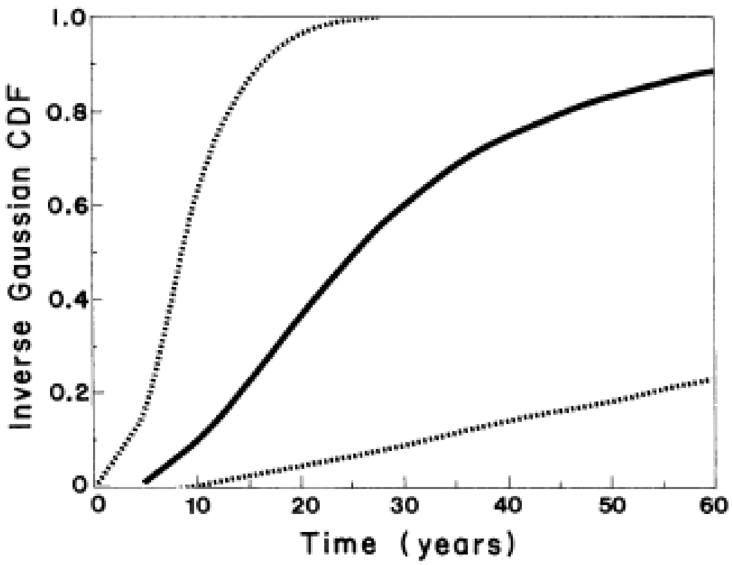


Figure 6-2 An example of an estimate of the cumulative probability distribution on the time to extinction, including uncertainty (Dennis et al. 1991). The solid line is the median estimate and the dotted lines are the 0.05 and the 0.95 probability levels, respectively.

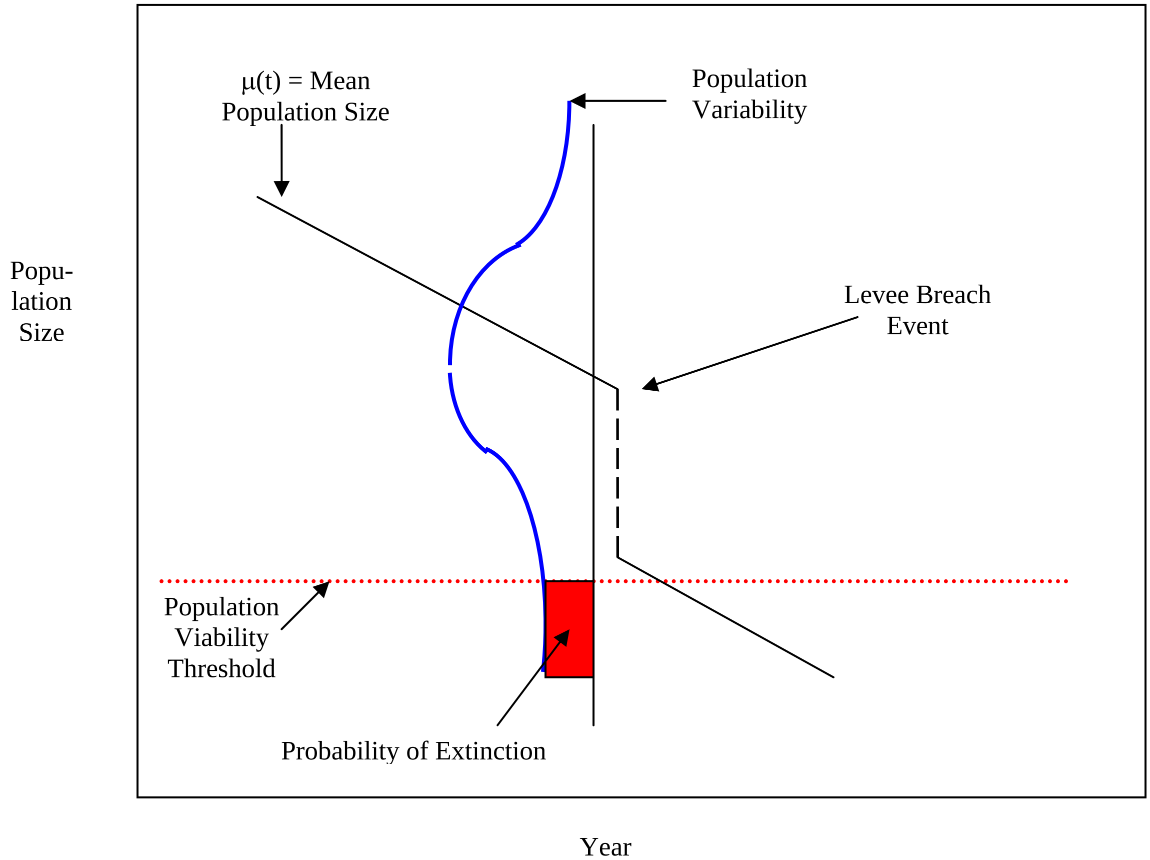


Figure 6-3 Schematic illustration coupling the aquatic species immediate impact model and the Dennis Model (Dennis et al. 1991) to estimate the probability of extinction. The diagonal line shows mean population size decreasing over time, though with variability and uncertainty around it (blue bell curve). The levee breach has an immediate negative impact on this population (shown by vertical dashed line), after which, the population resumes its mean rate of decline. The red-shaded area under the bell curve and below the population viability threshold (red dotted line) estimates the probability of extinction for this species.

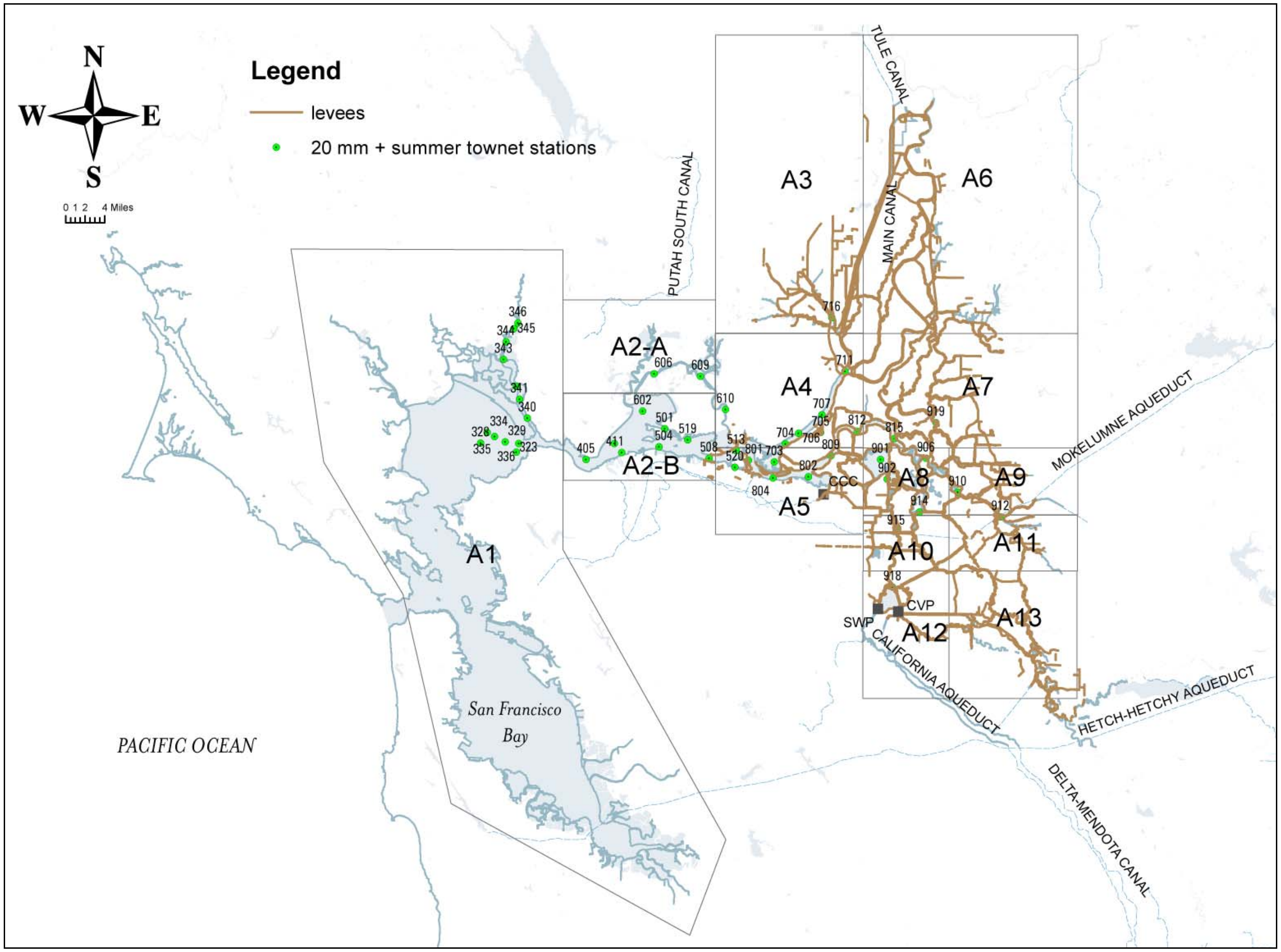


Figure 6-4. Analysis regions for assessing risk to fish sampling sites (20-mm Delta smelt survey) (CDFG 2006).

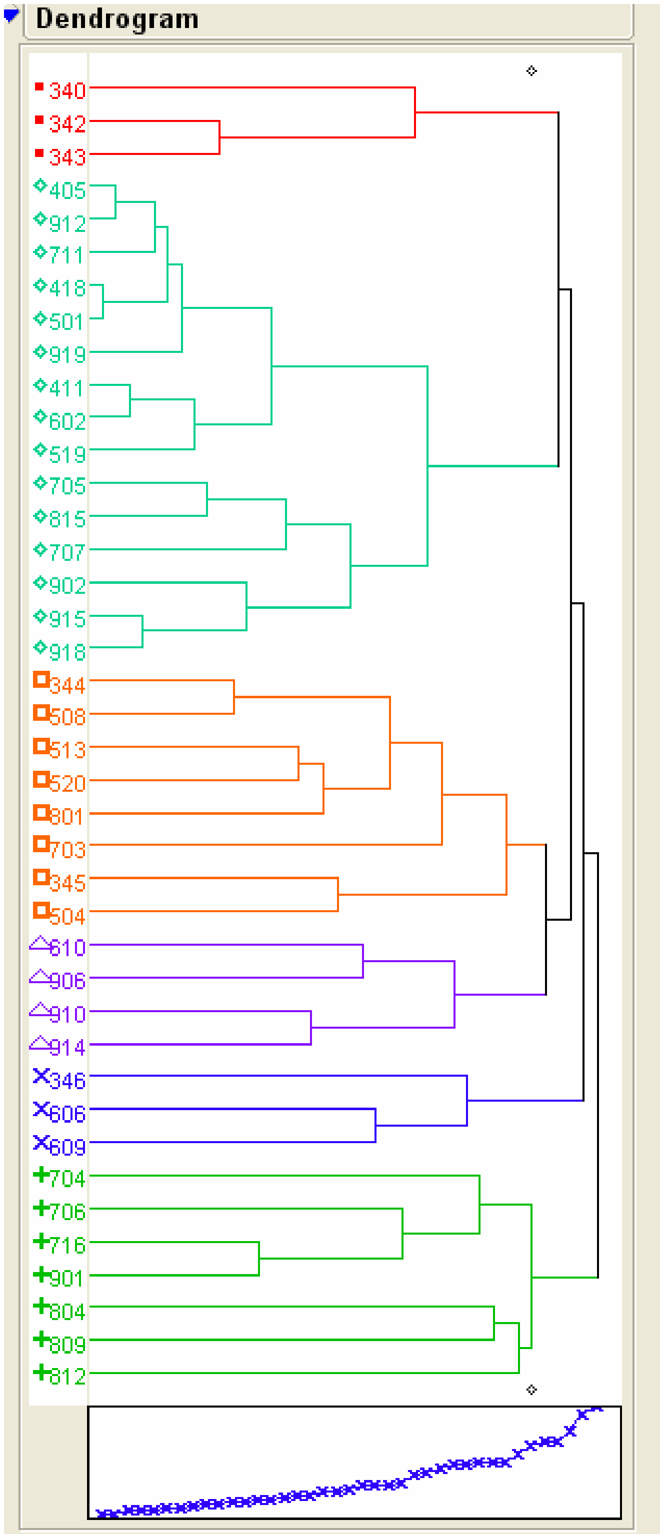


Figure 6-5. Sample dendrograms used in hierarchical cluster analysis of 20-mm CPUE data on delta smelt counts, March through May, 1996 to 2007.

