Final Report

Application of the Ecological Flows Tool to Complement Water Planning Efforts in the Delta & Sacramento River

Multi-Species Effects Analysis & Ecological Flow Criteria

EFT
Ecological Flows Tool
© The Nature Conservancy

Prepared for The Sacramento River Program of The Nature Conservancy
Ecosystem Restoration Program
Agreement E0720044

Application of the Ecological Flows Tool to Complement Water Planning Efforts in the Delta & Sacramento River

Multi-Species Effects Analysis & Ecological Flow Criteria

Prepared for:
The Sacramento River Program of The Nature Conservancy

Funded by:
California Department of Fish and Wildlife Ecosystem Restoration Program

Lead Authors:
Clint Alexander, Donald Robinson and Frank Poulsen

Agreement No. ERP-07D-P06 - DFG# E0720044

For inquiries on this report, contact:
Ryan Luster
The Nature Conservancy
rluster@tnc.org
1.530.897.6370 (ext. 213)

Suggested Citation:
Alexander, C.A.D., D.C.E. Robinson, F. Poulsen. 2014. Application of the Ecological Flows Tool to Complement Water Planning Efforts in the Delta & Sacramento River: Multi-Species effects analysis & Ecological Flow Criteria. Final Report toThe Nature Conservancy. Chico, California. 228 p + appendices.

Cover Photo:
Shasta Dam (*iStock* photo)

ESSA Technologies Ltd.
Vancouver, BC Canada V6H 3H4
www.essa.com

Organization of Report

To facilitate your ability to identify background and findings that are of most interest, this report is organized as follows:

Chapter 1. Overview – This Chapter describes the vision, history and goals of the project; its tasks and deliverable products to date. It describes categories of ecological flow needs assessment and how these needs are tackled by the Ecological Flows Tool.

Chapter 2. Ecological Flow Needs Considered and Methods – This Chapter summarizes the kinds of management actions that can be evaluated using EFT. It also describes the species and ecological needs which are considered by EFT, and includes high level narrative descriptions of the 25 indicators that form Sacramento River and Delta EFT. The Chapter also provides high level descriptions of each indicator along with *where* and *when* the indicator effects take place. This Chapter also provides a concise explanation of how each indicator's results are combined (rolled up) in different ways, to provide outputs that range from the detailed to high level summaries. In addition to describing various categories of outputs available from EFT, we provide an explanation of the different approaches to synthesizing outcomes and comparing results using a weight-of-evidence approach to develop higher level net effect conclusions. Descriptions of the external models that EFT leverages (e.g., CALSIM) which provide input to EFT are also provided in this Chapter (including how these models can be substituted for others as they become available). The Chapter also describes the methodology involved with using EFT to develop rule-sets and eco-friendly flow regimes for incorporation into other physical planning models.

Chapter 3. Recent EFT Applications – This Chapter provides a description of recent applications of EFT to water operation planning, with particular emphasis on multi-level results. This includes the first *full* application of EFT (SacEFT and DeltaEFT) to selected Bay Delta Conservation Plan alternatives. We include net effect summaries, summaries of physical change as well as detailed species and indicator results for several water operation and future climate scenarios. These effects analyses are structured according to defined comparisons intended to isolate water operation and conveyance effects, as well as anticipated effects associated with future climate change and human demand. A second major focus of this Chapter is to unveil results for a pilot study showing how EFT can be used to develop rule-sets and recommended flow regimes for incorporation into physical planning models (e.g., in this example, CALSIM). As an initial test of the approach, we illustrate results of the method as applied to winter Chinook and Delta smelt. A summary of a previous application of SacEFT to a North-of-the-Delta Offstream Storage investigation is also provided.

Chapter 4. **Where to From Here?** – Isolates the biggest lessons learned over more than 10 years of work, and plots a course for the next phase of coupled, multi-species, ecological flow decision support for the Sacramento River and Delta.

Appendix A – Provides the original backgrounder report that was provided prior to the first Sacramento River Ecological Flows Tool design workshop. While it is superseded by the SacEFT Record of Design in Appendix B, this companion document illustrates the structured workshop and peer review approach taken in the development of SacEFT.

Appendix B – Provides the Record of Design for the Sacramento River Ecological Flows Tool. A standalone report, this document provides additional detail about the development and technical implementation of each SacEFT indicator too voluminous for inclusion in the main body of this report.

Appendix C – Provides the original backgrounder report that was provided prior to the first Delta Ecological Flows Tool design workshop. While it is superseded by the DeltaEFT Record of Design in Appendix D, this companion document illustrates the structured workshop and peer review approach taken in the development of DeltaEFT.

Appendix D – Provides the Record of Design for the Delta Ecological Flows Tool. A standalone report, this document provides additional detail about the development and technical implementation of each DeltaEFT indicator too voluminous for inclusion in the main body of this report.

Appendix E – Provides the software user guide for the Ecological Flows Tool Reader software.

Appendix F – Isolates and provides the systematic indicator screening & selection criteria used to guide decisions about what species and habitat indicators to include in EFT.

Appendix G – This Appendix provides details on the *default* relative suitability thresholds used to establish EFT's roll-up ratings of good, fair and poor annual performance by indicator. These suitability thresholds help characterize outputs, are fully configurable, but are only *one type* of information provided by EFT.

Appendix H – A comprehensive listing of all EFT input and output locations mapped to each species and performance indicator.

Appendix I – This Appendix provides a complete list of EFT derived rule-sets and recommended flow/water temperature regimes for all species and indicators.

Table of Contents

List of Figures

List of Tables

List of Abbreviations, Measurement Units and Fundamental Terms

Abbreviations

BA	Biological Assessment
BASW	Bank Swallow
BDCP	Bay Delta Conservation Plan
BO	Biological Opinion
CALSIM	California's monthly hydrosystem planning tool
CDEC	California Data Exchange Center
CEQA	California Environmental Quality Act
CRSS	Colorado River Simulation System
CS	Chinook salmon
CVP	Central Valley Project (California)
Delta	San Joaquin-Sacramento Delta
DeltaEFT	Delta Ecological Flows Tool
DEM	Digital Elevation Model
DFG	California Department of Fish and Game
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
DRR	Delivery Reliability Report
DS	Delta smelt
DSM2	(San Francisco) Delta Simulation Model version 2 (California)
DWR	California Department of Water Resources
EBC	Existing Biological Condition
EC	Electroconductivity
EFT	Ecological Flows Tool (includes SacEFT for the Sacramento River, and DeltaEFT for the Delta)
EHW	Extreme High Water
EIS/R	Environmental Impact Study/Report
ELT	Early Long Term (2025)
ERP	Ecosystem Restoration Program
ESO	Expected Starting Operations
FC	Fremont Cottonwood
GCID	Glenn-Colusa Irrigation District
GIS	Geographic Information System
GS	Green sturgeon
HEC-5Q	Flood control and conservation systems simulation model
HEC-RAS	Hydrologic Engineering Center River Analysis System
HOS	High Output Scenario
ICIF	ICF International
ID	Invasive deterrence
IFIM	Instream Flow Incremental Methodology
IHA	Index of Hydrologic Alteration

IMF	Instream Minimum Flow
LLT	Late Long Term (2060)
LOS	Low Output Scenario
LS	Longfin smelt
LWD	Large Woody Debris
MTL	Mean Tide Level
NAA	No Action Alternative
NEPA	National Environmental Policy Act
NMFS	National Marine Fisheries Service
NMFS BO	National Marine Fisheries Service Biological Opinion
NOAA	National Oceanic and Atmospheric Administration
NODOS	North-of-the-Delta Offstream Storage
OCAP	Operations Criteria and Plan
PHABSIM	Physical Habitat Simulation
PI	Performance Indicator
PPIC	Public Policy Institute of California
PTM	Particle Tracking Model
RKI	River Kilometer Index
RM	River mile
ROA	Restoration Opportunity Area
RPA	Reasonable and Prudent Alternative
SacEFT	Sacramento River Ecological Flows Tool
SAIC	Science Applications International Corporation
SLWRI	Shasta Lake Water Resources Investigation
SRWQM	Sacramento River Water Quality Model
SS	Splittail
SWP	State Water Project (California)
SWRCB	State Water Resources Control Board
TNC	The Nature Conservancy
TUGS	The Unified Gravel-Sand sediment transport model
TW	Tidal wetlands
TXFR	Transfer
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service
USFWS BO	United States Fish and Wildlife Service Biological Opinion
USGS	United States Geological Survey
USRDOM	United States Bureau of Reclamation Daily Operations Model (Sacramento River, California)
VEC	Valued Ecosystem Component
WRESL	Water Resources Simulation Language (used in CALSIM)
WUA	Weighted Usable Area
WY	Water Year
WYT	Water Year Type
X2	Distance (km) from the Golden Gate Bridge to the location of the low salinity zone, defined as 2‰ bottom salinity

Measurement Units

%	Percent (a fraction of one hundred)
‰	Permille (a fraction of one thousand)
cfs	cubic feet per second
cm	centimeter
ft	feet (ft^2 = square feet)
ha	hectare
kcfs	thousand cubic feet per second
km	kilometer
m	meter
MAF	million acre-feet
mm	millimeter

Fundamental Terms and Concepts

Indicator Performance indicator Metric Valued Ecosystem Component (VEC) Performance measure	Throughout this report, the word "indicator" is used in a general sense as it commonly is in applied science, without specific reference to how different authors occasionally decide to customize meanings of this (plastic) word. In this report, an "indicator" is analogous to a "performance indicator", or "metric", or "valued ecosystem component" (VEC). For our purposes, these words refer synonymously to any element of the environment that has ecological, economic, social or cultural significance. Subtleties and nuances as to whether an indicator "suggests, gets close to, approximates" but does not provide an objective "measure" are easily resolved by reviewing the actual definition for the indicator (or performance indicator, *etc.*). All of these terms are used to answer the question, 'how do I know' whether an action, or some fundamental natural driving conditions in the environment are causing things (that have value) to get better, worse or stay the same. The lack of a distinction between an *indicator*, or a *metric* is actually useful as it opens up more options as to what is an acceptable way to assess 'how do I know'. Decision makers, stakeholders, and members of the general public can make judgments and decisions with "indicators" just as well as "metrics" so long as the terms are clearly defined and logically linked to something of value.
EFT baseline simulation	An EFT baseline simulation was used for some indicators to inform decisions about relative suitability thresholds (see Section 2.7.2 for details). EFT baseline simulations are selected to maximize the range of water year types and year to year variation in flow conditions based on available data. Because of the requirement for long-term, high-resolution datasets (both temporal and spatially), this typically necessitated selection of the available long-term historical record. Historical data includes modified, regulated, artificial flows following construction of major dams, diversions and pumping plants. For some indicators (when the historic record was short), the EFT baseline combined the available historic data with simulated no action or reference case data. See Section 2.7.2.

Historical flows
The measured empirical flows that occurred during the selected period of record (for our purposes, typically some continuous sequence of years within 1939-2002). These flows often include a shifting mixture of modified, regulated, artificial (potentially "degraded") flows following construction and operation of dams, diversions, conveyance structures and pumping plants. Shifting climate change effects on precipitation and other hydrologic processes are also embedded. When the time series is long enough, they will also include a range of water year types and related flow variations that even though regulated, still manage to "show through" in the historic dataset.

Historical flows ≠ natural / pristine / unregulated / unmodified / unimpaired flows.

Natural flows
Natural flows represent the pristine, unmodified, unregulated, unaltered flows that would occur in the absence of any human presence, infrastructure, modifications, hydrosystem operations, water withdrawals and related land-use changes (e.g., forestry, agriculture). In this report, this is merely a theoretical concept. We do not use natural flows in our simulations (because they are not available).

Unimpaired flows
Reverse engineered flows found by attempting to remove the effects of reservoirs and diversions on *existing hydrology time-series*. These flows are thought of as a proxy for natural flows. Challenges with these estimates are manifold, and include absence of the effects of levees, channelization 'improvements', wetland storage and related evaporation processes, forest practices, groundwater interactions, *etc*. Unimpaired flow estimates are typically not performed for a wide range of locations, are often monthly in temporal resolution, and typically rely on volume correlations, precipitation correlations, subbasin to subbasin extrapolations and other techniques that produce unquantifiable errors.

Reference case scenario
Represents a chosen point of comparison, or baseline, that embeds any number of assumptions about the level of human development, climate change, and baseline system operations.

Study scenario
Represents an action scenario that contains alternative assumptions about any one or more of the level of human development, climate, and system operations. Depending on the chosen reference case scenario, the chosen study scenario can be used to isolate a specific effect, such as a system operation and conveyance change or a change in expected future climate (or both).

Executive Summary

The Need

Beginning with the launch of the current phase of this project in October 2008 and extending through to its conclusion in 2014, the Ecological Flows Tool (EFT) project has had the goal of improving water planning in the Sacramento River and the San Joaquin-Sacramento Delta. The waters which flow through these two ecoregions are among the most highly regulated anywhere in the world, serving over 20 million people, supporting a $40 billion agriculture industry, and sustaining diverse, although highly altered, ecosystems. Because of a chronic inability to find "balance" in the trade-offs among competing objectives and resource demands, the Delta is universally regarded to be in crisis. A central challenge in managing the Sacramento River and Delta is evaluating how alternative river management scenarios are likely to impact different components of the ecosystem. Our project directly addresses this challenge. Aided by over 70 scientists and managers since the project's 2004 inception, we have developed an integrated bio-physical tool that characterizes how a suite of focal species are expected to respond to alternative flow, river bank, and gravel management scenarios. EFT interfaces with existing water management tools, and is intended to be used to support the recovery of the Delta and Sacramento River ecosystems that are currently managed primarily to meet human water delivery needs.

An important challenge that has faced water managers has been the gap in scientifically credible, representative, flow-based ecological models which can be linked to appropriate physical hydrological models at a daily (or finer) resolution and at biologically relevant locations. EFT has helped to fill this gap through the development of submodel algorithms which simulate the physical needs of 13 representative focal species (and habitats) across the Sacramento River and Delta ecoregions. The peer-reviewed species submodels are made up of 25 key life-history indicators, each of which is driven by relevant measures of flow, water temperature, channel migration, salinity and/or stage at a daily timescale. In addition to coupling multiple ecological indicators to the physical inputs simulated by a standard suite of hydrological tools for evaluating operations and conveyance alternatives (CALSIM, SRWQM, DSM2 and their numerous components), EFT is linked to models of channel migration, soil erosion and sediment transport. This enables evaluations of the potential benefits not only of flow modifcation, but also of riprap removal and gravel augmentation.

By design, the development of each EFT indicator is based on a logical progression of steps that begins with the development of cause-effect conceptual models which link the physical regime to representative life-history stages of the focal species. Based on the implementation of these models, it is possible in a second step to identify flow management regimes that best meet critical needs of specific life-history stages. Prior to the creation of the EFT model and software, much of the knowledge related to focal species and their needs was isolated in reports, papers and disconnected models and tools that were difficult to access. EFT provides an integrated framework that can synthesize a very wide range of ecological information to allow far more comprehensive consideration of environmental needs than was previously possible. This level of synthesis and integration makes it possible to identify and address trade-offs among multiple focal species.

The outputs created by EFT are varied to meet the needs of different users. For research biologists familiar with the physical needs and temporal patterns of each focal species' life-history, daily and location specific graphs can be produced for any flow scenario and year, showing how each indicator and its driving physical processes vary by location and date. This allows users with specialized knowledge to evaluate model behavior and predictions at the finest scale. Other animated data visualizations are included for Delta species and performance indicators. For system managers and operators, a synthesis of detailed results is provided through a simple suitability rating system (Good/Fair/Poor "traffic light" assessments). These can be visualized by year or can be combined ("rolled up") even further by pooling years, for a very broad comparison of relative performance of alternative scenarios.

EFT Applications

The demand for and value of the Ecological Flows Tool is reflected in its use in several major investigations in the last few years. These investigations began with the use of the Sacramento River (SacEFT) branch of the decision analysis tool in 2011, to evaluate relative ecological effects of several alternative North-of-the-Delta Offstream Storage (NODOS) scenarios. The results of that analysis were considered in the interim joint environmental impact study/report (EIS/R) and revealed mixed impacts, depending on species and indicators. Most recently, we applied the *full* EFT model to selected Bay Delta Conservation Plan (BDCP) alternatives (a focus of Chapter 3). The analysis of BDCP scenarios included scenarios for expected starting operations (ESO), low output (LOS), and high output (HOS), as well as for climate change. Prior to the full EFT analysis of BDCP alternatives, a subset of focal species models (Sacramento River salmonids and green sturgeon) were used as part of the set of tools brought to bear on the BDCP EIS/R effects anlaysis. In addition to these three analyses, a prototype version of SacEFT (previous project phase) was used to study some of the early alternatives being considered as part of the Shasta Lake Resource Investigation. In all, EFT has demonstrated its ability to incorporate physical inputs simulated by a widely-used suite of planning tools and to provide defensible ecological outputs which have been used as part of the decision-making process for each investigation.

EFT analyses of the BDCP alternatives show that overall, the LOS BDCP alternative is preferable for species completing life-history stages in the Sacramento River (especially fall-run Chinook, late fall-run Chinook and spring-run Chinook) while the HOS BDCP alternative is preferable for San Joaquin-Delta species (especially longfin smelt and, to a lesser degree, Delta smelt). Fall-run Chinook, late fall-run Chinook and splittail do better under all BDCP alternatives considered ("winners"), while green sturgeon, deterence of invasives, and brackish wetland habitats are expected to experience deteriorating conditions. Spring-run Chinook are expected to do the most poorly under ESO and HOS alternatives in terms of spawning habitat, egg-to-fry survival, and redd dewatering. In general, juvenile stranding losses increase, particularly for winter-run Chinook. Delta temperature stress on winter-run Chinook also increases over all Early Long Term (ELT) alternatives. Likewise, Delta temperature stress is also elevated over all ELT alternatives for steelhead. While LOS ecosystem benefits are superior for species in the Sacramento River, results from HOS are generally very similar. *The various trade-offs noted*, the HOS alternative is likely the most preferable in terms of delivering ecological benefits. EFT results suggest the HOS is more likely to benefit Delta smelt and the LOS is predicted to be detrimental to longin smelt.

With a few exceptions, the climate change signal and effects in the BDCP study generally dwarfed the operational alternatives considered, especially in the Late Long Term period (LLT) (2065). Even though compensation was *not* the general outcome, the BDCP alternatives do have the potential to provide some offsetting benefits to help cope with climate change effects. In particular, spawning habitat is improved by the conveyance and operations in BDCP alternatives for fall-run Chinook and spring-run Chinook (LOS alternative only). Delta rearing conditions are improved by notching of the Fremont Weir associated with the ESO, LOS and HOS BDCP alternatives, offsetting losses that are otherwise expected for late fall-run, winter-run and, to a lesser degree, spring-run Chinook. Spring-run Chinook also receive compensatory offsets of otherwise detrimental climate change effects from the LOS scenario, in terms of reductions to redd dewatering losses and improved Sacramento River rearing conditions. A caveat with these improvements lies in the relative benefit of the flow mediated improvements versus the detrimental effects of warming spawning, rearing and Delta water temperatures.

Analyses of the EFT BDCP scenarios – all of which include changes in future climate and sea level – highlight the need for greater focus on efforts to mitigate for climate change itself. The magnitude of climate effects in the BDCP analyses shows the inadequacy of simply comparing whether certain operations are better or worse relative to a progressively deteriorating baseline, meanwhile ignoring the downward trend of the baseline itself. Studies which ignore such changes to the baseline divert attention from the cumulative total change in ecological conditions and can mask what can often be striking differences between historic operations and those proposed. Use of a historical reference case was recommended by the Delta Science Panel in its review of BDCP, even though the approach is unwelcome by some who feel that use of a historical record is a flawed reference with numerous shifts in operational standards and climate. The counterpoint to this critque is that the use of a historical reference case enables the study of the level of cumulative change, regardless of whether it is produced by climate change, changes in operations and conveyance, or increasing human water demand.

During the initial development of EFT's conceptual models and algorithms, communication between the physical driving models and EFT was completely unidirectional. The hydrologic models (CALSIM, DSM2 and related tools) provided input to EFT, which in turn was run to create multi-species ecological effects output. As we gained familiarity with the hydrologic models, it became apparent that the ability of EFT to simulate positive ecological outcomes could be harnessed to improve the rule-sets used in the physical models themselves. To test this ability, we conducted an initial pilot study using only a few of the 25 EFT indicators (for winter-run Chinook and Delta smelt) where analysis of EFT flow traces and conceptual models were used to create new rules for CALSIM that attempted to improve outcomes for these two focal species.

The initial pilot investigation demonstrated that the operation of the California water system can be changed to make timing of releases from Shasta Dam more beneficial to selected species without adverse consequences on storage and water exports. However, it also highlighted the inherent trade-offs between species and life-stages and how applying the same rule-set for a given water year type every year actually constrains options and contributes to the inability to adequately balance trade-offs.

Where To From Here?

There is a pressing need to develop greater awareness of the value of flexibility to manage ecosystem trade-offs over time within and among objectives. The detailed applications of EFT in Chapter 3 crystalize the fact that it is impossible to achieve all ecosystem objectives – let alone the co-equal goals of meeting human, agricultural and environmental needs – each and every year. There are plain, irreconcilable and ceaseless trade-offs that must be tracked and confronted, with winners and losers in different years depending on hydrologic conditions and priorities. These trade-offs do not occur because of a failure to create clever enough models that magically find the optimal solution; rather, an optimal solution does not exist. In Chapter 4 we describe a paradigm shift involving seeing balance as a condition which does not involve the same species or objectives losing (or winning) unnecessarily often. A key element is state-dependent priorities instead of one-size-fits-all water year rules. Under state-dependent priorities, flows are optimized for different species according to the recurrence interval necessary to support healthy population conditions along with ongoing tracking of the recent history of conditions and related ecosystem outcomes.

The further improvement of interaction between EFT and the hydrologic models is the current “leading edge” of inquiry for the EFT model. Implementing the new paradigm will require extending the modeling system by adding the capability to perform dynamic, state-dependent, multi-objective optimization with highly parallel simulations. This will enable the exploration of a much broader solution-space for multiple ecological criteria. An important aspect of this ongoing research is the application of ecosystem and water management rules which vary ("on", "off") according to the recent history of hydrologic conditions and the “most needy” ecological indicators.

Human communities, agricultural users and the ecosystems of the Sacramento River and San Joaquin-Delta are all facing very pressing challenges. EFT represents a large investment in the synthesis and integration of a vast body of knowledge and tools to respond to these challenges. It is a successful and rare example of a coupled, interacting model of operations, hydrodynamics, and multi-species ecosystem and geomorphic responses between the linked Sacramento River and Delta ecoregions; the kind of approach envisioned by the CALFED Science Advisory Panel in 2008, and subsequently by the Delta Science Council and a variety of other cross-disciplinary researchers (e.g., PPIC, UC Davis).

More than ever, there is great value and potential in the development and application of integrative modeling tools. EFT provides a robust framework for the joint collaborative work of experts and resource managers to come together to explore, develop, test and improve solutions to California's water management problems. Scientific uncertainties, coupled with the time required for iterative learning, will mean that the development of ecological flow recommendations will take many years and undergo periods of surprise and change. With its emphasis on specific cause-effect linkages based on functional flow, EFT provides a solid framework that remains open to testing, enhancement and adaptation over time.

1 Overview

This report presents results from the multi-year Ecological Flows Tool project (Project) whose goal was to provide a more complete understanding of multi-species' flow regime needs and how water management operations across the San Joaquin-Sacramento Delta and the Sacramento River can better meet these needs.

With the aid of over 70 scientists and managers since the Project's inception in 2004, the Ecological Flows Tool (EFT) team was amongst the first to quantify how specific components of the Sacramento River and San Joaquin-Sacramento Delta flow regimes can be "specialized" to promote key ecosystem functions in support of smarter, more eco-friendly flow management (TNC *et al.* 2008). Ecological flow management is widely recognized as one important tool toward promoting the resilience and recovery of native species. Many river-dependent plants and animals are strongly influenced by and have adapted to a river's natural variation in flow, and many fish and riparian species possess traits that allow them to tolerate or exploit certain flow conditions. While not the only stressor, the alteration of river flow regimes and related habitat losses associated with dam, diversion, and other water supply operations is one of the leading causes of declines in imperiled aquatic ecosystems (Arthington *et al.* 1991, 2006; Richter *et al.* 1996, 1997; Stanford *et al.* 1996; Poff *et al.* 1997; IFC 2002; Postel and Richter 2003; Tharme 2003; Petts 2009; Fleenor *et al.* 2010; Carlisle *et al.* 2010; Poff and Zimmerman 2010; Poff *et al.* 2010; National Research Council 2012; Hanak *et al.* 2013).

Quantifying the critical features of an ecologically beneficial flow regime for multiple aquatic and riparian species that are compatible with water supply delivery for human needs is fraught with both system uncertainty and trade-offs over conflicting values. Our approach to these challenges involves greater awareness of the need for flexibility to balance trade-offs over time, rather than seeking an elusive, singular and static point of balance.

The Project attacks one of the central problems faced by environmental water managers: lack of representative, credible, integrated functional flow criteria that are explicitly linked with physical models over large spatial scales. Unlike approaches which focus on a small number of simplified and static ecosystem needs, EFT describes 25 site specific, functional flow algorithms (based on conceptual models) for 13 representative species and key habitats across the Sacramento River and Delta ecoregions. We include life-history stage indicators for both listed and non-listed species and habitats. EFT's life-history stage conceptual models are then linked with multiple physical models of flow, water temperature, salinity, stage, channel migration and sediment transport to enable ecological effects analyses. Additionally, we have used the tool to both develop and test flexible, dynamic (state-dependent) flow criteria for incorporation into other models.

It is important to stress that restoring functional elements of a flow regime is not the same as restoring a "natural" or pre-regulated or unimpaired flow regime. In our nearly 10 years of work developing and applying EFT, and guided by the advice of many exceptional scientists and managers, we have been concerned with defining *representative critical functions* and quantifying a pattern of variation that can over time balance needs amongst multiple species. Within this context, three overarching challenges confront assessment and prescription of ecological (or environmental) flows. The first challenge is how to credibly characterize and define cause-effect conceptual models to describe how *representative* components of linked ecosystems respond to flow regime alterations. The second challenge is using these models to quantify acceptable target flow criteria and departures from natural flow regimes that will maintain specific critical features of the ecosystem (especially those that support endangered species recovery). The third and most vexing problem is deciding how to reconcile trade-offs amongst alternative ecosystem values and water supply needs for human use through time. The extensive body of work accomplished in this Project and summarized in this report offers an important contribution to how all three of these challenges might be navigated.

Prior to EFT, much of the important information on focal species existed in hard-to-access isolated reports and unconnected models and tools. EFT has integrated and synthesized a wide array of disparate information, linking ecological submodels to existing physical planning models, and providing a major advance in the water community's capabilities for more rapidly assessing multiple ecological trade-offs. Developing and peer reviewing these flow-habitat-biota hypotheses has been aided by a sustained collaboration with over 70 aquatic biologists, hydrologists, geomorphologists and hydrosystem engineers during the selection of EFT's focal species, indicators, and the subsequent algorithm development since 2004 (ESSA 2011, 2013).

All models are conceptualizations of reality and are often thought of as aggregate hypotheses that describe how different variables of interest are linked and influenced by interacting physical, habitat and biological processes. Modeling ecosystem relationships is often used to assess ecosystem health or, in the case of flow regime assessments, to determine trade-offs between human water uses and ecological needs (Rapport *et al.* 1998). Because of the high uncertainty and lack of understanding surrounding the complex interactions of communities of species with their physical environments (e.g., lagged compensatory density-dependent survival mechanisms), many modeling approaches emphasize physical limiting factors and other habitat variables. The implicit assumption is that more functional habitat will – all else being equal – support higher abundances. A step beyond physical habitat modeling (alone) is to model a specific set of species and life-stages by defining explicit linkages with changes in important habitats. In other words, many habitat (and life-stage specific focal species) models simulate the *potential* for lower/higher adult abundance. However, due to compensatory dynamics that often drive population level responses outside of a given life-stage time period, more high-quality habitat at a particular (usually juvenile) life-stage does not always translate to a higher abundance of adults.

In response to these limitations, some researchers attempt to develop full life-cycle population representations that predict space-time abundance of a particular species or even the individual behavior and movement of a species as they are born, grow, develop into adults and reproduce. This significant additional detail, and the aim of predicting changes over time in adult abundance or population viability (or recovery potential), comes with a price; single-species models are typically “data hungry” and require intensive calibration procedures to tune life-cycle responses to the available historic datasets. The Delta Science Panel review of BDCP concluded: "There are no life-cycle models that integrate the factors that BDCP will influence" (DSP 2014, pg. 13).

Because we used a functional flow approach that emphasizes *specific* cause-effect linkages, the formulation of EFT's indicators[1] is open to testing and adaptation through time as new data and understanding emerge. Indeed, the uncertainties surrounding how multiple stressors and flow management interact (e.g., nonlinear responses, invasive species, water quality changes, *etc.*) can make a flow regime target that seems adequate today of less value in the future (Hanak *et al.* 2011). EFT provides a framework that allows new indicators to be added, and others dropped through time as knowledge evolves. Our approach to identifying the desired flow regime is therefore more aptly described as "functional" than "natural". By carefully choosing a *representative* range of species and ecosystem functions over a broad geographic scale, variation and consequences of different flow regimes can be quantified and trade-offs brought into clearer focus.

1.1 Project History and Goals

“The panel believes it is essential that a sense of urgency be developed for initiating a dedicated project to build a simplified ecosystem model that is tailored to assess responses to changes in conveyance facilities. This project could build upon existing modeling capabilities…but will require that a full-time multidisciplinary team be devoted to the project for at least several years.”

CALFED Science Advisory Panel, June 24, 2008

This Final Report synthesizes the outcomes of the Ecological Flows Tool project (Project), launched in October 2008 and completed in April 2014 entitled: "Complementing Water Planning Efforts for the Delta and Sacramento River: Application of the Ecological Flows Tool for The San Joaquin-Sacramento Delta and Sacramento River". Chapter 2 summarizes EFT focal species, performance indicators (PIs), and analysis methods. In addition to describing categories of outputs, we provide an explanation of the different approaches to synthesizing outcomes and generating higher level net effect conclusions.

[1] Refer to the List of Abbreviations, Measurement Units and Fundamental Terms for a definition of "indicator" and other core concepts used throughout this report.

Chapter 2 also describes external models currently used by EFT as well as the methodology involved with using EFT to develop rule-sets for eco-friendly flow regimes. In particular, Chapter 3 focuses on findings and lessons from three major applications of EFT. In Chapter 3 we present results from an application of EFT to selected North-of-the-Delta Offstream Storage (NODOS), Delta Conservation Plan (BDCP) alternatives[2] as well as describe an initial *pilot test* using EFT to derive ecological flow criteria for inclusion in CALSIM. We then perform a subsequent "full circle" effects analysis using EFT to measure the ecosystem benefits and trade-offs of these *initial* (and incomplete) eco-friendly criteria we added to CALSIM. Chapter 4 concludes with logical next steps and promising new avenues for future research. The Project was designed and managed by The Nature Conservancy (TNC) and ESSA Technologies Ltd. (the Project Team).

The origins of this Project are in part an outgrowth of nearly three decades of conservation work by The Nature Conservancy (TNC) and its partners in the Middle Sacramento River. TNC received CALFED Ecosystem Restoration Program (ERP) funding in 2004 (grant ERP−02D−P61) to expand the ecological considerations and scientific foundation of water management decisions in the Upper and Middle Sacramento River, from Keswick Reservoir to Colusa. Referred to as the Sacramento River Ecological Flows Study (the Flows Study), work on a variety of tasks was completed between 2004 and 2008 (TNC *et al.* 2008). One of these tasks was the design and development, by TNC and ESSA Technologies Ltd., of a prototype decision analysis tool – the Sacramento River Ecological Flows Tool (SacEFT), which incorporated biophysical habitat models for six Sacramento River species, linked to physical models of flow, water temperature, channel migration and sediment transport. That effort was completed in 2008 and culminated in completing the first phase of EFT.

On the strength of the foundational work under the Flows Study (TNC *et al.* 2008), TNC was awarded an additional grant by the Ecosystem Restoration Program (ERP-07D-P06 / DFG# E0720044) in 2008 to refine and expand the capability of SacEFT for application to the San Joaquin-Sacramento Delta.

Extending the SacEFT decision analysis tool to incorporate Delta targets and management actions has: 1) allowed the first phase ERP funds to be leveraged; 2) achieved economies of scale through efficient application of a proven approach to link and integrate biophysical models; 3) provided a focal point for further assembling and quantifying important, representative functional cause-effect linkages in the Delta ecoregion; and, most significantly 4) created new capability to integrate species' trade-off evaluations between the Sacramento and Delta ecoregions. This approach unites the ability to evaluate ecological effects in both of these highly linked ERP ecoregions and draws additional attention to trade-offs associated with management actions between Sacramento River

[2] Note: This effects analysis application is performed, **written and interpreted by our team**, and applies both SacEFT and DeltaEFT. Previously, *portions* of SacEFT version 2 were considered by external BDCP Consultants as part of the vast BDCP effects analysis.

Basin dam operations and changes proposed in the Delta. Using EFT, it is possible to simultaneously assess whether actions contemplated in one ecoregion jeopardize the considerable conservation progress and investment in the other. To our knowledge, no other trade-off evaluation tool exists that integrates how ecoregions and multiple species performance indicators relate to one another and the general magnitude of these trade-off interactions.

1.1.1 Project Goals

The goals and findings of the Flows Study (and associated initial work on SacEFT) are documented in TNC *et al.* (2008). The Ecological Flows Tool Project (ERP-07D-P06 / DFG# E0720044), the subject of this Final Report, had **four** goals:

1. Complete expert peer review and refine SacEFT, to further increase the robustness of analyses and technical credibility for application to relevant water management planning and effects analysis efforts evaluating Sacramento River targets.
2. Facilitate the incorporation of the most robust and defensible findings from various Delta planning efforts and on-going studies[3], and incorporate them into a DeltaEFT branch of the existing decision analysis tool, thereby integrating the strongly linked Sacramento River and San Joaquin-Sacramento Delta ecoregions.
3. Apply both SacEFT and DeltaEFT (collectively referred to as EFT) to relevant water management planning efforts to highlight the ecological trade-offs in both ecoregions. Work with relevant water management agencies to identify and evaluate notable water operation scenarios that have been proposed (e.g., North-of-the-Delta Offstream Storage (NODOS), Bay Delta Conservation Plan (BDCP), Shasta Lake Resource Investigation, Bureau of Reclamation's Operating Criteria and Plan (OCAP) Review/Remand, DWR's System Re-Operation Program).
4. Effectively communicate the knowledge gained to agency managers and stakeholders, as well as to the public.

1.2 Vision - Multiple Ecological Flow Needs

The vision for EFT is to link physical hydrogeomorphic models (flow, water temperature, sediment transport, meander migration) to a representative set of ecosystem performance indicators in a decision analysis tool for evaluating multiple ecosystem trade-offs both in the Sacramento River and Delta. Our inclusion of a broad suite of ecological considerations in water-planning exercises catalyzes clearer communication of new, dynamic, flexible ecological flow targets and guidelines, and makes it more efficient to take these targets into account during water operation and conveyance investigations. From the beginning, a high priority of the EFT team has been to select *representative* species and ecological indicators

[3] Primarily studies available between 2008 and 2012.

that capture the essence of existing scientific understanding. We have aimed for a multi-species, multi-indicator approach while being careful to avoid paralysis caused by too broad a sphere of concern. We believe we have approximated a “Goldilocks” level of detail for components in EFT. While some EFT indicators can be quite sophisticated and others relatively simplistic, we have worked hard to achieve an overall balance of credibility and level of detail. We made a conscious design decision to avoid detailed data-hungry single-species models that, while comprehensive in their attempt to represent all life-history processes for that species, may suffer from a statistical challenge just as problematic as model over-simplification — equifinality[4] (multiple combinations of parameters that reproduce historic observations yet may yield different future predictions). Details on the formal focal habitat/species filtering and screening criteria (vetting process) used for DeltaEFT are provided in Appendix F.

EFT works by integrating 25 site specific, functional flow algorithms (conceptual models) for 13 representative species and key habitats across the Sacramento River and Delta ecoregions, with widely used hydrogeomorphic models. EFT's life-history stage conceptual model algorithms are then linked with multiple physical hydrogeomorphic models of flow, water temperature, salinity, channel migration and sediment transport (e.g., CALSIM, USRDOM, SRWQM, DSM2) to enable ecological effects analyses, as well as development and testing of flexible, dynamic (state-dependent) flow criteria. In this way, EFT transparently relates multiple attributes of the flow regime to multiple species’ life-history needs, providing a more comprehensive understanding of the effects of water operations on representative focal species and their habitats. The functional relationships that relate to EFT’s performance indicators are based on the best available science, and represent the collective knowledge of more than 70 scientists from state and federal agencies, consulting firms, and research institutions who have participated in our workshops since 2005 or who wrote primary papers on which the functional relationships are based.

We show in this report how EFT contributes to a more comprehensive understanding of how proposed changes to water operations infrastructure and management (and future climate conditions) affect species and their habitats. EFT does not solve social value decisions about whether a particular action or alternative is "good" or "bad." Rather, EFT is designed to provide information about the positive, neutral, and/or negative effects of a particular alternative, across a suite of representative focal species and their habitats. Importantly, this includes trade-offs that exist among multiple species’ needs. EFT’s intuitive outputs make it clear how actions implemented for the benefit of one geographic area or focal species may affect (positively and/or negatively) another area or focal species. For example, EFT can demonstrate how altering Sacramento River flows to meet export

[4] It is endemic to mechanistic modeling of complex open environmental systems that there are many different model structures and many different parameter sets within a chosen model structure that may be acceptable in reproducing historically observed behavior of that system. This is called 'equifinality'. This is more than an academic concern if mechanistic models fit to historic data are relied upon to predict *future* trajectories of a variable of interest in detail. This is a significant concern when different (equally plausible in terms of fit to historical data) parameter sets produce different future trajectories.

pumping schedules in the Delta affects focal species' performance indicators both in the Sacramento River and the Delta. This ecoregional trade-off capability is unique to EFT.

As demonstrated in Chapter 3, EFT is also useful for developing functional flow guidelines. Because of the multi-species approach, EFT helps communicate how to prioritize trade-offs among ecological objectives and adjust these priorities based on emerging conditions (e.g., water year types) and the ability to realize different objectives over time. These guidelines and criteria, based on EFT analyses, can be simplified for use in physical hydrosystem models such as new WRESL and other policy/rule statements in models like CALSIM and CalLite. Over time and with appropriate testing and optimization, this will improve the ecological flow guidelines contained in these tools.

1.3 Ecological Flow Needs: 'What' are they?

Ecological (or environmental) flows are concerned with access to and distribution of water to sustain the biodiversity and natural services provided by aquatic and riparian ecosystems. They refer to the quality, quantity, timing, and shape of flow regimes that support ecosystem functions, processes and resilience. The natural flow paradigm treats flow as the "master variable" needed to drive natural variation of hydrologic regimes to protect native biodiversity and the evolutionary potential of aquatic and riparian ecosystems (Arthington *et al.* 1991, 2006; Richter *et al.* 1996, 1997; Stanford *et al.* 1996; Poff *et al.* 1997; IFC 2002; Postel and Richter 2003; Tharme 2003; Petts 2009; Fleenor *et al.* 2010; Carlisle *et al.* 2010; Poff and Zimmerman 2010; Poff *et al.* 2010; Hanak *et al.* 2013). Ecological flow assessments are concerned with determining the flow regime required (or the acceptable departure from the original flow regime) to maintain specified, valued features of the ecosystem. Consideration of a single, minimum threshold flow, to the exclusion of other ecologically relevant flows (Tennant 1976), has been considered for some time to be an unacceptable approach to instream flow management. Because of the important functions of extreme flows and flow variation through time, maintaining a consistent base flow year after year is a management strategy that has also fallen from favor.

Methods for assessing ecological flow needs have emerged, ranging from screening the degrees of change and risks over large spatial areas with readily available data (e.g., Richter *et al.* 1996; Olden and Poff 2003; Poff *et al.* 2010; Sanderson *et al.* 2011) to site-specific, bottom-up, causally-reasoned functional flow methods applied to specific locations and species (e.g., Bovee *et al.* 1998; Parasiewicz 2001; Jowett and Davey 2007; Conallin *et al.* 2010). As different methods focus on different questions, they are all valuable for advancing understanding of ecological flow needs. Top-down approaches are generally concerned with agile risk identification and prioritization over broad spatial scales (using readily available data) while bottom-up methods emphasize identification of causally-reasoned functional flows for specific species and habitats, in specific river segments. Depending on how their eco-hydrologic performance indicators were developed, it may be possible to convert the outcomes from top-down methods into ecological flow criteria/guidelines that can be used in other decision support systems. Bottom-up methods are sometimes (but not always) more expensive to undertake, due to their more demanding site and species specific data requirements and the need for more detailed cause-effect conceptual models that link physical data to specific habitat or species life-history survival outcomes.

The four different general methods for producing ecological flow need recommendations are summarized in Table 1.1.

Table 1.1: Common methodologies for determining environmental flows (Alexander *et al.* 2013, and references therein).

eFlow Methodology	Description
1. Expert opinion and rules of thumb	Ecological flow needs generated by a group of domain specialists in aquatic biology/ecology or fluvial geomorphology (or related discipline). Normally, said experts will have many person-decades of experience. An example of an expert opinion assessment is recommending the 10^{th} percentile of mean annual discharge and asserting that these maintain river health (e.g., Tennant Method, Q_{90}). The best expert assessments involve individuals from a range of relevant disciplines (biology, geomorphology, ecology, hydrology), agencies, institutions or firms to ensure views are representative and impartial. These "desktop" methods have the benefit of being quick and inexpensive to develop with low data needs, but have been criticized as being simplistic and failing to encompass a full understanding of river processes. Ecological flows generated using this approach are more heuristic, qualitative, opinion-based and more difficult to "test" (prove/disprove). While their ultimate verisimilitude may be as strong as the other flow need recommendations from other methods, "acceptance" of expert opinion guidelines tends to be more open to debate, and there are usually more defined "camps" of supporters (believers) and non-supporters (non-believers).
2. Generalized hydrologic indices	Use changes in simple hydraulic variables (statistical metrics) as a surrogate for habitat factors of target biota. These methods are relatively easy to implement, requiring only minimal data. Includes the Index of Hydrologic Alteration (IHA) and other metrics of the degree of pre- and post-regulation/depletion change to flow regime, or other measures comparing unimpaired flows/historic flows with current flows. This approach does not use explicit characterization of target species life-history needs and consequences, does not on its own quantify available habitat, nor make other specific inferences on ecological responses. Often, recommendations from these methods are considered subjective. On their own, these methods do not help resolve specific ecological effect size changes inherent in the different degrees of flow regime departure / alteration. When the degree of response of a specific Valued Ecosystem Component (VEC) is linked with levels of hydrologic alteration, these indicators may be characterized as statistical/empirical

eFlow Methodology	Description
	relationships, or as functional flows (depending on details of how degree of alteration was linked with the VEC).
3. Empirical/ statistical relationships	The relationship is indicated between flow or other driving explanatory variable and native species abundance or desired habitat area (or other desired ecological attribute), but a step-by-step cause-effect prediction from physical variable to habitat change to biological response is not made (the mechanism is not clearly articulated, but is instead, "within" the data). These approaches may use models of the quantity and suitability of physical habitats to support target species under different flow regimes (e.g., IFIM, PHABSIM). Habitat simulation methodologies that develop empirical relationships can provide high resolution habitat-flow relationships but tend to focus on single species, not whole ecosystems. IFIM/PHABSIM and related method outputs are restricted to flow-hydraulic habitat relationships and often show poor linkages with biological responses. Other empirical/statistical approaches develop relationships that can be combined with a hydrologic index or with causally-reasoned functional flows.
4. Causally-reasoned functional flows	Are developed for specific species and habitats, in specific river reaches, and are generally based on cause-effect box-arrow conceptual models linking flow and other variables (e.g., water temperature, channel migration, sediment transport) with changes in important physical habitats through in some cases, to life-history survival mechanisms of the species of interest. Ecological flows derived in this manner (process modeling) require additional site and species specific data, and other physical habitat measurements and/or modeling, and are the most amenable to direct hypothesis testing/validation. Fleenor *et al.* (2010) describe this and other hydrologic and statistical methods that are commonly applied. When multiple functional flows are developed for a representative suite of species and habitats, these methods are the most holistic methods. Developing flow need criteria from these more rigorous methods also tends to generate higher resource and data requirements.

The four categories of ecological flow methods described above in Table 1.1 are ordered in terms of the level of scientific rigor applied to creating their underlying rationale and body of evidence. Functional flows provide the highest degree of explicit cause-effect reasoning between flows, important habitat attributes, and survival and productivity measures for target species. Different ecological and recreational flow need recommendations may be based on one, two or more of these methods. The majority of EFT's performance indicators are developed using method 4 and secondarily 3.

1.4 Summary of Project Tasks & Deliverables

To meet the Project goals, our work was organized into three tasks:

- Task 1: SacEFT Model Refinements and Application.
- Task 2: DeltaEFT Model Development to Evaluate Flow Needs for Delta Species.
- Task 3: Project Management, Draft and Final Report.

The Project work plan involved over 20 subtasks (Table 1.2) that were completed over a period of five years. The bulk of our work was designing, building and peer reviewing SacEFT (version 2.0) and DeltaEFT (version 1.1). EFT indicator development involved a number of important interrelated tasks: 1) expert design and review workshops (moving from conceptual model to cause-effect rules, algorithms); 2) database development; 3) data loading/configuration (and related data hunting); 4) programming; 5) output visualization development; 6) user interface programming; 7) developing relative suitability thresholds for EFT indicators; and 8) testing/bug fixing (iterative). Chapter 2 summarizes EFT's species and performance indicators with links to detailed Records of Design for both SacEFT and DeltaEFT.

This Draft Final Report integrates the capabilities of SacEFT and DeltaEFT to assess effects of selected BDCP alternatives and shows how other data were used to develop and assess the effectiveness of EFT-derived ecological flows criteria in CALSIM (Chapter 3).

Table 1.2: Project tasks and associated deliverables.

Task	Deliverables
Task 1: SacEFT Model Refinements and Application	☐ Task 1.1 - Facilitate SacEFT Model Refinement Workshop ☐ Task 1.2a - Draft SacEFT Model Refinements Workshop Technical Memo ☐ Task 1.2b - Final SacEFT Model Refinements Workshop Technical Memo ☐ Task 1.4 - Updated SacEFT v2.0 Design Document [Appendix B] ☐ **Task 1.3 - SacEFT Application to Relevant Water Management Scenarios [Chapter 3, *this document*]** ☐ Task 1.5 - Refined SacEFT v2.0 Software and Install Pack ☐ Task 1.3b - SacEFT Application to NODOS Admin EIS/R ☐ **Task 1.3c - Finalize and test alternative ecological flow requirements for Sacramento River-dependent targets [Chapter 3, Appendix I, *this document*]** ☐ Task 1.7 - Task 1 Quarterly Reports (*multiple*)
Task 2: DeltaEFT Model Development to Evaluate Flow Needs for Delta Species	☐ Task 2.2a - Draft DeltaEFT Backgrounder Report ☐ Task 2.2b - Final DeltaEFT Backgrounder Report [Appendix C] ☐ Task 2.3 - Facilitate DeltaEFT Model Design Workshop ☐ Task 2.9a - Initial DeltaEFT Outreach Presentations ☐ Task 2.4a - Draft DeltaEFT Design Guidelines ☐ Task 2.4b - Final DeltaEFT Design Guidelines [Appendix D] ☐ Task 2.5a - DeltaEFT alpha version ☐ Task 2.5b - DeltaEFT beta version ☐ Task 2.5c - DeltaEFT Database and Software, v1.0 ☐ Task 2.7 - Simple DeltaEFT User's Guide [Appendix E] ☐ Task 2.5d - Final DeltaEFT Database and Software (v.1.1), including new intuitive spatial visualizations ☐ Task 2.6 - DeltaEFT Install Pack and Webpage ☐ **Task 2.9d - Develop and test alternative ecological flow requirements for Delta-dependent targets [Chapter 3, Appendix I, *this document*]** ☐ *TNC Task 1: Incorporate longfin smelt abundance index to DeltaEFT* ☐ Task 2.10 - Task 2 Quarterly Reports (*multiple*)

Task	Deliverables
Task 3: Project Management, Draft and Final Report	☐ Task 3.2: Support Work Scope, Contract Documentation ☐ *TNC Task 2.1: Support for analysis and incorporation of Draft Final BDCP alternatives into Draft Final Report [**this document**]* ☐ **Task 3.3: Draft Final Report [this document, especially Chapter 3]** ☐ *TNC Task 2.2: Support for analysis and incorporation of Final BDCP alternatives into Final Report [in progress]* ☐ **Task 3.4: Final Report [in progress]** ☐ Task 3.1: Quarterly Reports

Given the volume of products, the Ecosystem Restoration Program has established a dedicated web site (www.wildlife.ca.gov/erp/erp_proj_delta_eft.aspx) to make the following available:

- ☐ Original SacEFT Backgrounder Report (from previous Flows Study, ESSA 2005) [Appendix A]
- ☐ Flows Study Final Report (from previous Flows Study, TNC *et al.* 2008)
- ☐ Updated SacEFT v2.0 Record of Design (Task 1.4) [Appendix B]
- ☐ SacEFT Application to NODOS Admin EIS/R (Task 1.3b)
- ☐ Final DeltaEFT Backgrounder Report (Task 2.2b) [Appendix C]
- ☐ Final DeltaEFT v.1.1 Record of Design (Task 2.4b) [Appendix D]
- ☐ Simple EFT User's Guide (Task 2.7) [Appendix E]
- ☐ Final EFT Reader Software and Installation Webpage [i.e., delivers both refined SacEFT v2.0 Software and Install Pack (Task 1.5) & DeltaEFT Install Pack (Task 2.6)]

Following is a summary of the primary deliverables produced under the ERP grant to TNC:

1999-2007 (prior to Agreement No. E0720044)

In 1999, TNC initiated a pilot study on mechanisms affecting riparian vegetation recruitment along the Sacramento River. These studies suggested that a variety of altered riverine processes were limiting natural recruitment of riparian vegetation. The Sacramento River Ecological Flows Study was initiated to address such processes and to complement existing revegetation efforts. It also expanded the scope of investigations to address the needs of both terrestrial and aquatic species. The Flows Study effort began in 2001, with the submittal of a proposal by the Ecological Flows team to the CALFED Ecosystem Restoration Program (ERP). After extensive reviews by CALFED, independent technical reviewers, and individual stakeholders, the Study was funded in 2004 under CALFED Grant No. ERP-02D-P61 to The Nature Conservancy. The goals, tasks and deliverables of this first major phase are described in TNC *et al*. (2008). One of the Flows Study tasks included design and development of version 1.0 of the Sacramento River Ecological Flows Tool (SacEFT).

2008

The Project Team delivered the SacEFT v.1 Model Review Workshop October 7 & 8, 2008 in Chico California with over 30 participants (Task 1.1). ESSA completed a draft SacEFT Model Refinements Workshop Technical Memo (November 5, 2008), and distributed it to workshop participants for comments (Task 1.2a). ESSA incorporated TNC suggestions and workshop participant peer review comments to complete a final SacEFT Model Refinements Workshop Technical Memo (December 17, 2008). The document defined understanding of enhancement options arising from peer review of SacEFT v.1, and prioritized them according to effort, feasibility and importance (Task 1.2b). In parallel, our team completed the DeltaEFT Backgrounder document December 23, 2008, a key input in advance of the DeltaEFT design workshop (planned for January 2013).

2009

The Project Team planned a 2-day DeltaEFT Model Design Workshop January 27 & 28, 2009 in Rancho Cordova to elicit the essential information needed to: 1) design the DeltaEFT Model; 2) determine priority candidate focal species, habitats and functional relationships; and 3) define the candidate management scenarios to apply in DeltaEFT. The Model Design Workshop was attended by 29 experts in the areas of Delta ecology and biology, physical modelers, and water managers with in-depth knowledge of existing data sets, fish population biology, and environmental water gaming.

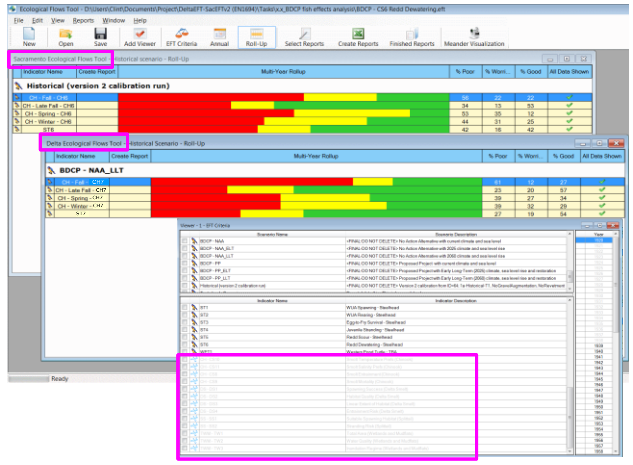
On November 16, 2009, ESSA delivered an on-line training seminar for the SacEFT v.1 Reader software.

2010

On February 22 to 24, 2010 we also presented materials (poster and brochure) at the California Water Environmental Modeling Forum, and co-presented DeltaEFT to experts attending this conference in Monterrey California. We also prepared and co-delivered a presentation on DeltaEFT to the State Water Resource Control Board in Sacramento on February 25, 2010.

Task 1.5 – Refined SacEFT v.2 software and install pack (database, indicator algorithm changes, Graphical User Interface enhancements, related software programming and Excel reporting changes) – was completed in the spring of 2010. ESSA software developers also completed revisions to the install pack

software program, to link to the appropriate EFT Reader database. This included a new deployment web site (October 2010) for users to register to receive the EFT Reader download.



In June 2010, we completed DeltaEFT Design Guidelines (Task 2.4b). The document is based on an extensive literature review associated with the development of the DeltaEFT Backgrounder, input from experts attending the DeltaEFT Model Design Workshop (January 2009), subsequent literature reviews following the lifting of the grant freeze in October 2009, and select one-on-one follow-up with modeling experts.

SacEFT v.2 was immediately put into service to conduct an effects analysis for six BDCP alternatives, delivered June 23, 2010 to Science Applications International Corporation (SAIC). Results included: 1) a high-level summary of SacEFT focal species performance indicator trends; 2) a summary of ecological performance of the BDCP alternatives for SacEFT v.2's steelhead (*Oncorhynchus mykiss*), green sturgeon (*Acipenser medirostris*), and Chinook salmon (*O. tshawytscha*) performance indicators (this analysis compared the percentage of years that had favorable conditions during the six simulations, including the change between the no action alternative and the proposed project in each of three time periods); and 3) an example of specific target water temperatures for green sturgeon egg incubation relative to the expected water temperatures that occur under the BDCP PP-LLT scenario. Our team completed the first prototype (or alpha version) of DeltaEFT subsequently in July 2010 (using temporary placeholder datasets).

On October 18, 2010, we were granted access to key data requested by our team on March 4, 2010; these data were needed to develop and test the prototype version of DeltaEFT. This period was punctuated by multiple rounds of non-disclosure agreement negotiations between TNC and California's Department of Water Resources (DWR) (related to BDCP confidentiality). Once we received the requested matching CALSIM, SRWQM and DSM2 data, our team focused on reviewing and beginning to sequentially load datasets into the DeltaEFT database, and address numerous unrelated data gaps/issues thereafter.

2011

In February 2011, we delivered SacEFT presentations at California Water Environmental Modeling Forum (Pacific Grove/Monterey), and in March 2011 we responded to a request by DWR (and subsequently TNC) to apply SacEFT v.2 to the North-of-the-Delta Off-stream Storage Administrative Draft Environmental Impact Study (NODOS Admin EIS/R). (The decision to focus on NODOS EIS/R temporarily slowed progress on development of DeltaEFT, which was previously slowed by numerous challenges acquiring required historical and modeled physical input datasets, and navigating non-disclosure / confidentiality issues.)

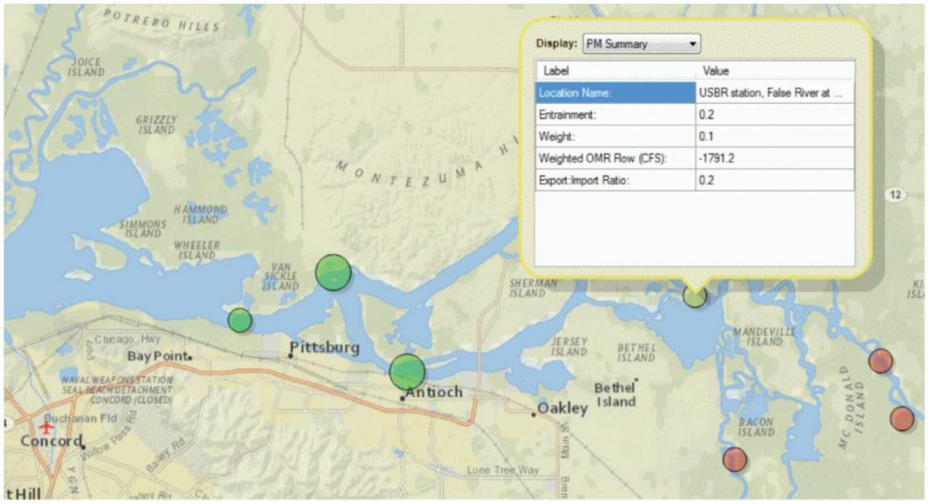
On March 3, 2011 we presented SacEFT with a focus on the bank swallow (*Riparia riparia*) habitat potential model to the Bank Swallow Technical Advisory Committee at the University of California, Davis. This expert review identified several important refinements to finalize the model's sophisticated spatial calculations. These refinements were not identified during the SacEFT v.1 review workshop.

In September 2011 we completed Task 1.3b – SacEFT Application to NODOS Admin EIS/R (TNC and ESSA 2012). Here we performed Sacramento River Chinook, steelhead, green sturgeon, Fremont cottonwood (*Populus fremontii*) and bank swallow effects analysis associated with five NODOS alternatives. This included use of SacEFT v.2 to capture changes in the percentage of years in the simulation period that report favorable indicator ratings. The structure of this analysis mirrored the results package delivered as part of the SacEFT v.2 BDCP effects analysis for Chinook, steelhead and green sturgeon (under Subtask 1.3).

In August 2011, and the following December 2011, our team completed the alpha and beta versions of DeltaEFT (Tasks 2.5a and 2.5b respectively). Testing, refinement and development continued in sprints during and after this period until May 2012 when ESSA completed version 1.0 of DeltaEFT (Task 2.5c). The timing of the opportunity to contribute to the San Joaquin-Sacramento Delta Conservation Plan's ecological effects analysis using SacEFT delayed progress on completing the first full version of DeltaEFT.

2012

In July 2012, the ESSA team completed DeltaEFT version 1.1 (Subtask 2.5d). This version of the software more clearly and effectively communicates Delta Ecological Flows Tool (DeltaEFT) outputs and trade-offs by providing intuitive spatial visualizations (output reports) in the EFT graphical user interface.



Example of map-based output information for DS4: Index of risk of entrainment.

Indicator performance indicators for the Sacramento River were accessible through the EFT Reader software tool as traffic light roll-ups and as graphic and tabular reports in Excel. However, some of DeltaEFT's indicators required spatially-explicit reports. The new spatial visualization features added to DeltaEFT output now make it clear “where” things are and reveal patterns of spatial variation in DeltaEFT indicator performance. The re-release of DeltaEFT as version 1.1 also triggered creation of a new installation program and associated web page (Task 2.6), available here: http://essa.com/tools/eft/download/.

On August 3, 2012 we completed updating the User Guide for the EFT system. This included a description of functionality for the updated Graphical User Interface for DeltaEFT. This User Guide is integrated into the Help menu of the EFT Reader software, and directs users to the following web site: http://eft-userguide.essa.com/. Delivery of the EFT User Guide[5] on-line simplifies maintenance and updates. The User Guide includes:

- A summary of application requirements.
- A Quick Start Tutorial, including how to install the EFT Reader (with associated screen images).
- Step-by-step instructions for all major User Interface components.

On September 19, 2012 we completed the first DeltaEFT analysis, applying the tool to four *preliminary* San Joaquin-Sacramento Delta Conservation Plan alternatives (including two baseline/reference cases and climate change alternatives). These preliminary results were presented to the State Water Resource Control Board staff in

[5] This is not a "Design Document", but a simple introduction to operation of the EFT Reader software (both SacEFT and DeltaEFT).

Sacramento on October 3, 2012. A second presentation on DeltaEFT was delivered as part of a panel presentation to the State Water Resource Control Board's formal workshop hearings on November 13, 2012[6]. These important efforts went towards fulfilling obligations under Subtask 2.9c of the grant ("DeltaEFT Presentations to Individual Agencies").

In December 2012, efforts focused on preparations for the DeltaEFT peer review workshop, scheduled for January 30, 2013 in Sacramento. This included agenda preparation, logistical input, meeting invitation support, and beginning to prepare presentation materials. While not a formal Project deliverable, we also documented review feedback from the January 2013 workshop.

2013-2014

In January 2013, the DeltaEFT as-built Design Document was revised (longfin smelt, *Spirinchus thaleichthys*, added). Work developing and testing alternative ecological flow requirements for Sacramento River and Delta-dependent targets was conducted from the summer of 2013 through to December 2013, and is the subject of Chapter 3. In November 2013, we added longfin smelt to DeltaEFT v.1.1, updated the Design Document, and then initiated the final EFT effects analysis on selected BDCP scenarios (Chapter 3, this report). That effects analysis modeling was completed in late January 2014.

[6] See: www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/wrkshp3/leowinternitz.pdf

2 Core Methods & Ecological Flow Needs Considered

This Chapter summarizes EFT's key concepts, approaches and methods, specifically:

- the kinds of management alternatives that can be evaluated using EFT (Section 2.1);
- the objectives and functional ecological flow needs considered in EFT and their key attributes (Sections 2.2 - 2.5);
- a description of our coupled modeling approach (Section 2.6);
- a review of the different categories of available EFT outputs (Section 2.7);
- a summary of how different effects are distinguished based on the structure of the trade-off comparison (Section 2.8); and finally,
- how EFT rule-sets can be integrated within systems operation models (Section 2.9).

EFT's multi-species, multi-indicator paradigm provides a "portfolio" approach for assessing how different flow and habitat restoration combinations suit the different life stages of target species. In so doing, EFT transparently relates attributes of the flow regime to multiple species' life-history needs in an overall effort at careful organization of representative functional flow needs. This provides a robust scientific framework for evaluating and prescribing ecological flow guidelines contributing to the understanding of water operation effects on focal species and their habitats.

EFT's focal species and performance indicators (PIs) are frequently split into two geographic regions: the Sacramento River ecoregion, where SacEFT is applied between Keswick (RM 301) and Colusa (RM 143); and the Delta ecoregion defined from a location just above Fremont Weir (RKI 182) and extending downstream into the Delta west and east of the mainstem river (Figure 2.1), where DeltaEFT is applied.

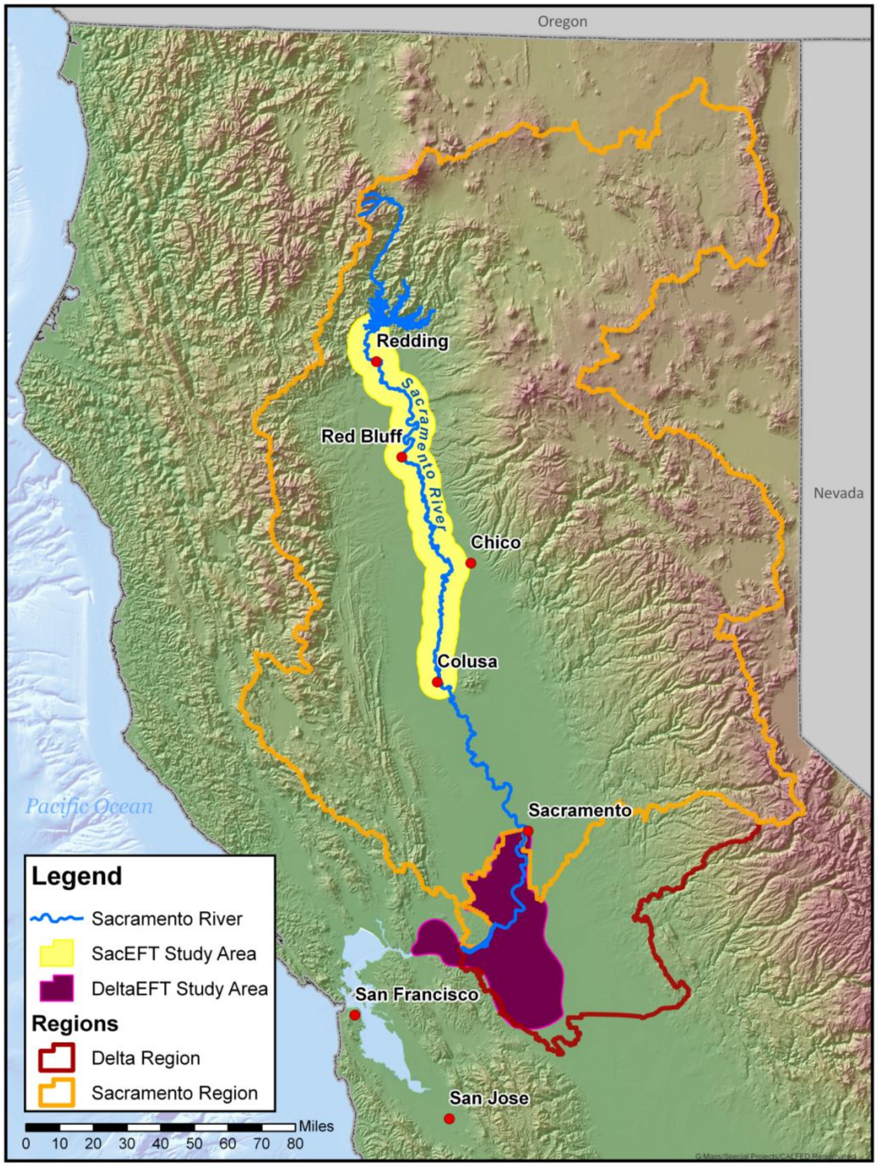


Figure 2.1: The two ecoregions of EFT: Sacramento River (SacEFT) and DeltaEFT (DeltaEFT).

Every decision support modeling exercise must include assumptions about what is included and excluded in order to keep the effort tractable. Details on the formal focal species and indicator screening and selection process used for EFT are provided in Appendix F.

Vetting of candidate species and indicators was further achieved through expert design and review workshops (two for SacEFT and two for DeltaEFT). These workshops were used to further review candidate conceptual model algorithms for the indicators that would be built into EFT. Workshop participants met in plenary to review the project background, learn about the intended scope and use of the model, and consider candidate conceptual models and our approach to evaluating trade-offs. Participants then worked through issues of model scope, bounds and integration of the candidate submodels. Subgroups then focused on refining the details and high priority pathways of each conceptual submodel. The intention was to identify a small subset of priority performance indicators per focal species to integrate into EFT. Subsequent peer review workshops were held to review test applications of initial versions of these models in both SacEFT and DeltaEFT.

An overview of the species and habitat indicators in EFT are provided in the sections that follow.

For economy, this Chapter does not attempt to reiterate algorithm details and assumptions of EFT's life-history stage conceptual models. Appendix A and Appendix D provide detailed as-built Records of Design for both the SacEFT and DeltaEFT branches of the tool.

2.1 Management Actions That Can Be Evaluated Using EFT

This section describes the range of management actions that can be evaluated using EFT. The specific alternatives evaluated in Chapter 3 are presented in Sections 3.3.2 and 3.4.2.

2.1.1 Reservoir Operations and Conveyance

The primary emphasis of EFT is to provide ecological trade-off information and recommend ecological flow criteria for water storage, conveyance and operation alternatives. Flow related management actions that can be evaluated using EFT include: 1) external climate forcing (historical or future) and human population demands; 2) Sacramento River Dam and diversion operations; 3) Delta conveyance and pumping operations; and 4) the coordinated operational criteria that are nested within Sacramento River and Delta (e.g., D-1641 with/without Biological Opinions). These represent a "four box" conceptual framework for communicating scenario elements (Figure 2.2). Each of these "boxes" represents multiple “levers” that can be changed, any of which can impact conditions in the Sacramento River and Delta. Different rules in these "boxes" ultimately translate into different flow regimes (Figure 2.3).

2.1.2 Bank Protection and Gravel Augmentation Evaluation

In addition to analyzing effects of alternative flow and water temperature regimes, SacEFT enables comparisons of rock removal and gravel augmentation actions. However, the alternatives studied in this report do not include gravel augmentation or bank protection modifications. Additional information on the coupled models used to support SacEFT effects analyses of these management actions are described in Section 2.6.

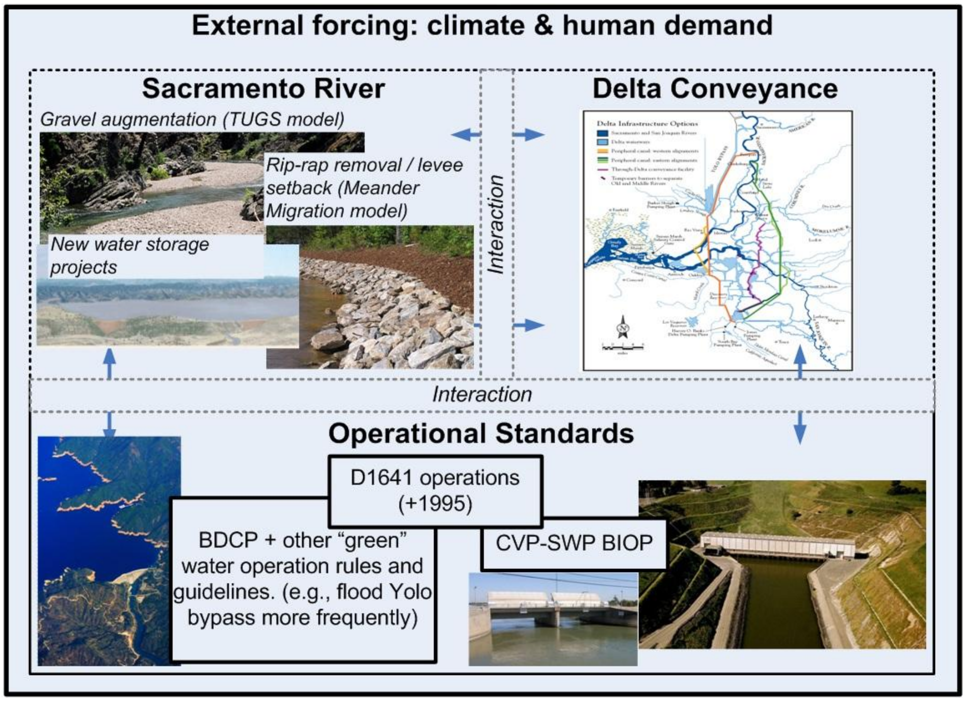


Figure 2.2: "Four box" conceptual framework for characterizing flow management actions that can be evaluated using EFT.

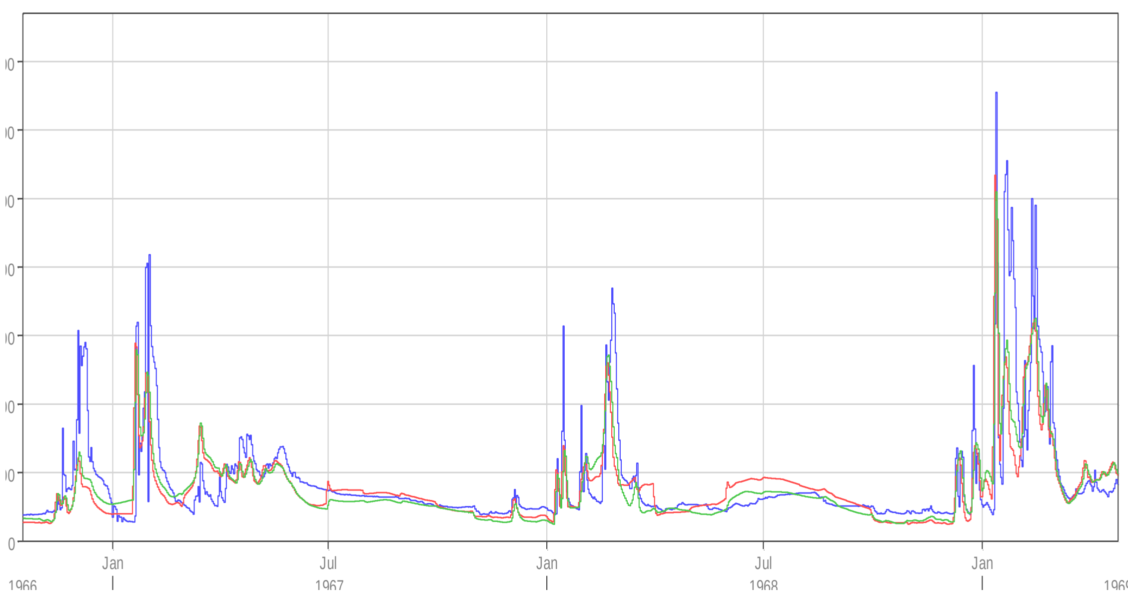


Figure 2.3: Different climate forcing, operational standards, or conveyance features of the Sacramento River and/or San Joaquin-Sacramento Delta translate into alternate flow regimes (different colored lines). The specifics of what each of these flow traces represents will depend on the details. The different flow traces provided here are for illustration purposes only.

2.2 Sacramento River Ecoregion Ecological Objectives & Performance Indicators

A total of six species groups and 12 distinct performance indicators are represented within the SacEFT ecoregion (Figure 2.4). In the case of salmonids, steelhead trout and four Chinook run-types share a common PI framework.

Figure 2.4: SacEFT includes the six species groups shown.

The PIs are listed along with a narrative summary in Table 2.1. More details about the PI calculation and default relative suitability thresholds are presented in Section 2.7.2 and Appendix G. Functional details are available in Appendix A (ESSA 2011). Key attributes of each performance indicator (e.g., units, key index locations) are provided in Section 1.1.

Table 2.1: Summary of SacEFT ecological objectives for each focal species and their associated performance indicators.

	Focal Species & Habitats	Ecological Objectives	Performance indicators	
Sacramento River	Fremont cottonwood	Maximize areas available for riparian initiation, and rates of initiation success at individual index sites.	**FC1** **FC2**	Cottonwood seedling initiation index Risk of scour after successful initiation
	Bank swallow	Maximize availability of suitable nesting habitat	**BASW1** **BASW2**	Suitable habitat potential (bank length, m) Risk of inundation and bank sloughing during nesting
	Western pond turtle habitat, mainstem Sacramento River	Maximize availability of habitat for foraging, basking, and predator avoidance	**LWD1**	Index of old vegetation recruited to Sacramento River (ha)
	Green sturgeon	Maximize quality of habitat for egg incubation	**GS1**	Egg-to-larvae survival (proportion)
	Chinook salmon Steelhead trout	Maximize quality of habitat for adult spawning	**CS1**	Area suitable spawning habitat (000s ft^2)
		Maximize quality of habitat for egg incubation	**CS3** **CS5** **CS6**	Thermal egg-to-fry survival (proportion) Redd scour (scour days) Redd dewatering (proportion)
		Maximize availability and quality of habitat for juvenile rearing	**CS2** **CS4**	Area suitable rearing habitat (000s ft^2) Juvenile stranding (index)

As shown, while we include multiple subcomponent effects at a variety of life-stages (in the case of salmonids), we intentionally avoid attempting to measure effects at the population level. Attempting to build detailed ecological models that make *accurate* predictions of ecosystem behavior is challenging and usually not possible in complex, open natural systems (Oreskes *et al.* 1994). Non-stationarity and equifinality[7] become particularly important challenges in parameter/calibration rich models often necessitating a leap of faith when applying them to future conditions. These models are often sensitive to assumed initial starting conditions. Additionally, most population-level life-cycle models do not themselves integrate all of the factors that are influenced by a particular action. So while the target level of detail and end output metric may be more palatable with life-cycle models,

[7] It is endemic to mechanistic modeling of complex open environmental systems that there are many different model structures and many different parameter sets within a chosen model structure that may be acceptable in reproducing historically observed behavior of that system. This is called 'equifinality'. This is more than an academic concern if mechanistic models fit to historic data are relied upon to predict future trajectories of a variable of interest in detail. This is a significant concern when different (equally plausible in terms of fit to historical data) parameter sets produce different future trajectories.

the number of assumptions and sensitivity of the tools to these assumptions is generally very high, and in some cases may obscure the "true" accuracy of predictions.

While life-cycle modeling can aid in the determination of net effects for a species when sub-stage effects are inversely correlated, *it is still possible to draw overall conclusions about the effect of alternative scenarios in their absence*. As described in Section 2.6 and in Chapter 3 we gauge overall effects of flow management and climate change using weight of evidence net effect scoring. Where feasible, our indicators also weight life-stage outcomes by the proportion of the population in that life-stage that is affected. An excessive pre-occupation on life-cycle models as "the solution" to effects analysis does not serve the cause of realistic expectation management. For example, Roni *et al*. (2011) in a comprehensive evaluation of salmon habitat restoration in Puget Sound, concluded:

> “Given the large variability in fish response (changes in density or abundance) to restoration, 100% of the habitat would need to be restored to be 95% certain of achieving a 25% increase in smolt production for either species. Our study demonstrates that considerable restoration is needed to produce measurable changes in fish abundance at a watershed scale.”

Ultimately, ongoing adaptive management and long-term monitoring programs are required to continually test and improve conceptual models of all forms. Conceptual models and performance indicator algorithms used in EFT can in the interim help determine whether different actions are more likely than not to increase resilience and help species cope with ever changing conditions.

2.2.1 Fremont Cottonwood Initiation (FC1)

The concepts behind the Fremont cottonwood response variable trace from Mahoney and Rood’s (1998) recruitment box model, bolstered by site-specific field studies performed by Roberts *et al.* (2002, 2003). Seeds of Fremont cottonwood disperse between mid-April and mid-June (Apr-15 to Jun-21 is default in SacEFT), and seeds that land on non-inundated ground begin to develop roots which grow down toward the water table. The SacEFT model assumes that the water table elevation is identical with the river stage, and then adds a further 30 cm above the water table to account for a capillary fringe zone. As water elevation drops with declining river stage, seedlings will survive as long as their roots are able to maintain contact with the water table inside a period of drought tolerance prescribed by the model (five days). Hence for successful initiation, the water table cannot decline at a rate that exceeds the taproot growth rate, defined as 22 mm d^{-1} (with five day "grace period" to allow for up/down fluctuations in river stage that may temporarily desiccate the initiating seedling). Should a seedling develop a taproot of 50 cm, it is assumed to reach a source of permanent groundwater sufficient to keep it alive through the remainder of its first year. Further details can be found in ESSA (2011).

The calculation of Fremont cottonwood seedling survival is made at a sequence of ”nodes” along 11 index cross sections along the Sacramento River. Two field studies (Roberts *et al.* 2002 and Roberts 2003) provide the data necessary to apply this model to three intensively studied locations (RM 172, 183, and 192) while nine other index cross sections and matching stage-discharge curves were obtained from HEC-RAS. These cross sections are located at RM 159, 164, 165, 172, 183, 185.5, 192, 195.75, 199.75, 206 and 208.25.

SacEFT's riparian initiation model calculates whether a single seedling in the center of each of these "nodes" along 11 cross sections would or would not survive given a particular flow regime during the critical life-history period. The node count of surviving seedlings (Figure 2.5) is then used as an index of seedling initiation success (more being better). Furthermore, SacEFT only makes this calculation for cross sectional nodes that are in the *target elevation zone for initiation*, which is defined as anything above 8,500 cfs elevation + 3 ft. Calculations for locations and river stages below and above this height are ignored.

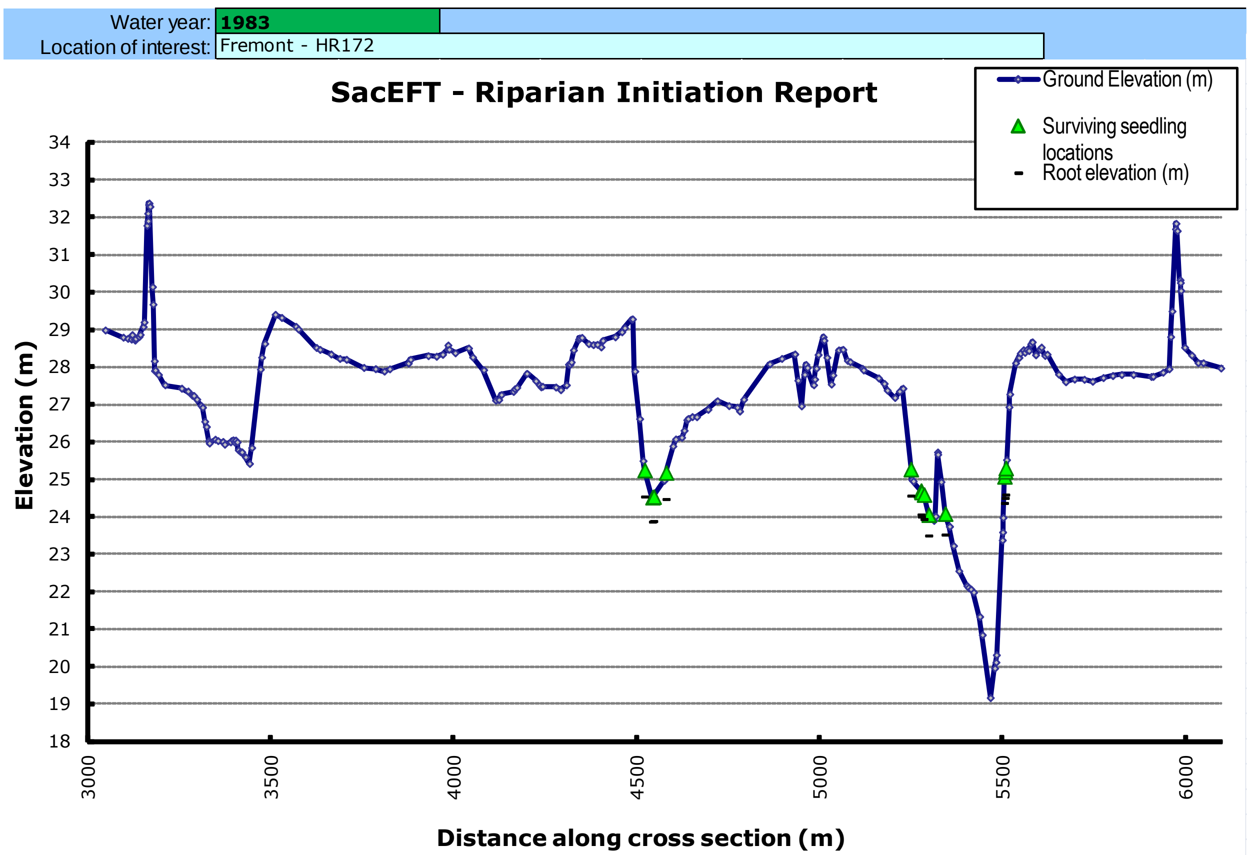


Figure 2.5: Example SacEFT output report for Fremont cottonwood at a specific cross section.