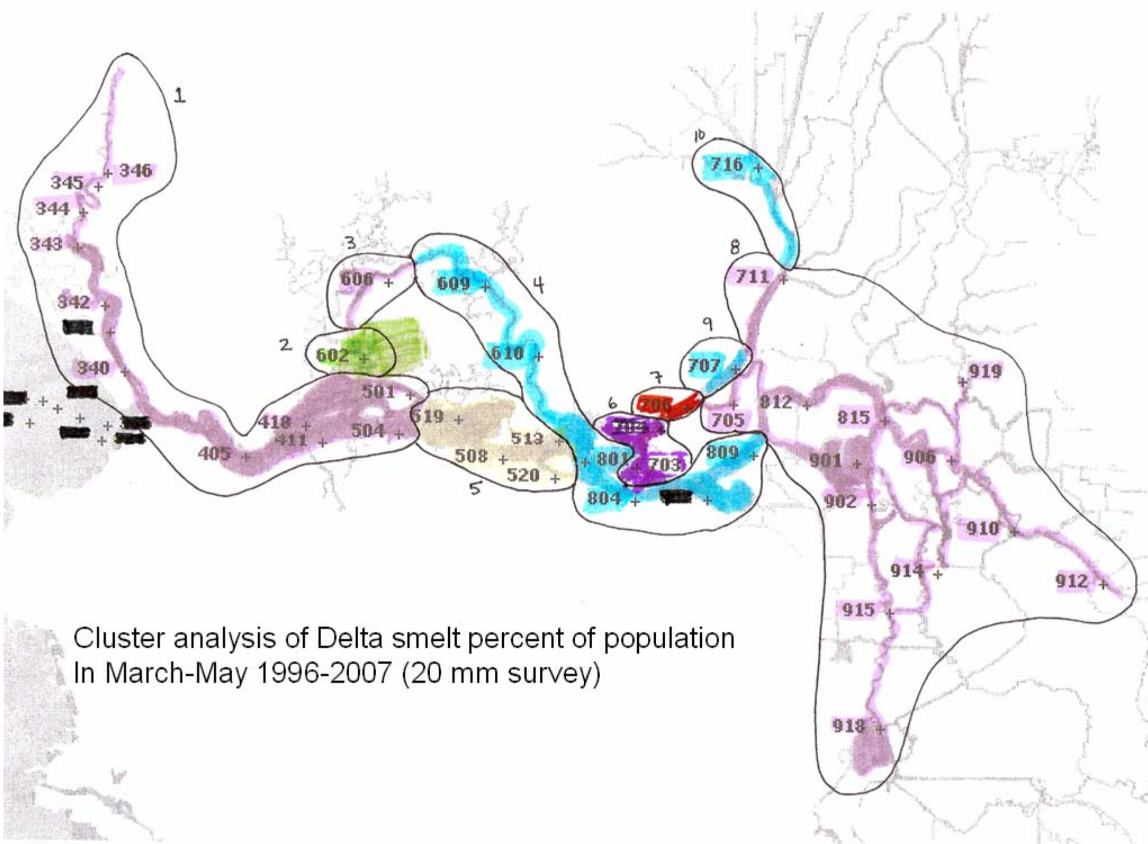


Figure 6-6. Sample results of hierarchical cluster analysis of 20-mm CPUE data on delta smelt counts, March through May, 1996 to 2007

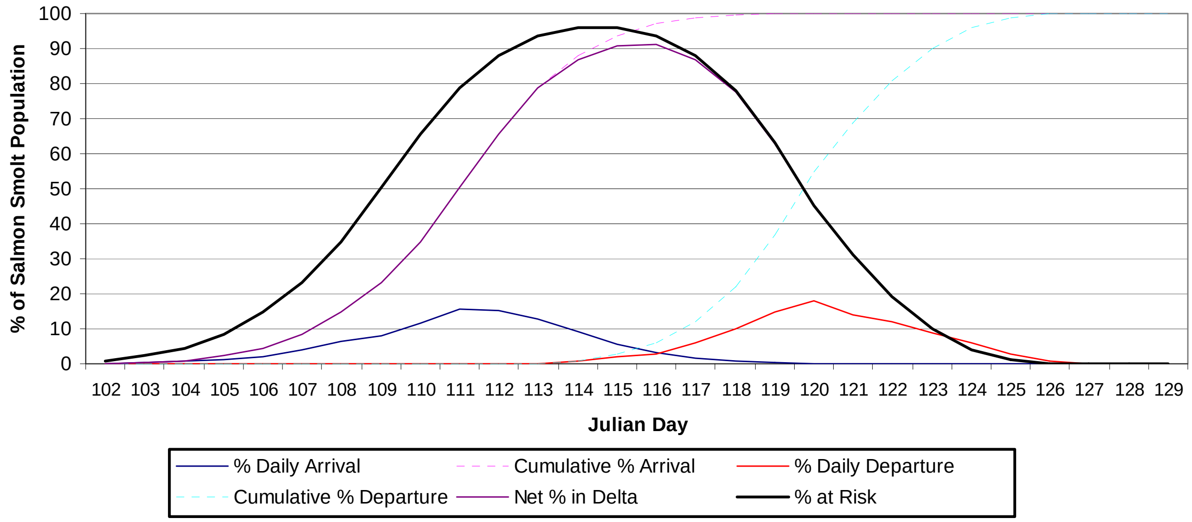
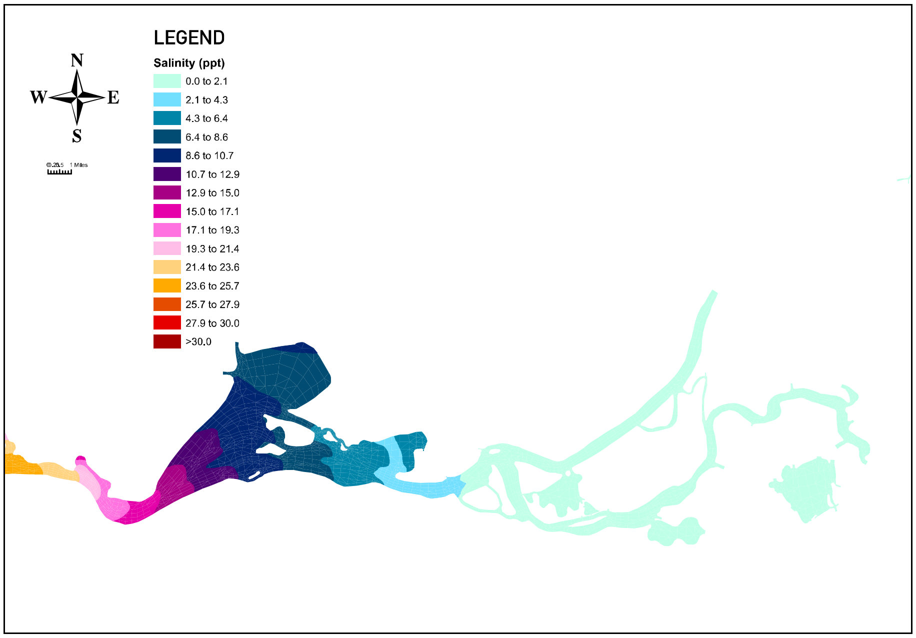


Figure 6-7. Demonstration of methodology to calculate daily and cumulative arrival and departure percentages of Chinook salmon smolt population, as well as percentage at risk of island entrainment, by Julian Day. Data and residence time estimates used to generate this figure are fictitious and used for demonstration purposes only.

Figure 6-8. Aerial view of Webb Tract. The area inside the red circle at right is the location of a previous levee breach and its associated scour hole. The hole is approximately 446 feet wide, 1700 feet long, and 35 feet deep.

(A)



(B)

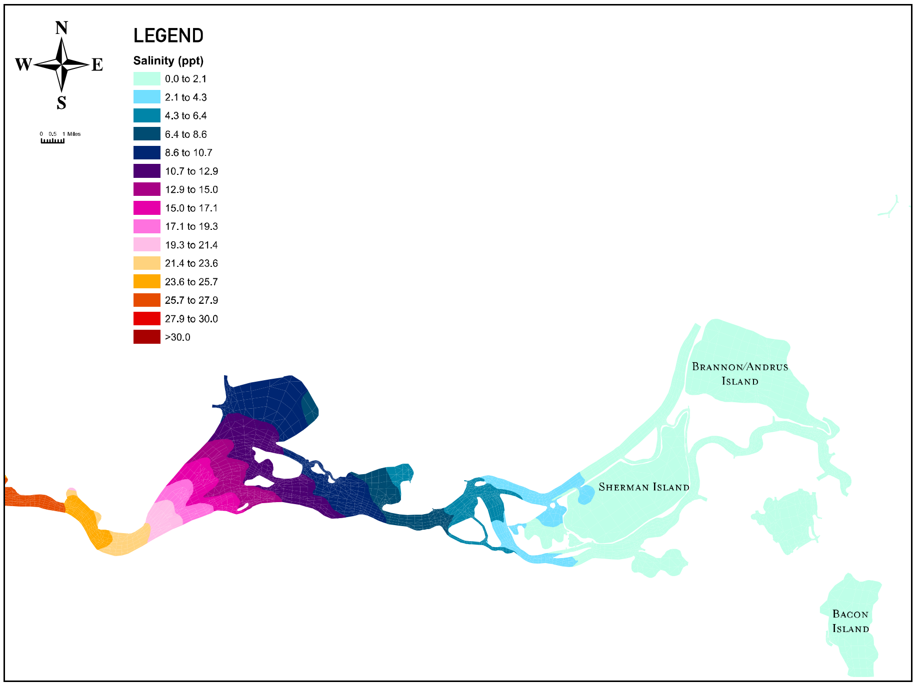
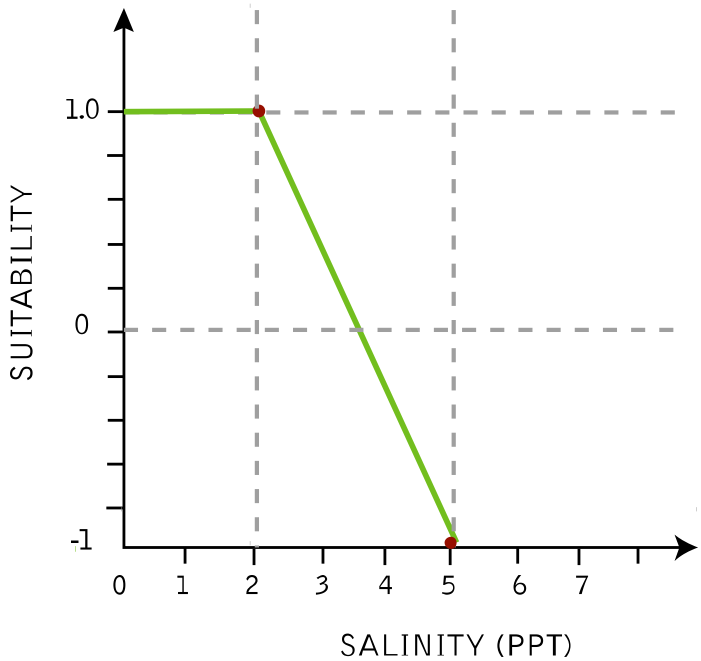


Figure 6-9 Example of salinity changes following levee-failure. Panel (A) represents baseline salinities on a hypothetical July 2 (based on 1992 hydrology). Panel (B) represents changes in salinity conditions two hours after the failure of three levees in the Delta (RMA 2006).

	% Loss to CVP/SWP Pumping		
	Juv. DS	Adult DS	Salmon
Wet Jan			
Normal Jan			
Dry Jan			
Wet Feb			
Normal Feb			
Dry Feb			
Wet Mar			
Normal Mar			

Figure 6-10. Example portion of final look-up form for output for CVP/SWP entrainment modeling; records percent of populations lost to export entrainment by three "water-month" types.



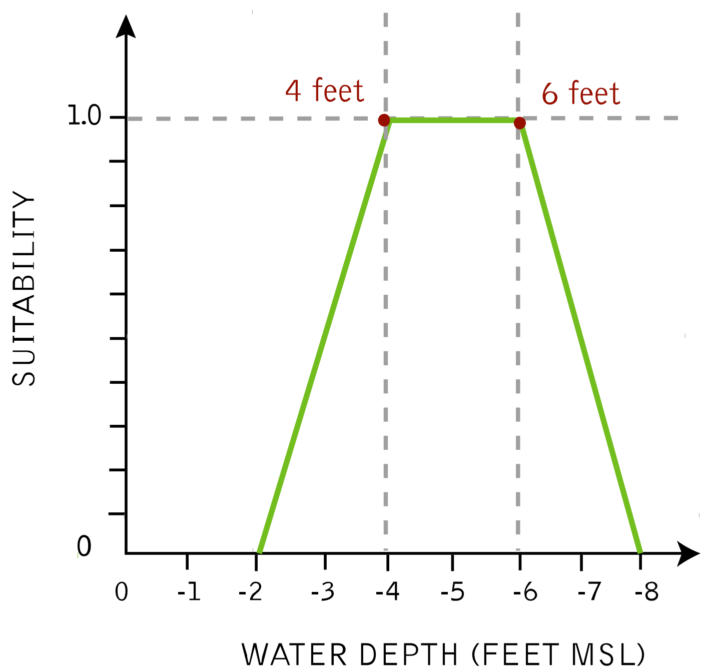
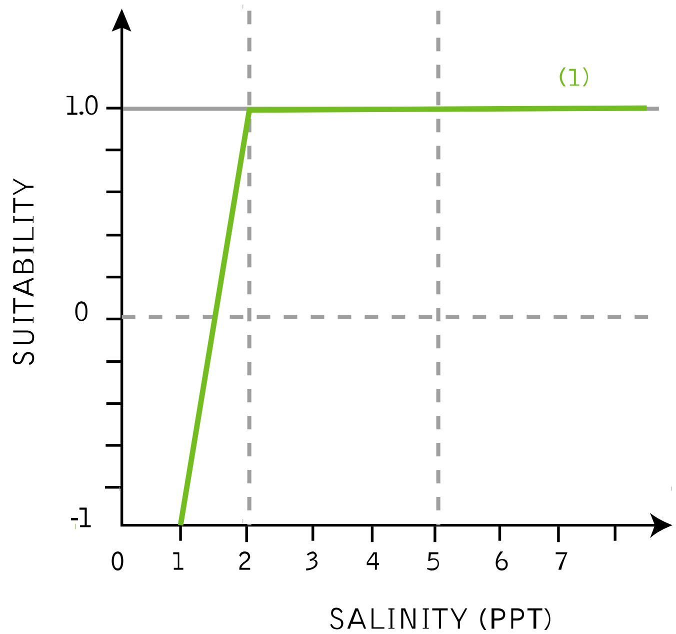
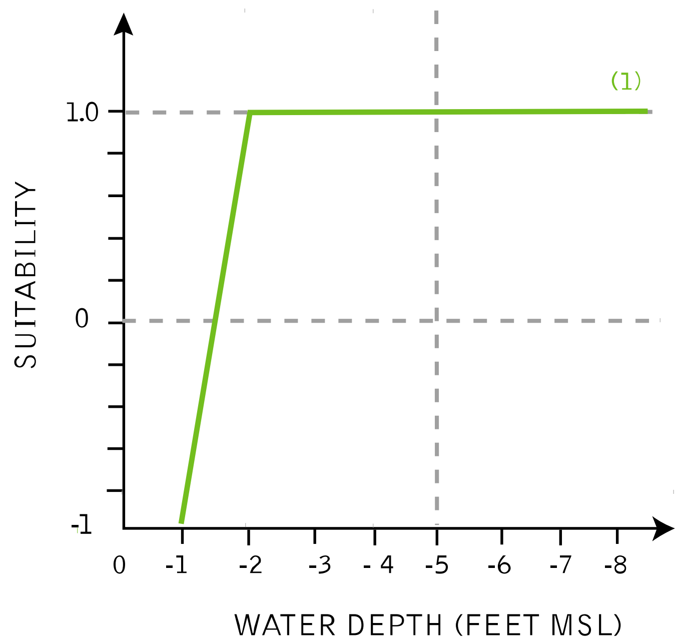


Figure 6-11. *Egeria densa* suitability curves.





(1) Carlton et al. 1990

Figure 6-12 *Corbula* suitability curves.

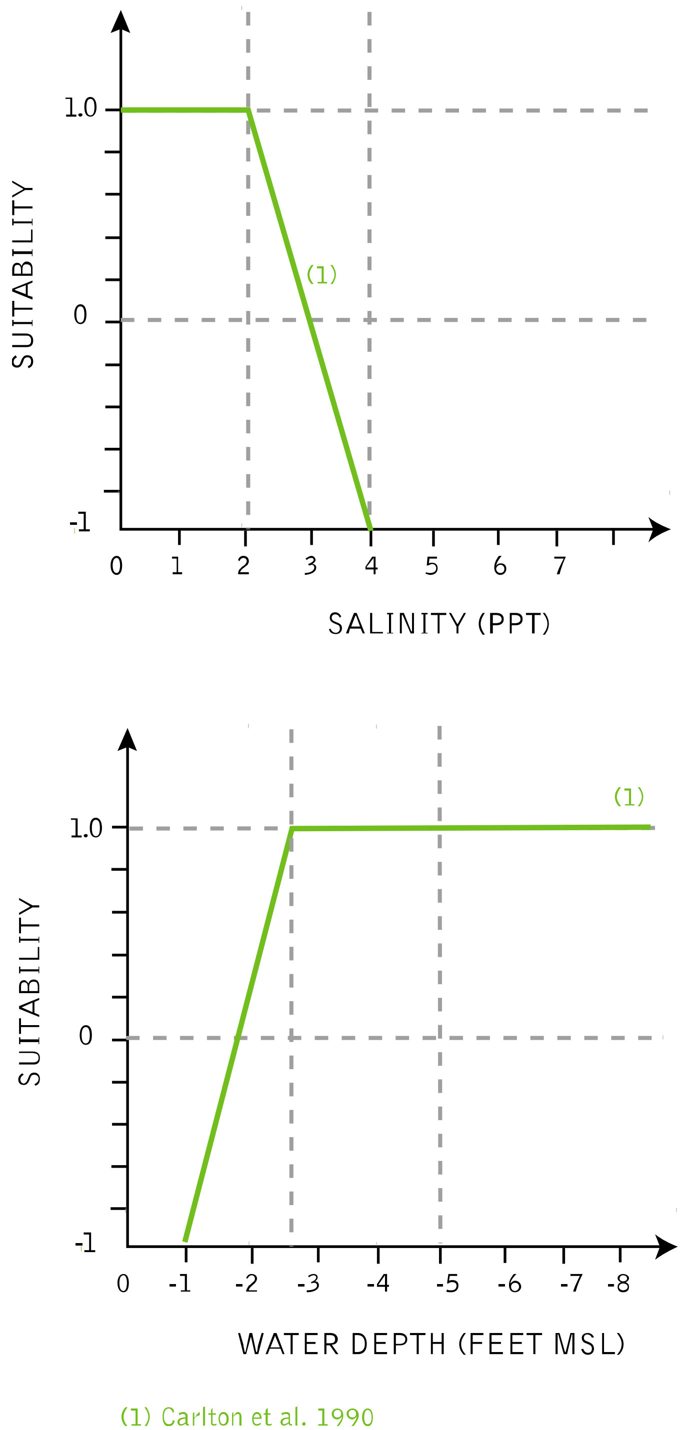


Figure 6-13 *Corbicula* suitability curves

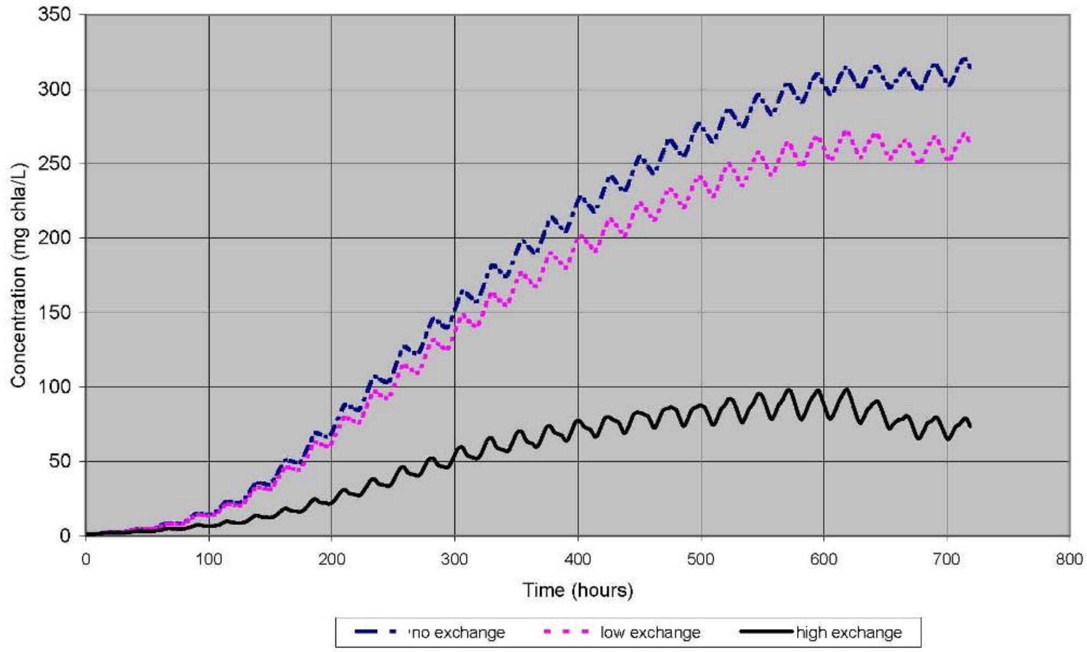


Figure 6-14 Concentration of phytoplankton (as chlorophyll a) on flooded island for different amounts of exchange with the river

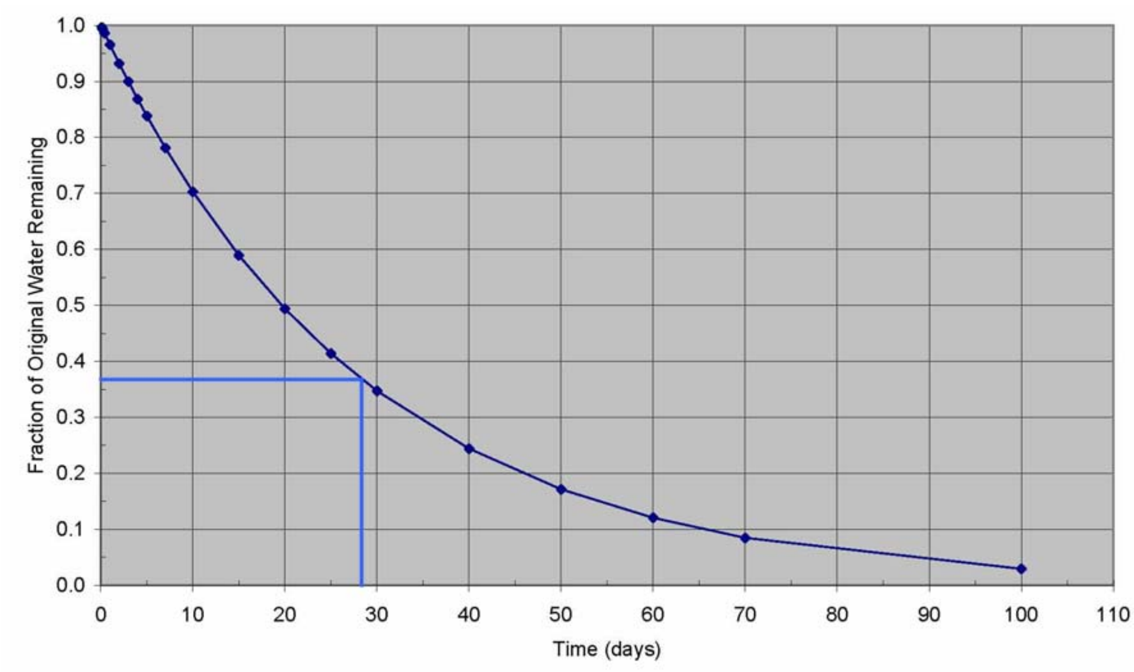


Figure 6-15 Example of residence time for 30,000 acre flooded island with 100-feet breach

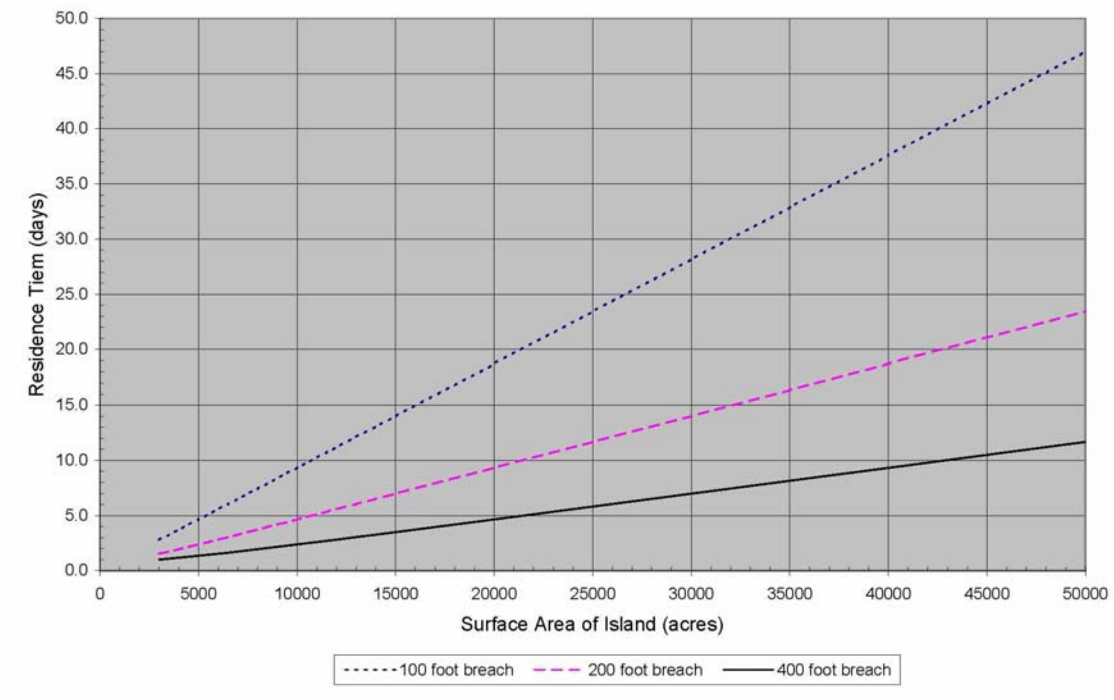


Figure 6-16 Average residence time for flooded Delta islands for different breach and island sizes