At present, with the existing 11 cross sections, the value 53 surviving nodes within the target elevation range (summed over all cross sections) was found by visual inspection to represent “good” initiation success, from historical flow data sorted descending (best to worst counts for each year) over the 66 year historical record. The lower threshold bound of performance (i.e., "poor") on successfully initiating nodes over these 11 cross sections was assigned to a node count ≤36.

Details on all *default relative suitability thresholds* used to "roll-up" EFT results are discussed in more detail in Section 2.7.2 and Appendix G.

2.2.2 Fremont Cottonwood Scour (FC2)

Newly initiated (but not yet “established”) Fremont cottonwood seedlings are susceptible to high flow events that inundate the seedlings and mobilize the gravel and sand containing their root systems. In EFT, scour risk is quantified by determining whether flow thresholds of 80,000 cfs and 90,000 cfs are exceeded in the first year following fair or good initiation (FC1) years. Additional background is provided in ESSA (2011).

2.2.3 Bank Swallow Habitat Potential (BASW1)

Bank swallows nest and rear their young in burrows along the river banks, and prefer soils with particular characteristics, burrowing depth, and burrow age. Burrows remain habitable for about three years and are abandoned after that due to ectoparasites and other factors which degrade the quality of burrows over time. The meandering of the (unrocked) river channel occurs naturally during high flow events, creating new bank swallow burrowing/nesting areas. Coupled to a river Meander Migration model (ESSA 2011), EFT simulates and reports the length of suitable bank habitat areas produced annually from approximately Butte City (RM 170) to Woodson Bridge (RM 222). Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.4 Bank Swallow Nest Inundation (BASW2)

During their spring and early summer nesting period, bank swallows and their young are susceptible to extremely high flows that can inundate nesting burrows, drowning the nestlings. EFT tracks high flow events known to be associated with dangerously high river stage elevations, at four representative locations. During the nesting period these flows and water levels, while potentially creating future nesting sites, will induce high mortality for the current year’s cohort of nesting bank swallows. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.5 Large Woody Debris Recruitment (LWD1)

Recruitment of old, mature vegetation is an important habitat requirement for western pond turtles (*Actinemys marmorata*) and is used as a proxy measurement for potential habitat quality in the main channel of the Sacramento River. While western pond turtles utilize oxbow habitats and sloughs, they are also capable of utilizing the main channel under appropriate conditions. To calculate the amount of large woody debris recruited to the main channel, EFT incorporates results from its spatially explicit bank erosion model combined with GIS mapping of mature forest vegetation, to calculate the amount of taller vegetation added to the river each year. As with the BASW1 performance indicator, bank erosion calculations are driven by the Meander Migration model. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.6 Green Sturgeon Egg Survival (GS1)

Green sturgeon eggs are susceptible to overheating during the April to July spawning and 14-day larval development period of each day-cohort. Warm water temperatures during egg incubation increase the number of embryos that develop abnormally and reduce hatching success. Specifically, water temperatures above 17°C reduce egg survival and are lethal above 20°C. SacEFT uses modeled daily water temperature at two equally-weighted spawning index locations to simulate the proportion of survival for the larval young-of-year. Annual summaries are the average of the two locations. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.7 Chinook & Steelhead Spawning Habitat (CS1)

Salmonids (four seasonal run-types of Chinook plus steelhead trout) prefer to spawn in streams with a specific combination of water depth, velocity and gravel composition. EFT incorporates these preferences based on the River2D model and combines them with daily flow during the spawning period to calculate and report the weighted available habitat area for spawning (WUA) at up to five index reaches of the Upper Sacramento River[8]. Each run-type follows a calendar which divides the run-type into daily cohorts over the spawning period. The performance indicator for each reach is calculated by weighting the WUA on each spawning day by the proportion of adult spawners present during the run-specific spawning period. Annual summaries are calculated by taking the average of all the reaches (see Figure 2.6). Because substrate is one of the components of WUA, changes to substrate composition can affect the overall value of the spawning beds. EFT can incorporate substrate changes through linkage to The Unified Gravel-Sand model (TUGS; see Section 2.6.4), which simulates the addition and transport of gravel.

[8] Readers interested in why a particular index site was chosen, details of the weighting rules, *etc*. are referred to Appendix A.

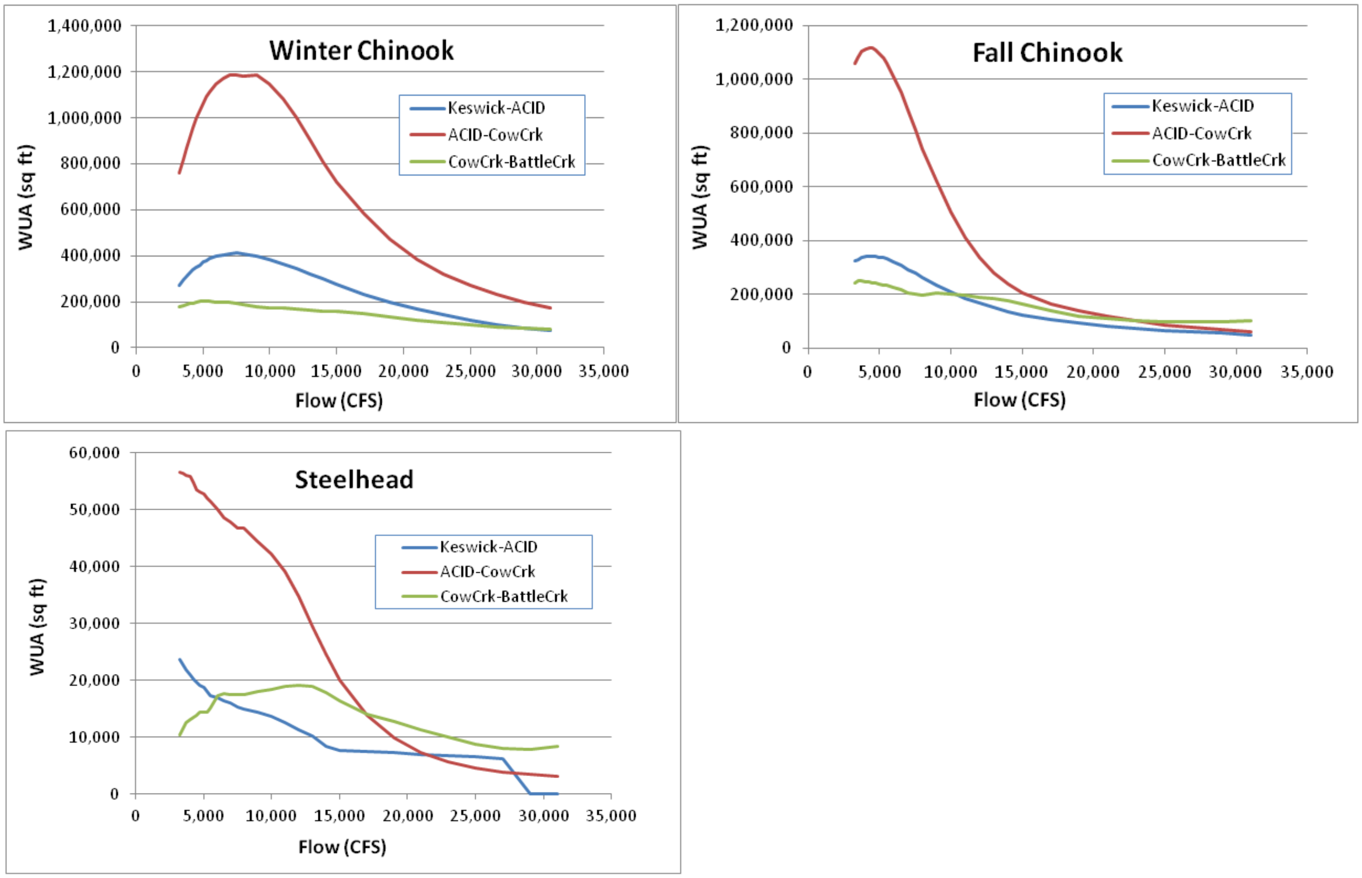


Figure 2.6: Example spawning WUA relationships for winter-run Chinook, fall-run Chinook and steelhead for three river segments used by SacEFT. Source/Adapted from: USFWS (2003).

Performance indicator details and science foundation references are provided in ESSA (2011).

> There is a common misperception that habitat potential is equivalent to spawning abundance in the EFT model. This is not the case: none of the Chinook or steelhead performance indicators include explicit treatment of adult spawning populations. They are measures of **habitat potential** only, and not of how many actual spawners, eggs or juveniles make use of the potential habitat. This means that a simulation may result in high spawning WUA (good habitat potential) but in the real world there could be situations where very few spawners are present to take advantage of the good habitat (e.g., due to poor ocean conditions, overfishing, straying or differential use of alternative tributary habitats, etc.).

2.2.8 Chinook & Steelhead Egg-to-Fry Survival (CS3)

The developing eggs of each of the four seasonal run-types of Chinook and steelhead trout have specific water temperature requirements to successfully mature. EFT uses relationships borrowed from the SALMOD model (Bartholow and Heasley 2006), along with daily water temperature at up to five index reaches to simulate the maturation and proportional survival of developing eggs. Each run-type follows a calendar which divides the run-type into daily cohorts over the spawning period. The PI is measured at the reach by weighting survival using the relative density of each spawning day-cohort. Annual summaries are calculated by taking the average of all the reaches. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.9 Chinook & Steelhead Redd Scour (CS5)

Spawning redds contain the developing eggs of each of the four seasonal run-types of Chinook and steelhead trout, and are susceptible to extremely high flow events that mobilize the redd gravel, killing a proportion of the developing eggs/embryos. EFT combines these high flow events with the species and run-type specific spawning and egg development calendar to calculate and report the frequency of two levels of extreme flow events at up to five index reaches, when the developing eggs are sensitive to scour. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.10 Chinook & Steelhead Redd Dewatering (CS6)

Spawning redds contain the developing eggs of each of the four seasonal run-types of Chinook and steelhead trout, and are susceptible to declining flows that expose and desiccate the spawning redds. EFT incorporates empirical relationships developed from GIS bathymetric models to calculate the proportion of spawning WUA habitat exposed during periods of declining flows which occur between the spawning day and the emergence of each juvenile day-cohort at up to five index reaches. Each run-type follows a calendar which divides the run-type in each reach into daily cohorts over the spawning period, followed by a temperature-based egg development period. The PI is measured at the reach by weighting the index of dewatering exposure using the relative density of each spawning day-cohort. Annual summaries are calculated by taking the average of all the reaches. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.11 Chinook & Steelhead Juvenile Rearing Habitat (CS2)

Juveniles of each of the four seasonal run-types of Chinook and steelhead trout prefer to rear in streams with a specific combination of water depth and velocity. EFT incorporates these preferences from the River2D model and combines them with daily flow during the rearing period to calculate and report the weighted available habitat area for rearing (WUA) at up to five index sections of the Upper Sacramento River. Each run-type follows a calendar which divides the run-type into daily cohorts over the rearing period which comes after the end of egg-maturation. The performance indicator at the reach is then weighted by the relative density of rearing juveniles present throughout the species and run-specific rearing period. Annual summaries are calculated by taking the average of all the reaches. Performance indicator details and science foundation references are provided in ESSA (2011).

2.2.12 Chinook & Steelhead Juvenile Stranding (CS4)

Free swimming juveniles of each of the four seasonal run-types of Chinook and steelhead trout typically reside in their natal stream for three to 12 months after emerging from the gravel. During this period they are susceptible to declining flows that may strand them in side channels, exposing them to high water temperatures, desiccation and other factors that heighten rates of mortality. EFT incorporates empirical relationships developed from GIS bathymetric models to calculate these effects at up to five index reaches of the Sacramento River. Because juveniles are able to avoid stranding (unlike eggs), it is not possible to calculate a proportion of juveniles stranded. Instead, stranding is calculated using the same methodology as redd dewatering (CS6), to provide an index for each reach, of the proportion of juveniles exposed to stranding during periods of declining flow. The performance indicator is weighted by the relative density of juveniles present during the species and run-specific rearing period. Annual summaries are calculated by taking the average of all the reaches. Performance indicator details and science foundation references are provided in Appendix A (ESSA 2011).

2.2.13 Chinook & Steelhead – What life-history Attributes are 'Most' Limiting?

Recognizing the commentary above, reviewers of the EFT salmon models and related performance indicators often request definitive statements about the overall net species effect when EFT indicator results are mixed. For example, "the models do not clearly tell us whether improvements in spawning habitat and smolt growth will or will not compensate for other factors, such as temperature stress". Another classic example in SacEFT is that rearing WUA and juvenile stranding results are often inversely correlated[9]. A helpful approach to this conundrum is to consider some of the fundamental life-history properties of each run of Chinook and steelhead (including the timing of these events). We discuss some of the fundamental characteristics of each Chinook run-type below and how these observations can assist in shaping general interpretation of the importance of various EFT salmon indicators (i.e., those that tend, all else equal, to be more/less limiting).

The biological significance of a reduction in available spawning habitat varies at the population level in response to a number of factors, including adult escapement. By far, fall-run Chinook are presently the most numerous (primarily as a result of considerable

---

[9] This is because potential rearing habitat in SacEFT is used as an input to weight the impact of juvenile stranding, making it inevitable that as more rearing habitat is created it exposes proportionally more juveniles to stage-flow recession events.

hatchery supplementation) and widely distributed salmon in the Central Valley, and not reliant on the upper Sacramento River mainstem. They return from the ocean during June through November and spawn from early October through late December. Fall-run juveniles enter the ocean at comparably smaller sizes due to the fact that they emigrate relatively soon after emergence, relying more on early ocean growth than the other run types (Vogel and Marine 1991; NMFS 1997, 2009; Moyle *et al.* 2008).

A daily average water temperature of 60°F (15.6°C) is considered the upper temperature limit for growth and rearing of outmigrating Chinook juveniles (NMFS 1997). Currently, a 56°F (13.3°C) compliance point is used at Bend Bridge near the town of Red Bluff. Water temperatures below this point warm rapidly. Summer water temperatures in many California rivers already exceed 71.6°F (22°C) (Katz *et al.* 2012). Thus, small thermal increases in summer water temperatures can result in suboptimal or lethal conditions and consequent reductions in salmonid distribution and abundance.

The migration of juvenile Chinook salmon from their riverine origin to the food-rich ocean is considered one of the most vulnerable periods of the life-cycle. Mark recapture studies with fall-run Chinook salmon have suggested that salmon smolts entering the central Delta via the Delta Cross Channel and Georgiana Slough have a much lower survival index than those remaining in the mainstem Sacramento River (NMFS 1997). An important refuge and stronghold for foraging and growth, access to productive floodplain rearing habitat is expected to be a major benefit to all run types of Chinook, especially given historical habitat loss and simplification.

Late fall-run Chinook spawn December through January, when water temperatures are the least difficult to manage. They migrate and spawn at times when the rivers are high, cold, and turbid, hence, spawning flows are generally *not* the primary limiting factor (NMFS 1997, 2009). Late fall-run Chinook are found mostly in the Sacramento River between the Red Bluff Diversion Dam and Keswick Dam. Small numbers also spawn in Battle Creek, Cottonwood Creek, Clear Creek, Mill Creek, as well as in the Yuba and Feather Rivers. Like fall-run Chinook, this population is also largely sustained by hatchery production. Late fall-run Chinook normally benefit from conservation actions taken for winter-run Chinook (Moyle *et al*. 2008; NMFS 2009).

Spring-run Chinook make use of the mainstem Sacramento River and several tributaries. As a consequence, spawning habitat in the mainstem Sacramento River is a concern but not the primary stressor/limiting factor (NMFS 1997, 2009). Only three extant independent populations exist, and they are especially vulnerable to disease or catastrophic events because they are in close proximity. Water temperatures during adult migration, holding, and spawning are one of the most significant stressors for this run type. Adult spring-run Chinook salmon require freshwater streams with cold temperatures over the summer and suitable gravel for reproduction. Spring-run Chinook salmon are immature when upstream migration begins and need to hold in suitable habitat for several months prior to spawning.

While immature, the maximum suitable water temperature for holding is 59°F (15°C) to 60°F (15.6°C) (NMFS 1997). Suitable water temperatures for adult spring-run Chinook salmon migrating upstream to spawning grounds range from 57°F (13.9°C) to 67°F (19.4°C) (NMFS 1997). Emergence typically occurs from January through as late as May (NMFS 2009). For maximum embryo survival, water temperatures during incubation should be between 41ºF (5°C) and 55.4ºF (13°C) and oxygen levels must be close to saturation (Moyle 2002, as cited in NMFS 2009). Fortunately, in many streams these temperatures are frequently possible during the November to January incubation period. The Central Valley spring-run Chinook salmon population is spatially confined to relatively few remaining streams, continues to display broad fluctuations in abundance, and a large proportion of the population (i.e., in Butte Creek) faces the risk of high mortality rates due to elevated water temperatures during the adult holding period (NMFS 2009). Additionally, Delta conditions are considered more of a limiting factor for spring-run (and winter-run) relative to the fall runs (NMFS 2009).

Spawning escapements of winter-run Chinook salmon in the Sacramento River have declined from near 100,000 in the late 1960s to less than 200 in the early 1990s (Good *et al.* 2005, as cited in NMFS 2009). The construction and operation of Shasta Dam immediately reduced the winter-run Chinook salmon range from four independent populations to just one (NMFS 2009). As a result, winter-run Chinook spawn almost entirely in the Sacramento River and a few tributaries upstream of Red Bluff. NMFS winter-run Chinook recovery plans list Sacramento River spawning flows and embryo incubation flow fluctuations amongst the highest stressor categories/limiting factors (NMFS 2009). The remaining available spawning habitat, including the mainstem Sacramento River, is currently maintained with cool water releases from Shasta and Keswick dams. Adults arrive as early as December, with spawning occurring from March through August. Water temperatures are the second most highly weighted stressor category in National Oceanic and Atmospheric Administration (NOAA) Fisheries winter-run Chinook recovery planning documents (NMFS 2009). The embryo incubation life stage (includes the June to August period) of winter-run Chinook salmon is very sensitive to elevated water temperatures (NMFS 2009). Preferred water temperatures for Chinook salmon egg incubation and embryo development range from 46°F (7.8°C) to 56°F (13.3°C) (NMFS 1997). A significant reduction in egg viability occurs at water temperatures above 57.5°F (14.2°C) and total mortality may occur at 62°F (16.7°C) (NMFS 1997). Additionally, dropping incubation flows from 13,000 cfs to 5,500 cfs would result in dewatering 21% of winter-run redds (USFWS 2006).

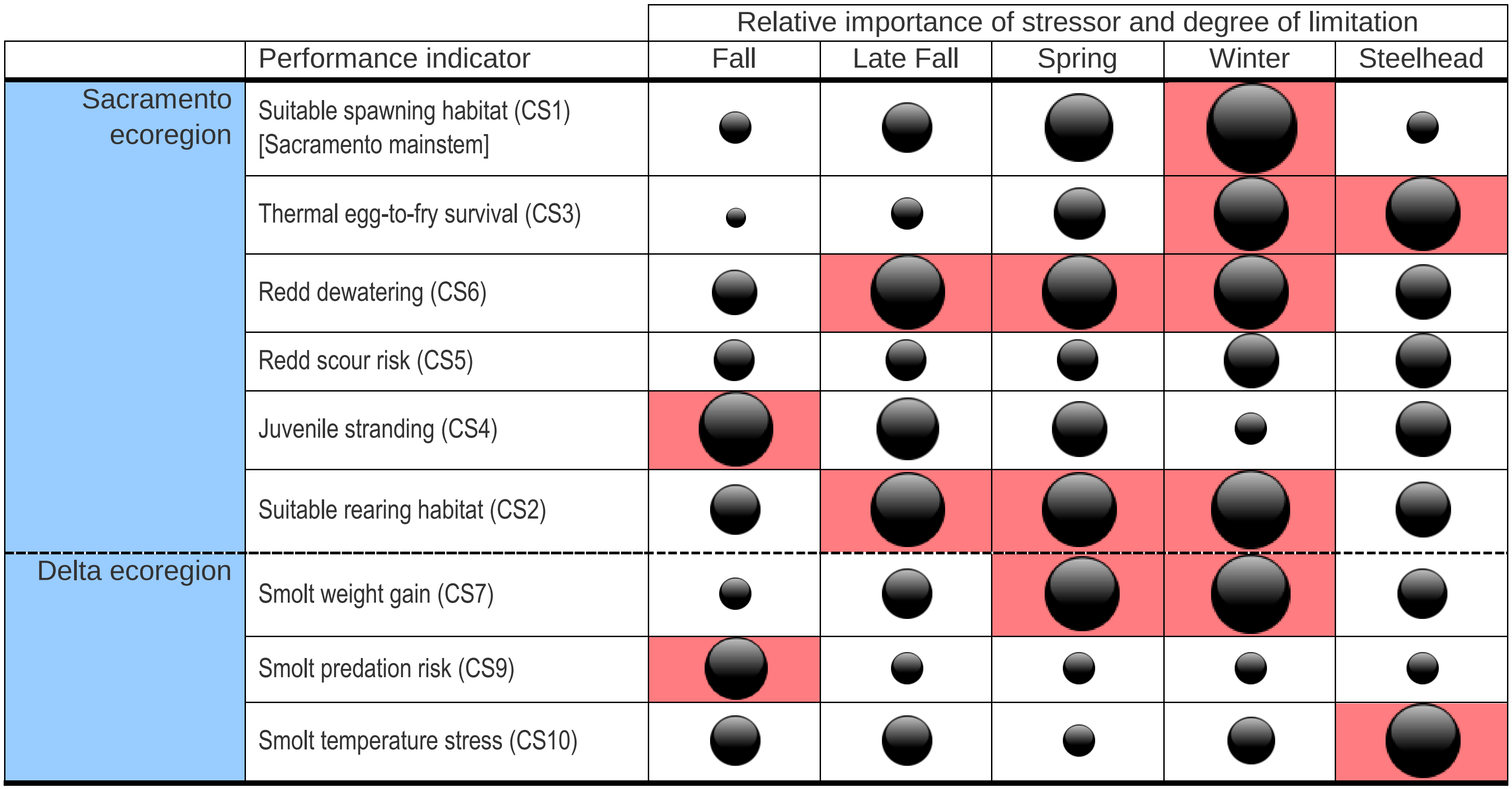
Winter-run Chinook spend much longer in freshwater and typically enter the ocean at comparably larger sizes. As a consequence, Delta conditions represent a relatively greater limiting factor for winter-run (and spring-run) than for the fall runs. Water temperatures in the Delta are generally suitable throughout the winter-run Chinook salmon adult immigration and holding life stage period except for during June and July. Water temperatures in the

Delta likely do not adversely affect winter-run Chinook salmon juveniles until the late spring (NMFS 1997).

Steelhead use tributaries extensively, and are not restricted/reliant on the Sacramento River mainstem. In the Central Valley, steelhead are also produced in large quantities by hatcheries, not by wild spawning fish. Steelhead use seasonal habitats of intermittent streams for spawning and rearing. As a consequence, water temperatures are one of the most important stressors for this species (NMFS 2009).

The overall importance of each stressor, the relative degree each is thought to be limiting for EFT salmon performance indicators, is shown in Table 2.2.

Table 2.2: Relative importance of each EFT salmon performance indicator by run type. Details on Delta performance indicators are provided below.



2.3 Key Attributes of SacEFT Performance Indicators

Most of EFT's performance indicators are calculated on a daily (or finer) time-step at multiple index locations. Naturally, these daily calculations come in many different units appropriate to the performance indicator (e.g., square feet of suitable habitat, survival rates, counts of surviving cottonwood seedlings, *etc.*). Further, the daily calculations for most aquatic performance indicators (see above) are weighted by the appropriate life-history distributions as well as by differences in habitat quantity/quality among the modeled index sites. For example, if a sudden dramatic low flow event occurs at the very beginning or very end of the egg incubation period for a particular Chinook run-type, the weighted effect on the overall cumulative redd dewatering performance indicator (CS6) will be negligible.

Table 2.3 summarizes the units, overall nature of the calculations and general location weighting and roll-up methods for SacEFT performance indicators (details are available in ESSA 2011). Related background on driving physical data and fundamental concepts behind EFT are provided in Section 2.6. The default relative suitability threshold assumptions used to "roll-up" annual water year performance are given in Section 2.7.2 and Appendix G.

Table 2.3: SacEFT performance indicators (SacEFT Ecoregion) – units, overall calculation, weighting and roll-up attributes.

Indicator Name	Native units	PI Calculation	Location weights/roll-up
FC1 Cottonwood initiation	Index	Daily stage recession at selected cross sections is coupled to potential root growth during seed dispersal period	Annual sum of counts of successful initiation at 10 locations between RM 159–208
FC2 Cottonwood scour risk	Index	Very high scouring flow during good FC1 years reduces survival	Sum over all cross sections and cross section nodes (no weighting)
BASW1 Bank swallow habitat potential	Bank length (m)	Annual new river bank exposed due to channel migration	River bends from RM 170-222 are added
BASW2 Bank swallow inundation risk	Index	High scouring flow during nest period reduces survival	Four locations with equal weight are averaged
LWD1 Large woody debris recruitment	Area (ha)	GIS-based areas of old-growth vegetation are coupled to channel migration	Total channel migration on old growth river bends are added from RM 170-222
GS1 Green sturgeon egg-to-larvae survival	Survival Proportion (0–1)	Daily temperature above physiological limit reduces survival	Two locations with equal weight are averaged

Indicator Name	Native units	PI Calculation	Location weights/roll-up
CS1 Chinook & steelhead spawning habitat	WUA (000s ft2)	Sum of daily WUA multiplied by daily calendar weight during the spawning period	Up to five locations are weighted equally to allow for summing WUA across all locations
CS3 Chinook & steelhead egg-to-fry survival	Survival Proportion (0–1)	Cumulative egg-to-fry survival during egg-development period, weighted by daily spawning distribution	Up to five locations are weighted equally to allow for averaging across all locations
CS5 Chinook & steelhead redd scour	Peak flow (scour days)	Number of days exceeding scouring flow criteria	Up to five locations are weighted equally for averaging across all locations
CS6 Chinook & steelhead Redd dewatering	Proportion (0–1)	Cumulative exposure from weighted daily spawning distribution and daily decline in flow during the egg development period	Up to five locations are weighted equally to allow for averaging across all locations
CS2 Chinook & steelhead rearing habitat	WUA (000s ft2)	Weighted average rearing area based on spawning emergence distribution and residency period	Up to five locations are weighted equally to allow for summing WUA across all locations
CS4 Chinook & steelhead juvenile stranding	Stranded juveniles (index)	Index of cumulative juvenile stranding based on weighted spawning-emergence distribution and residency period	Up to five locations are weighted equally to allow for averaging across all locations

2.3.1 Ecologically Important Index Locations

The study area of SacEFT extends from Keswick Dam to Colusa. Each performance indicator in SacEFT is referenced to at least one, usually multiple locations, either at a point location or along a reach. SacEFT currently uses either USRDOM or USRWQM daily modeled flows. Daily water temperatures for SacEFT are also provided by USRWQM. Appendix H summarizes the spatial location and resolution for all performance indicators in SacEFT, and provides the mapping of how CALSIM, USRDOM and USRWQM modeled output locations map to location in EFT.

2.3.2 Ecologically Important Life-history Timing

Almost all of SacEFT indicators have a sub-annual temporal component which is important to the simulation of life histories. Details on key life-history timing windows for SacEFT indicators are summarized in Table 2.4 and described in ESSA (2011).

Table 2.4: Summary of timing information relevant to the SacEFT focal species. Lightly shaded regions denote the 25% "tails" for some indicators. *Source:* salmonids: SALMOD (Bartholow and Heasley 2006, ultimately Vogel and Marine 1991); all other indicators: ESSA 2011.

Performance Indicator	J	F	M	A	M	J	J	A	S	O	N	D
Fremont Cottonwood Initiation (FC1)												
Fremont Cottonwood Scour (FC2)												
Bank Swallow N (BASW1)												
Bank Swallow Sloughing (BASW2)												
Green Sturgeon Egg (GS1)												
Large Woody Debris (LWD1)												
Spring Spawning (CS 1)												
Spring Egg (CS 3,5,6)												
Spring Juvenile (CS 2,4)												
Fall Spawning (CS 1)												
Fall Egg (CS 3,5,6)												
Fall Juvenile (CS 2,4)												
Late Fall Spawning (CS 1)												
Late Fall Egg (CS 3,5,6)												
Late Fall Juvenile (CS 2,4)												
Winter Spawning (CS 1)												
Winter Egg (CS 3,5,6)												
Winter Juvenile (CS 2,4)												
Steelhead Spawning (CS 1)												
Steelhead Egg (CS 3,5,6)												
Steelhead Juvenile (CS 2,4)												

2.4 San Joaquin-Sacramento Delta Ecoregion Ecological Objectives & Performance Indicators

A total of seven focal species and habitats and their 13 distinct PIs are represented within the DeltaEFT ecoregion (Figure 2.7). In the case of salmonids, steelhead trout and four Chinook run-types share a common PI framework.

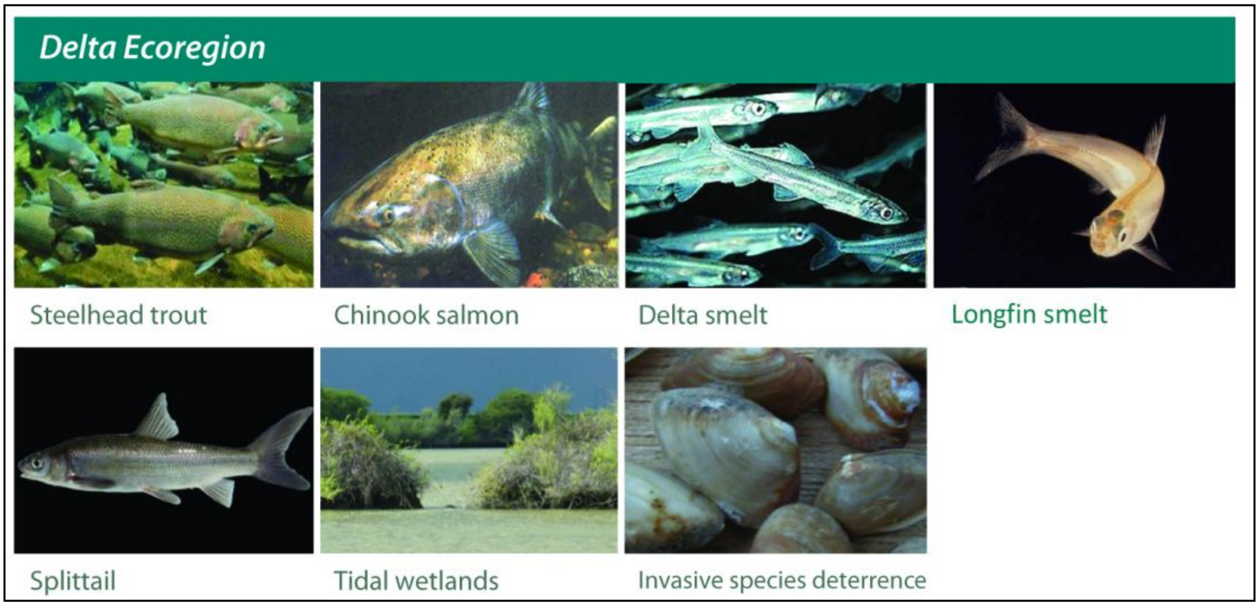


Figure 2.7: DeltaEFT includes the seven species and habitat groups shown.

The PIs are listed along with a narrative summary in Table 2.5. More details about the PI calculation and default relative suitability thresholds are presented in Section 2.7.2 and Appendix G. Functional details are available in Appendix D (ESSA 2013). Key attributes of each performance indicator (e.g., units, key index locations) are provided in Section 2.5.

Table 2.5: Summary of DeltaEFT ecological objectives for each focal species and their associated performance indicators.

	Focal Species & Habitats	Ecological Objectives	Performance Indicators	
Delta Ecoregion	Chinook salmon Steelhead trout	Promote smolt weight gain by providing enhanced rearing in Yolo Bypass	**CS7**	Juvenile development in Yolo Bypass (% weight gain)
		Reduce non-entrainment mortality through flow management in Bay-Delta	**CS9**	Juvenile mortality risk (passage time) (d)
		Provide preferred temperature range for resident smolts	**CS10**	Juvenile temperature stress (°C-d)
	Delta smelt	Provide cold water spawning habitat	**DS1**	Spawning success (index)
		Provide appropriate adult abiotic environment	**DS2**	Habitat suitability (index)
		Reduce entrainment risk through effect of flow on X2 location	**DS4**	Entrainment risk (index)
	Longfin smelt	Provide appropriate abiotic environment	**LS1**	Abundance (index)
	Splittail	Provide extensive period for spawning	**SS1**	Potential spawning habitat (proportion)
	Tidal wetlands	Provide productive habitat for ecosystem	**TW1**	Brackish wetland area (ha)
		Provide appropriate abiotic environment	**TW2**	Freshwater wetland area (ha)
	Invasive deterrence	Suppress invasive aquatic vegetation	**ID1**	Suppression of Brazilian waterweed *Egeria* (index)
		Suppress invasive clams	**ID2**	Suppression of overbite clam *Corbula* (index)
			ID3	Suppression of Asiatic clam *Corbicula* (index)

As shown, while we include multiple subcomponent effects at a variety of life stages (in the case of salmonids), we intentionally avoid attempting to measure effects at the population level. Attempting to build detailed ecological models that make *accurate* predictions of ecosystem behavior is challenging and usually not possible in complex, open natural systems (Oreskes *et al.* 1994). As described in Section 2.6 and in Chapter 3 we instead gauge overall effects of flow management and climate change using weight of evidence net effect scoring. Where feasible, our indicators also weight life-stage outcomes by the proportion of the population in that life stage that is affected. **While life-cycle modeling can aid in the determination of net effects for a species when sub-stage effects are inversely correlated, it is still possible to draw overall conclusions about the effect of alternative scenarios in the absence of such detailed modeling.** Ultimately, ongoing adaptive management and long-term monitoring programs are required to continually test and improve conceptual models of all forms.

2.4.1 Chinook & Steelhead Juvenile Development in Yolo Bypass (CS7)

When it is inundated during sustained periods of high flow, Yolo Bypass provides a high quality off-channel environment for enhanced growth of the four seasonal run-types of migrating Chinook and steelhead. During their downstream passage from Knights Landing to Mallard Island, juveniles follow migration calendars that are unique to the run-type. Day-cohorts travel along multiple routes based on a go-with-the-flow rule, potentially migrating over Fremont Weir, Sacramento Weir or through the main channel of the Sacramento River. While travelling along up to three routes, migration distance varies with daily flow at locations along the route, and growth rate depends on the temperature and productivity of the route. The annual PI for the entire year-cohort is measured as the proportional contribution to total biomass gain for the subset of the entire population travelling along each route. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.2 Chinook & Steelhead Predation Risk (CS9)

During their downstream migration, juveniles of the four seasonal run-types of Chinook and steelhead are exposed to predators. Routes or scenarios which offer shorter migration times will have lower mortality. During their downstream migration from Hood to Mallard Island, juveniles follow calendars that are unique to the run-type. Predation risk is currently defined for the main channel of the Sacramento River only. Daily migration distance varies with flow, measuring the passage time from the upstream location at Hood, to the downstream location at Rio Vista. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.3 Chinook & Steelhead Thermal Stress (CS10)

During their downstream migration, juveniles of the four seasonal run-types of Chinook and steelhead are exposed to different thermal environments. Day-cohorts of each run-type follow calendars that are unique to the run-type, migrating from Hood to Mallard Island based on a go-with-the-flow rule, through six alternative routes in the western and eastern Delta. Along each route, daily migration distance varies with flow, and growth rate depends on the temperature along the route. Routes and days which are cooler or warmer than the physiological optimum will result in lower growth over the course of their passage, providing a measure of thermal stress in units of absolute value degree-days. The annual PI for the entire year-cohort is measured as the proportional contribution to degree-days for the subset of the entire population travelling along each route. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.4 Delta Smelt Spawning Success (DS1)

Spawning success of Delta smelt (*Hypomesus transpacificus*) is based on evidence which suggests that spring water temperatures affect the spawning success of the population. The DS1 index is modeled as the longest duration of continuous days with optimal spawning conditions. Those conditions are defined as days with an average temperature between 12 and 16°C (the range associated with peak occurrence of ripe females), which also coincides with salinities <6‰, an empirical upper threshold, below which over 90% of Delta smelt are observed. DS1 is simulated at 22 locations selected to be representative of the entire Delta. Since spawning locations are unknown, all locations are weighted equally. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.5 Delta Smelt Habitat Suitability (DS2)

The DS2 habitat suitability performance indicator is based on the widely-used X2-Habitat Index relationship that was incorporated into the Reasonable and Prudent Alternative (RPA) for the 2008 Delta Smelt Biological Opinion. The relationship is based on a model that estimates the probability of occurrence of Delta smelt as a function of water temperature, Secchi depth (a surrogate for turbidity), and specific conductance (a proxy for salinity). The daily X2 location is estimated based on historical and modeled data from five salinity stations in the Sacramento River between river kilometer 54 and 92. The salinity gradient between stations is assumed to be linear, and the location of the 2‰ concentration which defines the X2 position is found by interpolating between stations. The relative suitability threshold breakpoints are equivalent to the X2 targets of 74 and 81 km described in the 2008 Delta Smelt Biological Opinion. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.6 Delta Smelt Entrainment Risk (DS4)

The index of risk of entrainment for Delta smelt is based on a Particle Tracking Model (PTM) which simulates the fate of particles released at 20 sites in the Delta under a range of inflows and exports. Entrainment is simulated as the proportion of particles which ultimately end up at the Central Valley Project (CVP) or State Water Project (SWP) water export facilities. In order to utilize the results from the PTM, which simulates passive, neutrally buoyant particles, it is applied only to the larval and juvenile life-stages, which have a limited capacity for active swimming. Using the entrainment simulations, the model is based on a logistic regression relating the Export:Import ratio to entrainment, using daily combined Old River and Middle River flow, weighted by a calendar-based spawning probability relationship. Finally multiple locations in the Delta are combined based on weights derived from empirical sampling studies. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.7 Longfin Smelt Abundance Index (LS1)

The longfin smelt abundance index is based on a statistical relationship developed by Mount *et al.* (2013). The study developed a linear regression model relating the average X2 value from January to June to a Log10 transformation of the annual index of longfin smelt abundance from the fall midwater trawl survey. The relationship was developed for three time periods and we applied the regression coefficients based on 2003 to 2012 data, i.e., after the pelagic organisms decline. The daily X2 location is estimated based on historical and modeled data from five salinity stations in the Sacramento River between river kilometer 54 and 92. The salinity gradient between stations is assumed to be linear and the location of the 2‰ concentration is found by interpolating between stations. Performance indicator details and references are provided in ESSA (2013).

2.4.8 Splittail Potential Spawning Habitat (SS1)

Sacramento splittail (*Pogonichthys macrolepidotus*) spawn in shallow flowing waters characterized by dense vegetation, low temperature and high clarity. Although they may spawn opportunistically at any time, most spawning in Yolo Bypass occurs between February and April. Eggs are deposited in waters of <2 m in depth and undergo a shallow-water development period of 15 days before they can tolerate greater depths. Potential spawning habitat in Yolo Bypass is simulated over the spawning calendar using an empirical relationship between flow and depth, so that each day's flow can be converted to the area <2 m depth. Using the flow-area relationship, each day-cohort is simulated over its development period, and the minimum area during that period is used to assign a spawning potential score for the day-cohort. The score for each day-cohort is then scaled by the maximum possible habitat area (about 32 acres), to derive a weighted proportional area which can then be summed over the spawning calendar to provide the correctly weighted proportional spawning area for the year. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.9 Brackish Wetland Area (TW1)

The brackish wetland performance indicator is used to estimate the wetland area under different EFT scenarios. Three index locations within Suisun Bay are used to represent brackish conditions near sites identified as BDCP Restoration Opportunity Areas (ROAs), and include a range of tidal influences and salinity concentrations. The ROAs themselves are excluded, as they are mostly located in managed wetlands or farmed lands that have subsided, whose elevation will have to be raised in order to recreate a functional tidal wetland. Brackish wetland is calculated as the area at the index locations between annual Mean Tide Level (MTL) and Extreme High Water (EHW), based on simulations of hourly stage (water elevation). These two thresholds are combined with a LiDAR-based Digital

Elevation Model (DEM) to compute the area within the two elevations. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.10 Freshwater Wetland Area (TW2)

The freshwater wetland performance indicator is used to estimate the wetland area under different EFT scenarios. Two index locations (Shin Kee Tract, Big Break) are used to represent freshwater conditions near sites identified as BDCP ROAs. The ROAs themselves are excluded, as they are mostly located in managed wetlands or farmed lands that have subsided, whose elevation will have to be raised in order to recreate a functional tidal wetland. Freshwater wetland is calculated as the area at the index locations between Mean Tide Level (MTL) and Extreme High Water (EHW), based on simulations of hourly stage (water elevation). These two thresholds are combined with a LiDAR-based Digital Elevation Model (DEM) to compute the area within the two elevations. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.11 Brazilian Waterweed Suppression (ID1)

The ID1 performance indicator is a categorical indicator which models the likelihood of suppression of Brazilian waterweed (*Egeria densa)*, using simple rules based on expert assessment of the role of variations in net Delta outflow and salinity in two regions (eastern Suisun Bay and the western part of the interior Delta), using a total of eight measurement locations to calculate the average salinity for a region. Brazilian waterweed prefers a nearly freshwater environment of <5‰, and according to this model there is a high likelihood of suppression if salinity exceeds 10‰ for three months between May and October in at least 40% of all years. This condition is expected to be met predominantly during low flow years. Combined with consistent higher salinity, the categorical response model is further influenced by the rate of salinity change, so that rapid “shocks” of increased salinity improve the likelihood of suppression. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.12 Overbite Clam Suppression (ID2)

The ID2 performance indicator is a categorical indicator which models the likelihood of suppression of the overbite clam (*Corbula amurensis)*[10], using simple rules based on expert assessment of variations in net Delta outflow and salinity in three regions within the eastern Suisun Bay and the western part of the interior Delta, using a total of 15 measurement locations to calculate the average salinity for a region. The overbite clam prefers a brackish environment of 5‰ - 10‰, and according to this model there is a high likelihood of suppression if salinity lies below 3‰ or above 30‰ between December and April, in at least half of all years. The non-brackish condition is expected to be met predominantly during very high flow years. Combined with these constraints, the categorical response model is

[10] The species is also known as *Potamocorbuila amurensis*

also affected by the rate of salinity change, so that rapid “shocks” of decreased salinity improve the likelihood of suppression. Performance indicator details and science foundation references are provided in ESSA (2013).

2.4.13 Asiatic Clam Suppression (ID3)

The ID3 performance indicator is a categorical indicator which models the likelihood of suppression of Asiatic clam (*Corbicula fluminea*) larvae and young recruits, using simple rules based on expert assessment of variations in net Delta outflow and salinity in two regions (eastern Suisun Bay and the western part of the interior Delta) using a total of eight measurement locations to calculate the average salinity for a region. The Asiatic clam prefers a nearly freshwater environment of <10‰, and according to this model there is a high likelihood of suppression if salinity exceeds 12‰ for three months between May and October in at least 40% of all years. This condition is expected to be met predominantly during low flow years. Combined with consistent higher salinity, the categorical response model is further influenced by the rate of salinity change, so that rapid “shocks” of increased salinity improve the likelihood of suppression. Performance indicator details and science foundation references are provided in ESSA (2013).

> Details on all *default relative suitability thresholds* used to summarize and "roll-up" EFT results are discussed in more detail in Section 2.7.2 and Appendix G.

2.5 Key Attributes of DeltaEFT Performance Indicators

Table 2.6 summarizes the units, overall nature of the calculations, and general location weighting and roll-up methods for DeltaEFT performance indicators (details are available in ESSA 2013). Related background on driving physical data and fundamental concepts behind EFT are provided in Section 2.6. The relative suitability threshold assumptions used to "roll-up" annual water year performance are given in Section 2.7.2 and Appendix G.

Table 2.6: DeltaEFT performance indicators (Delta Ecoregion) – units, overall calculation, weighting and roll-up attributes.

Indicator Name	Native units	PI Calculation	Location weights/roll-up
CS7 Chinook & steelhead juvenile development in Yolo	Weight gain (%)	% weight gain for each day-cohort on each route; high flow routes have more fish	Up to three routes through delta network, weighted to allow addition of routes
CS9 Chinook & steelhead juvenile mortality risk	Passage Time (days)	Passage days for each day-cohort on each route; high flow routes have more fish	One route through delta network
CS10 Chinook & steelhead juvenile temperature preference	Thermal stress (°C-days)	Degree-days departure from optimum temperature for each day-cohort on each route; high flow routes have more fish	Six routes through delta network, weighted to allow addition of routes
DS1 Delta smelt spawning success	Index (days)	Daily temperature and salinity at numerous locations are compared to observed preferences during spring spawning period	All 24 locations are equally weighted with the daily spawning calendar to average optimum days across all locations
DS2 Delta smelt habitat suitability	Index	Based on fitted relationship between X2 location and abiotic needs in Sep-Dec period	Annual average of index value over period
DS4 Delta smelt entrainment risk	Entrainment Proportion (0–1)	Daily entrainment risk at numerous sites based on spawning calendar coupled to Particle Tracking Model results and Old & Middle River flow	Annual sum of entrainment based on daily weights
LS1 Longfin smelt abundance	Index	Based on fitted relationship between X2 location and longfin smelt abundance in Jan-Jun period	Only one location
SS1 Splittail spawning habitat	Proportion maximum (0–1)	Daily proportion of total possible habitat area during peak spawning period	Annual sum of daily-weighted percentage in Yolo Bypass
TW1 Brackish tidal wetland	Area (ha)	Area in upper tidal zone, based on GIS/DEM maps	Annual sum in 3 brackish water index locations
TW2 Freshwater tidal	Area (ha)	Area in upper tidal zone, based on GIS/DEM maps	Annual sum of 2 freshwater index locations

Indicator Name	Native units	PI Calculation	Location weights/roll-up
wetland			
ID1 Egeria suppression	Index	High mid-year salinity, consistently over years, including "shocks" of rapid change	Annual average index over 8 locations in 2 regions
ID2 Corbula suppression	Index	High or low winter-spring salinity, consistently over years, including "shocks" of rapid change	Annual average index over 15 locations in 3 regions
ID3 Corbicula suppression	Index	High mid-year salinity, consistently over years, including "shocks" of rapid change	Annual average index over 8 locations in two regions

2.5.1 Ecologically Important Index Locations

Each performance indicator in DeltaEFT is referenced to at least one location (usually multiple locations) either at a point location or at a polygon or series of alternative routes. Depending on the performance indicator, DeltaEFT currently uses one or more of four physical outputs simulated by DSM2: flow, electroconductivity, water temperature, and/or stage. Location names assigned by DSM2 and the California Data Exchange Center (CDEC) are not fully standardized. Appendix H summarizes the spatial location and resolution for all performance indicators in DeltaEFT, which also provides the mapping of how DSM2 modeled output locations map to location in EFT.

2.5.2 Ecologically Important Life-history Timing

Almost all of DeltaEFT indicators have a sub-annual temporal component that is important to the simulation of its life-history. Details on key life-history timing windows for DeltaEFT indicators are summarized in Table 2.7, and described in ESSA (2013).

Table 2.7: Summary of timing information relevant to the DeltaEFT focal species. Lightly shaded regions denote the 25% "tails" for some indicators.

Performance Indicator	J	F	M	A	M	J	J	A	S	O	N	D
Spring smolt migration (CS 7,9,10)	■	■	■	■	■□	□						■
Fall smolt migration (CS 7,9,10)			■	■	■	■						
Late Fall smolt migration (CS 7,9,10)	■	■	■	■	■				■	■	■	■
Winter smolt migration (CS 7,9,10)	□■	■	■	□					□	□	□	□
Steelhead smolt migration (CS 7,9,10)	□	□	□	■	■	■□	□					
Delta smelt spawning success (DS1)		■	■	■	■							
Delta smelt habitat suitability (DS2)									■	■	■	
Delta smelt entrainment risk (DS4)			□■	■	■	■□	□					
Longfin smelt abundance (LS1)	■	■	■	■	■	■						
Splittail spawning habitat (SS1)		□■	■	■□								
Brackish tidal wetland (TW1)												
Freshwater tidal wetland (TW2)												
Egeria suppression (ID1)			■	■	■	■	■	■	■	■		
Corbula suppression (ID2)	■	■	■	■								■
Corbicula suppression (ID3)					■	■	■	■	■	■		

2.6 Coupled Modeling – Hydrologic & Physical Foundations

In our experience, and reiterated by many workshop participants during the history of this project, it is exceedingly rare for "one" decision support platform to satisfy all objectives. Model coupling offers a practical and feasible way forward to overcome a number of gaps and limitations. **Coupled modeling** — the approach used by EFT — involves sequentially running independent models, and matching model outputs from the preceding tool with the input requirements of the next model in the chain. EFT uses a coupled hydrologic and physical modeling foundation based on existing physical models that are commonly used for water planning in California's Central Valley. Rather than reinventing models, EFT currently utilizes output data sets from the daily disaggregation of CALSIM II, USRWQM, DSM2, and other models that are used to investigate water delivery and other standards set for the CVP and SWP in California (Figure 2.8). EFT utilizes these data and adds ecological calculations to evaluate effects on multiple ecosystem targets. This is accomplished by loosely coupling groups of models and running them serially, rather than attempting to "build in" EFT algorithms directly into the external physical models[11] (or vice versa). EFT focal species submodels are integrated and centered on a single relational database. The EFT software's graphical user interface, model controller and analysis engine, and output reporting tools, connect to and interact with this central database over the internet.

Figure 2.8 shows the external physical modeling system on top of which EFT provides an ecological effects "plug-in". Some of these models generate results for the Sacramento

[11] Though Chapter 4 describes a pilot investigation that demonstrates how EFT flow criteria can be extracted and transplanted into CALSIM.

River ecoregion, others for the Delta ecoregion (or both). A brief summary and links to further references on these foundational hydrologic modeling tools are provided below.

In addition to these models, select gauging records are used for river discharge, stage, salinity, and water temperatures. Using data from models and stream gauges permits mixed prospective and retrospective analyses.

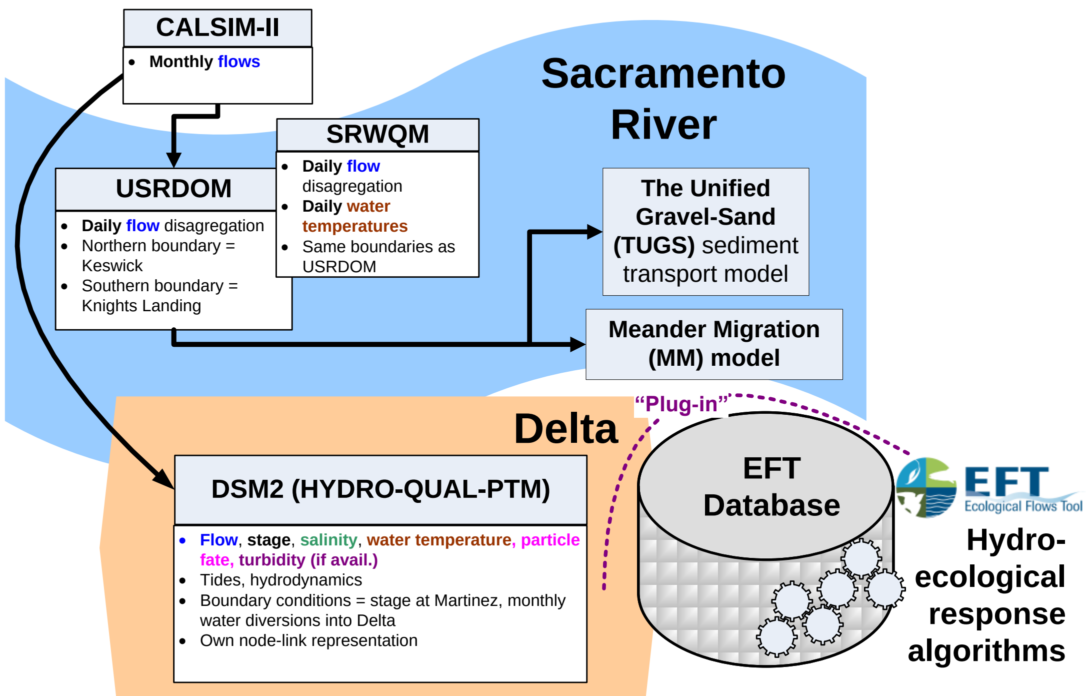


Figure 2.8: Current EFT hydrologic foundation. EFT is designed to swap in any model which provides data at the locations shown in Appendix H.

2.6.1 CALSIM II

The California Department of Water Resources (DWR)/U.S. Bureau of Reclamation (Reclamation) CALSIM II planning model is used to simulate the operation of the CVP and SWP over a range of hydrologic conditions. CALSIM II is a generalized reservoir-river basin simulation model that allows for specification and achievement of user-specified allocation targets, or goals (Draper *et al.* 2004). CALSIM II represents the most commonly used planning model for the SWP and CVP system operations and has been used in many previous system-wide evaluations of SWP and CVP operations as well as BDCP. CALSIM II produces monthly outputs for river flows and diversions, reservoir storage, Delta flows and exports, Delta inflow and outflow, deliveries to project and non-project users, and controls on project operations.

Inputs to CALSIM II include water diversion requirements (water demands), stream accretions and depletions, rim basin inflows, irrigation efficiencies, return flows, nonrecoverable losses, and groundwater operations. Sacramento Valley and tributary rim basin hydrologies are developed using a process designed to adjust the historical sequence of monthly stream flows over an 82-year period (1922 to 2003) to represent a sequence of flows at a future level of development.

The CALSIM II simulation model uses single time-step optimization techniques to route water through a network of storage nodes and flow arcs based on a series of user-specified relative priorities for water allocation and storage. Physical capacities and specific regulatory and contractual requirements are input as linear **constraints** to the system operation using the water resources simulation language (WRESL). The process of routing water through the channels and storing water in reservoirs is performed by a mixed integer **linear programming solver**. For each timestep, the solver maximizes the objective function to determine a solution that delivers or stores water according to the specified **priorities** and satisfies all system constraints. The sequence of solved linear programming problems represents the simulation of the system over the period of analysis.

Adjustments to historic water supplies are determined by imposing future level land use on historical meteorological and hydrologic conditions. The resulting hydrology represents the water supply available from Central Valley streams to the CVP and SWP at a future level of development. CALSIM II uses rule-based algorithms for determining deliveries to North-of-the-Delta and South-of-the-Delta CVP and SWP contractors. This delivery logic uses runoff forecast information, which incorporates uncertainty and standardized rule curves. The rule curves relate storage levels and forecasted water supplies to project delivery capability for the upcoming year. The delivery capability is then translated into SWP and CVP contractor allocations which are satisfied through coordinated reservoir-export operations.

Reclamation's 2008 Operations Criteria and Plan (OCAP) Biological Assessment (BA) Appendix D provides more information about CALSIM II (USBR 2008a).

CALSIM II results are also used to estimate water quality, hydrodynamics, and particle tracking in the DSM2 model. The outputs feed into temperature models including the Upper Sacramento River Water Quality Model (USRWQM) and the Reclamation Temperature Model, and have been used to inform other habitat and biological assessments.

2.6.2 USRDOM / USRWQM

USRDOM

The Upper Sacramento River Daily Operations Model (USRDOM) is designed to model the flows and related operations in the upper Sacramento River from Keswick to Knights Landing on a daily timescale. The model is designed to simulate both low flow (water supply) and high flow (flood) operations in order to improve the weak performance of the Upper Sacramento River Water Quality Model (USRWQM) at flows above 15,000 cfs. A critical element is the local runoff between Keswick Reservoir and Bend Bridge where cumulative flows from unregulated tributaries can exceed 100,000 cfs during large rainfall or flooding events. Daily outputs such as inflows, outflows, diversions and end-of-the day storage conditions are used as inputs to USRWQM instead of using the results from a CALSIM II daily disaggregation routine. The full 82-year period of monthly CALSIM II operations data is translated to a daily timestep by a utility called CAL2DOM. It uses inputs and outputs from CALSIM II, USRDOM hydrology, and other datasets to compute inflows, diversions, and evaporation rates for USRDOM. Because the spatial resolution between USRDOM and CALSIM II is inconsistent, the CAL2DOM utility also disaggregates and consolidates flow data. USRDOM was developed using the HEC-5 software, the same software used by the USRWQM. The model has previously been used to evaluate the potential benefits and impacts of the North-of-the-Delta Off-stream Storage (NODOS) program. A more detailed description of USRDOM and the temporal downscaling process is included in a CH2M Hill development and calibration report (CH2M Hill 2011).

USRWQM

The Upper Sacramento River Water Quality Model (USRWQM)[12] was developed using the HEC-5Q framework to simulate mean daily (using 6-hour meteorology) reservoir and river temperatures at key locations on the Sacramento River. The timestep of the model is daily and provides water temperature each day for the 82 year hydrologic period used in CALSIM II. The model has been used in the previous CVP and SWP system operational performance evaluations as well as BDCP. Monthly flows from CALSIM II for an 82-year period (water years 1922 to 2003) are used as input into the USRWQM after being temporally downsized to daily average flows. Temporal downscaling is performed on the CALSIM II monthly average tributary flows to convert them to daily average flows for HEC-5Q input. Monthly average flows are then converted to daily tributary inflows based on 1921 through 1994 daily historical record (one of three historical records for three aggregate inflow areas). The HEC-5 component of USRWQM simulates daily flow operations in the upper Sacramento River.

A more detailed description of USRWQM and the temporal downscaling process is included in an RMA calibration report (RMA 2003). For more information on the USRWQM, see Appendix H of Reclamation's 2008 OCAP BA (USBR 2008b).

2.6.3 Meander Migration and Bank Erosion Model

To enable the modeling of bank swallow habitat (BASW1) and recruitment of large woody debris (LWD1), SacEFT has been explicitly coupled with a Meander Migration Model, developed by University of California, Davis researchers (Larsen 1995; Larsen and Greco 2002; Larsen *et al.* 2006b) that calculates channel migration using a simplified form of equations for fluid flow and sediment transport developed by Johannesson and Parker (1989). The model considers the effects of a variable hydrograph on meander migration

[12] This model is also referred to synonymously as USRWQM and SRWQM HEC-5Q depending on the analyst and author.

rates. The underlying hypothesis is that the bank migration rate, when thresholds are exceeded, is linearly related to the sum of the cumulative excess stream power in the same time interval (Larsen *et al.* 2006a).

The Meander Migration Model requires the following six input values, which reflect the hydrology of the watershed and the hydraulic characteristics of the channel: initial channel planform location, "characteristic discharge", reach-average median particle size of the bed material, reach-average width, depth, and slope. The crux of the model is the calculation of the velocity field. The analytic solution for the velocity results from the simultaneous solution of six partial differential equations representing fluid flow and bedload transport. An initial calibration also plays a critical role. To calibrate the model, researchers use the channel planform centerline from two years for which centerlines can be accurately delineated using digitized aerial photos. The calibration process consists of adjusting the erosion and hydraulic parameters in the Meander Migration Model until the simulated migration closely matches the observed migration. The erosion potential map is initially determined from GIS coverages and delineates areas of higher and lower erosion potential due to differences in land cover, soil, and geology. The erosion potential map is then adjusted in the near-channel-bank areas by calibrating the channel centerlines between the two time periods. See Larsen and Greco (2002) for details.

As applied and configured for SacEFT, the Meander Migration Model focuses on three river segments located between RM 170-185, 185-201, and 201-218. The model has also been previously applied in various locations between Red Bluff (RM 243) and Colusa (RM 143).

The finest unit of resolution of interest is **a bend**. We apply a fixed zonal concept based on segments, using the locally well-known concept of river miles to reference these bends. While we recognize that channel alignment has changed significantly since the U.S. Army Corps of Engineers 1964 centerline survey, the critical consideration is that these locations be "well-known" and consistent across SacEFT's submodels. This in no way inhibits the spatial accuracy of meander migration calculations; it just simplifies the manner in which specific bends are identified. As described earlier, for purposes of determining the suitability of bank swallow nesting habitat, the exact locations of individual bends of interest are still in *approximately* the same zones whether at RM 191 or RM 208. Knowing ***exactly*** where it is does not help us answer questions related to bank swallow nesting habitat.

ESSA has developed a GIS-based erosion model that allows users to combine the predictions from the Meander Migration Model with other spatial information, such as soil and vegetation information. Each year, the model simulates the location of the river channel, the area of eroded banks and the location of the banks at the end of the year. The location of the river channel is calculated from the centerline based on the assumption that the distance from the local channel to the bank remains constant during the simulation. The eroded area for each year is defined as the channel area overlapping the previous year's banks. The river banks at the end of the year are calculated by subtracting the eroded area from the banks at the start of the year. Figure 2.9 shows an example of change of centerlines simulated by the Meander Migration Model over a period of 56 years.

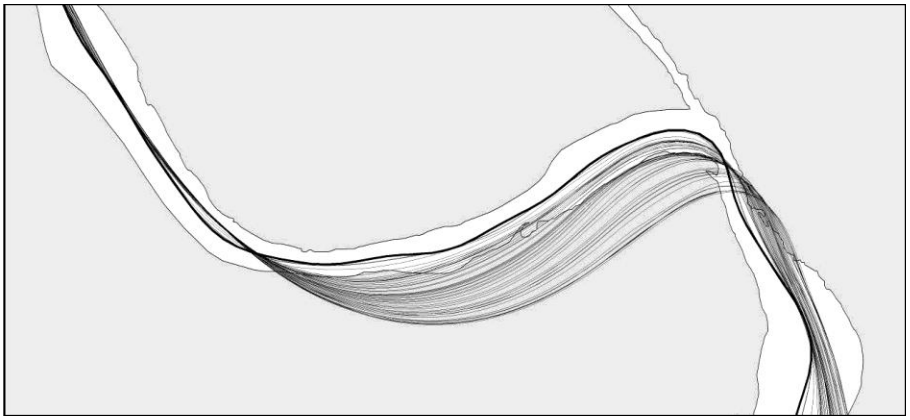


Figure 2.9. Meander Migration and Bank Erosion Model – example of centerlines for 56 years for one scenario.

The bank erosion is simulated by finding the distance between this and last year's centerlines and eroding the bank by the same distance. The distance between centerlines is found in 0.25 m intervals by gradually increasing the width of a buffer from last year's centerline and determining the segments of this year's centerline that are within this area of interest. The centerline segments are then used to erode the bank by locating the nearest bank in the direction the centerline is migrating and remove the bank to the same depth as the distance between centerlines. This approach yields bank variable width erosion with high precision (Figure 2.10). The new bank locations are then used to calculate next year's erosion.

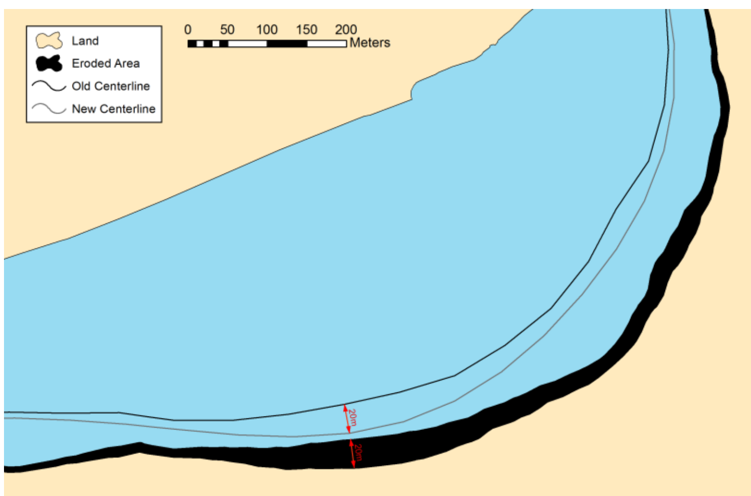


Figure 2.10. Meander Migration and Bank Erosion Model – variable erosion example.

2.6.4 The Unified Gravel-Sand Model (TUGS)

Stillwater Sciences has developed The Unified Gravel-Sand (TUGS) model to simulate how bed mobilization and scour affect grain size distribution, including the fraction of sand in both the surface and subsurface layers (Cui 2007). TUGS simulates changes in grain size by accounting for how sediment flux interacts with sediment in both the surface and subsurface of the channel bed. TUGS is capable of providing a variety of grain size-specific transport estimates for gravel and sand, and of tracking these two classes of sediment by their proportions in surface and subsurface layers. The model can be used to assess the effects of different management scenarios (e.g., gravel augmentation, flow releases to increase the frequency of bed mobilization and scour, reduction in fine sediment supply) on salmonid spawning habitat.

Though most existing bedload transport models can predict sediment transport rates and bed surface/subsurface textures as a function of sediment supply and routing, they generally have ignored the presence of sand. Including fractions of sand in surface and subsurface grain size distributions is of interest for evaluating the extent and quality of salmonid spawning habitat. Surface grain size distributions can support estimates of available spawning habitat in terms of the availability of spawning-sized gravel, and subsurface grain size distributions, especially the fraction of sand, and can support estimates of spawning gravel quality. The TUGS model is designed to fulfill this need by simulating how bed mobilization and scour affect grain size distribution, including the fraction of sand, in both the surface and subsurface.

As described in Cui (2007), The Unified Gravel-Sand (TUGS) Model employs:

a) the surface-based bedload equation of Wilcock and Crowe (2003);

b) a combination of the backwater equation and the quasi-normal flow assumption for flow;

c) Exner equations for sediment continuity on a fractional basis, including both gravel and sand, and the process of gravel abrasion;

d) the bedload, surface layer, and subsurface gravel transfer function of Hoey and Ferguson (1994) and Toro-Escobar *et al.* (1996); and

e) a hypothetical surface-subsurface sand transfer function.

The model also uses existing cross sections developed by the Army Corps of Engineers and DWR as part of the Sacramento and San Joaquin River Basins Comprehensive Study.

The TUGS model can be applied to any reach of the Sacramento River for which channel cross sections and surface and subsurface grain size data are available, and has been calibrated for the Sacramento River using existing bulk sampling data collected by DWR in 1980, 1984, and 1994. Stillwater Sciences has added to the dataset by collecting new bulk samples in the upper and middle Sacramento River in 2005, at locations sampled previously by DWR.

Two default scenarios were incorporated into SacEFT. The first is a “No Gravel” scenario that assumes no gravel injection to the rivers, although small amounts of natural sand and gravel are present. The second scenario, “Gravel Injection”, contains a single gravel injection in Water Year (WY) 1940, with no subsequent additions (Table 2.8). As part of the TUGS calibration process, a third “zero gravel” scenario was also developed using historical flow at Keswick and *historical* gravel additions from 1981 to 2006.

Table 2.8: Location of TUGS simulation segments and amount of supplementary gravel added in the case of the “Gravel Injection” scenario (not used in this report).

Upper RM	Lower RM	Gravel Injection (m3) (injection scenario only)
301.956	299.800	
299.800	297.000	179,423δ (234,677 yd3)
297.000	295.600	
295.600	292.400	188,662δ (246,760 yd3)
292.400	289.375	

δ These are bulk amounts, assuming a gravel porosity of 0.4.

SacEFT requires annual estimates of the gravel grain size-distribution at each of five river segments in order to calculate the Weighted Useable Area available for spawning (ST1/CH1). This habitat estimate is then used as one of the inputs to calculate subsequent performance indicators for egg maturation, survival, and juvenile rearing. In the absence of gravel data, no calculations are possible for these linked components. For the current SacEFT effects analyses in this report, we used the “No Gravel” addition dataset developed using historical flow data at Keswick (RM 301) to define how substrate composition changes in the simulations. This scenario involves modest historical gravel injections and assumptions about the initial sediment storage (Stillwater Sciences 2007).

Note: The SacEFT results included in this report use the default "No Gravel" addition dataset.

2.6.5 DSM2

DSM2 is a one-dimensional hydrodynamic and water quality simulation model used to simulate hydrodynamics, water quality, and particle tracking in the Sacramento-San Joaquin Delta (USBR 2008c). It is the most commonly used planning model for Delta tidal hydraulic and salinity modeling and is capable of describing the existing conditions in the Delta, as well as performing simulations for the assessment of incremental environmental impacts caused by future facilities and operations.

The DSM2 model has three separate components: HYDRO, QUAL, and PTM. HYDRO simulates velocities and water surface elevations and provides the flow input for QUAL and PTM. EFT uses these standard DSM2-HYDRO outputs to predict changes in flow rates and depths, and their effects on covered species, as a result of the BDCP and climate change.

The QUAL module simulates the fate and transport of conservative and non-conservative water quality constituents, including salts, given the flow field simulated by HYDRO. EFT uses these standard outputs to estimate changes in salinity, and their effects on covered species, as a result of the BDCP and climate change. Reclamation's 2008 OCAP BA Appendix F provides more information about DSM2 (USBR 2008c).

DSM2-PTM simulates pseudo 3-D transport of neutrally buoyant particles based on the flow field simulated by HYDRO. It simulates the transport and fate of individual particles traveling throughout the Delta. The model uses velocity, flow, and stage output from the HYDRO module to monitor the location of each individual particle using assumed vertical and lateral velocity profiles and specified random movement to simulate mixing. PTM has multiple applications ranging from visualization of flow patterns to simulation of discrete organisms such as fish eggs and larvae. Additional information on DSM2 can be found on the DWR Modeling Support Branch website at http://modeling.water.ca.gov/.

2.7 Categories of Available Outputs

2.7.1 Overview

Practical synthesis and integration of results for multiple scenarios, multiple species life-history stages, eco-regions and index locations is challenging. Various management scenarios and impacts on ecological indicators operate over a wide range of spatial and temporal scales and can be analyzed at differing levels of detail depending on the interests of the audience (e.g., high-level managers as well as technical staff and researchers). To overcome this challenge, the EFT software provides output that spans the range from location- and daily-detail through to high level ("rolled up") overviews of multiple indicators and scenarios.

While the software output interface makes use of a simple "traffic light" paradigm for expressing relative suitability (RS), this is only one type of output created by EFT. EFT's outputs can equally be used to provide effect size (ES) comparisons based on the natural units specific to each indicator, as well as map-based visualizations and animations. An overview of all EFT outputs can be found in Table 2.9. The remaining sections in this Chapter provide a summary of EFT's main categories of outputs. Readers will encounter these important output concepts throughout Chapter 3. We conclude with a description of how EFT outputs are used to generate target eco-flow rule-sets for each focal species and indicator (Section 2.7.8).

Table 2.9: Overview of all EFT outputs. The main categories of outputs are summarized in the remaining sections in this Chapter.

EFT Output	Description
RS summary	Compares the proportion of Good years for a performance indicator, across scenarios based on the tail of the distribution
NES summary	Compares changes to the performance indicator raw units median across scenarios
Multi-year rollup R/Y/G	Reports the % in each category to allow comparison of scenarios
Annual year rollup R/Y/G	Reports each year's R/Y/G to allow comparison of scenarios and identify patterns of performance
Physical changes summary	Compares changes in median monthly values in a table for physical attributes (flow, water temperature, salinity)
XL Reports	Allows detailed examination of indicator at each location, along with physical driving variables
Effect size boxplots	Compares performance indicator changes between scenarios in a boxplot format showing median, quartiles, range and outliers
Water year characterization boxplots	Compares performance indicator changes between water year types in a boxplot format showing median, quartiles, range and outliers
Spatial visualizations	Reports the location-based performance of an indicator on a map
X2 animations	Map-based animated daily time-series of the location of X2
Meander migration animation	Map-based animated annual time-series of the centerline of the Sacramento River

2.7.2 EFT Relative Suitability (RS) Thresholds

Context

Multiple scenarios, species, indicators, and year simulations create a very complex solution space. In the face of this complexity, EFT aims to integrate and clearly communicate the multiple ecological trade-offs associated with different water operation alternatives. This capability arises through a standardized approach for synthesizing results to reveal trade-offs across species and their indicators.

Most of EFT's 25 performance indicators are calculated on a daily (or finer) time-step at multiple index locations. Naturally, these daily calculations come in many different units appropriate to the performance indicator (e.g., square feet of suitable habitat, survival rates, counts of surviving cottonwood seedlings, *etc.*). Furthermore, the daily calculations for most aquatic performance indicators are also weighted by temporal life-history distributions as well as by differences in habitat quantity and quality across the modeled index sites. For example, if a sudden dramatic low flow event occurs at the very beginning or very end of the egg incubation period for a particular Chinook run-type, the overall effect on the redd dewatering performance indicator (CS6) will be negligible due to the low biological weighting associated with the "tail" of the temporal distribution.

The challenge of identifying "acceptable" and "unacceptable" changes in habitat conditions or focal species indicator results confronts all biological effects analysis methods. When screening results, the EFT output interface makes use of a simplified "traffic light" paradigm to provide an intuitive and high-level overview of whether a performance indicator is experiencing good/favorable conditions (Green), performing only fairly (Yellow), or is experiencing unfavorable/poor conditions (Red) on an annual time scale. This requires identification of two **suitability thresholds** for all performance indicators (a good/fair and a fair/poor threshold). Figure 2.11 shows a simple example of how the EFT software represents scenarios and years for one indicator.

Figure 2.11: Example SacEFT output showing annual results for the Fremont cottonwood initiation indicator (FC1) across six scenarios. Cottonwood initiation is not a process that is expected to occur every year, so the infrequency of favorable (Green) years in some scenarios is not necessarily an indicator of an unacceptable change.

Establishing Relative Suitability (RS) Thresholds

During the course of this work, despite several expert surveys, we were unable to elicit a single unequivocal standard for assigning a favorable, fair, or poor suitability rating to all EFT indicators. For example, there is no established absolute amount of Weighted Useable Area (WUA) or salmonid rearing habitat that is considered "favorable". To accommodate a variety of situations, EFT relative suitability thresholds are based on one of three general methods:

- **Absolute:** If available, we use absolute thresholds supported in the literature or recommended by expert opinion i.e., at design workshops, subsequent reviews of design materials (e.g., 95% survival, 80,000 cfs). If that fails, then
- **Discontinuity:** Use apparent discontinuities (curve-breaks) in the empirical historic (or proxy-historical) cumulative distribution of the natural units of the indicator. If that fails, then

- **Tercile:** Use the 1/3 and 2/3 breakpoints of the cumulative distribution if no clear curve-break discontinuities are apparent.

Using one of these three approaches (detailed in Table 2.10), suitability thresholds (dividing breakpoints for good/fair and fair/poor) were set for each indicator.[13] In the second and third approaches described above, suitability threshold identification requires an evaluation of the distribution of annual indicator value outputs to identify natural or tercile breaks. Details on assumptions that underpin default RS thresholds are provided in Table 2.10 and Appendix G.

Table 2.10: Summary of the default relative suitability (RS) thresholds and associated reference time periods used to rate EFT indicators as favorable, fair, or poor. Refer to Appendix G for additional details. Dates for some major infrastructure works are also indicated. [δ]

Indicator Name	Good [δ]		Threshold Setting Method			
			A	D	T	Years for D,T
Sacramento River Ecoregion						
Shasta Dam: construction began 1937, complete 1945 Keswick Dam: construction began 1941, complete 1950						
FC1 Cottonwood initiation		↑			✓	1943 – 2004 (H); n = 62
FC2 Cottonwood scour risk	↓		✓			–
BASW1 Bank swallow habitat potential		↑			✓	1940 – 1994 (H); n=55
BASW2 Bank swallow inundation risk	↓		✓			–
LWD1 Large woody debris recruitment		↑			✓	1940 – 1994 (H); n=55
GS1 Green sturgeon egg-to-larvae survival		↑	✓			–
CS1 Salmonid spawning habitat		↑		✓		1939 – 2002 (H); n=64
CS3 Salmonid egg-to-fry survival		↑	✓			–
CS5 Salmonid redd scour	↓		✓			–
CS6 Salmonid redd dewatering	↓			✓		1971 – 2002 (H); n=32
CS2 Salmonid rearing habitat		↑			✓	1939 – 2002 (H); n=64
CS4 Salmonid juvenile stranding	↓				✓	1971 – 2002 (H); n=32
Delta Ecoregion						
Banks pumping plant: complete 1963 Tracy pumping plant: construction began 1963, complete 1967						
CS7 Salmonid juvenile development in Yolo		↑		✓		2002 – 2007 (H); 1976 – 1991 (S); n=22
CS9 Salmonid juvenile mortality risk	↓			✓		2002 – 2007 (H); 1976 – 1991 (S); n=22
CS10 Salmonid juvenile temperature preference	↓			✓		2002 – 2007 (H); 1976 – 1991 (S); n=22
DS1 Delta smelt spawning success		↑			✓	2002 – 2010 (H); n=9

[13] Although fully configurable through the EFT database, relative suitability threshold changes are not made lightly, since every RS method result is founded on a preceding threshold setting exercise.

Indicator Name	Good [δ]		Threshold Setting Method			
			A	D	T	Years for D,T
DS2 Delta smelt habitat suitability		↑	✓			–
DS4 Delta smelt entrainment risk	↓				✓	1989 – 2000 (H); 1975 – 1991 (S); n=29
LS1 Longfin smelt abundance		↑			✓	2002 – 2008 (H); 1975 – 1991 (S); n=24
SS1 Splittail spawning habitat		↑			✓	1989 – 2010 (H); n=22
TW1 Brackish tidal wetland		↑			✓	2002 – 2006 (H); 1975 – 1991 (S); n=22
TW2 Freshwater tidal wetland		↑			✓	1997 – 2010 (H); 1975 – 1991 (S); n=31
ID1 Egeria suppression		↑	✓			–
ID2 Corbula suppression		↑	✓			–
ID3 Corbicula suppression		↑	✓			–

[δ] *Key to Good:* ↑ = More of the indicator is better; ↓ = Less of the indicator is better. *Key to Threshold Setting Method:* A = Absolute; D = Discontinuity; T = Tercile. *Key to Years:* H = Historical observations; S = Simulated/proxy data intended to portray a typical condition.

Figure 2.12 shows an example of this sorted ("cumulative") distribution with selected threshold breakpoints. As might be expected, the native units of each plot vary with the performance indicator (see ESSA 2011, 2013).

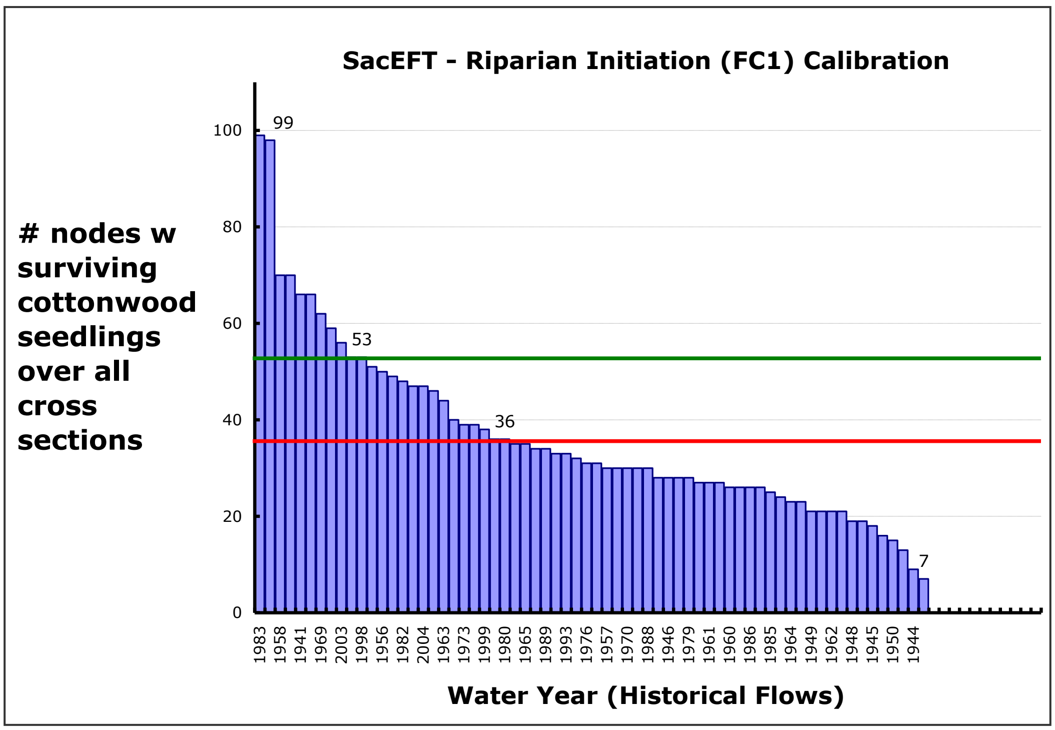


Figure 2.12: Annual sorted results and relative suitability thresholds for the SacEFT Fremont cottonwood initiation (FC1) performance indicator run using historic observed flows (WY1938-2003). Breakpoints are indicated by horizontal lines. This definition of threshold suitability also takes into consideration comparisons with aerial photographs of historically strong cottonwood recruitment at study sites vs. model results (abstracted from ESSA (2011), Figure 3.2 [Appendix B]).

EFT baseline simulation

Distributional outputs like Figure 2.12 are the result of an EFT baseline simulation (a model run typically based on a continuous historical time series *sometime* between 1939 and 2002; details depend on species and PI, refer to Appendix G). Each EFT baseline simulation was selected to maximize the range of water year types and year to year variation in flow conditions based on available high-resolution data. Because of the requirement for long-term, high-resolution datasets (both temporal and spatially), this typically required selection of data available from the long-term historical record. Historical data include modified, regulated, artificial flows following construction and operation of major dams, diversions and pumping plants. Historical flow (and water temperature) datasets also include different stanzas and changes in driving climate.

Note: In this report, historic flows ≠ natural / pristine / unregulated / unmodified / unimpaired flows. Historical flows are just that — the measured empirical flows which occurred during the selected period of record. Hence, these flows can and will include a shifting mixture of modified, regulated, artificial (potentially "degraded") flows following construction and operation of dams, diversions, conveyance structures and pumping plants. However, when the time series is long enough, they will also include a range of water year types and related flow variations that even though regulated, still manage to "show through" in the historic dataset.

For some DeltaEFT indicators, when the historic record was too short, the EFT baseline combined the available historic data with a simulated no action proxy historical flow simulation. Details are described below and in Appendix G.

Hence, it is important to recognize that EFT's baseline simulations do *not* use (nor claim to use) natural, unregulated, pristine flows. Pristine unregulated flows *do not exist* at the temporal (daily), and spatial resolution (Appendix H), over the range of water years (multiple decades) required by EFT to establish baseline conditions.

While there have been various efforts to remove the effects of reservoirs and diversions on existing hydrological time-series (so called unimpaired flows), these estimates do not include removal of the effects of levees, channelization “improvements”, wetland storage and related evaporation processes, forest practices, groundwater-surface water interactions, *etc.* Moreover, unimpaired flow estimates (with all of these various embedded limitations) are calculated at a limited number of locations (usually below rim dams and at the end of major rivers entering the San Joaquin-San Francisco Delta), not the wide range of sites (Appendix H) required to calculate EFT's functional performance indicators, and often only at a monthly resolution. Further, volume correlations, precipitation correlations, subbasin to subbasin extrapolations, and other (murky) techniques are embedded in the unimpaired flow datasets used in the Central Valley[14]. This represents a series of limitations (or at least unquantified errors) that make these unimpaired datasets unsuitable/inappropriate for use in EFT.

EFT emphasizes multiple functional flows. Functional flows are a distinct concept from natural flows. The functional flow needs represented in EFT's indicators are not dependent on the existence of "natural" (or unregulated or pristine, etc.) flows. Rather, the life-history needs of various species identified during conceptual model and related algorithm development — while they would no doubt show more frequent and better levels of response under natural, pristine, unregulated flows — still do generate positive, neutral and negative levels of response when confronted with variation shown in long-term historic flow records (even though regulated, artificial, modified). In this way, functional flows help to identify achievement of attenuated (or mimicked) natural processes in the presence of regulated/managed changes. While it would be ideal to have a long-term, high-resolution natural (or pristine or unregulated, etc.) flow record, EFT's functional flow indicators do not rely upon the existence of these (currently unavailable) flows.

Interpretation of EFT RS thresholds

While some indicators shown in Table 2.10 are based on an "absolute" scale (via expert opinion or from a Biological Opinion), most RS thresholds are based on records of historic flow, some of which extend for many decades with the resulting empirically-driven indicator results broken into low, medium and high categories to define the default suitability thresholds (e.g., Figure 2.12). When new reference case and study scenarios are run, their RS outputs are computed using these same default thresholds (via tercile/discontinuity curve-break analyses).

Conventionally, the RS comparisons are expressed as the arithmetic difference in the percentage of good/favorable years between scenarios. For example, if 22% of years are good in the reference case scenario and 37% of years are good in a study scenario, the RS comparison will be +15%, as shown in Table 2.11. This can be thought of as measuring the change in the proportion of years in the upper (good) tail of the distribution of years.

A helpful complement to establishing RS thresholds is to identify historical years when a performance indicator was known to have experienced favorable or poor performance. In some cases, our suitability threshold decisions were informed by these types of comparisons (e.g., for Fremont cottonwood), where records of favorable and poor years were measured and documented in such a way that enabled the units of the EFT performance indicator to be related to these observations. Despite best efforts however, repeated surveys of experts during our follow-up on input during EFT design workshops did not yield high response rates on "absolute" suitability thresholds for many EFT performance

[14] Methods at Rim Dams are more reliable, but not useful at the locations required by EFT's functional performance indicators.

indicators. This is in part due to the derived nature of EFT performance indicators (e.g., "Weighted Useable Area" vs. "Adult Spawning Abundance").

While the RS method provides a methodology that is fully internally consistent for comparing scenario results (i.e., a comparison of multiple scenarios using the same performance indicator will always provide an accurate picture of which water management scenarios are "better" than others), it does not necessarily provide a concrete inference about the ecological significance of a particular effect. For example, it is possible for a year that ranks as "good" with this method to be biologically suboptimal. Similarly, a year that ranks as "poor" may not be biologically meaningful and therefore, the need to carefully interpret results is always present.

Table 2.11: EFT effects analysis – high-level roll-up using the relative suitability (RS) method. The method reports the percentage change in the years with good/favorable conditions compared to a reference case. This standardizes the comparison units in terms of a relative suitability rating and is internally consistent and able to accurately identify alternatives that are better or worse. The RS method does not provide an assessment of ***absolute*** suitability.

Focal species	Performance indicator (incomplete listing)	Effect Alternative vs. Reference case			
		Alt. 1	Alt. 2	Alt. 3	
Upper and Middle Sacramento River Indicators					
Fall Chinook	Suitable spawning habitat (CS1)	15	16	15	
Late Fall Chinook	Suitable spawning habitat (CS1)	-3	-5	-2	
Winter Chinook	Juvenile stranding (CS4)	-14	-18	-17	
	Suitable rearing habitat (CS2)	10	26	4	

2.7.3 Annual RS Roll-up

An example of the annual RS output created directly by the EFT software is shown in Figure 2.13. These annual roll-up summaries group performance indicator results for selected scenarios together, and within each scenario show the annual ranking of selected indicators. They can help to identify water years that exert a strong signal across all scenarios. This information can be shown "optically" as in Figure 2.13 or in tabular form per the example in Table 2.11.

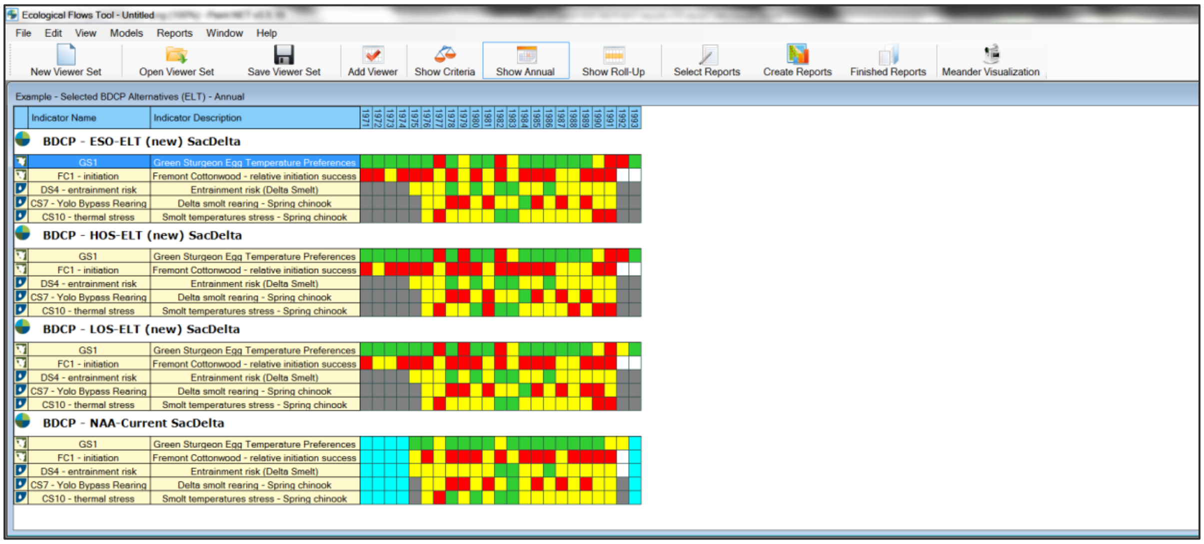


Figure 2.13: An example of the RS method applied to annual roll-up ratings for four scenario groups and five indicators.

2.7.4 Multi-year RS Roll-up

The highest level of RS synthesis provided by EFT is the multi-year roll-up. Once again grouped by scenario, Figure 2.14 shows the percentage of years in the simulation having favorable, fair, and poor conditions, utilizing the same results as the annual roll-up.

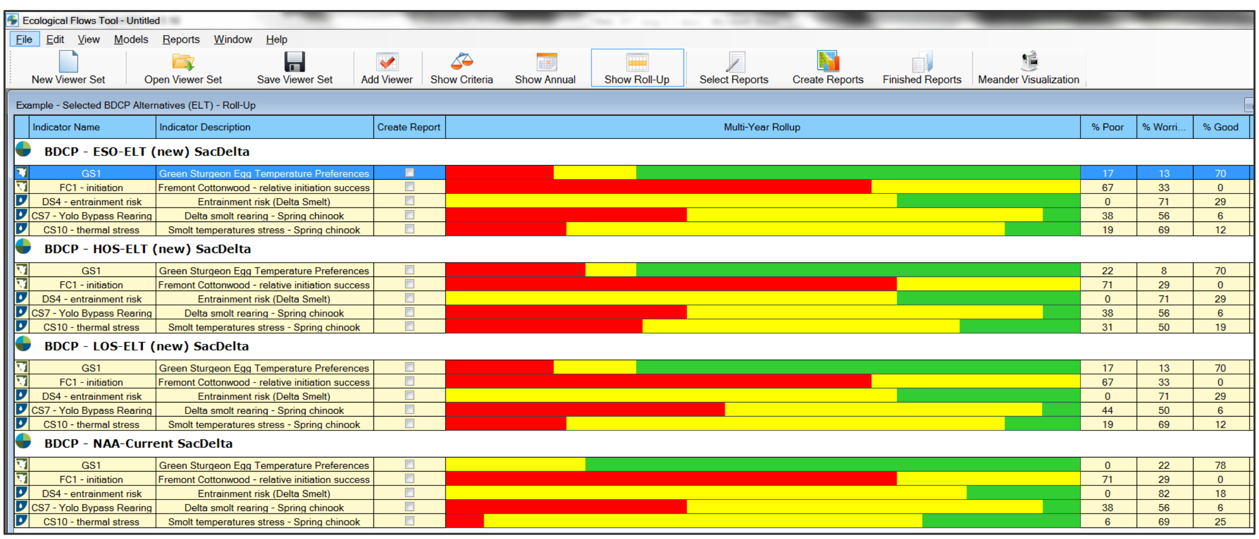


Figure 2.14: An example of the RS method applied to multi-year roll-up ratings for four scenario groups and five indicators.

The RS method does not provide a quantitative assessment of absolute suitability by conveying the absolute size of the effect. Changes like +15% gain in favorable years are a convenient way to compare scenarios but carry no statistical inference (like α=0.05).

RS-based differences between alternatives may be more sensitive to changes at the tails of the annual distribution, compared to the methods based on Effect Size (described below). Using this method, boundary effects can mean that a small percent change may cause a year to switch ranks. A few indicators may also have a narrow range.[15]

In summary, the RS synthesis method tends to emphasize changes in the favorable and poor ends of indicator performance distributions rather than the central tendency. While the method provides a useful framework for screening results, it can suffer from boundary effects and hyper-sensitivity if the relative suitability thresholds are set too narrow. The *key benefit* of the RS method is that it removes units and standardizes comparisons in terms of a common suitability rating relative to a chosen reference case. The best use of the RS method is therefore to serve as a *screening tool* to compare scenario results in association with additional synthesis methods. The annual and multi-year RS roll-ups are internally consistent and will correctly identify alternatives that are better or worse for a given indicator.

2.7.5 EFT Syntheses Based on Effect Size (ES)

Context

A companion synthesis we use involves comparing multi-year median values for each indicator for each alternative so that the modeled Effect Size (ES) can be considered in terms of the raw units. As with the RS synthesis method, this approach also makes use of a reference case to provide comparative percentage changes but in this case, the change is expressed in terms of the raw units. Like RS methods, the sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case (see Table 2.10). Depending on preferences, visual color shading like that shown in Table 2.12 can be applied to help the reader decode the direction and magnitude of positive and negative changes. In this report we highlight positive changes from the baseline case with green shading and negative changes with red shading; using stronger shades to indicate greater departure from the baseline. The threshold used to set these visual cues is itself a judgment decision. We chose a ±10% change in median values as a convention. This does not provide an absolute basis for judging whether an indicator difference is suitable or acceptable; rather, this threshold change provides a convenient way to compare ES changes amongst alternatives, but carries no statistical inference (like $\alpha=0.05$) on its own. Because ES differences are based on changes to the multi-year median values, the ES approach is expected to be more muted relative to the tail-oriented RS method, which is subject to greater changes.

[15] Relative suitability thresholds for all performance indicators are fully configurable in the EFT database (Appendix G).

As with the RS method described in Section 2.7.2, the ES synthesis method is best used as a screening tool to compare results based on changes in the median of the distribution of indicator results.

Table 2.12: EFT effects analysis – multi-year analysis using the Effect Size (ES) synthesis method. This view presents the multi-year median values for each alternative with percentage differences, and preserves the native units of each performance indicator. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Arbitrary green and red shadings are used to help decode patterns by categorizing levels of positive and negative changes: 5-10%, 10-20% and >20%. While the native units of each performance indicator are provided, these changes too do not provide an assessment of absolute suitability.

Focal species	Performance indicator (incomplete listing)	Reference case	Alt. 1	Alt. 2	Alt. *n*
Upper and Middle Sacramento River Indicators					
Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	3,738	4,081 (9.2%)	4,069 (8.9%)	3,998 (6.9%)
Late Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,272	1,195 (-6.0%)	1,187 (-6.7%)	1,232 (-3.1%)
Winter Chinook	Juvenile stranding index (CS4)	0.085	0.106 (-2.1%)	0.094 (-0.9%)	0.101 (-1.6%)
	Suitable rearing habitat (CS2; 000s ft^2)	37,153	37,602 (1.2%)	37,804 (1.8%)	37,101 (-0.1%)

Effect Size Boxplots

In order to explore potentially meaningful changes flagged by the RS and ES methods, we can dig deeper into selected potential effects by plotting median effects across all years by location, and preserve the level of variation using boxplots (e.g., Figure 2.15). This can be used to show both the level of variation overall amongst alternative- as well as location-specific effects. Grouping results by water year type is a further elaboration of this kind of analysis.

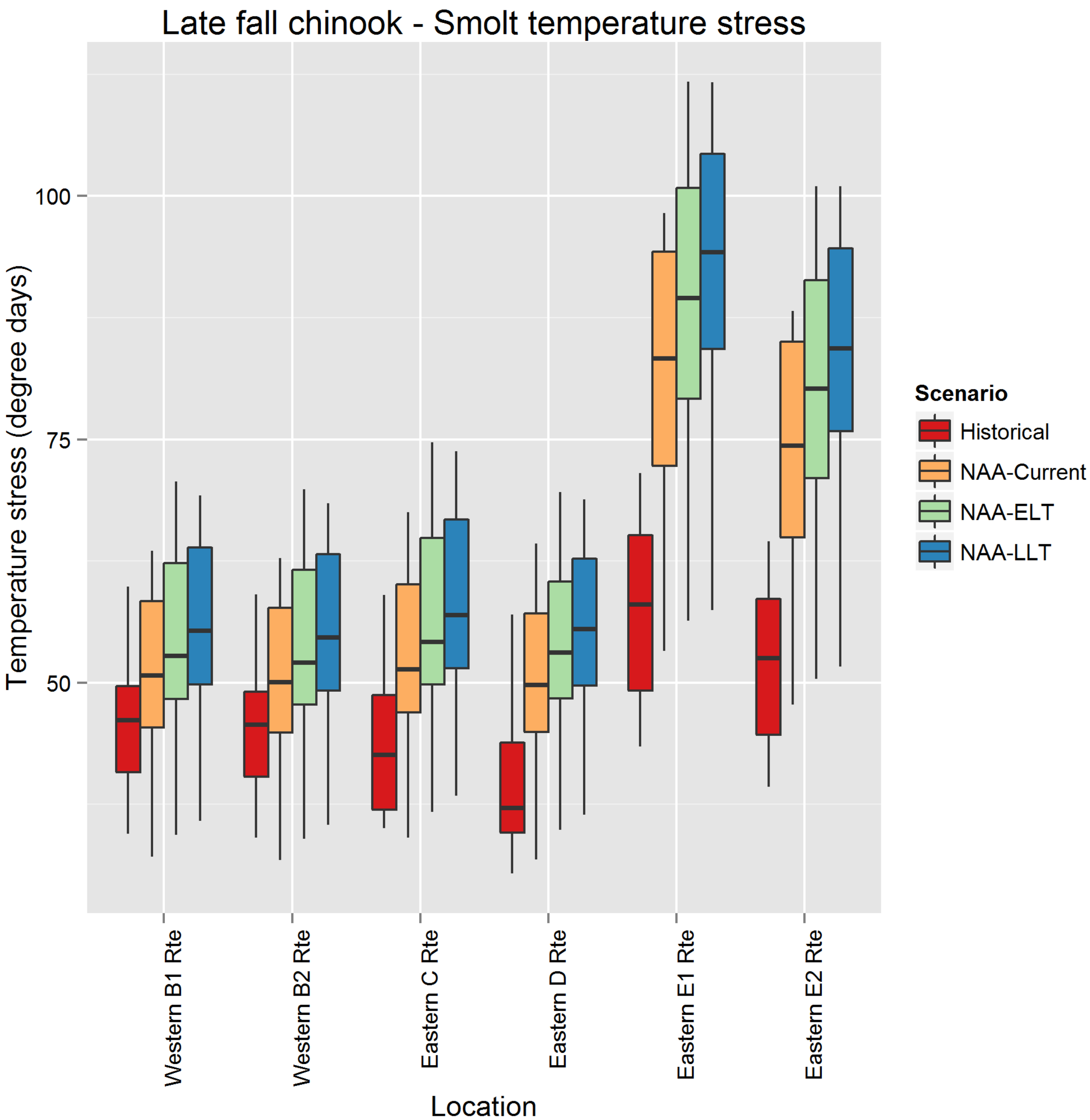


Figure 2.15: Boxplot of temperature stress for fall-run Chinook (CS10) showing median value by location for alternative scenarios, including 25th and 75th percentiles (edge of boxes) as well as tails of extreme values (lines). These ES summary plots are available by alternative over all locations, as shown above with results for individual locations, and can also be stratified by water year type.

2.7.6 Within Year Daily Results

In selected cases we also review detailed daily results and make use of the spatial visualization (mapping and animation) features of EFT. These detailed outputs are important when interpreting effects that have been screened as being potentially meaningful (e.g., Figure 2.16; Figure 2.17). These outputs are automated through the EFT software (and are distinct / independent of the RS and ES methods).

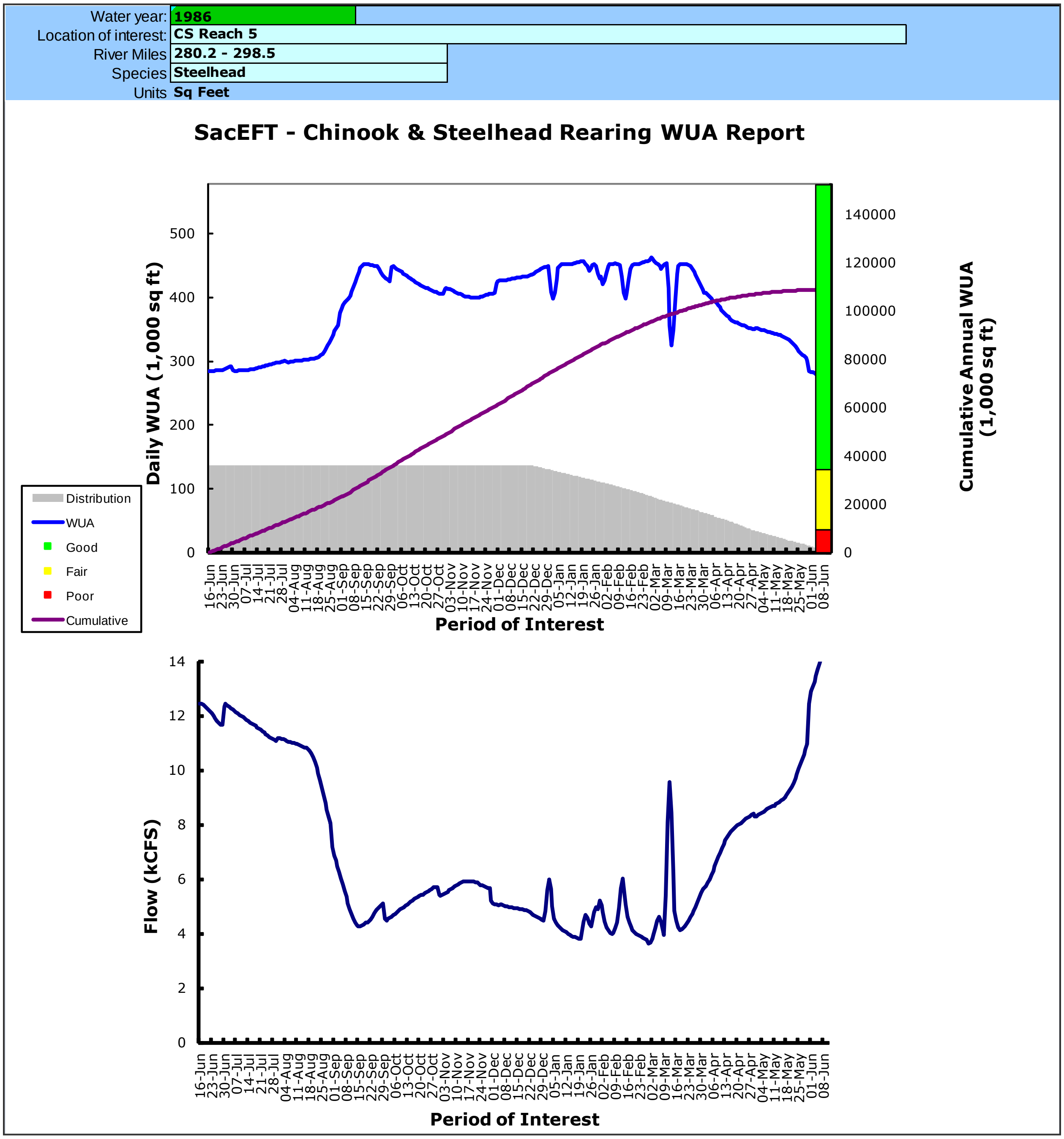


Figure 2.16: Steelhead rearing habitat (CS2) results for a year rated as favorable.

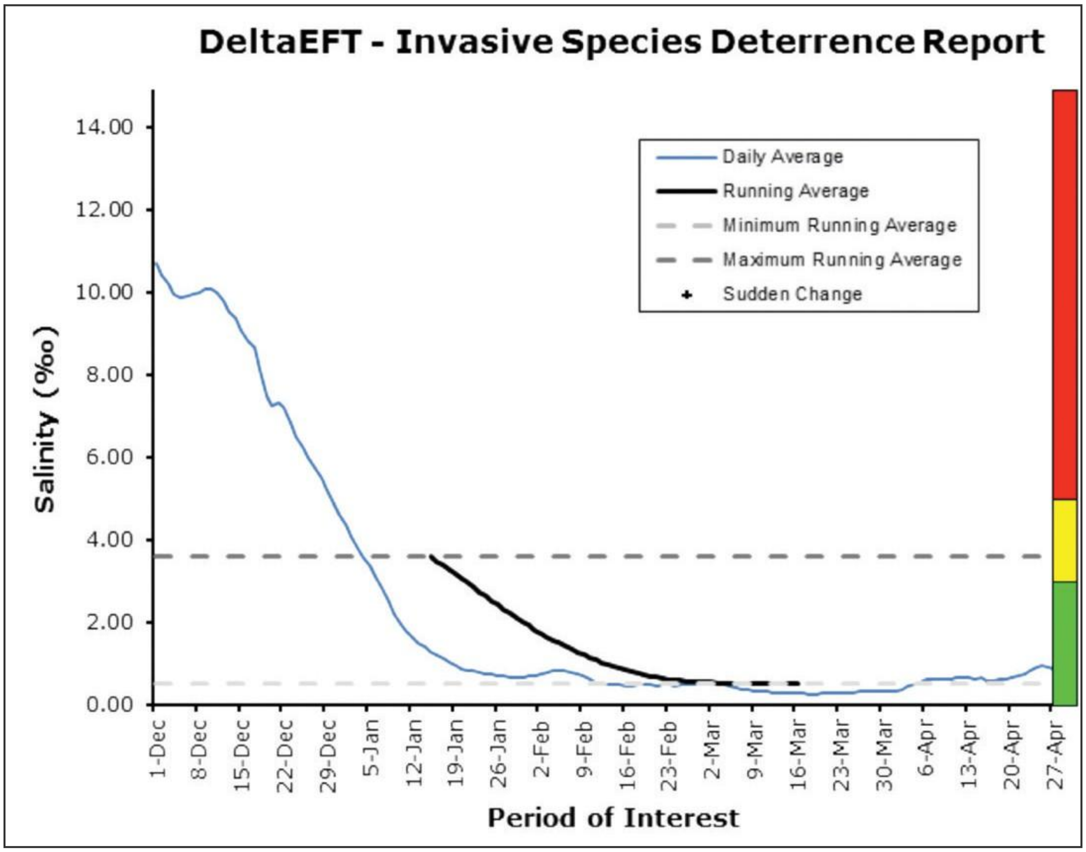


Figure 2.17: DeltaEFT invasive species deterrence result for a year rated as favorable.

All daily site-specific data are recorded in EFT's database, which can be used for further custom analyses.

2.7.7 Spatial Visualizations and Animations (DeltaEFT only)

In the Delta, unique spatial dynamics can exert control over the consequences of different flow regimes. To help users understand these patterns, DeltaEFT includes spatial visualizations and animations for various performance indicators. This provides another important method for interpreting and communicating results. Figure 2.18 shows an example of a screen capture from the Annual Spatial report for DS4: Index of risk of entrainment for Delta smelt. This example shows results for each location for a year with fair performance. Dots are colored based on expected entrainment. Green dots are less than 5%, yellow dots are 5 – 25% and red dots are greater than 25%. Dots are also scaled based on their spatial weight. Note that locations closer to the water export facilities generally have high entrainment and low spatial weights.

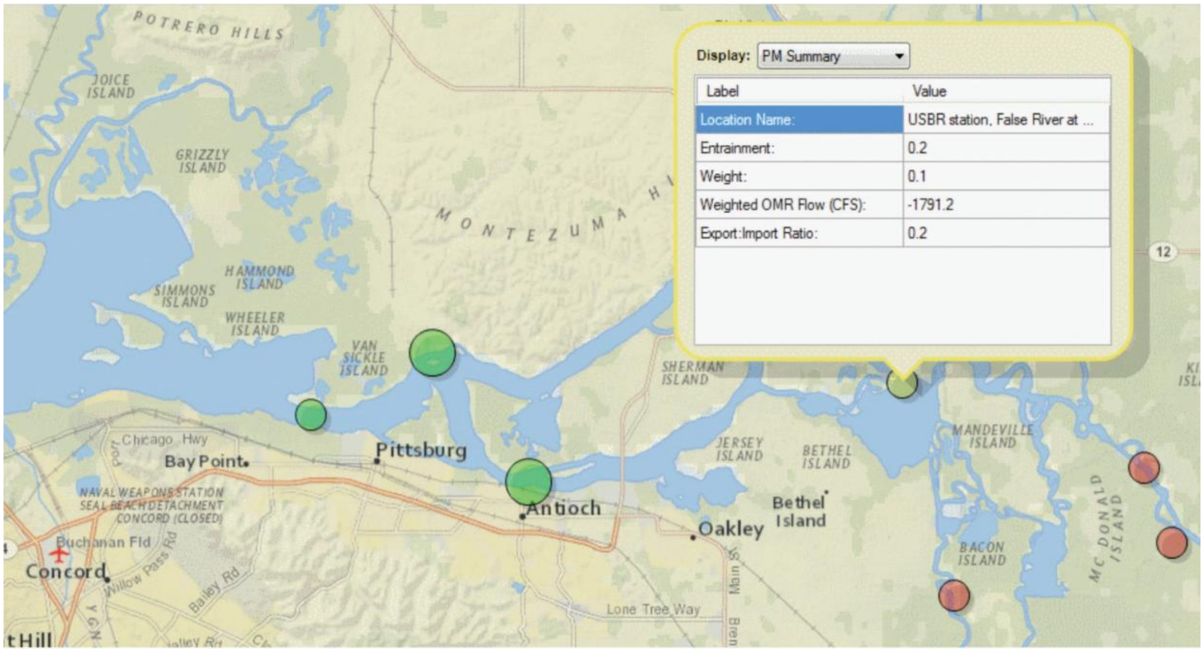


Figure 2.18: An example screen capture from the Annual Spatial report for DS4: Index of risk of entrainment for Delta smelt, showing the performance at each location. Dots are colored based on the magnitude of entrainment. Green dots are locations where expected entrainment of smelt larvae in those areas are less than 5%, yellow dots are 5 – 25% and red dots are more than 25%. Dot-sizes also reflect their spatial weight (i.e., the average relative abundance of smelt present in the different index areas).

2.7.8 Development of Target Ecological Flow Criteria

Results for EFT's 25 functional performance indicators can be analyzed to identify the emergent preferred ecological conditions and rule-sets that support favorable relative suitability ratings (presented in detail in Appendix I). A fundamental step in this process involves analysis of flow traces (or traces of water temperature or other physical drivers) that are associated with favorable suitability. These eco-friendly rule-sets can then be incorporated and tested within external modeling platforms capable of handling the necessary resolution of these rules.

Section 2.9 elaborates how we use EFT eco-friendly rule-sets and incorporate them into other systems operation models (CALSIM example). In Section 3.4, we present results of a first pilot study to apply some of these EFT derived rule-sets to CALSIM.

2.8 Structured Comparisons & EFT Analysis Steps

There are a very large number of ways to explore and compare operation/conveyance effects and climate effects for the Sacramento River and Delta amongst EFT's multiple species and indicators. In the case of EFT's salmonid indicators, there are over 200 possible "effects" comparisons. To systematically manage this *daunting* task, our analyses follow a structured approach. A fundamental element of this approach involves making comparisons with a defined reference case. As described below, the nature of the reference case and study scenarios determines whether an analysis is focused on operation/conveyance effects or climate change effects.

2.8.1 Role of the Reference Case

A challenge and frequent controversy surrounding National Environmental Policy Act (NEPA) and California Environmental Quality Act (CEQA) effects investigations is the establishment of a reference case for the comparison of alternatives and the analysis of the effects of alternative project implementations on priority species (Mount *et al.* 2013). The reference case represents a chosen point of comparison, or baseline, which embeds any number of assumptions about the level of human development, climate change, and baseline system operations. Using a reference case provides relative simplicity and side-steps questions related to the absolute predictive accuracy of models by focusing exclusively on the difference between study scenarios compared to the reference case, isolating the impacts of the alternatives in question. This is the common approach adopted by DWR in many analyses of BDCP alternatives as well as in previous analyses of NODOS project alternatives.

This practice notwithstanding, use of a historical reference case was recommended by the Delta Science Panel in its review of BDCP (DSP 2014), even though the approach is unwelcome by some who feel that the historical record is a flawed reference given that it includes numerous shifts in operational standards and climate. The counterpoint is that use of a historical reference case enables study of the level of cumulative change (regardless of whether it is produced by climate change, changes in operations and conveyance, or increasing patterns of human water demand).

When interested in the cumulative level of change, EFT effects analyses that use historical conditions as the reference case (Section 3.4 includes examples of this reference comparison) provide managers with supplementary information and perspective about the degree to which proposed future actions may contribute toward the recovery of priority species. For example, knowing that three study comparisons differ in their indicator effects by 5% versus a future reference case, while a historical reference is 25% different, provides perspective on the magnitude of cumulative change already "ratcheted into" the system.

2.8.2 Operation and Conveyance Effects

In traditional comparisons, effects analyses use a standard No Action Alternative (NAA) reference case[16] with study scenarios (or alternatives) matched to the equivalent time period. Therefore, these comparisons hold climate and demand effects fixed and differences reflect only the signal associated with the alternative operations and conveyance details amongst the scenarios. In this report, this is called an operation and conveyance effect. While it ignores cumulative changes, this is the comparison that is typically of regulatory interest in CEQA/NEPA EIS/R studies.

2.8.3 Future Climate and Water Demand Effects

In our EFT effects analyses of selected BDCP alternatives, we also assess the effect of climate change and future levels of development and water demand on EFT species and performance indicators by comparing the NAA-Current to NAA-ELT (Early Long Term) to NAA-LLT (Late Long Term) study scenarios. These comparisons isolate the effect of varying future climate, water demand, and development (while holding operation and conveyance changes constant).

2.8.4 Cumulative Change

As mentioned above, to demonstrate how historical conditions can provide supplementary information to EFT analyses, our Pilot Analysis of ecological flows (Section 3.4) includes a historical reference case alongside the more typical simulated reference case. This comparison illustrates the degree of cumulative system change.

2.8.5 Water Year Effects

Another comparison that can be structured is to stratify outputs according to Water Year Type. Comparisons like those found in Section 3.3.3 show the effect of particular categories of water supply, regardless of climate and operation/conveyance assumptions.

2.8.6 Typical EFT Effects Analysis Steps

All comparative analyses (including those in Chapter 3) generally follow a systematic presentation that:

1. starts with a high level summary of overall findings;
2. compares changes in the driving physical variables themselves (flow, water temperature, salinity, etc.);
3. examines the changes to species functional performance indicators using different methods;

[16] These acronyms are all defined in detail in Section 3.3.2.

4. provides indicator level summaries using RS outputs and associated synthesis method;
5. provides indicator level summaries using the ES outputs and associated synthesis method; and
6. ends with a weight of evidence net effect score that combines the RS and ES results.

All these components are described in detail below, with Section 3.3.3 providing a detailed study of the sequential, structured approach applied to selected BDCP alternatives.

Physical Change

Our EFT subcomponent effects analyses typically proceed in four stages. *First*, we conduct an assessment of the degree of physical change amongst the alternative scenarios. This is an essential first step, since any lack of contrast in fundamental flow, water temperature, San Joaquin-Sacramento Delta salinity, *etc.* means that there will be no reason to expect meaningful changes in EFT performance indicators. For both the Sacramento River and Delta ecoregions, we identify a small number of representative physical locations and review the median and percent differences in key physical variables on a monthly basis.

Comparisons among months are expressed as percentage difference based on the difference between the median of the study scenario compared to the median of the reference case. To help detect patterns and differences, green and red shading is used to highlight three levels of positive and negative changes: 5-10%, 10-20% and >20%. Monthly exceedance plots are also available.

Application of Relative Suitability (RS)

As the second step, we screen alternatives for high-level effects using the Relative Suitability (RS) synthesis method. Details of the strengths and limitations of this method are described in detail in Section 2.7.2. The RS method is a comparison of the percentage of years with a favorable relative suitability classification for the study scenario, compared to the percentage of favorable years in a reference case scenario.

This method will generally show higher sensitivity to changes in the upper (or lower) tail of performance distributions rather than the central tendency of performance.

As a convention, we use ±10% difference in the percentage of favorable years between scenarios as a signal of potentially meaningful change when summarizing findings using the RS method. More granular presentations using the RS method use six levels of positive and negative changes: ≤-10%; -5% to -10%; -4%; -3% to +4%; +5% to +10%; and ≥10%.

Application of Effect Size (ES)

In the third step, alternatives are screened for high-level effects using multi-year median Effect Size (ES) synthesis method. Details of the strengths and limitations of this method are described in detail in Section 2.7.5. The ES method measures the change in the median value of the multi-year set of results, comparing results of each study scenario with a reference case scenario. Because it is focused on the median of a multi-year distribution (over all locations), the ES method will tend to show smaller changes when compared to the RS method, which measures changes to the tails of the distribution and can be sensitive to boundary effects.

As a convention, we use a ±5% change in the median multi-year performance of a given indicator to signal a potentially meaningful change when summarizing findings using the ES method. In general, the ES comparisons with a 5% threshold for median change generally produce a smaller, more stringent set of differences as compared to the RS method.

We stress that these two methods (RS and ES) are complementary and do not provide equivalent, interchangeable effects information. Further, our ±10% (RS) and ±5% (ES) change levels are *conventions*. As with EFT's default suitability thresholds, these levels can easily be changed/customized.

Net Effect Score (NES)

Relying on either the RS or ES method may limit the ability to detect meaningful differences between scenarios. To address uncertainty in the overall assessment, including the challenge of integrating multiple attributes (indicators) for single species, we calculate a Net Effects Score (NES). The NES is based on a consistent logic that considers the weight of evidence provided by the RS and ES methods, *penalizing discrepancies when our two major effects analysis methods differ*.

Effects analysis results that show potentially meaningful levels of change for *both* RS and ES comparisons receive a higher qualitative ranking for strength of evidence. We also provide a mechanism for lowering the score for results that have large uncertainty around the ES (all-years median) effect, and raising the score when the uncertainty is smaller.

Finally, when the fundamental scenario definition includes actions that on first principles provide a clear explanatory mechanism (e.g., notching of Fremont Weir), if *either* our RS or ES method shows a potentially meaningful effect, those cases receive a higher NES (Table 3.35). While many important nuances are not visible in this type of presentation, this nevertheless provides an executive level summary of heuristic conclusions based on our best judgment interpreting EFT effects analysis results.

Definition of Net Effect Scores (NES)

The highest NES is a 6. NES scores increase when the RS and ES methods both agree that there is a potentially meaningful effect. Scores further increase when results have less variation around the mean effect size. The definitions for all possible NES scores are:

- **Blank/No Score:** Neither the RS nor ES summary method generates a potential change that passes our ±10% and ±5% thresholds. No meaningful effect.
- **+/-** Mixed effects -- indicators for same species show benefits and penalties (i.e., Chinook/steelhead), but the net effect is difficult to determine.
- **1-RS** RS summary method shows a potential effect (passes ±10% threshold). However, the results are highly variable.
- **1-ES** ES summary method shows a potential effect (passes ±5% threshold). However, the results are highly variable.
- **2-RS** RS summary method shows a potential effect of ±10% change or more in favorable years, with clear signal to noise (less variability), yet the ES summary view shows the inverse effect (potentially contradictory evidence).
- **2-ES** ES summary method shows a potential effect of ±5% change in absolute median effect size, with clear signal to noise (less variability), yet the RS summary view shows the inverse effect (potentially contradictory evidence).
- **3-RS** RS summary method shows a potential effect of ±10% change or more in favorable years, with clear signal to noise (less variability), and the ES summary view does not meet threshold (no contradictory evidence).
- **3-ES** ES summary method shows a potential effect of ±5% change in absolute median effect size, with clear signal to noise (less variability), and the RS summary view does not meet threshold (no contradictory evidence).
- **4** Both summary views agree on the direction of the potential effect, and both pass the threshold for a potentially meaningful effect. However, both show a highly variable spread in results.
- **5** Both summary views agree on the direction of the potential effect, and both pass the threshold for a potentially meaningful effect with clear signal to noise (less variability).
- **6** Either category "3","4" or "5" + a fundamental, clear mechanistic link to scenario description.

Table 2.13 shows a partial example of an NES analysis. Higher numeric NES scores indicate greater confidence in the significance of positive or negative change in the study scenario, compared to the reference case.

Table 2.13: An example showing the result of the Net Effect Score (NES) analysis applied to one of a suite of BDCP case studies. A complete table of NES results is presented in Table 3.35. Shading indicates positive (green) and negative (red) changes from the reference case.

Early Long Term (ELT) Studies Relative to NAA-ELT Reference Case						
Sacramento River Ecoregion						
	ESO		**LOS**		**HOS**	
	+	−	+	−	+	−
Fall	**5**		**5**		**5**	
Late Fall	1-ES		1-ES			
Spring	3-ES		**5**		3-RS	
Winter		2-ES		2-ES		**5**
Steelhead	1-ES					
Bank swallow						
Green Sturgeon						
Cottonwood	1-ES		1-ES			
Woody Debris	1-RS				1-RS	
Delta Ecoregion						
Fall						
Late Fall	+/−		+/−		+/−	
Spring						
Winter	+/−		+/−		+/−	
Steelhead		3-ES		3-ES		2-ES
Splittail	**6**		**6**		**6**	
Delta smelt				**6**		
Longfin smelt					**6**	
Invasives		3-ES		**4**		3-ES
Tidal wetlands						

Interpretation

To interpret the meaning and mechanisms behind stronger NES signals requires digging into the specific EFT indicators, the physical changes which are relevant to the specific indicators, and the potential mechanisms by which the physical drivers interact with the indicator. Many of these deeper analyses can be done using the more detailed presentations of physical change and the RS/ES analysis which underlies the high level score. Some very fine-scale analyses of daily-scale events may require further investigation through a study of the model design documents (ESSA 2011, 2013) coupled with a study of within-year daily results by location.

2.9 Integrating EFT with Systems Operations Models

The general steps and methods required to create and test the linkage between EFT eco rule-sets and system operations models are outlined below.

In Section 3.4 we present results of this first pilot study to apply EFT derived rule-sets to CALSIM. Hence, this methods section, and Section 3.4 are intended to be read together.

2.9.1 Definition of Ecological Flow Criteria

For the majority of EFT's 25 performance indicators, we analyzed results to create a summary of preferred ecological flow rule-sets (presented in detail in Appendix I). A fundamental step is analysis of flow traces (or water temperature or other physical driver results) associated with favorable suitability. Leveraging the EFT relational database, and data analysis exercises like those shown in Figure 2.19, help the EFT investigators identify flow patterns and timing that were correlated with favorable outcomes for each species and performance indicator.

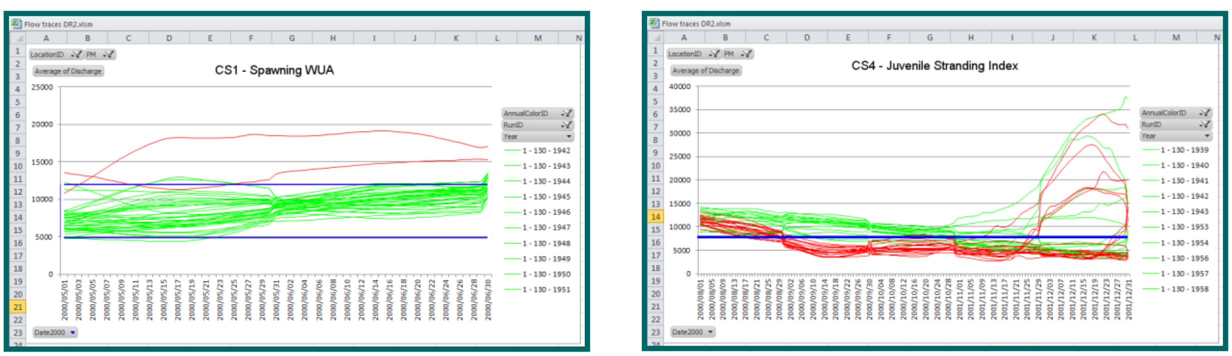


Figure 2.19: Example flow traces underpinning EFT Ecological Flows criteria and rule-sets. Individual water year traces are colored based on the indicator's relative performance suitability in EFT. For winter-run Chinook suitable spawning habitat (CS1), good performance years are bounded by average flows between 5,000 and 12,000 cfs (left panel). For juvenile stranding risk (CS4), poor performance is associated with flows below 7,000 cfs (right panel).

Based on flow (or other) trace analysis and conceptual model interpretation, criteria and rule-sets were then summarized using the standardized format shown in Table 2.14 and given in Appendix I (timing, magnitude of minimum and maximum flows, location and other properties). EFT eco rule-set analyses show that rules for driving physical data are sometimes clearly correlated with the favorable outcome, while others such as redd dewatering (CS5) have no obvious relationship with flow.

2.9.2 Selection of Subset of Ecological Flow Criteria for Pilot Application

Our initial pilot study (Section 3.4) reduced EFT's 25 indicators to flow criteria for two species: winter-run Chinook (Table 2.14) and Delta smelt (Table 2.15). These species were chosen based on their threatened status and because one was found in the Upper Sacramento and the other the Delta.

Table 2.14: Initial EFT Ecological Flow rules for winter-run Chinook.

Sacramento River													
Chinook (winter-run)													
Indicator	CS1-CS6			Integrated									
Timing	O	N	D	J	F	M	A	M	J	J	A	S	**Range**
								12	12				CS1: Spawning WUA, Max
								5	5				CS1: Spawning WUA, Min
													CS3: Thermal Egg Mortality, no constraint
													CS6: Redd Dewatering, no constraint
													CS5: Redd Scour, no constraint
													CS4: Juvenile Stranding, Max no constraint
	7	7	7								7	7	CS4: Juvenile Stranding, Min
	8	8	8								8	8	CS2: Rearing WUA , Max
	3.5	3.5	3.5								3.5	3.5	CS2: Rearing WUA, Min
	8	8	8					12	12		8	8	Integrated: Max
	7	7	7					5	5		7	7	Integrated: Min
Location	Sacramento River above Clear Creek (RM290)												

Table 2.15: Initial EFT Ecological Flow rules for Delta smelt entrainment risk.

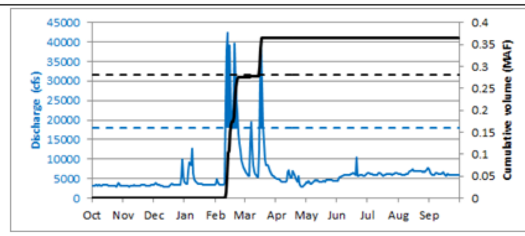
San Joaquin-Sacramento Delta	
Delta smelt	
Indicator	DS4 — Entrainment index
Timing	O N D J F M A M J J A S
Locations	Combined Old + Middle River (OLD R A BACON ISLAND CA, ROLD024, 11313405) + (MIDDLE R AT MIDDLE RIVER CA, RMID015, 11312676)
Variable & Condition	≤ Normal WYT: $Q_{avg} > -2{,}000$cfs > Normal WYT: $Q_{avg} > 0$cfs
Other Triggers	Juvenile smelt detected through trawls
Recurrence	Annually
Potential conflicts & trade-offs	May conflict with export objectives
References	Kimmerer and Nobriga (2008)

The pilot rules shown in these tables were subsequently "downgraded" to a coarser monthly resolution on which CALSIM II operates (see Section 2.6.1), and include the following basic properties:

1. Minimum and maximum flows;
2. Two locations: Sacramento River at Keswick flows (winter-run Chinook) and combined Old and Middle River flows (Delta smelt entrainment);
3. When cold water storage criteria are not met, and during drought conditions, our EFT rule-sets are not triggered (“Off-ramping”); and
4. Use of maximum flow limits in non-target months to save water for minimum flows in subsequent simulation years (“water banking”).

An initial exploration of rules for bank swallow (Table 2.16) was discontinued when it was apparent that the downscaling of the flow requirements for bank swallow habitat was too complex for an initial exploratory study.

Table 2.16: Summary of ecological flow criteria for protection of Sacramento River bank swallow habitat potential. WYT = Water Year Type.

Bank Swallow		
Indicator	BASW1	Habitat potential
Objective & Rationale	Maximize availability of suitable nesting habitat	
Timing	O N D J F M A M J J A S	
Location	Hamilton City (RM199, SACRAMENTO R NR HAMILTON CITY CA, 11383800)	
Variable & Condition	Below normal WYT: Release a volume of 0.28 MAF above 18,000 cfs if target not met in preceding two years Normal and wetter WYT: Release a volume of 2.8 MAF above 18,000 cfs if target not met in preceding two years	
Other Triggers	Attempt for WYT < N if target not met in preceding two years	
Recurrence	At least every 3 years	
Potential conflicts & trade-offs	Avoid during Bank Swallow nesting period (BASW2). Reservoir water supply management (draw-down/drought management). BASW1 also benefits Large Woody Debris recruitment.	
Additional Details The daily volume in cubic feet is calculated as the volume released above the 18.000cfs threshold: $DailyVolume = \begin{Bmatrix} 0 \ \ if \ Q < 18{,}000cfs \\ (Q - 18{,}000cfs) \times 86{,}400s \end{Bmatrix}$ The Cumulative Volume over the water year is the sum of all Daily Volumes converted to MAF. $Cumulative\ Volume = \sum_{i=1}^{365} DailyVolume_i \times 2.3 \times 10^{-11} \frac{\text{ft}^3}{\text{MAF}}$	 Example. The continuous blue line shows daily flow, the stippled blue line marks the threshold and the filled blue areas show the daily volume released above the threshold. The continuous black line shows the cumulative volume of water released once the threshold has been reached; which in this year exceeds the threshold of 0.28 MAF for dry and critical years, shown by the stippled black line.	

2.9.3 Selection of Reference Study

The selection of the reference study is described in Section 3.4.2.

2.9.4 Implementation of CALSIM Rules

The pilot monthly ecological flow criteria were integrated into CALSIM using CALSIM's native WRESL language and integrated with the over 700 existing WRESL files containing existing CALSIM rules. In this way coarse-scale EFT-derived operational rules are inserted into the existing CALSIM rule-set, and then tested to see whether the system responds to the candidate ecological flow criteria for the target EFT species indicators (as well as non-target EFT indicators).

Minimum ecological flow criteria for winter-run Chinook were implemented for Sacramento River at Keswick and included as two separate CALSIM actions for May to June and August to December (Figure 2.20). The minimum flow criterion was modified so that it was not implemented if it would meaningfully impact cold water storage ("cold water storage rule") or under drought conditions ("off-ramping rule") (Figure 2.21). Both of these rules are common in other CALSIM actions and were adopted to avoid improving one indicator to a meaningful level while penalizing another indicator, such as egg-stage thermal survival.

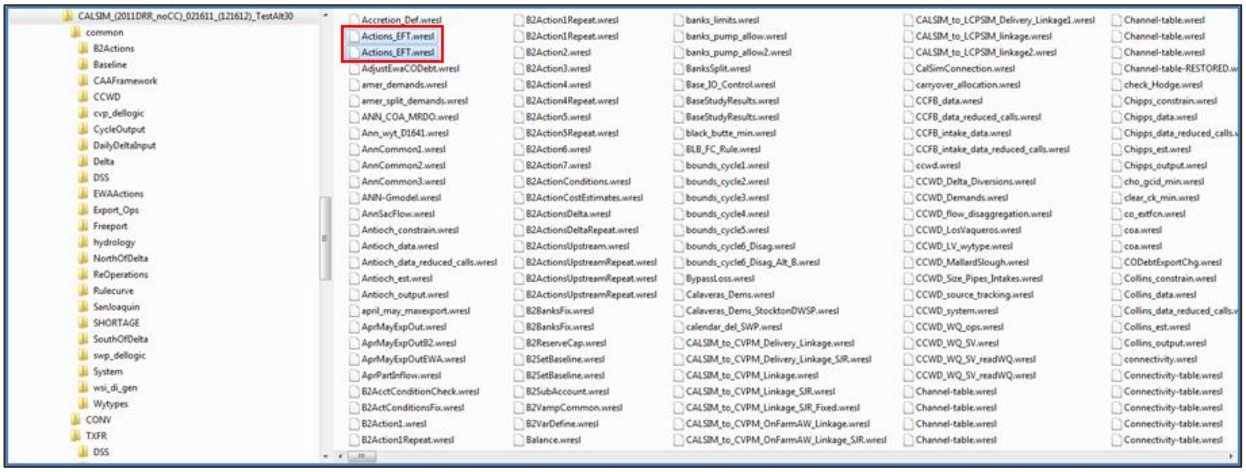


Figure 2.20: The pilot monthly ecological flow criterion was integrated into CALSIM using CALSIM's native WRESL language and integrated with the over 700 existing WRESL files containing existing CALSIM rules. The EFT WRESL files are highlighted in red.

```
define EFT_C5MIF {value 0.}


define EFT_C105MIF_MayJun {
        case ShastaColdOffRamp {
            condition  S1(-1) + S4(-1) + S44(-1) < ColdStorTarg
            value 0.}
        case CritCondOffRamp {
            condition wyt_NODOS + prev_wyt_SAC >= 8
            value 0.}
        case Action {
            condition month == MAY .or. month == JUN
            value 5000.}
        case ActionAugToDec {
            condition month == AUG .or. month == SEP .or. month == OCT .or. month == NOV .or. month == DEC
            value 7000.}
         case Zero {
            condition always
            value  0. }
        }

define EFT_C105MIF {value max(EFT_C105MIF_MayJun,0.)}
```

Cold water storage "rule"

Off-ramping "rule"

Min flows May and June

Min flows Aug to Dec

Figure 2.21: CALSIM operation rules written as WRESL-language statements for minimum flows. Four rules are implemented: minimum flow for two different time periods, a "cold water storage rule" and an "off-ramping rule". See text for details.

During initial (and iterative) test screening of CALSIM, we found that minimum flows could not be met due to lack of water in Shasta Reservoir unless water was held back early in the water year. This led to the creation and implementation of a "water banking rule" (Figure 2.22) which holds water back in January to April and July by introducing a maximum flow *not directly related to the ecological flow criteria developed*. Introducing a "water bank" rule meaningfully improved performance toward achieving target minimum flows.

```
/* Maximum flows */
define EFT_C5MAX {
        case Action {
            condition month == MAY .or. month == JUN
            value 12000.}
        case ActionAugToDec {
            condition month == AUG .or. month == SEP .or. month == OCT .or. month == NOV .or. month == DEC
            value 8000.}
        case Zero {
            condition always
            value  10000. }

        }

define C5_EXC_EFT {std kind 'FLOW-EXCESS-INSTREAM' units 'CFS'}
define C5_BELOW_MAX { std kind 'FLOW' units 'CFS'}

goal EFTaction {
  lhs C5_BELOW_MAX
    rhs       EFT_C5MAX
    lhs>rhs   constrain
    lhs<rhs   penalty 0 }
goal C5_EFT_MAX { C5 = C5_BELOW_MAX + C5_EXC_EFT}
```

Max flows May and June

Max flows Aug to Dec

Water banking "rule"

Figure 2.22: CALSIM rules as WRESL-statements for maximum flows. Three rules are implemented: maximum flow for two different time periods and a "water banking rule". See text for details.

Priority weights for each rule are an important element of CALSIM that influences how the model optimizes operations. The EFT rule-sets for winter-run Chinook and Delta smelt used in our pilot study were assigned the same weight as the existing CALSIM minimum flow criteria for other tributaries and species (i.e., we did not change/increase priorities for our EFT criteria).

2.9.5 Iterative Scenario Screening

The scenarios were screened using five CALSIM models of increasing complexity, ranging from a model of the Upper Sacramento River only to the full CALSIM model (Table 2.17). The screening steps were introduced to reduce computation time and study different ways of CALSIM rule implementation. It was during the learning period associated with this iterative approach, that the development of a "water bank" rule took place.

Before settling on the final rules, we iteratively screened draft rule-sets based on their ability to meet the EFT ecological flow criteria, as well as their impact on storage and exports (Figure 2.23). Any scenarios that made conditions worse than the reference case under drought conditions (e.g., drawing reservoirs further down) were rejected. Next, the scenarios were compared side-by-side to evaluate which scenario was meeting the flow criteria more frequently, including a focus on improving performance in months that were not doing well in the reference case. Finally, our screening evaluated changes to Delta exports to avoid any clearly unrealistic reductions. For example, zero exports in any given month would likely lead to human health consequences and were cause for rejection, resulting in a further search for operational rules that were able to jointly meet ecological and hydrosystem requirements.

Table 2.17: CALSIM screening models. Five CALSIM models of increasing complexity were used to screen different implementations of the monthly ecological flow criteria.

Screening model	Description
Upper Sacramento River Model without non-EFT objectives	Includes Sac R Reservoirs and River down to Knights Landing; Weights for objectives not related to EFT rules and reservoir operations set to zero
Upper Sacramento River Model	Includes Sac R Reservoirs and River down to Knights Landing
Delta Model	Simulates 4 of 17 CALSIM full-model steps Includes Delta and Reservoirs (operated for the Delta) Fixed set of allocations (CVP, SWP) Does not include San Joaquin, fixed set of Vernalis salinities/flows
All CALSIM regions	Simulates 4 of 17 CALSIM full-model steps, all regions
Full model	Similar to DRR study; all full-model steps, all regions

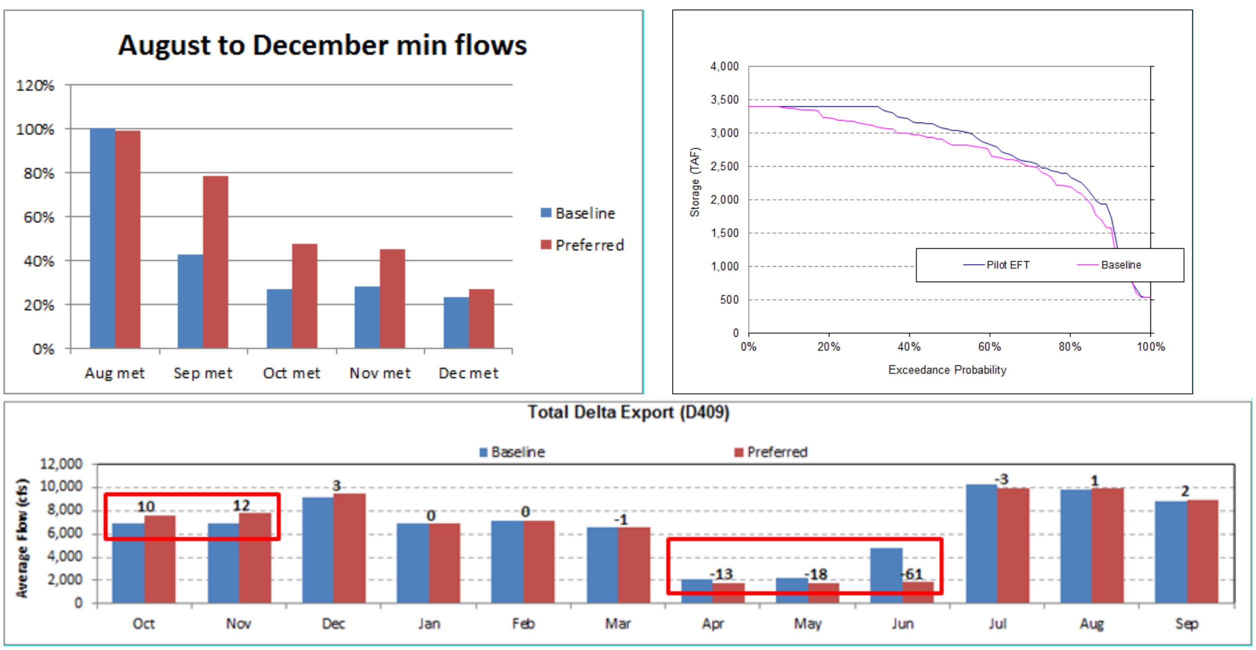


Figure 2.23: Scenarios were screened based on their ability to meet the ecological flow criteria (upper left panel), their impact on storage (upper right panel) and exports (lower panel).

3 Recent EFT Applications

3.1 Overview

State and Federal agencies have requested EFT be used to evaluate future operational changes to existing water projects as well as new water projects. To date, these include: North-of-the-Delta Offstream Storage, Shasta Lake Water Resources Investigation, the Bay Delta Conservation Plan, and the System Reoperation Program. EFT's applications are of direct relevance to the Department of Water Resources, the U.S. Bureau of Reclamation, the State Water Resources Control Board, and potentially several other State and Federal Agencies (U.S. Fish and Wildlife Service, U.S. Army Corp of Engineers) engaged in environmental water planning and ecological effects analysis. Chapter 3 of this report provides an updated effects analysis for selected San Joaquin-Sacramento Delta Conservation Plan alternatives. Ecological effects analysis projects we have completed to date are listed below, along with those that are in progress, sorted by primary agency sponsor.

California Department of Water Resources

1. **North-of-the-Delta Offstream Storage Investigation** (NODOS, or Sites Reservoir) www.water.ca.gov/storage/northdelta/index.cfm

In 2011, at the request of DWR, TNC analyzed the interim proposed operations for Sites Reservoir. Our analyses of the proposed operations were considered in the Administrative Draft of the joint EIS/R produced by the Bureau of Reclamation and DWR (TNC and ESSA 2012). This previous application of SacEFT to interim NODOS alternatives is *very* briefly summarized in Section 3.2.

The focus of Chapter 3 is on results of the first complete SacEFT and DeltaEFT effects analysis for selected BDCP alternatives, as well as presenting results of a pilot investigation applying EFT derived eco-friendly rule-sets to CALSIM. Neither of these two later applications have previously been documented.

2. **Bay Delta Conservation Plan** (BDCP)
http://baydeltaconservationplan.com/Home.aspx

TNC has been working with DWR since mid-2012 to analyze the BDCP alternatives. Under guidance from TNC, ESSA was contracted with SAIC (Science Applications International Corporation) and more recently ICFI (ICF International), contractors to DWR, to provide upstream effects analyses on Sacramento River fisheries related to the BDCP. We provided SacEFT effects analyses of draft alternatives in the fall of 2012, restricted to upstream salmonid and green sturgeon impacts. BDCP consultants incorporated their interpretation of these results into the fall 2013 EIR/EIS which accompanies the BDCP studies.

Section 3.3 of this report provides the first complete effects analysis of selected BDCP alternatives for all SacEFT and DeltaEFT species and indicators.

3. **System Reoperation Program**
www.water.ca.gov/system_reop

DWR has requested TNC explore opportunities for how EFT may be used in DWR's System Reoperation Program. Authorized by the California legislature, the program directs DWR to conduct planning and feasibility studies to identify potential options for the reoperation of the state's flood protection and water supply systems that will optimize the use of existing facilities and groundwater storage capacity. Studies carried out during the reoperation program shall incorporate appropriate climate change scenarios and be designed to determine the potential to achieve the following objectives:

- water supply reliability;
- flood hazard reduction; and
- ecosystem protection and restoration.

These objectives will be achieved by:

- integrating flood protection and water supply systems;
- re-operating the existing system in conjunction with effective groundwater management; and
- improving existing water conveyance systems.

State Water Resources Control Board (SWRCB)

4. **Instream Flow Requirements and Delta Flow Criteria** [In progress]
www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows

At the request of the SWRCB, TNC staff made presentations throughout 2012 to SWRCB staff charged with creating in-stream flow requirements for a suite of streams in California, and supporting Delta Flow Criteria development and review.

The purpose of these presentations was to educate SWRCB staff about how EFT works and how it may help the SWRCB formulate flow criteria.

Chapter 3 also presents results of our initial pilot study of how to formulate and simplify instream flow requirements for consideration by the SWRCB and other parties.

U.S. Bureau of Reclamation

5. **Shasta Lake Water Resources Investigation** (SLWRI)
http://www.usbr.gov/mp/slwri/

SacEFT version 1 was applied to early versions of proposed operations related to raising Shasta Dam under the previous Flows Study (circa 2005) (see TNC *et al.* 2008). The SLWRI is proposing to increase the size of Shasta Lake and implement significant changes to the Sacramento and Delta flow regime. These changes could have significant positive and negative impacts to both Sacramento River and Delta dependent species and habitat forming processes.

6. **Central Valley Project/State Water Project Coordinated Operation Criteria, Biological Opinions (USFWS, NMFS), Remand**

In 2008, the U.S. Fish and Wildlife Service (USFWS) issued its Biological Opinion (BO) on the effects of the Coordinated Operation of the Central Valley Project (CVP) and State Water Project (SWP) in California. The USFWS BO concluded that as proposed, the coordinated operation of the CVP and SWP is likely to jeopardize the continued existence of Delta smelt and adversely modify Delta smelt critical habitat. The USFWS BO included a Reasonable and Prudent Alternative (RPA) designed to allow the projects to continue operating without causing jeopardy or adverse modification. On December 15, 2008 the Bureau of Reclamation provisionally accepted and then implemented the USFWS RPA. The National Marine Fisheries Service (NMFS) issued its final BO on the effects of the long-term operation of the CVP and SWP in June 2009. The NMFS BO concluded that the long-term operation of the CVP and SWP, as proposed, was likely to jeopardize the continued existence of listed salmonids, green sturgeon, and Southern resident killer whale (*Orcinus orca*), and destroy or adversely modify associated critical habitat. Some of the BO measures have subsequently been Remanded by the courts, and are the subject of ongoing review and negotiation.

EFT would provide directly relevant effects analysis support for the species covered by this type of investigation on the Sacramento River and Delta.

3.2 Effects Analysis Application of SacEFT to North-of-the-Delta Offstream Storage Investigation

3.2.1 Introduction

TNC and ESSA (2012) provided a SacEFT effects analysis evaluation of the *interim* North-of-the-Delta Offstream Storage (NODOS) Investigation prior to the detailed NODOS EIS/R and Feasibility Report. That report presented detailed modeling results on how a set of focal species associated with the Sacramento River may be impacted (negatively and positively) by the Investigation's alternatives. Information on other measures (rip rap removal and gravel augmentation) were also included.

The North-of-the-Delta Offstream Storage (NODOS) Investigation is evaluating potential offstream surface water storage by constructing Sites Reservoir near the Sacramento River, downstream from Shasta Dam and west of Maxwell California (Figure 3.1). The high-level NODOS objectives are to:

- improve water supply reliability for agricultural, urban, and environmental uses;
- improve drinking, agricultural and environmental water quality in the Delta;
- provide flexible hydropower generation to support integration of renewable energy sources; and
- increase survival of anadromous and endemic fish populations.

The proposed interim NODOS alternatives include a number of Ecosystem Enhancement Actions. Using SacEFT, we evaluated three *interim* study alternatives (Table 3.1) versus two reference cases (current conditions and an NAA alternative). Additional details on the study alternatives are summarized in TNC and ESSA (2012).

Table 3.1: Interim Plan Formulation Alternatives – NODOS Investigation. Details subject to change. Information provided by the NODOS investigation planning team, DWR (August 2011).

Alternative	A	B	C
Storage Capacity			
Sites Reservoir	1.27 MAF	1.81 MAF	1.81 MAF
Conveyance Capacities (to Sites Reservoir)[1]			
Tehama-Colusa Canal	2,100 cfs	2,100 cfs	2,100 cfs
Glenn Colusa Irrigation District Canal	1,800 cfs	1,800 cfs	1,800 cfs
New Delevan Pipeline[2] Diversion Release	 2,000 cfs 1,500 cfs	 0 cfs [3] 1,500 cfs	 2,000 cfs 1,500 cfs
Operations Priorities (Primary Planning Objectives)			
Long Term (all years)	EESA[4] Power[5]	EESA[4] Power[5]	EESA[4] Power[5]
Driest Periods (drought years)	M&I	M&I	M&I
Average to Wet Periods (non-drought years)	Water Quality Level 4 Refuge Agricultural	Water Quality Level 4 Refuge Agricultural	Water Quality Level 4 Refuge Agricultural

Notes:

1. Diversions through the TC Canal, Glenn-Colusa Irrigation District (GCID) Canal, and Delevan Pipeline are allowed in any month of the year.
2. New Delevan Pipeline can be operated June through March (April and May are reserved for maintenance).
3. A pump station, intake, and fish screens are not included for the Delevan Pipeline for Alternative B. For Alternative B, the Delevan Pipeline will be operated for releases only from Sites Reservoir to the Sacramento River year round.
4. Ecosystem Enhancement Storage Account (EESA) related operations are a function of specific conditions, and operating criteria that are defined uniquely for each action.
5. Includes dedicated pump/generation facilities with an additional dedicated after-bay/fore-bay (enlarged Funks Reservoir) used for managing conveyance of water between Sites Reservoir and river diversion locations.

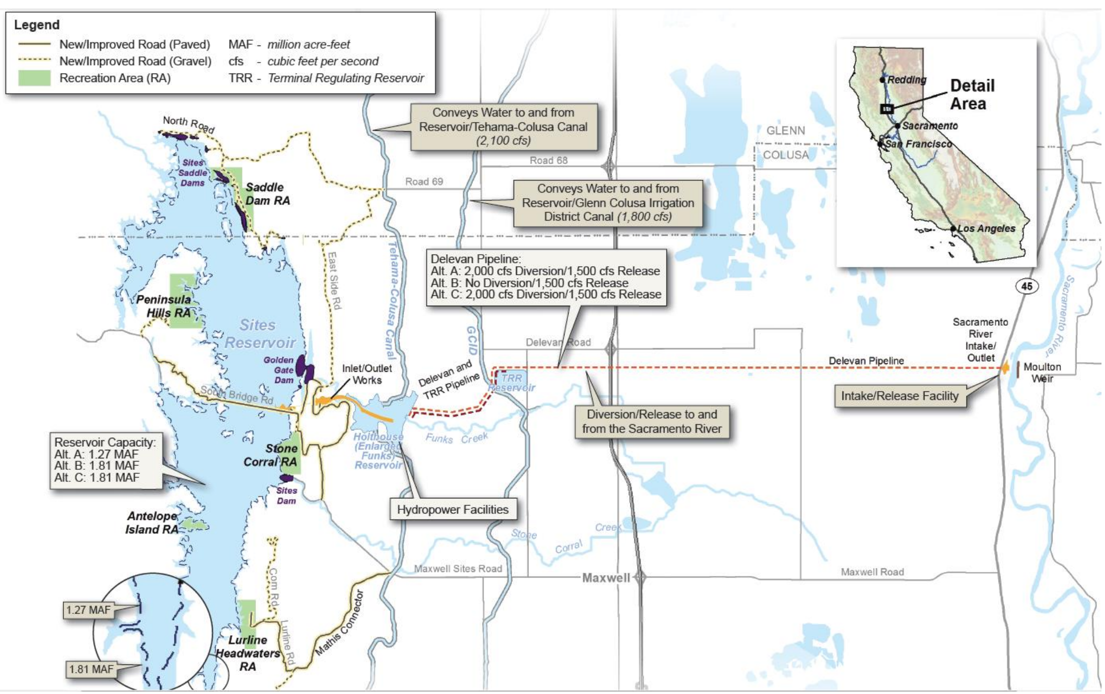
Key:

cfs = cubic feet per second
CVP = Central Valley Project
EESA = ecosystem enhancement storage account
MAF = million acre-feet
M&I = municipal and industrial
SWP = State Water Project
TAF = thousand acre-feet

Our NODOS ecological effects analysis was organized by species for the following eight comparisons:

Comparison	NODOS Alternative (SacEFT ID)	Compared to (SacEFT ID)
1	No Action Alternative (134)	Existing Conditions (132)
2	A (136)	Existing Conditions (132)
3	A (136)	No Action Alternative (134)
4	B (139)	Existing Conditions (132)
5	B (139)	No Action Alternative (134)
6	C (140)	Existing Conditions (132)
7	C (140)	No Action Alternative (134)
8 $^{\delta}$	No Action Alternative (134)	Historic conditions (118)

$^{\delta}$ Comparison 8 was not used in our report to assess NODOS effects. Instead, it provided a reference case for cumulative effects.



(b)

Figure 3.1: Artist's rendition of the Sites Reservoir location relative to the Sacramento River. This figure is for illustration purposes only and is not intended to represent the final or preferred Plan Alternative.

3.2.2 Summary of Findings

Relative to the existing conditions reference case, study comparisons #1, #2, #4 and #6 reveal mixed results depending on the species and performance indicator (PI) (see TNC and ESSA (2012) for details). In all cases, performance indicators relating to thermally modulated egg mortality (GS1, ST3, CH4) showed either no appreciable impact owing to any of the NODOS Investigation study alternatives (A, B, C) or a small beneficial impact. Relative to steelhead and Chinook salmon, green sturgeon eggs (GS1) received the largest benefits in terms of thermal egg mortality reduction.

Overall, steelhead appeared to be most favored by NODOS Alternative B (TNC and ESSA 2012). NODOS Alternative A favored fall Chinook, followed closely by NODOS Alternative B. Late fall-run Chinook are least impacted by NODOS Alternative B. Spring-run Chinook clearly encounter a higher proportion of favorable conditions under NODOS Alternative B. Acknowledging the downward performance of rearing WUA (CH2), winter-run Chinook experience the highest proportion of favorable conditions under NODOS Alternative C. NODOS Alternative A was the next most favorable for winter-run Chinook.

Overall, riparian focal species performance indicators (FC1, FC2, BASW2 and BASW1) appeared to see most benefit from NODOS Alternative C, followed by NODOS Alternative A (TNC and ESSA 2012).

For steelhead and winter-run Chinook, juvenile stranding changes (ST4/CH4) were inversely related relative to rearing WUA (ST2/CH2) (TNC and ESSA 2012). These effects are partially offsetting, but the exact outcome depends on the response of steelhead and winter-run Chinook to stage recession events (worse during day than at night) and on the survival benefits attributable to better rearing habitat conditions.

Table 3.2: Operation and conveyance effects are shown for different NODOS scenarios in the Sacramento River ecoregion using the change in the percentage of favorable years relative to existing conditions (RS method). Numbers in brackets refer to the increased percentage of simulation years having a favorable rating. **Results of these meander/erosion model dependent performance indicators are for the Sacramento River channel with existing revetment (no revetment removal).

Focal species	Performance indicator	Action Alternatives vs. Existing Conditions			
		NAA (comparison 1)	Alt A (comparison 2)	Alt B (comparison 4)	Alt C (comparison 6)
Fremont Cottonwood	Initiation success (FC1)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Post-initiation scour risk (FC2)	+ (+9)	++ (+20)	ni (+2)	++ (+25)
Bank Swallows	Habitat potential/suitability (BASW1)**	ni (+/-0)	- (-4)	- (-5)	ni (- 3)
	Peak flow during nesting period (BASW2)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
Western Pond Turtles	Large Woody Debris Recruitment (LWD)**	ni (-3)	ni (-3)	ni (-3)	ni (-3)
Green Sturgeon	Egg temperature preferences (GS1)	ni (+1)	+ (+6)	+ (+8)	+ (+8)
Steelhead	Spawning WUA (ST1)	ni (+/- 0)	ni (+2)	ni (+2)	ni (+2)
	Thermal egg mortality (ST3)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Redd Dewatering (ST6)	ni (+/-0)	+ (+5)	+ (+6)	+ (+5)
	Redd Scour (ST5)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (ST4)	ni (+/-0)	- (-6)	- (-4)	- (-7)
	Rearing WUA (ST2)	ni (-3)	+ (+5)	+ (+5)	+ (+5)
Fall Chinook	Spawning WUA (CH1)	ni (+2)	ni (-2)	ni (-2)	- (-5)
	Thermal egg mortality (CH3)	ni (+1)	ni (+3)	ni (+1)	ni (+3)
	Redd Dewatering (CH6)	ni (+/-0)	+ (+4)	ni (+2)	+ (+4)
	Redd Scour (CH5)	ni (+/-0)	ni (+/-0)	ni (-1)	ni (-1)
	Juvenile Stranding (CH4)	ni (+/-0)	ni (-3)	- (-4)	- (-4)
	Rearing WUA (CH2)	ni (+/-0)	+(+7)	+ (+7)	+ (+7)
Late Fall Chinook	Spawning WUA (CH1)	ni (+/-0)	ni (-3)	ni (-3)	ni (-3)
	Thermal egg mortality CH3)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Redd Dewatering (CH6)	ni (+/-0)	ni (+2)	ni (+3)	ni (+2)
	Redd Scour (CH5)	ni (+/-0)	ni (+2)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (CH4)	ni (-3)	- (-9)	- (-6)	- (-9)
	Rearing WUA (CH2)	ni (-1)	ni (+3)	+ (+5)	ni (+2)
Spring Chinook	Spawning WUA (CH1)	ni (+/-0)	ni (+3)	ni (+3)	ni (+2)
	Thermal egg mortality (CH3)	ni (-2)	ni (+3)	+ (+4)	ni (+3)

Focal species	Performance indicator	Action Alternatives vs. Existing Conditions			
		NAA (comparison 1)	Alt A (comparison 2)	Alt B (comparison 4)	Alt C (comparison 6)
	Redd Dewatering (CH6)	ni (-1)	++ (+11)	++ (+12)	+ (+9)
	Redd Scour (CH5)	ni (+2)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (CH4)	ni (-1)	ni (+2)	ni (+2)	ni (+2)
	Rearing WUA (CH2)	ni (+1)	- (-8)	- (-8)	- (-8)
Winter Chinook	Spawning WUA (CH1)	- (-5)	++ (+10)	+ (+9)	++ (+10)
	Thermal egg mortality (CH3)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+2)
	Redd Dewatering (CH6)	ni (-1)	+ (+4)	+ (+4)	+ (+4)
	Redd Scour (CH5)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (CH4)	+ (+4)	ni (+3)	ni (+3)	+ (+8)
	Rearing WUA (CH2)	- (-8)	- (-4)	- (-8)	- (-5)

Legend

++ strong beneficial impact owing to project alternative
+ small beneficial impact owing to project alternative
ni negligible detected impact owing to project alternative
- small negative impact owing to project alternative
-- strong negative impact owing to project alternative

Table 3.3: Operation and conveyance effects are shown for different NODOS scenarios in the Sacramento River ecoregion using the change in the percentage of favorable years relative to the No Action Alternative (RS method). Numbers in brackets refer to the increased percentage of simulation years having a favorable rating. **Results of these meander/erosion model dependent performance indicators are for the Sacramento River channel with existing revetment (no revetment removal).

Focal species	Performance indicator	Action Alternatives vs. No Action Alternative			
		Existing (comparison 1)	Alt A (comparison 3)	Alt B (comparison 5)	Alt C (comparison 7)
Fremont Cottonwood	Initiation success (FC1)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Post-initiation scour risk (FC2)	- (-9)	++ (+11)	- (-7)	++ (+16)
Bank Swallows	Habitat potential/suitability (BASW1)**	ni (+/-0)	- (-4)	- (-5)	ni (-3)
	Peak flow during nesting period (BASW2)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
Western Pond Turtles	Large Woody Debris Recruitment (LWD)**	ni (+3)	ni (+/-0)	ni (+/-0)	ni (+/-0)
Green Sturgeon	Egg temperature preferences (GS1)	ni (-1)	+ (+5)	+ (+7)	+ (+7)

Focal species	Performance indicator	Action Alternatives vs. No Action Alternative			
		Existing (comparison 1)	Alt A (comparison 3)	Alt B (comparison 5)	Alt C (comparison 7)
Steelhead	Spawning WUA (ST1)	ni (+/- 0)	ni (+2)	ni (+2)	ni (+2)
	Thermal egg mortality (ST3)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Redd Dewatering (ST6)	ni (+/-0)	+ (+5)	+ (+6)	+ (+5)
	Redd Scour (ST5)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (ST4)	ni (+/-0)	- (-6)	- (-4)	- (-7)
	Rearing WUA (ST2)	ni (+3)	+ (+8)	+ (+8)	+ (+8)
Fall Chinook	Spawning WUA (CH1)	ni (-2)	- (-4)	- (-4)	- (-7)
	Thermal egg mortality (CH3)	ni (-1)	ni (+2)	ni (+/-0)	ni (+2)
	Redd Dewatering (CH6)	ni (+/-0)	+ (+4)	ni (+2)	+ (+4)
	Redd Scour (CH5)	ni (+/-0)	ni (+/-0)	ni (-1)	ni (-1)
	Juvenile Stranding (CH4)	ni (+/-0)	ni (-3)	- (-4)	- (-4)
	Rearing WUA (CH2)	ni (+/-0)	+ (+7)	+ (+7)	+ (+7)
Late Fall Chinook	Spawning WUA (CH1)	ni (+/-0)	ni (-3)	ni (-3)	ni (-3)
	Thermal egg mortality (CH3)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Redd Dewatering (CH6)	ni (+/-0)	ni (+2)	ni (+3)	ni (+2)
	Redd Scour (CH5)	ni (+/-0)	ni (+2)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (CH4)	ni (+3)	- (-6)	ni (-3)	- (-6)
	Rearing WUA (CH2)	ni (+1)	+ (+4)	+ (+6)	ni (+3)
Spring Chinook	Spawning WUA (CH1)	ni (+/-0)	ni (+3)	ni (+3)	ni (+2)
	Thermal egg mortality (CH3)	ni (+2)	+ (+5)	+ (+6)	+ (+5)
	Redd Dewatering (CH6)	ni (+1)	++ (+12)	++ (+13)	++ (+10)
	Redd Scour (CH5)	ni (-2)	ni (-2)	ni (-2)	ni (-2)
	Juvenile Stranding (CH4)	ni (+1)	ni (+3)	ni (+3)	ni (+3)
	Rearing WUA (CH2)	ni (-1)	- (-9)	- (-9)	- (-9)
Winter Chinook	Spawning WUA (CH1)	+ (+5)	++ (+15)	++ (+14)	++ (+15)
	Thermal egg mortality (CH3)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+2)
	Redd Dewatering (CH6)	ni (-1)	+ (+5)	+ (+5)	+ (+5)
	Redd Scour (CH5)	ni (+/-0)	ni (+/-0)	ni (+/-0)	ni (+/-0)
	Juvenile Stranding (CH4)	- (-4)	ni (-1)	ni (-1)	+ (+4)
	Rearing WUA (CH2)	+ (+8)	+ (+4)	ni (+/-0)	ni (+3)

Legend

++	strong beneficial impact owing to project alternative
+	small beneficial impact owing to project alternative
ni	negligible detected impact owing to project alternative
-	small negative impact owing to project alternative
--	strong negative impact owing to project alternative

Overall

Overall, the rank order preferred NODOS action alternative (i.e., highest proportion of favored conditions / least impact across all performance indicators) by focal species group is provided in Table 3.4. Table 3.4 also illustrates that, as currently defined, none of the interim NODOS alternatives favor all SacEFT focal species.

Table 3.4: Rank order performance of interim NODOS alternatives by SacEFT focal species or group.

Focal Species (group)	Most favorable NODOS alternative	Next most favorable NODOS alternative
Riparian focal species	NODOS Alternative C	NODOS Alternative A
Green Sturgeon	No significant difference in performance amongst NODOS A, B or C	
Steelhead	NODOS Alternative B	n/a
Fall Chinook	NODOS Alternative A	n/a
Late Fall Chinook	NODOS Alternative B	n/a
Spring Chinook	NODOS Alternative B	
Winter Chinook	NODOS Alternative C	NODOS Alternative A

That no one alternative was beneficial for all focal species considered in SacEFT was not surprising, given that different species, and even different life stages of a given species, are responsive to different conditions and habitat attributes.

With respect to fisheries resources, we recommend that the detailed results presented in TNC and ESSA (2012) be considered in conjunction with the results from other modeling exercises (weight of evidence).

For terrestrial species, which are being given less consideration outside of SacEFT, we were concerned with Alternative B which, according to SacEFT, has the most negative impacts relative to Alternatives A and C. Alternative B, which does not include the construction of a pumping station and the Delevan Pipeline, is expected to adversely impact bank swallows and not yield the benefits to cottonwood that are found in Alternatives A and C.

These results suggest that from an ecosystem management standpoint, it is favorable to include a diversion point that is far downstream of the Glenn-Colusa Irrigation District (GCID) diversion. Doing so would allow water to be routed through a relatively longer reach of the Middle Sacramento River before being withdrawn for the new storage facility. Allowing water to remain in the river as long as possible before diverting it to the storage facility would enhance geomorphic processes such as bank erosion and sediment deposition, both of which are important for creating nesting cutbanks for swallows and appropriate recruitment sites for cottonwoods.