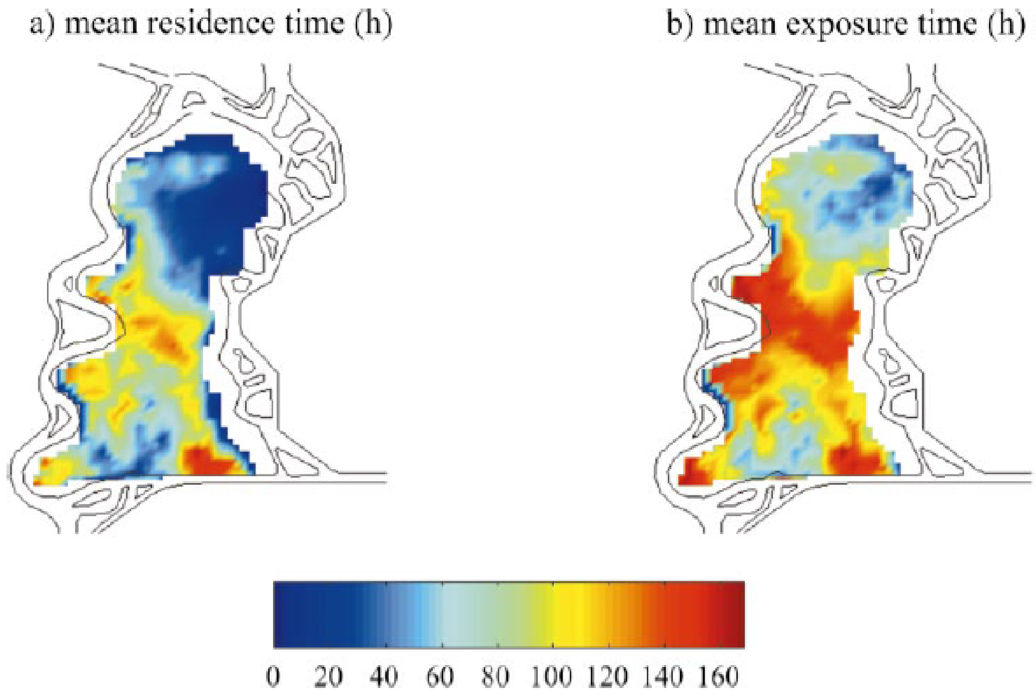


Figure 6-17. Variation in residence time in Mildred Island (Monsen et al. 2002). (a) Mean residence time and (b) mean exposure time for June 1999. The mean reflects the average value from several scenarios described in Monsen et al. (2002). The maximum time of 168 hours reflects the end of the simulation rather than the maximum residence or exposure time. Exposure is the measure of the total time a particle spends inside the boundaries of Mildred Island during the simulation, whereas residence time reflects the time the particle stayed in the domain before exiting once. Mildred Island has a 170-m wide breach in the northeast corner and a shallow (1-m deep) 50-m breach in the south. The average residence time estimated by Monsen et al. is 185 hours (7.7 days) but as short as 1 day or less near the main breach.

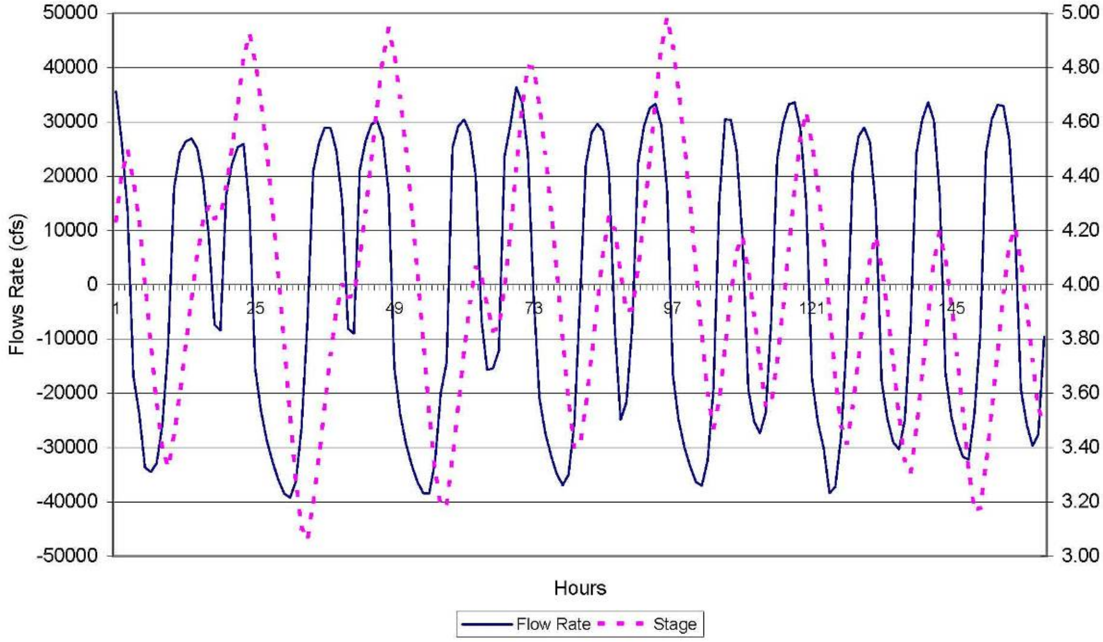


Figure 6-18 Predicted inflow, outflow, and stage from 12,000-acre flooded island, 15 feet deep with 300-foot-wide breach.

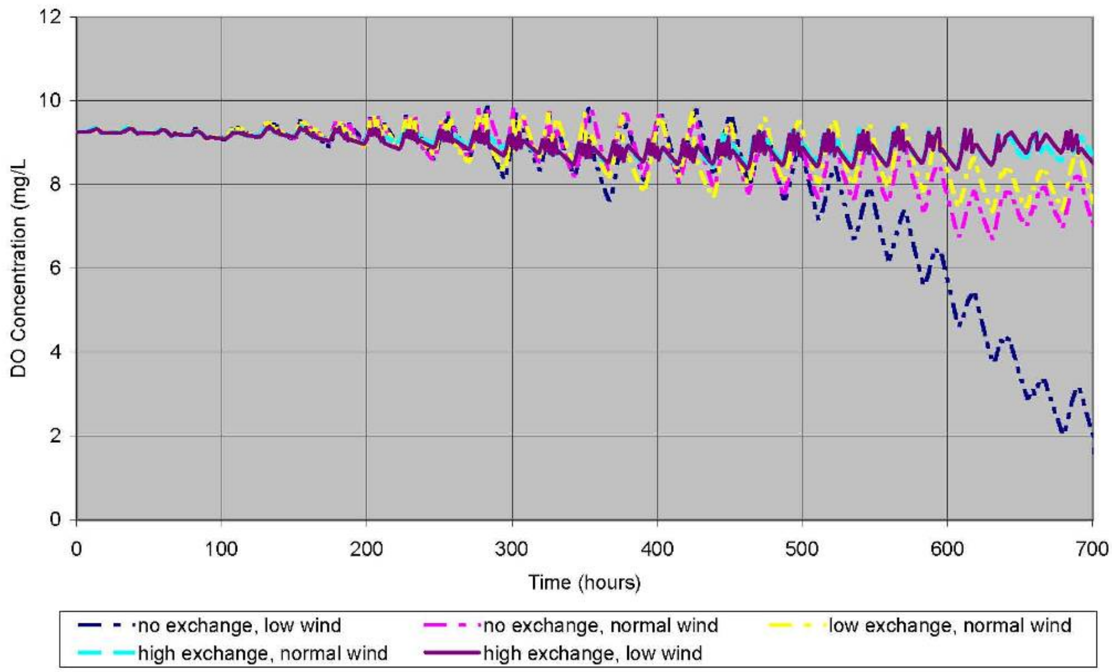


Figure 6-19 Illustrative example of the impacts to dissolved oxygen on a flooded island under different amounts of exchange between island and river.