3.3 Effects Analysis Application of EFT to Selected Bay Delta Conservation Plan Scenarios

3.3.1 Introduction

The Bay Delta Conservation Plan (BDCP) is one of the largest Habitat Conservation Plans ever envisioned. In a letter addressed to the Deputy Secretary of the U.S. Department of Interior, BDCP was characterized as "...a multi-generational bulwark against climate change's impacts to the foundational water supply for 25 million people and three million acres of farmland." BDCP was developed to reconcile the co-equal goals of improving water supply reliability while ensuring recovery and protection of aquatic and riparian species, including endangered species permit requirements for operations of the Federal Central Valley Project (CVP) and the State Water Project (SWP). The Plan includes proposals for new points of diversion in the North Delta, new operations criteria, extensive floodplain and tidal marsh restoration, and new governance, oversight and some contemplation of adaptive management and related science programs. The Plan applicants are seeking Habitat Conservation Plan (HCP)/Natural Communities Conservation Plan (NCCP) permits that will guide water exports and habitat management for 50 years (BDCP 2013).

Once a vast marsh and floodplain with meandering channels and sloughs, the Delta did, and though diminished, still does, provide a vital migratory corridor and dynamic rearing habitat for a rich diversity of fish, wildlife, and plants. The Delta today is vastly altered by a system of manmade levees and dredged waterways constructed to support farming and urban development, and to provide flood protection for local towns and cities. The natural flows in the Delta have also been substantially altered by operation of the dams and diversions of the State Water Project (SWP) and Central Valley Project (CVP), which deliver water to millions of Californians. In certain portions of the Delta, fish are pulled toward and into the export pumps where they can become impinged, disoriented and trapped. In addition to flows, many other factors affect species productivity and resilience in the Delta, including: water quality issues (e.g., salinity, dissolved oxygen and toxic substances); an alarming array of nonnative species; hatchery management; overfishing; and complex interacting, non-stationary food webs, and related primary production and predation dynamics.

With so many unprecedented and relentless changes, California has struggled for several decades to balance competing demands for the Delta's resources. Several Delta species are now listed under state and federal laws to prevent extinction, and they have come to symbolize the estuary's compromised ecology. At stake are California's natural heritage and its water, food and economic security. In response to these challenges, the BDCP includes 67 goals and 165 objectives for 56 fish and terrestrial species, their habitats, and the Delta ecosystem. The BDCP goes on to detail 22 separate conservation measures intended to reverse the decline of the Delta's native fish, plant and wildlife species (BDCP 2013). To do so, nested within the SWP/CVP's acutely constrained regulatory environment, these measures include *attempts* to improve more ecologically functional flow patterns through the Delta, as well as measures for accelerated habitat restoration (30,000 acres of aquatic habitat over the next 15 years), including reconnecting floodplains and tidal habitats. BDCP documentation suggests that as conservation measures are being implemented and monitoring data become available, an adaptive management and coordinated science process will be used to inform whether adjustments to the conservation measures (including flow management) are necessary to improve their effectiveness. The initial analysis of these measures and associated alternatives and impacts to humans and the environment are described in a separate document – the Bay Delta Conservation Plan Environmental Impact Report/Environmental Impact Statement (BDCP 2013).

While portions of SacEFT were used as part of the larger upstream effects analysis of BDCP, this Chapter represents the first complete effects analysis using EFT (SacEFT and DeltaEFT) of selected BDCP alternatives. Rather than being limited to a few species and the relative suitability outputs of EFT, our BDCP effects analysis provides a deeper exploration using all EFT performance indicators and outputs to provide new insights about Sacramento River and Delta effects and trade-offs.

3.3.2 Reference Case & Alternative Scenarios

From among the numerous scenarios developed and assessed over the course of the BDCP EIS/R (Table 3.6), a subset of four scenarios emerged as leading candidates for future water conveyance, capacity, operation and habitat restoration. These four are the scenarios that have been used in our EFT effects analysis. Specifically, we evaluated the performance of: a No Action Alternative (NAA) with existing conveyance infrastructure; an Expected Starting Operation (ESO); a High Outflow Scenario (HOS) where the facilities are operated in a way that allows for occasional high spring and fall outflows; and a Low Outflow Scenario (LOS) with lower spring and fall outflows. Further details on these alternatives are described below in Table 3.6.

The effects analysis portion of BDCP is one of the most complex modeling efforts of its kind, and certainly the most complex ever attempted in the Delta. The basis for the BDCP analysis is hydrologic simulation modeling that provides flow, water elevations, temperature and salinity at various locations throughout the Delta and its upstream areas. All BDCP hydrosystem simulations are founded on the use of the CALSIM II model, disaggregating its monthly output into daily flow and temperature using the USRDOM and USRWQM models (see Section 2.6). The DSM2 model is used to simulate the hydrosystem-ocean system downstream of Sacramento, including Fremont Weir and Yolo Bypass. The HYDRO and QUAL modules of DSM2 provide flow and stage, and temperature and electroconductivity, respectively (Section 2.6). The simulations are based on a set of CALSIM and DSM2 input files provided by DWR and described in BDCP (2012b).

Currently, the preferred alternative is to construct a new point of diversion in the North Delta on the Sacramento River near Freeport, with the goal of completion in 2025. This diversion is to have three screened intakes that will divert water into forebays and a pair of 40 foot diameter tunnels (side by side, buried more than 150 feet below ground) capable of transmitting a maximum of 9,000 cfs by gravity feed. These tunnels will link to existing SWP and CVP export facilities located in the South Delta (Figure 3.2). The construction and combined operations of these facilities — typically referred to as dual facilities (new North Delta and existing South Delta export pumps) — are the foundation of the plan. In addition to more eco-friendly water operations, BDCP pairs construction of this infrastructure with extensive physical conservation measures to mitigate impacts of the project and recover and protect 'covered' species (e.g., Table 3.5). The primary difference among the BDCP alternatives is the timing and magnitude of pumping and releases. The BDCP calls for increasing exports in wet years and reducing them in dry years, taking advantage of the increased operational flexibility provided by two new points of diversion. If this operational approach were followed in real-world practice, this would reduce stress on Delta ecosystems during drier periods.

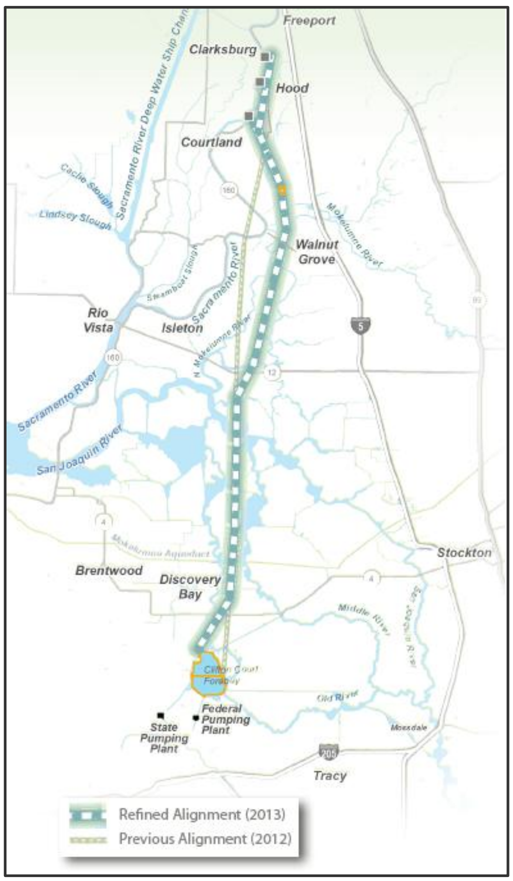


Figure 3.2: General map showing proposed (August 2013) North Delta point of diversion and new conveyance tunnels to State and Federal pumping plants in the South Delta [Source:http://baydeltaconservationplan.com/Libraries/Dynamic_Document_ Library/ Map_of_Proposed_BDCP_Changes_8-15-13.sflb.ashx].

The habitat restoration features shown below (Table 3.5) are common to all the BDCP alternatives, all of which are absent from the NAA simulations. These restoration activities are independent of the conveyance options and hydrosystem operation.

Table 3.5: Summary of BDCP physical restoration actions.

65,000 acres of restored freshwater and brackish tidal habitat within the BDCP Restoration Opportunity Areas
10,000 acres of seasonally inundated floodplain habitat within the North, East, and/or South Delta
20 linear miles of channel margin habitat enhancement in the Delta
5,000 acres of restored valley/foothill riparian habitat
2,000 acres of restored grassland and 8,000 acres of protected or enhanced grassland within BDCP Conservation Zones 1, 8, and/or 11
Restored vernal pool complex to achieve no net loss and 600 acres of protected vernal pool complex within Conservation Zones 1, 8, and/or 11
400 acres of restored non-tidal freshwater marsh within Conservation Zones 2 and 4
400 acres of protected alkali seasonal wetland complex in Conservation Zones 1, 8, and 11
17,000 – 33,000 acres of protected agricultural habitat areas

While EFT does consider restoration, flows and water temperatures in the Yolo Bypass, EFT does not address the potential benefits of other physical habitat restoration measures.

While a major feature carried forward in the BDCP alternatives is the voluminous current operational obligations (e.g., "Operate in accordance with State Water Board D-1641"), the BDCP alternatives do include some additional hydrosystem changes in some scenarios, which have significant potential for biological impacts. These include: the addition of a notch to Fremont Weir[17]; changes to the management of the Delta Cross Channel gate; changes to exports; and the inclusion of Fall X2 management (Table 3.6).

When present, Fall X2 management is intended to increase fall outflow, improving habitat for Delta smelt in wet years. BDCP operational changes also include criteria for: operation of Fremont Weir/Yolo Bypass; Delta inflow and outflow; Delta Cross Channel gate operations; Rio Vista minimum instream flows; and Delta water quality and residence time. Specific details are only documented directly in CALSIM II WRESL files and cannot be ascertained from the publically available BDCP documentation.

The BDCP scenarios attempt to account for and isolate the effect of future climate and anticipated levels of development and water demand by simulating two sets of plausible future conditions. The first snapshot-in-time is “Early Long Term” (ELT), which represents

[17] Fremont Weir is notched in some scenarios to provide a more consistent water supply at the southern end of Yolo Bypass, improving habitat for splittail.

an ensemble-forecast (BDCP 2012a) future climate around the year 2025, at which time a substantial number of habitat restoration activities will have taken place and a new dual conveyance system will be in operation. The second snapshot-in-time is “Late Long Term” (LLT), which represents an ensemble-forecast future climate around the year 2060, along with full implementation and operation of the BDCP conservation strategy. Both the ELT and LLT projections include the effect of climate change in seasonal hydrology (amount and timing of runoff), changes to seasonal air temperature, and increase in sea level.

To provide a reference case against which the BDCP simulations can be compared, three “No Action Alternative” (NAA) simulations are used. The NAA alternatives (for different time periods) represent water conveyance and operation without the addition of a new conveyance system or restoration. NAA-Current represents near-present (2015) conditions, while the NAA-ELT and NAA-LLT scenarios represent conditions around 2025 and 2060, respectively, including climate change and sea level rise. By comparing the NAA simulations with the action alternatives (ESO, HOS and LOS), it is possible to identify changes due solely to climate/sea level and those due to the operational features of the action alternative.

The key features of the BDCP alternatives and NAA simulations are listed below (Table 3.6). As noted above, all BDCP scenarios share the same habitat remediation measures to reduce other stressors. Each action alternative also includes operational criteria for water supply infrastructure, habitat conservation components, and measures to reduce the impact of other stressors on other species. Outside of water exports and habitat conditions, stressors that are considered by the larger BDCP EIS/R (but are not considered by EFT) include exposure to contaminants, competition, predation and changes to the ecosystem and food web caused by non-native species.

Table 3.6: Summary of reference case (NAA: No Action Alternative) scenario and three BDCP action alternatives (ESO: Expected Starting Operations; LOS: Low Output Spring; HOS: High Output Spring). Three time periods are present in combination with the scenarios: Current (2015), Early Long Term (ELT, 2025) and Late Long Term (LLT, 2060).

Name	Conveyance modifications	Level of human demand	Climate change	Major operational features
NAA-Current = No Action Alternative = EBC2	Current hydrosystem: no changes to size/number of dams, capability of Delta pumps, gates. Fremont Weir **NOT** notched.	Current (2015) demand	Current climate (2015), inflows and sea level conditions	The BDCP reference case for the hydrosystem without changes to conveyance or habitat; habit conservation components described above not present. **No High Spring X2 outflow** **No High Fall X2 outflow**
NAA-ELT		**2025** projected level of development and demand	Future climate centered on ensemble prediction for **2025** period; 15 cm mean sea level rise	Operations based on State Water Board D-1641, USFWS (2008), NMFS (2009) **No High Spring X2 outflow** **High Fall X2 outflow**
NAA-LLT		**2060** projected level of development and demand	Future climate centered on ensemble prediction for **2060** period; 45 cm mean sea level rise	
ESO-ELT = Expected Starting Operations = H3 = Alt 4	9,000 cfs via three intakes of 3,000 cfs each between Clarksburg and Walnut Grove in the North Delta, feeding two 40-ft diameter gravity fed tunnels buried more than 150ft below ground, and running approx. 30 miles to South Delta pumps.	**2025** projected demand	Future climate centered on ensemble prediction for **2025** period; 15 cm mean sea level rise	Operations based on State Water Board D-1641, USFWS (2008), NMFS (2009) New intake facility operational Restoration actions not fully implemented **No High Spring X2 outflow** **High Fall X2 outflow**
ESO-LLT = Expected Starting Operations = H3 = Alt 4		**2060** projected demand	Future climate centered on ensemble prediction for **2060** period; 45 cm mean sea level rise	

<table>
<tr><th>Name</th><th>Conveyance modifications</th><th>Level of human demand</th><th>Climate change</th><th>Major operational features</th></tr>
<tr><td>LOS-ELT
= Low Output Spring
= H1</td><td rowspan="2">Fremont Weir modified (notched). Currently flow onto the Yolo Bypass only occurs when the Verona gauge exceeds 55,000 cfs. Modifications to the Fremont Weir would allow 1,000 cfs to flow onto the floodplain when flow at Verona exceeds 25,000 cfs. Flow through the Weir would climb to 6,000 cfs when the river approaches 55,000 cfs.</td><td>2025 projected demand</td><td>Future climate centered on ensemble prediction for 2025 period; 15 cm mean sea level rise</td><td>Operations based on State Water Board D-1641, USFWS (2008), NMFS (2009)

New intake facility operational

Restoration actions not fully implemented

No High Spring X2 outflow
No High Fall X2 outflow</td></tr>
<tr><td>HOS-ELT
= High Output Spring
= H4</td><td>2025 projected</td><td>Future climate centered on ensemble prediction for 2025 period; 15 cm mean sea level rise</td><td>Operations based on State Water Board D-1641, USFWS (2008), NMFS (2009)

New intake facility operational

Restoration actions not fully implemented

High Spring X2 outflow
High Fall X2 outflow</td></tr>
</table>

What may not be clear from the short descriptions of these alternatives is that upstream reservoir operations and Delta export operations are highly constrained by a myriad of upstream and downstream consumptive uses and related flow and water quality regulations. These constraints significantly reduce the operational flexibility of the dual facilities, greatly limiting the degree of contrast in the simulated results for these BDCP scenarios, which reduces contrast in the EFT effects analysis results. The current regulatory and infrastructure constraints on operations limit the ability of BDCP to fully explore compatible options for meeting the co-equal export and ecosystem objectives. The action alternatives admitted into the BDCP analysis represent a fraction of the solution space that is truly available to realize objectives.

3.3.3 BDCP Results and Discussion

Presenting EFT findings requires describing results for two ecoregions (Sacramento River and Delta), 13 species, 25 performance indicators, multiple driving physical datasets and the emergent synthesis of alternatives given by two companion methods (RS, ES methods). Given the breadth of results, we organize EFT effects analysis outcomes in the following structured order:

1. First, we look at the **degree of physical change** amongst alternative scenarios being evaluated (median changes in flow, water temperatures, salinity at select index locations).
2. Next, we present high level effect roll-ups based on the **Relative Suitability (RS) synthesis** methodology (see Section 2.7.2), which compares changes in the proportion of favorable years amongst alternatives.
3. Third, we perform a companion synthesis where the raw (no suitability scoring assigned) multi-year median values are compared amongst alternatives (termed **Effect Size (ES)** results, see Section 2.7.5). Correspondence between the RS and ES methods adds additional confidence in conclusions beyond the signal from either method alone.
4. Finally, we conclude with a **species net effect summary**, looking at the number of performance indicators that surpass our chosen thresholds for meaningful change (either a ±10% change in count of favorable values for RS, or a ±5% change in median values for the ES synthesis method). This is a preliminary step leading to the overall Net Effect Score (NES) for each species. NES addresses uncertainty in the overall assessment, including the challenge of integrating multiple independent attributes (indicators) for single species. The NES is based on a consistent logic that considers the weight of evidence provided by the RS and ES methods, penalizing discrepancies when the two major effects analysis methods differ.

Physical Changes among Alternative Scenarios

The material in this section summarizes key flow, water temperature and salinity changes associated with the selected BDCP alternatives. We first establish the general nature of these physical changes prior to venturing into biological interpretation.

Sacramento River

Flow

For the early long-term (2025) alternatives, Table 3.7 shows median May and June flows are higher under LOS-ELT alternative and lower in November relative to the NAA-ELT reference scenario. All three alternatives (ESO-ELT, LOS-ELT and HOS-ELT) generate lower median flows in September and November relative to NAA-ELT.

Table 3.7: Flow values at Keswick and Hamilton City are shown for selected BDCP scenarios at the Early Long Term (ELT) future climate period. [δ]

Month	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Flow - Keswick				
January	4,226	4,120 (-2.5%)	4,383 (3.7%)	4,097 (-3.0%)
February	4,151	4,294 (3.4%)	4,181 (0.7%)	3,985 (-4.0%)
March	4,379	4,442 (1.4%)	4,380 (0.0%)	4,391 (0.3%)
April	5,465	5,512 (0.9%)	5,639 (3.2%)	5,446 (-0.3%)
May	7,082	7,310 (3.2%)	7,474 (5.5%)	7,173 (1.3%)
June	10,502	11,031 (5.0%)	11,070 (5.4%)	10,503 (0.0%)
July	13,810	14,081 (2.0%)	14,144 (2.4%)	13,861 (0.4%)
August	10,139	10,015 (-1.2%)	9,922 (-2.1%)	10,482 (3.4%)
September	7,017	6,182 (-11.9%)	6,202 (-11.6%)	6,103 (-13.0%)
October	5,936	5,858 (-1.3%)	5,976 (0.7%)	6,115 (3.0%)
November	5,420	4,549 (-16.1%)	4,468 (-17.6%)	4,597 (-15.2%)
December	4,025	4,060 (0.9%)	4,139 (2.8%)	3,980 (-1.1%)

Month	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Flow - Hamilton City				
January	9,950	10,362 (4.1%)	10,628 (6.8%)	10,131 (1.8%)
February	12,602	12,662 (0.5%)	12,755 (1.2%)	12,545 (-0.5%)
March	10,716	10,903 (1.7%)	10,969 (2.4%)	10,775 (0.5%)
April	6,348	6,356 (0.1%)	6,475 (2.0%)	6,402 (0.8%)
May	6,645	6,948 (4.6%)	7,031 (5.8%)	6,699 (0.8%)
June	7,931	8,302 (4.7%)	8,356 (5.4%)	7,949 (0.2%)
July	10,455	10,604 (1.4%)	10,503 (0.5%)	10,203 (-2.4%)
August	7,626	7,501 (-1.6%)	7,432 (-2.5%)	7,834 (2.7%)
September	6,880	5,971 (-13.2%)	6,036 (-12.3%)	5,923 (-13.9%)
October	5,926	5,862 (-1.1%)	6,022 (1.6%)	6,149 (3.8%)
November	7,079	5,852 (-17.3%)	5,512 (-22.1%)	5,860 (-17.2%)
December	6,858	6,628 (-3.4%)	7,034 (2.6%)	6,703 (-2.3%)

[δ] The **NAA-ELT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

For the late long-term (2060s) climate change period, median flow is higher April - June and reduced in August and November under the ESO-LLT scenario relative to NAA-LLT (Table 3.8).

Table 3.8: Flow values at Keswick and Hamilton City are shown for selected BDCP scenarios at the Late Long Term (LLT) future climate period. [δ]

Month	NAA-LLT Reference case (243)	ESO-LLT (243)
Keswick		
January	4,219	4,281 (1.5%)
February	4,059	4,199 (3.5%)
March	4,347	4,445 (2.2%)
April	5,493	5,710 (4.0%)
May	6,820	7,479 (9.7%)
June	10,994	12,126 (10.3%)
July	14,236	13,988 (-1.7%)
August	10,521	9,872 (-6.2%)
September	6,737	7,069 (4.9%)
October	6,521	6,586 (1.0%)
November	5,071	4,588 (-9.5%)
December	3,939	4,047 (2.8%)

Month	NAA-LLT Reference case (243)	ESO-LLT (243)
Hamilton City		
January	10,176	10,003 (-1.7%)
February	12,519	12,673 (1.2%)
March	10,654	10,812 (1.5%)
April	6,414	6,807 (6.1%)
May	6,796	7,619 (12.1%)
June	8,496	9,407 (10.7%)
July	10,940	10,682 (-2.4%)
August	8,080	7,373 (-8.8%)
September	6,623	6,951 (5.0%)
October	6,580	6,520 (-0.9%)
November	7,181	5,846 (-18.6%)
December	6,772	6,844 (1.1%)

[δ] The **NAA-LLT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Table 3.9 most clearly shows the expected change in median flow associated with climate change. With NAA-Current as the reference case, there is a progressive reduction in median flows February to May, with increased flows June to November (exclusive of August) as one moves from the early long term to late long term.

Table 3.9: Flow values at Keswick and Hamilton City are shown for three future climate and demand scenarios. δ

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Flow - Keswick			
January	4,190	4,226 (0.9%)	4,219 (0.7%)
February	4,323	4,151 (-4.0%)	4,059 (-6.1%)
March	4,312	4,379 (1.5%)	4,347 (0.8%)
April	5,956	5,465 (-8.3%)	5,493 (-7.8%)
May	7,648	7,082 (-7.4%)	6,820 (-10.8%)
June	10,415	10,502 (0.8%)	10,994 (5.6%)
July	13,061	13,810 (5.7%)	14,236 (9.0%)
August	10,476	10,139 (-3.2%)	10,521 (0.4%)
September	6,040	7,017 (16.2%)	6,737 (11.5%)
October	6,043	5,936 (-1.8%)	6,521 (7.9%)
November	5,009	5,420 (8.2%)	5,071 (1.2%)
December	4,274	4,025 (-5.8%)	3,939 (-7.9%)

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Flow - Hamilton City			
January	9,917	9,950 (0.3%)	10,176 (2.6%)
February	12,655	12,602 (-0.4%)	12,519 (-1.1%)
March	11,063	10,716 (-3.1%)	10,654 (-3.7%)
April	6,556	6,348 (-3.2%)	6,414 (-2.2%)
May	6,749	6,645 (-1.5%)	6,796 (0.7%)
June	7,857	7,931 (0.9%)	8,496 (8.1%)
July	9,533	10,455 (9.7%)	10,940 (14.8%)
August	7,901	7,626 (-3.5%)	8,080 (2.3%)
September	5,831	6,880 (18.0%)	6,623 (13.6%)
October	5,970	5,926 (-0.7%)	6,580 (10.2%)
November	6,047	7,079 (17.1%)	7,181 (18.8%)
December	7,005	6,858 (-2.1%)	6,772 (-3.3%)

δ The **NAA-Current** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

The Cumulative Excess Streampower, defined as the sum of flows above a threshold of 425 cms at Hamilton City and strongly correlated with river meander migration, is relatively similar between the BDCP scenarios at approximately 2.5 million cms (Table 3.10). Counterintuitively, the Cumulative Excess Streampower increases in the Early and Late Long Term future climate period by 4.9% and 8.9% respectively.

Table 3.10: Excess Cumulative Streampower at Hamilton City (Cumulative Excess Streampower is defined as the sum of flows above a threshold of 425 cms).

	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Excess Cumulative Streampower				
Total	2,515,800	2,550,698 (1.4%)	2,579,698 (2.5%)	2,543,941 (1.1%)

	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)	
Excess Cumulative Streampower				
Total	2,399,198	2,515,800 (4.9%)	2,612,365 (8.9%)	

Water Temperature

For the early long-term (2025) alternatives, and using NAA-ELT as the reference case, simulated median water temperatures are expected to remain relatively constant between project alternatives, with a maximum difference between the BDCP alternative and NAA-ELT of approximately 3% for both the Keswick and Hamilton City locations. The maximum difference between ESO-LLT and NAA-LLT in the Late Long Term future climate period is approximately 2% for both the Keswick and Hamilton City locations.

Relative to near current conditions (NAA-current reference case), median water temperatures become progressively warmer in all months, especially August to February (Table 3.11). The predicted maximum median increase in temperature is 1.6°C (12.9%) in October.

Table 3.11: Water temperature values (degrees C) at Keswick and Hamilton City are shown for three future climate and demand scenarios.[δ]

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Temperature - Keswick			
January	7.9	8.3 (4.5%)	8.8 (10.4%)
February	7.6	8.1 (6.0%)	8.5 (12.0%)
March	8.2	8.6 (5.2%)	9.1 (11.3%)
April	8.9	9.4 (4.9%)	9.9 (10.3%)
May	9.5	10.0 (5.2%)	10.4 (9.3%)
June	10.0	10.3 (3.1%)	10.6 (6.0%)
July	10.5	10.8 (2.8%)	11.4 (8.5%)
August	11.2	11.8 (5.9%)	12.6 (12.4%)
September	12.3	12.8 (4.5%)	13.6 (11.0%)
October	12.2	13.0 (6.4%)	13.8 (12.9%)
November	11.6	12.2 (5.3%)	12.9 (11.2%)
December	9.9	10.3 (3.8%)	10.8 (9.4%)

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Temperature - Hamilton City			
January	7.0	7.5 (7.0%)	8.0 (15.1%)
February	8.2	8.7 (6.7%)	9.2 (12.6%)
March	10.3	10.7 (4.3%)	11.3 (9.8%)
April	12.9	13.4 (3.8%)	14.0 (8.6%)
May	15.0	16.0 (6.3%)	16.4 (9.2%)
June	15.9	16.5 (4.0%)	17.0 (7.0%)
July	16.4	16.8 (2.7%)	17.5 (6.5%)
August	16.7	17.6 (5.2%)	18.4 (10.3%)
September	16.4	16.9 (3.0%)	17.9 (9.0%)
October	13.3	14.1 (6.3%)	14.8 (11.8%)
November	10.2	10.9 (6.9%)	11.6 (13.6%)
December	7.6	8.0 (5.9%)	8.6 (13.9%)

[δ] The **NAA-Current** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

San Joaquin-Sacramento Delta

Flow

For the early long-term (2025) alternatives, median flows are generally higher October to January and June (except LOS-ELT in November, which shows a *reduction* in flow at Mallard Island), and lower in July and August (Table 3.12). ESO-ELT and LOS-ELT produce lower March to May flows (Table 3.12). Median flow at Old and Middle River is more positive for all BDCP scenarios relative to the NAA-ELT in all months except April and May (Table 3.12).

These patterns are generally preserved when comparing ESO-LLT relative to the NAA-LLT (Table 3.13).

Table 3.12: Flow values at Mallard Island and Old and Middle River are shown for selected BDCP scenarios at the Early Long Term (ELT) future climate period. δ

Mon	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Flow - Mallard Island				
Jan	16,617	17,771 (6.9%)	18,649 (12.2%)	18,672 (12.4%)
Feb	19,449	19,718 (1.4%)	19,783 (1.7%)	19,817 (1.9%)
Mar	29,135	27,564 (-5.4%)	27,837 (-4.5%)	27,864 (-4.4%)
Apr	15,904	14,791 (-7.0%)	14,791 (-7.0%)	16,220 (2.0%)
May	11,719	10,833 (-7.6%)	10,841 (-7.5%)	12,068 (3.0%)
Jun	7,638	8,164 (6.9%)	8,281 (8.4%)	8,072 (5.7%)
Jul	7,176	5,864 (-18.3%)	6,046 (-15.8%)	5,705 (-20.5%)
Aug	4,024	3,401 (-15.5%)	3,440 (-14.5%)	3,395 (-15.6%)
Sep	8,752	8,648 (-1.2%)	3,668 (-58.1%)	8,731 (-0.2%)
Oct	3,668	6,736 (83.6%)	6,595 (79.8%)	6,499 (77.2%)
Nov	8,316	9,957 (19.7%)	7,627 (-8.3%)	9,848 (18.4%)
Dec	7,295	9,668 (32.5%)	9,895 (35.6%)	9,496 (30.2%)

Mon	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Flow - Old and Middle River				
Jan	-3,779	-1,709 (54.8%)	-1,888 (50.0%)	-1,441 (61.9%)
Feb	-3,314	-1,930 (41.8%)	-1,796 (45.8%)	-1,824 (45.0%)
Mar	-1,997	-861 (56.9%)	-836 (58.1%)	-671 (66.4%)
Apr	189	-550 (-390.3%)	-667 (-452.1%)	-311 (-264.1%)
May	-394	-862 (-119.0%)	-862 (-118.9%)	-564 (-43.3%)
Jun	-3,339	-2,103 (37.0%)	-2,096 (37.2%)	-1,660 (50.3%)
Jul	-9,618	-7,462 (22.4%)	-7,279 (24.3%)	-4,482 (53.4%)
Au	-9,314	-4,160 (55.3%)	-4,052 (56.5%)	-4,503 (51.7%)
Sep	-6,711	-3,612 (46.2%)	-4,607 (31.3%)	-3,387 (49.5%)
Oct	-5,294	-2,148 (59.4%)	-2,359 (55.4%)	-2,090 (60.5%)
Nov	-4,923	-3,445 (30.0%)	-4,541 (7.8%)	-3,265 (33.7%)
Dec	-6,562	-5,168 (21.2%)	-5,091 (22.4%)	-5,072 (22.7%)

δ The **NAA-ELT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Table 3.13: Flow values at Mallard Island and Old and Middle River are shown for selected BDCP scenarios at the Late Long Term (LLT) future climate period. [δ]

Month	NAA-LLT Reference case (243)	ESO-LLT (243)
Mallard Island		
January	17,359	18,238 (5.1%)
February	19,858	19,954 (0.5%)
March	29,511	26,743 (-9.4%)
April	15,793	14,587 (-7.6%)
May	11,479	10,853 (-5.5%)
June	8,003	7,635 (-4.6%)
July	8,540	5,904 (-30.9%)
August	4,191	2,916 (-30.4%)
September	9,102	9,802 (7.7%)
October	5,640	7,516 (33.3%)
November	7,986	9,410 (17.8%)
December	8,255	9,717 (17.7%)

Month	NAA-LLT Reference case (243)	ESO-LLT (243)
Old and Middle River		
January	-3,678	-2,293 (37.7%)
February	-3,264	-1,972 (39.6%)
March	-2,174	-1,276 (41.3%)
April	-672	-1,003 (-49.3%)
May	-1,026	-1,404 (-36.8%)
June	-3,191	-2,382 (25.4%)
July	-7,504	-4,728 (37.0%)
August	-7,539	-3,904 (48.2%)
September	-4,978	-2,003 (59.8%)
October	-4,178	-1,952 (53.3%)
November	-4,418	-2,963 (32.9%)
December	-5,574	-4,098 (26.5%)

[δ] The **NAA-LLT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Table 3.14 shows the expected change in median flow associated with climate change. Monthly median patterns are less coherent, with the exception of increasing flows September to November, and a tendency for decreased flows February to June and August.

Table 3.14: Flow values at Mallard Island and Old and Middle River are shown for three future climate and demand scenarios. [δ]

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Flow - Mallard Island			
January	16,281	16,617 (2.1%)	17,359 (6.6%)
February	20,170	19,449 (-3.6%)	19,858 (-1.6%)
March	31,947	29,135 (-8.8%)	29,511 (-7.6%)
April	16,104	15,904 (-1.2%)	15,793 (-1.9%)
May	11,819	11,719 (-0.8%)	11,479 (-2.9%)
June	8,703	7,638 (-12.2%)	8,003 (-8.0%)
July	6,217	7,176 (15.4%)	8,540 (37.4%)
August	4,725	4,024 (-14.8%)	4,191 (-11.3%)
September	5,637	8,752 (55.3%)	9,102 (61.5%)
October	3,198	3,668 (14.7%)	5,640 (76.3%)
November	6,253	8,316 (33.0%)	7,986 (27.7%)
December	7,442	7,295 (-2.0%)	8,255 (10.9%)

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Flow - Old and Middle River			
January	-3,897	-3,779 (3.0%)	-3,678 (5.6%)
February	-3,156	-3,314 (-5.0%)	-3,264 (-3.4%)
March	-2,239	-1,997 (10.8%)	-2,174 (2.9%)
April	-518	189 (136.5%)	-672 (-29.6%)
May	-910	-394 (56.7%)	-1,026 (-12.7%)
June	-3,358	-3,339 (0.6%)	-3,191 (5.0%)
July	-8,912	-9,618 (-7.9%)	-7,504 (15.8%)
August	-7,425	-9,314 (-25.4%)	-7,539 (-1.5%)
September	-6,485	-6,711 (-3.5%)	-4,978 (23.2%)
October	-6,380	-5,294 (17.0%)	-4,178 (34.5%)
November	-5,923	-4,923 (16.9%)	-4,418 (25.4%)
December	-5,601	-6,562 (-17.2%)	-5,574 (0.5%)

[δ] The **NAA-Current** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Water Temperature

For the Early Long Term (2025) alternatives, and using NAA-ELT as the reference case, simulated median water temperatures are expected to remain relatively constant between project alternatives with differences between the BDCP alternative and NAA being 0.5°C or less for both the Port Chicago and Terminous locations for both the ELT and LLT future climate periods.

Moving from the Early Long Term to the Late Long Term, median water temperatures become progressively warmer, especially September to May (Table 3.15). Median water temperatures show the least change (though still warmer) June to August (Table 3.15).

Table 3.15: Water temperature values (degrees C) at Port Chicago and Terminous are shown for three future Climate and Demand scenarios. δ

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Temperature - Port Chicago			
January	9.2	9.4 (2.0%)	9.9 (6.8%)
February	10.8	11.2 (3.4%)	11.4 (5.6%)
March	13.2	13.5 (2.3%)	13.9 (4.7%)
April	14.9	15.5 (4.3%)	15.7 (5.6%)
May	17.3	17.9 (3.5%)	18.1 (4.6%)
June	19.4	19.8 (2.4%)	20.1 (3.6%)
July	20.6	21.1 (2.2%)	21.4 (3.5%)
August	20.5	20.9 (1.9%)	21.2 (3.5%)
September	19.6	19.9 (1.2%)	20.5 (4.3%)
October	17.5	17.9 (2.1%)	18.2 (4.2%)
November	14.6	14.8 (1.3%)	15.2 (3.8%)
December	10.5	10.9 (3.3%)	11.2 (6.5%)

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Temperature - Terminous			
January	9.8	10.3 (5.0%)	10.5 (7.4%)
February	11.6	11.9 (3.2%)	12.1 (4.4%)
March	13.8	14.1 (2.5%)	14.5 (5.5%)
April	14.9	15.7 (5.4%)	16.0 (7.2%)
May	17.5	18.3 (4.3%)	18.5 (5.5%)
June	19.7	20.2 (2.7%)	20.6 (4.4%)
July	21.2	21.9 (2.9%)	22.3 (4.8%)
August	21.0	21.5 (2.2%)	22.0 (4.7%)
September	19.8	20.2 (1.9%)	20.9 (5.5%)
October	17.2	17.9 (4.2%)	18.3 (6.8%)
November	14.1	14.4 (2.1%)	15.1 (6.6%)
December	10.3	10.6 (3.4%)	11.2 (9.6%)

δ The **NAA-Current** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Salinity

Median salinity (measured as EC) at Collinsville (Table 3.16) is lower under the ESO-ELT scenario relative to the NAA-ELT in January, July, and October to December, and higher in February to May. Median salinity is lower under the LOS-ELT scenario relative to the NAA-ELT in January, July and October, and higher in February to May, September and November to December. Median salinity is lower under the HOS-ELT scenario relative to the NAA-ELT in January, May, and October to December, and higher in February to April and July to August.

The difference between BDCP scenarios is that median salinity is lower in May and higher in July for the HOS-ELT scenario than the other two alternatives, and salinity is higher in September, November and December for the LOS-ELT scenario than the other two alternatives.

Median salinity (measured as EC) at Port Chicago (Table 3.16) is lower under the ESO-ELT scenario relative to the NAA-ELT in January and October to December, and higher in February to April. Median salinity is lower under the LOS-ELT scenario relative to the NAA-ELT in January and October, and higher in February to April and November to December. Median salinity is lower under the HOS-ELT scenario relative to the NAA-ELT in January and October to December, and higher in February and March.

The difference between BDCP scenarios is that median salinity is higher in March and lower in April for the HOS-ELT scenario than the other two alternatives, and salinity is higher in November and December for the LOS-ELT scenario than the other two alternatives.

Table 3.16: EC (a proxy for salinity) values at Collinsville and Port Chicago are shown for selected BDCP scenarios at the Early Long Term (ELT) future climate period. δ

Mon	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
EC - Collinsville				
Jan	2,325	1,292 (-44.4%)	1,359 (-41.5%)	1,306 (-43.8%)
Feb	523	569 (8.9%)	592 (13.3%)	563 (7.7%)
Mar	223	269 (20.3%)	272 (21.6%)	279 (24.7%)
Apr	419	504 (20.2%)	505 (20.4%)	450 (7.4%)
May	1,090	1,267 (16.2%)	1,260 (15.6%)	973 (-10.7%)
Jun	2,838	2,715 (-4.3%)	2,741 (-3.4%)	2,703 (-4.7%)
Jul	4,342	3,979 (-8.4%)	3,992 (-8.1%)	4,617 (6.3%)
Aug	5,878	6,159 (4.8%)	6,065 (3.2%)	6,273 (6.7%)
Sep	7,822	8,185 (4.6%)	8,832 (12.9%)	8,213 (5.0%)
Oct	8,501	5,133 (-39.6%)	6,129 (-27.9%)	5,113 (-39.9%)
Nov	5,343	4,479 (-16.2%)	6,353 (18.9%)	4,541 (-15.0%)
Dec	3,972	3,456 (-13.0%)	5,434 (36.8%)	3,404 (-14.3%)

Mon	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
EC - Port Chicago				
Jan	9,525	7,978 (-16.2%)	8,086 (-15.1%)	7,945 (-16.6%)
Feb	3,910	4,354 (11.4%)	4,418 (13.0%)	4,343 (11.1%)
Mar	1,947	2,148 (10.3%)	2,216 (13.8%)	2,437 (25.1%)
Apr	4,000	4,630 (15.7%)	4,601 (15.0%)	4,137 (3.4%)
May	6,990	7,244 (3.6%)	7,174 (2.6%)	6,680 (-4.4%)
Jun	10,873	10,435 (-4.0%)	10,380 (-4.5%)	10,395 (-4.4%)
Jul	12,982	12,700 (-2.2%)	12,748 (-1.8%)	13,194 (1.6%)
Aug	15,154	15,257 (0.7%)	15,162 (0.1%)	15,402 (1.6%)
Sep	17,075	17,293 (1.3%)	17,609 (3.1%)	17,334 (1.5%)
Oct	17,480	14,402 (-17.6%)	15,536 (-11.1%)	14,614 (-16.4%)
Nov	13,732	12,094 (-11.9%)	15,314 (11.5%)	12,037 (-12.3%)
Dec	13,092	12,208 (-6.8%)	14,823 (13.2%)	12,074 (-7.8%)

δ The **NAA-ELT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Median salinity (measured as EC) at Collinsville (Table 3.17) is lower under the ESO-LLT scenario relative to the NAA-LLT in January and September to December, and higher in March to August. Median salinity at Port Chicago is lower under the ESO-LLT scenario relative to the NAA-LLT in January and October to December, and higher in February to April and August.

Table 3.17: EC (a proxy for salinity) values at Collinsville and Port Chicago are shown for selected BDCP scenarios at the Late Long Term (LLT) future climate period. [δ]

Month	NAA-LLT Reference case (243)	ESO-LLT (243)
EC - Collinsville		
January	2,422	1,358 (-43.9%)
February	633	660 (4.3%)
March	238	310 (30.4%)
April	504	640 (26.9%)
May	1,694	1,789 (5.6%)
June	2,822	3,091 (9.5%)
July	3,569	4,902 (37.3%)
August	5,521	6,926 (25.4%)
September	8,070	7,247 (-10.2%)
October	6,369	3,656 (-42.6%)
November	5,670	3,845 (-32.2%)
December	4,233	3,458 (-18.3%)

Month	NAA-LLT Reference case (243)	ESO-LLT (243)
EC - Port Chicago		
January	9,979	7,973 (-20.1%)
February	4,468	4,727 (5.8%)
March	2,410	2,901 (20.4%)
April	4,747	5,105 (7.5%)
May	8,103	8,359 (3.2%)
June	10,992	10,879 (-1.0%)
July	12,774	13,365 (4.6%)
August	14,829	16,058 (8.3%)
September	17,258	16,529 (-4.2%)
October	15,687	12,101 (-22.9%)
November	13,620	11,542 (-15.3%)
December	13,293	12,101 (-9.0%)

[δ] The **NAA-LLT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Median salinity (measured as EC) at Collinsville is lower in November and December, and higher in January, February, and April to June in the Early Long Term future climate period relative to current (Table 3.18). Median salinities are lower July and October to December, and higher in January to June in the Late Long Term future climate period relative to current.

Median salinity (measured as EC) at Port Chicago is lower in November and December, and higher in January to June in the Early Long Term future climate period relative to current (Table 3.18). Median salinities are lower October to December, and higher in January to June in the Late Long Term future climate period relative to current.

Table 3.18: EC (a proxy for salinity) values at Collinsville and Port Chicago are shown for three future Climate and Demand scenarios. δ

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
EC - Collinsville			
January	1,800	2,325 (29.2%)	2,422 (34.6%)
February	418	523 (25.1%)	633 (51.4%)
March	214	223 (4.2%)	238 (11.0%)
April	354	419 (18.5%)	504 (42.6%)
May	907	1,090 (20.1%)	1,694 (86.7%)
June	2,512	2,838 (13.0%)	2,822 (12.4%)
July	4,396	4,342 (-1.2%)	3,569 (-18.8%)
August	5,636	5,878 (4.3%)	5,521 (-2.0%)
September	7,815	7,822 (0.1%)	8,070 (3.3%)
October	8,564	8,501 (-0.7%)	6,369 (-25.6%)
November	8,859	5,343 (-39.7%)	5,670 (-36.0%)
December	5,454	3,972 (-27.2%)	4,233 (-22.4%)

Month	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
EC - Port Chicago			
January	8,916	9,525 (6.8%)	9,979 (11.9%)
February	2,937	3,910 (33.1%)	4,468 (52.1%)
March	1,269	1,947 (53.4%)	2,410 (89.8%)
April	3,473	4,000 (15.2%)	4,747 (36.7%)
May	6,245	6,990 (11.9%)	8,103 (29.7%)
June	10,015	10,873 (8.6%)	10,992 (9.8%)
July	13,026	12,982 (-0.3%)	12,774 (-1.9%)
August	14,856	15,154 (2.0%)	14,829 (-0.2%)
September	16,721	17,075 (2.1%)	17,258 (3.2%)
October	17,471	17,480 (0.0%)	15,687 (-10.2%)
November	17,376	13,732 (-21.0%)	13,620 (-21.6%)
December	14,918	13,092 (-12.2%)	13,293 (-10.9%)

δ The **NAA-Current** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Ecoregion & Indicator Specific High-level Summary of Relative Suitability

The following high level effect roll-ups are tied to the RS methodology described in Section 2.8.6. Table 3.19 to Table 3.21 show results of this summary methodology for the Sacramento River ecoregion, based on the EFT relative suitability definition and the change in the percentage of years assigned to a favorable outcome. A further synthesis of these tabular results is the subject of Table 3.35 and its associated summary.

Sacramento River (SacEFT)

Table 3.19: Operation and conveyance effects are shown for selected BDCP scenarios in the Sacramento River ecoregion at the Early Long Term (ELT) future climate period using the change in the percentage of favorable years reported for each indicator (RS method). $^{\delta}$

Focal species	Performance indicator	BDCP Scenario (3 columns below) vs. NAA-ELT Reference case (233)			
		ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)	
Upper and Middle Sacramento River Indicators					
Fall Chinook	Suitable spawning habitat (CS1)	15	16	15	
	Thermal egg-to-fry survival (CS3)	1	0	1	
	Redd dewatering (CS6)	-3	3	-5	
	Redd scour risk (CS5)	0	0	0	
	Juvenile stranding (CS4)	1	4	-2	
	Suitable rearing habitat (CS2)	0	-4	-1	
Late Fall Chinook	Suitable spawning habitat (CS1)	-3	-5	-2	
	Thermal egg-to-fry survival (CS3)	0	0	0	
	Redd dewatering (CS6)	0	-2	0	
	Redd scour risk (CS5)	-1	-1	-1	
	Juvenile stranding (CS4)	-7	-8	-2	
	Suitable rearing habitat (CS2)	-3	-9	0	
Spring Chinook	Suitable spawning habitat (CS1)	-2	28	-6	
	Thermal egg-to-fry survival (CS3)	-7	-5	3	
	Redd dewatering (CS6)	-3	12	-4	
	Redd scour risk (CS5)	0	0	0	
	Juvenile stranding (CS4)	-1	-6	0	
	Suitable rearing habitat (CS2)	9	4	10	
Winter Chinook	Suitable spawning habitat (CS1)	-9	-8	0	
	Thermal egg-to-fry survival (CS3)	0	3	3	
	Redd dewatering (CS6)	-3	-9	0	
	Redd scour risk (CS5)	0	0	0	
	Juvenile stranding (CS4)	-14	-18	-17	
	Suitable rearing habitat (CS2)	10	26	4	
Steelhead	Suitable spawning habitat (CS1)	-1	-1	0	
	Thermal egg-to-fry survival (CS3)	0	0	0	
	Redd dewatering (CS6)	0	0	-2	
	Redd scour risk (CS5)	0	0	0	

Focal species	Performance indicator	BDCP Scenario (3 columns below) vs. NAA-ELT Reference case (233)			
		ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)	
Upper and Middle Sacramento River Indicators					
	Juvenile stranding (CS4)	-5	-2	-2	
	Suitable rearing habitat (CS2)	3	5	2	
Bank Swallow	Suitable potential habitat (BASW1)	2	2	2	
	Nest inundation/sloughing (BASW2)	0	0	0	
Green Sturgeon	Egg-to-larval survival (GS1)	3	2	2	
Fremont Cottonwood	Cottonwood initiation index(FC1)	0	0	0	
	Risk scour after initiation (FC2)	1	-2	0	
Large Woody Debris	Old vegetation recruited to river (LWD1)	3	2	2	

δ The **NAA-ELT** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, 5-10%, ≥10% = Dark Green.

Table 3.20: Operation and conveyance effects are shown for selected BDCP scenarios in the Sacramento River ecoregion at the Late Long Term (LLT) future climate period using the change in the percentage of favorable years reported for each indicator (RS method). $^{\delta}$

Focal species	Performance indicator	BDCP Scenario (1 column below) vs. NAA-LLT Reference case (243)			
		ESO-LLT (244)			
Upper and Middle Sacramento River Indicators					
Fall Chinook	Suitable spawning habitat (CS1)	19			
	Thermal egg-to-fry survival (CS3)	0			
	Redd dewatering (CS6)	3			
	Redd scour risk (CS5)	-2			
	Juvenile stranding (CS4)	5			
	Suitable rearing habitat (CS2)	-2			
Late Fall Chinook	Suitable spawning habitat (CS1)	0			
	Thermal egg-to-fry survival (CS3)	0			
	Redd dewatering (CS6)	2			
	Redd scour risk (CS5)	0			
	Juvenile stranding (CS4)	0			
	Suitable rearing habitat (CS2)	-14			

Focal species	Performance indicator	BDCP Scenario (1 column below) vs. NAA-LLT Reference case (243)			
		ESO-LLT (244)			
Upper and Middle Sacramento River Indicators					
Spring Chinook	Suitable spawning habitat (CS1)	-3			
	Thermal egg-to-fry survival (CS3)	-12			
	Redd dewatering (CS6)	-1			
	Redd scour risk (CS5)	0			
	Juvenile stranding (CS4)	-5			
	Suitable rearing habitat (CS2)	10			
Winter Chinook	Suitable spawning habitat (CS1)	-9			
	Thermal egg-to-fry survival (CS3)	-2			
	Redd dewatering (CS6)	-2			
	Redd scour risk (CS5)	0			
	Juvenile stranding (CS4)	-12			
	Suitable rearing habitat (CS2)	5			
Steelhead	Suitable spawning habitat (CS1)	-5			
	Thermal egg-to-fry survival (CS3)	0			
	Redd dewatering (CS6)	4			
	Redd scour risk (CS5)	0			
	Juvenile stranding (CS4)	-5			
	Suitable rearing habitat (CS2)	1			
Bank Swallow	Suitable potential habitat (BASW1)	2			
	Nest inundation/sloughing (BASW2)	0			
Green Sturgeon	Egg-to-larval survival (GS1)	-1			
Fremont Cottonwood	Cottonwood initiation index(FC1)	0			
	Risk scour after initiation (FC2)	-7			
Large Woody Debris	Old vegetation recruited to river (LWD1)	-3			

δ The **NAA-LLT** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, 5-10%, ≥10% = Dark Green.

Table 3.21: Climate and demand effects are shown for selected No Action Alternative (NAA) scenario at two future climate periods in the Sacramento River ecoregion using the change in the percentage of favorable years reported for each indicator (RS method). $^{\delta}$

Focal species	Performance indicator	BDCP Scenario (2 columns below) vs. NAA-Current Reference case (225)			
		NAA-ELT (233)	NAA-LLT (243)		
Upper and Middle Sacramento River Indicators					
Fall Chinook	Suitable spawning habitat (CS1)	-6	-13		
	Thermal egg-to-fry survival (CS3)	-6	-25		
	Redd dewatering (CS6)	2	-1		
	Redd scour risk (CS5)	-4	-2		
	Juvenile stranding (CS4)	-8	-10		
	Suitable rearing habitat (CS2)	2	4		
Late Fall Chinook	Suitable spawning habitat (CS1)	-5	-5		
	Thermal egg-to-fry survival (CS3)	0	0		
	Redd dewatering (CS6)	-7	-6		
	Redd scour risk (CS5)	-2	-6		
	Juvenile stranding (CS4)	-5	-18		
	Suitable rearing habitat (CS2)	19	17		
Spring Chinook	Suitable spawning habitat (CS1)	-14	-22		
	Thermal egg-to-fry survival (CS3)	-21	-52		
	Redd dewatering (CS6)	-11	-20		
	Redd scour risk (CS5)	0	0		
	Juvenile stranding (CS4)	0	-3		
	Suitable rearing habitat (CS2)	-3	-7		
Winter Chinook	Suitable spawning habitat (CS1)	-12	-26		
	Thermal egg-to-fry survival (CS3)	-9	-23		
	Redd dewatering (CS6)	5	5		
	Redd scour risk (CS5)	0	0		
	Juvenile stranding (CS4)	5	5		
	Suitable rearing habitat (CS2)	-24	-31		
Steelhead	Suitable spawning habitat (CS1)	1	3		
	Thermal egg-to-fry survival (CS3)	0	0		
	Redd dewatering (CS6)	-1	-4		
	Redd scour risk (CS5)	-3	-3		
	Juvenile stranding (CS4)	0	0		
	Suitable rearing habitat (CS2)	-2	-6		
Bank Swallow	Suitable potential habitat (BASW1)	1	4		
	Nest inundation/sloughing (BASW2)	1	1		
Green Sturgeon	Egg-to-larval survival (GS1)	-21	-56		

Focal species	Performance indicator	BDCP Scenario (2 columns below) vs. NAA-Current Reference case (225)			
		NAA-ELT (233)	NAA-LLT (243)		
Upper and Middle Sacramento River Indicators					
Fremont Cottonwood	Cottonwood initiation index(FC1)	-2	-6		
	Risk scour after initiation (FC2)	4	4		
Large Woody Debris	Old vegetation recruited to river (LWD1)	2	5		

δ The **NAA-Current** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, 5-10%, ≥10% = Dark Green.

San Joaquin-Sacramento Delta (DeltaEFT)

High level effect roll-ups are closely tied to the RS methodology described in Section 2.8.6. Table 3.22 to Table 3.24 show results of this methodology for the Sacramento River ecoregion, based on the EFT relative suitability definition and the change in the percentage of years assigned to a favorable outcome. A synthesis of these tabular results is presented in Table 3.35**.**

Table 3.22: Operation and conveyance effects are shown for selected BDCP scenarios in the Delta ecoregion at the Early Long Term (ELT) future climate period using the change in the percentage of favorable years reported for each indicator (RS method). δ

Focal species	Performance indicator	BDCP Scenario (3 columns below) vs. NAA-ELT Reference case (233)			
		ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)	
Delta Indicators					
Fall Chinook	Smolt weight gain (CS7)	6	6	6	
	Smolt predation risk (CS9)	0	0	0	
	Smolt temperature stress (CS10)	0	0	0	
Late Fall Chinook	Smolt weight gain (CS7)	50	50	44	
	Smolt predation risk (CS9)	-6	-6	-6	
	Smolt temperature stress (CS10)	-6	-6	-6	
Spring Chinook	Smolt weight gain (CS7)	6	6	6	
	Smolt predation risk (CS9)	0	0	0	
	Smolt temperature stress (CS10)	0	0	6	
Winter Chinook	Smolt weight gain (CS7)	37	37	43	
	Smolt predation risk (CS9)	0	0	0	

Focal species	Performance indicator	BDCP Scenario (3 columns below) vs. NAA-ELT Reference case (233)			
		ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)	
Delta Indicators					
	Smolt temperature stress (CS10)	-12	-12	0	
Steelhead	Smolt weight gain (CS7)	6	6	13	
	Smolt predation risk (CS9)	-6	-6	-6	
	Smolt temperature stress (CS10)	0	0	0	
Splittail	Proportion max spawning habitat (SS1)	82	82	82	
Delta Smelt	Spawning success (DS1)	0	0	6	
	Habitat suitability index (DS2)	6	0	6	
	Larval & juvenile entrainment (DS4)	0	0	0	
Longfin Smelt	Abundance index (LS1)	0	0	0	
Invasive Deterrence	Brazilian waterweed suppression (ID1)	-6	-12	-6	
	Overbite clam suppression (ID2)	-6	-6	-6	
	Asiatic clam suppression (ID3)	0	0	0	
Tidal Wetlands	Brackish wetland area (TW1)	0	0	0	
	Freshwater wetland area (TW2)	–	–	–	

δ The **NAA-ELT** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, 5-10%, ≥10% = Dark Green.

Table 3.23: Operation and conveyance effects are shown for selected BDCP scenarios in the Delta ecoregion at the Late Long Term (LLT) future climate period using the change in the percentage of favorable years reported for each indicator (RS method). δ

Focal species	Performance indicator	BDCP Scenario (1 column below) vs. NAA-LLT Reference case (243)			
		ESO-LLT (244)			
Delta Indicators					
Fall Chinook	Smolt weight gain (CS7)	6			
	Smolt predation risk (CS9)	-6			
	Smolt temperature stress (CS10)	0			
Late Fall Chinook	Smolt weight gain (CS7)	31			
	Smolt predation risk (CS9)	0			
	Smolt temperature stress (CS10)	0			
Spring Chinook	Smolt weight gain (CS7)	0			
	Smolt predation risk (CS9)	0			

Focal species	Performance indicator	BDCP Scenario (1 column below) vs. NAA-LLT Reference case (243)			
		ESO-LLT (244)			
Delta Indicators					
	Smolt temperature stress (CS10)	0			
Winter Chinook	Smolt weight gain (CS7)	31			
	Smolt predation risk (CS9)	0			
	Smolt temperature stress (CS10)	-6			
Steelhead	Smolt weight gain (CS7)	-6			
	Smolt predation risk (CS9)	0			
	Smolt temperature stress (CS10)	0			
Splittail	Proportion max spawning habitat (SS1)	82			
Delta Smelt	Spawning success (DS1)	6			
	Habitat suitability index (DS2)	0			
	Larval & juvenile entrainment (DS4)	11			
Longfin Smelt	Abundance index (LS1)	0			
Invasive Deterrence	Brazilian waterweed suppression (ID1)	6			
	Overbite clam suppression (ID2)	-6			
	Asiatic clam suppression (ID3)	0			
Tidal Wetlands	Brackish wetland area (TW1)	-59			
	Freshwater wetland area (TW2)	-35			

δ The **NAA-LLT** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, 5-10%, ≥10% = Dark Green.

Table 3.24: Climate and demand effects are shown for selected No Action Alternative (NAA) scenario at two future climate periods in the Delta ecoregion using the change in the percentage of favorable years reported for each indicator (RS method). δ

Focal species	Performance indicator	BDCP Scenario (2 columns below) vs. NAA-Current Reference case (225)			
		NAA-ELT (233)	NAA-LLT (243)		
Delta Indicators					
Fall Chinook	Smolt weight gain (CS7)	-17	-23		
	Smolt predation risk (CS9)	0	0		
	Smolt temperature stress (CS10)	-6	-12		
Late Fall Chinook	Smolt weight gain (CS7)	-12	-12		
	Smolt predation risk (CS9)	0	-6		

Focal species	Performance indicator	BDCP Scenario (2 columns below) vs. NAA-Current Reference case (225)			
		NAA-ELT (233)	NAA-LLT (243)		
Delta Indicators					
	Smolt temperature stress (CS10)	0	-6		
Spring Chinook	Smolt weight gain (CS7)	-6	0		
	Smolt predation risk (CS9)	-7	-7		
	Smolt temperature stress (CS10)	-12	-12		
Winter Chinook	Smolt weight gain (CS7)	-6	-6		
	Smolt predation risk (CS9)	0	0		
	Smolt temperature stress (CS10)	-19	-25		
Steelhead	Smolt weight gain (CS7)	-13	-7		
	Smolt predation risk (CS9)	0	-6		
	Smolt temperature stress (CS10)	-6	-6		
Splittail	Proportion max spawning habitat (SS1)	2	2		
Delta Smelt	Spawning success (DS1)	2	-4		
	Habitat suitability index (DS2)	0	0		
	Larval & juvenile entrainment (DS4)	11	0		
Longfin Smelt	Abundance index (LS1)	-6	-6		
Invasive Deterrence	Brazilian waterweed suppression (ID1)	6	-6		
	Overbite clam suppression (ID2)	0	0		
	Asiatic clam suppression (ID3)	0	0		
Tidal Wetlands	Brackish wetland area (TW1)	-35	-35		
	Freshwater wetland area (TW2)	-23	-29		

δ The **NAA-Current** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, 5-10%, ≥10% = Dark Green.

Ecoregion & Indicator Specific Effect Size Results

Sacramento River (SacEFT)

Operation and Conveyance Effects

Operation and conveyance effect size results presented below are based on the ES methodology described in Section 2.8.6. Table 3.25 and Table 3.26 show results of this methodology for the Sacramento River ecoregion. The following section summarizes BDCP effects in which the median effect differs by more than 5% from the reference case. A further synthesis of these effects is the subject of Table 3.35 and its associated summary.

Table 3.25: Operation and conveyance effect sizes are shown for selected BDCP scenarios at the Early Long Term (ELT) future climate period using the median difference Effect Size (ES) method (preserving the native units of each indicator). $^{\delta}$

Focal species	Performance indicator	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Upper and Middle Sacramento River Indicators					
Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	3,738	4,081 (9.2%)	4,069 (8.9%)	3,998 (6.9%)
	Thermal egg-to-fry survival (CS3, proportion)	0.996	0.996 (0.0%)	0.996 (0.0%)	0.997 (0.1%)
	Redd dewatering (CS5; proportion)	0.050	0.040 (0.9%)	0.039 (1.0%)	0.040 (0.9%)
	Redd scour risk (CS6; scour days)	0	0	0	0
	Juvenile stranding index (CS4)	0.166	0.166 (0.0%)	0.166 (0.0%)	0.165 (0.1%)
	Suitable rearing habitat (CS2; 000s ft^2)	62,761	62,000 (-1.2%)	60,347 (-3.8%)	62,601 (-0.3%)
Late Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,272	1,195 (-6.0%)	1,187 (-6.7%)	1,232 (-3.1%)
	Thermal egg-to-fry survival (CS3, proportion)	1.000	1.000 (0.0%)	1.000 (0.0%)	1.000 (0.0%)
	Redd dewatering (CS5; proportion)	0.053	0.054 (-0.1%)	0.060 (-0.7%)	0.054 (0.0%)
	Redd scour risk (CS6; scour days)	0	0	0	0
	Juvenile stranding index (CS4)	0.045	0.048 (-0.3%)	0.045 (0.0%)	0.046 (0.1%)
	Suitable rearing habitat (CS2; 000s ft^2)	52,573	52,050 (-1.0%)	51,374 (-2.3%)	52,274 (-0.6%)
Spring Chinook	Suitable spawning habitat (CS1; 000s ft^2)	914	1,009 (10.4%)	1,048 (14.7%)	896 (-2.0%)
	Thermal egg-to-fry survival (CS3, proportion)	0.979	0.965 (-1.4%)	0.971 (-0.7%)	0.978 (0.0%)
	Redd dewatering (CS5; proportion)	0.055	0.068 (-1.3%)	0.044 (1.1%)	0.069 (-1.3%)
	Redd scour risk (CS6; scour days)	0	0	0	0
	Juvenile stranding index (CS4)	0.201	0.224 (-2.3%)	0.202 (-0.1%)	0.224 (-2.3%)
	Suitable rearing habitat (CS2; 000s ft^2)	66,998	68,136 (1.7%)	65,610 (-2.1%)	68,559 (2.3%)
Winter Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,447	1,418 (-2.0%)	1,419 (-1.9%)	1,446 (0.0%)
	Thermal egg-to-fry survival (CS3, proportion)	0.997	0.995 (-0.2%)	0.997 (0.0%)	0.996 (-0.1%)

Focal species	Performance indicator	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Upper and Middle Sacramento River Indicators					
	Redd dewatering (CS5; proportion)	0.014	0.017 (-0.2%)	0.015 (-0.1%)	0.015 (-0.1%)
	Redd scour risk (CS6; scour days)	0	0	0	0
	Juvenile stranding index (CS4)	0.085	0.106 (-2.1%)	0.094 (-0.9%)	0.101 (-1.6%)
	Suitable rearing habitat (CS2; 000s ft^2)	37,153	37,602 (1.2%)	37,804 (1.8%)	37,101 (-0.1%)
Steelhead	Suitable spawning habitat (CS1; 000s ft^2)	72	70 (-2.8%)	70 (-2.0%)	70 (-2.7%)
	Thermal egg-to-fry survival (CS3, proportion)	1.000	1.000 (0.0%)	1.000 (0.0%)	1.000 (0.0%)
	Redd dewatering (CS5; proportion)	0.050	0.050 (0.0%)	0.047 (0.3%)	0.048 (0.1%)
	Redd scour risk (CS6; scour days)	0	0	0	0
	Juvenile stranding index (CS4)	0.397	0.417 (-2.0%)	0.407 (-1.0%)	0.406 (-0.9%)
	Suitable rearing habitat (CS2; 000s ft^2)	133,901	137,065 (2.4%)	136,015 (1.6%)	134,725 (0.6%)
Bank Swallow	Suitable potential habitat (BASW1; length, m)	35,316	35,197 (-0.3%)	34,734 (-1.6%)	35,280 (-0.1%)
	Nest inundation/sloughing risk (BASW2)	13,976	14,068 (-0.7%)	14,141 (-1.2%)	13,905 (0.5%)
Green Sturgeon	Egg-to-larval survival (GS1; proportion)	0.967	0.970 (0.2%)	0.967 (0.0%)	0.968 (0.1%)
Fremont Cottonwood	Cottonwood initiation index (FC1)	24	26 (8.3%)	26 (6.3%)	24 (0.0%)
	Risk scour after initiation (FC2)				
Large Woody Debris	Old vegetation recruited to river (LWD1; ha)	1.25	1.41 (13.2%)	1.25 (0.2%)	1.41 (13.1%)

$^{\delta}$ The **NAA-ELT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of indicators measured as percentages or proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Table 3.26: Operation and conveyance effect sizes are shown for selected BDCP scenarios at the Late Long Term (LLT) future climate period using the median difference Effect Size (ES) method (preserving the native units of each indicator). $^{\delta}$

Focal species	Performance indicator	NAA-LLT Reference case (243)	ESO-LLT (243)
Upper and Middle Sacramento River Indicators			
Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	3,729	4,003 (7.4%)
	Thermal egg-to-fry survival (CS3, proportion)	0.981	0.976 (-0.5%)
	Redd dewatering (CS5; proportion)	0.056	0.048 (0.7%)
	Redd scour risk (CS6; scour days)	0	0
	Juvenile stranding index (CS4)	0.173	0.172 (0.1%)
	Suitable rearing habitat (CS2; 000s ft^2)	62,279	61,665 (-1.0%)
Late Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,304	1,268 (-2.8%)
	Thermal egg-to-fry survival (CS3, proportion)	0.999	0.999 (0.0%)
	Redd dewatering (CS5; proportion)	0.063	0.060 (0.3%)
	Redd scour risk (CS6; scour days)	0	0
	Juvenile stranding index (CS4)	0.056	0.057 (-0.1%)
	Suitable rearing habitat (CS2; 000s ft^2)	53,088	51,009 (-3.9%)
Spring Chinook	Suitable spawning habitat (CS1; 000s ft^2)	867	860 (-0.8%)
	Thermal egg-to-fry survival (CS3, proportion)	0.892	0.843 (-4.9%)
	Redd dewatering (CS5; proportion)	0.070	0.075 (-0.5%)
	Redd scour risk (CS6; scour days)	0	0
	Juvenile stranding index (CS4)	0.220	0.216 (0.4%)
	Suitable rearing habitat (CS2; 000s ft^2)	64,986	68,257 (5.0%)
Winter Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,407	1,383 (-1.7%)
	Thermal egg-to-fry survival (CS3, proportion)	0.981	0.978 (-0.4%)

Focal species	Performance indicator	NAA-LLT Reference case (243)	ESO-LLT (243)
Upper and Middle Sacramento River Indicators			
	Redd dewatering (CS5; proportion)	0.014	0.015 (-0.1%)
	Redd scour risk (CS6; scour days)	0	0
	Juvenile stranding index (CS4)	0.092	0.090 (0.2%)
	Suitable rearing habitat (CS2; 000s ft^2)	36,695	36,723 (0.1%)
Steelhead	Suitable spawning habitat (CS1; 000s ft^2)	74	72 (-2.7%)
	Thermal egg-to-fry survival (CS3, proportion)	0.999	1.000 (0.0%)
	Redd dewatering (CS5; proportion)	0.050	0.048 (0.2%)
	Redd scour risk (CS6; scour days)	0	0
	Juvenile stranding index (CS4)	0.405	0.411 (-1.3%)
	Suitable rearing habitat (CS2; 000s ft^2)	133,719	134,602 (0.7%)
Bank Swallow	Suitable potential habitat (BASW1; length, m)	35,090	35,643 (1.6%)
	Nest inundation/sloughing risk (BASW2)	14,079	14,447 (-2.6%)
Green Sturgeon	Egg-to-larval survival (GS1; proportion)	0.935	0.933 (-0.2%)
Fremont Cottonwood	Cottonwood initiation index (FC1)	25	29 (16.0%)
	Risk scour after initiation (FC2)		
Large Woody Debris	Old vegetation recruited to river (LWD1; ha)	1.30	1.06 (-18.6%)

δ The **NAA-LLT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of indicators measured as percentages or proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Salmonids

Median suitable spawning habitat (CS1) rises relative to NAA-ELT for fall-run Chinook under all BDCP scenarios: 9.2%, 8.9% and 6.9% for ESO-ELT, LOS-ELT and HOS-ELT respectively (Figure 3.3).

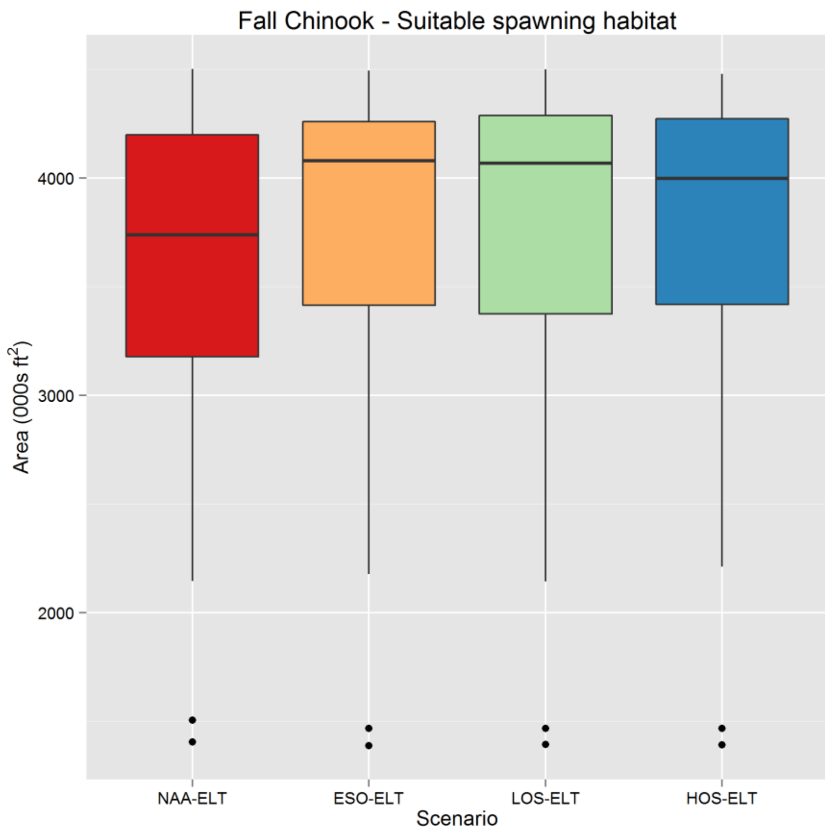


Figure 3.3: Fall-run Chinook spawning habitat (CS1) area under three BDCP scenarios, in comparison to the NAA-ELT baseline scenario.

Median suitable spawning habitat (CS1) declines relative to NAA-ELT for late fall-run Chinook under the ESO-ELT and LOS-ELT BDCP scenarios: –6.0% and –6.7% respectively (Figure 3.4). There is considerable variation within each project level.

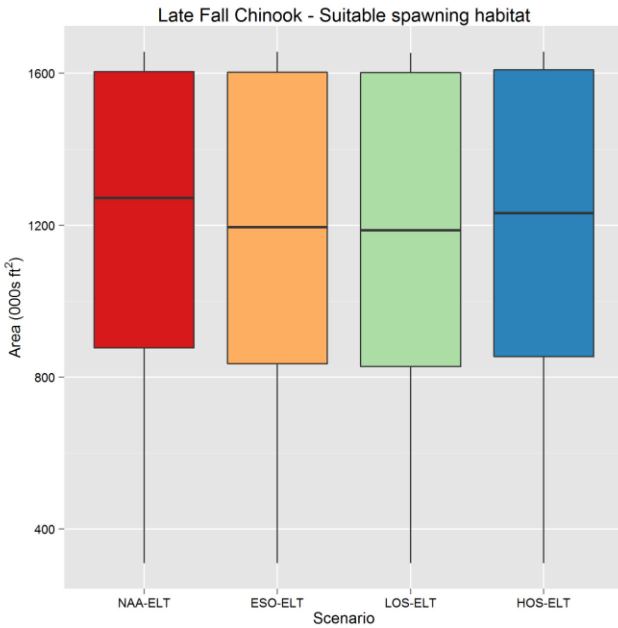


Figure 3.4: Late fall-fun Chinook spawning habitat (CS1) area under three BDCP scenarios, in comparison to the NAA-ELT baseline scenario.

Median suitable spawning habitat (CS1) increases relative to NAA-ELT for spring-run Chinook under two BDCP scenarios: 10.4% and 14.7% for ESO-ELT and LOS-ELT (Figure 3.5).

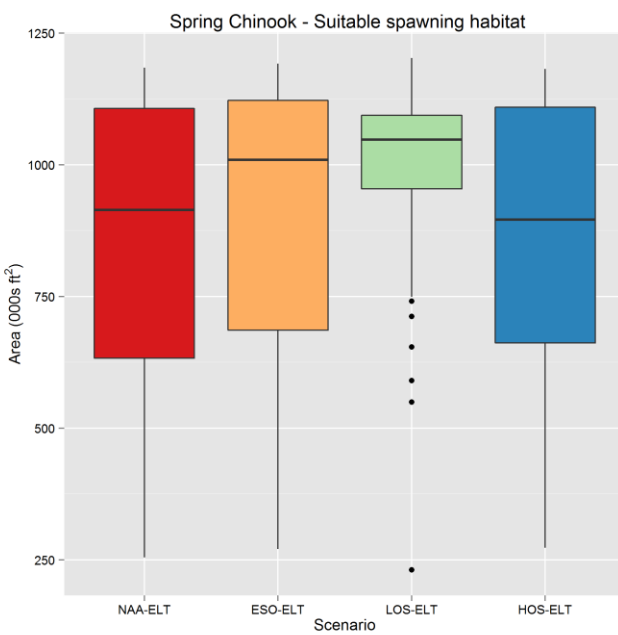


Figure 3.5: Spring-run Chinook spawning habitat (CS1) area under three BDCP scenarios, in comparison to the NAA-ELT baseline scenario.

Green Sturgeon

The median green sturgeon egg survival (GS1) is expected to remain fairly constant under all BDCP project scenarios. Median project mortality differs from the reference case of 96.7% survival by at most 0.2% (Table 3.25). Comparisons using an LLT reference case are similarly very small (Table 3.26).

Fremont Cottonwood

The median Fremont cottonwood initiation (FC1) is expected to remain fairly constant under all BDCP project scenarios, with slight improvement under ESO-ELT and LOS-ELT (8% and 6% respectively) (Figure 3.6). The HOS-ELT scenario produces no effect.

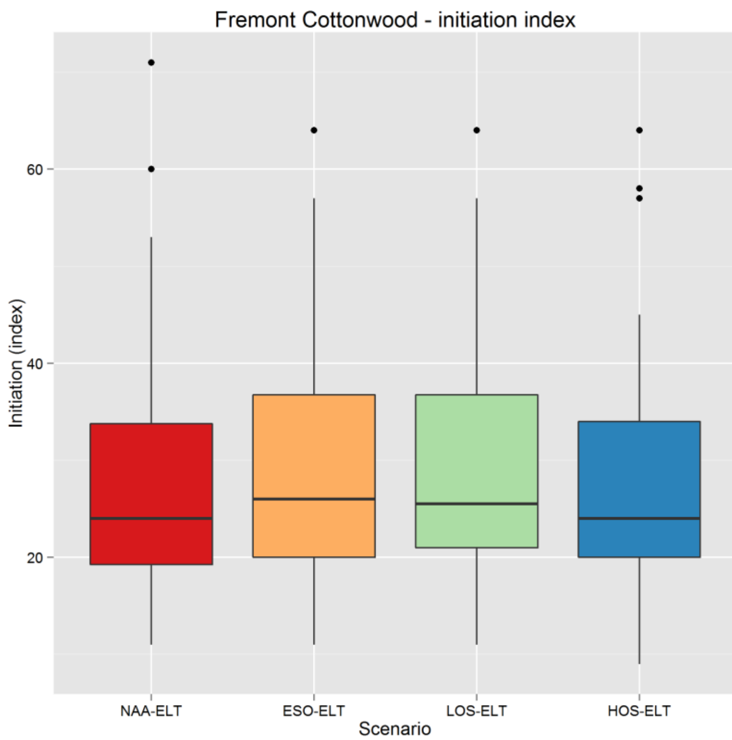


Figure 3.6: Fremont cottonwood initiation success (FC1) under three BDCP scenarios, in comparison to the NAA-ELT baseline scenario.

Bank Swallow

The median suitable potential habitat (BASW1) for bank swallows is expected to remain relatively constant between project alternatives at approximately 35 km.

The median nest inundation/sloughing risk (BASW2) for bank swallows is expected to remain relatively constant between project alternatives.

Large Woody Debris Recruitment

For old vegetation recruitment, we expected different results than for bank swallow habitat, as bank swallow habitat needs to be eroded to a minimum of 1 m which requires a minimum increase in stream power.

The median annual input of old vegetation recruited to the river (LWD) is expected to increase relative to NAA-ELT under two BDCP scenarios: 13.1% and 13.2% for ESO-ELT and HOS-ELT, respectively (Figure 3.7, upper left panel). The expected increases are small relative to annual variations (expected increase is 0.16 ha, high quartile above 5 ha) and the individual water year differences may not be meaningful (Figure 3.7, upper right panel).

The median input of old vegetation recruited to the river (LWD) is expected to decrease for ESO-LLT relative to NAA-ELT by 18.6% (Figure 3.7, lower left panel). The expected decreases are small relative to annual variations (expected increase is 0.24 ha, high quartile above 5 ha) and the individual water year differences do not appear to be meaningful (Figure 3.7, lower right panel).

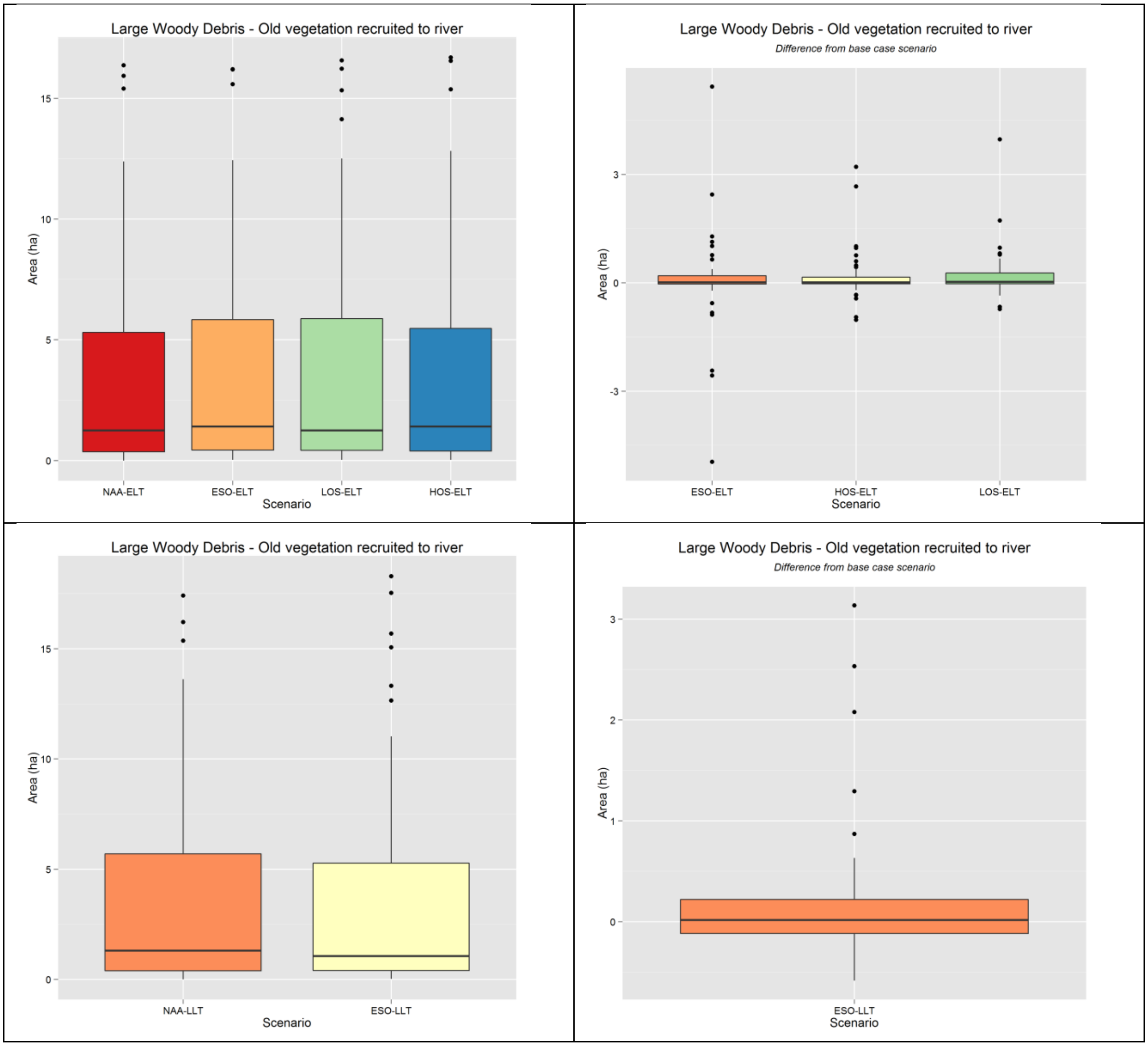


Figure 3.7: Median large woody debris input (LWD1) to the river under three BDCP scenarios, in comparison to the NAA-ELT baseline scenario (upper left panel) and under one BDCP scenario in comparison to the NAA-LLT baseline scenario (lower left panel). Individual year differences for the ELT and LLT periods are shown in the upper right and lower right panels, respectively.

Future climate and demand effects

Climate and demand effect size results are closely tied to the ES methodology described in Section 2.8.6. Table 3.27 shows results of this methodology for the Sacramento River ecoregion. The following section summarizes Climate/Demand effects in which the median effect differs by more than 5% from a reference case comparative response. A synthesis of these effects is presented in Table 3.35**.**

Table 3.27: Climate and demand effect sizes are shown for the No Action Alternative (NAA) scenario at three future climate periods using the median difference Effect Size (ES) method (preserving the native units of each indicator). δ

Focal species	Performance indicator	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Upper and Middle Sacramento River Indicators				
Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	3,876	3,738 (-3.6%)	3,729 (-3.8%)
	Thermal egg-to-fry survival (CS3, proportion)	0.999	0.996 (-0.3%)	0.981 (-1.9%)
	Redd dewatering (CS5; proportion)	0.053	0.050 (0.3%)	0.056 (-0.3%)
	Redd scour risk (CS6; scour days)	0	0	0
	Juvenile stranding index (CS4)	0.153	0.166 (-1.3%)	0.173 (-2.0%)
	Suitable rearing habitat (CS2; 000s ft^2)	61,935	62,761 (1.3%)	62,279 (0.6%)
Late Fall Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,352	1,272 (-5.9%)	1,304 (-3.6%)
	Thermal egg-to-fry survival (CS3, proportion)	1.000	1.000 (0.0%)	0.999 (-0.1%)
	Redd dewatering (CS5; proportion)	0.044	0.053 (-1.0%)	0.063 (-2.0%)
	Redd scour risk (CS6; scour days)	0	0	0
	Juvenile stranding index (CS4)	0.033	0.045 (-1.2%)	0.056 (-2.3%)
	Suitable rearing habitat (CS2; 000s ft^2)	50,703	52,573 (3.7%)	53,088 (4.7%)
Spring Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,058	914 (-13.6%)	867 (-18.1%)
	Thermal egg-to-fry survival (CS3, proportion)	0.997	0.979 (-1.9%)	0.892 (-10.5%)
	Redd dewatering (CS5; proportion)	0.044	0.055 (-1.1%)	0.070 (-2.6%)
	Redd scour risk (CS6; scour days)	0	0	0
	Juvenile stranding index (CS4)	0.201	0.201 (0.0%)	0.220 (-0.9%)
	Suitable rearing habitat (CS2; 000s ft^2)	63,130	66,998 (6.1%)	64,986 (2.9%)

Focal species	Performance indicator	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Upper and Middle Sacramento River Indicators				
Winter Chinook	Suitable spawning habitat (CS1; 000s ft^2)	1,471	1,447 (-1.7%)	1,407 (-4.4%)
	Thermal egg-to-fry survival (CS3, proportion)	1.000	0.997 (-0.3%)	0.981 (-1.9%)
	Redd dewatering (CS5; proportion)	0.016	0.014 (0.1%)	0.014 (0.1%)
	Redd scour risk (CS6; scour days)	0	0	0
	Juvenile stranding index (CS4)	0.092	0.085 (0.7%)	0.092 (0.2%)
	Suitable rearing habitat (CS2; 000s ft^2)	37,953	37,153 (-2.1%)	36,695 (-3.3%)
Steelhead	Suitable spawning habitat (CS1; 000s ft^2)	72	72 (-0.5%)	74 (2.2%)
	Thermal egg-to-fry survival (CS3, proportion)	1.000	1.000 (0.0%)	0.999 (-0.1%)
	Redd dewatering (CS5; proportion)	0.043	0.050 (-0.7%)	0.050 (-0.7%)
	Redd scour risk (CS6; scour days)	0	0	0
	Juvenile stranding index (CS4)	0.393	0.397 (-0.4%)	0.405 (-1.2%)
	Suitable rearing habitat (CS2; 000s ft^2)	134,213	133,901 (-0.2%)	133,719 (-0.4%)
Bank Swallow	Suitable potential habitat (BASW1; length, m)	34,782	35,316 (1.5%)	35,090 (0.9%)
	Nest inundation/sloughing risk (BASW2)	13,673	13,976 (-2.2%)	14,079 (-3.0%)
Green Sturgeon	Egg-to-larval survival (GS1; proportion)	0.989	0.967 (-2.2%)	0.935 (-5.4%)
Fremont Cottonwood	Cottonwood initiation index (FC1)	23.5	24 (2.1%)	25 (6.4%)
	Risk scour after initiation (FC2)			
Large Woody Debris	Old vegetation recruited to river (LWD1; ha)	1.27	1.25 (-1.8%)	1.30 (2.6%)

$^{\delta}$ The **NAA-Current** scenario serves as a comparative reference case with percentage differences shown below absolute median effects. Percentage differences for indicators measured as proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Salmonids

Median suitable spawning habitat (CS1) of late fall-run Chinook is reduced by 5.9% from NAA-Current to NAA-ELT (Figure 3.8).

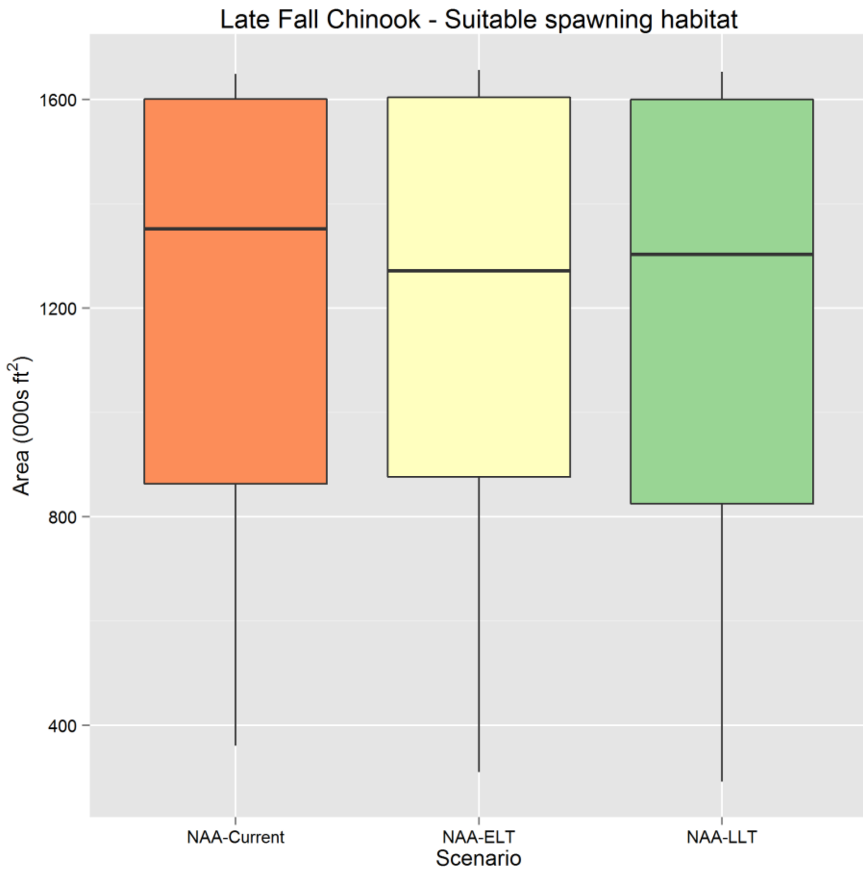


Figure 3.8: Late fall-run Chinook suitable spawning habitat (CS1) area under the NAA-ELT and NAA-LLT scenarios, compared to the NAA-Current reference case.

Median spring-run Chinook spawning habitat (CS1) is reduced by 13.6% and 18.1% in NAA-ELT and NAA-LLT, respectively compared to NAA-Current reference case. Median egg-stage thermal mortality (CS3) increases by 10.5% in the NAA-LLT scenario, relative to the same reference case. Median juvenile rearing habitat (CS2) increases by 6.1% in the NAA-ELT scenario (Figure 3.9).

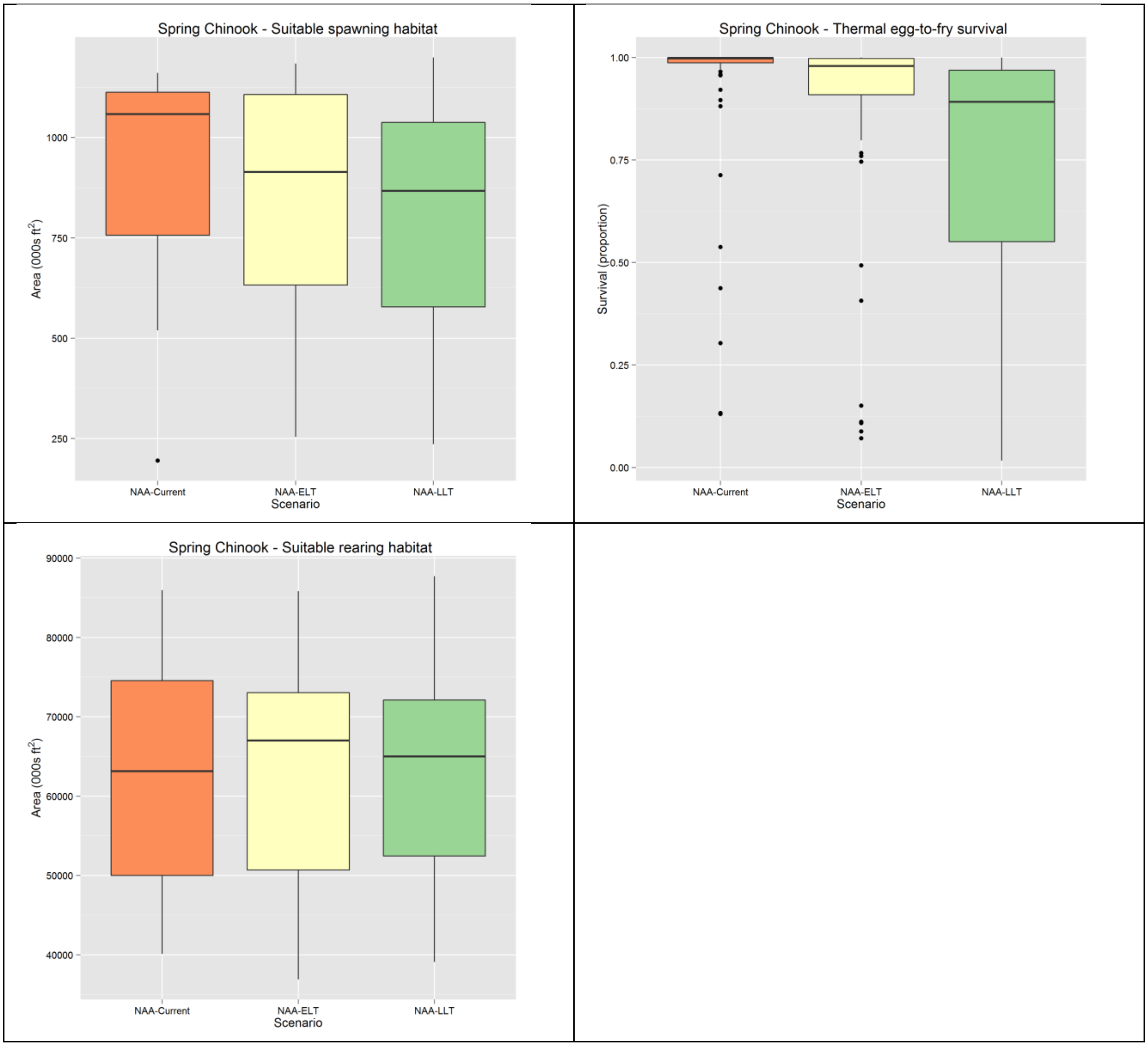


Figure 3.9: Spring-run Chinook suitable spawning habitat area (CS1, upper left panel), thermal egg-to-fry survival (CS3, upper right panel), and juvenile rearing habitat (CS2, lower left panel) under the NAA-ELT and NAA-LLT scenarios, compared to the NAA-Current reference case.

Green Sturgeon

Median green sturgeon egg survival (GS1) is meaningfully altered in the NAA-LLT scenario, declining by 5.4%, from 98.9% in the NAA-Current reference case scenario to 93.5% survival in the 2060 period (Figure 3.10, Table 3.27). A less meaningful 2.2% reduction is also seen in the intermediate NAA-ELT (2030) scenario. These results agree with High level Effect Roll-up analyses (RS method) where the number of favorable years is reduced by 21% and 56% for ELT and LLT, respectively (Table 3.21).

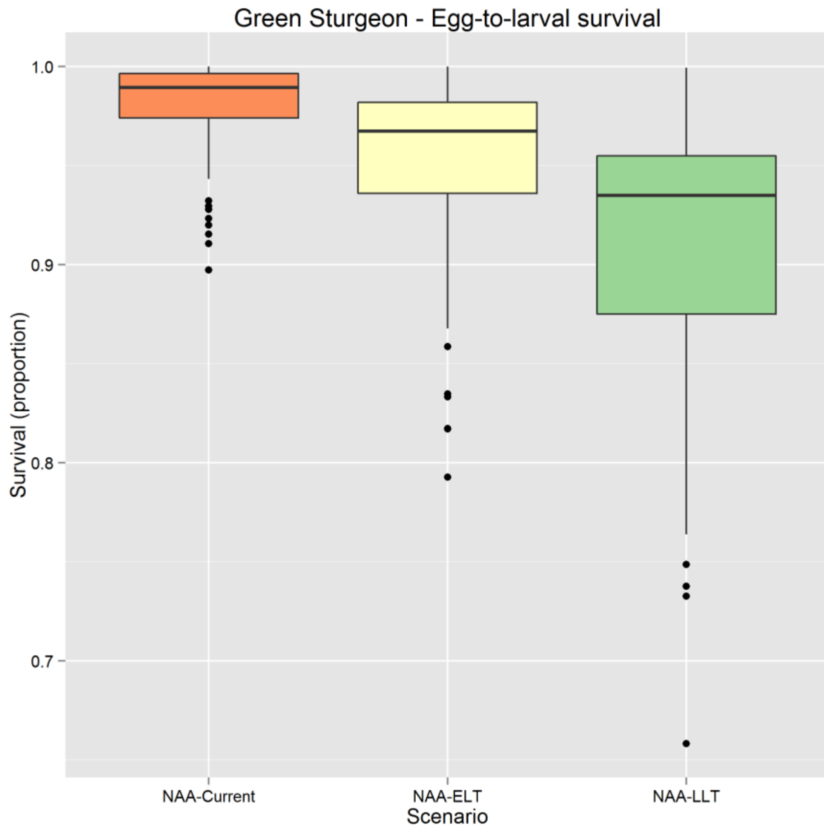


Figure 3.10: Green sturgeon egg survival (GS1) under the NAA-ELT and NAA-LLT scenarios compared to the NAA-Current reference case.

Fremont Cottonwood

Fremont cottonwood initiation comparisons involving future LLT climate (as represented in BDCP alternatives) do not show meaningful change.

Bank Swallow

The median suitable potential habitat (BASW1) for bank swallows is expected to remain relatively constant under different future climates and demands at approximately 35 km.

The median nest inundation/sloughing risk (BASW2) for bank swallows is expected to remain relatively constant under different future climates and demands.

Large Woody Debris Recruitment

The median large woody debris (LWD) input to the Sacramento River is expected to remain relatively constant under different future climates and demands at approximately 1.25 ha.

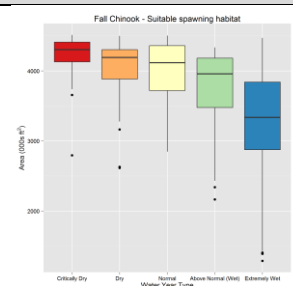
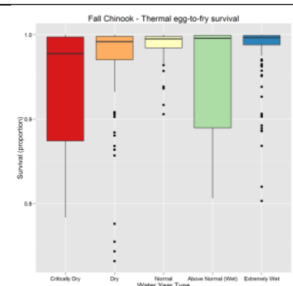
Water year characterization

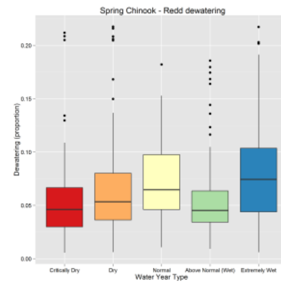
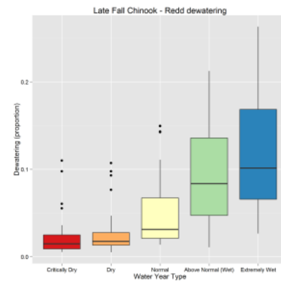
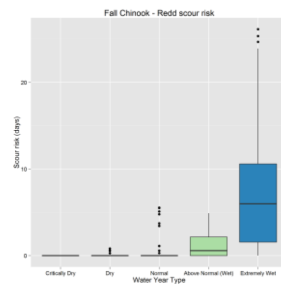
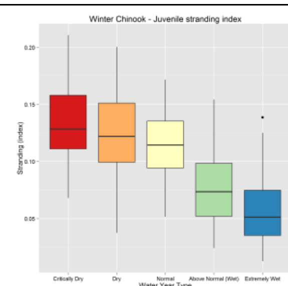
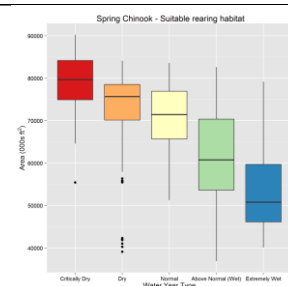
Although they cannot be compared directly to a reference case, for many indicators, Water Year effects are larger than operation and conveyance effects. The following section describes these effects indicator by indicator.

Salmonids

Differences among water years are seen for most salmonid indicators, with one or two simple patterns that are quite consistent across all run types. These are summarized in Table 3.28. The most meaningful indicator for Water Year effects is the juvenile stranding index (CS4). This index behaves in a straightforward manner based on the relationship between channel bathymetry and flow (see short description in Section 2.2.12). During low flow periods, preferred juvenile habitat can change markedly with small changes to flow, due to the wetted channel being confined near the flatter bottom portion of the overall channel.

Table 3.28: Summary of Water Year patterns observed for salmonid indicators from the Sacramento River ecoregion.

<table>
<tr><th>Indicator</th><th>Run type</th><th>Pattern</th><th>Explanation</th><th>Typical Boxplot</th></tr>
<tr><td>Suitable spawning habitat (CS1)</td><td>All</td><td>Declining in wetter years</td><td>Peak salmonid spawning habitat occurs at lower flow</td><td>
</td></tr>
<tr><td rowspan="2">Thermal egg-to-fry survival (CS3)</td><td>Fall, Spring, Winter</td><td>More variable in Critically Dry, Above Normal years</td><td>High between-year flow variability for salmonids with an egg period outside spring</td><td>
</td></tr>
<tr><td>Late fall, Steelhead</td><td>Negligible</td><td>Salmonid egg period coincides with consistent cool high spring flow (see Table 2.4)</td><td></td></tr>
</table>

Indicator	Run type	Pattern	Explanation	Typical Boxplot
Redd dewatering (CS6)	Fall, Spring, Winter	Fairly insensitive	Flow variability is similar across Water Year types for salmonids with an egg period outside the spring	
	Late fall, Steelhead	**Increasing in wetter years**	Flow variability is highest in wetter years for salmonids with an egg period during the spring	
Redd scour risk (CS5)	Fall, Spring, Winter	**Highest in Extremely Wet**	High risk in very wet years for salmonids with an egg period in lower flow seasons	
	Late fall, Steelhead	Negligible	Egg period coincides with consistent high cool flow in spring	
Juvenile stranding index (CS4)	All	**Declining in wetter years**	Channel bathymetry is more sensitive to fluctuations in drier years, when flow is near the bottom of the channel	
Suitable rearing habitat (CS2)	All	**Declining in wetter years**	Peak salmonid rearing habitat occurs at lowerer flow	

Green Sturgeon

Green sturgeon egg survival (GS1) is meaningfully lower in critically dry water years (Figure 3.11) and highest in normal Water Year types.

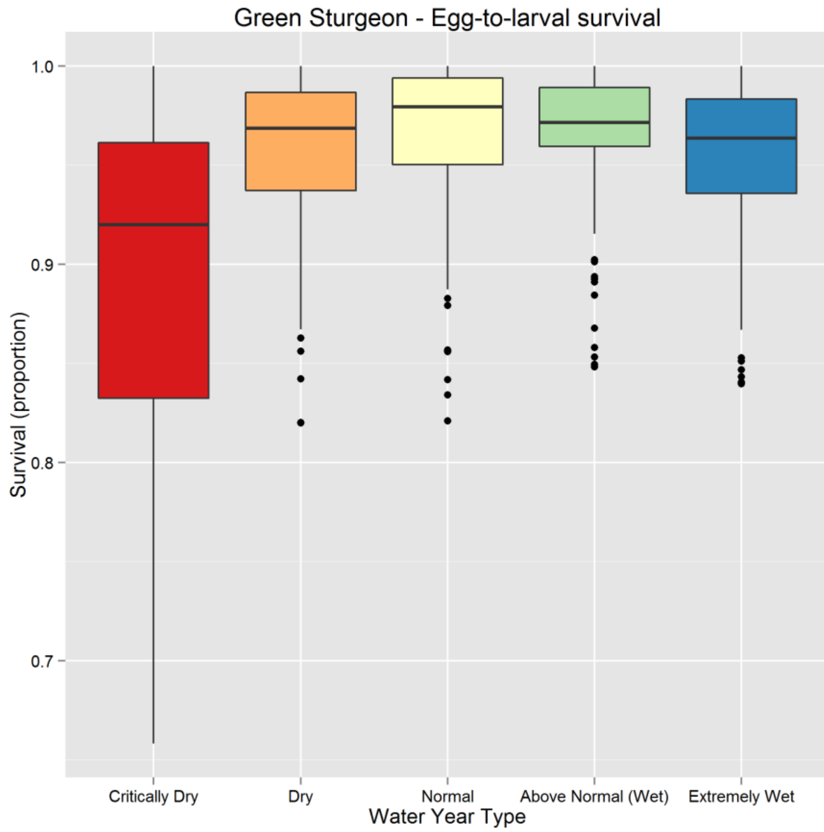


Figure 3.11: Median green sturgeon egg survival (GS1) by Water Year type.

Fremont Cottonwood

Median Fremont cottonwood initiation (FC1) was significantly higher in extremely wet water years, but otherwise relatively constant (Figure 3.12). Interestingly, the lowest median initiation was observed in normal water years relative to dry years. This may be explained by different operational rules in normal years that are associated with more rapid rates of hydrograph recession.

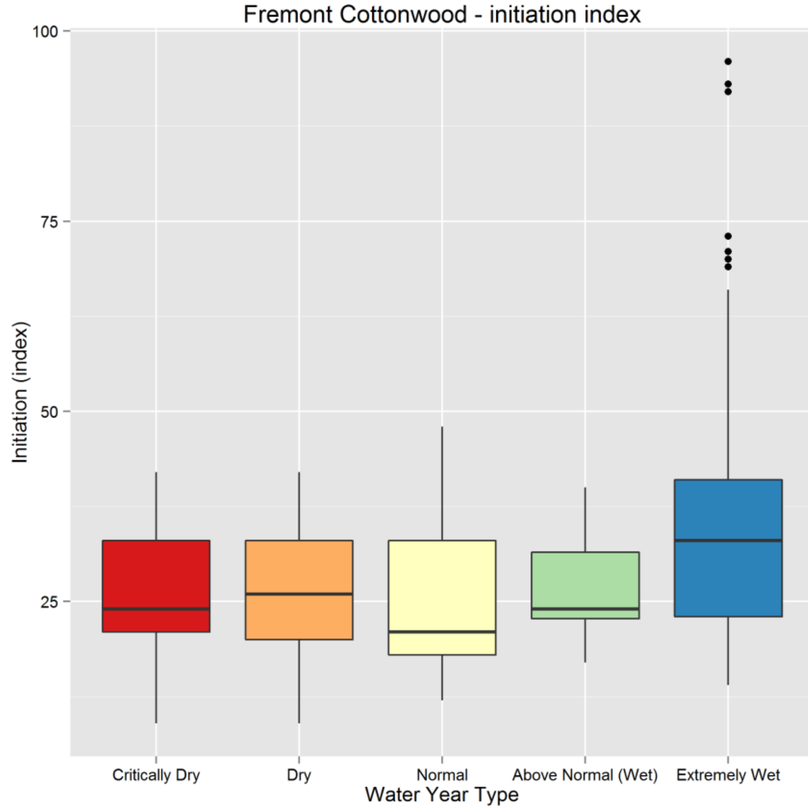


Figure 3.12: Median Fremont cottonwood initiation (FC1) by Water Year type.

Bank Swallow

The median suitable potential habitat (BASW1) for bank swallows is meaningfully lower in critically dry years when the weighted suitable length is almost half of the estimate length in extremely wet years (Figure 3.13, left panel).

The median nest inundation/sloughing risk (BASW2) for bank swallows increases in wetter water year types (Figure 3.13, right panel).

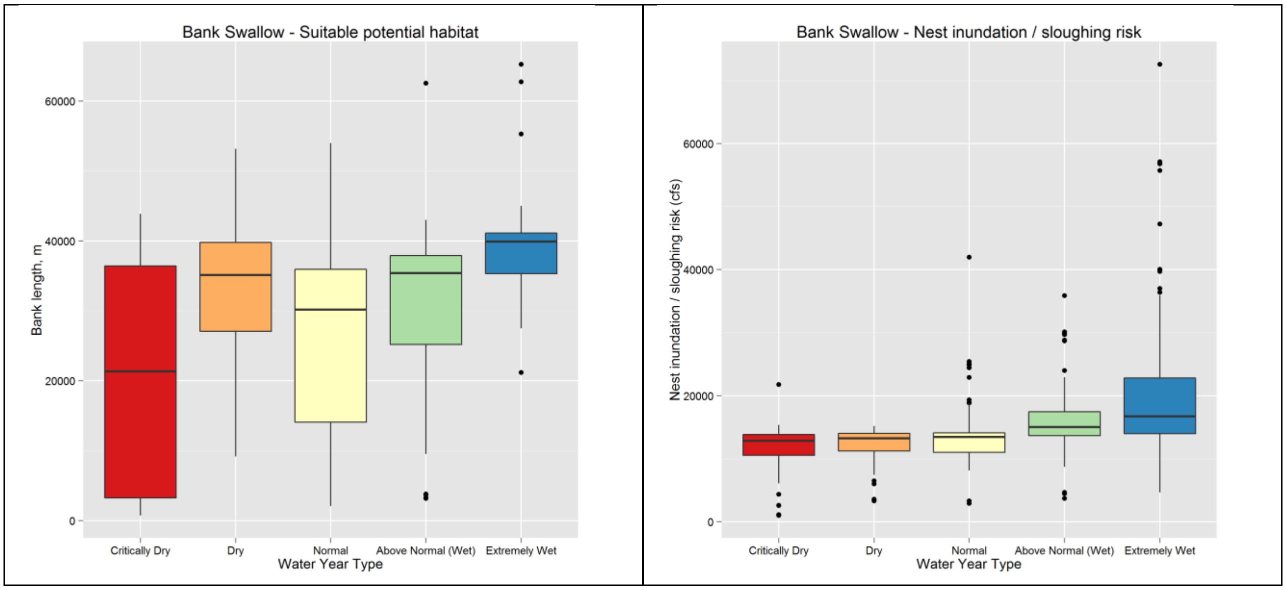


Figure 3.13: Median suitable potential habitat (BASW1) for bank swallows by Water Year type, showing suitable potential habitat (left panel) and nest inundation/sloughing risk (right panel).

Large Woody Debris Recruitment

The median large woody debris (LWD) input increases meaningfully in wetter water year types, with the median for extremely wet water years being approximately five times higher than the overall median (Figure 3.14).

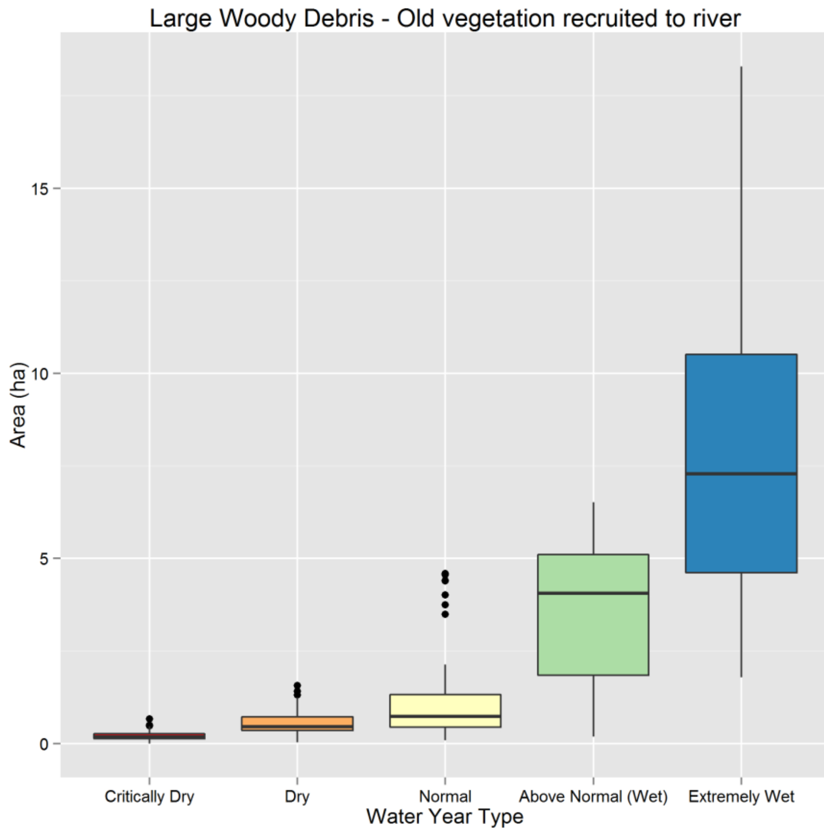


Figure 3.14: Median large woody debris input (LWD1) to the Sacramento River by Water Year type.

San Joaquin-Sacramento Delta (DeltaEFT)

Operation and conveyance effects

Effect size results are based on the ES methodology described in Section 2.8.6. Table 3.29 and Table 3.30 show results of this methodology for the Delta ecoregion. The following section summarizes BDCP effects in which the median effect differs by more than 5% from a reference case comparative response. A synthesis of these effects is presented in Table 3.35**.**

Table 3.29: Operation and conveyance sizes are shown for selected BDCP scenarios at the Early Long Term (ELT) future climate period using the median difference Effect Size (ES) method (preserving the native units of each indicator). $^{\delta}$

Focal species	Performance indicator	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Delta Indicators					
Fall Chinook	Smolt weight gain (CS7; %)	19.1	19.6 (0.4%)	19.5 (0.4%)	19.4 (0.2%)
	Smolt predation risk (CS9; passage days)	15.5	16.1 (-3.9%)	16.1 (-3.6%)	16.0 (-2.8%)
	Smolt temperature stress (CS10; degree day)	113.4	117.9 (-3.9%)	117.9 (-3.9%)	116.7 (-2.9%)
Late Fall Chinook	Smolt weight gain (CS7; %)	29.0	34.2 (5.2%)	34.2 (5.2%)	34.3 (5.3%)
	Smolt predation risk (CS9; passage days)	15.6	16.1 (-3.6%)	16.5 (-5.9%)	16.3 (-4.4%)
	Smolt temperature stress (CS10; degree day)	60.8	66.0 (-8.6%)	66.9 (-10.1%)	66.6 (-9.7%)
Spring Chinook	Smolt weight gain (CS7; %)	23.0	25.0 (2.0%)	24.7 (1.7%)	24.8 (1.8%)
	Smolt predation risk (CS9; passage days)	15.6	15.8 (-1.4%)	15.7 (-0.8%)	16.0 (-2.7%)
	Smolt temperature stress (CS10; degree day)	87.1	88.8 (-2.0%)	88.7 (-1.8%)	90.4 (-3.9%)
Winter Chinook	Smolt weight gain (CS7; %)	30.3	35.1 (4.8%)	35.2 (4.9%)	35.0 (4.7%)
	Smolt predation risk (CS9; passage days)	14.7	15.4 (-5.2%)	15.4 (-4.9%)	15.4 (-5.2%)
	Smolt temperature stress (CS10; degree day)	42.5	47.3 (-11.3%)	47.2 (-11.2%)	47.1 (-11.0%)
Steelhead	Smolt weight gain (CS7; %)	17.7	18.4 (0.7%)	18.3 (0.6%)	18.5 (0.8%)
	Smolt predation risk (CS9; passage days)	15.8	16.2 (-2.7%)	16.0 (-1.8%)	16.4 (-4.2%)
	Smolt temperature stress (CS10; degree day)	113.3	122.1 (-7.7%)	121.9 (-7.6%)	123.9 (-9.3%)
Splittail	Proportion max spawning habitat (SS1)	0.000	0.156 (15.6%)	0.160 (16.0%)	0.182 (18.2%)
Delta Smelt	Spawning success (DS1; optimal days)	33.0	33.4 (1.2%)	33.4 (1.2%)	33.4 (1.2%)
	Habitat suitability index (DS2)	3,456	3,514 (1.7%)	3,047 (-11.8%)	3,501 (1.3%)

Focal species	Performance indicator	NAA-ELT Reference case (233)	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)
Delta Indicators					
	Larval & juvenile entrainment proportion (DS4)	0.054	0.055 (0.0%)	0.055 (-0.1%)	0.051 (0.4%)
Longfin Smelt	Abundance index (LS1)	66.6	65.6 (-1.4%)	63.8 (-4.2%)	72.8 (9.4%)
Invasive Deterrence	Brazilian waterweed suppression (ID1)	9.1	8.9 (-2.1%)	8.9 (-2.1%)	8.9 (-2.7%)
	Overbite clam larval suppression (ID2)	2.7	3.3 (-25.2%)	3.3 (-25.4%)	3.3 (-25.0%)
	Asiatic clam larval suppression (ID3)	9.1	8.9 (-2.1%)	8.9 (-2.1%)	8.9 (-2.7%)
Tidal Wetlands	Brackish wetland area (TW1; ha)	705.5	672.2 (-4.7%)	672.2 (-4.7%)	672.2 (-4.7%)
	Freshwater wetland area (TW2; ha)	283.7	273.7 (-3.5%)	273.7 (-3.5%)	273.7 (-3.5%)

$^{\delta}$ The **NAA-ELT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of indicators measured as percentages or proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Table 3.30: Operation and conveyance sizes are shown for selected BDCP scenarios at the Late Long Term (LLT) future climate period using the median difference Effect Size (ES) method (preserving the native units of each indicator).[δ]

Focal species	Performance indicator	NAA-LLT Reference case (243)	ESO-LLT (243)
Delta Indicators			
Fall Chinook	Smolt weight gain (CS7; %)	17.7	18.2 (0.5%)
	Smolt predation risk (CS9; passage days)	15.7	16.3 (-4.1%)
	Smolt temperature stress (CS10; degree day)	115.1	120.7 (-4.9%)
Late Fall Chinook	Smolt weight gain (CS7; %)	28.3	32.9 (4.6%)
	Smolt predation risk (CS9; passage days)	15.5	16.1 (-3.9%)
	Smolt temperature stress (CS10; degree day)	64.3	68.6 (-6.6%)
Spring Chinook	Smolt weight gain (CS7; %)	22.1	24.2 (2.1%)
	Smolt predation risk (CS9; passage days)	15.6	15.8 (-1.4%)
	Smolt temperature stress (CS10; degree day)	88.1	92.3 (-4.8%)
Winter Chinook	Smolt weight gain (CS7; %)	29.6	34.7 (5.1%)
	Smolt predation risk (CS9; passage days)	14.7	15.3 (-3.7%)
	Smolt temperature stress (CS10; degree day)	46.1	51.1 (-10.8%)
Steelhead	Smolt weight gain (CS7; %)	16.4	16.9 (0.5%)
	Smolt predation risk (CS9; passage days)	15.7	16.0 (-2.5%)
	Smolt temperature stress (CS10; degree day)	119.4	126.7 (-6.1%)
Splittail	Proportion max spawning habitat (SS1)	0.000	0.153 (15.3%)
Delta Smelt	Spawning success (DS1; optimal days)	33.7	34.3 (1.8%)
	Habitat suitability index (DS2)	3,423	3,655 (6.8%)

Focal species	Performance indicator	NAA-LLT Reference case (243)	ESO-LLT (243)
Delta Indicators			
	Larval & juvenile entrainment proportion (DS4)	0.062	0.060 (0.1%)
Longfin Smelt	Abundance index (LS1)	59.0	55.9 (-5.1%)
Invasive Deterrence	Brazilian waterweed suppression (ID1)	8.9	8.9 (-0.3%)
	Overbite clam larval suppression (ID2)	2.9	3.5 (-21.4%)
	Asiatic clam larval suppression (ID3)	8.9	8.9 (-0.3%)
Tidal Wetlands	Brackish wetland area (TW1; ha)	773.1	657.5 (-15.0%)
	Freshwater wetland area (TW2; ha)	302.3	266.5 (-11.8%)

δ The **NAA-LLT** scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. Comparisons of indicators measured as percentages or proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Salmonids

No meaningful effects are seen for fall-run Chinook. Median smolt weight gain in Yolo Bypass (CS7) improves markedly for late fall-run Chinook under all project scenarios, increasing by 5.2% for ESO-ELT and LOS-ELT, and by 5.3% under the HOS-ELT scenario (Figure 3.15, upper left panel, Figure 3.16, Figure 3.17). Exposure to smolt predation (CS9) increases by 5.9% in the LOS-ELT scenario, compared to the NAA-ELT reference case. The other project scenarios also increase slightly. Smolt temperature stress (CS10) becomes more extreme under all BDCP scenarios, increasing by 8.6%, 10.1% and 9.7% under the ESO-ELT, LOS-ELT and HOS-ELT scenarios respectively (Figure 3.15). A similar 6.6% operation and conveyance effect also exists for the LLT comparison under the ESO-LLT comparison.

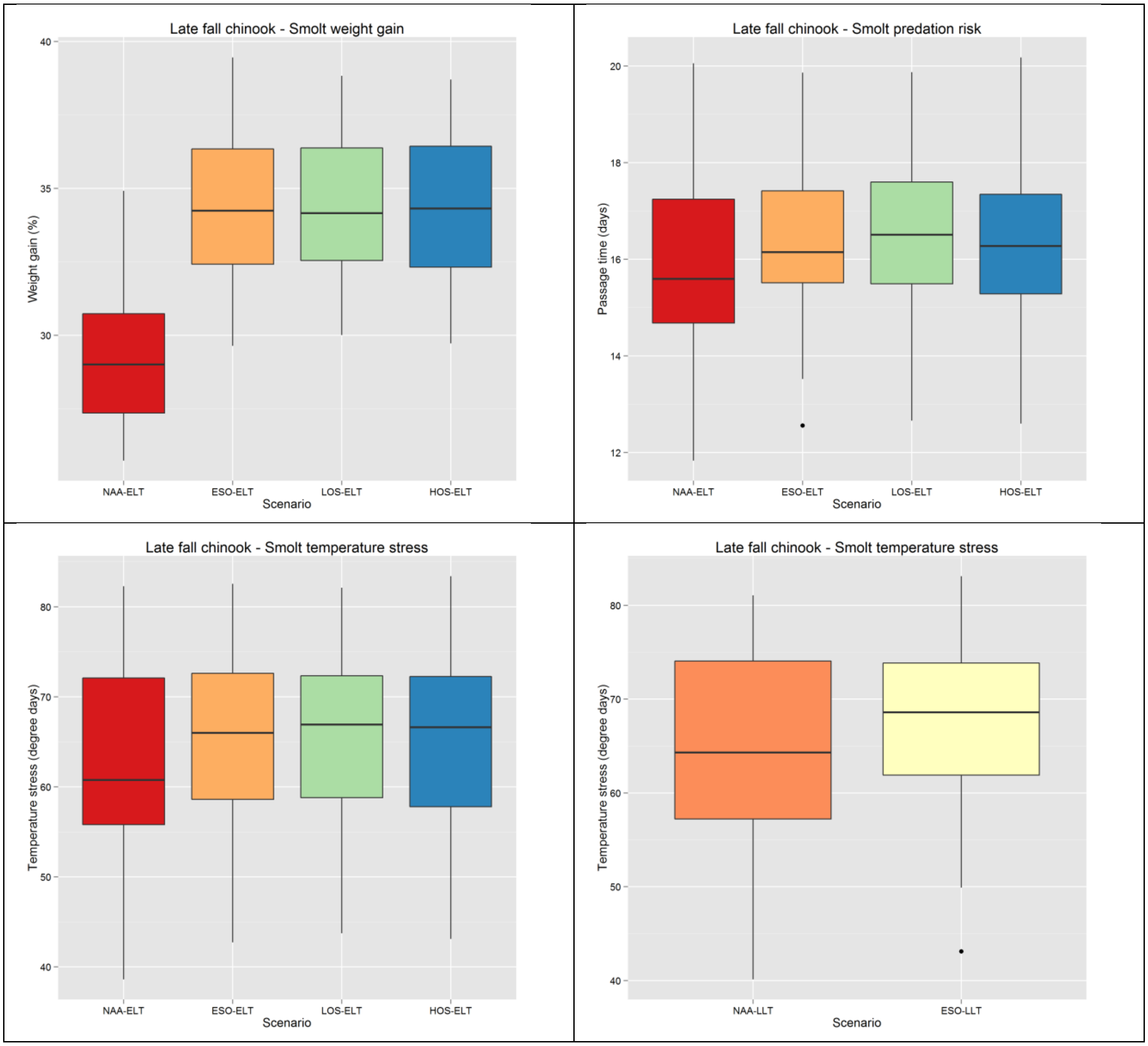


Figure 3.15: Late fall-run Chinook smolt weight gain (CS7, upper left panel), smolt predation risk (CS9, upper right panel), and smolt temperature stress (CS10, lower left panel) under three BDCP scenarios compared to the NAA-ELT reference case. The lower right panel shows smolt temperature stress (CS10) effects for the ESO-LLT scenario, compared to the NAA-LLT reference.

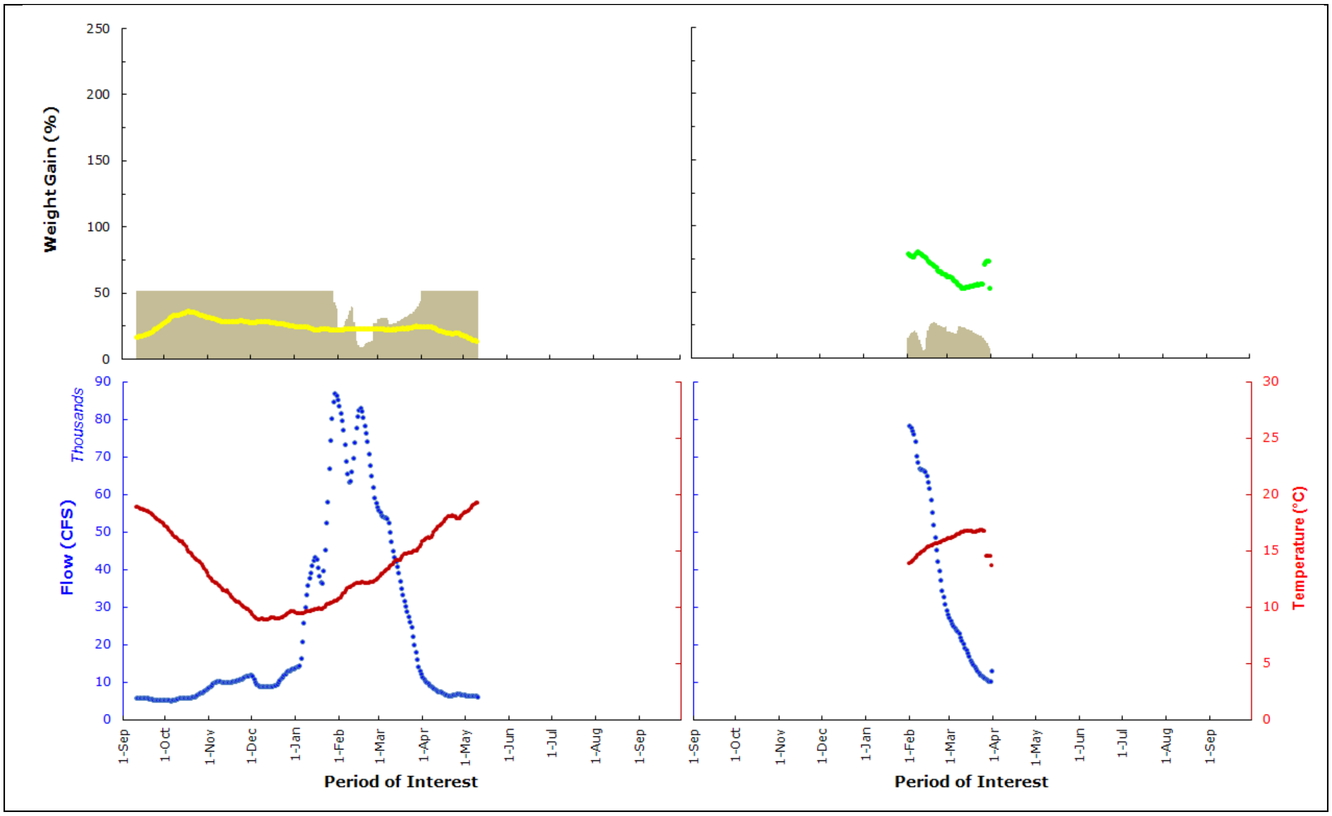


Figure 3.16: Composite view of a detailed Excel report created by EFT software, showing details of smolt weight gain in Yolo Bypass (CS7) under the NAA-ELT scenario in WY1986. In this year the performance of late fall-run Chinook is driven by the high proportion of the cohort travelling via the main-stem. The shaded region in the upper left panel shows the proportion of the year-cohort travelling this route, and the heavy yellow line shows percent weight gain for each day-cohort along that route. Flow and temperature (degrees C) experienced by each day-cohort are shown in the lower left panel. The smaller proportion travelling via Fremont Weir is shown by the shaded area in the upper right panel, along with percent weight gain on that route. The small proportion of the year-cohort travelling via Sacramento Weir is not shown here, but the overall outcome for the year is given a fair (Yellow) ranking, based on 30.2% weight gain overall, comprised of 25% gain for 88% travelling through the mainstem, 89% gain for 9% travelling via Fremont Weir, and 57% for 2% travelling via Sacramento Weir.

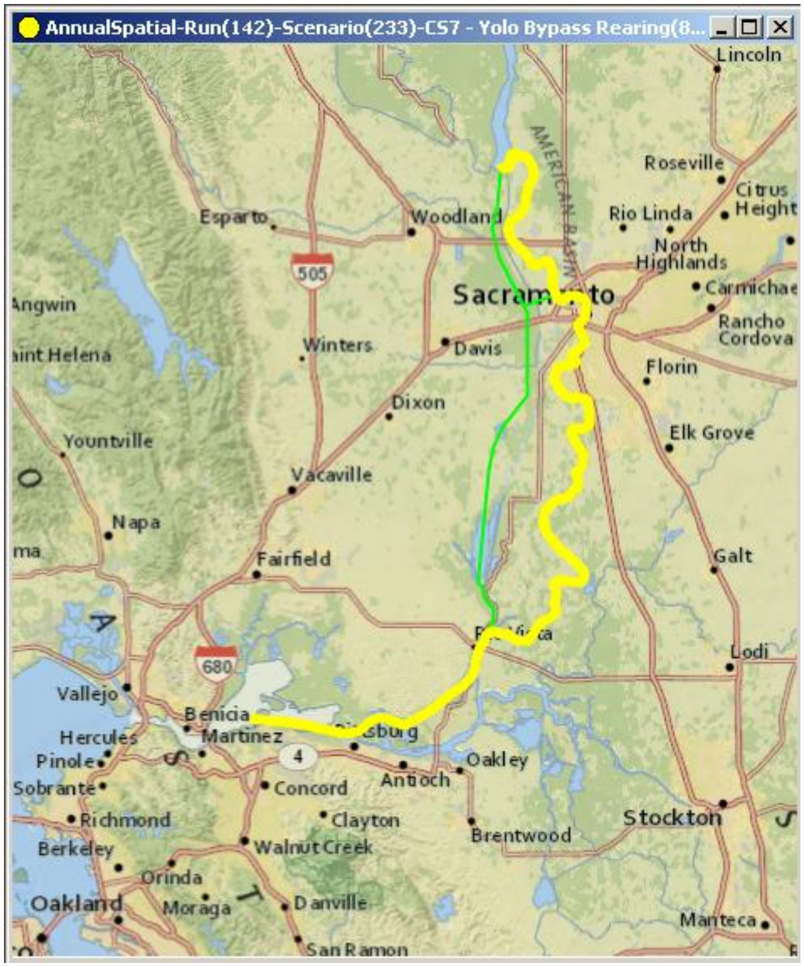


Figure 3.17: Detailed visualization report show locations of smolt weight gain in Yolo Bypass (CS7) under the NAA-ELT scenario in WY1986. In this year, weight gain in late fall-run Chinook is driven by the high proportion of the cohort travelling via the main-stem (heavy yellow line), improved by the small proportion which migrates via Fremont Weir and Sacramento Weir (fine green lines), resulting in a fair (Yellow) year overall.

Median smolt weight gain in Yolo Bypass (CS7) improves for winter-run Chinook under the ESO-LLT scenario, increasing by 5.1% compared to the NAA-LLT reference case (Figure 3.18). In the same figure, median smolt predation risk (CS9) increases meaningfully by 5.2% in the ESO-ELT and HOS-ELT scenarios, compared to the NAA-ELT reference case. Smolt temperature stress (CS10) becomes more extreme for winter-run Chinook under all BDCP scenarios, increasing by 11.3%, 11.2% and 11.0% under the ESO-ELT, LOS-ELT and HOS-ELT scenarios respectively (Figure 3.18). A similar 10.8% operation and conveyance effect increase also is seen for the LLT comparison under the ESO-LLT scenario.

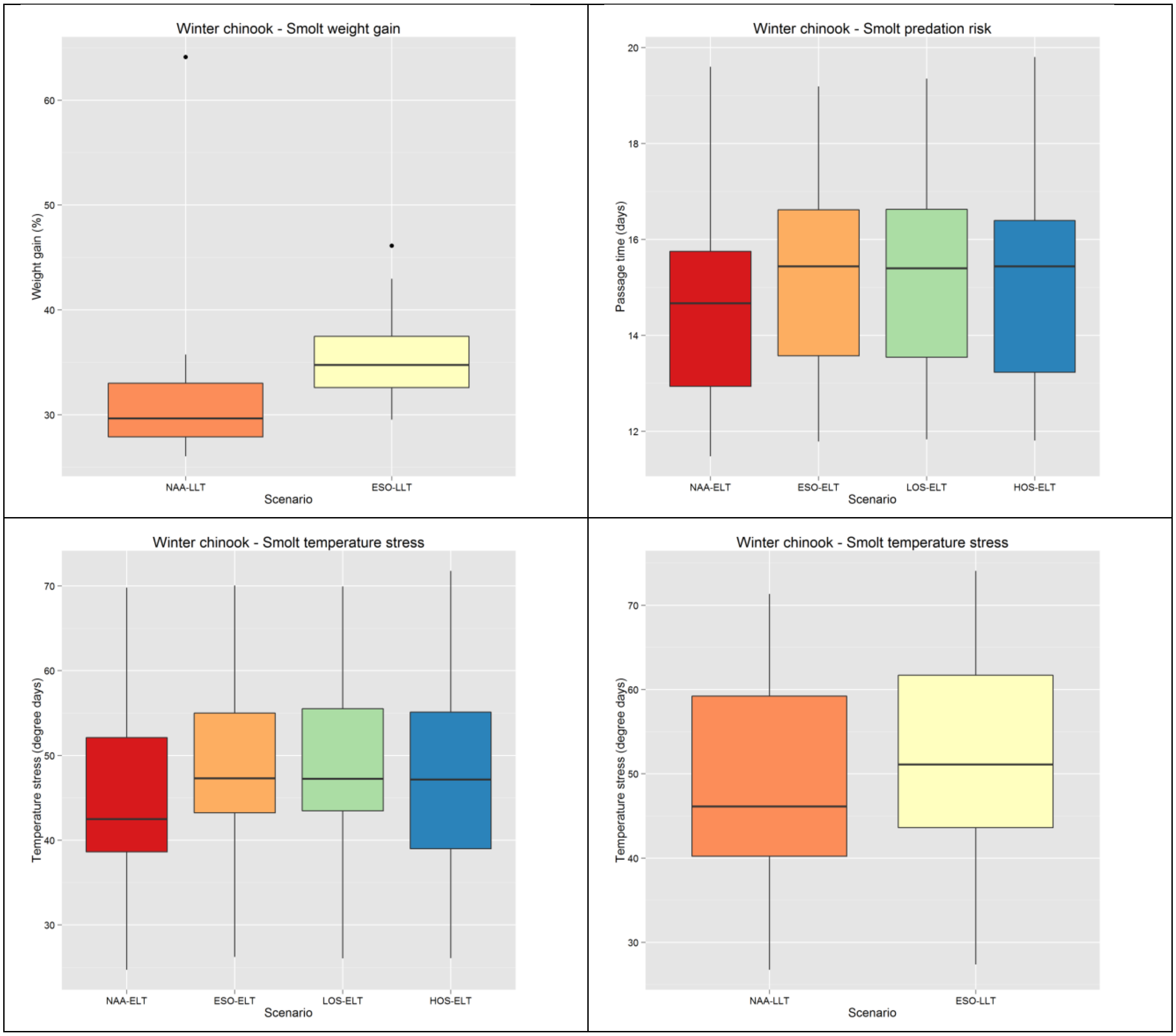


Figure 3.18: Winter-run Chinook smolt weight gain (CS7) under the ESO-LLT scenario compared to the NAA-ELT reference case (upper left panel). Winter-run Chinook smolt predation risk (CS9, upper right panel) and smolt temperature stress (CS10, lower left panel) under three BDCP scenarios compared to the NAA-ELT reference case. Smolt temperature stress (CS10) effects for the ESO-LLT scenario, compared to the NAA-LLT reference case (lower right panel).

Median smolt temperature stress (CS10) becomes more extreme for steelhead under all BDCP Early Long Term (ELT, 2030) scenarios, increasing by 7.7%, 7.6% and 9.3% under the ESO-ELT, LOS-ELT and HOS-ELT scenarios respectively (Figure 3.19 left panel, Figure 3.20 and Figure 3.21). A similar 6.1% operation and conveyance effect also exists for the ESO-LLT scenario, compared to the NAA-LLT reference case.

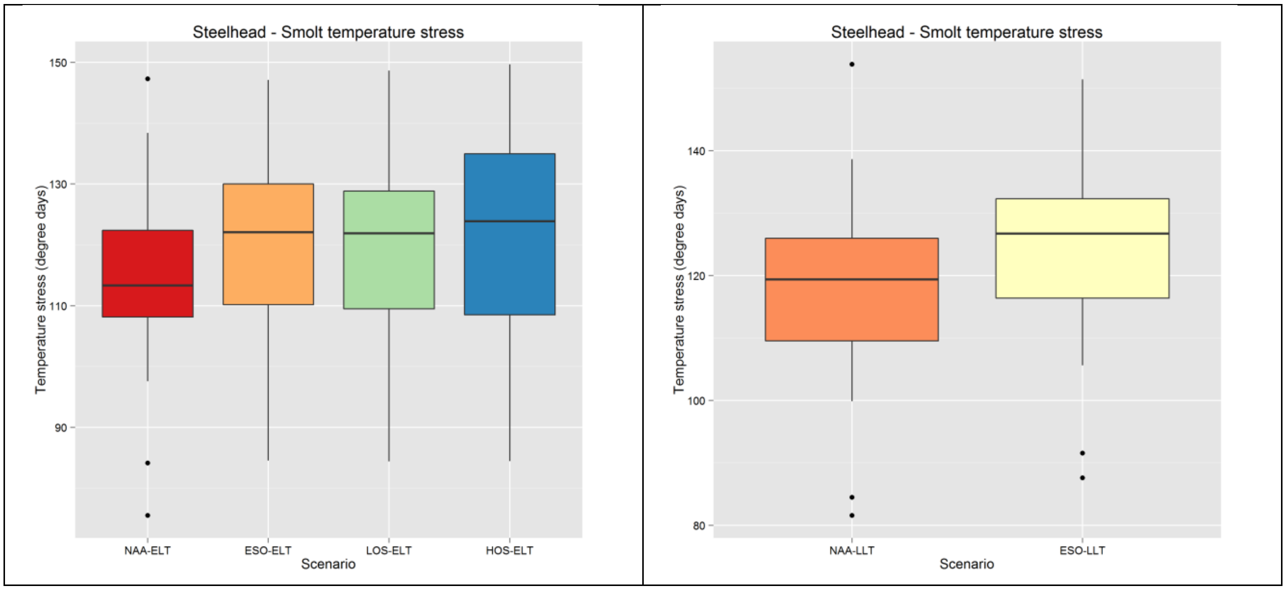


Figure 3.19: Steelhead smolt temperature stress (CS10) effects under three BDCP scenarios compared to the NAA-ELT reference case (left panel); and for the ESO-LLT scenario compared to the NAA-LLT reference case (right panel).

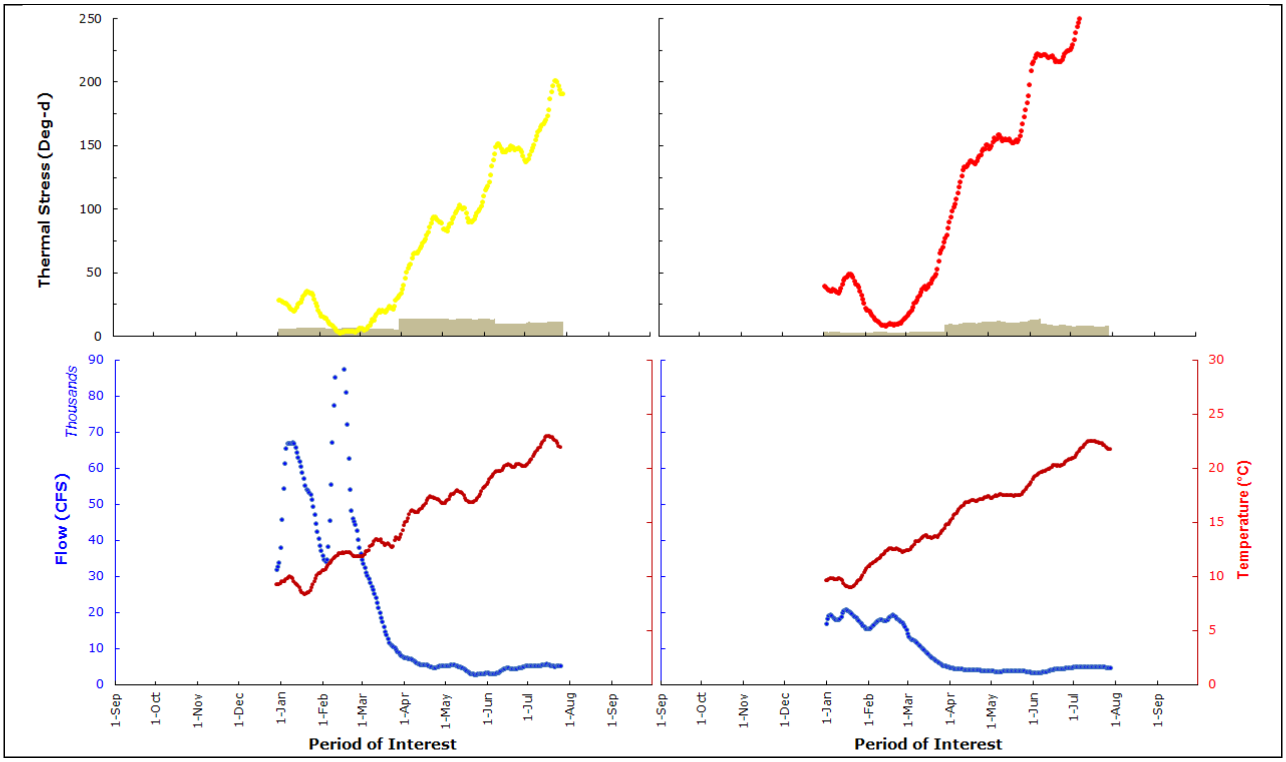


Figure 3.20: Composite view of a detailed Excel report created by EFT software, showing details of smolt temperature stress (CS10) under the NAA-ELT scenario in WY1980. In this year the performance of steelhead is driven by the higher proportion of the cohort travelling in more western routes (left panel, see Figure 3.21). The shaded region in the upper left panel shows the proportion of the year-cohort travelling in the western route B1, and the heavy yellow line shows thermal stress for each day-cohort along that route. Flow and temperature (degrees C) experienced by each day-cohort are shown in the lower left panel. A meaningful proportion travels through an eastern route through Georgiana Slough (E2), where thermal stress is higher due to increased temperature near the end of the migration period. The overall outcome for the year is given a fair (Yellow) ranking, based on 98 °C-days overall, comprised of 85 °C-days for 17% of the year cohort travelling along route B1, 143 °C-days for 12% of the year cohort traveling along route E1%, with the remainder divided among the four other routes. The overall annual stress for the year-cohort is 98 °C-days.

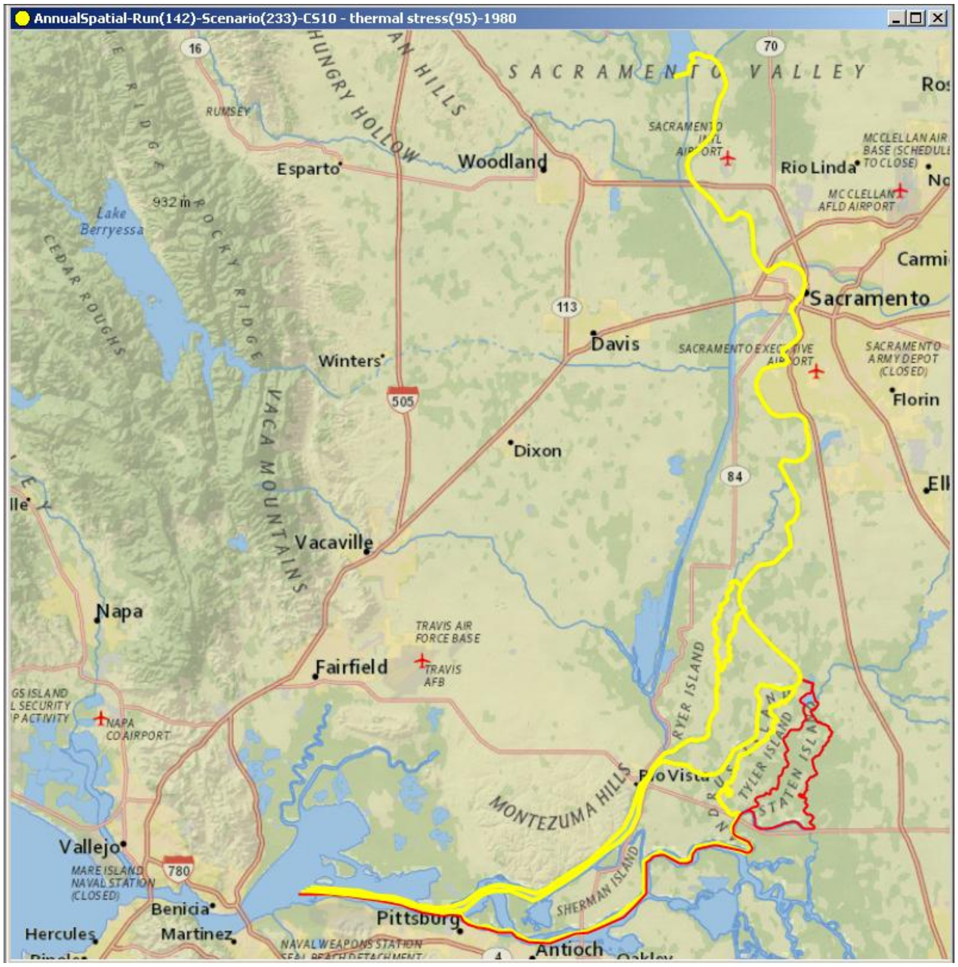


Figure 3.21: Detailed visualization report show locations of smolt temperature stress (CS10) under the NAA-ELT scenario in WY1980. In this year temperature stress in steelhead is driven by the high proportion of the cohort travelling via the main-stem and more western routes (yellow lines), but degraded in the more easterly routes (red lines), resulting in a fair (Yellow) year overall.

Splittail

The median proportion of maximum spawning habitat for splittail (SS1) is expected to increase meaningfully relatively to NAA-ELT under all three BDCP scenarios, from 0 to 0.156, 0.160 and 0.182 for ESO-ELT LOS-ELT and HOS-ELT (Figure 3.22, left panel). The change is expected to be meaningful as the changes in all individual water years are above zero (Figure 3.22, right panel). The change is most likely due to a notch constructed in the Fremont Weir as part of the BDCP scenarios (Section 3.3.2).

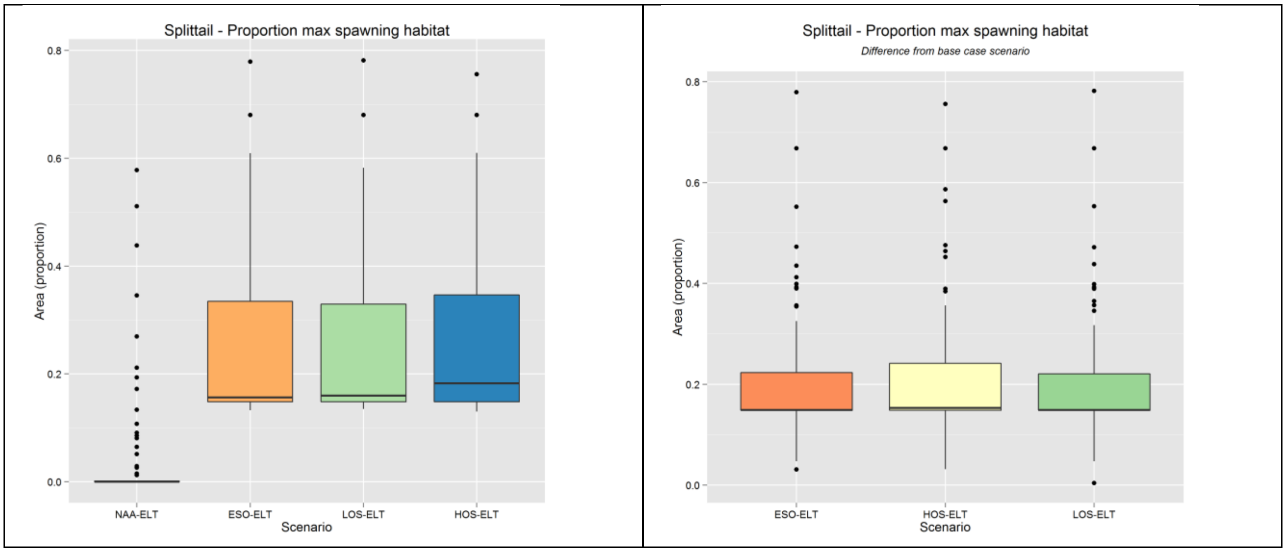


Figure 3.22: Median proportion of maximum spawning habitat for splittail (SS1) under three BDCP scenarios (left panel) compared to the NAA-ELT reference case, and showing annual differences relative to the NAA-ELT baseline scenario (right panel).

Delta Smelt

The median spawning success for Delta smelt (DS1) is expected to remain relatively constant between project alternatives at approximately 33 days of optimal spawning conditions annually.

The median habitat suitability index for Delta smelt (DS2) is expected to decrease relative to NAA-ELT under the LOS-ELT BDCP scenario by 11.8% (Figure 3.23, upper left panel). The change is expected to be meaningful since most individual water year differences are meaningfully negative (Figure 3.23, upper right panel).

The median habitat suitability index is expected to increase relative to NAA-LLT under the ESO-LLT scenario by 6.8% (Figure 3.23, lower left panel). The change is most likely meaningful since the distribution of individual water year differences is skewed towards positive (Figure 3.23, lower right panel).

The entrainment risk for Delta smelt (DS4) is expected to remain relatively constant between project alternatives. A proportion of 0.055 of the population of larvae and juvenile Delta smelt is estimated to be entrained and differences between estimated entrainment proportions for project alternatives are expected to be less than 0.004.

Overall, Delta smelt are expected to do worse in the LOS scenario in the Early-Long Term, and better in the ESO scenario in the Late-Long Term, making the ESO scenario preferable for Delta smelt.

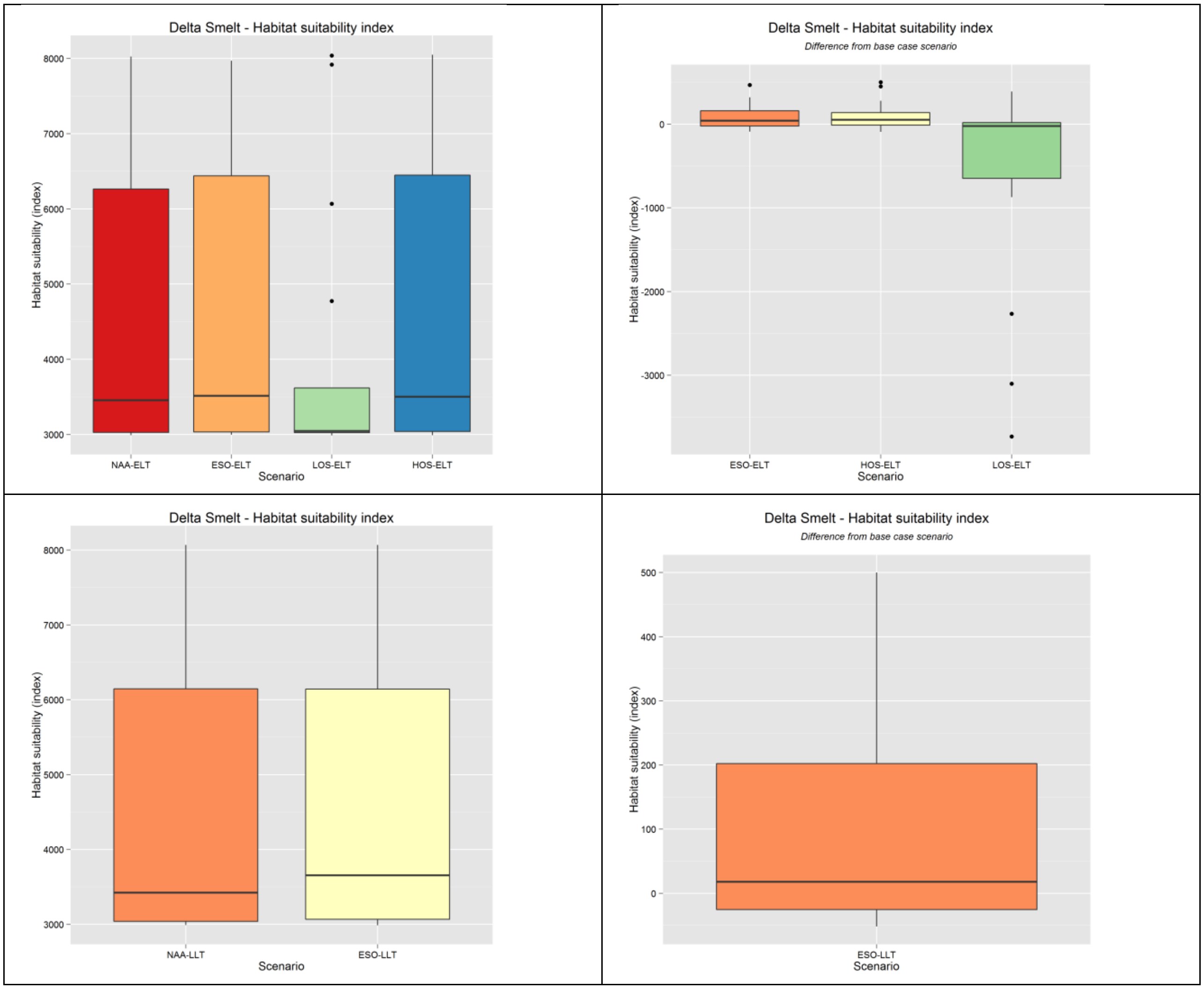


Figure 3.23: Median Delta smelt habitat suitability index (DS2) under three BDCP scenarios relative to NAA-ELT baseline (upper left panel), and the ESO-LLT scenario relative to the NAA-LLT baseline (lower left panel). Individual year differences for the ELT and LLT periods are shown in the upper right and lower right panels, respectively.

Longfin Smelt

The median abundance index for longfin smelt (LS1) is expected to increase relative to NAA-ELT under the HOS-ELT BDCP scenario by 9.4% (Figure 3.24, upper left panel). The change is most likely meaningful since most individual water year differences are positive

(Figure 3.24, upper right panel). The improvement is most likely due to the occasional high spring outflows included only in the operations of the HOS scenario (Chapter 3.2).

The median abundance index is expected to decrease slightly relative to NAA-LLT under the ESO-LLT BDCP scenario, i.e., by 5.1% (Figure 3.24, lower left panel). The change is most likely not meaningful since individual water year differences are both positive and negative (Figure 3.24, lower right panel).

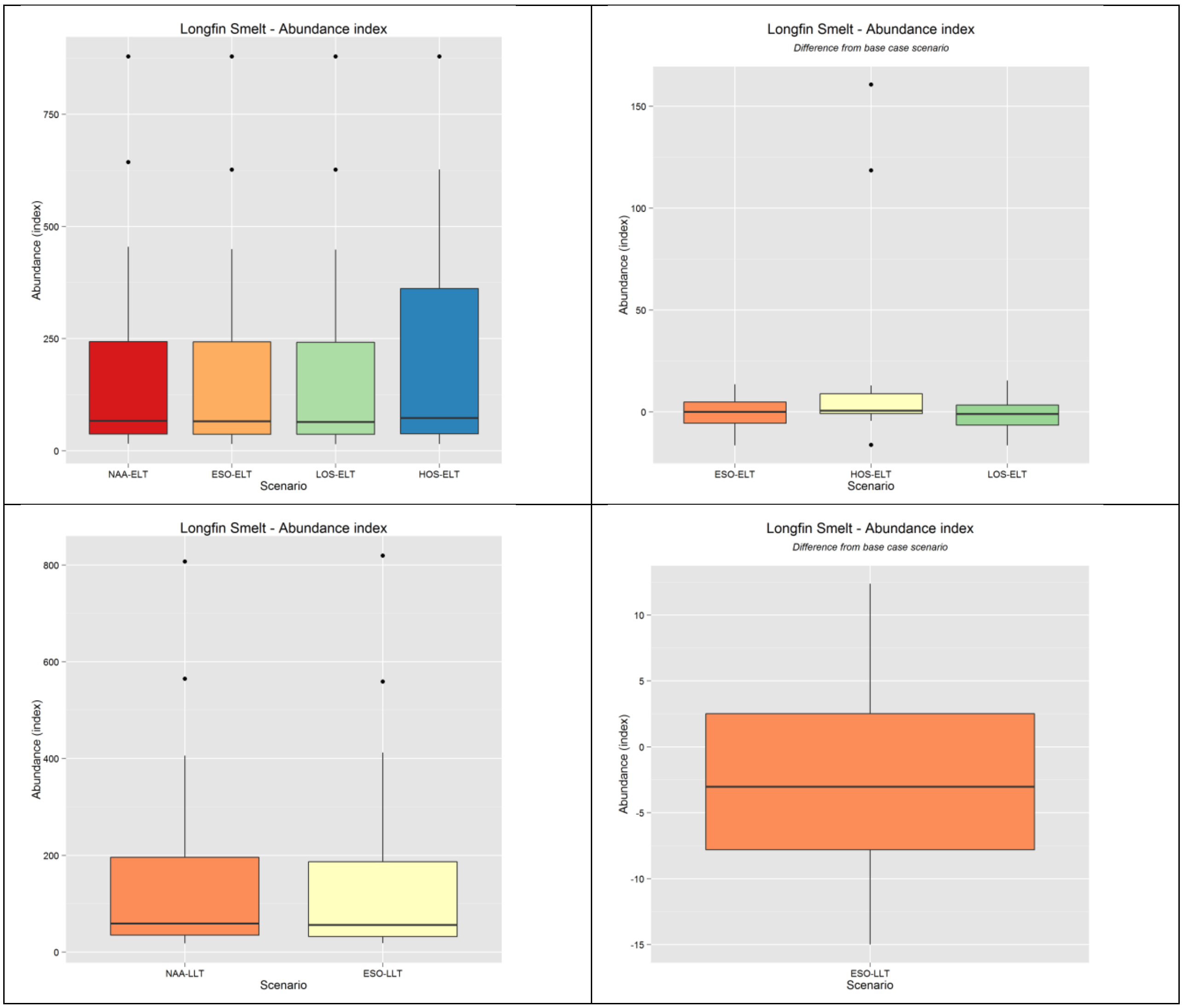


Figure 3.24: Median longfin smelt abundance index (LS1) under three BDCP scenarios relative to the NAA-ELT baseline (upper left panel), and ESO-LLT relative to the NAA-LLT baseline (lower left panel). Individual year differences for the ELT and LLT periods are shown in the upper right and lower right panels, respectively.

Invasive Deterrence

The index of median Brazilian waterweed suppression (ID1) is expected to remain relatively constant between project alternatives with an estimated maximum three month average salinity from May to October of 8.9‰ for the ‘Chipps Island to Oakley’ region.

The median overbite clam larval suppression (ID2) is expected to decrease relative to NAA-ELT for all three BDCP scenarios as estimated minimum three month average salinities increase from December to April from 2.7‰ to 3.3‰ for the ‘680 Bridge to Chipps Island’ region (Figure 3.25, left panel). The change is expected to be meaningful since almost all individual water year differences are positive (Figure 3.25, right panel). This increase in average salinity is due to the increased salinity at Port Chicago in February and March for all BDCP scenarios, and also in April for ESO and LOS (Table 3.16).

The median Asiatic clam larval suppression (ID3) is expected to remain relatively constant between project alternatives with an estimated maximum three month average salinity from May to October of 8.9‰ for the ‘Chipps Island to Oakley’ region.

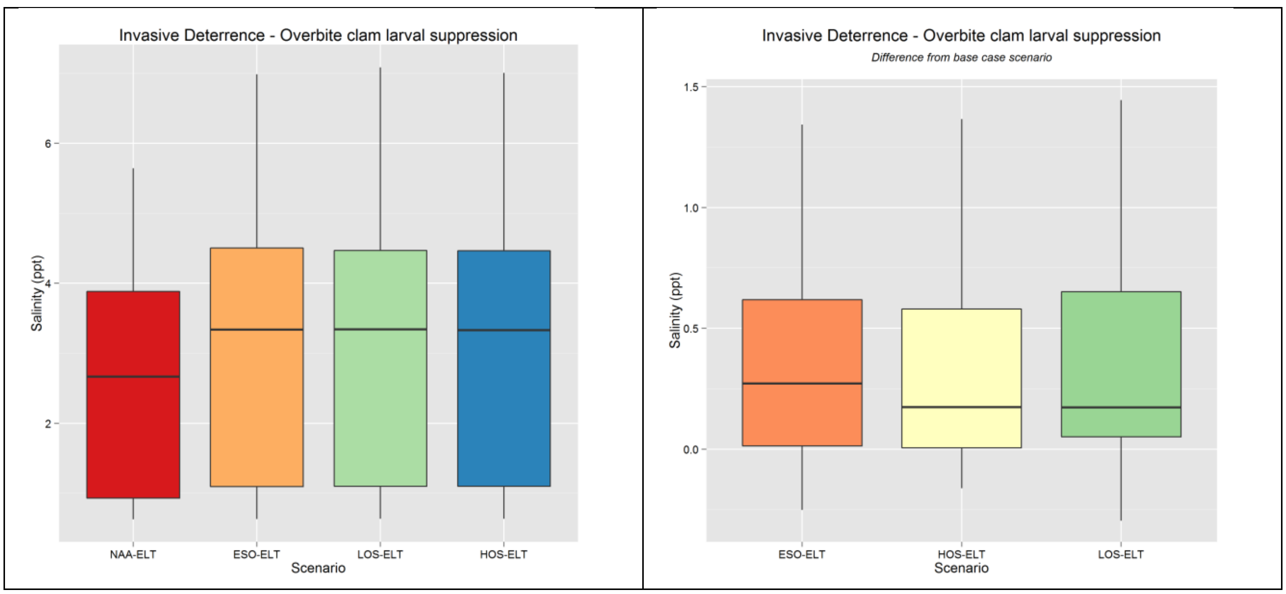


Figure 3.25: Median overbite clam larval suppression (ID2) under three BDCP scenarios relative to the NAA-ELT baseline (left panel), and showing individual year differences relative to the ELT baseline (right panel).

Tidal Wetlands

The median brackish wetland area (TW1) is expected to remain relatively constant between project alternatives in the Early Long Term with an estimated area of approximately 700 ha. The median brackish wetland area is expected to decrease in the Late Long Term for ESO-LLT relative to NAA-LLT by 9% (Figure 3.26, upper left panel). The difference is expected to be meaningful as all individual water year differences are negative (Figure 3.26, upper right panel).

The median freshwater wetland area (TW2) is expected to remain relatively constant between project alternatives in the Early Long Term with an estimated area of approximately 280 ha. The median Freshwater wetland area is expected to decrease in the Late Long Term for ESO-LLT relative to NAA-LLT by 5.9% (Figure 3.26, lower left panel). The difference is expected to be meaningful as all individual water year differences are negative (Figure 3.26, lower right panel).

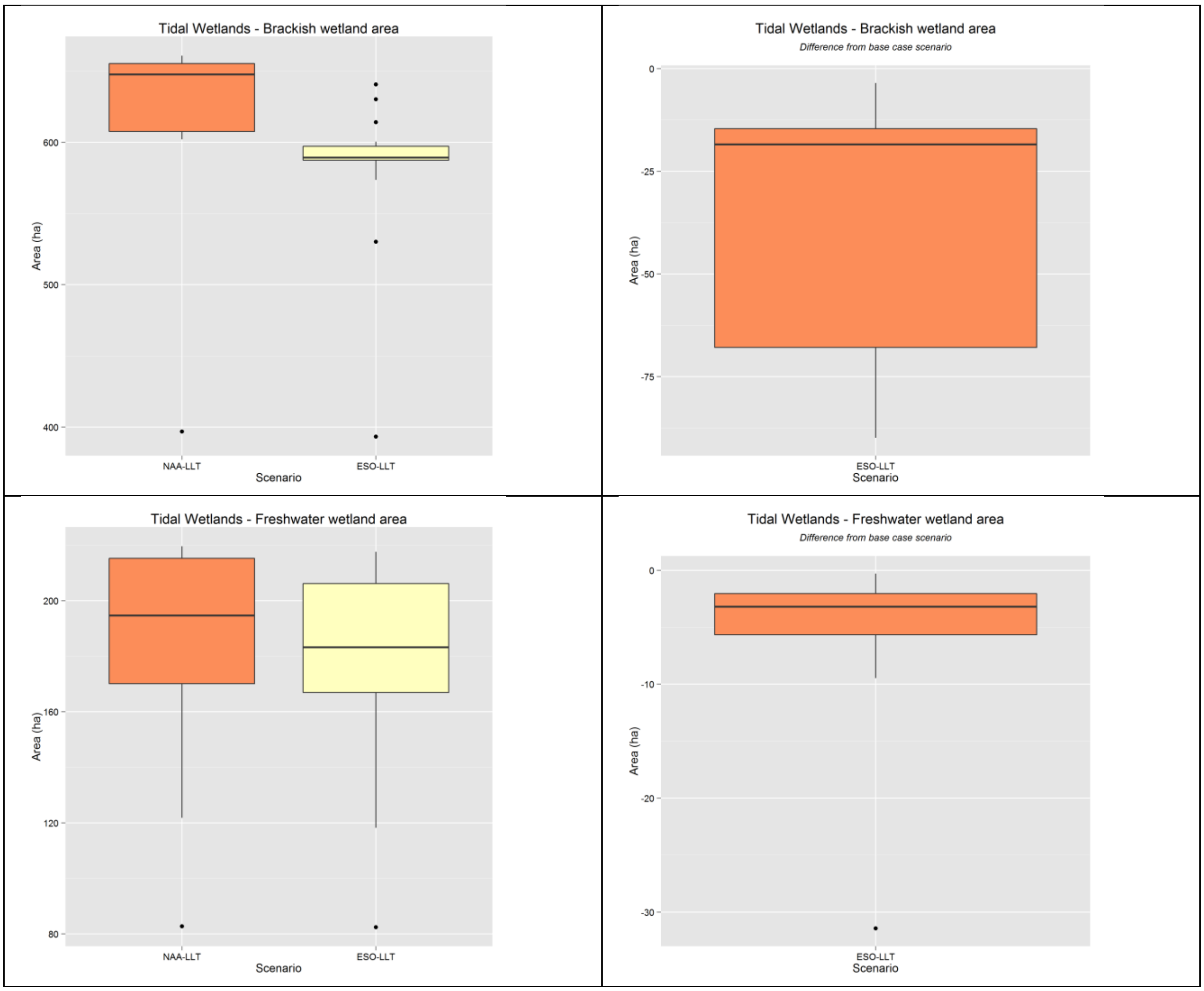


Figure 3.26: Median brackish (TW1) and freshwater (TW2) wetland area in the Late Long Term for ESO-LLT relative to NAA-LLT (upper left and lower left panels, respectively), and showing individual year differences relative to the LLT base case (upper and lower right panels).