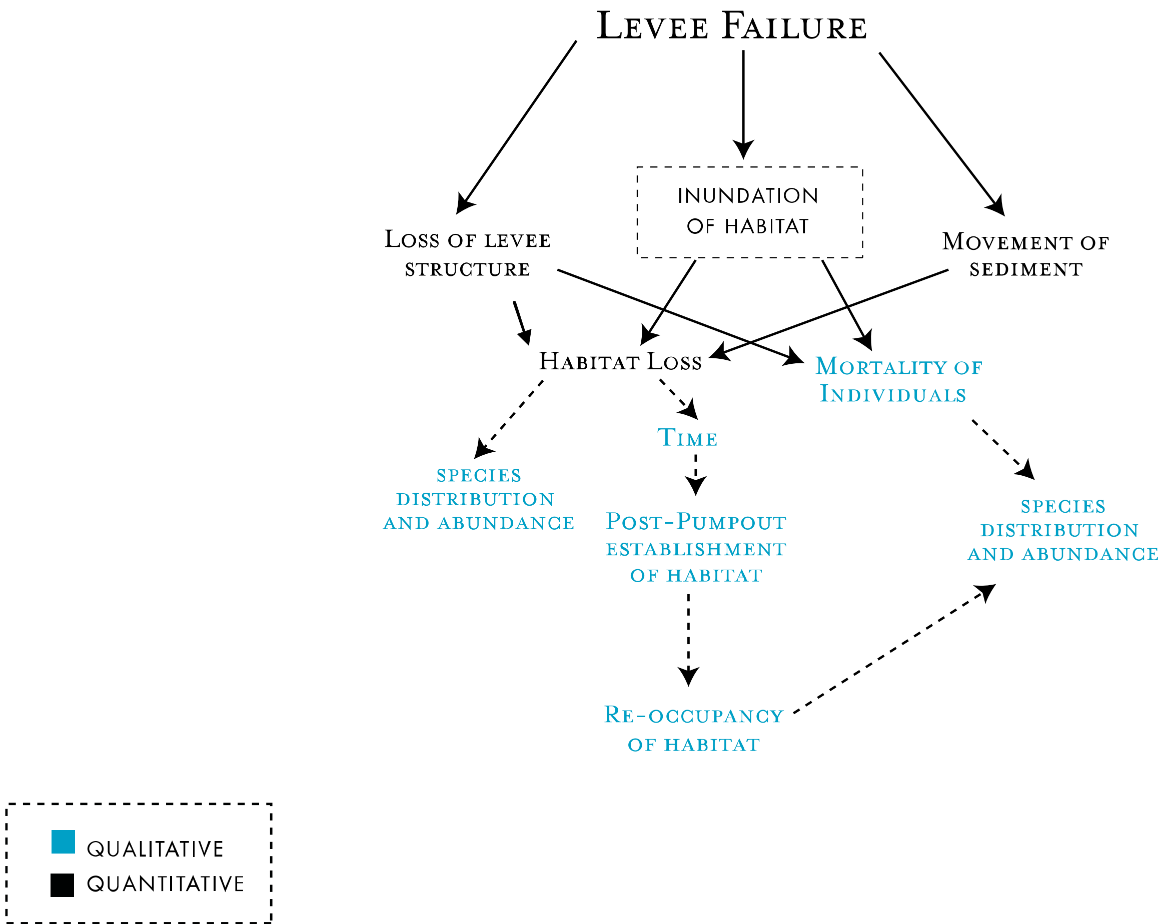


Figure 6-20a Conceptual model of terrestrial ecosystem impact mechanisms

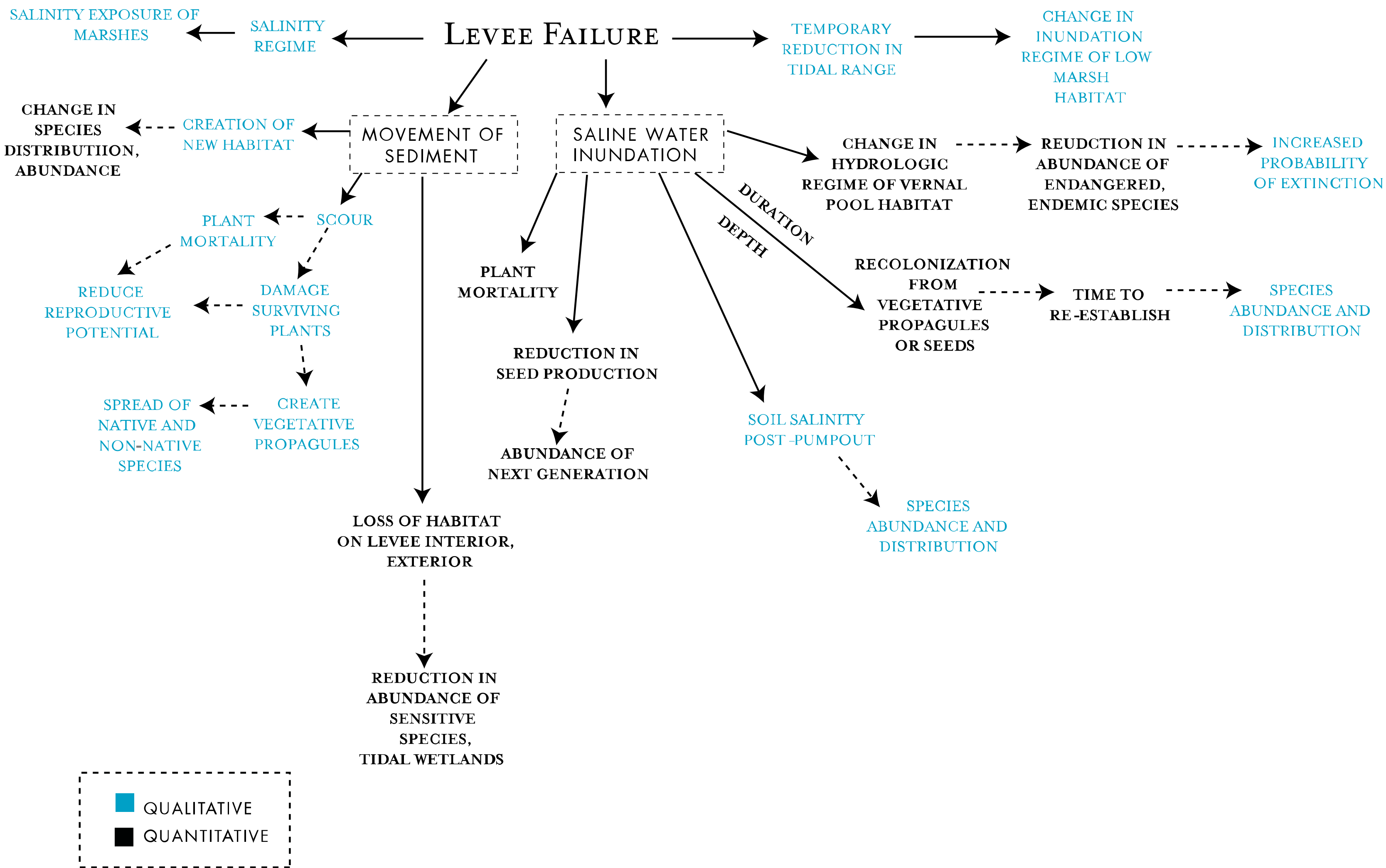


Figure 6-20b Conceptual model of vegetation ecosystem impact mechanisms.

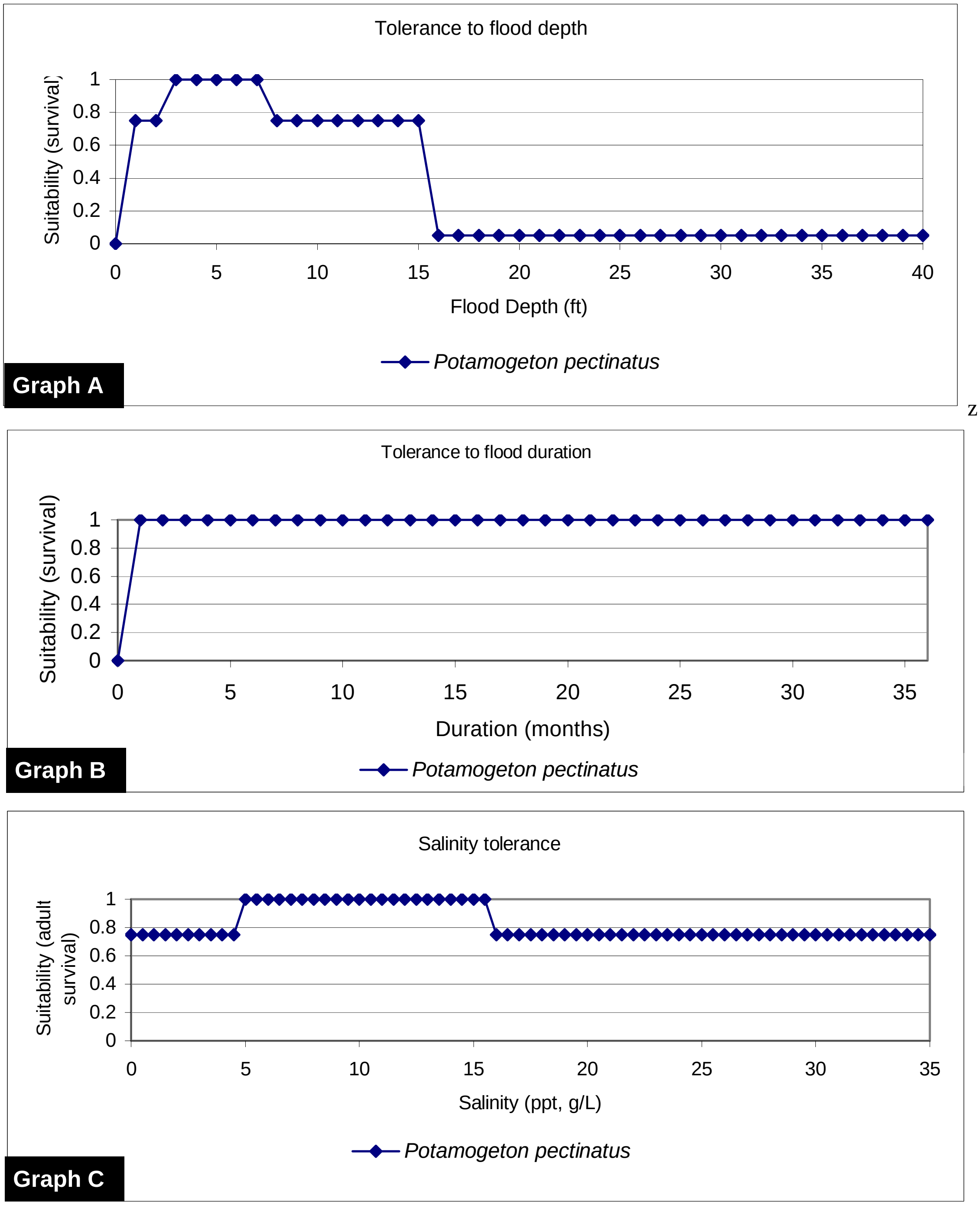


Figure 6-21 Tolerance of focal species (pondweed [*Potamogeton pectinatus]*) to flood depth (Graph A), flood duration (Graph B), and salinity (Graph C).

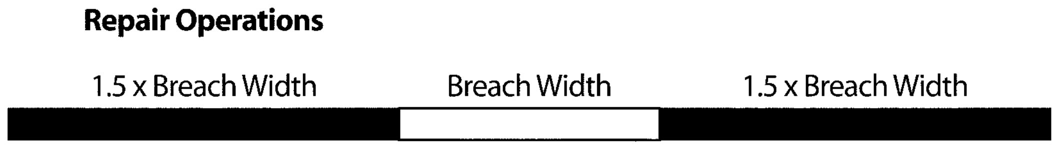


Figure 6-22 Schematic of the area on the channel-side of the levee impacted by a levee breach and repair operations.

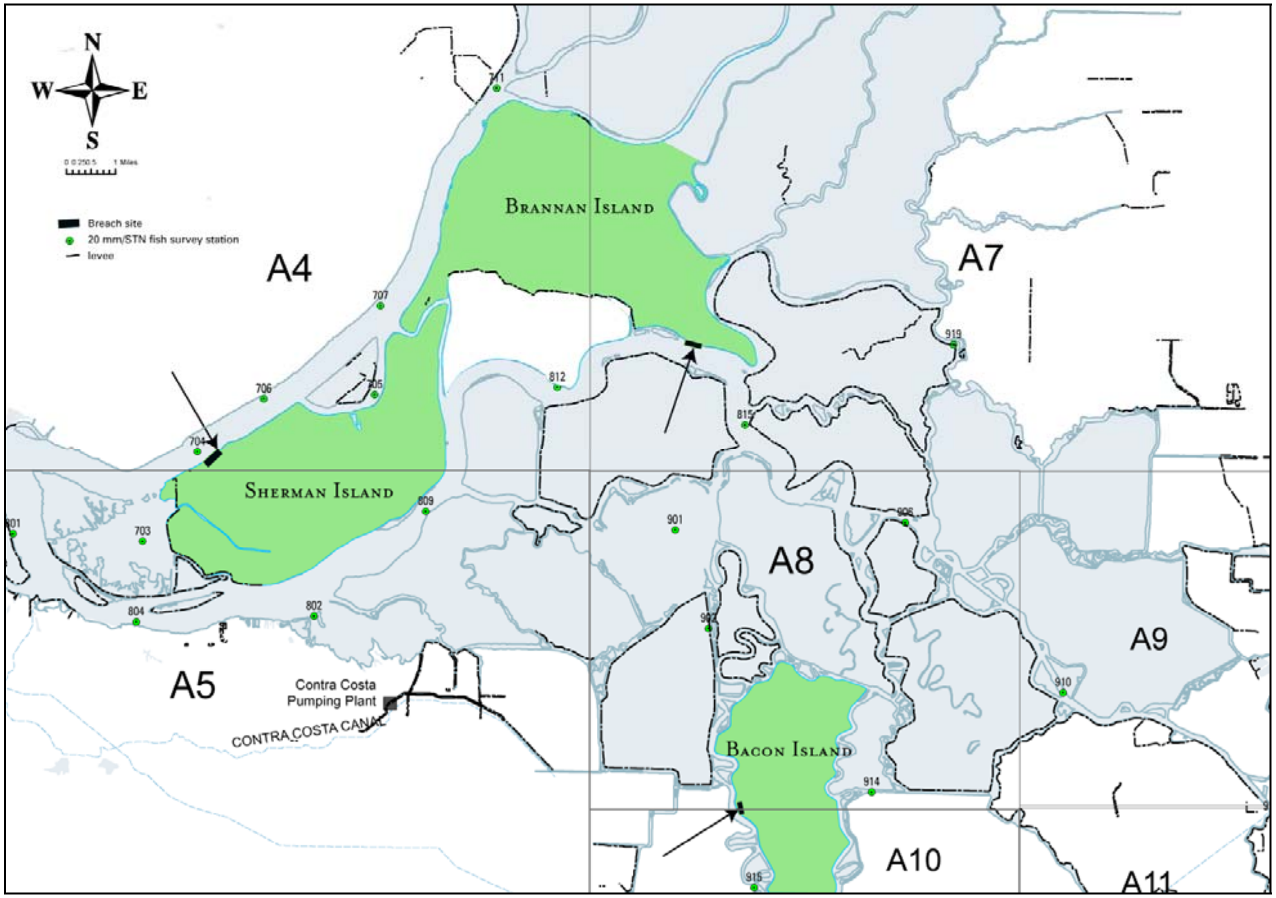


Figure 7-1 Hypothetical three-breach sequence: Location of breaches.

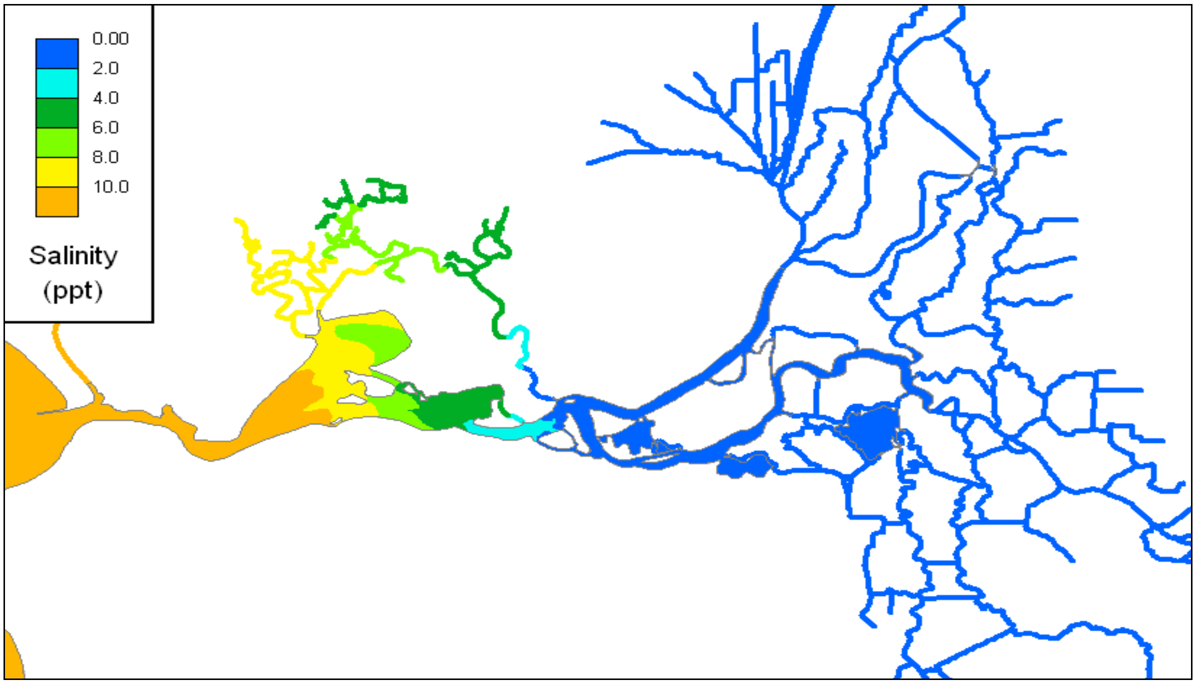


Figure 7-2 Three breach scenario: Salinity levels in base conditions in the Delta and Suisun Marsh. Base conditions are measured immediately after the breach at July 2, hr 0:00. The position of X_2 is in Suisun Bay (RMA 2006).

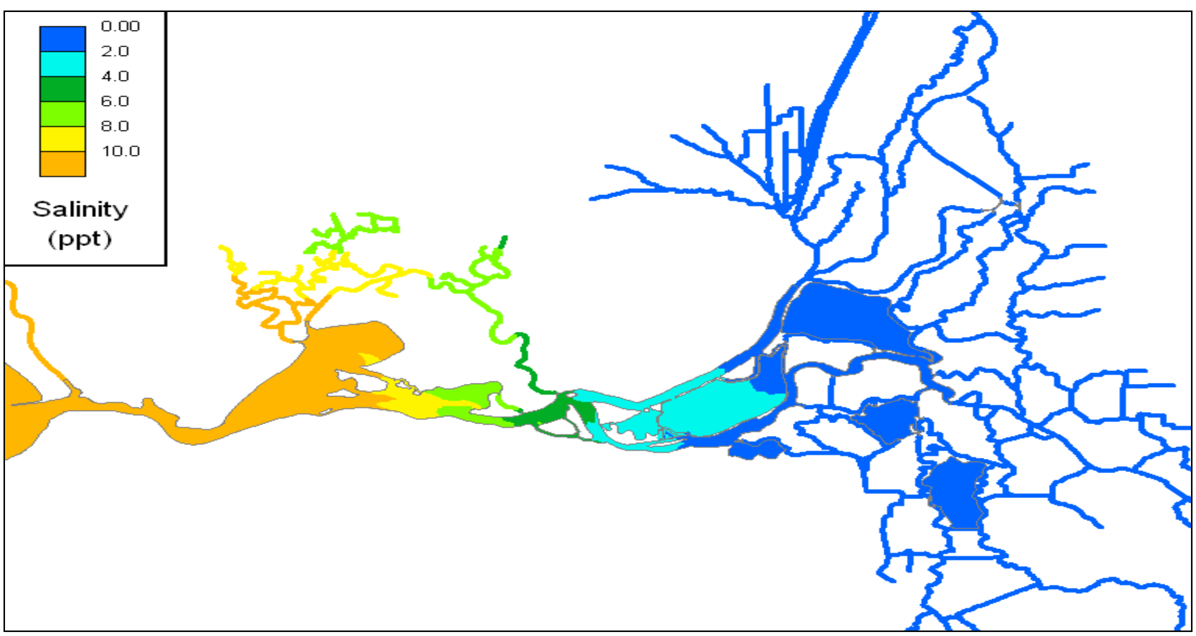


Figure 7-3 Three-breach scenario: Salinity levels in the Delta and Suisun Marsh 20 days after levee breaches. July 20, hr 0:00. The location of X_2 is within the flooded Sherman Island (RMA 2006).

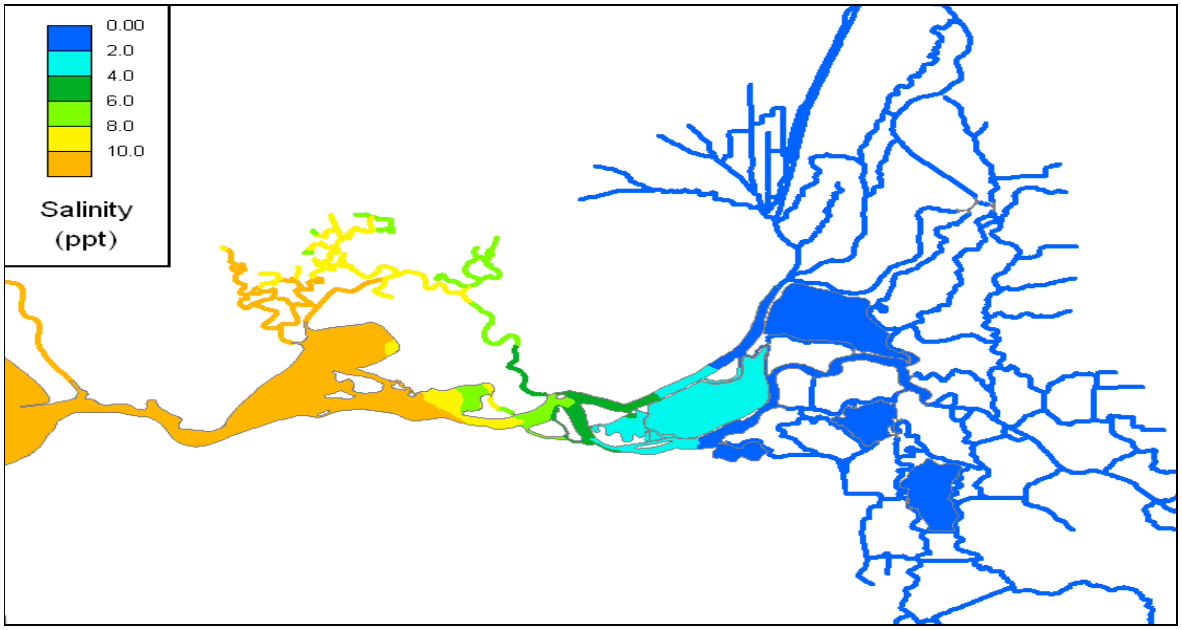


Figure 7-4 Three-breach scenario: Salinity levels in Suisun Marsh and the Delta approximately a month after levee breaches. July 27 hr 23:00. The location of X_2 is throughout the flooded Sherman Island (RMA 2006).

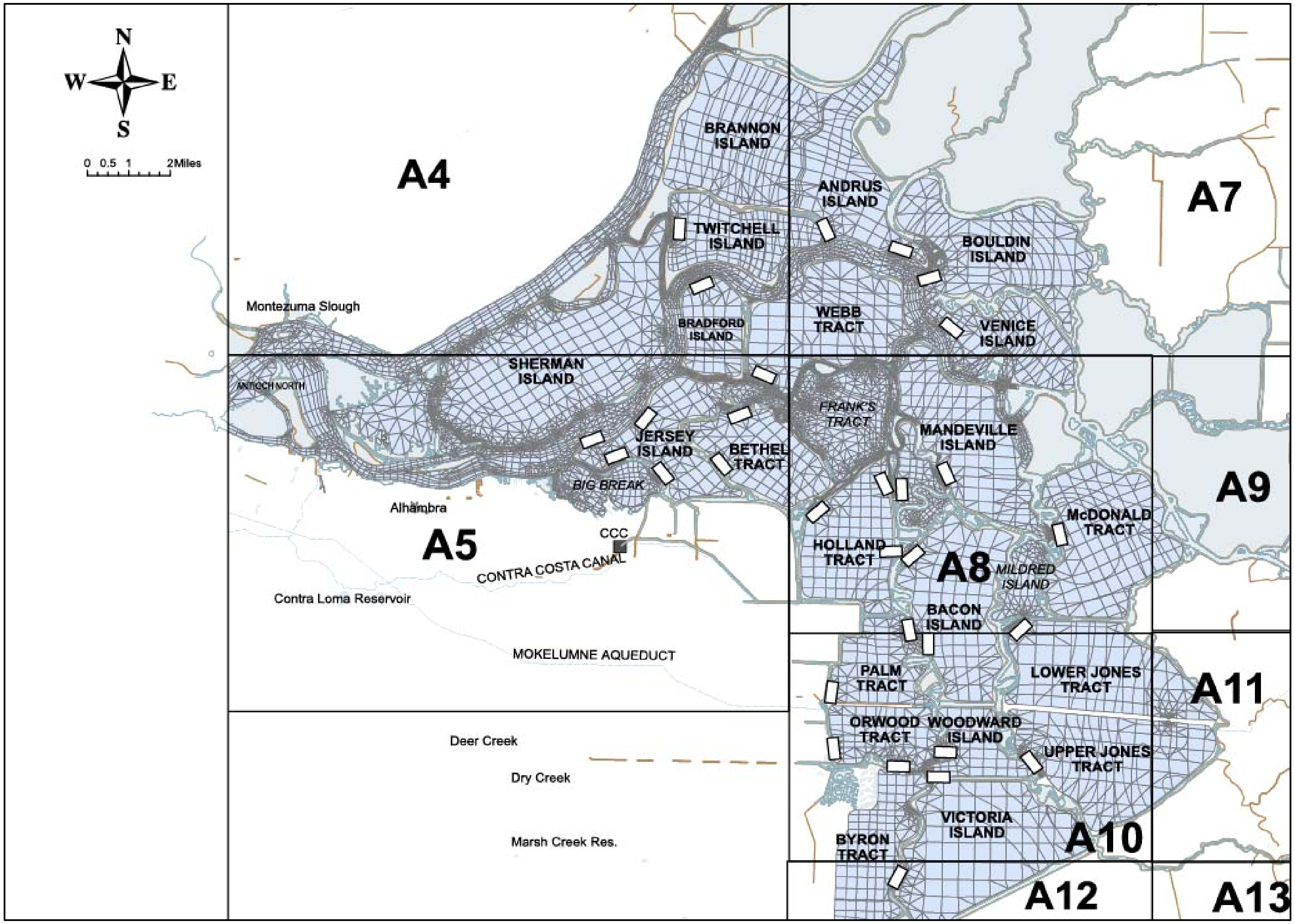


Figure 7-5. Thirty-breach scenario: Approximate breach locations.

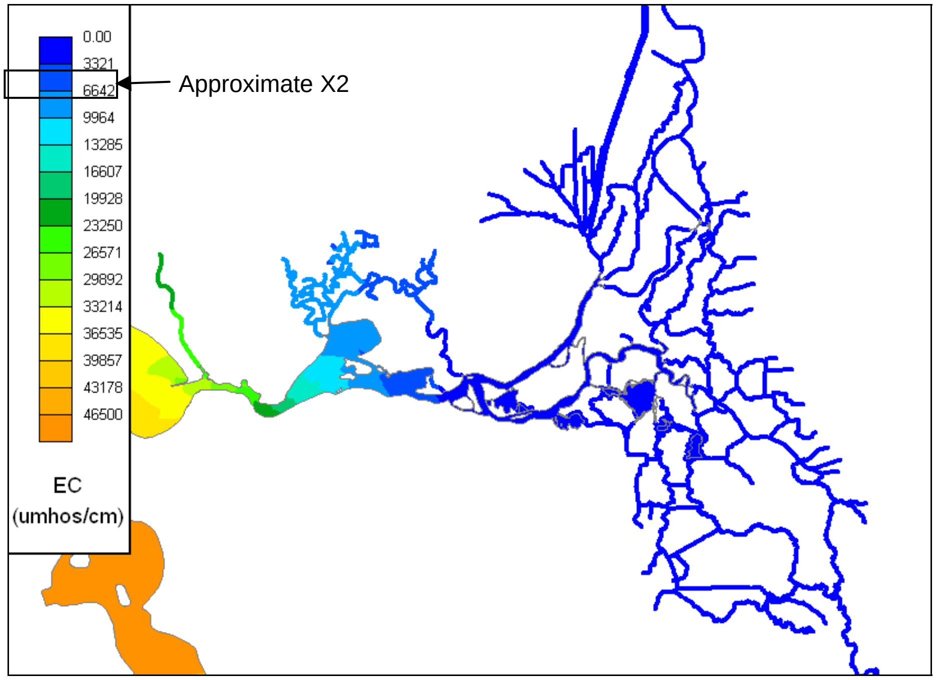


Figure 7-6. Thirty-breach scenario: Salinity levels and X_2 in baseline conditions in the Delta and Suisun Marsh. Baseline conditions were assessed immediately before the thirty-breach event (RMA 2006).