Future climate and demand effects

Climate and demand effect size results are closely tied to the ES methodology described in Section 2.8.6. Table 3.31 shows results of this methodology for the Delta ecoregion. The following section summarizes Climate/Demand effects in which the median effect differs by more than 5% from a reference case comparative response. A synthesis of these effects is presented in Table 3.35.

Table 3.31: Climate and demand effect sizes are shown for the No Action Alternative (NAA) scenario at three future climate periods using the median difference Effect Size (ES) method, preserving the native units of each indicator. $^{\delta}$

Focal species	Performance indicator	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Delta Indicators				
Fall Chinook	Smolt weight gain (CS7; %)	21.2	19.1 (-2.0%)	17.7 (-3.4%)
	Smolt predation risk (CS9; passage days)	15.3	15.5 (-1.5%)	15.7 (-2.5%)
	Smolt temperature stress (CS10; degree day)	101.7	113.4 (-11.6%)	115.1 (-13.2%)
Late Fall Chinook	Smolt weight gain (CS7; %)	29.8	29.0 (-0.8%)	28.3 (-1.4%)
	Smolt predation risk (CS9; passage days)	15.7	15.6 (0.7%)	15.5 (1.1%)
	Smolt temperature stress (CS10; degree day)	58.2	60.8 (-4.3%)	64.3 (-10.4%)
Spring Chinook	Smolt weight gain (CS7; %)	24.2	23.0 (-1.3%)	22.1 (-2.1%)
	Smolt predation risk (CS9; passage days)	15.4	15.6 (-1.4%)	15.6 (-1.2%)
	Smolt temperature stress (CS10; degree day)	84.2	87.1 (-3.4%)	88.1 (-4.5%)
Winter Chinook	Smolt weight gain (CS7; %)	30.4	30.3 (-0.1%)	29.6 (-0.7%)
	Smolt predation risk (CS9; passage days)	14.5	14.7 (-1.2%)	14.7 (-1.7%)
	Smolt temperature stress (CS10; degree day)	39.6	42.5 (-7.3%)	46.1 (-16.5%)
Steelhead	Smolt weight gain (CS7; %)	19.7	17.7 (-2.0%)	16.4 (-3.3%)
	Smolt predation risk (CS9; passage days)	15.6	15.8 (-0.8%)	15.7 (-0.2%)

Focal species	Performance indicator	NAA-Current Reference case (225)	NAA-ELT (233)	NAA-LLT (243)
Delta Indicators				
	Smolt temperature stress (CS10; degree day)	106.7	113.3 (-6.2%)	119.4 (-11.8%)
Splittail	Proportion max spawning habitat (SS1)	0.000	0.000	0.000
Delta Smelt	Spawning success (DS1; optimal days)	33.3	33.0 (-0.8%)	33.7 (1.2%)
	Habitat suitability index (DS2)	3,023	3,456 (14.3%)	3,423 (13.2%)
	Larval & juvenile entrainment proportion (DS4)	0.059	0.054 (0.4%)	0.062 (-0.3%)
Longfin Smelt	Abundance index (LS1)	95.8	66.6 (-30.5%)	59.0 (-38.5%)
Invasive Deterrence	Brazilian waterweed suppression (ID1)	9.1	9.1 (0.4%)	8.9 (-1.4%)
	Overbite clam larval suppression (ID2)	2.1	2.7 (-25.7%)	2.9 (-36.9%)
	Asiatic clam larval suppression (ID3)	9.1	9.1 (0.4%)	8.9 (-1.4%)
Tidal Wetlands	Brackish wetland area (TW1; ha)	750.7	705.5 (-6.0%)	647.8 (-13.7%)
	Freshwater wetland area (TW2; ha)	288.9	283.7 (-1.8%)	194.6 (-32.6%)

$^{\delta}$ The **NAA-Current** scenario serves as a comparative reference case with percentage differences shown below absolute median effects. Percentage differences for indicators measured as proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Salmonids

Median smolt temperature stress (CS10) for fall-run Chinook becomes more extreme under the two future scenarios, increasing by 11.6% and 13.2% under the NAA-ELT and NAA-LLT scenarios respectively (Figure 3.27).

Late fall-run Chinook smolts experience a 10.4% increase in median thermal stress (CS10) in the NAA-LLT scenario, compared to the NAA-Current scenario (Figure 3.27).

Winter-run Chinook smolts experience similar increases in median thermal stress (CS10) of 7.3% and 16.5% in the NAA-ELT and NAA-LLT scenarios, compared to the reference case (Figure 3.27).

Steelhead smolts experience similar increases in median thermal stress (CS10) of 6.2% and 11.8% in the NAA-ELT and NAA-LLT scenarios, compared to the reference case (Figure 3.27).

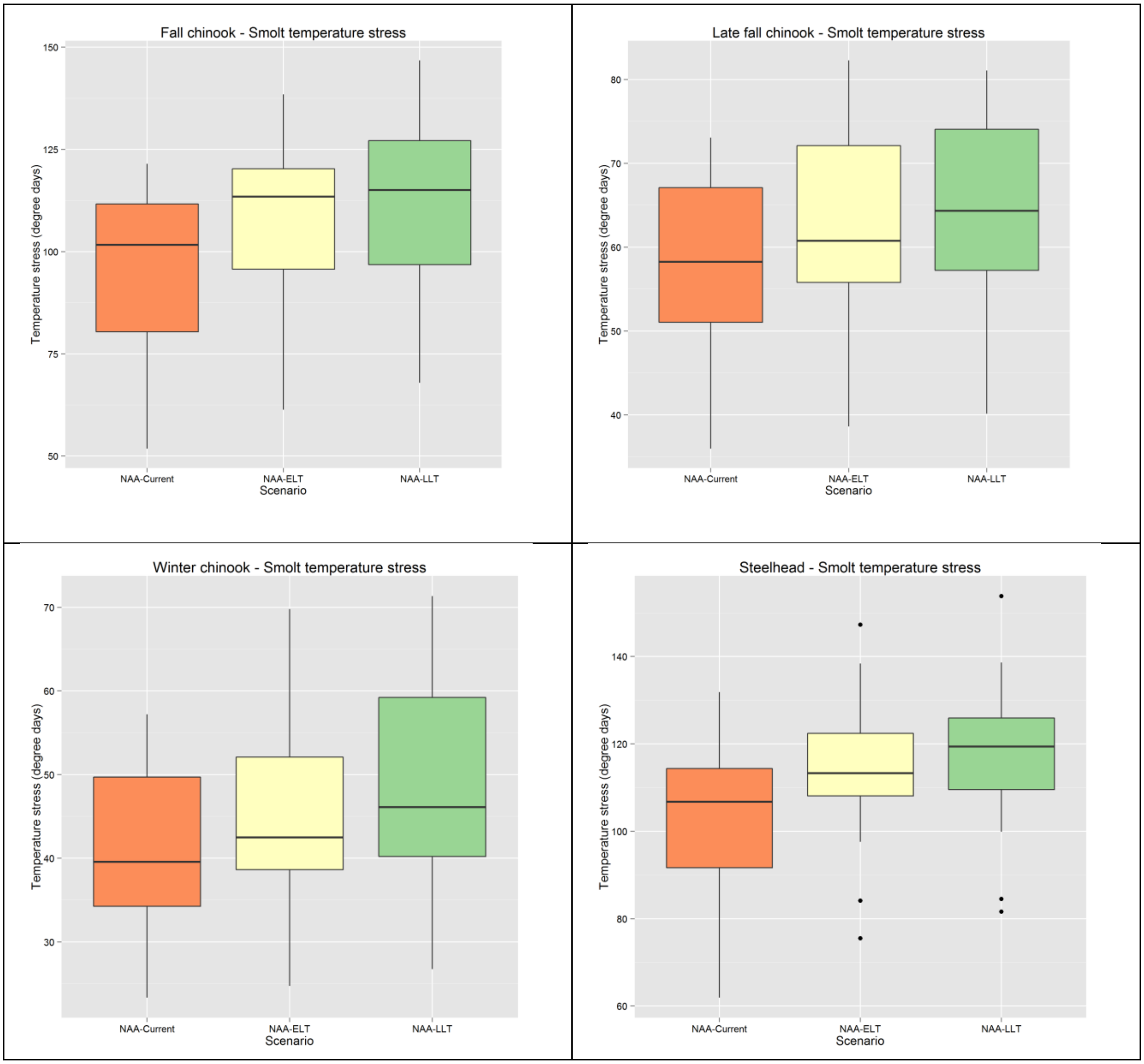


Figure 3.27: Smolt temperature stress (CS10) in the Early Long Term (ELT, 2030) and Late Long Term (LLT, 2060) period compared to the NAA-Current reference case for fall-run Chinook (upper left panel), late fall-run Chinook (upper right panel), winter-run Chinook (lower left panel), and steelhead (lower right panel).

Splittail

The median proportion of maximum spawning habitat for splittail (SS1) is expected to remain constant under different future climates and demands.

Delta Smelt

The median spawning success for Delta smelt (DS1) is expected to remain relatively constant under different future climates and demands at approximately 33 optimal days.

The median habitat suitability index for Delta smelt (DS2) is expected to increase relative to the NAA-Current scenario under future climates and demands: 14.3% and 13.2% for NAA-ELT and NAA-LLT (Figure 3.28, left panel). The change is expected to be meaningful since the majority of individual water year differences are positive (Figure 3.28, right panel). The improvement is most likely due to the inclusion of Fall X2 actions under the ELT and LLT scenarios for NAA (Chapter 3.2).

The entrainment risk for Delta smelt (DS4) is expected to remain relatively constant under different future climates and demands at approximately 0.055.

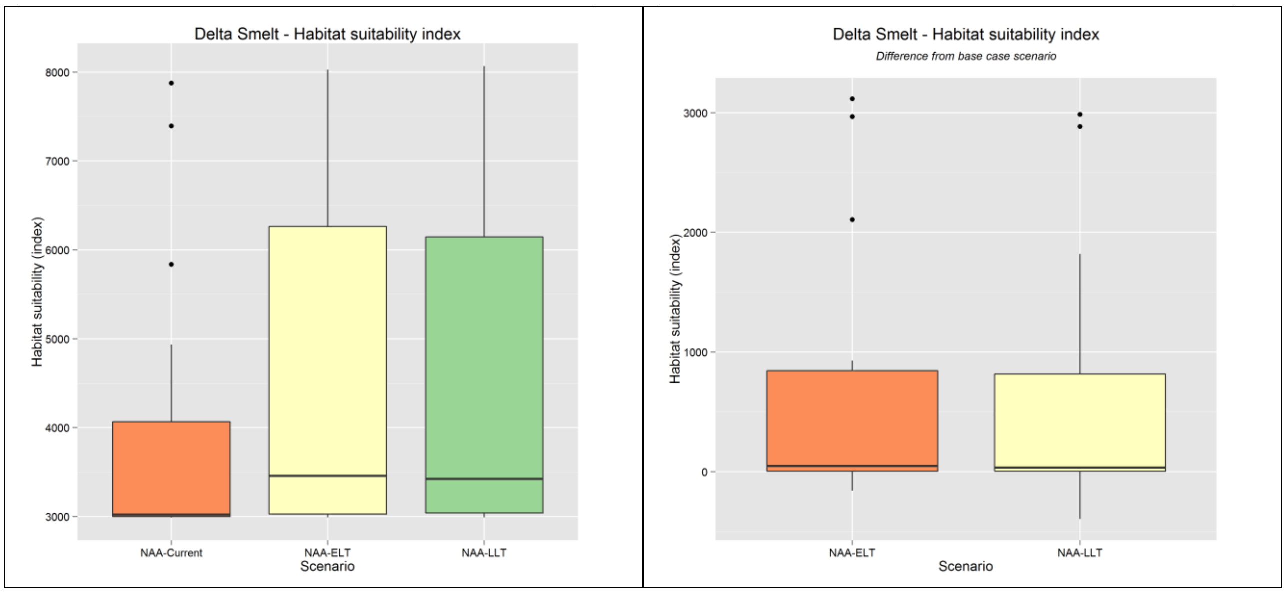


Figure 3.28: Median Delta smelt habitat suitability index (DS2) under future climate and demand relative to the NAA-Current baseline (left panel), showing individual year differences relative to the baseline scenario (right panel).

Longfin Smelt

The median abundance index for longfin smelt (LS1) is expected to decrease relative to the NAA-Current scenario under the future climate and demand scenarios: 30.5% and 38.5% for NAA-ELT and NAA-LLT (Figure 3.29, left panel).The change is expected to be meaningful since almost all of individual water year differences are negative (Figure 3.29, right panel). The deterioration is most likely due to the increased salinity in Suisun Bay caused by sea level rise (Chapter 3.2).

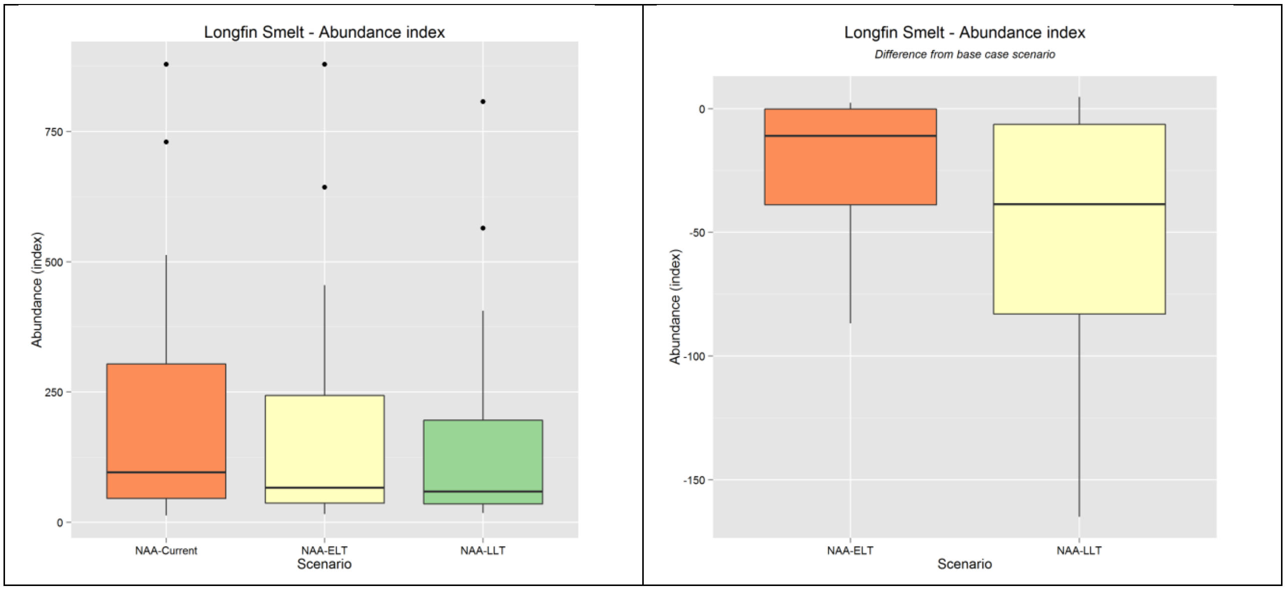


Figure 3.29: Median longfin smelt abundance index (LS1) under future climate and demand relative to the NAA-Current baseline (left panel), showing individual year differences relative to the baseline (right panel).

Invasive Deterrence

The median Brazilian waterweed suppression (ID1) is expected to remain relatively constant under future climates and demands with an estimated maximum three month average salinity from May to October of 8.9‰ for the ‘Chipps Island to Oakley’ region.

The median overbite clam larval suppression (ID2) is expected to decrease relative to NAA-Current for future climates and demands. The estimated minimum three month average salinity from December to April increases from 2.1‰ in the current future climate period to 2.7‰ in the Early Long Term and 2.9‰ in the Late Long Term for the ‘680 Bridge to Chipps Island’ region (Figure 3.30, left panel). The change is expected to be meaningful since almost all individual water year differences are positive (Figure 3.30, right panel). The deterioration is most likely due to the increased salinity in Suisun Bay caused by sea level rise (Chapter 3.2).

The median Asiatic clam larval suppression (ID3) is expected to remain relatively constant under future climates and demands with an estimated maximum three month average salinity from May to October of 8.9‰ for the ‘Chipps Island to Oakley’ region.

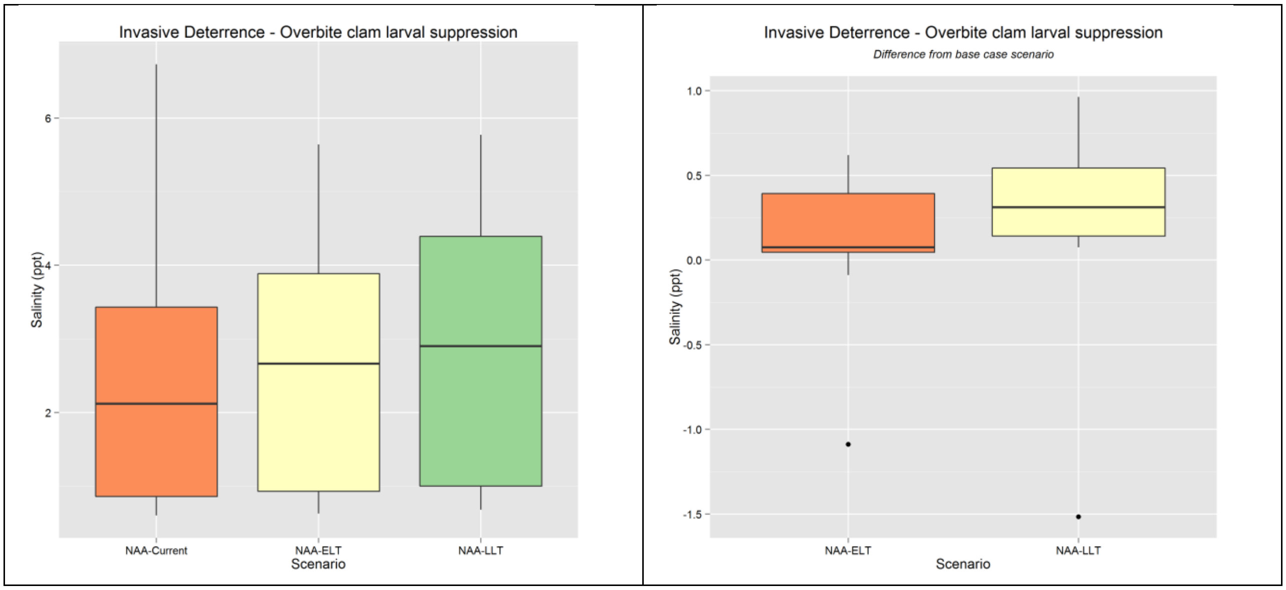


Figure 3.30: Median overbite clam larval suppression (ID2) under future climate and demand relative to the NAA-Current baseline (left pane), showing individual year differences relative to the baseline (right panel).

Tidal Wetlands

The median brackish wetland area (TW1) is expected to decrease relative to NAA-Current under future climates and demands: 6.0% and 13.7% for NAA-ELT and NAA-LLT (Figure 3.31, upper left pane). The change is expected to be meaningful since almost all individual water year differences are negative for NAA-ELT and all water year differences are negative for NAA-LLT (Figure 3.31, upper right pane). This change is driven by sea-level rise.

The median freshwater wetland area (TW2) is expected to decrease in the Late Long Term by 32.6% for NAA-LLT relative to NAA-Current (Figure 3.31, lower left pane). The change is expected to be meaningful since all water year differences are negative for NAA-LLT (Figure 3.31, lower right pane).

Note, these projected changes do not consider the potential opportunity for physical restoration to offset or reverse these losses.

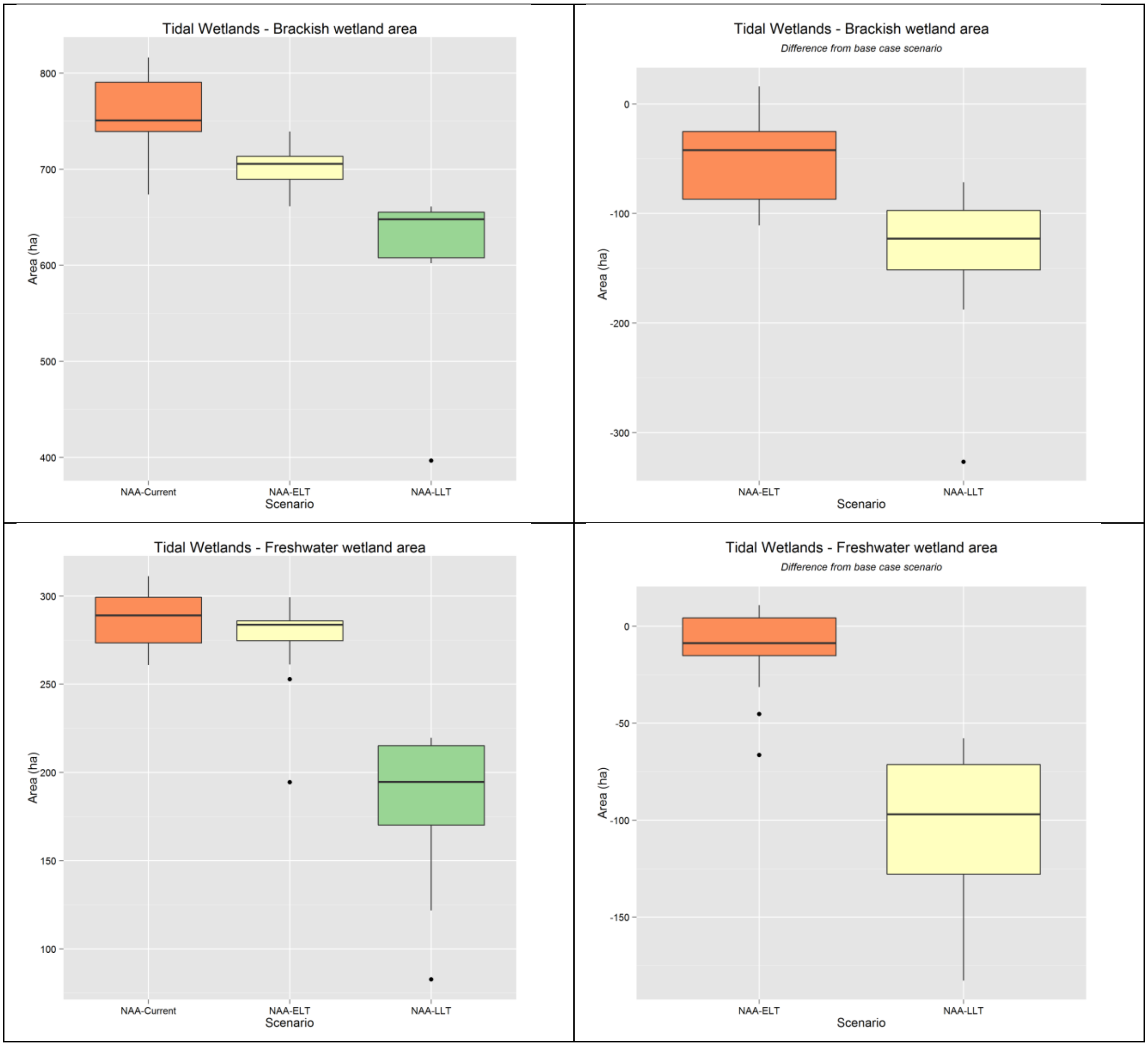


Figure 3.31: Median brackish (TW1) and freshwater (TW2) wetland area under future climate and demand scenarios relative to the NAA-Current baseline (upper left and lower left panels, respectively), showing individual year differences relative to the baseline (upper and lower right panels).

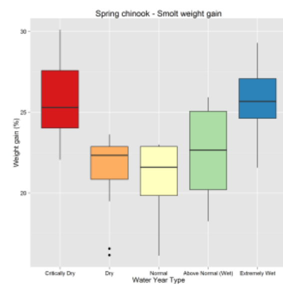
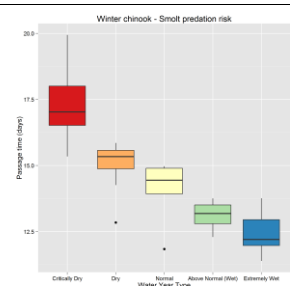
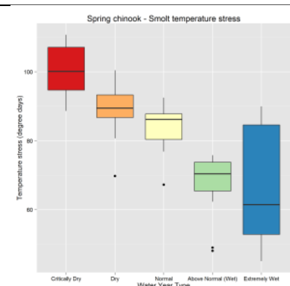
Water year characterization

Although they cannot be compared directly to a reference case, for many indicators, Water Year effects are larger than operation and conveyance effects. The following section describes these effects indicator by indicator.

Salmonids

Differences among water years are seen for all salmonid indicators in the Delta ecoregion, with simple patterns that are consistent across all run types. These are summarized in Table 3.32. One of the more interesting patterns is for smolt weight gain (CS7), which benefits in both low and high flow years, for reasons that are given in the table.

Table 3.32: Summary of Water Year patterns observed for salmonid indicators from the San Joaquin-Delta ecoregion.

Indicator	Run type	Pattern	Explanation	Typical Boxplot
Smolt weight gain (CS7)	All	Improved in extreme years	Peak salmonid growth is enhanced with longer residence time (lower flow dry years) and more substantial proportion of the cohort in Yolo (wetter years).	
Smolt predation risk (CS9)	All	Declining in wetter years	Predation risk is reduced in high flow years with shorter passage time	
Smolt temperature stress (CS10)	All	Declining in wetter years	Smolt stress is reduced in cooler high flow years	

Splittail

The median proportion of maximum spawning habitat for splittail (SS1) increases meaningfully in wetter Water Year types, with the median for extremely wet water years being almost twice the amount expected in normal and drier Water Year types (Figure 3.32).

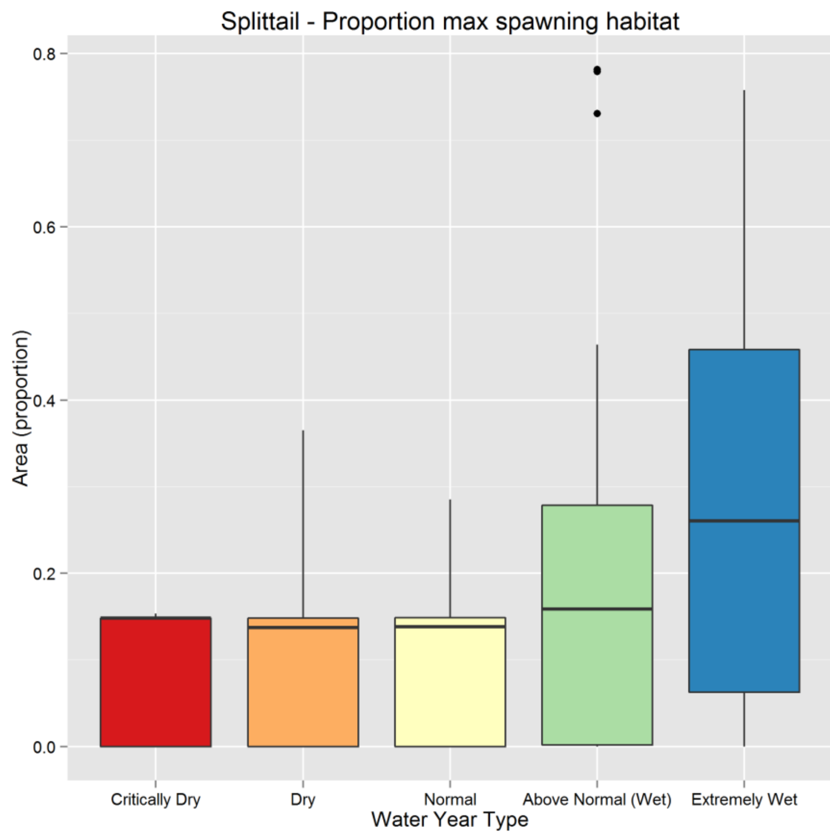


Figure 3.32: Median proportion of maximum spawning habitat for splittail (SS1) by Water Year type.

Delta Smelt

The median spawning success for Delta smelt (DS1) is expected to remain relatively constant between Water Year types.

The median habitat suitability index for Delta smelt (DS2) is expected to increase meaningfully in above normal and extremely wet water years (Figure 3.33, left panel) with median habitat suitability index in extremely wet water years being more than twice the value of normal and drier Water Year types.

The entrainment risk for Delta smelt (DS4) is expected to decrease meaningfully in above normal and extremely wet water years (Figure 3.33, right panel) with median entrainment risk in extremely wet water years being almost half the value of normal and drier Water Year types.

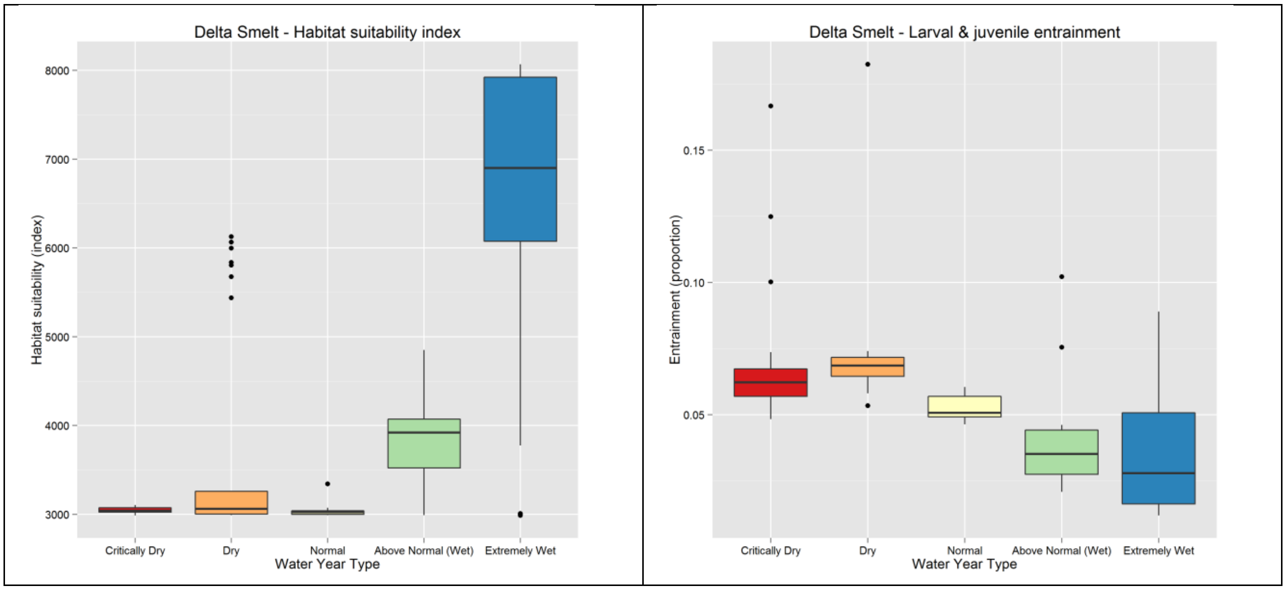


Figure 3.33: Median habitat suitability index for Delta smelt (DS2, left panel) and entrainment risk for Delta smelt (DS4, right panel) by Water Year type.

Longfin Smelt

The median abundance index for longfin smelt (LS1) is expected to be relatively higher in above normal and extremely wet Water Year types (Figure 3.34) with median abundance index values being approximately twice that of drier years.

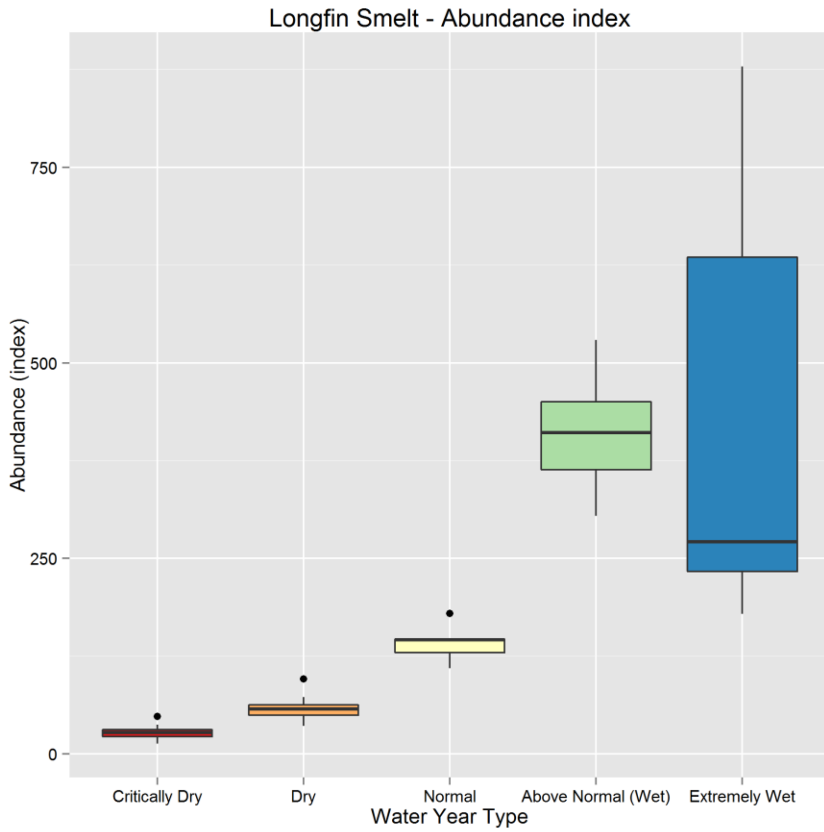


Figure 3.34: Median abundance index for longfin smelt (LS1) by Water Year type.

Invasive Deterrence

The median Brazilian waterweed suppression (ID1) is expected to decrease in wetter Water Year types as maximum three month average salinity from May to October decreases for the 'Chipps Island to Oakley' region (Figure 3.35, upper left panel).

The median overbite clam larval suppression (ID2) is expected to increase meaningfully in wetter Water Year types as minimum three month average salinity from December to April decreases for the '680 Bridge to Chipps Island' region (Figure 3.35, upper right panel).

The median Asiatic clam larval suppression (ID3) is expected to decreases in wetter Water Year types as maximum three month average salinity from May to October decreases for the 'Chipps Island to Oakley' region (Figure 3.35, lower left panel).

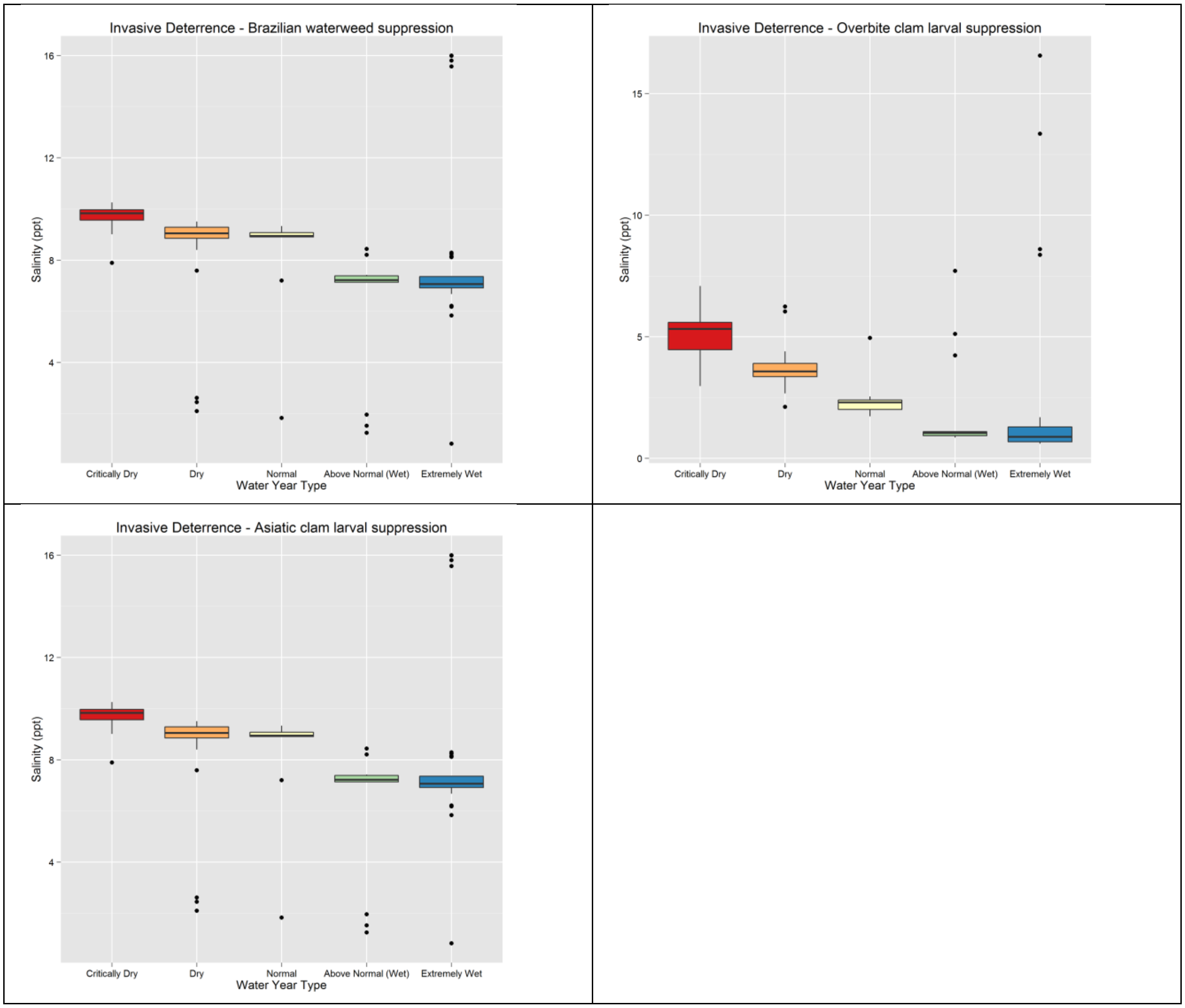


Figure 3.35: Median Brazilian waterweed suppression (ID1, upper left panel), overbite clam larval suppression (ID2, upper right panel), and Asiatic clam larval suppression (ID3, lower left panel) by Water Year type.

Tidal Wetlands

Both the brackish (TW1) and freshwater (TW2) wetland area remains highly variable in all Water Year types without any distinguishable pattern.

Summary of Species Net Effects

Table 3.34 and Table 3.33 demonstrate that among the salmonids, fall-run Chinook, spring-run Chinook (LSO alternative only), and late fall-run Chinook benefit from BDCP alternatives. Fall-run Chinook (all three alternatives) and spring-run Chinook (LOS alternative only) are beneficiaries that show meaningful improvement in suitable spawning habitat (CS1). Likewise, late fall-run Chinook benefit from improvements to flows during rearing (CS2, CS7) relative to current conditions (this is in part associated with the conditions in the NAA-ELT reference case itself, *not* from any additional features of the three operational alternatives). Some of the improvement in Delta rearing habitat conditions (and pre-smolt growth, CS7) for late fall-run Chinook may be offset by increased temperature stress (CS10). Overall Net Effect Scores (NES) are provided in Table 3.35.

EFT results show that overall, the LOS BDCP alternative is preferable for species completing life-history stages in the Sacramento River (especially fall-run Chinook, late fall-run Chinook and spring-run Chinook) while the HOS BDCP alternative is preferable for San Joaquin-Delta species (especially longfin smelt and, to a lesser degree, Delta smelt) (Table 3.36). Fall-run Chinook, late fall-run Chinook, and splittail do better under all BDCP alternatives considered ("winners"), while green sturgeon, deterrence of invasives and brackish wetland habitats are expected to experience deteriorating conditions (Table 3.36). Overall, the HOS alternative is likely the most preferable in terms of delivering ecological benefits. While LOS ecosystem benefits are superior for species in the Sacramento River, results from HOS are generally very similar. EFT results suggest the HOS is more likely to benefit Delta smelt and the LOS is predicted to be detrimental to longin smelt.

In general, results for winter-run Chinook, steelhead, bank swallows, Fremont cottonwood and large woody debris recruitment do not show any clear discriminatory results amongst these BDCP alternatives. Fremont cottonwood initiation (FC1) and vegetation recruitment to the mainstem Sacramento River (LWD1) show only small marginal responses to BDCP alternatives without any clear large differential effects amongst the alternatives considered.

Spring-run Chinook are expected to do the most poorly under ESO and HOS alternatives in terms of spawning habitat (CS1), egg-to-fry survival (CS3), and redd dewatering (CS6).

In general, juvenile stranding (CS4) losses increase, particularly for winter-run Chinook. Delta temperature stress (CS10) on winter-run Chinook also increases over all ELT alternatives. Likewise, Delta temperature stress (CS10) is also elevated over all ELT alternatives for steelhead.

Green sturgeon are expected to do worse under future climate conditions due to rising water temperatures (GS1).

Splittail are clear winners in all BDCP scenarios. For splittail, this is due to the Fremont Weir notch included in all project alternatives. Sacramento River large woody debris improves under the ESO and HOS scenarios according to the ES method, but not when looking at the RS difference.

Results suggest Delta smelt habitat (DS2) is reduced under LOS, although the magnitude of this reduction is marginal, while longfin smelt does better under HOS (ES results) relative to the other alternatives.

The ability to suppress overbite clam larvae (ID2) is weakened under all BDCP scenarios. Likewise, Brazilian waterweed suppression (ID1) is reduced somewhat under the LOS scenario.

Brackish wetland area shows considerable declines owing to sea level rise under the ELT climate future (noting that EFT results do not include potential benefits of physical habitat restoration).

The impact of future climate and demand is significantly stronger than the impact from alternative operations and conveyance. The negative effects of future climate and demand are readily apparent, particularly in the LLT period (Table 3.35). Spring-run Chinook in particular suffer under projected future climate conditions, with most notable effects on all temperature sensitive species (especially the CS10 indicator). Steelhead, bank swallow, Fremont cottonwood, large woody debris, and splittail do not show meaningful effects under the future climate and demand scenarios considered here.

While compensation is not the general outcome, the BDCP alternatives do provide some offsetting benefits to help cope with climate change effects. In particular spawning habitat (CS1) is improved by the conveyance and operations in BDCP alternatives for fall-run Chinook and spring-run Chinook (LOS alternative only). Delta rearing conditions (CS7) are improved by notching of the Fremont Weir associated with the ESO, LOS and HOS BDCP alternatives, offsetting losses that are otherwise expected for late fall-run, winter-run and, to a lesser degree, spring-run Chinook. Spring-run Chinook also receive compensatory offsets of otherwise detrimental climate change effects from *the LOS scenario*, in terms of reductions to redd dewatering losses (CS6) and improved Sacramento river rearing conditions (CS2).

Delta smelt habitat shows improvement using the ES method for both future epochs, due to a change in operations as Fall X2 action is assumed implemented in the ELT and LLT epochs.

Table 3.33: Summary of Project vs Climate/Demand effects for Sacramento River and Delta ecoregion, as measured by the RS difference [δ].

	Project Relative to NAA-ELT						Climate & Demand Relative to NAA-Current			
Upper & Middle Sacramento River Ecoregion										
	ESO		**LOS**		**HOS**		**ELT**		**LLT**	
	+	**−**	**+**	**−**	**+**	**−**	**+**	**−**	**+**	**−**
Fall	1*		1*		1*					1*,3,4
Late Fall							2		2	4
Spring			1*,6*		2			1,3,6		1,3,6
Winter	2*	4	2*	4		4		1,2*		1,2,3
Steelhead										
Bank swallow										
Green Sturgeon								1		1
Cottonwood										
Woody Debris										
Delta Ecoregion										
Fall								7		7,10
Late Fall	7		7		7			7		7
Spring								10		10
Winter	7	10	7	10	7			10		10
Steelhead					7			7		
Splittail	1		1		1					
Delta smelt							4			
Longfin smelt										
Invasives				1						
Tidal wetlands								1		1,2

[δ] Numbers indicate the number of the indicator with a meaningful (>10%) positive or negative change for each comparison; shaded green in '+' columns and red in '–' columns. *Key to salmonid indicators:* 1 = suitable spawning habitat, 2 = suitable rearing habitat, 3 = thermal egg-to-fry survival, 4 = juvenile stranding index, 6 = redd dewatering, 7 = smolt weight gain, 10 = smolt temperature stress. *Key to Cottonwood indicators:* 1 = initiation. *Key to Delta smelt indicators:* 4 = larval and juvenile entrainment. *Key to invasives indicators*: 1 = Brazilian waterweed suppression. Key to tidal wetlands: 1 = brackish, 2 = freshwater. "*" refers to an indicator result where ESO/LOS/HOS conveyance and operations largely compensate for expected climate change losses expected between the current and ELT time frame.

Table 3.34: Summary of Project vs Climate/Demand effects for Sacramento River and Delta ecoregion, as measured by the ES method [δ].

	Project Relative to NAA-ELT						Climate & Demand Relative to NAA-Current			
Upper & Middle Sacramento River Ecoregion										
	ESO		**LOS**		**HOS**		**ELT**		**LLT**	
	+	–	+	–	+	–	+	–	+	–
Fall	1		1		1					
Late Fall		1		1				1		
Spring	1		1				2	1		1,3
Winter										
Steelhead										
Bank swallow										
Green Sturgeon										1
Cottonwood	1		1							1
Woody Debris	1				1					
Delta Ecoregion										
Fall								10		10
Late Fall	7	10	7	9,10	7	10				10
Spring										
Winter		9,10		10		9,10		10		10
Steelhead		10		10		10		10		10
Splittail	1		1		1					
Delta smelt				2			2		2	
Longfin smelt					1			1		1
Invasives		2		2		2		2		2
Tidal wetlands								1		1,2

[δ] Numbers indicate the number of the indicator with a meaningful (>5%) positive or negative change for each comparison; shaded green in '+' columns and red in '–' columns. *Key to salmonid indicators:* 1 = suitable spawning habitat, 2 = suitable rearing habitat, 3 = thermal egg-to-fry survival, 4 = juvenile stranding index, 7 = smolt weight gain, 9 = smolt predation risk; 10 = smolt temperature stress. *Key to Cottonwood indicators:* 1 = initiation. *Key to Delta smelt indicators:* 2 = habitat suitability. *Key to invasives indicators*: 2 = overbite clam larval suppression. Key to tidal wetlands: 1 = brackish, 2 = freshwater.

Table 3.35: Overall weight of evidence and assessment of net effects by species, Sacramento River Ecoregion and Delta Ecoregion. Refer to legend below the table. The asterisk (*) indicates where ESO/LOS/HOS conveyance and operations partially offset expected climate change losses anticipated between the current and ELT time frame.

	Project Relative to NAA-ELT									Climate & Demand Relative to NAA-Current					
Upper & Middle Sacramento River Ecoregion															
	ESO			**LOS**			**HOS**			**ELT**			**LLT**		
	+		–	+		–	+		–	+		–	+		–
Fall	5			5			5								3-RS*
Late Fall (Benefits from ELT baseline)		1-ES			1-ES						+/–			+/–	
Spring	3-ES			5			3-RS					2-RS*			5
Winter		1-RS						1-RS				3-RS*			3-RS
Steelhead															
Bank swallow															
Green Sturgeon (Negative changes caused by ELT baseline)			3-RS			3-RS			3-RS			3-ES			5
Cottonwood		1-ES			1-ES									1-ES	
Woody Debris		1-RS						1-RS							
Delta Ecoregion															
Fall		+/–			+/–			+/–				5			5
Late Fall			3-ES			3-ES			2-ES			3-RS*			5
Spring		+/–			+/–			+/–				3-RS			3-RS
Winter			3-ES			3-ES			2-ES			5			5
Steelhead			3-ES			3-ES			2-ES			5			3-ES
Splittail	6			6			6								

Delta smelt		6			6		6	
Longfin smelt			6			3-ES		3-ES
Invasives	3-ES	4		3-ES		3-ES		3-ES
Tidal wetlands	3-RS	3-RS		3-RS		5		5

	Neither the RS nor ES summary method generates a potential change that passes our ±10% and ±5% thresholds. No meaningful effect.
+/-	Mixed effects -- indicators for same species show benefits and penalties (i.e., Chinook/steelhead), but the net effect is difficult to determine.
1-RS	RS summary method shows a potential effect (passes ±10% threshold). **However**, the results are **highly variable.**
1-ES	ES summary method shows a potential effect (passes ±5% threshold). **However**, the results are **highly variable.**
2-RS	RS summary method shows a potential effect of ±10% change or more in favorable years, with **clear signal to noise** (**less variability**), yet the ES summary view shows the *inverse effect* (potentially contradictory evidence).
2-ES	ES summary method shows a potential effect of ±5% change in absolute median effect size, with **clear signal to noise** (**less variability**), yet the RS summary view shows the *inverse effect* (potentially contradictory evidence).
3-RS	RS summary method shows a potential effect of ±10% change or more in favorable years, with **clear signal to noise** (**less variability**), and the ES summary view does not meet threshold (no contradictory evidence).
3-ES	ES summary method shows a potential effect of ±5% change in absolute median effect size, with **clear signal to noise** (**less variability**), and the RS summary view does not meet threshold (no contradictory evidence).
4	Both summary views agree on the direction of the potential effect, and both pass the threshold for a potentially meaningful effect. However, **both show a highly variable spread in results**.
5	Both summary views agree on the direction of the potential effect, and both pass the threshold for a potentially meaningful effect with **clear signal to noise** (**less variability**).
6	Either category "3","4" or "5" + a fundamental link to scenario description.

Table 3.36: Overall summary of "winners and losers" for the selected BDCP alternatives.

Focal species	*All Alternatives*	ESO-ELT (237)	LOS-ELT (238)	HOS-ELT (242)	Primary benefit / [Challenge]	Caveats
			Sacramento River species	San Joaquin-Delta species		
Fall Chinook	↑				CS1	
Late Fall Chinook	↑	<benefit from ELT baseline conditions, not the alternatives>			CS2, CS7 [CS10]	Delta thermal stress (CS10)
Spring Chinook		↓	↑	↓	CS1, CS6, CS2	
Winter Chinook	No clear discriminatory results/preferences amongst alternatives (though *some* evidence conditions better under HOS)					Delta thermal stress (CS10)
Steelhead	No clear discriminatory results/preferences amongst alternatives					Delta thermal stress (CS10)
Bank Swallows	No clear discriminatory results/preferences amongst alternatives					
Green sturgeon	↓				[GS1]	
Fremont cottonwood	No clear discriminatory results/preferences amongst alternatives					
Large woody debris	No clear discriminatory results/preferences amongst alternatives					
Splittail	↑				Fremont weir notch included in all project alternatives	
Delta Smelt			↓		[DS2]	
Longfin Smelt				↑	LS1	
Invasive Deterrence	↓				[ID2]	
Tidal Wetlands	↓				We do not consider physical habitat restoration effects in this EFT analysis (did not have post restoration DEM)	

3.3.4 Caveats & Limitations

There are approximately 22 different conservation measures in BDCP, many of which were not evaluated using EFT. EFT focuses on effects of flow operations, and also includes Yolo Bypass fisheries enhancement. However, we did not consider the potential food web effects of restoring 55,000 acres of tidal freshwater and brackish marsh, nor related effects of restoring 10,000 acres of transitional habitat (BDCP conservation measures 4 and 5), nor channel margin enhancements (BDCP conservation measure 6) (BDCP 2013). EFT analyses do not consider the issue of pelagic food webs. These BDCP physical restoration actions propose to improve zooplankton food sources for pelagic fish by helping to subsidize the lower trophic levels of pelagic food webs. The magnitude of any phytoplankton and zooplankton subsidy resulting from restored habitat depends on many factors and assumptions, none of which are presently included in EFT. Indeed there remains considerable uncertainty over the likely benefits of physical habitat restoration, and whether such actions are more likely sources or sinks for zooplankton that will result in food web pathways that benefit smelt and other target species (Mount *et al*. 2013; DSP 2014).

Our effects analysis does not address effects on every important species; instead we focus on the 13 species and habitats described in Chapter 2. For the species that are included, portions of the life-cycle are not included, e.g., the ocean phase of salmonid life-cycle is ignored for all Chinook run-types and for steelhead.

EFT's results are based on outputs from external hydrologic models (CALSIM, DSM2, etc.) These modeling tools contain high uncertainties when applied to future conditions such as sea level rise and water temperatures, and they do not include hydrodynamic effects of future tidal and intertidal restored lands (DSP 2014). The physical modeling suite used for BDCP involves exchanges of inputs and assumptions, including hand-offs between 1-, 2-, and 3-dimentional models, which creates error. These models also contain assumptions about assumed levels of operational "foresight" that can differ from what a real-world operator may have available. Further, the physical models used to assess BDCP only considered one configuration of future Restoration Opportunity Areas, but these simulations were not made available for use in our EFT effects analyses (we instead assumed the current Delta configuration under sea level rise). To date, there is no assessment of these model errors and how they impact BDCP results (Mount *et al*. 2013; DSP 2014). Any such errors or biases will be propagated forward into EFT ecological effects analysis results.

Another limitation of our analysis (not of EFT), is that the operational criteria embedded in the BDCP physical modeling were highly constrained, reducing assessment of a more complete range of operational flexibility at major reservoirs. Amongst others, these constraints included SWRCB water rights decision D1641, reservoir constraints (carry over storage, cold water pool management), and Biological Opinions (USFWS 2008 and NMFS 2009). These regulatory, operational and infrastructure constraints limit the ability of BDCP to fully explore and realize operations that may improve ecosystem conditions (Mount *et al*. 2013), and importantly, account for the sometimes "low contrast" in EFT effect size results. In other words, when the system is operated according to a rigid set of fixed, layered constraints, there are trade-offs managers simply cannot get around. Moreover, our findings should be accompanied with this caveat: EFT results apply only if the system were actually operated to achieve the flows indicated by the hydrosystem models. If rules are not in place to ensure Delta flows would actually be managed in the manner prescribed by the modeling, the potential effects shown by EFT will not be realized.

Hatchery programs in the Central Valley may pose threats to Chinook salmon stock genetic integrity (NMFS 2009, 2007). The long history of dependence on hatchery production to mitigate for habitat loss is a threat having deleterious genetic effects on wild stocks (Goodman 2005; Akari *et al*. 2008; Chilcote *et al*. 2011). The capacity for hatchery introgression to genetically interrupt local adaptation in naturally reproducing populations is particularly troubling because it likely reduces the capacity of “wild” stocks to track changes to physical habitats. The effects of hatchery propagation on "wild" Chinook and steelhead populations is not included in EFT effects analyses.

An estimated 5,000 to 40,000 tons of contaminants enter the Bay-Delta system annually (CALFED 2000). Contaminants entering the system are distributed by complex flow patterns influenced by inflow from the rivers and the amount of water being pumped from the Delta. Contaminants include inorganic substances such as heavy metals, nitrates and phosphates, organic contaminants such as PCBs, pesticides, plastics, detergents and fertilizers, and biological pathogens such as bacteria, viruses and protozoans (CALFED 2000). Effects of these point and non-point sources of contaminants are not considered in EFT.

Finally, flow management alone is not the complete answer to reconciling species to conditions in the Sacramento River and Delta. Non-flow actions *such as* physical habitat restoration, rip-rap removal, gravel augmentation, water quality improvement efforts, and removal of invasive species are an important part of an overall comprehensive rehabilitation plan.

3.4 Pilot Investigation: Incorporating EFT Derived Ecological Flow Criteria to CALSIM

3.4.1 Introduction

EFT development has concentrated on getting the science right: integrating multiple focal species indicators and their important habitats at a sufficient level of detail. Like other ecological models, EFT is applied “reactively” as a second stage effects analysis of CALSIM (or equivalent model) output. Until recently, loose coupling of EFT with other physical models, and serial simulations (CALSIM → USRDOM → Meander Migration/Bank Erosion → DSM2 →EFT) have restricted EFT modeling to the type of post-processing effects analysis and trade-off evaluation described in Section 3.3. As-is, this "one-way communication" limits opportunities to fully realize the goals of this tool. For some time, TNC and ESSA have envisioned running EFT in “prospective” or “proactive” mode by inserting simplified (but relevant) rule-sets for multiple functional species needs (derived from analysis of EFT output) into the physical driving models themselves. The ability to directly insert the additional insights obtained from EFT on preferred ecological rules into the hydrologic planning models themselves is an important "full circle" application of our research.

In this phase of the Project we: 1) summarized simplified but meaningful ecological flow rule-sets for all species and indicators in EFT; 2) initiated a pilot study where we selected *two of these species performance indicators* (one set of rules for a Sacramento River target, another for a Delta target) to insert into CALSIM II (while preserving rules that protected Shasta storage and Delta exports); and finally 3) imported *these* CALSIM results into EFT and performed an effects analysis for all species and performance indicators. Ultimately, we explored *whether it is possible to improve ecological conditions for the two target indicators without creating negative consequences on non-target species and water supply objectives.*

3.4.2 Pilot EFT Rule-Set Alternative Compared with Reference Case & Historical Scenarios

Due to confidentiality issues associated with the BDCP EIS/R, we were unable to access WRESL configuration files for the BDCP CALSIM II model. Instead, our Ecological Flows pilot study was based on the simulations used to complete the 2011 Delivery Reliability Report [DRR 2011] (DWR 2010a, 2010b, 2012), an analysis of current and near future demand needs which is updated every two years by DWR (see Table 3.37). We used this publically available DRR future (2031) scenario as our system operation reference case, to test and compare our attempts to insert new ecological flow (Pilot Study) rule-sets on top of the DRR CALSIM II configuration. We subsequently applied EFT to analyze effects both for the DRR reference case and the Pilot Study ecological rule-sets we inserted to modify this reference case.

The DRR (2011) future scenario includes anticipated demand conditions for the year 2031, incorporating current operating restrictions caused by the Biological Opinions (BOs) issued in December 2008 and June 2009 by the U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS), which govern State Water Project (SWP) and Central Valley Project (CVP) operations. The scenario features improved adherence to the existing BOs and changes in system operation for current conditions. Of particular note, the 2011 DRR scenarios calculate daily spills at the Fremont and Sacramento weirs, which are of particular use for EFT simulations.

Future (2031) conditions are based on anticipated future demand only, and neither climate change nor sea level rise is included in the simulation.[18] A detailed discussion of the model

[18] Draft DRR 2013 simulations include climate change and sea level rise, but have not yet been released.

assumptions used for DRR studies, including the BOs and an overview of the CALSIM II software, can be found in the 2009 Delivery Reliability Report (DWR 2010a, 2010b).[19]

Use of a historical reference case has been recommended by the Delta Science Panel. Such a comparison provides perspective on how much cumulative change has already been "locked in" and allows for assessment of total cumulative change (relative to the historical reference case). While it may be impractical to return to past levels of development and of demand and operations, using a sufficiently long historical reference case informs managers about the degree to which proposed future actions (e.g., including the conditions associated with the chosen reference case) may contribute towards recovery of priority species, and provides context for ongoing efforts to improve habitat and to rehabilitate fish populations.

Results in this section include comparison of historical conditions with the DRR 2011 reference case to illustrate this form of change. *However*, we excluded comparison of historical conditions for EFT performance indicators when any of the following occurred:

1. Historical time series were too short (the historical simulation included fewer than half the years present in the simulated reference case scenario[20]);
2. The frequency of dry or wet water years was substantively different between the historical simulation and the simulated reference case scenario;
3. There were substantial differences between the physical locations used in the historical simulation vs. the reference case simulation.

[19] A technical addendum for the DRR 2011 study has not been posted by DWR.
[20] If the historical simulation included twenty or more years, it was <u>not</u> excluded based on this criterion.

Table 3.37: Summary of conditions used for the reference case ecological flow scenario and the modified version including pilot study rule-sets for winter-run Chinook and Delta smelt.

Name	Conveyance modifications	Level of human demand	Climate change	Major operational features
Reference case: 2011 DWR Delivery Reliability Operations (DRR)	None. Current hydrosystem (as of 2011). No changes to size/number of dams, capability of Delta pumps, gates	Future (2031) demand	Does not include climate change or sea level rise	Incorporates State Water Board D-1641 including NMFS Biological Opinions (2008, 2009) Simulations also include San Joaquin restoration actions and improved daily simulation of Fremont and Sacramento Weir spills No notch in Fremont Weir High Fall X2 outflow
As above + **EFT Pilot Study rule-sets for Winter Chinook and Delta smelt**	As above	As above	As above	As above and Winter Chinook: Flow at Clear Creek Aug to Dec: 7,000 – 8,000 cfs May to Jun: 5,000 – 12,000 cfs Delta smelt: Combined Old and Middle River flow Normal and wetter Water Year Types Apr & June: > 0 cfs Below Normal Water Year Types: Apr & Jun: > 2,000 cfs "Off-ramping" and "water banking" strategies for drought years and low-flow months

3.4.3 EFT Ecological Flow Criteria & Initial Rule-sets Tested

For this pilot analysis, we used EFT to derive ecologically beneficial rule-sets for **winter-run Chinook and Delta smelt**. Winter-run Chinook and Delta smelt were chosen based on their threatened status and differing location: Upper Sacramento and Delta. Specifically, we implemented flows that would provide more beneficial conditions for winter-run Chinook spawning WUA (CS1), juvenile stranding (CS4) and rearing WUA (CS2). Thermal egg mortality (CS3), redd dewatering (CS6) and redd scour (CS5) were *not* targeted for improvement in our EFT rule-set because all three sources of mortality were either relatively low or impossible to address using a monthly model (CALSIM). Entrainment risk (DS4) was targeted for Delta smelt. Actions were already included in the DRR reference case to improve spawning success (DS1) and habitat suitability (DS2). Based on the selected species and performance indicators, EFT rule-sets that targeted more beneficial flows were established for May, June and August to December for the Sacramento River, and from April to June for changes to Old and Middle River flows in the Delta (see Section 2.9.2; Table 2.14 and Table 2.15). Additional details of this important step are described in Section 2.7.8.

3.4.4 Results and Discussion

The results from this pilot study have shown that, even though the California water system is highly constrained, there is still room to improve conditions for various species by changing operations without undue effects on water supply. However, the results also reinforce the challenge of trade-offs between species, and the absence of a singular win-win-win option.

The implementation of the proposed EFT flow targets in CALSIM generated altered flows in the Sacramento River in July to December, from April to May, and again from September to December in the Old and Middle River in the Delta. CALSIM-modeled Sacramento River flows did not experience a meaningful change (relative to the DRR baseline) in May and June because the reference scenario flows were already commonly in the preferred flow range during these months. Hence, we found that conditions could potentially be improved for winter-run Chinook spawning by focusing on a narrower range of flows. The EFT rule-set applied to CALSIM also decreased Sacramento River flows in July and August relative to the reference scenario (that in the baseline case, were often above 8 kcfs recommended for winter-run Chinook rearing WUA). In September to December, when Sacramento River flows were typically below the 7 kcfs recommended for winter-run Chinook juvenile stranding, the EFT rule-set generated the desired increased flows.

The pilot EFT rule-set improved performance for winter-run Chinook juvenile stranding, but not for spawning WUA. The modified flows reduced juvenile stranding by lessening the month to month changes. Winter-run Chinook spawning WUA did not improve because the recommended flows were already being achieved using the rule-set in the reference DRR scenario. Winter-run Chinook juvenile rearing habitat did not benefit because the EFT rule-set generated higher August to December flows. The lack of improvement for winter-run Chinook rearing WUA was also a trade-off with juvenile stranding, as lower flows in August to December are assumed to increase rearing WUA and worsen juvenile stranding. With additional iteration, this issue could potentially be refined in future EFT ecological rule-sets.

In the Delta, our EFT rule-set generated some delays in water exports from spring to fall, leading to more positive flow in the Old and Middle River in April to June and more negative flows from September to December. Although the pilot EFT rule-set did result in more positive flows in April, May and June in the Old and Middle River, the reduction in Delta smelt entrainment was small. This is most likely because reverse flows are already uncommon in April and May under the reference case scenario, and the improvement the EFT rule-set generates in June has limited benefit on entrainment as most spawning is already over (only 16% of spawning occurs in June).

Effects on non-target species

While they were not specifically targeted, some other species also benefited from the changes caused by the pilot EFT rule-set. Bank swallow nest inundation/sloughing risk decreased, most likely due to the lower flows in July, which were much higher in the reference scenario. The benefit to bank swallows is due to holding back water in the reservoirs (known as “water banking”, see Section 2.9.4) for release later in the water year, a subsidiary rule we established both to manage Shasta water storage and support achievement of winter-run Chinook ecological flows.

The improvements for winter-run Chinook and bank swallows generated by the pilot EFT rule-set reduced suitable spawning habitat (CS1) for fall-run and spring-run Chinook, both of which decline by about 10% (lower WUA in August to October as flows increase to support flows for the targeted winter-run Chinook and Delta smelt indicators). With the initial EFT rule-set, spring-run Chinook experienced a mix of positive and negative effects.

Level of Physical Change among Alternatives

Sacramento River

Flow

Median flows are lower for the pilot study scenario relative to the reference case in July and August, and higher in September to December, for both Keswick and Hamilton City (Table 3.38).

Median flows were higher historically from water years 1939 to 2004 relative to the reference case in January to May, September and December, and lower in July for Keswick (Table 3.38). Median flows were higher historically from water years 1939 to 2004 relative to the reference case in January to September and December, and lower in November for Hamilton City.

Table 3.38: Flow at Keswick and Hamilton City is shown for the reference case, pilot study and historical scenarios with percentage differences shown next to absolute flows. δ

Mon	Reference case (229)	Pilot (231)	Historical (118)
Keswick			
Jan	4,073	4,122 (1.2%)	6,260 (53.7%)
Feb	4,327	4,398 (1.6%)	7,360 (70.1%)
Mar	4,450	4,453 (0.1%)	5,990 (34.6%)
Apr	5,290	5,350 (1.1%)	6,560 (24.0%)
May	6,604	6,614 (0.1%)	8,950 (35.5%)
Jun	10,674	10,680 (0.1%)	10,200 (-4.4%)
Jul	13,160	11,354 (-13.7%)	11,500 (-12.6%)
Aug	10,604	9,648 (-9.0%)	10,700 (0.9%)
Sep	6,767	7,814 (15.5%)	7,770 (14.8%)
Oct	6,083	7,009 (15.2%)	5,830 (-4.2%)
Nov	5,441	7,020 (29.0%)	5,395 (-0.8%)
Dec	4,298	6,369 (48.2%)	5,990 (39.4%)

Mon	Reference case (229)	Pilot (231)	Historical (118)
Hamilton City			
Jan	8,875	8,899 (0.3%)	10,400 (17.2%)
Feb	11,481	11,643 (1.4%)	13,747 (19.7%)
Mar	10,645	10,761 (1.1%)	11,450 (7.6%)
Apr	6,930	6,947 (0.3%)	8,970 (29.4%)
May	6,428	6,439 (0.2%)	9,939 (54.6%)
Jun	8,137	8,094 (-0.5%)	9,295 (14.2%)
Jul	9,386	7,768 (-17.2%)	9,905 (5.5%)
Aug	7,749	6,995 (-9.7%)	9,274 (19.7%)
Sep	6,353	7,325 (15.3%)	7,095 (11.7%)
Oct	5,848	6,956 (19.0%)	5,760 (-1.5%)
Nov	7,149	8,610 (20.4%)	6,390 (-10.6%)
Dec	7,269	8,703 (19.7%)	8,241 (13.4%)

δ Comparison of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Water Temperature

Median water temperature is 5.1% lower in September under the pilot EFT rule-set for Keswick (Table 3.39). Downstream at Hamilton City, temperatures are similar for the two scenarios with the maximum temperature difference for the pilot EFT rule-set being 0.7°C (less than 5%) higher median temperatures in July.

Median water temperatures were higher historically from 1970 to 2001 relative to the reference case in January, February and December for Keswick (Table 3.39). Historical temperatures for Hamilton City were unavailable for comparison.

Table 3.39: Temperature (degrees C) at Keswick is shown for the reference case, pilot study and historical scenarios with percentage differences shown next to absolute temperatures. δ

Month	Reference case (229)	Pilot (231)	Historical (118)
Temperature - Keswick			
January	8.0	8.0 (0.2%)	9.2 (16.0%)
February	7.7	7.7 (0.1%)	8.5 (10.9%)
March	8.4	8.4 (0.2%)	8.7 (3.9%)
April	9.3	9.3 (0.0%)	9.3 (-0.3%)
May	9.8	9.8 (-0.1%)	9.8 (-0.8%)
June	10.2	10.3 (0.5%)	10.4 (1.4%)
July	10.8	11.1 (2.8%)	11.0 (2.0%)
August	11.4	11.3 (-0.9%)	11.5 (1.2%)
September	12.3	11.7 (-5.1%)	12.0 (-2.3%)
October	12.5	12.0 (-3.9%)	12.3 (-1.9%)
November	11.7	11.7 (-0.8%)	12.0 (2.3%)
December	9.9	9.9 (0.6%)	10.8 (9.1%)

δ Comparison of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

San Joaquin-Sacramento Delta

Flow

At Mallard Island in Suisun Bay, the only difference is higher flows in June and December for the pilot EFT rule-set relative to the reference case (Table 3.40). For the Old and Middle River location, which is primarily controlled by the operations of the water export facilities, flows are more positive in April to June and more negative in September to December for the pilot EFT rule-set relative to the reference case.

Historical flows for Mallard Island and Old and Middle river were unavailable for comparison.

Table 3.40: Flow values at Mallard Island and Old and Middle River are shown for the reference case and pilot EFT rule-set with percentage differences shown next to absolute flows. δ

Month	Reference case (229)	Pilot (231)
Mallard Island		
January	16,763	16,468 (-1.8%)
February	20,281	20,234 (-0.2%)
March	29,977	30,440 (1.5%)
April	16,332	16,619 (1.8%)
May	11,968	12,046 (0.6%)
June	8,975	10,732 (19.6%)
July	6,501	6,297 (-3.1%)
August	4,588	4,517 (-1.6%)
September	9,714	9,534 (-1.9%)
October	4,096	4,183 (2.1%)
November	8,400	8,594 (2.3%)
December	8,250	8,978 (8.8%)

Month	Reference case (229)	Pilot (231)
Old and Middle River		
January	-4,208	-4,294 (-2.0%)
February	-3,222	-3,202 (0.6%)
March	-2,000	-2,035 (-1.7%)
April	112	339 (201.6%)
May	-326	137 (142.1%)
June	-3,479	-1,782 (48.8%)
July	-10,140	-10,107 (0.3%)
August	-9,935	-9,935 (0.0%)
September	-6,949	-7,656 (-10.2%)
October	-6,086	-6,730 (-10.6%)
November	-5,206	-5,617 (-7.9%)
December	-6,385	-7,437 (-16.5%)

δ Comparison of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Water Temperature

Median temperatures in the San Joaquin-Sacramento Delta are almost identical between the two scenarios at both Port Chicago in Suisun Bay and Terminous in the Eastern Delta, with differences being less than 0.1°C.

Historical temperatures for Port Chicago and Terminous were unavailable for comparison due to gaps in historical records.

Salinity

Median salinity (measured as EC) is lower in June, November and December for the pilot EFT rule-set at the Collinsville location (Table 3.41). Downstream at the Pittsburg location in Suisun Bay, salinity is lower in May, November and December under the pilot EFT rule-set.

Historical salinities for Collinsville were unavailable for comparison. Median salinities were lower historically from 1997 to 2011 relative to the reference case in January, February, May and August and higher in March, April, June, July November and December for Pittsburg (Table 3.41). The reason Pittsburg is more saline in the fall relative to the reference case is most likely that the reference case includes the Fall X2 action (see Chapter 3.4.2) which was introduced in 2008 and not considered for most of the historical years.

Table 3.41: Salinity (measured as EC) values at Collinsville and Port Pittsburg are shown for the reference case, pilot study and historical scenarios with percentage differences shown below the absolute EC. $^{\delta}$

Month	Reference case (229)	Pilot (231)
EC - Collinsville		
January	1,466	1,477 (0.8%)
February	511	499 (-2.3%)
March	216	216 (0.0%)
April	350	340 (-2.8%)
May	880	858 (-2.5%)
June	2,413	2,223 (-7.9%)
July	4,156	4,205 (1.2%)
August	5,321	5,243 (-1.5%)
September	6,812	6,536 (-4.0%)
October	7,819	7,516 (-3.9%)
November	6,915	5,922 (-14.4%)
December	3,698	3,177 (-14.1%)

Month	Reference case (229)	Pilot (231)	Historical (118)
EC - Pittsburg			
January	2,604	2,624 (0.8%)	1,716 (-34.1%)
February	906	927 (2.3%)	779 (-14.0%)
March	261	259 (-0.5%)	478 (83.4%)
April	627	602 (-3.9%)	1,485 (137.0%)
May	1,653	1,563 (-5.4%)	1,527 (-7.6%)
June	3,813	3,643 (-4.5%)	4,450 (16.7%)
July	6,295	6,347 (0.8%)	6,768 (7.5%)
August	7,546	7,487 (-0.8%)	7,083 (-6.1%)
September	9,262	9,010 (-2.7%)	9,127 (-1.5%)
October	10,489	10,084 (-3.9%)	10,233 (-2.4%)
November	9,592	8,472 (-11.7%)	12,081 (25.9%)
December	5,752	5,126 (-10.9%)	9,671 (68.1%)

δ Comparison of months measured as percentages are based on the simple arithmetic difference in comparison to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Ecoregion & Indicator Specific High-level Summary of Relative Suitability

The high level effect roll-ups in this section are tied to the RS methodology described in Section 2.8.6. Table 3.42 and Table 3.43 show the results of applying this methodology to the Sacramento River and Delta ecoregions in the pilot study, based on the EFT relative suitability definition and the change in the percentage of years assigned to a favorable outcome. A synthesis of these tabular results is presented in Table 3.46.

Sacramento River (SacEFT)

Table 3.42: Ecological flow effects are shown for selected pilot study and historical scenarios in the Sacramento River ecoregion, using the change in the percentage of favorable years reported for each indicator (RS method). δ

Focal species	Performance indicator	EFT Pilot Rule-Set & Historical Flow vs. DRR 2011 Reference case (229)			
		Pilot (231)	Historical (118)		
	Upper and Middle Sacramento River Indicators				
Fall Chinook	Spawning WUA (CS1)	-14	17		
	Thermal egg survival (CS3)	4	-7		
	Redd Dewatering (CS6)	-1	19		
	Redd Scour (CS5)	0	6		
	Juvenile Stranding (CS4)	0	26		
	Rearing WUA (CS2)	-5	6		
Late Fall Chinook	Spawning WUA (CS1)	-2	-11		
	Thermal egg survival (CS3)	0	0		
	Redd Dewatering (CS6)	1	5		
	Redd Scour (CS5)	0	13		
	Juvenile Stranding (CS4)	0	7		
	Rearing WUA (CS2)	3	-30		
Spring Chinook	Spawning WUA (CS1)	-15	3		
	Thermal egg survival (CS3)	11	-8		
	Redd Dewatering (CS6)	45	-22		
	Redd Scour (CS5)	2	2		
	Juvenile Stranding (CS4)	5	22		
	Rearing WUA (CS2)	-12	13		
Winter Chinook	Spawning WUA (CS1)	35	19		
	Thermal egg survival (CS3)	2	-1		
	Redd Dewatering (CS6)	26	22		

Focal species	Performance indicator	EFT Pilot Rule-Set & Historical Flow vs. DRR 2011 Reference case (229)			
		Pilot (231)	Historical (118)		
	Upper and Middle Sacramento River Indicators				
	Redd Scour (CS5)	0	6		
	Juvenile Stranding (CS4)	34	-5		
	Rearing WUA (CS2)	-10	-10		
Steelhead	Spawning WUA (CS1)	-1	-14		
	Thermal egg survival (CS3)	0	0		
	Redd Dewatering (CS6)	-3	2		
	Redd Scour (CS5)	3	15		
	Juvenile Stranding (CS4)	2	30		
	Rearing WUA (CS2)	-13	6		
Bank Swallow	Habitat Potential (BASW1)	0	23		
	Flow Suitability (BASW2)	0	-33		
Green Sturgeon	Egg Temperature Preference (GS1)	-7	13		
Fremont Cottonwood	Seedling Initiation (FC1)	–	11		
	Scour Risk (FC2)	7	19		
Large Woody Debris	LWD Recruitment (LWD)	-	17		

δ The **DRR (2011)** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, ≥10% = Dark Green.

San Joaquin-Sacramento Delta (DeltaEFT)

Table 3.43: Ecological flow effects are shown for selected pilot study and historical scenarios in the Delta ecoregion, using the change in the percentage of favorable years reported for each indicator (RS method). δ

Focal species	Performance indicator	EFT Pilot Rule-Set & Historical Flow vs. DRR 2011 Reference case (229)			
		Pilot (231)	Historical (118)		
	Delta Indicators				
Fall Chinook	Yolo Bypass Rearing (CS7)	-6	N/A		
	Predation Risk (CS9)	0			
	Thermal Stress (CS10)	0			
Late Fall Chinook	Yolo Bypass Rearing (CS7)	-6			
	Predation Risk (CS9)	0			

Focal species	Performance indicator	EFT Pilot Rule-Set & Historical Flow vs. DRR 2011 Reference case (229)			
		Pilot (231)	Historical (118)		
Delta Indicators					
	Thermal Stress (CS10)	0			
Spring Chinook	Yolo Bypass Rearing (CS7)	0			
	Predation Risk (CS9)	0			
	Thermal Stress (CS10)	0			
Winter Chinook	Yolo Bypass Rearing (CS7)	-6			
	Predation Risk (CS9)	7			
	Thermal Stress (CS10)	0			
Steelhead	Yolo Bypass Rearing (CS7)	-7			
	Predation Risk (CS9)	0			
	Thermal Stress (CS10)	0			
Splittail	Spawning Habitat (SS1)	0	-2		
Delta Smelt	Spawning Success (DS1)	0	N/A		
	Habitat Quality (DS2)	0			
	Entrainment Risk (DS4)	6	-9		
Longfin Smelt	Abundance Index (LS1)	-	N/A		
Invasive Deterrence	*Egeria* suppression (ID1)	6			
	Corbula suppression (ID2)	0			
	Corbicula suppression (ID3)	-			
Tidal Wetlands	Brackish area (TW1)	NULL			
	Freshwater area (TW2)	NULL			

δ The **DRR (2011)** scenario serves as a comparative reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green, yellow and red shading are used to highlight 6 levels of positive and negative changes: ≤ –10% = Red, –5% to –10% = Pink, –4% = Yellow, –3% to +4% = White, +5% to +9% = Light Green, ≥10% = Dark Green. Cells marked 'N/A' are missing either because a scenario was not simulated, or because the results were removed following the screening process described in Section 3.4.2

Ecoregion & Indicator Specific Effect Size Results

Pilot study effect size results are tied to the ES methodology described in Section 2.8.6. Table 3.44 and Table 3.45 show the results of this methodology applied to the Sacramento River and Delta ecoregions, respectively. The following sections summarize BDCP effects in which the median effect differs by more than 5% from a reference case comparative response. A synthesis of these effects is presented in Table 3.34.

Sacramento River (SacEFT)

Table 3.44: Pilot study, historical and reference case flow effect sizes are shown for using the median difference Effect Size (ES) method (preserving the native units of each indicator). The DRR 2011 scenario serves as a reference case, with percentage differences shown below absolute median effects. $^{\delta}$

Focal species	Performance indicator	Reference case (229)	Pilot (231)	Historical (118)
Upper and Middle Sacramento River Indicators				
Fall Chinook	Suitable spawning habitat (000s ft²)	3,681	3,356 (-8.8%)	4,022 (9.2%)
	Thermal egg-to-fry survival (proportion)	0.999	1.000 (0.1%)	0.994 (-0.5%)
	Redd dewatering (proportion)	0.049	0.064 (-1.6%)	0.028 (2.0%)
	Redd scour risk (scour days)	1	1	0
	Juvenile stranding index	0.182	0.180 (0.2%)	0.136 (4.6%)
	Suitable rearing habitat (000s ft²)	64,205	63,605 (-0.9%)	58,498 (-8.9%)
Late Fall Chinook	Suitable spawning habitat (000s ft²)	1,449	1,403 (-3.2%)	1,250 (-13.7%)
	Thermal egg-to-fry survival (proportion)	1.000	1.000 (0.0%)	1.000 (0.0%)
	Redd dewatering (proportion)	0.045	0.044 (0.0%)	0.039 (0.6%)
	Redd scour risk (scour days)	0	0	0
	Juvenile stranding index	0.082	0.083 (-0.1%)	0.067 (1.5%)
	Suitable rearing habitat (000s ft²)	52,598	53,362 (1.5%)	49,549 (-5.8%)
Spring Chinook	Suitable spawning habitat (000s ft²)	988	868 (-12.1%)	945 (-4.4%)
	Thermal egg-to-fry survival (proportion)	0.998	1.000 (0.2%)	0.989 (-0.8%)
	Redd dewatering (proportion)	0.045	0.017 (2.8%)	0.070 (-2.5%)
	Redd scour risk (scour days)	0	0	0
	Juvenile stranding index	0.213	0.185 (2.8%)	0.179 (3.4%)
	Suitable rearing habitat (000s ft²)	65,224	61,630 (-5.5%)	70,715 (8.4%)
Winter Chinook	Suitable spawning habitat (000s ft²)	1,440	1,493 (3.7%)	1,462 (1.5%)

	Thermal egg-to-fry survival (proportion)	0.999	1.000 (0.0%)	0.999 (0.0%)
	Redd dewatering (proportion)	0.016	0.012 (0.3%)	0.013 (0.3%)
	Redd scour risk (scour days)	0	0	0
	Juvenile stranding index	0.083	0.045 (3.8%)	0.080 (0.3%)
	Suitable rearing habitat (000s ft^2)	37,222	37,075 (-0.4%)	37,223 (0.0%)
Steelhead	Suitable spawning habitat (000s ft^2)	76	75 (-0.8%)	70 (-8.4%)
	Thermal egg-to-fry survival (proportion)	1.000	1.000 (0.0%)	1.000 (0.0%)
	Redd dewatering (proportion)	0.045	0.050 (-0.5%)	0.039 (0.6%)
	Redd scour risk (scour days)	0	0	0
	Juvenile stranding index	0.432	0.404 (2.8%)	0.399 (3.3%)
	Suitable rearing habitat (000s ft^2)	134,566	131,309 (-2.4%)	132,450 (-1.6%)
Bank Swallow	Suitable potential habitat (length, m)			
	Nest inundation/sloughing risk	12,870	10,890 (15.4%)	10,284 (20.1%)
Green Sturgeon	Egg-to-larval survival (proportion)	0.987	0.977 (-1.0%)	1.000 (1.3%)
Fremont Cottonwood	Cottonwood initiation index	21	21 (0.0%)	30.5 (45.2%)
	Risk scour after initiation			
Large Woody Debris	Old vegetation recruited to river (ha)	0.30	0.30 (0.0%)	

δ Comparisons of indicators measured as percentages or proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%.

Salmonids

Median suitable spawning habitat (CS1) declines by 8.8% relative to the DRR 2011 reference case for fall-run Chinook (Figure 3.36). Both the reference case and pilot EFT rule-set are lower than historical spawning habitat, which is about 9% above the reference case.

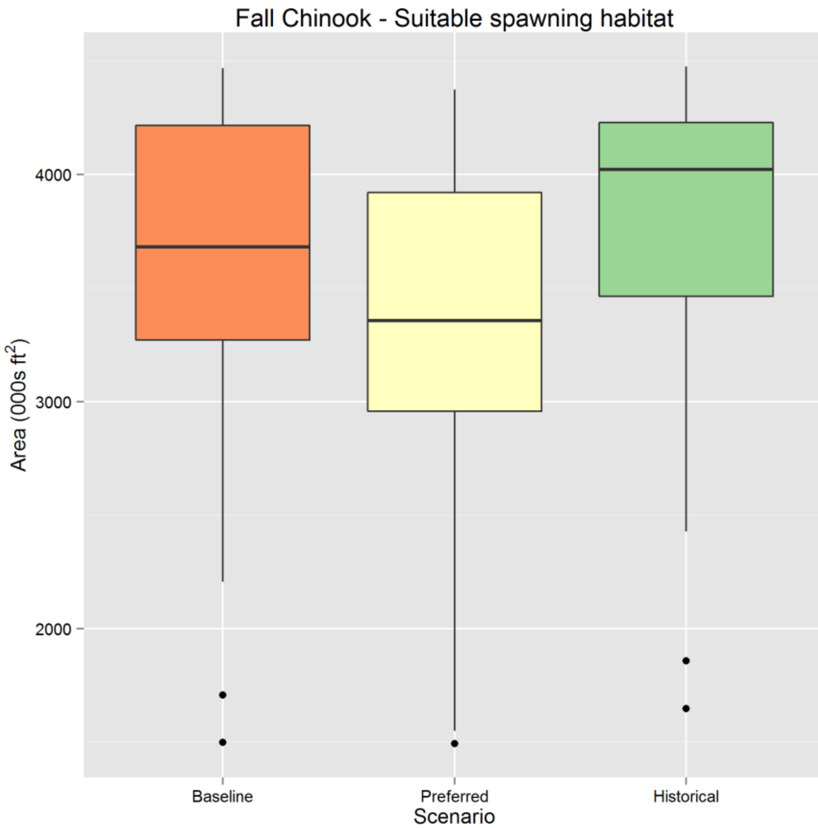


Figure 3.36: Fall-run Chinook spawning habitat (CS1) area for historical and preferred scenarios relative to the DRR 2011 reference case scenario.

Late fall-run Chinook indicators are not meaningfully different from one another for the DRR reference case and pilot EFT rule-sets. However, compared to the historical scenario, both DRR scenarios show declines of over 10% for suitable spawning habitat (CS1) and around 5% for suitable rearing habitat (CS2) (Figure 3.37).

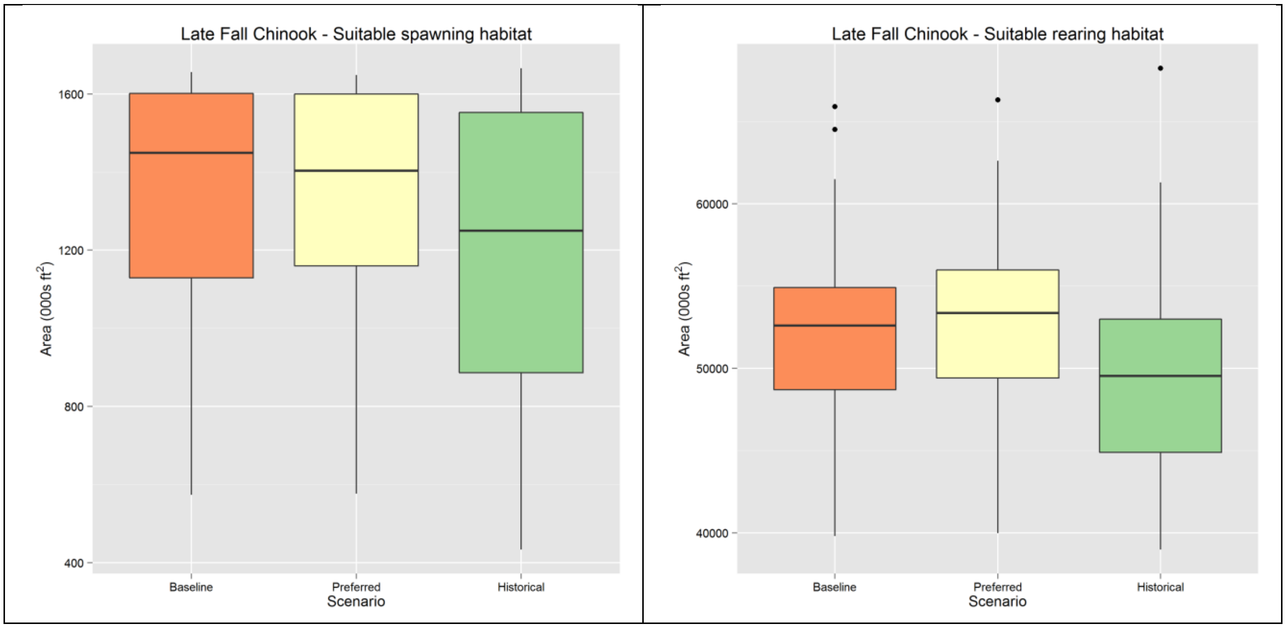


Figure 3.37: Late fall-run Chinook suitable spawning habitat (CS1, left panel) and suitable rearing habitat (CS2, right panel) for both DRR simulations relative to the historical scenario.

Median suitable spawning habitat (CS1) declines by 12.1% relative to the DRR 2011 reference case and historical scenario for spring-run Chinook (Figure 3.38). Median juvenile rearing habitat (CS2) declines by 5% relative to the DRR reference case, and both DRR scenarios provide about 5% less rearing habitat than the historical scenario.

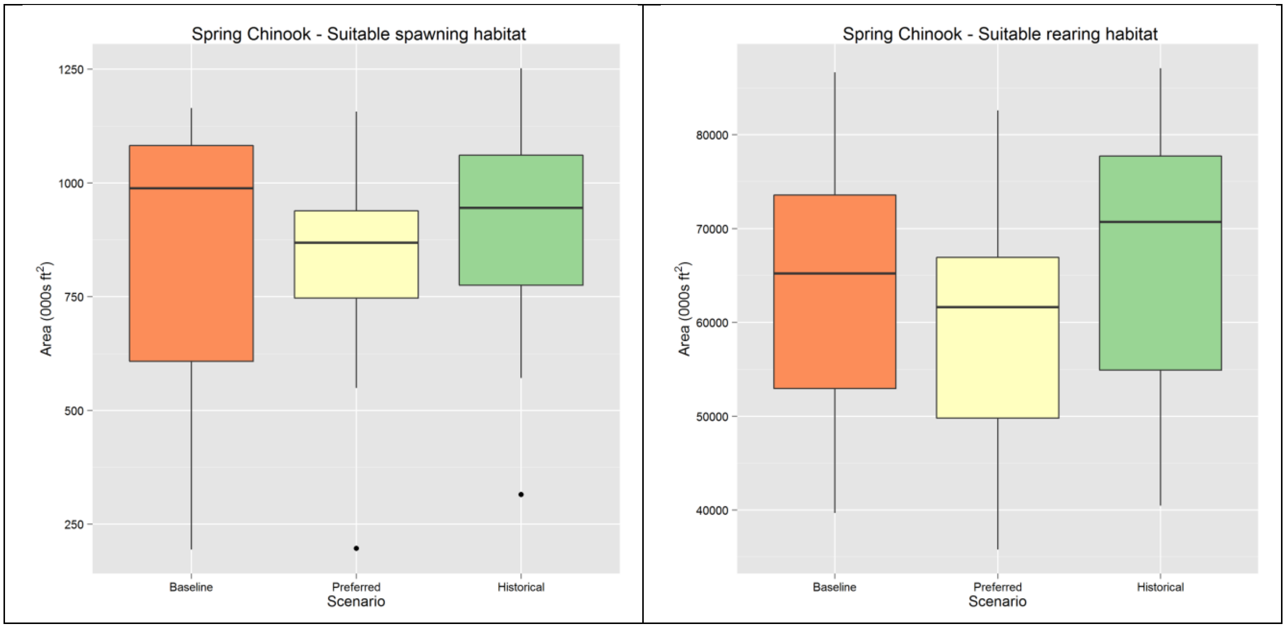


Figure 3.38: Spring-run Chinook spawning habitat (CS1, left panel) and juvenile rearing habitat (CS2, right panel) for both DRR simulations relative to the historical scenario.

Steelhead median suitable spawning habitat (CS1) is improved for both DRR scenarios relative to the historic scenario (Figure 3.39), but the two DRR scenarios are not meaningfully different from one another.

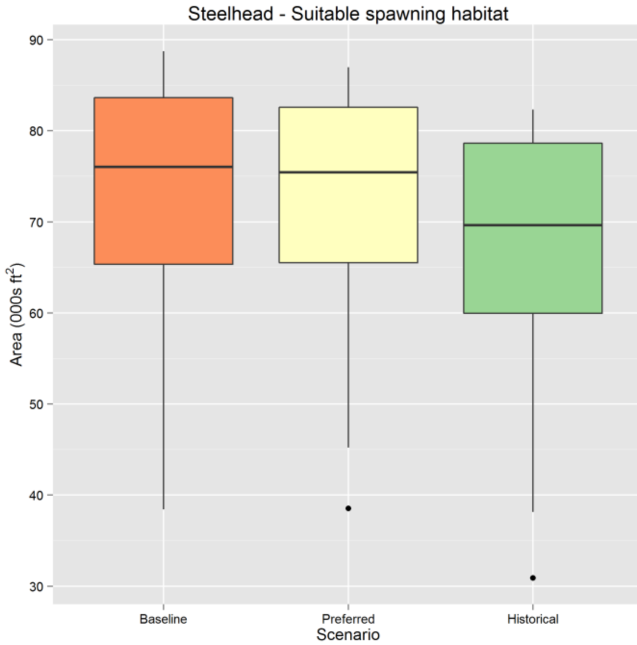


Figure 3.39: Suitable spawning habitat for steelhead (CS1) for both DRR simulations relative to the historical scenario.

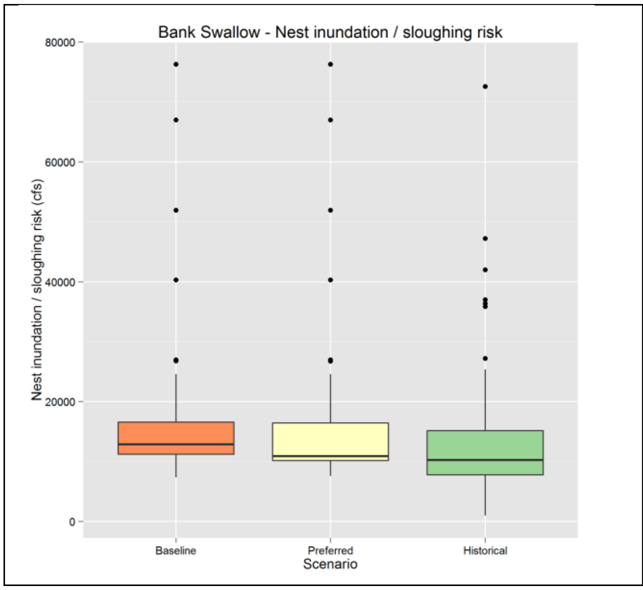
Green Sturgeon

Green sturgeon egg survival (GS1) is not meaningfully affected by the pilot EFT rule-set, improving very slightly by 1% relative to the DRR 2011 reference case (Table 3.44). The reference case is also not meaningfully different from the historical scenario.

Bank swallow

The median suitable potential habitat (BASW1) for bank swallows is not simulated for the pilot study.

The median nest inundation/sloughing risk (BASW2) for bank swallows is expected to decrease by 15.4% under the pilot EFT rule-set (Figure 3.40, left panel). The median nest inundation/sloughing risk was historically 20.1% lower than the reference case. The change under the pilot EFT rule-set is expected to be meaningful since most individual water year differences are negative (Figure 3.40, right panel). Historical individual water years cannot be compared to reference case.



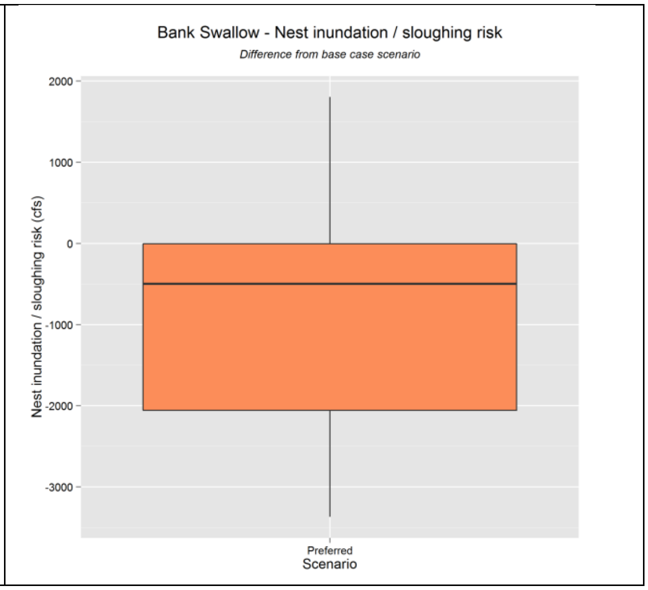


Figure 3.40: Median nest inundation/sloughing risk (BASW2) for bank swallow under the pilot EFT rule-set relative to reference case and historical scenarios (left panel), showing individual year differences relative to base case scenario (right panel).

Fremont Cottonwood

As shown in Table 3.44, Fremont cottonwood initiation did not change between the pilot EFT rule-set and the reference case. However, cottonwood initiation is 45% higher under historical conditions compared to the reference case (Figure 3.41). While numerous factors (operations, climate and water demand) have changed between 1943 and 2004, the historical comparison illustrates the degree of cumulative change locked into the 2011 DRR reference case and the expected direction of the effect of these changes on Fremont cottonwood initiation (Figure 3.41).

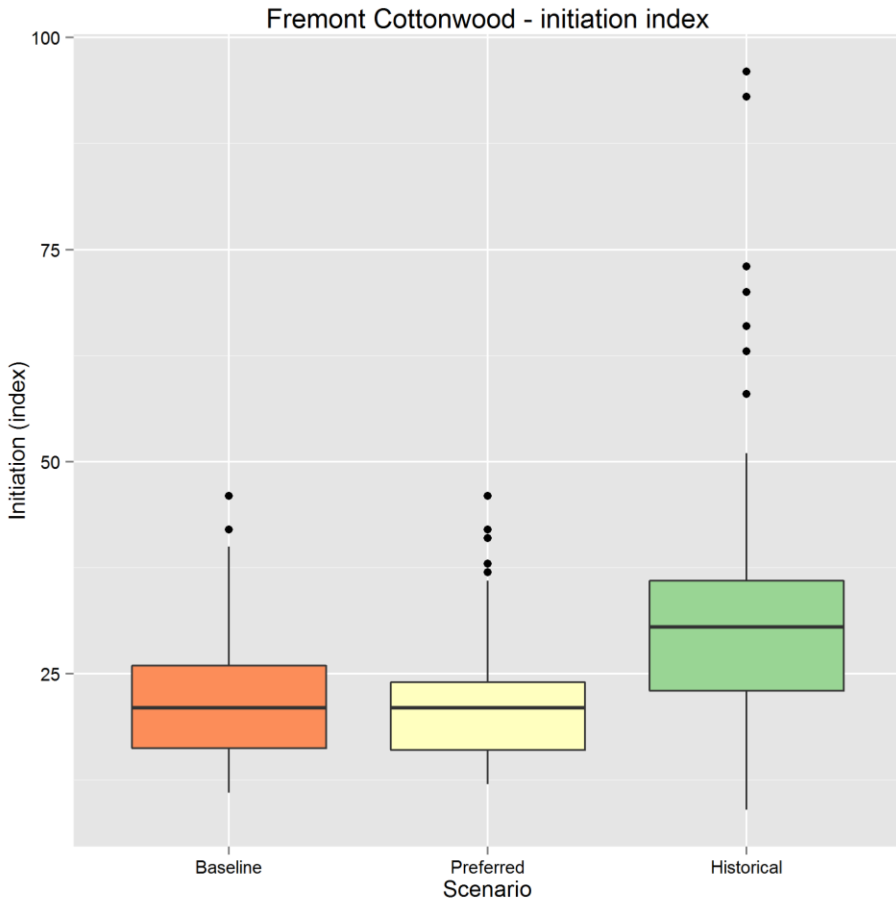


Figure 3.41: Median Fremont cottonwood initiation success (FC1) for the pilot EFT rule-set relative to the reference case and the historical (1943-2004) scenario.

Large woody debris recruitment

Not simulated for the pilot study.

San Joaquin-Sacramento Delta (DeltaEFT)

Table 3.45: Pilot study and historical flow effect sizes are shown for the median difference Effect Size (ES) method (preserving the native units of each indicator). The DRR 2011 scenario serves as a comparative reference case, with percentage differences shown below absolute median effects. $^{\delta}$

Focal species	Performance indicator	Reference case (229)	Pilot (231)	Historical (118)
Bay Delta Indicators				
Fall Chinook	Smolt weight gain (%)	20.2	18.6 (-1.6%)	**N/A**
	Smolt predation risk (passage days)	15.2	15.3 (-1.0%)	**N/A**
	Smolt temperature stress (degree day)	105.1	106.8 (-1.6%)	**N/A**
Late Fall Chinook	Smolt weight gain (%)	29.1	28.8 (-0.3%)	**N/A**
	Smolt predation risk (passage days)	15.5	15.3 (1.4%)	**N/A**
	Smolt temperature stress (degree day)	57.3	56.6 (1.2%)	**N/A**
Spring Chinook	Smolt weight gain (%)	23.6	22.4 (-1.2%)	**N/A**
	Smolt predation risk (passage days)	15.3	15.5 (-1.3%)	**N/A**
	Smolt temperature stress (degree day)	84.3	87.2 (-3.4%)	**N/A**
Winter Chinook	Smolt weight gain (%)	29.7	29.6 (-0.1%)	**N/A**
	Smolt predation risk (passage days)	14.4	14.3 (0.9%)	**N/A**
	Smolt temperature stress (degree day)	40.3	40.0 (0.8%)	**N/A**
Steelhead	Smolt weight gain (%)	19.3	17.6 (-1.7%)	**N/A**
	Smolt predation risk (passage days)	15.5	15.8 (-2.2%)	**N/A**
	Smolt temperature stress (degree day)	109.4	112.2 (-2.5%)	**N/A**
Splittail	Proportion max spawning habitat	0.000	0.000	0.000
Delta Smelt	Spawning success (optimal days)	34.3	34.1 (-0.5%)	**N/A**

	Habitat suitability index	3,653	3,724 (1.9%)	3,260 (-10.7%)
	Larval & juvenile entrainment proportion	0.053	0.051 (0.2%)	0.095 (-4.1%)
Longfin Smelt	Abundance index	N/A	N/A	N/A
Invasive Deterrence	Brazilian waterweed suppression	8.8	8.7 (-1.5%)	N/A
	Overbite clam larval suppression	2.7	2.6 (3.8%)	N/A
	Asiatic clam larval suppression	8.8	8.7 (-1.5%)	N/A
Tidal Wetlands	Brackish wetland area (ha)	N/A	N/A	N/A
	Freshwater wetland area (ha)	N/A	N/A	N/A

$^{\delta}$ Comparisons of indicators measured as percentages or proportions are based on the simple arithmetic difference in comparison to the reference case; all other indicators are based on the proportional difference in comparison to the reference case. The sign of the difference depends on whether the indicator improves (more is better) or declines (more is worse) relative to the reference case. Green and red shadings are used to highlight 3 levels of positive and negative changes: 5-10%, 10-20% and >20%. Cells marked 'N/A' are missing either because a scenario was not simulated, or because the results were removed following the screening process described in Section 3.4.2

Salmonids

Under the pilot EFT rule-set there are no meaningful improvements or declines to any salmonid run-type in the Delta ecoregion. Comparisons with historic data are not possible due to the short time series of data.

Splittail

The median proportion of maximum spawning habitat for splittail (SS1) is expected to remain constant under all three scenarios.

Delta Smelt performance indicators

The median spawning success for Delta smelt (DS1) is expected to remain relatively constant between project alternatives at approximately 34 days of optimal spawning conditions annually.

The median habitat suitability index for Delta smelt (DS2) is expected to remain relatively constant between project alternatives at approximately 3,700. The median historical habitat suitability index was 10.7% lower than the reference case (Figure 3.42). This is most likely due to historically higher salinities in Suisun Bay relative to the reference case (Chapter 3.2) caused by the inclusion of Fall X2 action under the reference case, which was only in effect for a few of the historical years (Chapter 3.4.2). The change is expected to be significant due to the decrease in both median and variation.

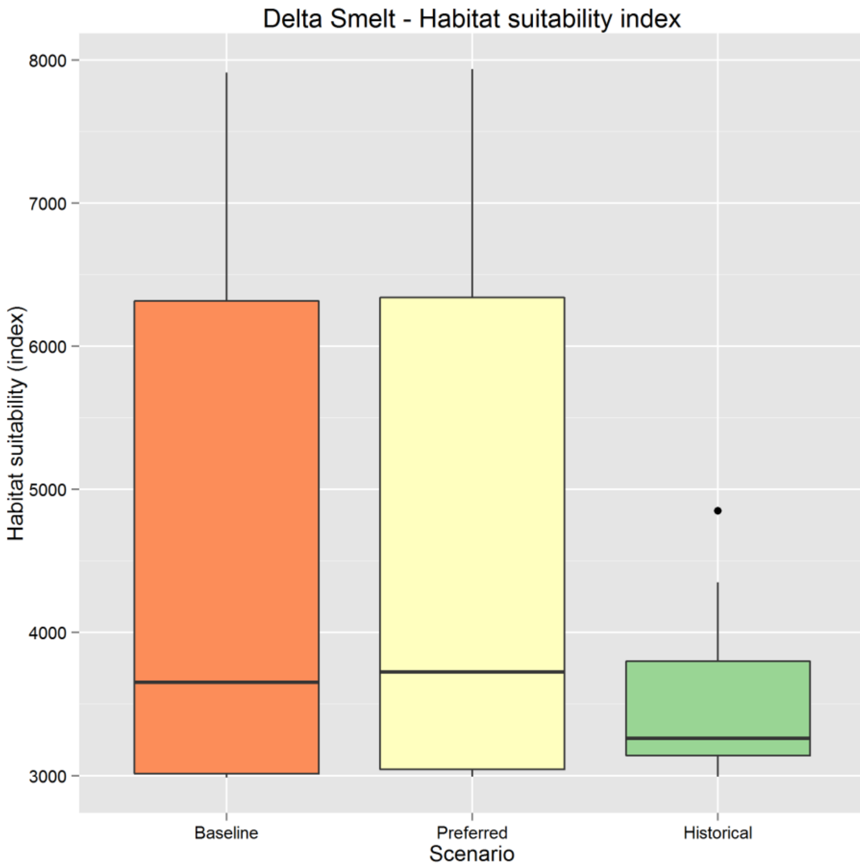


Figure 3.42: Median historical habitat suitability index (DS2) relative to reference and preferred scenarios.

Longfin Smelt

Not simulated for the pilot study.

Invasive deterrence

The median Brazilian waterweed suppression (ID1) is expected to remain relatively constant between project alternatives with an estimated maximum three month average salinity from May to October of approximately 8.8‰ for the ‘Chipps Island to Oakley’ region.

The median overbite clam larval suppression (ID2) is expected to remain relatively constant between project alternatives with an estimated minimum three month average salinity from December to April of approximately 2.7‰.

The median Asiatic clam larval suppression (ID3) is expected to remain relatively constant between project alternatives with an estimated maximum three month average salinity from May to October of approximately 8‰ for the 'Chipps Island to Oakley' region.

Tidal wetlands

Not simulated for the pilot study.

Summary of Species Net Effects

Table 3.46 provides differing views on the benefits and costs of the pilot EFT rule-set (and historical conditions) compared to the 2011 DRR reference case. The pilot EFT rule-set is expected to substantively improve conditions for winter-run Chinook and bank swallows in the Sacramento River. Delta smelt entrainment *was* slightly improved using the pilot EFT rule-set but the absolute effect was less than 5% (because reverse flows are already uncommon in April and May under the reference case scenario). However, the pilot EFT rule-set leads to deterioration in performance for fall-run Chinook and steelhead in the Sacramento River relative to the reference case (Table 3.47). Conditions for all other species are expected to remain largely unchanged.

The EFT rule-set in particular targeted improving suitable spawning habitat for winter-run Chinook (CS1). When evaluated with the RS method, this indicator showed marked improvement: a 35% increase in the number of favorable years, while the absolute all-year median increase in suitable spawning area was just under 5%. Further, benefits generated by the EFT rule-set for winter-run Chinook came at the expense of lower suitable spawning habitat (CS1) for fall-run and spring-run Chinook, both of which decline by about 10%. Unlike fall-run Chinook, which are maintained by large-scale hatchery supplementation, and spring-run Chinook, which make extensive use of tributaries and do not rely on the mainstem Sacramento River for spawning, winter-run Chinook make extensive use of the mainstem Sacramento River upstream of Red Bluff.

Table 3.46: Summary of pilot study and historical effects for Sacramento River and Delta ecoregion, as measured by the RS (left) and ES (right) methods. [δ]

RS Methodology				
Sacramento River Ecoregion				
	Reference case: DRR baseline			
	Pilot EFT rule-set		Historical	
	+	–	+	–
Fall		1	1,4,6	
Late Fall			5	1,2
Spring	3,6	1,2	2,4	6
Winter	1,4,6		1,6	2
Steelhead		2	4,5	1
Bank swallow				
Green Sturgeon				
Cottonwood				
Woody Debris				
Delta Ecoregion				
Minor improvement (reduction) in Delta Smelt entrainment, otherwise, no meaningful change				

ES Methodology				
Sacramento River Ecoregion				
	Reference case: DRR baseline			
	Pilot EFT rule-set		Historical	
	+	–	+	–
Fall		1	1	2
Late Fall				1,2
Spring		1,2	2	
Winter				
Steelhead			2	1
Bank swallow	2		1,2	
Green Sturgeon				
Cottonwood			1	
Woody Debris	N/A		N/A	
Delta Ecoregion				
Minor improvement (reduction) in Delta Smelt entrainment, otherwise, no meaningful change				

[δ] Numbers indicate the internal PI-number of the indicator with a meaningful (>10%) positive or negative change for each comparison; shaded green in '+' columns and red in '–' columns. *Key to salmonid indicators:* 1 = suitable spawning habitat, 2 = suitable rearing habitat, 3 = thermal egg-to-fry survival, 4 = juvenile stranding index, 5 = redd scour, 6 = redd dewatering risk. Cells marked 'N/A' are missing either because a scenario was not simulated, or because the results were removed following the screening process described in Section 3.4.2.

Reduction of larval and juvenile entrainment of Delta smelt was also targeted for improvement by the EFT ecological flow rules. Although the pilot EFT rule-set does result in more positive flows in April, May and June (Table 3.40), and results in an improvement in all water years (Figure 3.43 and Figure 3.44), the median reduction of entrainment is expected to be small. This is most likely because reverse flows are already uncommon in April and May under the reference case scenario, and the meaningful improvement in June has little impact on entrainment as most spawning is already over (only 16% of spawning occurs in June).

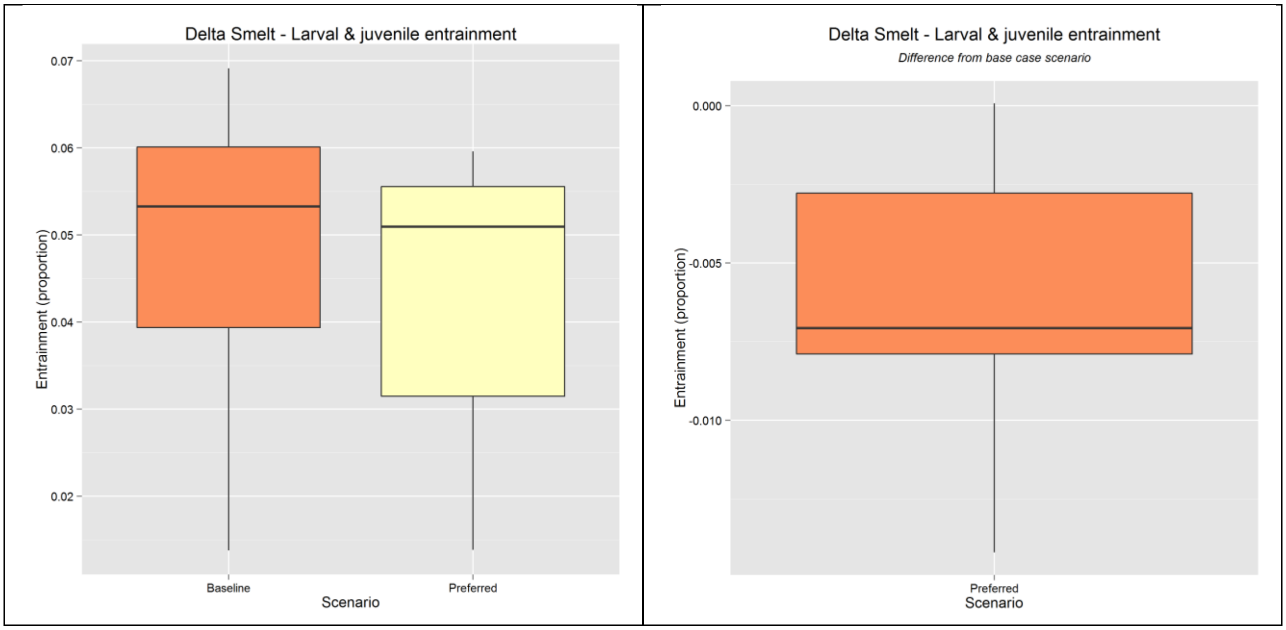
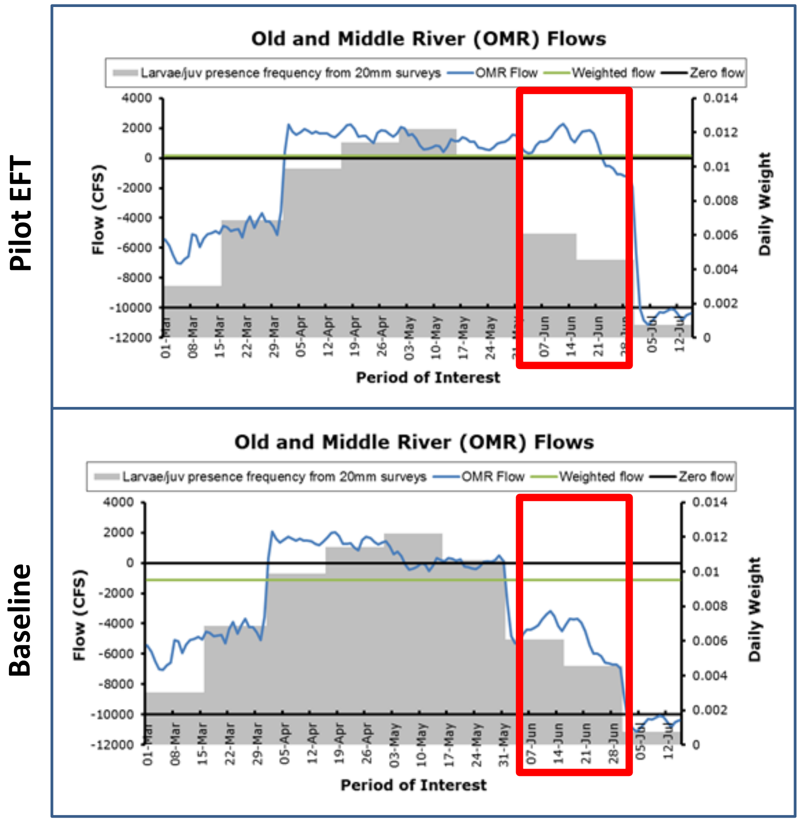


Figure 3.43: Median Delta smelt entrainment risk (DS4) relative to the DRR 2011 reference case scenario (left panel), showing individual year difference relative to baseline scenario (right panel).



DS4 example

- Positive OMR flow in June in Pilot EFT flows scenario
- Entrainment reduced from 5.3% to 3.9%
- June weighting is only 16%

Figure 3.44: Example DS4 results for the same sample year before/after EFT rule-set. The graphs show OMR reverse flows and Delta smelt entrainment were in some years improved under the pilot EFT rule-set (absolute median effect was less than 5%).

Table 3.47: Overall weight of evidence and assessment of net effects by species, Sacramento River Ecoregion and Delta Ecoregion. Refer to legend below the table.

Scenario Relative to DRR 2011						
Sacramento River Ecoregion						
	Pilot Study			**Historical**		
	+		−	+		−
Fall			5	3-RS		
Late Fall						5
Spring		+/−			+/−	
Winter	3-RS				+/−	
Steelhead			3-RS		+/−	
Bank Swallow	3-ES					
Green Sturgeon						
Cottonwood						
Woody Debris						
Delta Ecoregion						
	No meaningful change			N/A		

(blank)	Neither the RS nor ES summary method generates a potential change that passes our ±10% and ±5% thresholds. No meaningful effect.
+/-	Mixed effects -- indicators for same species show benefits and penalties (i.e., Chinook/steelhead), but the net effect is difficult to determine.
1-RS	RS summary method shows a potential effect (passes ±10% threshold). **However**, the results are **highly variable.**
1-ES	ES summary method shows a potential effect (passes ±5% threshold). **However**, the results are **highly variable.**
2-RS	RS summary method shows a potential effect of ±10% change or more in favorable years, with **clear signal to noise** (**less variability**), yet the ES summary view shows the *inverse effect* (potentially contradictory evidence).
2-ES	ES summary method shows a potential effect of ±5% change in absolute median effect size, with **clear signal to noise** (**less variability**), yet the RS summary view shows the *inverse effect* (potentially contradictory evidence).
3-RS	RS summary method shows a potential effect of ±10% change or more in favorable years, with **clear signal to noise** (**less variability**), and the ES summary view does not meet threshold (no contradictory evidence).
3-ES	ES summary method shows a potential effect of ±5% change in absolute median effect size, with **clear signal to noise** (**less variability**), and the RS summary view does not meet threshold (no contradictory evidence).
4	Both summary views agree on the direction of the potential effect, and both pass the threshold for a potentially meaningful effect. However, **both show a highly variable spread in results**.
5	Both summary views agree on the direction of the potential effect, and both pass the threshold for a potentially meaningful effect with **clear signal to noise** (**less variability**).
6	Either category "3","4" or "5" + fundamental link to scenario description.

3.4.5 Caveats & Limitations

This was only our first pilot effort and considered merely two species: Delta smelt and winter-run Chinook. Our initial results highlight the opportunity for additional improvement by further refining the implementation of our EFT rule-sets and including additional species. Future work will consider additional species, and emphasize dynamic, state-dependent rules that do not attempt the same static optimization for every objective.

Other general caveats and limitations are described in Section 3.3.4.

4 Where to From Here?

With the aid of over 70 scientists and managers since 2004, our Project team was amongst the first to quantify how multiple components of the Sacramento River and San Joaquin-Sacramento Delta flow regimes can be modified to promote key ecosystem functions in support of smarter, more eco-friendly flow management (TNC *et al.* 2008). Unlike approaches which focus on a small number of simplified and static ecosystem needs, EFT describes 25 site specific, functional flow algorithms (conceptual models) for 13 representative species and key habitats across the Sacramento River and Delta ecoregions. We include life-history stage indicators for both listed and non-listed riparian and aquatic species and habitats. EFT's life-history stage conceptual models are then coupled with multiple physical models of flow, water temperature, salinity, stage, channel migration, and sediment transport to enable ecological effects analyses. From the beginning, a high priority of the EFT team has been to select representative species and ecological indicators that capture the essence of existing scientific understanding and ecosystem range. We have aimed for a multi-species, multi-indicator approach while being careful to avoid pitfalls caused by too broad a sphere of concern or too much detail on any one species.

This Chapter does not attempt to survey or "pick the best solution" for reconciling the vexing challenge of managing the Sacramento River and Delta for people and environmental values. We instead isolate the biggest lessons learned over more than 10 years of work, and plot a course for the next phase of coupled, multi-species, ecological flow decision support for the Sacramento River and Delta.

Our recommended ecological flow action agenda follows.

4.1 A New Paradigm: Flexible Ecosystem Priorities

The enduring challenge confronting the management of water in the Sacramento-San Joaquin Delta is deciding how to balance and reconcile trade-offs amongst inversely correlated ecosystem values and water supply needs. Indeed the Sacramento San-Joaquin Delta is universally regarded to be in “crisis” because of an inability to find "balance" in the trade-offs among competing objectives and resource demands[21].

The detailed applications of EFT presented in Chapter 3 crystalize the fact that it is impossible to achieve all ecosystem objectives — let alone the co-equal goals of balancing human and ecosystem needs — each and every year. There are plain, irreconcilable and ceaseless trade-offs that must be tracked and confronted, with winners and losers in

[21] Delta Science Council, 2013 Year in Review.

different years, depending on hydrologic conditions and priorities. These trade-offs do not occur because of a failure to create clever enough models that magically find the optimal solution. Rather, they exist because a single, unchanging optimal solution *does not exist*. For example, restored floodplains may require higher flows at some locations and times to seasonally activate, creating conditions which are not ideal for mainstem Sacramento River spawning flows. Alternatively, non-natural flow patterns might sometimes be useful in suppressing invasive species but create conditions which are not favorable for other indicator species.

The paradigm shift which we propose requires seeing balance as a condition which does not involve the same species or objectives losing (or winning) unnecessarily often. The EFT pilot investigation described in Section 3.4 illustrates that the operation of the California water system *can* be changed to make timing of releases from Shasta Dam more beneficial to selected species without adverse consequences on storage and water exports. However, it also highlights the inherent trade-offs between species and life-stages, and how applying the same rule-set for a given water year type every year actually *constrains* options and contributes to the inability to adequately balance ecosystem trade-offs.

For its part, BDCP did not consider the full range of reservoir operational modifications possible. Instead, it focused on a very narrow range of optimizations related to Delta exports rather than a more complete, more flexible analysis of system-wide reservoir re-operation. In particular, it placed constraints on Sacramento River reservoir operations associated with existing regulations on water temperature and downstream flow requirements. The objective for BDCP was to fix these established regulations, and evaluate how the new conveyance facilities could be used to maximize Delta exports within these constraints. This was the primary reason that the differences amongst BDCP alternatives were not large (see Section 3.3.3).

Using daily resolution modeling tools, our approach emphasizes a bottom-up assessment of opportunities to achieve ecosystem flow needs. This includes relaxing traditional constraints (e.g., precise timing of exports) as part of the initial search, while still meeting the primary flood safety and water supply requirements related to carry-over storage and export volumes. This approach would create a far better opportunity to discover sets of beneficial multi-objective outcomes.

There is a pressing need to develop greater awareness of the value of flexibility to manage ecosystem trade-offs over time. California's native fish and riparian species have adapted to the State's widely variable climate. These evolutionary adaptations have helped species persist during extended droughts and other forms of extreme water fluctuation. As examples of natural flexibility, there are four run-types of Chinook salmon, each of which is adapted to a different season and habitat that overlap in both. Adults can return from the ocean anywhere from two to six years of age. Juvenile Chinook may choose to hold in cold water refuge habitat or migrate immediately to the ocean. While the ability to exploit their adaptive range is now limited by dams that block cold-water refuge habitats, simplified channelized disconnected habitats, hatcheries that are simplifying life-history variations, and a Delta full of alien predators — some residual adaptive capacity nevertheless remains.

4.1.1 Smart, State-dependent Priorities

The adaptive range possessed by many species allows for a reasoned level of flexibility when approaching ecosystem flow management. This feature of species life-history adaptation can be exploited to develop 'state-dependent' priorities. Instead of one-size-fits-all solution, establishing state-dependent priorities require tracking the recent history of water availability and related habitat conditions experienced by priority species and then *dynamically adjusting priorities based on this history* (Figure 4.1). For example, favorable Fremont cottonwood initiation does not need to happen every year to sustain a healthy population: a decadal frequency is perhaps sufficient. Correlated with this statement, the natural hydrologic conditions necessary to support a strong cohort of initiating Fremont cottonwood are also infrequent. It therefore makes sense for water operations to take advantage of water years that are conducive to establishing cottonwood seedlings at the sufficient frequency of recurrence. This will mean that other ecological objectives, such as objectives for salmon or smelt will need to be reduced or even turned off when the history of conditions develop to favor another heretofore neglected species. In contrast, three consecutive years of poor spawning or rearing conditions for salmonids should logically prompt a substantial increase in efforts to intervene to improve conditions before there is risk of losing an entire cohort.

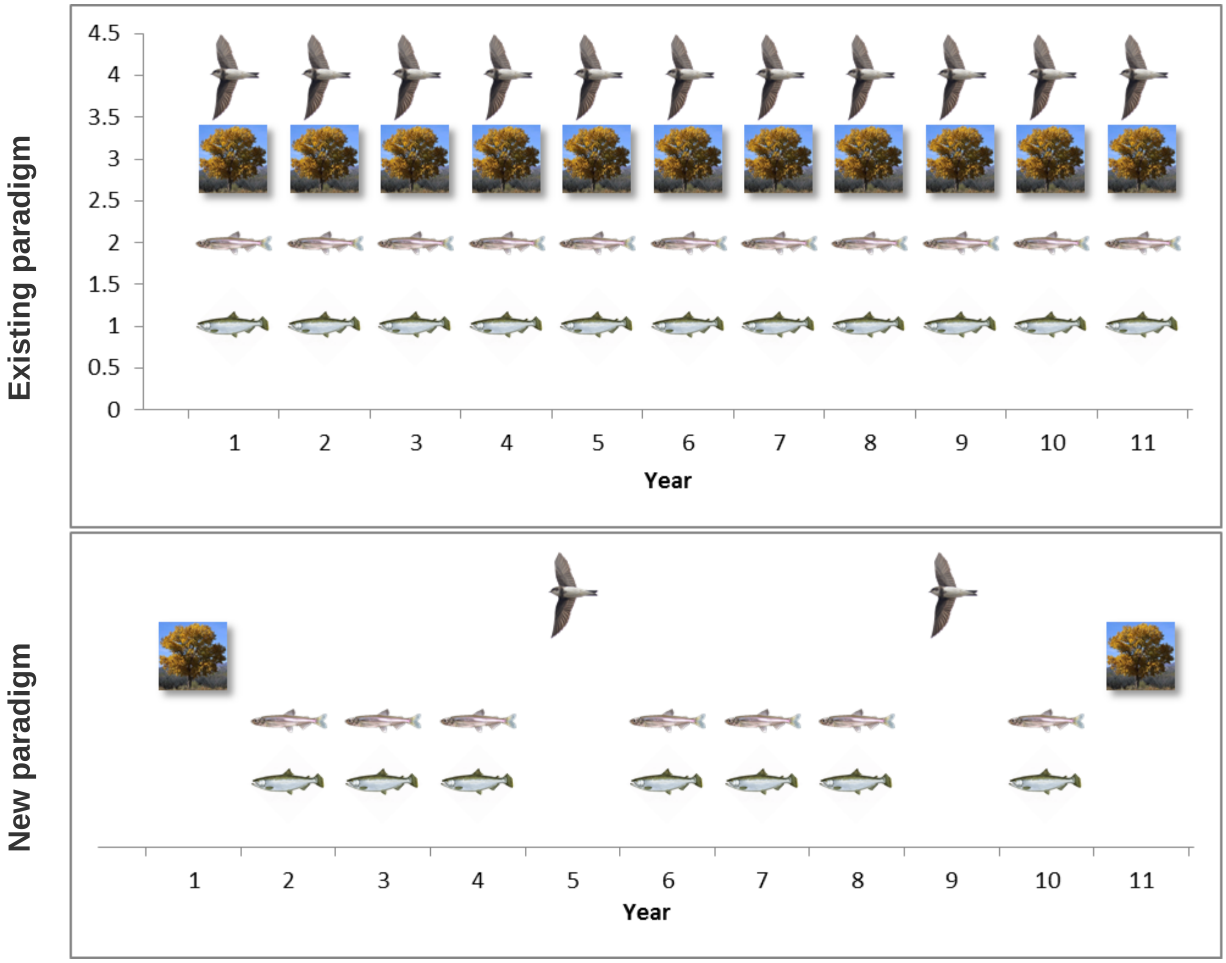


Figure 4.1: *Hypothetical* example of state-dependent priorities (for illustrative purposes only, not a realistic prescription). The existing paradigm attempts to optimize releases for all species in all years (with rules based on water-year type). Under state-dependent priorities, flows are optimized for different species according to the recurrence interval necessary to support healthy population conditions (e.g., in this example, every 10 years for Fremont cottonwoods, for Chinook and Delta smelt in 3 out of 4 years and for bank swallows every 4 years). The choice of priority would also depend on the water availability conditions in any given year.

4.1.2 Recognize Multiple, Equally Acceptable Solutions Exist

Further advancing our pilot ecological flow study (Section 3.4), evaluating "optimal" water operations for the full suite of EFT species indicators, including introduction of state-dependent priorities, will require a different approach. In our pilot study, target flows were described as a range of flows beneficial to a species and life-stage, e.g., winter-run Chinook spawning habitat performance was found to be good if flows were between 5 and 12 kcfs in May and June (Appendix I). In the pilot study, flow optimization was a manual process where native CALSIM WRESL files were edited to achieve EFT target flows (Section 2.9.1; Appendix I). In this way, we did not identify optimal single-objective solutions. This would require evaluating the effect of alternative flows on the raw calculated values of each species/habitat performance indicator (raw effect size). Further, finding optima also generally requires modeling hundreds of simulations to find convergence (our pilot study performed manual what-if simulations).

When considering multiple and often inversely correlated objectives, there is no *single* optimal solution (set of rules). Instead, there exists a set of candidate solutions that are all considered equally desirable (Figure 4.2, panel c). Identifying the full set of equally desirable solutions allows managers to select among alternatives after seeing the nature of the relationship amongst trade-offs. Lastly, the existing type of single-objective analysis also has the disadvantage of forcing us to decide which objective is more important *a priori*.

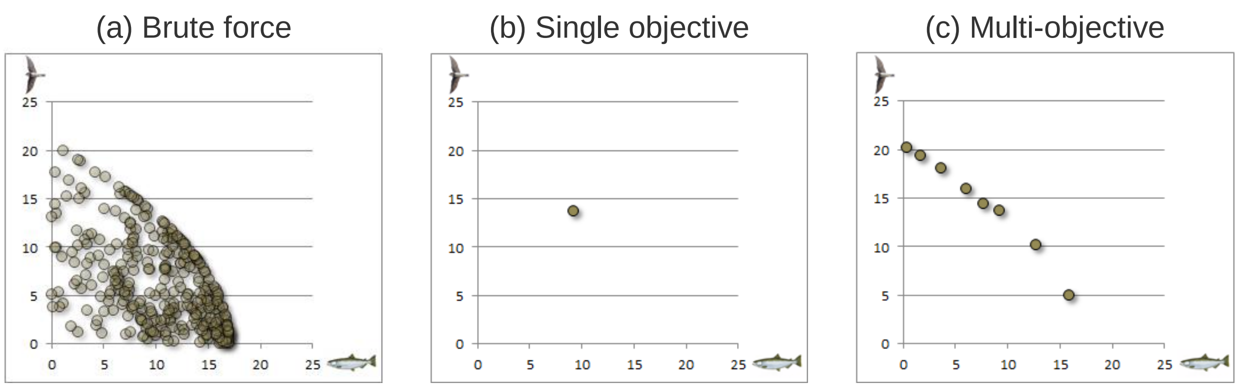


Figure 4.2: Hypothetical trade-off example for two different species objectives. The brute force approach (a) involves a search that generates many sub-optimal solutions. The single objective approach (the current paradigm) identifies only one candidate solution, but doesn't allow managers and scientists to evaluate the full range of trade-offs (b). The multi-objective approach (c) allows managers to select the most appropriate trade-off from the full set of equally suitable solutions.

In our intial pilot study (Section 3.4), flow optimization was a manual process where native CALSIM WRESL files were edited based on the expected response of EFT performance indicators to flow patterns (Figure 4.3, upper panel). While many elements (including EFT) will continue to be used, implementing this new paradigm will require a very different modeling system capable of running hundreds of simulations in parallel. We recommend an automated implementation that uses a batch run coordinator with a multiple-objective optimization algorithm (Figure 4.3, lower panel).

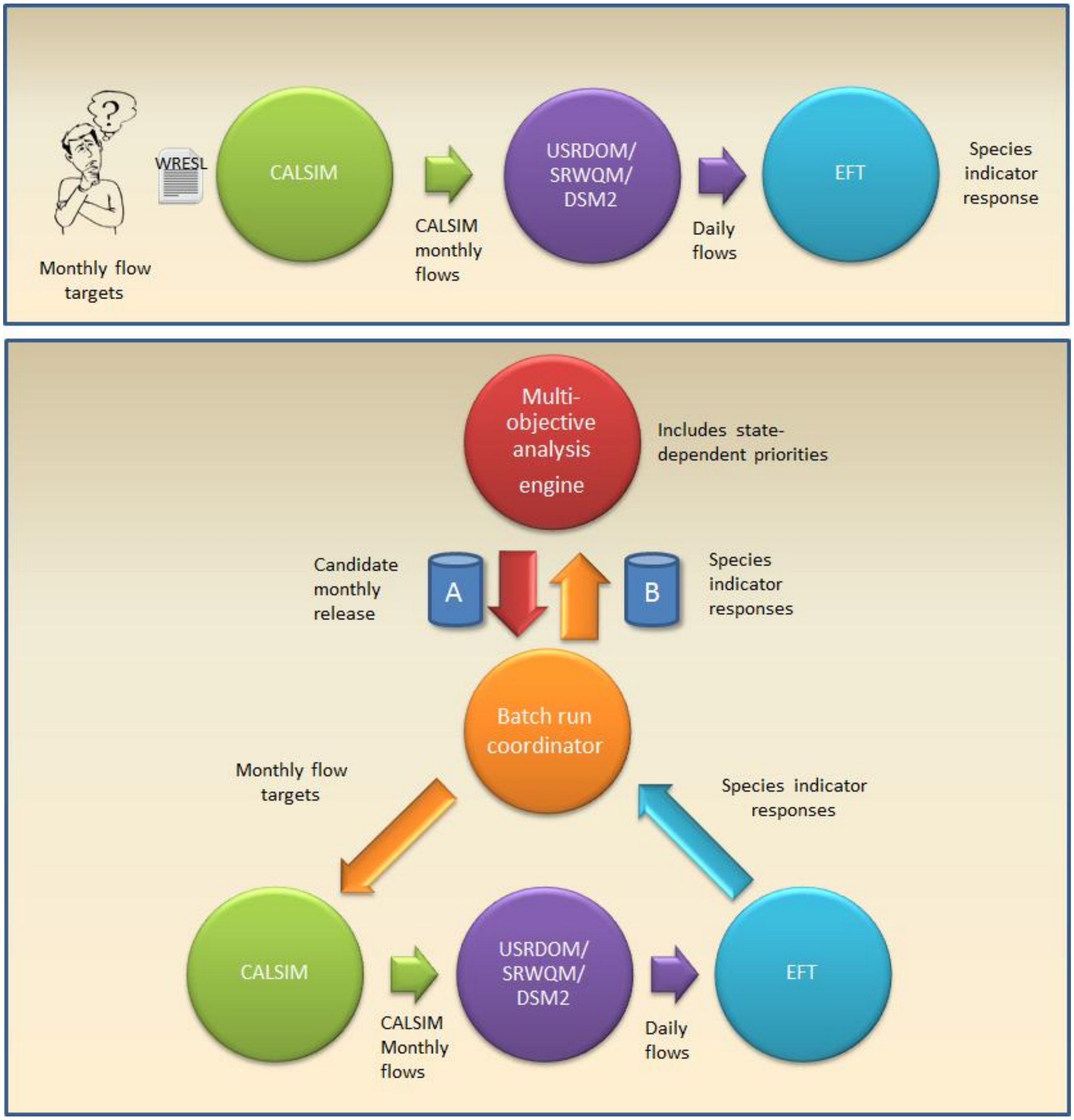


Figure 4.3: Recommended multiple objective, state-dependent ecological flow optimization system (lower panel) vs. approach used in pilot study (upper panel). In the pilot study, the flow optimization was largely a manual process (upper panel) where an operator would edit native CALSIM WRESL files. In the recommended system (lower panel) the modeling suite would be automated by a batch run coordinator so hundreds of scenarios can be simulated. In addition to the batch run coordinator, a key feature would be a new multi-objective analysis engine with implementation of state-dependent priorities. The optimization engine would communicate with the batch run coordinator and store histories of trial flow releases and related multi-species responses.

The batch run coordinator would send monthly releases from Shasta Dam to CALSIM using a lookup table that is accessed from CALSIM using logic that would be implemented so that CALSIM does not need to be recompiled. The batch run coordinator would then trigger the full modeling suite (CALSIM, USRDOM, SRWQM, DSM2 and EFT) and keep track of indicator responses (in raw units) to the alternative monthly releases in a given water year. This will allow each model in the modeling suite to be run individually and potentially in parallel. As new results become available from the coordinator, the optimization engine would use them to create the next generation of improved scenarios (scoring and tracking results for all performance indicators).

The new state-dependent priority component would be based on how frequently a species requires favorable conditions in order to sustain a healthy population. For example, Fremont cottonwood initiation does not need to happen every year to sustain a healthy population (once a decade is generally considered sufficient). Under the existing paradigm, a one-size-fits-all approach to water releases is assumed, which attempts to achieve the same targets based on the water year type but not on the recent history experienced by different species. Our recommended smart, state-dependent paradigm will prioritize releases based on the time since a species has last experienced favorable conditions relative to the recurrence necessary to maintain a healthy population. The multi-objective optimization engine will penalize alternatives that fail to meet the target return frequency of beneficial flows for a given species and performance indicator. Additionally, solutions will also be influenced by the state of natural inflows.

4.2 Other Promising Avenues

4.2.1 Sustained Refinement & Application of EFT

The Ecological Flows Tool has successfully coupled models of operations and hydrodynamics with multi-species ecosystem and geomorphic response models across a geographic area which spans the Sacramento River and Delta. It provides a very successful and rare example of the synthesis and integration of a vast amount of scientific knowledge across multiple disciplines. Given the advances that have been made since 2004, leveraging the investment in EFT through continued development and application will be far more cost-effective than duplication or re-invention.

The approach adopted in the development of EFT is precisely the kind envisioned by the CALFED Science Advisory Panel in 2008, and subsequently by the Delta Science Council and a variety of other cross-disciplinary researchers (e.g., PPIC, UC Davis). More than ever, there is value in coupled modeling tools that promote experts and resource managers coming together to explore, develop, test and improve solutions to California's water management problems.

The magnitude of Sacramento San-Joaquin Delta challenges, the scientific uncertainties, and the time required to learn and iterate means developing ecological flow recommendations will take many years and undergo periods of surprise and change. Hence, the tools used to harness and synthesize this knowledge must also be continuously updated and maintained.

Scientists (and modelers) are expected to observe, hypothesize (model), predict, check evidence, change, revise hypotheses (models), and repeat. As with any quantitative decision support tool, the knowledge it contains comes from a particular point in time and must be adaptively updated. It is imperative to continuously learn and periodically adapt EFT so that it continues to track the always evolving state of science. This will require ongoing funding investments.

In EFT, we intentionally use a functional flow approach that emphasizes *specific* cause-effect linkages. This formulation of EFT's indicators is open to testing and adaptation through time as experiments are completed and new data and understanding emerge. A logical place to start reviewing hypotheses and data used in EFT would include the advice and candidate suggestions received from invited experts during a technical review workshop of DeltaEFT held in January 2013.

Isolate & Branch Individual Submodels

Some stakeholders have expressed an interest in being able to run individual SacEFT components for smaller, specific, targeted analyses, e.g., applying the SacEFT submodels of soil erosion, bank swallow, and large woody debris recruitment. With a relatively small amount of effort, these submodels could be designed to run in a standalone form, without any requirement to install SacEFT itself, while still remaining fully integrated within EFT. This would support opportunities for light-weight screening analyses prior to evaluation of multi-species effects.

Managed Hosting & Maintenance

Beyond making an install pack available, most software systems require dedicated ongoing managed hosting, updating, and support for tool users. Consideration should be given to a long-term plan for management and updating of the EFT software. Without a basic commitment to long-term maintenance, software tools eventually dwindle into obsolescence.

Training

Securing funding investments to create and deliver training courses on the appropriate use and application of EFT in detailed effects analyses and related investigations should be considered.

4.2.2 Even More Attention to Climate Change Mitigation

Results of EFT BDCP analyses for the anticipated late long term (LLT) (2060) period climate conditions (see Section 3.3.3) highlight the need for more focus on efforts to mitigate for climate change itself, not just whether certain operations are better/worse relative to a worsening future baseline. The climate change signal and effects in the BDCP study generally dwarfed the operational alternatives considered.

Studies that only use baselines based on future (deteriorated) conditions and constraints shift attention away from cumulative total change in ecological conditions. Such administrative decisions may mask what can often be striking differences between historic operations and those proposed. Use of a historical reference case was recommended by the Delta Science Panel in its review of BDCP (DSP 2014), even though the approach is unwelcome by some who feel that use of a historical record is a flawed reference given that it includes numerous shifts in operational standards and climate. The counterpoint to this argument is that the use of a historical reference case enables study of the level of cumulative change, regardless of whether it is produced by climate change, changes in operations and conveyance, or increasing human water demand.

4.2.3 Don't Just Plan: Implement Real-time Ecological Modeling

While both are important, there is a disproportionate amount of effort devoted to water planning models in California. More effort should be invested in real-time, in-season operational tools that incorporate multiple ecological flow needs. Planning models like CALSIM, DSM2 and related planning models do not and cannot capture behavioral uncertainty, nor can they represent the true operational flexibility that exists. For example, Mount *et al*. (2013) were concerned that some of the modeled flow operations for certain BDCP scenarios would not actually occur in real operations. Indeed the degree to which actual operations follow simulated operations can vary substantially (especially as the resolution of most of the planning models is monthly).

More fundamentally, in-season modeling tools *that are used* by operators day to day have a greater impact on actual, on-the-ground decisions[22]. If real-time operational tools do not adequately build-in ecological flow guidelines and targets derived from related modeling (including results from EFT and other studies) then planning tools will remain academic.

4.2.4 Leadership Coalescence

The management of river and estuarine ecosystems to protect valued species and habitats is one of California's least coordinated water management activities. Too many agencies and groups have roles leading to fragmentation of leadership and responsibility. Successful environmental flow management is more likely to occur if there is a transparent and

[22] e.g., the Okanagan Fish/Water Management Tool (www.douglaspud.org/Pages/where-did-all-of-these-sockeye-come-from.aspx)

science-based program linked to relevant decision support tools and the outcomes of adaptive management and monitoring. This ought to include the creation of a real-time, Ecological Water Operations Management Team (E-WOMT)[23]. Members of the E-WOMT would include those with deep background and experience in aquatic ecology in addition to traditional hydrologists and engineers familiar with CVP and SWP coordinated operations.

A functioning E-WOMT, informed by both a rigorous adaptive management program and a package of appropriate integrated decision support tools (including new real-time ecological modeling tools), would be a giant step forward in *routinely doing* multiple objective trade-off decision-making.

[23] In a recent blog post, Dr. Peter Moyle suggested forming a triage panel: convening a panel of state and federal fishery scientists with authority to decide which species are in greatest need of "environmental flows" from reoperation of dams. http://californiawaterblog.com/2014/02/17/why-and-how-to-save-native-salmon-during-a-severe-drought

Acknowledgements

We would like to extend our thanks to the Ecosystem Restoration Program for funding this work and for all their assistance managing Grant ERP-07D-P06; E0720044 to The Nature Conservancy. Mary Dunne, the ERP grant manager, provided excellent grant management services during the course lifetime of the grant to TNC.

We thank The Nature Conservancy for providing grant managmenet support. Ryan Luster was The Nature Conservancy project manager for this project. Greg Golet, Maurice Hall, Rodd Kelsey, Ryan Luster, and Jeanette Howard provided valuable reviews of this Final Report. Wendie Duron provided grant support. Finally, The Nature Conservancy provided invaluable conduits for obtaining data and making contacts with key researchers and agency management.

We thank the over 70 scientists (listed in Appendix C: Delta Ecological Flows Tool Backgrounder Report) who have contributed to the EFT project over the years through participating in our workshops and reviewing documents. You provided invaluable time to the EFT project for which we are very grateful.

5 References and Further Reading

Abell, R., M. Thieme, E. Dinerstien, and D. Olson. 2002. A sourcebook for conducting biological assessments and developing biodiversity visions for ecoregion conservation. Volume II: Freshwater ecoregions. World Wildlife Fund, Washington, D.C.

Alexander, C.A.D. 2004. Riparian initiation, scour and Chinook egg survival models for the Trinity River. Notes from a model review meeting held September 3rd to 5th, 2003. 2nd Draft prepared by ESSA Technologies Ltd., Vancouver, BC for McBain and Trush, Arcata, CA. 29 p.

Alexander, C.A.D., C.N. Peters, D.R. Marmorek, and P. Higgins. 2006. A decision analysis of flow management experiments for Columbia River mountain whitefish (*Prosopium williamsoni*) management. Canadian Journal of Fisheries and Aquatic Sciences 63: 1142-1156.

Alexander, C.A.D., E. Olson, J. Carron. 2013. Integrated Water Management in the Colorado River Basin: Evaluation of Decision Support Platforms and Tools. Final Report. Prepared by ESSA Technologies Ltd. and Hydros Consulting for the Colorado River Program of The Natural Conservancy. Boulder, Colorado. 107 pp. + appendices.

Anderson, R. and G. Stewart. 2007. Impacts of stream flow alterations on the native fish assemblage and their habitat availability as determined by 2D modeling and the use of fish population data to support instream flow recommendations for the sections of the Yampa, Colorado, Gunnison and Dolores Rivers in Colorado. Colorado Division of Wildlife Aquatic Wildlife Research. Special Report Number 80.

Arthington A.H., J.M. King, J.H. O'Keefe, S.E. Bunn, J.A. Day, B.J. Pusey, D.R. Bluhdorn, and R. Tharme. 1991. Development of a holistic approach for assessing environmental flow requirements of riverine ecosystems. *In* Water Allocation for the Environment: Proceedings of an International Seminar and Workshop, J.J. Pigram and B.A. Hooper (eds). The Centre for Water Policy Research, University of New England Armidale, Australia: 69-76.

Arthington A.H., S.E. Bunn, N.L. Poff, and R.J. Naiman. 2006. The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications 16: 1311-1318.

Bartholow, J.M. and V. Heasley. 2006. Evaluation of Shasta Dam scenarios using a salmon production model. Draft Report to U.S. Geological Survey. 110 pp.

BDCP (Bay Delta Conservation Plan). 2013. Public Review Draft BDCP EIR/EIS. http://baydeltaconservationplan.com/Home.aspx. Many thousands of pages and Appendices.

Example sub-elements[24]:

BDCP (Bay Delta Conservation Project). 2012a. BDCP effects analysis Appendix 5.A.2 – Climate Change Approach and Implications for Aquatic Species. 126 p. [http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/Public_Draft_BDCP_A

[24] We do not attempt a comprehensive citation of all BDCP documents. The bulk of what is relevant in this report relates to the BDCP Effects Analyses (Appendix 5).

ppendix_5A_-_2_-_Climate_Change_Approach_and_Implications_for_Aquatic_Species.sflb.ashx; accessed 12-February-2014]

BDCP (Bay Delta Conservation Project). 2012b. BDCP effects analysis-Appendix C.A – CALSIM and DSM2 Results. 286 p. [http://baydeltaconservationplan.com/Libraries/Dynamic_Document_Library/BDCP_Effects_Analysis_-_Appendix_5_C_-_Attachment_C_A_-_CALSIM_and_DSM2_Modeling_Results_for_the_Evaluated_Starting_Operations_Scenarios_3-27-13.sflb.ashx; accessed 12-February-2014]

Benigno, G.M. and T.R. Sommer. 2009. Just add water: sources of chironomid drift in a large river floodplain. Hydrobiologia 600: 297-305.

Bennett, W.A. 2005. Critical assessment of the Delta smelt population in San Francisco estuary, California. San Francisco Estuary and Watershed Science 3(2): Article 1. [http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art1/; accessed 20-November-2008]

Bestgen, K.R., P. Budy, and W.J. Miller. 2011. Status and trends of flannelmouth sucker *Catostomus latipinnis*, bluehead sucker *Catostomus discobolus*, and roundtail chub *Gila robusta*, in the Dolores River, Colorado, and opportunities for population improvement: Phase II Report. Final report submitted to the Lower Dolores Plan Working Group-Legislative Committee. Larval Fish Laboratory Contribution 166 and Intermountain Center for River Rehabilitation and Restoration 2011(2): 1-55 + appendices.

Bovee, K.D. 1982. A guide to stream habitat analysis using the instream flow incremental methodology. Instream Flow Information Paper 12. FWS/OBS-82/26. U.S. Department of Fisheries and Wildlife Services, Washington, D.C.

Bovee, K.D., B.L. Lamb, J.M. Bartholow, C.B. Stalnaker, J. Taylor, and J. Henriksen. 1998. Stream habitat analysis using the instream flow incremental methodology. Biological Resources Division Information and Technology Report United States Geological Survey, Fort Collins, Colorado.

Bradford, M.J., Taylor, G.C., Allan, J.A., and P.S. Higgins. 1995. An experimental study of the stranding of juvenile Coho salmon and Rainbow trout during rapid flow decreases in winter conditions. North American Journal of Fisheries Management 15: 473-479.

CALFED. 2000. Ecosystem Restoration Program Plan Volume 1 Ecological Attributes of the San Francisco Bay-Delta Watershed Final Programmatic EIS/EIR.

Carlisle D., D. Wolock, and M. Meador. 2010. Alteration of stream flow magnitudes and potential ecological consequences: a multiregional assessment. Frontiers in Ecology and the Environment. doi: 10.1890/100053.

Cole, T.M. and S.A. Wells. 2003. CE-QUAL-W2—A two-dimensional, laterally averaged, hydrodynamic and water quality model, version 3.2: Vicksburg, MS, U.S. Army Engineering and Research Development Center, Instruction Report EL-03-01.

Conallin J., E. Boegh, and J.K. Jensen. 2010. Instream physical habitat modelling types: an analysis as stream hydromorphological modelling tools for EU water resource managers. International Journal of River Basin Management 8: 93-107.

Cooper, D.J. and D.C. Andersen. 2012. Novel plant communities limit the effects of a managed flood to restore riparian forests along a large regulated river. River Research and Applications 28(2): 204-215.

Cooper, D.J., D.C. Andersen, and R.A. Chimner. 2003. Multiple pathways for woody plant establishment on floodplains at local to regional scales. Journal of Ecology 91(2): 182-196.

Cross, W. F., C.V. Baxter, K.C. Donner, E.J. Rosi-Marshall, T.A. Kennedy, R.O. Hall Jr., R.S. Rogers, *et al.* 2011. Ecosystem ecology meets adaptive management: food web response to a controlled flood on the Colorado River, Glen Canyon. Ecological Applications 21(6): 2016-2033.

CRSCI. 2013. Map available online at: http://www.crcsi.com.au/Research/Commissioned-Research/Remote-Sensing-for-MDBA

Cui, Y. 2007. The Unified Gravel-Sand (TUGS) Model: Simulating sediment transport and gravel/sand grain size distributions in gravel-bedded rivers. Water Resources Research 43:W10436, doi:10.1029/2006WR005330.

DSP (Delta Science Panel). 2014. Delta Science Panel Independent Review Panel Report: BDCP Effects Analysis Review, Phase 3. Report to the Delta Science Program. Prepared by Parker, A., C. Simenstad, T.L. George, N. Monsen, G. Ruggerone, and J. Skalksi. Delta Stewardship Council Delta Science Program. Sacramento, California. 80 pp. + appendices.

Delta Smelt Biological Opinion. 2008. The Sacramento Fish and Wildlife Office's Biological Opinion (BiOp) on the Long-Term Operational Criteria and Plan (OCAP) effects on Delta Smelt. U.S. Department of the Interior, Fish and Wildlife Service. December 15, 2008.140 pp. [http://www.fws.gov/sfbaydelta/documents/SWP-CVP_OPs_BO_12-15_final_OCR.pdf; accessed 28-September-2012]

Draper, A.J., A. Munévar, S.K. Arora, E. Reyes, N.L. Parker, F.I. Chung, and L.E. Peterson. 2004. CALSIM: Generalized Model for Reservoir System Analysis. American Society of Civil Engineers, Journal of Water Resources Planning and Management 130(6).

DWR (California Department of Water Resources). 2010a. The State Water Project Delivery Reliability Report 2009: State of California, Natural Resources Agency, Department of Water Resources, Sacramento, CA. August 2010. 58 pp. + appendices. [http://baydeltaoffice.water.ca.gov/swpreliability/Reliability2010final101210.pdf; accessed 05-February-2014]

DWR (California Department of Water Resources). 2010b. The State Water Project Delivery Reliability Report 2009: Technical Addendum, State of California, Natural Resources Agency, Department of Water Resources, Sacramento, CA. August 2010.

DWR (California Department of Water Resources). 2012. The State Water Project Final Delivery Reliability Report 2011, State of California, Natural Resources Agency, Department of Water Resources, Sacramento, CA. June 2012. 63 pp. + appendices. [http://baydeltaoffice.water.ca.gov/swpreliability/FINAL_2011_DRR.pdf; accessed 05-February-2014]

Ellison, A.M., M.S. Bank, B.D. Clinton, E.A. Colburn, K. Elliott, C.R. Ford, *et al.* 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. Frontiers in Ecology and the Environment 3: 479-486.

ESSA (ESSA Technologies Ltd.). 2005. Sacramento River Decision Analysis Tool: Workshop Backgrounder. Prepared for The Nature Conservancy, Chico, CA. 75 pp.

ESSA (ESSA Technologies Ltd.). 2008. Delta Ecological Flows Tool: Backgrounder (Final Draft). Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 121 pp.

ESSA (ESSA Technologies Ltd.). 2011. Sacramento River Ecological Flows Tool (SacEFT): Record of Design (v.2.00). May 2011 revision. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 111 p. + appendices.

ESSA (ESSA Technologies Ltd.). 2013. The Delta Ecological Flows Tool: Record of Design (v.1.1). Final. December 2013 revision. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 142 pp. + appendix.

ESSA (ESSA Technologies Ltd.). 2014. Ecological Flows Tool Reader (v 4) – User Guide. Prepared for The Nature Conservancy, Chico, CA. 28 pp.

Fleenor, W., W. Bennett, P. Moyle, and J. Lund. 2010. On developing prescriptions for freshwater flows to sustain desirable fishes in the Sacramento-San Joaquin Delta. Submitted to the State Water Resources Control Board regarding flow criteria for the Delta necessary to protect public trust resources. Center for Watershed Sciences, University of California, Davis. 46pp.

Feyrer, F., T. Sommer, and W. Harrell. 2006. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. Hydrobiologia 573: 213-226.

Haines, G.B., D. Irving, and T. Modde. 2004. White River Base Flow Study for Endangered Fish, Colorado and Utah, 1995-1996. Final Report prepared for the Upper Colorado River Endangered Fish Recovery Program, Denver, CO.

Halleraker, J.H., S.J. Saltveit, A. Harby, J.V. Arnekliev, H.P. Fjeldstad, and B. Kohler. 2003. Factors influencing stranding of wild juvenile Brown trout (*Salmo trutta*) during rapid and frequent flow decreases in an artificial stream. River Research and Applications 19: 589-603.

Harper, E.B., J.C. Stella, and A.K. Fremier. 2011. Global sensitivity analysis for complex ecological models: a case study of riparian cottonwood population dynamics. Ecological Applications 21(4): 1225-1240.

Hilborn, R. and M. Mangel. 1997. The ecological detective: confronting models with data. Monographs in Population Biology No. 28, Princeton University Press, Princeton, New Jersey. 315 pp.

Higgins, J. and R. Esselman (eds.). 2006. Ecoregional Assessment and Biodiversity Toolbox. The Nature Conservancy. Arlington, Virginia.

Hoey, T.B. and R.I. Ferguson. 1994. Numerical simulation of downstream fining by selective transport in gravel bed rivers: Model development and illustration. Water Resources Research 30: 2251-2260.

Hughes, F.M.R., W.M. Adams, E. Muller, C. Nilsson, K.S. Richards, N. Barsoum, *et al.* 2001. The importance of different scale processes for the restoration of floodplain woodlands. Regulated Rivers–Research and Management 17: 325-345.

Huizinga, M. and R.A. Fridell. 2012. Trends in the native fish assemblage and identification of temperature and flow limiting factors in the Virgin River between Pah Tempe Hot Springs and the Washington Fields Diversion 2002-2010. Publication Number 11-35. Utah Department of Natural Resources, Division of Wildlife Resources. Salt Lake City, Utah.

Instream Flow Council (IFC). 2002. Instream Flows for Riverine Resource Stewardship. 410 pp.

Johannesson, H. and G. Parker. 1989. Linear theory of river meanders. *In* River Meandering, S. Ikeda and G. Parker G (eds.). Water Resources Monographs, 12. AGU: Washington; 181–214.

Jowett I.G. and A.J.H. Davey. 2007. A comparison of composite habitat suitability indices and generalized additive models of invertebrate abundance and fish presence–habitat availability. Transactions of the American Fisheries Society 136: 428-444.

Katz, J., P.B. Moyle, R.M. Quiñones, J. Israel, and S. Purdy. 2013. Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental biology of fishes 96(10-11): 1169-1186.

Kaval, P. 2011. Ecosystem Service Valuation of the Colorado River Basin. Prepared for the Nature Conservancy. 92 pp.

Kimmerer, W.J. and M.L. Nobriga. 2008. Investigating particle transport and fate in the Sacramento-San Joaquin Delta using a particle tracking model. San Francisco Estuary and Watershed Science 6(1) Article 4.

Larsen, E.W. 1995. Mechanics and modeling of river meander migration. Ph.D. Dissertation. Civil Engineering.

Larsen, E.W. and S.E. Greco. 2002. Modeling channel management impacts on river migration: a case study of Woodson Bridge State Recreation Area, Sacramento River, California, USA. Environmental Management 30: 209.224.

Larsen, E.W., A.K. Fremier, and S.E. Greco. 2006a. Cumulative effective stream power and bank erosion on the Sacramento River, CA, USA. Journal of American Water Resources Association 42: 1077-1097.

Larsen, E.W., E. Girvetz, and A. Fremier. 2006b. Assessing the effects of alternative setback levee scenarios employing a river meander migration model. Environmental Management 37: 880-897.

Lund, J., E. Hanak, W. Fleenor, W. Bennett, R. Howitt, J. Mount, and P. Moyle. 2010. Comparing Futures for the Sacramento-San Joaquin Delta. Berkeley, CA. University of California Press and Public Policy Institute of California.

Lytle, D.A. and D.M. Merritt. 2004. Hydrologic regimes and riparian forests: a structured population model for cottonwood. Ecology 85: 2493-2503.

Mahoney, J. and S. Rood. 1998. Streamflow Requirements for Cottonwood Seedling Recruitment—An Integrative Model. Wetlands 18(4): 634-645. doi:10.1007/BF03161678.

Merritt, D.M. and N.L.R. Poff. 2010. Shifting dominance of riparian *Populus* and *Tamarix* along gradients of flow alteration in western North American rivers. Ecological Applications 20: 135-152.

Michener, W.K. and R. Haeuber. 1998. Flooding: natural and managed disturbances. BioScience 48: 677-680.

Mount, J., W. Fleenor, B. Gray, B. Herbold, and W. Kimmerer. 2013. Panel review of the draft Bay Delta Conservation Plan. Saracino & Mount LLC, Sacramento, CA. 152 pp.

Moyle, P.B. 2002. Inland fishes of California. Revised edition. University of California Press, Berkeley.

Moyle, P.B., B. Herbold, D.E. Stevens, and L.W. Miller. 1992. Life-history and status of Delta smelt in the Sacramento-San Joaquin estuary, California. Transactions of the American Fisheries Society 121: 67-77.

Moyle, P.B., J.A. Israel, and S.E. Purdy. 2008. Salmon, Steelhead, and Trout in California: Status of an Emblematic Fauna. Center for Watershed Sciences, University of California Davis. A report commissioned by California Trout.

Moyle, P.B., J.V.E. Katz, and R.M. Quiñones. 2011. Rapid decline of California's native inland fishes: a status assessment. Biological Conservation 144: 2414-2423.

Moyle, P., W. Bennett, J. Durand, W. Fleenor, B. Gray, E. Hanak, J. Lund, and J. Mount. 2012. Where the wild things aren't: making the Delta a better place for native species. Public Policy Institute of California. San Francisco, CA. 55 pp. [http://www.ppic.org/main/publication.asp?i=1025; accessed 19-February-2014].

Moyle, P.B., J.D. Kiernan, P.K. Crain, and R.M. Quiñones. 2013. Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach. PLoS One. doi: 10.1371/journal.pone.0063883.

NMFS (National Marine Fisheries Service). 1997. Proposed Recovery Plan for the Sacramento River Winter - Run Chinook Salmon. Long Beach, CA: National Marine Fisheries Service, Southwest Region.

NMFS (National Marine Fisheries Service). 2009. Biological Opinion and Conference Opinion on the long-term operations of the Central Valley Project and State Water Project. United States Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service Southwest Region. Long Beach, CA. 844pp + 5 appendices.

NMFS (National Marine Fisheries Service). 2009. Public Draft Recovery Plan for the Evolutionarily Significant Units of Sacramento River winter - run Chinook salmon and Central Valley spring - run Chinook salmon and the distinct population segment of Central Valley steelhead. Sacramento Protected Resources Division. October 2009.

Nowak, K., J. Prairie, B. Rajagopalan, and U. Lall. 2010. A nonparametric stochastic approach for multisite disaggregation of annual to daily stream flow. Water Resources Research 46 (W08529). doi:10.1029/2009WR008530.

Olden J.D. and N.L. Poff. 2003. Redundancy and the choice of hydrologic indices for characterizing stream flow regimes. River Research and Applications 19: 101-121.

Oreskes, N., K. Schrader-Frechette, and K. Belitz. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science 263: 641-646.

Parasiewicz P. 2001. MesoHABSIM: a concept for application of instream flow models in river restoration planning. Fisheries 26: 6-13.

Parasiewicz P. and M.J. Dunbar. 2001. Physical habitat modelling for fish: a developing approach. Large Rivers/ Supplement to Archiv für Hydrobiologie 12/135: 239-268.

Patten D.T. 1998. Riparian ecosystems of semi-arid North America: diversity and human impacts. Wetlands 18: 498-512.

Perry, W.R., J.R. Skalski, P.L. Brandes, P.T. Sandstrom, A.P. Klimley, A. Ammann, and B. MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento-San Joaquin River delta. North American Journal of Fisheries Management 30: 142-156.

Petts, G.E. 2009. Instream Flow Science for Sustainable River Management. Journal of the American Water Resources Association (JAWRA) 45(5): 1071-1086. doi: 10.1111/j.1752-1688.2009.00360.x.

Podger, G., A. Yang, A. Brown, J. Teng, R. Power, and S. Seaton. 2010. Proposed River Modelling Methods and Integrated River System Modelling Framework Design for use in Basin Plan Modelling. CSIRO: Water for a Healthy Country National Research Flagship.

Poff, N.L., J.D. Allan, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation and restoration. Bioscience 47: 769-784.

Poff, N.L. and J.Z.H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55: 194-205. doi: 10.1111/j.1365– 2427.2009.02272.x.

Poff, N.L., B.D. Richter, A.H. Arthington, S.E. Bunn, R.J. Naiman, E. Kendy, M. Acreman, C. Apse, B.P. Bledsoe, M.C. Freeman, J. Henriksen, R.B. Jacobson, J.G. Kennen, D.M. Merritt, J.H. O'Keeffe, J.D. Olden, K. Rogers, R.E. Tharme, and A. Warner. 2010. The ecological limits of hydrologic alteration (ELOHA): a new framework for developing regional environmental flow standards. Freshwater Biology 55: 147-170.

Postel, S. and B. Richter. 2003. Rivers for life: managing water for people and nature. Island Press.

Quartarone, F. 1993. Historical accounts of upper Colorado River basin endangered fish. Final Report Submitted to Recovery Implementation Program for the Endangered Fishes of the Upper Colorado River Basin, U.S. Fish and Wildlife Service, Denver, CO. 66 pp.

Rapport, D.J., R. Costanza, and A.J. McMichael. 1998. Assessing ecosystem health. Trends in Ecology and Evolution 13: 397-402.

Richter, B.D., J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10: 1163-1174.

Richter, B.D, J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need? Freshwater Biology 39: 231-249.

RMA (Resource Management Associates, Inc.). 2003. Draft Upper Sacramento River Water Quality Modeling with HEC-5Q: Model Calibration and Validation. December 2003.

Roberts, M.D. 2003. Beehive Bend subreach addendum to: a pilot investigation of cottonwood recruitment on the Sacramento River. Prepared by The Nature Conservancy. Chico, CA.

Roberts, M.D., D.R. Peterson, D.E. Jukkola, and V.L. Snowden. 2002. A pilot investigation of cottonwood recruitment on the Sacramento River. Prepared by The Nature Conservancy. Chico, CA.

Roni, P., G.R. Pess, T.J. Beechie, and S.A. Morley. 2011. Estimating salmon and steelhead response to watershed restoration: How much restoration is enough? North American Journal of Fisheries Management 30: 1469-1484.

Sanderson, J.S., N. Rowan, T. Wilding, B.P. Bledsoe, W.J. Miller, and N.L. Poff. 2011. Getting to scale with environmental flow assessment: the Watershed Flow Evaluation Tool. River Research and Applications 28(9): 1369-1377. doi: 10.1002/rra.1542.