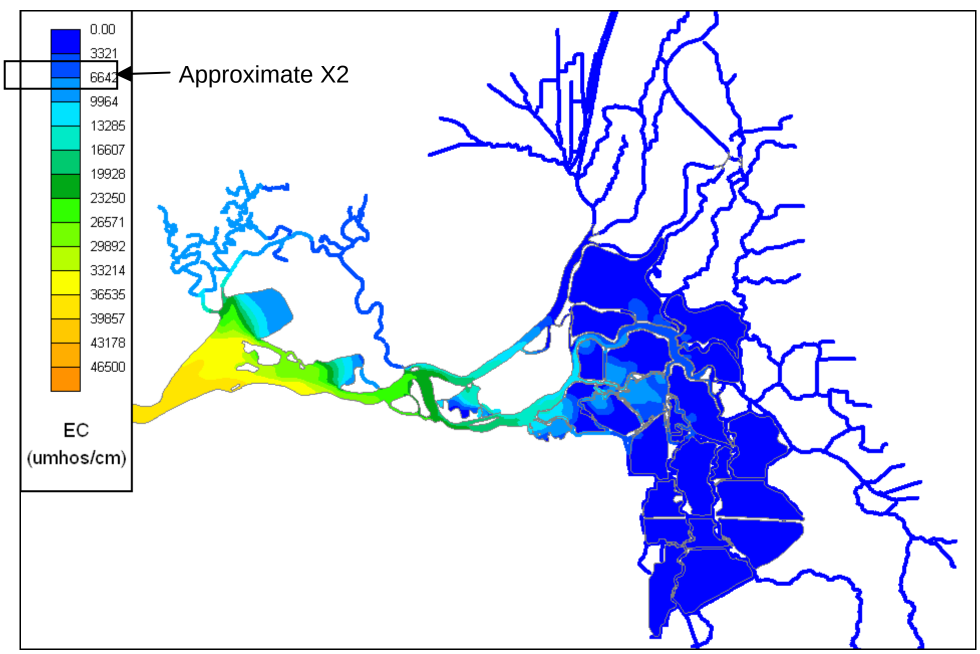


Figure 7-7 Thirty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh 24 hours after levee breaches (RMA 2006)

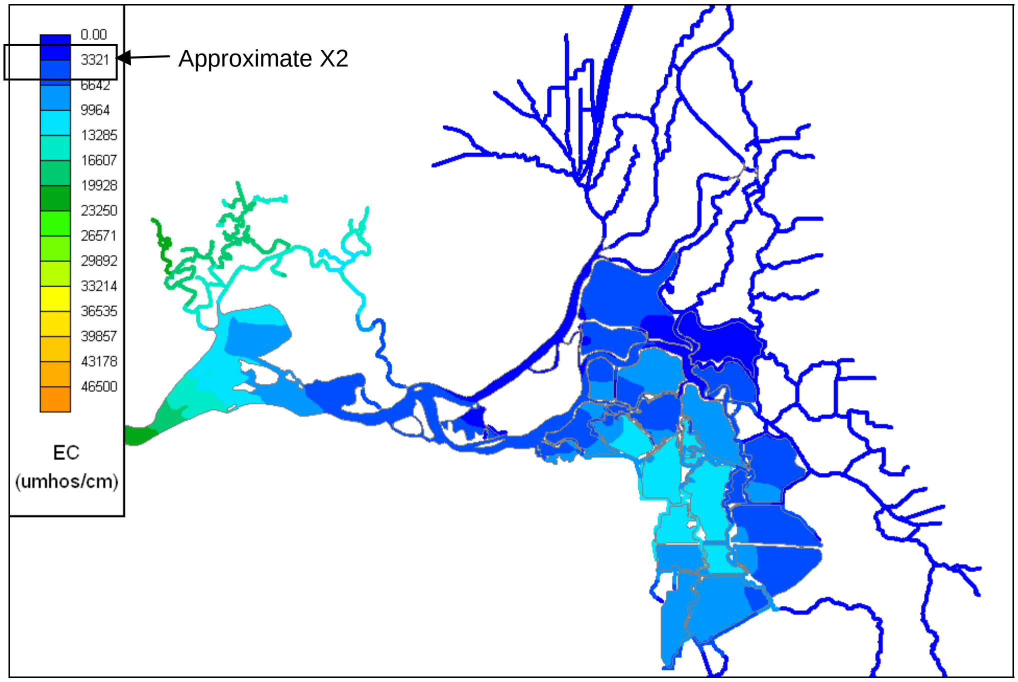


Figure 7-8 Thirty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh 1 month after levee breaches (RMA 2006)

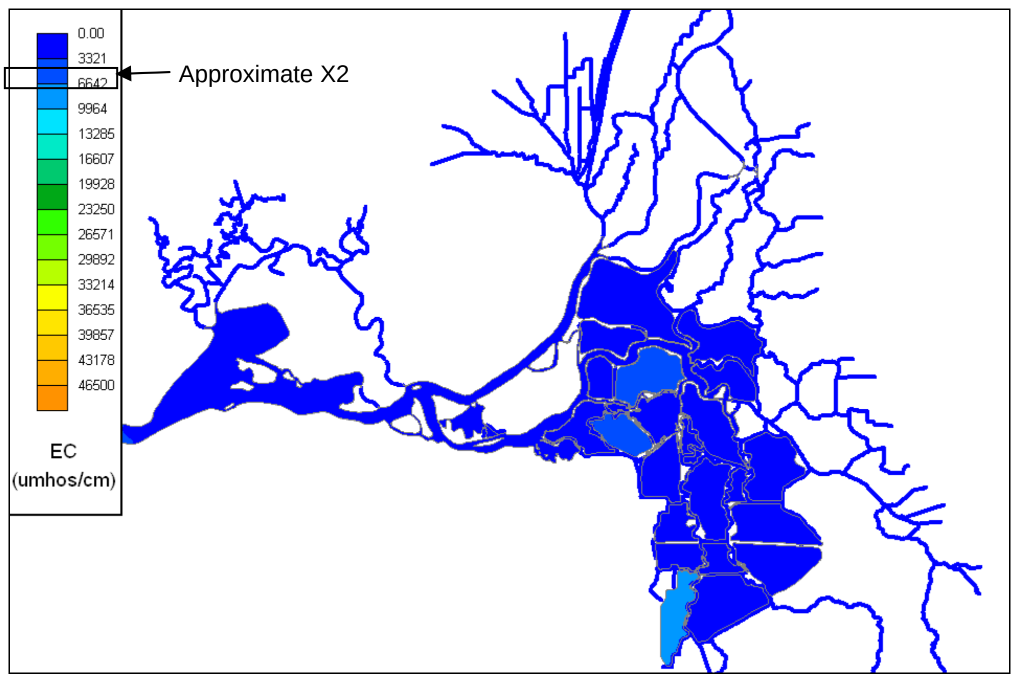


Figure 7-9 Thirty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh 1 year after levee breaches (RMA 2006)

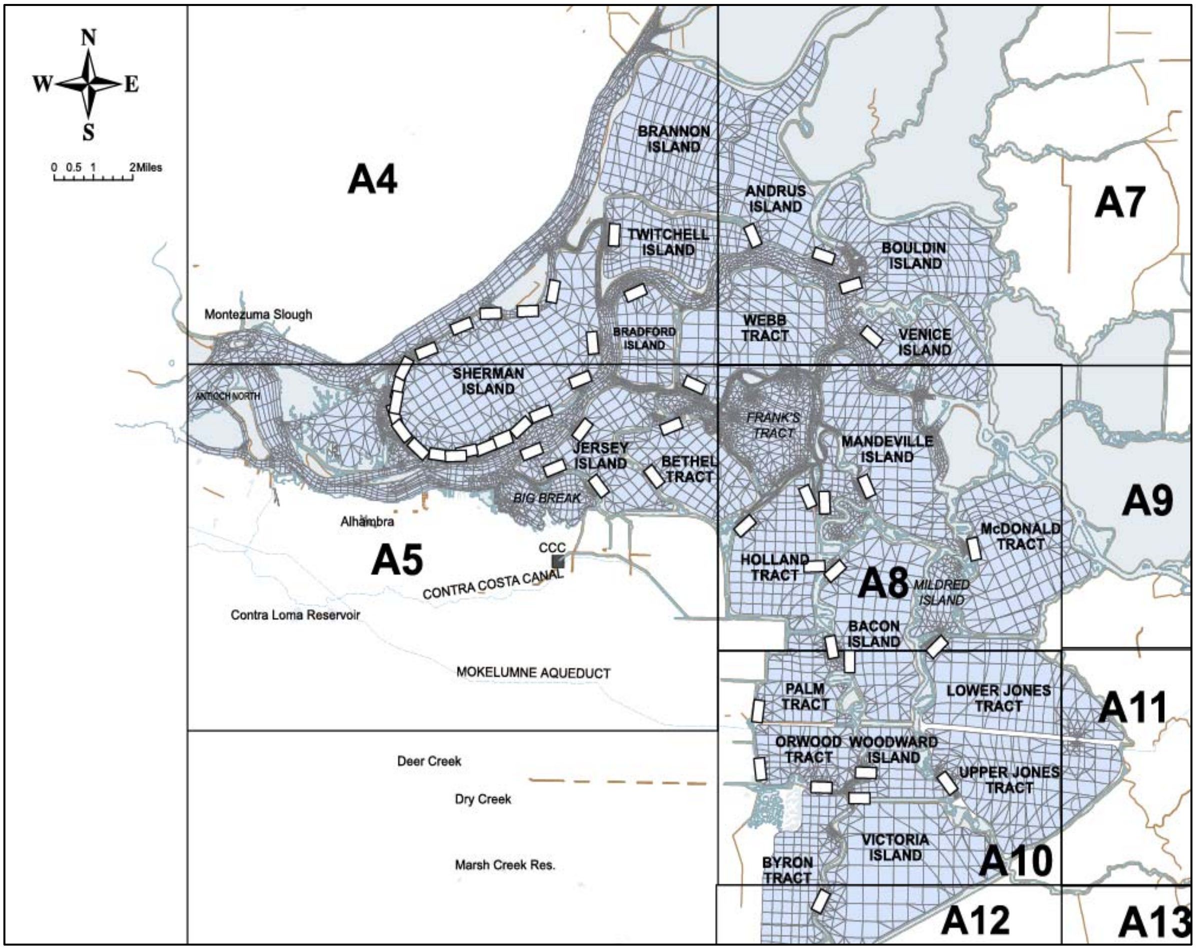


Figure 7-10 Fifty-breach scenario: Approximate breach locations. The breach locations are the same as in the thirty-breach scenario but with the addition of 20 levee breaches on Sherman Island

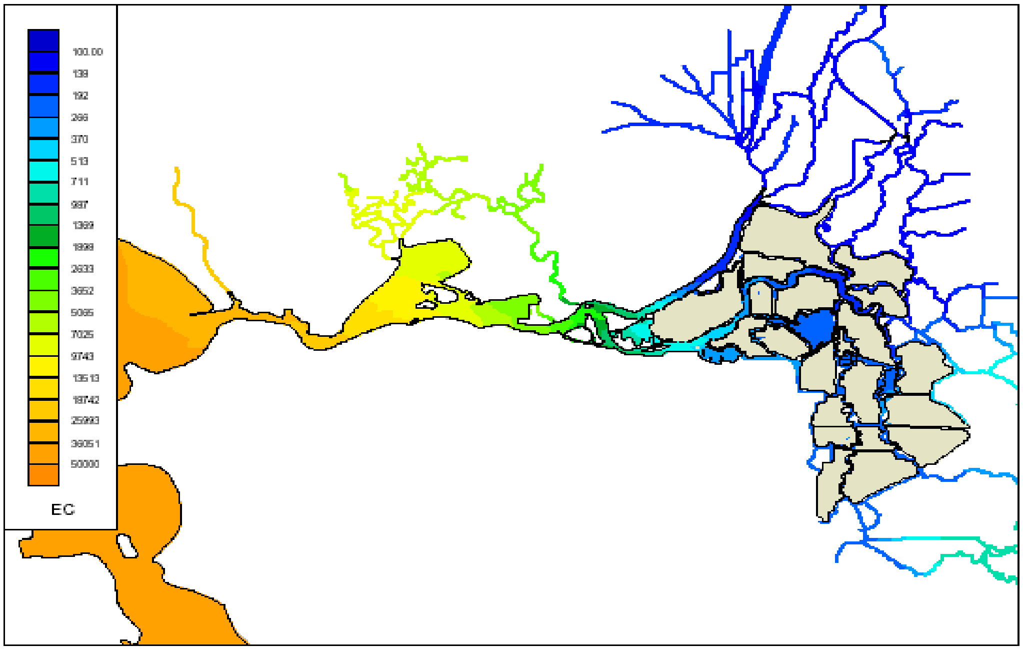


Figure 7-11 Fifty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh under baseline conditions. Baseline conditions were assessed immediately before the 50-breach case (RMA 2006)

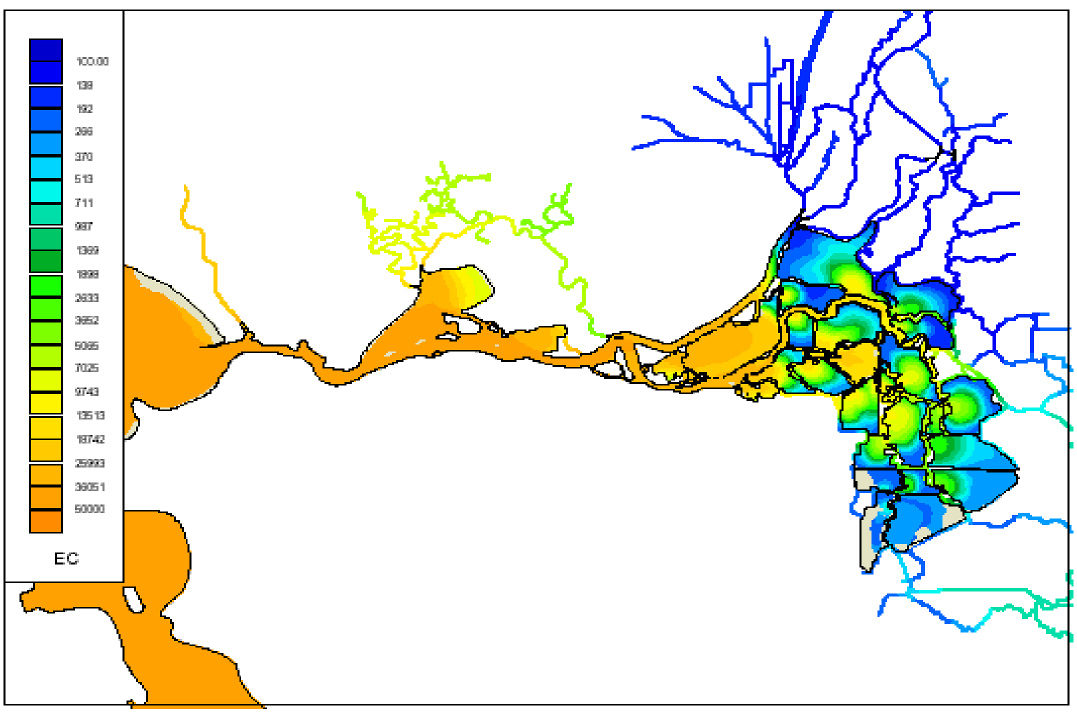


Figure 7-12 Fifty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh 24 hours after levee breaches (RMA 2006)

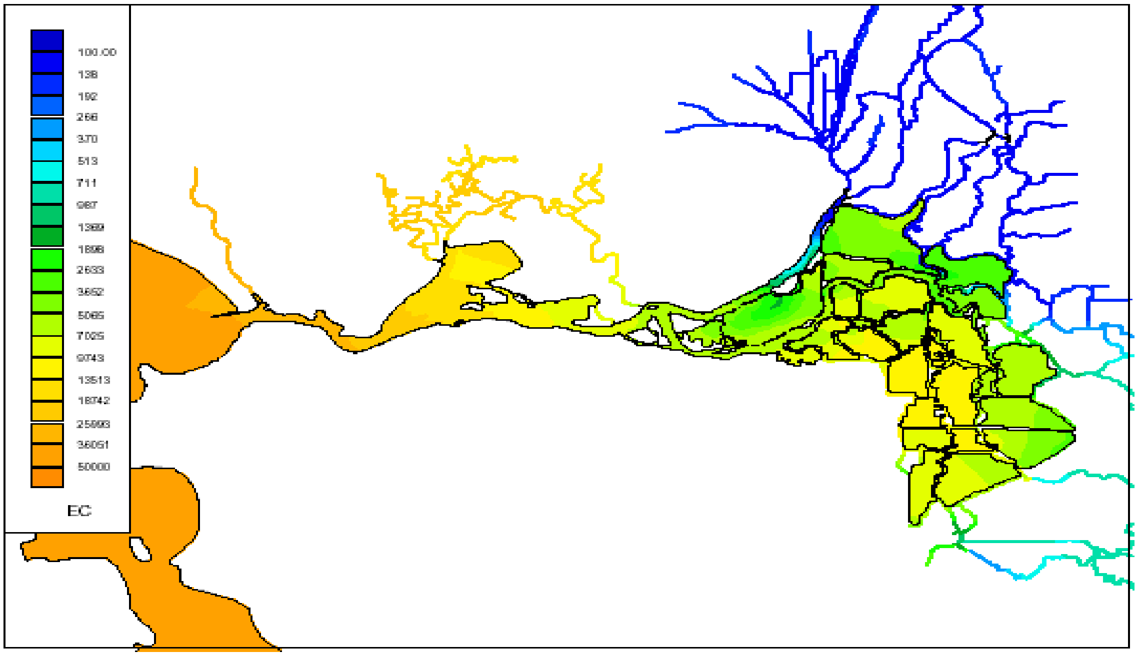


Figure 7-13 Fifty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh 1 month after levee breaches (RMA 2006)

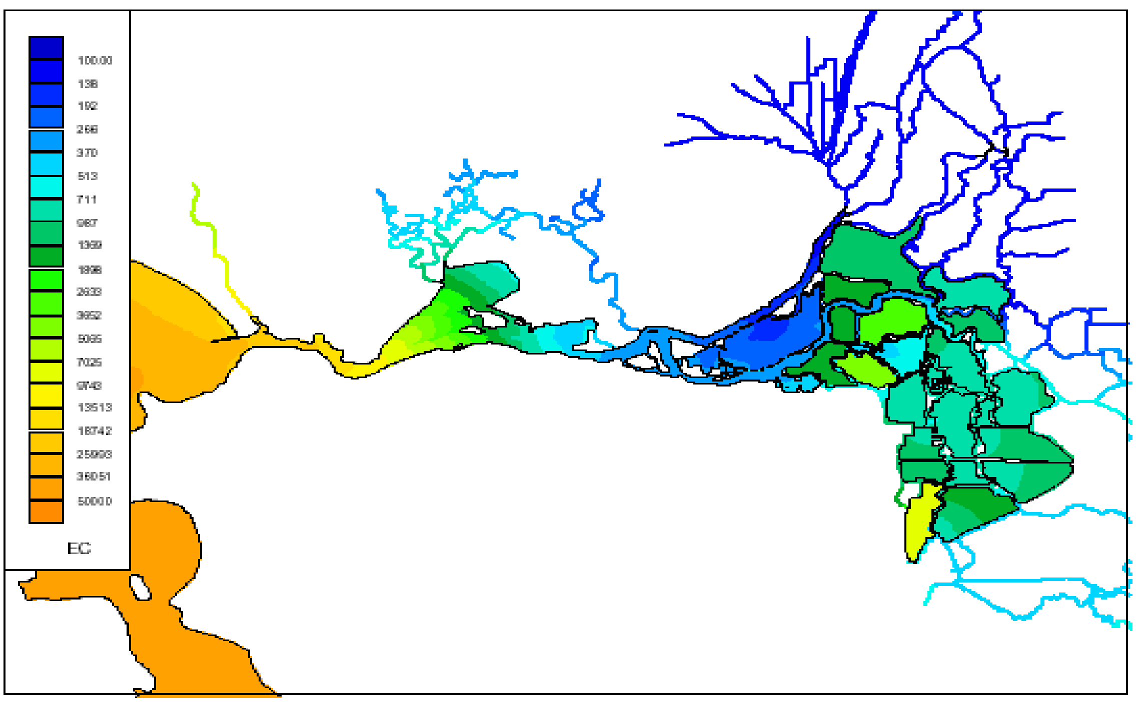


Figure 7-14 Fifty-breach scenario: Salinity levels and X_2 in the Delta and Suisun Marsh 1 year after levee breaches (RMA 2006)

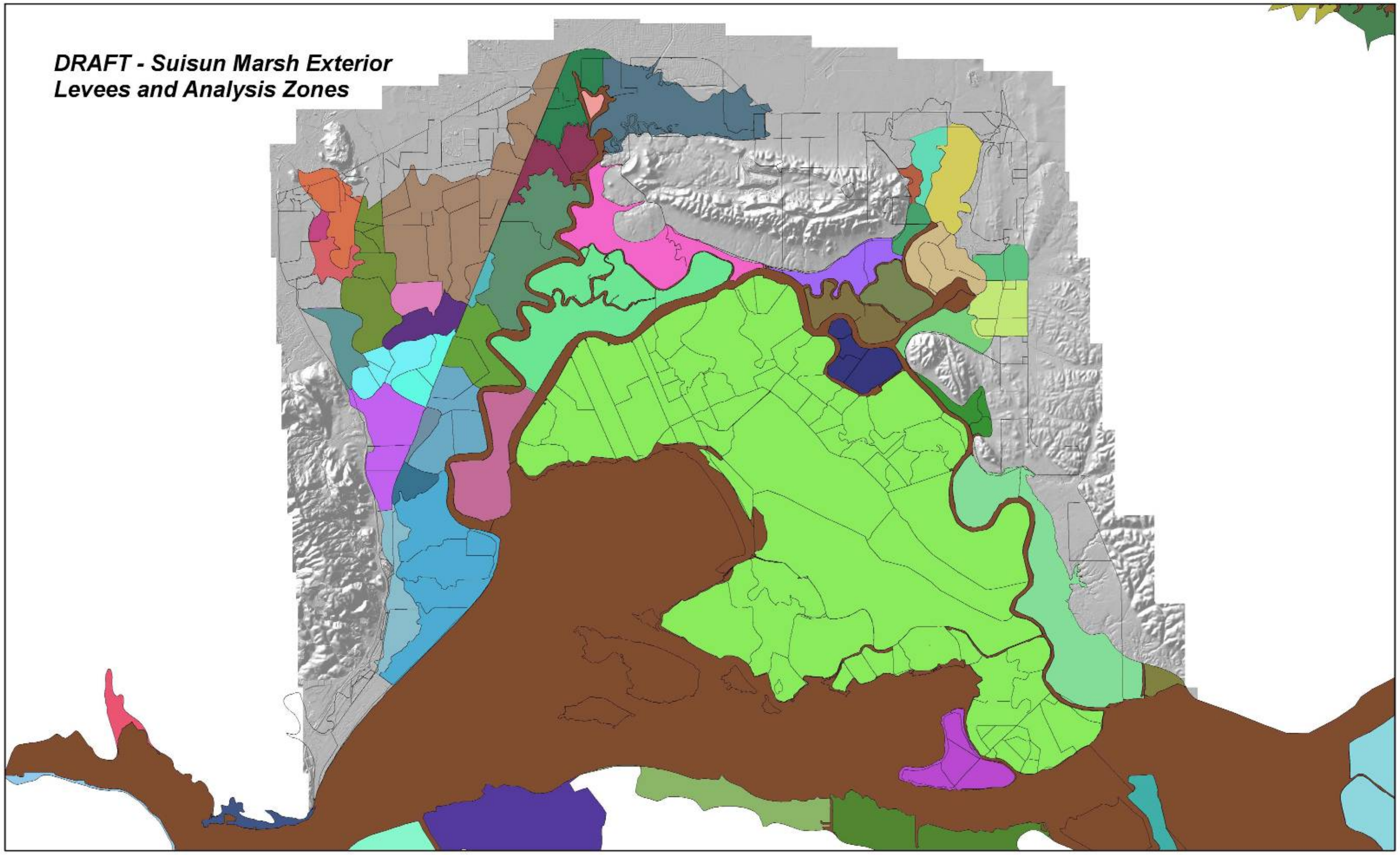


Figure 7-15 Suisun Marsh hypothetical levee breach: Areas flooded due to exterior levee breach of levees overlying 30 feet of organic material. Colors indicate the total area that would be flooded if an exterior levee on the perimeter of the colored area breached