Scott, M.L., G.T. Auble, and J.M. Friedman. 1997. Flood dependency of cottonwood establishment along the Missouri River, Montana, USA. Ecological Applications 7: 677-690.

Scruton, D.A., L.M.N. Ollerhead, K.D. Clarke, C. Pennell, K. Alfredsen, A. Harby, and D. Kelley. 2003. The behavioural response of juvenile Atlantic salmon (*Salmo salar*) and Brook trout (*Salvelinus fontinalis*) to experimental hydropeaking on a Newfoundland (Canada) river. River Research and Applications 19: 577-587.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 1998. Establishment of woody vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18: 557-590.

Shafroth, P.B., J.C. Stromberg, and D.T. Patten. 2002. Riparian vegetation response to altered disturbance and stress regimes. Ecological Applications 12: 107-123.

Shafroth P.B., A.C. Wilcox, D.A. Lytle, J.T. Hickey, D.C. Andersen, V.B. Beauchamp, A. Hautzinger, L.E. McMullen, and A. Warner. 2010. Ecosystem effects of environmental flows: modelling and experimental floods in a dryland river. Freshwater Biology 55: 68-85.

Shelbourn, J.E., J.R. Brett, and S. Shirahat. 1973. Effect of temperature and feeding regime on specific growth-rate of sockeye salmon fry (*Oncorhynchus nerka*), with a consideration of size effect. Journal of the Fisheries Research Board of Canada 30: 1191-1194.

Shelby, B., J.J. Vaske, and M.P. Donnely. 1996. Norms, standards and natural resources. Leisure Sciences 18: 103-123.

Sommer, T., L. Conrad, G. O'Leary, F. Feyrer, and W.C. Harrell. 2002. Spawning and rearing of splittail in a model floodplain wetland. Transactions of the American Fisheries Society 131: 966-974.

Sommer, T., R. Baxter, and B. Herbold. 1997. Resilience of splittail in the Sacramento-San Joaquin Estuary. Transactions of the American Fisheries Society 126: 961-976.

Southwick Associates. 2012. Economic contributions of outdoor recreation on the Colorado River and its tributaries. Prepared for Protect The Flows. May 3 2012. 53 pp.

Stanford JA, J.V. Ward, W.J. Liss, C.A. Frissell, R.N. Williams, J.A. Lichatowich, and C.C. Coutant. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391-413.

Stella, J.C., J.J. Battles, J.R. McBride, and B.K. Orr. 2010. Riparian seedling mortality from simulated water table recession, and the design of sustainable flow regimes on regulated rivers. Restoration Ecology 18(s2): 284-294.

Stella, J.C., M.K. Hayden, J.J. Battles, H. Piégay, S. Dufour, and A.K. Fremier. 2011. The role of abandoned channels as refugia for sustaining pioneer riparian forest ecosystems. Ecosystems 14(5): 776-790.

Stevens Jr., D.L. and A.R. Olsen. 2004. Spatially balanced sampling of natural resources. Journal of the American Statistical Association 99(465): 262-278.

Stillwater Sciences. 2007. Linking biological responses to river processes: Implications for conservation and management of the Sacramento River—a focal species approach. Final Report. Prepared by Stillwater Sciences, Berkeley for The Nature Conservancy, Chico, California.

Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and dynamics of Sonoran riparian forests. Rivers 2: 221-235.

Taylor J.P., D.B. Wester, and L.M. Smith. 1999. Soil disturbance, flood management, and riparian woody plant establishment in the Rio Grande floodplain. Wetlands 19: 372-382.

Tennant, D.L. 1976. Instream Flow Regimes for Fish, Wildlife, Recreation and Related Environmental Resources. Fisheries 1(4): 6-10.

Tharme, R.E. 2003. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Research and Applications 19(5-6): 397-441.

TNC (The Nature Conservancy). 2012. Flow Recommendations for Endangered Fish on the White River – Response to Major Concerns.

TNC and ESSA (The Nature Conservancy and ESSA Technologies Ltd.). 2012. SacEFT Analysis of the North-of-the-Delta Offstream Storage Investigation. The Nature Conservancy, Chico, CA. 73pp + appendices.

TNC *et al.* (The Nature Conservancy, Stillwater Sciences and ESSA Technologies Ltd.). 2008. Sacramento River Ecological Flows Study: Final Report. Prepared for CALFED Ecosystem Restoration Program. Sacramento, CA. 72 pp.

Toro-Escobar, C.M., G. Parker, and C. Paola. 1996. Transfer function for the deposition of poorly sorted gravel in response to streambed aggradation. Journal of Hydraulic Research 34: 35-54.

Trush, W.J., S.M. McBain, and L.B. Leopold. 2000. Attributes of an alluvial river and their relation to water policy and management. Proceedings of the National Academy of Sciences USA 97: 11858-11863.

Unger, P.A. 1994. Quantifying salinity habitat of estuarine species. IEP Newsletter 7(Autumn): 7-10. Available from: California Dept. of Water Resources, Division of Environmental Services. Sacramento, California.

USBR (U.S. Bureau of Reclamation). 2012. Colorado River Basin Water Supply and Demand Study. U.S. Department of the Interior, Bureau of Reclamation. 1697 pp.

USBR (U.S. Bureau of Reclamation). 2008a. Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment, Appendix D CALSIM-II Model, May 2008.

USBR (U.S. Bureau of Reclamation). 2008b. 2008 Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment, Appendix H Reclamation Temperature Model and SRWQM Temperature Model.

USBR (U.S. Bureau of Reclamation). 2008c. Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment, Appendix F DSM2 Model, May 2008.

USBR (U.S. Department of Interior). 2006. Operation of Flaming Gorge Dam, Final Environmental Impact Statement. United States Department of Interior, Bureau of Reclamation. Salt Lake City, Utah.

USFWS (U.S. Fish and Wildlife Service). 2013. Environmental Conservation Online System: Threatened and Endangered Species. [http://ecos.fws.gov; accessed 15-July-2013]

USFWS (U.S. Fish and Wildlife Service). 2008. The Sacramento Fish and Wildlife Office's Biological Opinion (BiOp) on the Long-Term Operational Criteria and Plan (OCAP) effects on Delta Smelt. U.S. Department of the Interior, Fish and Wildlife Service. December 15, 2008. 396 pp. [http://www.fws.gov/sfbaydelta/documents/SWP-CVP_OPs_BO_12-15_final_OCR.pdf; accessed 12-February-2014]

USFWS (U.S. Fish and Wildlife Service). 2006. Relationships between flow fluctuations and redd dewatering and juvenile stranding for Chinook salmon and steelhead in the Sacramento River between Keswick Dam and Battle Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service. Sacramento, CA. 94pp.

USFWS (U.S. Fish and Wildlife Service). 2005a. Flow-habitat relationships for fall-run Chinook salmon spawning in the Sacramento River between Battle Creek and Deer Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service. Sacramento, CA. 104pp.

USFWS (U.S. Fish and Wildlife Service). 2005b. Flow-habitat relationships for fall-run Chinook salmon rearing in the Sacramento River between Keswick Dam and Battle Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service. Sacramento, CA. 258pp.

USFWS (U.S. Fish and Wildlife Service). 2005c. Final Programmatic Biological Opinion on the Management Plan for Endangered Fishes in the Yampa River Basin. U.S. Department of the Interior, Fish and Wildlife Service. Denver, Colorado.

USFWS (U.S. Fish and Wildlife Service). 2003. Flow-habitat relationships for steelhead and fall, late-fall and winter-run Chinook salmon spawning in the Sacramento River between Keswick Dam and Battle Creek. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service. Sacramento, CA. 79pp.

USGS (U.S. Geological Survey). 2006. Defining Ecosystem Flow Requirements for the Bill Williams River, Arizona. U.S. Geological Survey Open File Report 2006-1314, 135 pp. [http://www.fort.usgs.gov/products/publications/21745/21745.pdf]

Vogel, D.A. and K.R. Marine. 1991. Guide to upper Sacramento River Chinook salmon life-history. CH2M HILL, Redding, California. Produced for the U.S. Bureau of Reclamation Central Valley Project. 55pp + appendices.

Walters, C., J. Korman, L.E. Stevens, and B. Gold. 2000. Ecosystem modeling for evaluation of adaptive management policies in the Grand Canyon. Conservation Ecology 4(2): 1. [http://www.consecol.org/vol4/iss2/art1/]

Whittaker, D., B. Shelby, W. Jackson, and R. Beschta. 1993. Instream flows for recreation: a handbook on concepts and research methods. U.S. Department of Interior, National Park Service, Anchorage, AK.

Wilcock, P.R. and J.C. Crowe. 2003. Surface-based transport model for mixed-size sediment. Journal of Hydraulic Engineering 129: 120-128.

Wilding, T.K. and J. Sanderson. 2010. Riparian vegetation methods for the watershed flow evaluation tool. A report to the non-consumptive needs committee of the Colorado Basin Roundtable. 42 pp.

Wilding, T.K. 2012. Regional methods for evaluating the effects of flow alteration on stream ecosystems. Ph.D. Dissertation. Colorado State University. 194 pp. Adviser: Nathan LeRoy Poff. DAI/B 74-01(E), Oct 2012 / 3523829.

Williams, C.A. and D.J. Cooper. 2005. Mechanisms of riparian cottonwood decline along regulated rivers. Ecosystems 8: 382-395.

Williams, J.E., A.L. Haak, N.G. Gillespie, and W.T. Colyer. 2007. The Conservation Success Index: synthesizing and communicating salmonid condition and management needs. Fisheries 32(10): 477-493.

Williams, J.G. 1996. Lost in space: minimum confidence intervals for idealized PHABSIM studies. Transactions of the American Fisheries Society 125: 458-465.

Appendix A: Sacramento River Ecological Flows Tool Backgrounder Report

ESSA Technologies Ltd. 2005. Sacramento River Decision Analysis Tool: Workshop Backgrounder. Prepared for The Nature Conservancy, Chico, CA. 75 p.

PDF available from: http://www.wildlife.ca.gov/erp/erp_proj_delta_eft.aspx

[Page Intentionally Blank]

Appendix B: Sacramento River Ecological Flows Tool (SacEFT v.2) Record of Design

ESSA Technologies Ltd. 2011. Sacramento River Ecological Flows Tool (SacEFT): Record of Design (v.2.00). May 2011 revision. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 111 p. + appendices.

PDF available from: http://www.wildlife.ca.gov/erp/erp_proj_delta_eft.aspx

[Page Intentionally Blank]

Appendix C: Delta Ecological Flows Tool Backgrounder Report

ESSA Technologies Ltd. 2008. Delta Ecological Flows Tool: Backgrounder (Final Draft). Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 121 p.

PDF available from: http://www.wildlife.ca.gov/erp/erp_proj_delta_eft.aspx

[Page Intentionally Blank]

Appendix D: The Delta Ecological Flows Tool (DeltaEFT v.1.1) Record of Design

ESSA Technologies Ltd. 2013. The Delta Ecological Flows Tool: Record of Design (v.1.1). Final. December 2013 revision. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 142 p.+ Appendix

PDF available from: http://www.wildlife.ca.gov/erp/erp_proj_delta_eft.aspx

[Page Intentionally Blank]

Appendix E: EFT Reader Software – User's Guide

ESSA Technologies Ltd. 2014. Ecological Flows Tool Reader (v 4) – User Guide. Prepared for The Nature Conservancy, Chico, CA. 28 p.

See: http://eft-userguide.essa.com/

PDF available from: http://www.wildlife.ca.gov/erp/erp_proj_delta_eft.aspx

[Page Intentionally Blank]

Appendix F: Indicator Screening & Selection Criteria

Every decision support modeling exercise must include assumptions about what is included and excluded in order to keep the effort tractable. This involves seeking a balance of representative indicators given the state of scientific knowledge, the types of *decisions* the tool is meant to support, and budgetary resources. Our study team recognizes it will be unrealistic to *eliminate* large-scale confounding influences that surround flow-related modeling in the Delta: e.g., changing oceanographic conditions, seismic threats, progression of invasive species regimes, changes in food web structure, or to account for potential release of contaminants from newly restored wetlands. Hence, there is a practical need to constrain our modeling efforts to a domain well inside the universe of “all things that might matter”. Indeed government agencies act all the time with imperfect information on all sorts of portfolios, including non-environmental subjects such as the economy. Our project team appreciates the importance of the larger picture, but that does not mean we can (or even need to) model it. Hence, the indicators that emerge from the criteria described below take an “all else equal” stance on potentially confounding factors. This allows us to avoid the paralysis that comes with trying to cover everything. This in no way suggests that these outside-DeltaEFT factors are unimportant, just that our universe of concern in developing the first version of the tool must, for practical reasons, be selective.

In support of the Sacramento River Ecological Flows Study (TNC *et al.* 2008), a set of selection criteria were developed as part of the Linkages Report component (Stillwater Sciences 2007). The application of these criteria on the Sacramento River allowed for standardized comparisons to be drawn among a pool of candidate habitat and focal species considerations, thus clarifying the selection process for the indicators chosen for SacEFT. Below, we adopt this approach for use in the Delta, with important additional considerations based on insights from recent multi-disciplinary synthesis activities (e.g., DRERIP) and our own experience (Figure F.1). While restoration priorities will continue to evolve in the Delta, the suite of focal habitats and indicators that are ultimately selected using these criteria should be representative of a number of the current and ongoing species needs. As with SacEFT, we approach the question of ecological water management needs from the perspective of focusing on specific life-history requirements of target species and/or ecosystem functions instead of addressing a set of population goals (e.g., we do not attempt to answer the question “tell me how many more fish I get for *x* acre-feet of water”). Our modeling emphasizes performance indicators (linked to management actions that humans can influence) for *some* of the most important general conditions needed for a target species to persist. While this does not rule out compensation in other parts of the life-cycle, we believe this approach is reasonable to assert that – all else equal – a particular set of hydrodynamic conditions are better than another.

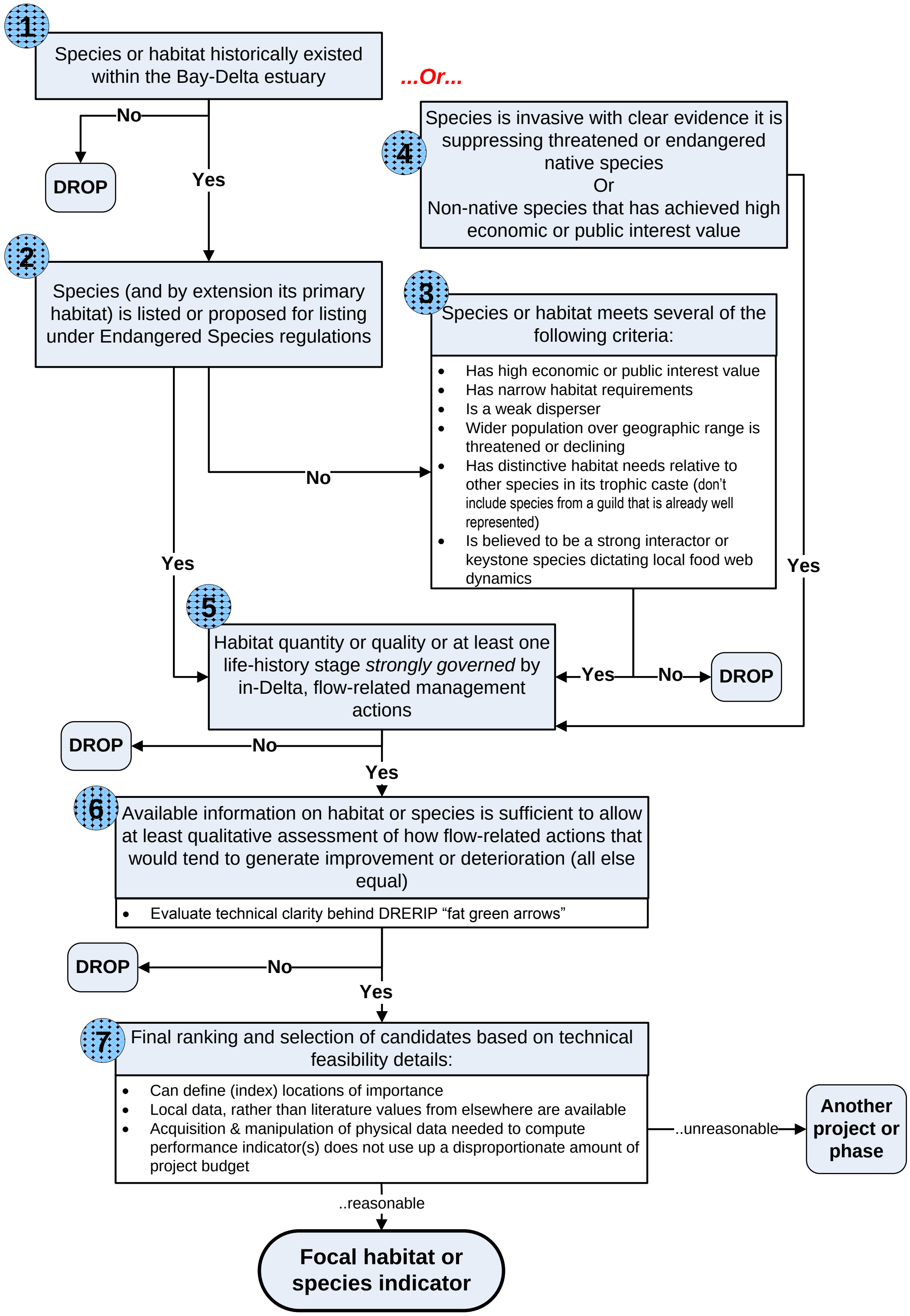


Figure F.1: Focal habitat, species filtering and screening criteria (vetting process) for EFT.

Step 1: The habitat or species historically existed within the Delta estuary

The first step of the vetting process involved determining if a candidate habitat or focal species existed historically within the study area. Under most circumstances, we assume these species will be those of primary ecological concern. This also allows for the re-introduction of an extirpated species, which can be a goal of a restoration program.

Because the Delta currently supports many invasive species, this first step of the vetting process does not eliminate non-native species from consideration. Instead, invasive species may be included in one of two ways, either (a) as species to include for the purpose of *deterrence* (reducing competitive advantage vs. native species) (e.g., overbite clam) or (b) as a valued species (e.g., striped bass) that has achieved high economic or other value to people. Though it is often infeasible to eradicate a non-native species once it has become widely established, management actions may help to control the abundance or distribution of targeted non-native species so that their adverse ecological effects are reduced, or, in the case of valued species, so that their benefits to society are increased.

Step 2: Is the species listed as endangered or threatened?

The second step of the vetting process acknowledged that the recovery of listed species constitutes a high social priority, both economically and ecologically. It also recognizes that listed species are often at the center of resource management conflicts, so that recovery of the species can be an important management goal as a means of reducing these conflicts that place restrictions on human activities. The endangered and threatened species that occur in an ecosystem often serve as focal species; however, the number of listed species that occur in the Delta area precludes the selection of every listed species. One of the functions of the focal species approach is to facilitate the organization and synthesis of a suite of broadly representative ecological indicators; however, this process can be undermined by the selection of too many focal species.

Step 3: Additional criteria for non-listed species

A series of criteria for non-listed species is available to enable capture of habitat or focal species indicators that are important even if that species is not listed. It is important to include non-listed species in order to capture potential ecosystem changes that tend to reduce these populations, which may in the future necessitate additional listings or otherwise exacerbate resource conflicts. Metaphorically speaking, “it is often better to place resources on stopping a neighborhood from catching on fire rather than sending all the fire trucks to put out the out-of-control blaze.” Criteria used to make these selections are:

- **High economic or public interest value**. This criteria recognizes the economic or social importance of certain species, such as species that are the focus of commercial fisheries (e.g., salmon) and sport fish that are the focus of recreational angling (e.g., steelhead, sturgeon).

- **Narrow habitat requirements**. The second criterion tests whether a species has narrow habitat requirements such that loss of that habitat type would pose a significant threat to the health of the population. For example, bank swallows nest in fresh vertical cut-banks composed of soils with a loamy-sandy texture and at least 1m in height, which represents a stringent mix of habitat conditions. Bank swallow colony sites also have a limited lifespan (< 5 years) because of bank slumping, rodent burrowing, and possibly parasite infestation. Consequently, activities that affect the frequency of bank erosion in zones of appropriately textured soils (e.g., bank protection, flow regulation, land conversion) can combine with the narrow habitat requirements of bank swallow to create a significant threat to population recruitment. For this reason and others, the bank swallow was selected as a focal species for SacEFT.

- **Weak disperser**. The third criterion identifies species that have difficulty dispersing to new areas, which prevents a species from establishing new sub-populations that can help mitigate the loss of an existing breeding population from a catastrophic event or persistent chronic mortality agent. For example, even though green sturgeon migrate thousands of miles through rivers, estuaries, and ocean, there are only three known spawning populations of green sturgeon, which suggests that the species has difficulty establishing new spawning sub-populations outside of the current populations in the Sacramento, Rogue, and Klamath rivers. As a consequence, a natural or anthropogenic event that eliminates habitat in one of these three river systems could dramatically reduce the range of the species.

- **Regional population declines**. This criterion acknowledges that population abundance and distribution provide two of the key metrics for assessing the health of a species. Regional population declines provide a warning signal that the species is under stress, thus providing a stimulus for identifying the factors affecting these populations, and revisiting the level of protection afforded to individual population hot spots. Continued population declines can also necessitate eventual protection under the Endangered Species Act, which generally intensifies conflicts over natural resources.

- **Distinctive habitat requirements relative to other species under consideration for protection**. This criterion extends the second, in that it is more valuable to choose species that utilize unique habitats (especially if these habitat needs are narrow) than to choose several different species with requirements for the same type of habitat.

- **Strong interactor**. The sixth criterion indicates that particular species can significantly influence natural communities through ecological interactions with other species. For example, a species may serve as an important prey species for a number of other species, such that a decline in its population can reduce the food base for other species and depress the abundance of an entire community (keystone species). Similarly, other species can affect a community by monopolizing available habitat and resources or by preying on a wide variety of species (e.g., the threat posed by an introduction of northern pike (*Esox lucius*) in Central Valley rivers). Other species can change the very nature of an ecosystem (e.g., Asian clam (*Potamocorbula amurensis*) converting portions of the Delta estuary from a pelagic to a benthic based ecosystem).

Step 4: Invasive species issues – deterrence or acceptance

This consideration supplements step 1, so that focal species are not limited to native species. Because the Delta currently supports many invasive species, invasive species may be included in one of two ways, either: (a) as species to include for the purpose of *deterrence* (reducing competitive advantage vs. native species); or (b) as a species that has achieved high economic or other value to people.

Step 5: Importance of in-Delta flow-related management actions on habitat quality, quantity or life-stage survival

DeltaEFT emphasizes evaluation of ecological flow management actions. It is not a system intended to simulate or predict population level consequences, food web dynamics, life-time fate and effects of contaminant mixtures, *etc.* As a simplifying principle, we adopt an “all else equal” approach, where we aim to synthesize, link and clearly present how a representative suite of ecological targets would tend to improve or degrade if more or less flow moved past/through/around different regions and structures in the Delta at particular times. Clearly, other important cause-effect pathways will modulate these outcomes in nature. Nevertheless, for the indicators in DeltaEFT it should be scientifically credible to state that if a certain Delta flow regime were repeated year over year, the indicator would be clearly pushed towards a more or less desirable state. In short, we are focused on variables that will allow target habitats and focal species indicators to trend upward. *Therefore, focal habitat and species indicators that are <u>not</u> strongly governed by flow actions in at least one critical life-history stage, fall outside our sphere of consideration in DeltaEFT version 1*.

The flow management focused DeltaEFT will therefore serve as a companion framework alongside other existing tools and research initiatives focused on generating resource management advice in the Delta.

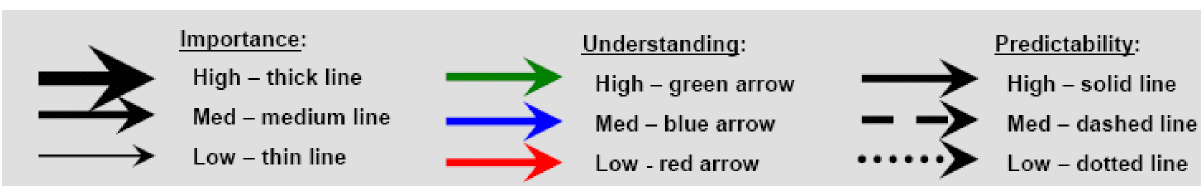
Step 6: Availability of information

This step assessed the technical feasibility and effort associated with generating the indicator. At a minimum, we must understand the general habitat requirements and life-history stages of the species for it to function as a focal species. Although it is preferable if this information is specific to the Sacramento-San Joaquin River Delta study area, knowledge of how a species interacts with its environment in a similar system is also of value. *Passing beyond this step requires an ability to draw a conceptual box-arrow model for the indicator, moving from flow related management actions, to habitat forming processes or physical habitat quality/quantity, to one or more life-history survival mechanisms, and finally to the indicator itself*.

Not re-inventing wheels: DRERIP "fat green arrows"

The CALFED Science Program has worked with the CALFED Ecosystem Restoration Program implementing agencies (DFG, USFWS, and NOAA Fisheries) on the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). The main DRERIP product is a series of species, physical process, habitat and chemical stressor conceptual models which collectively articulate the current (as of 2008) scientific understanding of important aspects of the Sacramento-San Joaquin River Delta ecosystem. DRERIP conceptual models are not quantitative, numeric computer models that can be "run" to determine the effects of actions. Rather they are designed to help inform discussions regarding expected outcomes resulting from restoration actions and document the scientific basis for those expectations. Some of the DRERIP models should also help serve as the basis for future development of more explicit, (semi-)quantitative models like DeltaEFT.

All DRERIP conceptual model pathways are coded according to "Importance", "Predictability", and "Understanding" of the linkages between drivers and outcomes. These definitions of importance, predictability, and understanding apply to each linkage, or cause-effect relationship, between an individual driver and individual outcome described in the conceptual models. The graphical forms of the conceptual models apply line color, thickness, and style to represent these three terms.



DRERIP Importance: "The degree to which a linkage controls the outcome relative to other drivers and linkages affecting that same outcome."

4 = High importance: expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population's natural productivity, abundance, spatial distribution and/or diversity (both genetic and life-history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics.
3 = Medium importance: expected sustained minor population effect or effect on large area or multiple patches of habitat

2 = Low importance: expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial or temporal habitat effects
1 = Minimal or no importance: Conceptual model indicates little or no effect

DRERIP Understanding: "The degree to which the performance or the nature of the outcome can be predicted from the driver."

4 = High predictability: Understanding is high and nature of outcome is largely unconstrained by variability in ecosystem dynamics, other external factors, or is expected to confer benefits under conditions or times when model indicates greatest importance.
3 = Medium predictability: Understanding is high but nature of outcome is dependent on other highly variable ecosystem processes or uncertain external factors. OR Understanding is medium and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
2 = Low predictability: Understanding is medium and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors OR Understanding is low and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
1 = Little or no predictability: Understanding is lacking OR Understanding is low and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors

DRERIP Predictability: "A description of the known, established, and/or generally agreed upon scientific understanding of the cause-effect relationship between a single driver and a single outcome."

4 = High understanding: Understanding is based on peer-reviewed studies from within system and scientific reasoning supported by most experts within system.
3 = Medium understanding: Understanding based on peer-reviewed studies from outside the system and corroborated by non peer-reviewed studies within the system.
2 = Low understanding: Understanding based on non peer-reviewed research within system or elsewhere.
1 = Little or no understanding: Lack of understanding. Scientific basis unknown or not widely accepted.

Within this framework, "fat green arrows" represent cause-effect pathways comprised of high-to-medium importance, understanding and predictability. *Consideration of the technical* *clarity behind DRERIP conceptual models fat green arrows was a component of our DeltaEFT vetting process*.

Step 7: Priority ranking of species

The information produced for each candidate habitat or species indicator in Steps 3, 5 and 6 facilitates a general ranking of species in this last step of the vetting process. These rankings are nominal: high, medium, low priority. *Species receiving high rankings need to have adequate information available (Step 6), have to be officially listed or meet 3 or more criteria listed under Step 3. High ranked indicators must also be able to provide statements of*:

- the index locations that are important;
- a clear, specific statement of the availability of any physical driving data needed from other models to compute the indicator; and
- the acquisition of this data must be believed to be practical, and not require a disproportionate amount of time (multiple months/years) or project resources (e.g., prohibitive $$ to pay for brand new hydrodynamic modeling)

Selection of the final suite of focal species therefore involved judgment, including giving thought to the representation of different assemblages or guilds and species that utilize a wide range of habitat types within the study area. The suite of indicators chosen for DeltaEFT should be relevant to a broad range of species. This breadth must be balanced with selecting too many focal species, which undermines the purpose of a focal species approach.

Overall indicator classification nomenclature for DeltaEFT

Keeping in mind the criteria above and our experience gained in the design and development of SacEFT, **we adopted our own categorization scheme that is in several regards similar to the DRERIP scheme (Table F.1).** This indicator classification and prioritization system is used from this point forwards in this document.

Table F.1: Classification concepts employed for the evaluation of EFT performance indicators.

Label	Explanation	Levels
I **Importance**	The degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome.	**4 = High:** Expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population's natural productivity, abundance, spatial distribution and/or diversity (both genetic and life-history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics. **3 = Medium:** Expected sustained minor population effect or effect on large area or multiple patches of habitat.

Label	Explanation	Levels
		2 = Low: Expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial or temporal habitat effects. **1 = Minimal:** Conceptual model indicates little or no effect.
U Understanding ("Clarity")	The degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s).	**4 = High:** Understanding is high and nature of outcome is largely unconstrained by variability in ecosystem dynamics, other confounding external factors. **3 = Medium:** Understanding is high but nature of outcome is moderately dependent on other variable ecosystem processes or uncertain external confounding factors. **2 = Low:** Understanding is moderate or low and/or nature of outcome is greatly dependent on highly variable ecosystem processes or other external confounding factors. Many important aspects are subject of active ongoing research. **1 = Minimal:** Understanding is lacking. Mainly subject of active ongoing primary research.
R Rigor ("Predictability")	The degree to which the scientific evidence supporting our understanding of a cause-effect relationship (linkage) is contested in the scientific literature or confounded by other information.	**4 = High:** Is generally accepted, peer reviewed empirical evidence, strong predictive power and understanding, evidence not contested or confounded. Data in support of the functional relationship is derived from direct Bay-Delta field observations. **3 = Medium:** Strong evidence but not conclusive, only medium strength predictive power, some evidence for competing hypotheses and/or confounding factors. Data in support of the functional relationship is derived from direct Bay-Delta field observations OR from field observations outside the Bay-Delta estuary. **2 = Low:** Theoretical support with some evidence, semi-quantitative relationships, several alternative hypotheses and/or confounding factors. Data in support of the functional relationship is derived from lab or theoretical studies without field evidence. **1 = Minimal:** Hypothesized based on theory and/or professional judgment, purely qualitative predictions, many alternative hypotheses and/or confounding factors. Support for the functional relationship is largely hypothetical and based on first principles.
F Feasibility	The degree to which input data necessary to calculate the proposed performance indicator can be delivered in a timely fashion (without external bottlenecks) and the amount of effort (relative to other possible indicators) needed to implement the cause-effect linkage in a computer model.	**4 = High:** Input data currently exists in a format easy to disseminate, can be delivered readily and the effort (time) associated with implementing the cause-effect linkage easily falls within project budget without sacrificing other indicators. **3 = Medium:** Input data currently exists (or can readily be generated by new model runs), and while it might need some additional formatting, can be delivered readily. The effort (time) associated with implementing the cause-effect linkage will fall within project budget subject to prioritization decisions elsewhere that remove some other indicators from consideration. **2 = Low:** Input data does not currently exist, but can be generated through additional analyses or external model runs. The time before this external work could be completed is or may be uncertain. The effort (time) associated with implementing the cause-effect linkage could be accommodated within the project budget, but a number of other indicators would need to be eliminated from consideration.

Label	Explanation	Levels
		1 = Minimal: Input data does not currently exist, and it is not clear if it can be generated through additional analyses or external model runs. The time before this external work could be completed is unacceptably long. The effort (time) associated with implementing the cause-effect linkage would take up a disproportionately high amount of the project budget, and the majority of other indicators would need to be eliminated.
P Priority	Overall priority ranking for including in DeltaEFT: **H**igh; **M**edium; **L**ow.	

Appendix G: Default Relative Suitability Thresholds

On the following pages, indicator specific tables provide all SacEFT and DeltaEFT performance indicator relative suitability threshold values for both Daily and Annual Roll-up of indicators. **These thresholds are not a statement of "absolute" suitability.** Values are fully configurable in the EFT database. The summary tables below are drawn from indicator relative suitability threshold descriptions in ESSA (2011, 2013). We highlight cases where there are major gradients in performance indicator thresholds. For detailed information on these relative suitability thresholds, readers should refer to ESSA Technologies (2011, 2013).

Sacramento River (SacEFT)

Chinook/Steelhead CS1 – Area suitable spawning habitat					
Suitability thresholds: Based on historical distribution of flows from 1939-2002 (64-yrs)					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	430060	195486	483840	415800	• Criteria: statistical distribution discontinuities • "More" is better • Units: square feet • Flow, spawning period, habitat preferences, affect distribution
Spring Chinook	607975	217913	448525	367675	
Fall Chinook	1006472	299678	779240	506000	
Late fall Chinook	520424	280581	446250	289800	
Steelhead	18692	13447	24435	19186	

Chinook/Steelhead CS3 – Thermal egg-to-fry survival					
Suitability thresholds: Based on 90% and 95% survival					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	95	90	95	90	• Criteria: absolute values • Units: % survival • Common threshold for all run-types
Spring Chinook	95	90	95	90	
Fall Chinook	95	90	95	90	
Late fall Chinook	95	90	95	90	
Steelhead	95	90	95	90	

Chinook/Steelhead CS5 – Redd scour					
Suitability thresholds: Distribution based on 5,000 and 10,000 cfs flow					
	Daily		Roll-up		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	N/A	N/A	5000	10000	Criteria: calibrated to 80RS years, "less" is better
Spring Chinook	N/A	N/A	5000	10000	Units: index flow (cfs)
Fall Chinook	N/A	N/A	5000	10000	No daily estimate
Late fall Chinook	N/A	N/A	5000	10000	Common physical threshold for all run-types
Steelhead	N/A	N/A	5000	10000	Very low risk for spring- , winters

Chinook/Steelhead CS6 – Redd dewatering					
Suitability thresholds: Based on historical distribution of flows from 1971-2002 (32-yrs)					
	Daily		Roll-up		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	3.976E-06	4.042E-05	0.015	0.03	• Criteria: statistical distribution discontinuities, "less" is better
Spring Chinook	6.184E-05	7.333E-04	0.07	0.13	• Daily units: proportion stranded
Fall Chinook	1.597E-05	1.910E-04	0.05	0.09	• Roll-up units: cumulative proportion stranded
Late fall Chinook	1.336E-05	1.846E-04	0.12	0.22	• Flow, spawning period, habitat preferences, affect distribution
Steelhead	1.181E-05	1.428E-04	0.10	0.17	• Very low risk for winter • Higher sensitivity/risk for Late-fall run Chinook.

Chinook/Steelhead CS2 – Area suitable rearing habitat					
Suitability thresholds: Based on tercile distribution of flows from 1939-2002 (64-yrs)					
	Daily		Roll-up		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	32532	9662	7497758	7350129	• Criteria: statistical distribution, terciles, "more" is better
Spring Chinook	98352	29539	18885832	13958748	• Daily units: square feet
Fall Chinook	48166	17573	14717925	10624775	• Roll-up units: cumulative square feet
Late fall Chinook	43604	13801	10107957	9109028	• Flow, number of reaches affect distribution
Steelhead	123583	30142	47816590	41352564	

Chinook/Steelhead CS4 – Juvenile Stranding					
Suitability thresholds: Based on tercile distribution of flows from 1971-2002 (32-yrs)					
	Daily		Roll-up		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	3.992E-05	3.017E-04	0.0516	0.1112	• Criteria: statistical distribution terciles, "less" is better
Spring Chinook	1.279E-04	9.165E-04	0.1199	0.2149	• Daily units: index
Fall Chinook	9.742E-05	5.464E-04	0.1065	0.2034	• Roll-up units: cumulative index
Late fall Chinook	5.109E-05	1.963E-04	0.0551	0.0710	• Flow, number of reaches affect distribution
Steelhead	1.417E-04	1.628E-03	0.3261	0.4141	• Late-fall may be more sensitive-responsive

Bank swallow BASW1 – suitable habitat potential					
Suitability thresholds: Terciles based on historical distribution of flows from 1940-1994 (55-yrs)					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Habitat potential	N/A	N/A	36882	27000	• Criteria: statistical distribution discontinuities, "more" is better • Units: meters suitable habitat • No daily estimate

Bank swallow BASW2 – inundation/sloughing risk					
Suitability thresholds: Flow thresholds based on expert opinion					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Nesting Peak Flow	0.1	0.01	≥ 2	< 1 (zero)	• "less" is better • Daily units: flow suitability index • Roll-up units: count of locations assigned Good rating within a year.

Green sturgeon GS1 – Egg-to-larval survival					
Suitability thresholds: Based on 90% and 95% survival					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Thermal Egg Mortality	N/A	N/A	95	90	• "less" is better • Units: % mortality

Fremont cottonwood FC1 – cottonwood seedling initiation					
Suitability thresholds: Terciles based on historical distribution of flows from 1943-2004 (62-yrs)					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Riparian Initiation Success	N/A	N/A	53	36	• Criteria: thresholds based on expert opinion and observation of Good initiation years, "more" is better • Units: count of cross section nodes with surviving stems or seedlings. • No daily estimate

Fremont cottonwood FC2 – scour risk after initiation					
Suitability thresholds: 80,000 cfs and 90,000 cfs scour flows based on expert opinion					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Riparian Scour Risk	N/A	N/A	80000	90000	• Criteria: thresholds based on expert opinion of scour events, "less" is better • Units: flow (cfs) • No daily estimate

Large woody debris LWD1 – old vegetation recruited to river					
Suitability thresholds: Terciles based on historical distribution of flows from 1940-1994 (55-yrs)					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Large Woody Debris recruitment	N/A	N/A	53333	11233	• "more" is better • Units: square meters riparian forest eroded to mainstem Sacramento River having forests taller than 34 ft. (height class 4 or higher). • No daily estimate

San Joaquin-Sacramento Delta (DeltaEFT)

Chinook/Steelhead CS7 – Juvenile development in Yolo Bypass					
Suitability thresholds: Based on historical distribution of flows from 2002-2007 (6-yrs) and NAA-Current scenario from 1976-1991 (22-yrs) [total 28-yrs]					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	32	24	32	24	• Criteria: statistical distribution discontinuities, "more" is better • Units: % weight gain • Flow, weir notching affect residency
Spring Chinook	32	24	32	24	
Fall Chinook	23	16	23	16	
Late fall Chinook	32	24	32	24	
Steelhead	23	16	23	16	

Chinook/Steelhead CS9 – Juvenile predation risk					
Suitability thresholds: Based on historical distribution of flows from 2002-2007 (6-yrs) and NAA-Current scenario from 1976-1991 (22-yrs) [total 28-yrs]					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	12	16	12	16	• Criteria: statistical distribution discontinuities, "less" is better • Units: residency days • High flow reduces exposure
Spring Chinook	12	16	12	16	
Fall Chinook	12	16	12	16	
Late fall Chinook	12	16	12	16	
Steelhead	12	16	12	16	

Chinook/Steelhead CS10 – Juvenile temperature stress					
Suitability thresholds: Based on historical distribution of flows from 2002-2007 (6-yrs) and NAA-Current scenario from 1976-1991 (22-yrs) [total 28-yrs]					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Winter Chinook	39	53	39	53	• Criteria: statistical distribution discontinuities, "less" is better • Units: degree-days difference from physiol. optimum • Higher flows better (cooler), but trade-off with weight gain (time)
Spring Chinook	68	100	68	100	
Fall Chinook	68	100	68	100	
Late fall Chinook	39	53	39	53	
Steelhead	68	100	68	100	

Splittail smelt SS1 – Proportion of maximum spawning habitat					
Suitability thresholds: Terciles based on historical data from 1989-2010 (22-yrs)					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Spawning Success	0.05	0.02	0.05	0.02	• "more" is better • Units: proportion of maximum habitat area

Delta smelt DS1 – Spawning success					
Suitability thresholds: Terciles based on historical distribution of flows from 2002-2010 (9-yrs)					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Spawn Success	N/A	N/A	36	25	• Criteria: statistical distribution, terciles, "more" is better • Units: longest duration of optimal days

Delta smelt DS2 – Habitat suitability index					
Suitability thresholds: Based on literature value (Delta smelt BiOp 2008) for X2 at 74 and 81km					
	Daily		Roll-up		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Habitat Quality Index	N/A	N/A	7261	4835	• "more" is better • Units: N/A

Delta smelt DS4 – Larval & juvenile entrainment					
Suitability thresholds: Terciles based on historical distribution of flows from 1998-2000 (9-yrs) and NAA-Current flows from 1975 to 1991 (17-yrs) [total 26-yrs]					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Entrainment Risk	N/A	N/A	0.04	0.1	• "less" is better • Units: %

Longfin smelt LS1 – Abundance					
Suitability thresholds: Terciles based on historical distribution of flows from 2002-2008 (7-yrs) and NAA-Current flows from 1975 to 1991 (17-yrs) [total 26-yrs]					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
Abundance Index	N/A	N/A	725	225	• Criteria: statistical distribution, terciles, "more" is better • Units: N/A

Invasive deterrence - Suppression					
Suitability thresholds: Uses literature values and expert opinion					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
ID1: Egeria densa	N/A	N/A	> 10 for 3+ months	> 5 for 2+ months	• Units: average salinity (‰) • Location roll-up: Annual performance is based on the most important region • Most important region: 'Chipps Island To Oakley' for ID1 and ID3, '680 Bridge to Chipps Island' for ID2
ID2: Corbula	N/A	N/A	< 3 or ≥ 30 for 3+ months	< 5 or ≥ 25 for 2+ months	
ID3: Corbicula	N/A	N/A	> 12 for 3+ months	> 7 for 2+ months	

Tidal Wetlands					
Suitability thresholds: TW1: Terciles based on historical distribution of stage from 2002-2006 (5-yrs) and NAA-Current stage from 1975 to 1991 (17-yrs) [total 22-yrs] TW2: Terciles based on historical distribution of stage from 1997-2010 (14-yrs) and NAA-Current stage from 1975 to 1991 (17-yrs) [total 31-yrs]					
	Daily		**Roll-up**		**Notes**
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
TW1: Brackish	N/A	N/A	7600000	7450000	• "more" is better
TW2: Freshwater	N/A	N/A	2960000	2780000	• Units: m^2

Appendix H: Master Register of EFT Input and Output Locations

This table shows all input and output locations used in the SacEFT and DeltaEFT ecoregions. **EFT Short Names** are intended to provide concise labels for figures, tables and text. **Gauge or Common Name** locations refer to point locations, usually used as input to EFT and represented either by a physical gauge or alternatively, by a modeled location within a simulation system such as CALSIM, DSM2 or EFT. Specifically, SacEFT currently uses either USRDOM or SRWQM daily modeled flows. DeltaEFT currently uses DSM2 for flows, electroconductivity, water temperature and stage. Daily water temperatures for SacEFT are provided by SRWQM. Location names assigned by DSM2 and CDEC are not fully standardized. Shading and Dots shown at some locations indicate gauges (actual or simulate) used as input to an indicator. **Letter Codes** for input variables for the indicators are: F=flow; T=temperature; E=electroconductivity; S=stage. Cells marked with shading only indication locations used as an output for the indicator. **Regional** and **Route** locations are collections of modeled points used to aggregate detailed location-based EFT output into meaningful geographic units. **River Codes:** FAL - False River; MID - Middle River; MOK - Mokelumne River; OLD - Old River; SAC - Sacramento River; SAN - San Juan River. **Slough Codes:** BAS - Barker Slough; CAS - Cache Slough; CBS - Chadbourne Slough; DUS - Dutch Slough; GES - Georgiana Slough; GYS - Goodyear Slough; MZS - Montezuma Slough; PRS - Piper Slough; SUS - Sutter Slough; STS - Steamboat Slough; SNS - Suisan Slough; YOL - Yolo Bypass.

SacEFT Ecoregion Locations

EFT Short Name	Gauge or Common Name Location	River Code	RM	DSM2 Name	CDEC Name	Gauge Owner	Native Code	CS1		CS3	CS6	CS5	CS4	CS2	GS1	BASW1	BASW2	FC1	FC2	LWD1				
								F	T	T	F	F	F	F	T	F	F	F	F	F				
Keswick (RM301)	SACRAMENTO R A KESWICK CA	SAC	301			USGS	11370500	●	●	●	●	●	●	●										
Clear Crk (RM289)	Clear Creek	SAC	288.9					●	●	●	●	●	●	●										
Cow Crk (RM280)	Cow Creek	SAC	280.2					●	●	●	●	●	●	●										
Balls Fy (RM277)	SACRAMENTO R A BALLS FERRY	SAC	277			CDEC	402507122113201	●	●	●	●	●	●	●										
Cottonwood Crk (RM273)	Cottonwood Creek	SAC	273.3					●	●	●	●	●	●	●										
Jellys Fy (RM267)	Jelly's Ferry	SAC	267					●	●	●	●	●	●	●										
Bend Bridge (RM260)	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA	SAC	260			USGS	11383730	●	●	●	●	●	●	●	●									
Red Bluff (RM243)	SACRAMENTO R NR RED BLUFF CA	SAC	243			USGS	11378000																	
Hamilton City (RM199)	SACRAMENTO R NR HAMILTON CITY CA	SAC	199			USGS	11383800								●	●	●	●	●	●				
Butte City (RM168)	SACRAMENTO R A BUTTE CITY CA	SAC	168			USGS	11389000											●	●					
Vina-Woodson	SACRAMENTO R A VINA BRIDGE NR VINA CA (Woodson Bridge)	SAC	???			USGS	11383730									●	●	●	●	●				
Tisdale	SAC_AT_TISDALE	SAC	???																					
Colusa (RM143)	SACRAMENTO R A COLUSA CA	SAC	143			USGS	11389500																	
EFT Short Name	**Region or Route Location**	**River Code**	**RM**	**DSM2 Name**	**CDEC Name**	**Gauge Owner**	**Native Code**																	
BASW - RM168	BASW2 - RM168	SAC	168																					
BASW - RM197	BASW2 - RM197	SAC	197																					
BASW - RM242	BASW2 - RM242	SAC	242																					
BASW - RM292	BASW2 - RM292	SAC	292																					
CS - RM217-242	CS Reach 2	SAC	217-242																					
CS - RM252-272	CS Reach 3	SAC	252-272																					
CS - RM272-280	CS Reach 4	SAC	272-280																					
CS - RM280-298	CS Reach 5	SAC	280.2 298.5																					
CS - RM298-302	CS Reach 6	SAC	298.5-302																					
FC - RM164	Fremont - HR164	SAC	164																					
FC - RM165	Fremont - HR165	SAC	165																					
FC - RM172	Fremont - HR172	SAC	172																					
FC - RM185	Fremont - HR185.5	SAC	185.5																					
FC - RM195	Fremont - HR195.75	SAC	195.75																					

FC - RM199	Fremont - HR199.75	SAC	199.75																					
FC - RM206	Fremont - HR206	SAC	206																					
FC - RM208	Fremont - HR208.25	SAC	208.25																					
FC - RM172	Fremont - RM172	SAC	172																					
FC - RM183	Fremont - RM183	SAC	183																					
FC - RM192	Fremont - RM192	SAC	192																					
Ord-Butte MM Bnd 1	Ord Bend - Butte City - Bend 1	SAC	170-185																					
Ord-Butte MM Bnd 2	Ord Bend - Butte City - Bend 2	SAC	170-185																					
Ord-Butte MM Bnd 3	Ord Bend - Butte City - Bend 3	SAC	170-185																					
Ord-Butte MM Bnd 4	Ord Bend - Butte City - Bend 4	SAC	170-185																					
Ord-Butte MM Bnd 5	Ord Bend - Butte City - Bend 5	SAC	170-185																					
Ord-Butte MM Bnd 6	Ord Bend - Butte City - Bend 6	SAC	170-185																					
Ord-Butte MM Bnd 7	Ord Bend - Butte City - Bend 7	SAC	170-185																					
Ord-Butte MM Bnd 8	Ord Bend - Butte City - Bend 8	SAC	170-185																					
Ord-Butte MM Bnd 9	Ord Bend - Butte City - Bend 9	SAC	170-185																					
Ord-Butte MM Bnd 10	Ord Bend - Butte City - Bend 10	SAC	170-185																					
Ord-Butte MM Bnd 11	Ord Bend - Butte City - Bend 11	SAC	170-185																					
Hamilton-Ord MM Bnd 1	Hamilton City - Ord Bend - Bend 1	SAC	185-201																					
Hamilton-Ord MM Bnd 2	Hamilton City - Ord Bend - Bend 2	SAC	185-201																					
Hamilton-Ord MM Bnd 3	Hamilton City - Ord Bend - Bend 3	SAC	185-201																					
Hamilton-Ord MM Bnd 4	Hamilton City - Ord Bend - Bend 4	SAC	185-201																					
Hamilton-Ord MM Bnd 5	Hamilton City - Ord Bend - Bend 5	SAC	185-201																					
Hamilton-Ord MM Bnd 6	Hamilton City - Ord Bend - Bend 6	SAC	185-201																					
Hamilton-Ord MM Bnd 7	Hamilton City - Ord Bend - Bend 7	SAC	185-201																					
Hamilton-Ord MM Bnd 8	Hamilton City - Ord Bend - Bend 8	SAC	185-201																					
Hamilton-Ord MM Bnd 9	Hamilton City - Ord Bend - Bend 9	SAC	185-201																					
Hamilton-Ord MM Bnd 10	Hamilton City - Ord Bend - Bend 10	SAC	185-201																					
Hamilton-Ord MM Bnd 11	Hamilton City - Ord Bend - Bend 11	SAC	185-201																					
Hamilton-Ord MM Bnd 12	Hamilton City - Ord Bend - Bend 12	SAC	185-201																					
Vina-Wdsn MM Bnd 1	MM Segment 3 - Vina - Bend 1	SAC	201-218																					
Vina-Wdsn MM Bnd 2	MM Segment 3 - Vina - Bend 2	SAC	201-218																					
Vina-Wdsn MM Bnd 3	MM Segment 3 - Vina - Bend 3	SAC	201-218																					
Vina-Wdsn MM Bnd 4	MM Segment 3 - Vina - Bend 4	SAC	201-218																					
Vina-Wdsn MM Bnd 5	MM Segment 3 - Vina - Bend 5	SAC	201-218																					
Vina-Wdsn MM Bnd 6	MM Segment 3 - Vina - Bend 6	SAC	201-218																					
Vina-Wdsn MM Bnd 7	MM Segment 3 - Vina - Bend 7	SAC	201-218																					
Vina-Wdsn MM Bnd 8	MM Segment 3 - Vina - Bend 8	SAC	201-218																					
Vina-Wdsn MM Bnd 9	MM Segment 3 - Vina - Bend 9	SAC	201-218																					
Vina-Wdsn MM Bnd 10	MM Segment 3 - Vina - Bend 10	SAC	201-218																					
Vina-Wdsn MM Bnd 11	MM Segment 3 - Vina - Bend 11	SAC	201-218																					
Vina-Wdsn MM Bnd 12	MM Segment 3 - Vina - Bend 12	SAC	201-218																					
Vina-Wdsn MM Bnd 13	MM Segment 3 - Vina - Bend 13	SAC	201-218																					
Vina-Wdsn MM Bnd 14	MM Segment 3 - Vina - Bend 14	SAC	201-218																					

DeltaEFT Ecoregion Locations

EFT Short Name	Gauge or Common Name Location	River Code	RM	RKI	DSM2 Name	CDEC Name	Gauge Owner	Native Code	CS7		CS9	CS10		DS1		DS2	DS4	SS1	LF1	TW1	TW2		ID1	ID2	ID3
									F	T	F	F	T	T	E	E	F	F	E	S	E	S	E	E	E
Knight	BUTTE CITY and SUTTER BYPASS	SAC	168			KNL	USGS	11389000	●	●															
Verona	SACRAMENTO R A VERONA CA	SAC				VON	USGS	11425500	●																
Sacramento (IST178)	SACRAMENTO R A SACRAMENTO CA	SAC	59.5	178	RSAC178	IST	USGS	11447500	●																
Freeport (FPT155)	SACRAMENTO R A FREEPORT CA	SAC		155	RSAC155	FPT	USGS	11447650	●																
Hood (SRH142)	SACRAMENTO RIVER AT HOOD	SAC		142	RSAC142	SRH	CDEC	382205121311300			●	●													
Above DCC (SDC128)	SACRAMENTO R AB DELTA CROSS CHANNEL CA	SAC		128	RSAC128	SDC	USGS	11447890	●	●	●	●	●												
Sac blw Georgina (GSS123)	SACRAMENTO R BL GEORGIANA SLOUGH CA	SAC		123	RSAC123	GSS	USGS	11447905	●	●	●	●	●	●	●										
Rio Vista (RVB101)	SACRAMENTO R A RIO VISTA CA	SAC		101	RSAC101	RVB,RIV	USGS	11455420	●		●			●	●								●	●	●
Ryer Isld	CACHE SLOUGH A RYER ISLAND	CAS			CACHE_RYER		USGS	11455350						●	●										
Emmaton (EMM92)	EMMATON (USBR)	SAC		92	RSAC092	EMM			●	●		●	●	●	●	●			●				●	●	●
Collinsville (CSE81)	COLLINSVILLE ON SACRAMENTO RIVER	SAC		81	RSAC081	CSE			●	●	●												●	●	●
Sutter Sl (SBP)	SUTTER BYPASS AT RD 1500 PUMP	SUS			SUT_US_MIN	SBP						●													
Steamboat Sl	Steamboat Slough	STS			STMBT_S							●													
Pittsburg (PTS77)	SAN FRANCISCO BAY A PITTSBURG CA	SAC		77	RSAC077	PTS	CDEC	380300121524201						●	●	●			●				●	●	●
Mallard (MAL75)	SUISUN BAY A MALLARD IS CA	SAC		75	RSAC075	MAL	USGS	11185185	●	●	●	●	●	●	●	●			●					●	
DCC	Delta Cross Channel	SAC			DCC							●	●							●	●	●			
Georgiana Sl (GGS)	GEORGIANA SLOUGH NR SACRAMENTO R	GES	50		GEORG_SL	GGS	USGS	11447903				●	●	●	●										
Fremont Weir (FRE244)	FREMONT WEIR SPILL TO YOLO BYPASS NR VERONA CA	SAC		244	RSAC244	FRE	USGS	11391021	●									●							
Sacramento Weir (182)	SACRAMENTO WEIR SPILL TO YOLO	SAC		182	RSAC182		USGS	11426000	●									●							
Walnut Grove (19)	N MOKELUMNE NR WALNUT GROVE CA	NMK		19	RMKL019		USGS	11336685				●	●	●	●										
Little Potato (STI8)	LITTLE POTATO SLOUGH NR TERMINOUS CA	SMK		8	RSMKL008	STI	USGS	11336800				●	●	●	●										
Port Chicago (PCT64)	PORT CHICAGO	SAC		64	RSAC064	PCT								●	●	●			●	●	●	●		●	
Jersey Point (JER18)	SAN JOAQUIN R A JERSEY POINT CA	SAN		18	RSAN018	JER	USGS	11337190						●	●					●	●	●			
Antioch (ANH7)	SAN JOAQUIN R A ANTIOCH CA	SAN		7	RSAN007	ANH	USGS	11337200						●	●								●	●	●
Tracy (MTB27)	MIDDLE RIVER AT TRACY BLVD	MID		27	RMIS027	MTB								●	●										
Rough & Ready (RRI58)	ROUGH AND READY ISLAND	SAN		58	RSAN058	RRI								●	●										
Martinez (MRZ54)	CARQUINEZ STRAIT A MARTINEZ CA	SAC		54	RSAC054	MRZ	USGS	11182450						●	●	●			●					●	
Venice Isld (VNI43)	SAN JOAQUIN R A VENICE ISLAND - TIDE GAUGE CA	SAN		43	RSAN043	VNI	CDEC	380301121294500						●	●										
San Andreas (SAL32)	SAN ANDREAS LANDING	SAN		32	RSAN032	SAL						●	●	●	●								●	●	●
Bacon Isld (BAC24)	OLD R A BACON ISLAND CA	OLD		24	ROLD024	OBI,BAC	USGS	11313405						●	●		●								
Borden (VIC23)	MIDDLE R AT BORDEN HWY NR TRACY CA	MID		23	RMID023	VIC	USGS	11312674																	
Stockton (SJG)	SAN JOAQUIN R BL GARWOOD BR A STOCKTON	SAN				SJG	USGS	11304810						●	●										
Middle R (MDM15)	MIDDLE R AT MIDDLE RIVER CA	MID		15	RMID015	MDM	USGS	11312676						●	●		●			●	●	●			
Holland Cut (HLL14)	HOLLAND CUT NR BETHEL ISLAND CA	OLD		14	ROLD014	HLL	USGS	11313431						●											
Beldon (BDL11)	BELDON LANDING	MZS		11	SLMZU011	BDL								●	●					●	●	●		●	
Steamboat-Sutter (SSS11)	DWR-CD 1479, 11km up Steamboat Slough, below Sutter Slough	SUS		11	SLSBT011	SSS						●	●	●	●										
Farrar (FRP9)	FARRAR PARK	DUS		9	SLDUT009	FRP									●								●	●	●
Barker (BKS2)	BARKER SLOUGH PUMPING PLANT (KG000000)	BAS		2	SLBAR002	BKS														●	●	●			
Bethel Isld (BET3)	BETHEL ISLAND	PRS		3	SLPPR003	BET																			
Goodyear (GYS3)	GOODYEAR SLOUGH	GYS		3	SLGYR003	GYS																			
Sunrise (SNC2)	SUNRISE CLUB	CBS		2	SLCBN002	SNC																		●	
National Steel (NSL25)	NATIONAL STEEL	MZS		25	SLMZU025	NSL																		●	
Volanti (VOL12)	VOLANTI	SNS		12	SLSUS012	VOL																		●	
Yolo	YOLO BYPASS NR WOODLAND CA	YOL			BYOLO040	YBY	USGS	11453000																	
Chipps	SUISUN BAY AT CHIPPS ISLAND CA	SAC		0			CDEC	380245121551001																	
Webb	USBR station, False River at Webb Tract	FAL		8	RFAL008																				

Oakley?	CONTRA COSTA CN NR OAKLEY CA			6	CHCC006	CNT	USGS	11337000
Holt	TURNER CUT NR HOLT CA				CFTRN000		USGS	11311300
Turner	USGS SJR-TC, San Joaquin River between Turner Cut and Columbia Cut	SAN		46	RSAN046			
EFT Short Name	Region or Route Location	River Code	RM	RKI	DSM2 Name	CDEC Name	Gauge Owner	Native Code
Interior Rgn	Oakley To Interior Delta							
Oakley Rgn	Chipps Island to Oakley							
Suisun Rgn	680 Bridge to Chipps Island							
Big Break Wtld	Big Break Wetland							
Montezuma Wtld	Montezuma Slough Wetland							
Ryer Wtld	Ryer Island Wetland							
Skinkee Wtld	Skinkee Tract Wetland							
Grizzly Wtld	Grizzly Bay Wetland							
Hood-RioVista Rte	Sacramento R - Hood to Rio Vista							
Knight-RioVista Rte	Sacramento R - Knights Ldg - Rio Vista							
Knight-Frmt Weir Rte	Sacramento R - Knights Ldg - Yolo via Fremont - Rio Vista							
Knight-Sac Weir Rte	Sacramento R - Knights Ldg - Yolo via Sacramento Weir - Rio Vista							
Western B1 Rte	Eastern Delta - through Sutter Slough to Suisun (B1)							
Western B2 Rte	Eastern Delta - through Steamboat Slough to Suisun (B2							
Eastern C Rte	Eastern Delta - through Georgiana Slough to Suisun (C)							
Eastern D Rte	Eastern Delta - through Georgiana Slough to Suisun (D)							
Eastern E1 Rte	Eastern Delta - through DCC, east branch to Georgiana to Suisun (E1)							
Eastern E2 Rte	Eastern Delta - through DCC, west branch to Georgiana to Suisun (E2)							

Appendix I: EFT Derived Flow Needs

The tables in this Appendix provide a compressed summary of the alternative formulations of **EFT derived ecological flow needs (rule-sets).** As described in section 2.9.1, a fundamental step is analysis of flow traces (or water temperature or other physical driver results) associated with favorable suitability. Leveraging the EFT relational database, data analysis exercises like those shown in Figure 2.19 help the EFT investigators identify flow patterns and timing that are correlated with favorable outcomes for each species and performance indicator.

Based on flow (or other physical) trace analysis and conceptual model interpretation, criteria and rule-sets are summarized using the standardized format shown in the series of tables below. These tables identify:

1. The focal species and indicator.
2. The objective and rationale for the indicator.
3. The critical life-history timing.
4. The key index locations that can be used to support the indicator.
5. A short description of the target ecological flow variables, target condition(s).
6. Additional details and other triggers (e.g., water year type).
7. The frequency of recurrence (many functional flow targets need *not* be achieved *every* year).
8. A short summary of potential conflicts and trade-offs with other objectives and EFT performance indicators.
9. List of foundational science references (taken from SacEFT and DeltaEFT Records of Design).

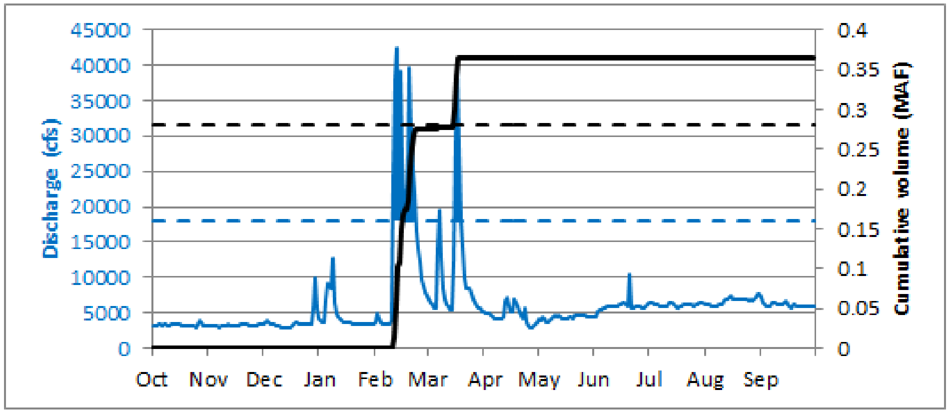
The standard design of these tables enables readers unfamiliar with the details to more quickly compare and contrast different ecological flow guidelines. Our EFT eco rule-set analyses show that rules for driving physical data are sometimes clearly correlated with the favorable outcome, while others such as redd dewatering (CS5) have no obvious simple relationship with flow.

CS1-6, Winter-run Chinook

The goal of this action is to provide a strong cohort year for winter-run Chinook, attempting to provide monthly minimum and maximum average daily flows that will satisfy the requirements of all performance indicators (CS1-CS6). Winter-run Chinook are selected since they have the highest threat status of the five salmonid run types. The table shows draft average flows (kCFS) for each month that satisfy the CS1 – CS6 criteria for winter-run Chinook. There are no constraints for CS3, CS6 and CS5. Data are taken from more detailed analyses of each run-type and from study of flow-traces.

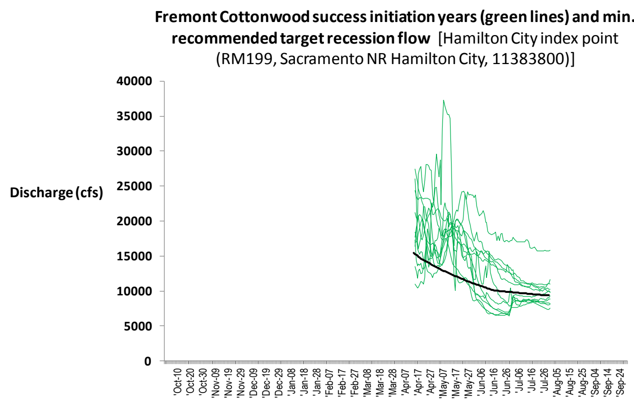
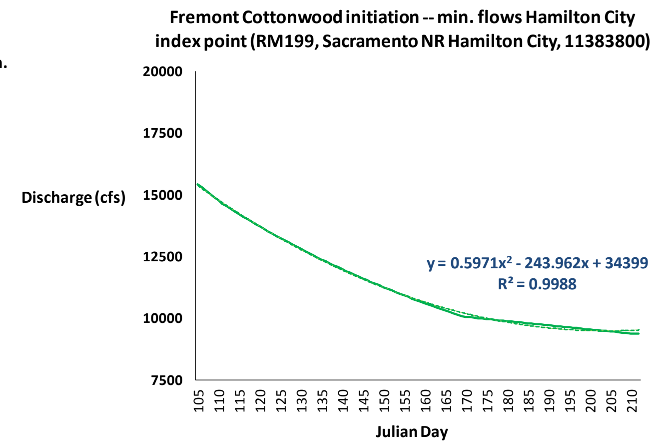
Sacramento River													
Chinook & Steelhead (Winter Run)													
Indicator	CS1-CS6	Integrated											
Timing	O	N	D	J	F	M	A	M	J	J	A	S	**Range**
								12	12				CS1: Spawning WUA, Max
								5	5				CS1: Spawning WUA, Min
													CS3: Thermal Egg Mortality, no constraint
													CS6: Redd Dewatering, no constraint
													CS5: Redd Scour, no constraint
													CS4: Juvenile Stranding, Max no constraint
	7	7	7								7	7	CS4: Juvenile Stranding, Min
	8	8	8								8	8	CS2: Rearing WUA , Max
	3.5	3.5	3.5								3.5	3.5	CS2: Rearing WUA, Min
	8	8	8					12	12		8	8	Integrated: Max
	7	7	7					5	5		7	7	Integrated: Min
Location	Sacramento River below Clear Creek (RM290)												

Sacramento River		
Bank Swallow		
Indicator	BASW1	Habitat potential
Objective & Rationale	Maximize availability of suitable nesting habitat (SacEFT Design Document Section 4.3.3, pp. 86-92)	
Timing	O N D J F M A M J J A S (shaded: O–M)	
Location	Hamilton City (RM199, SACRAMENTO R NR HAMILTON CITY CA, 11383800)	
Variable & Condition	<N WYT: Release a volume of 0.28 MAF above 18,000 cfs if target not met in preceding two years ≥N WYT: Release a volume of 2.8 MAF above 18,000 cfs if target not met in preceding two years *See **Additional Details** below*	
Other Triggers	Attempt for WYT < N if target not met in preceding two years	
Recurrence	At least every 3 years	
Potential conflicts & trade-offs	Avoid during Bank Swallow nesting period (BASW2). Reservoir water supply management (draw-down/drought management). BASW1 also benefits Large Woody Debris recruitment.	
References	Stillwater Sciences (2007)	

Sacramento River		
Bank Swallow		
Indicator	BASW1	Habitat potential
Additional Details	The daily volume in cubic feet is calculated as the volume released above the 18.000cfs threshold: $$DailyVolume = \begin{cases} 0 \;\; if \;\; Q < 18{,}000cfs \\ (Q - 18{,}000cfs) \times 86{,}400s \end{cases}$$ The Cumulative Volume over the water year is the sum of all Daily Volumes converted to MAF. $$CumulativeVolume = \sum_{i=1}^{365} DailyVolume_i \times 2.3 \times 10^{-11} \frac{\mathrm{ft}^3}{\mathrm{MAF}}$$  Example of cumulative volume above threshold of 18,000 cfs for water year 1989. The continuous blue line shows daily flow, the stippled blue line marks the threshold and the filled blue areas show the daily volume released above the threshold. The continuous black line shows the cumulative volume of water released once the threshold has been reached; which in this year exceeds the threshold of 0.28 MAF for dry and critical years, shown by the stippled black line.	

Sacramento River													
Bank Swallow													
Indicator	BASW2	Peak flow during nesting period											
Objective & Rationale	Minimize risk of nest inundation and bank sloughing during nesting (SacEFT Design Document Section 4.3.3, pp. 92-95)												
Timing	O	N	D	J	F	M	A	M	J	J	A	S	
Location	Hamilton City (RM199, SACRAMENTO R NR HAMILTON CITY CA, 11383800)												
Variable & Condition	Q ≤ 50,000 cfs												
Other Triggers	–												
Recurrence	tbd												
Potential conflicts & trade-offs	Reservoir flood storage management												
References	Stillwater Sciences (2007)												

Sacramento River		
Fremont Cottonwood		
Indicator	FC1	Relative initiation success
Objective & Rationale	Periodically provide recession flows that support areas for riparian initiation (as indexed by Fremont cottonwoods) *in the target zone for initiation* (i.e., riparian channel bank areas above **8,500 cfs elevation + 3ft**). Seeds that land on non-inundated ground begin to grow roots downward from the elevation at which they were deposited. While accounting for average capillary fringe height along the cross section (e.g., 30 cm), the rate of stage decline determines whether the cottonwood's root is able to maintain contact with the water table. As soon as the root depth is above the surface elevation + capillary fringe height, the seedling becomes non-viable (dies). Hence for successful initiation, the rate of stage decline cannot occur at a rate faster than the taproot growth rate (we use a taproot growth rate of 22 mm/day). In SacEFT, Cottonwood seedlings whose roots reach a depth of 50 cm are assumed to be successful in reaching some type of ephemeral groundwater moisture sufficient to keep them alive through the remainder of their first year. (SacEFT Design Document Section 4.3.4, pp. 96-100.)	
Timing	O N D J F M A M J J A S (shaded: A M J)	
Location	Hamilton City (RM199, SACRAMENTO R NR HAMILTON CITY CA, 11383800) Butte City (RM168, SACRAMENTO R A BUTTE CITY CA, 11389000)	
Variable & Condition	76 out of 108 days of flows (70%) at Hamilton City (RM199) between Apr-15 (105) and July-31 (212) equal or exceed flows predicted by the following equation: Min. target Q (cfs) = $0.5971x^2 - 243.962x + 34399$ (where x = Julian day)	

	 
Other Triggers	–
Recurrence	At least once every 8 years.
Potential conflicts & trade-offs	
References	Mahoney and Rood 1998; Roberts *et al.* 2002; Roberts 2003; HEC-RAS supplemented stage-discharge relations; Alexander 2004

Sacramento River													
Fremont Cottonwood													
Indicator	FC2	Young of year cottonwood seedling scour risk											
Objective & Rationale	Based on recommendations from the SacEFT refinements workshop, a second performance indicator has been included in SacEFT v.2 to capture the effects of scour events following riparian initiation. The rationale for including this second performance indicator is that gains made after successful riparian initiation (FC1 success) are moot if the seedlings are scoured out in the following year, i.e., there is no point expending large volumes of water to achieve riparian initiation, and then wiping out these benefits in year t+1 with a scouring flow. (SacEFT Design Document Section 4.3.4, pp. 96-102.)												
Timing	O	N	D	J	F	M	A	M	J	J	A	S	
Location	Hamilton City (RM199, SACRAMENTO R NR HAMILTON CITY CA, 11383800) Butte City (RM168, SACRAMENTO R A BUTTE CITY CA, 11389000)												
Variable & Condition	From August-1 in any year *t* that has successfully met the FC1 criterion, until July-31 year t+1, flows at Hamilton City (RM199) never exceed **85,000 cfs.**												
Other Triggers	Only relevant in year following successful achievement of FC1 flows (i.e., want to apply meaningful weighting to this criterion based on state of FC1).												
Recurrence	n/a (minimize / avoid following successful FC1 initiation year)												
Potential conflicts & trade-offs	Impossible to avoid during uncontrolled flood situations.												
References	Recommendations from Riparian ecologists at the SacEFT v.1 peer review and refinements workshop (see SacEFT Design Document Section 4.3.4, pp. 96-102).												

Sacramento River		
Chinook & Steelhead		
Indicator	CS1	Spawning Habitat (WUA)
Objective & Rationale	Spawning Weighted Usable Area (WUA) is calculated using daily cohorts of spawners based on bathymetry and 2D flow modeling at up to 5 intensively measured river segments. Gauges provide daily average flow over the spawning period for each location and run-type, predicting WUA (ft^2). The indicator accounts for spawning area only: subsequent exposure to thermal mortality or redd dewatering is not included. (SacEFT Design Document Section 4.3.1, pp.54-59.)	

Timing

O	N	D	J	F	M	A	M	J	J	A	S	
											■	Spring
	■											Fall
			■	■								Late-fall
							■	■				Winter
			■	■	■							Steelhead

Location	Sacramento River below Clear Creek (RM290)

Variable & Condition

6,000 < Q_{avg} < 10,000 cfs (weak R band at high Q)	Spring
4,000 < Q_{avg} < 8,000 cfs (R bands at low, high Q)	Fall
3,500 < Q_{avg} < 8,000 cfs (R band at high Q)	Late-fall
5,000 < Q_{avg} < 12,000 cfs (R bands at low, high Q)	Winter
3,500 < Q_{avg} < 10,000 cfs (R band at high Q)	Steelhead

Joint Timing

O	N	D	J	F	M	A	M	J	J	A	S	
	4		3.5	3.5	3.5		5	5			6	Q_{min} kcfs
	8		8	8	10		12	12			10	Q_{max} kcfs

Other Triggers	–
Recurrence	2 out of 3 years
Potential conflicts & trade-offs	
References	Vogel and Marine (1991), USFWS (2003, 2005a)

Sacramento River		
Chinook & Steelhead		
Indicator	CS6	Redd dewatering
Objective & Rationale	Redd dewatering is modeled using daily declining changes in discharge over the egg development period for each location and run-type combination, to calculate estimates of proportional redd loss. The indicator is based on the spawning calendar (CS1) and temperature-drive emergence (CS3), conditioned on previous dewatering events. (SacEFT Design Document Section 4.3.1, pp.76-80.)	

Timing

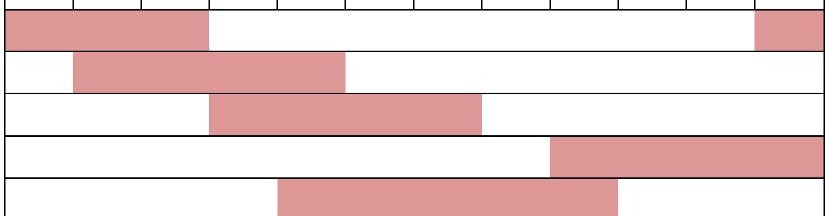
O	N	D	J	F	M	A	M	J	J	A	S	
												Spring
												Fall
												Late-fall
												Winter
												Steelhead

Location	Sacramento River below Clear Creek (RM290)	
Variable & Condition	Q_{max}< 10,000 cfs (R band above Q_{max})	Spring Fall Late-fall
	No Q-rule defined	Winter
	Q_{max}< 15,000 cfs (R band above Q_{max})	Steelhead

Joint Timing

O	N	D	J	F	M	A	M	J	J	A	S	
												Q_{min} kcfs
10	10	10	10	10	10	10	15	15			10	Q_{max} kcfs

Other Triggers	Daily time-scale recession; Winter-run especially sensitive
Recurrence	2 out of 3 years
Potential conflicts & trade-offs	Dewatering positively correlated with high spawning flow, daily recession
References	USFWS (2006)

Sacramento River		
Chinook & Steelhead		
Indicator	CS5	Redd scour
Objective & Rationale	Redd scour risk is based on the daily proportion of eggs present by run type and location coupled to categorical hazard classes at times when flow exceeds user-configured threshold values. Threshold values corresponding to the 90th percentile of 10-year peak flow (75,000 cfs) and 80th percentile of 5-year peak flow (55,000 cfs) define the Fair/Poor and Good/Fair thresholds, respectively. The daily proportion of eggs present is based on the spawning calendar (CS1) and temperature-based emergence (CS3). (SacEFT Design Document Section 4.3.1, pp.73-76.)	
Timing	O N D J F M A M J J A S 	Spring Fall Late-fall Winter Steelhead
Location	Sacramento River below Clear Creek (RM290)	
Variable & Condition	No Q-rule defined Jan: Q_{max} < 15,000 cfs (minimize R/G misclassification) Feb: Q_{max} < 30,000 cfs (minimize R/G misclassification) No Q-rule defined Mar: Q_{max} < 25,000 cfs (minimize R/G misclassification)	Spring Fall Late-fall Winter Steelhead
Joint Timing	O N D J F M A M J J A S J: 15, F: 30, M: 25	 Q_{min} kcfs Q_{max} kcfs
Other Triggers	–	
Recurrence	2 out of 3 years	
Potential conflicts & trade-offs		
References		

Sacramento River													
Chinook & Steelhead													
Indicator	CS4	Juvenile stranding											
Objective & Rationale	Juvenile stranding is modeled using daily declining changes in discharge over the juvenile rearing period, for each location and run-type combination. The initial daily distribution of rearing juveniles is based on the temperature-drive emergence function (see CS3) and the juvenile rearing WUA distribution (see CS2). Stranding for each day-cohort is cumulatively based on prior stranding events. (SacEFT Design Document Section 4.3.1, pp.68-73.)												
Timing	O	N	D	J	F	M	A	M	J	J	A	S	
													Spring
													Fall
													Late-fall
													Winter
													Steelhead
Location	Sacramento River below Clear Creek (RM290)												
Variable & Condition	Jan: Q_{min} > 5,000 cfs (minimize R/G misclassification)												Spring
	No Q-rule defined												Fall
	Sep: Q_{min} > 7,000 cfs (minimize R/Y misclassification)												Late-fall Winter
	Sep: Q_{min} > 8,500 cfs (minimize R/G misclassification)												Steelhead
Joint Timing	O	N	D	J	F	M	A	M	J	J	A	S	
				5								8.5	Q_{min} kcfs
													Q_{max} kcfs
Other Triggers	–												
Recurrence	2 out of 3 years												
Potential conflicts & trade-offs	Negatively correlated with juvenile rearing (CS2)												
References	USFWS (2006)												

Sacramento River		
Chinook & Steelhead		
Indicator	CS2	Rearing habitat (WUA)
Objective & Rationale	Rearing WUA is calculated using daily cohorts of juveniles after emergence, for each run-type at up to 5 river segments. Juvenile emergence is derived from daily average temperature applied to a temperature-driven egg-emergence function using the run-type's spawning calendar (see CS3). Chinook run-types remain in the system for 90 days following emergence; steelhead remain for one year. (SacEFT Design Document Section 4.3.1, pp.59-63.)	

Timing

O	N	D	J	F	M	A	M	J	J	A	S	
			■	■	■	■						Spring
						■	■	■	■			Fall
								■	■	■	■	Late-fall
■	■	■								■	■	Winter
■	■							■	■	■	■	Steelhead

Location	Sacramento River below Clear Creek (RM290)	
Variable & Condition	Jan: 3,500 < Q_{max}< 6,000 cfs (minimize R/G misclassification)	Spring
	No Q-rule defined	Fall
	Sep: 3,500 < Q_{max}< 9,000 cfs	Late-fall
	Sep: 3,500 < Q_{max}< 8,000 cfs	Winter
	Sep: 3,500 < Q_{max}< 9,700 cfs	Steelhead

Joint Timing

O	N	D	J	F	M	A	M	J	J	A	S	
			3.5								3.5	Q_{min} kcfs
			6								8	Q_{max} kcfs

Other Triggers	Daily time-scale recession
Recurrence	2 out of 3 years
Potential conflicts & trade-offs	Negatively correlated with juvenile stranding (CS4)
References	USFWS (2005b)

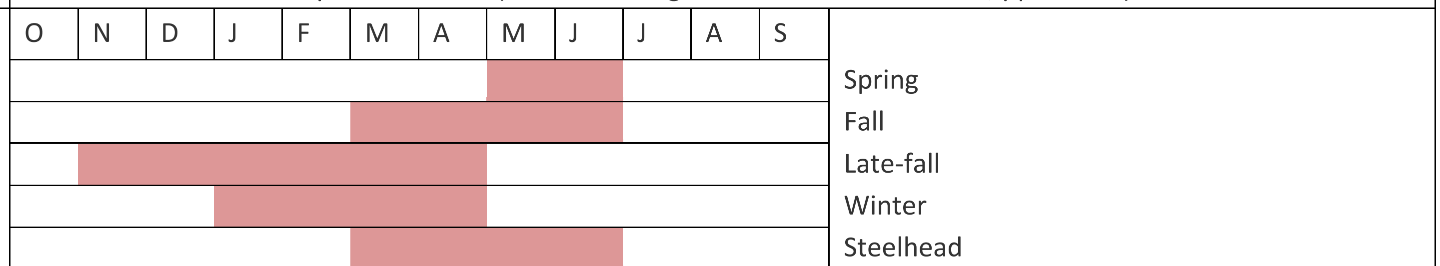
San Joaquin-Sacramento Delta		
Chinook & Steelhead		
Indicator	CS7	Juvenile rearing habitat (Yolo Bypass)
Objective & Rationale	During sustained high flow events, Yolo Bypass can provide a high quality environment for extended rearing and enhanced growth (Benigno and Sommer 2009, Sommer *et al.* 2001). These benefits become greater for juvenile Chinook and steelhead the longer they are able to take advantage of the productive food web available in the flooded Bypass. Besides additional food sources, the unique temperature and flow regime of the Bypass may confer additional benefits, such as additional time for growth, or a temperature environment that is closer to the optimum, compared to the mainstem. (DeltaEFT Design Document Section 2.2.1, pp. 40-54.)	
Timing	(see timing chart below)	
Location	Fremont Weir (FREMONT WEIR SPILL TO YOLO BYPASS NR VERONA CA, RSAC155, 11391021)	
Variable & Condition	Q_{avg} > 5,000 cfs spill for any continuous 30-day interval. *See **Additional Details** on next page*	
Joint Timing	(see joint timing chart below)	
Other Triggers	Sacramento River T_{avg} < 55 °F during spill period	
Recurrence	2 out of 3 years (Fleenor)	
Potential conflicts & trade-offs	Inversely correlated with Juvenile rearing habitat (CS7); should ***not*** attempt to concurrently achieve CS7 and CS9 flows in same year and same run-type. Inversely correlated with Chinook/Steelhead predation risk (CS9): increased Yolo flow typically reduces mainstem flow. With current Fremont weir elevation, flows required to accomplish this objective would cause mortality of nesting Bank Swallows (BASW2). Under some future climate change scenarios warm temperature can push juveniles above their physiological limit, and they may lose weight in Yolo. There may be bioenergetic trade-offs.	
References	Benigno and Sommer (2009), Sommer *et al.* (2001)	
Additional Details	Analysis of EFT results from Historical and NAA scenarios suggests a minimum flow of 13,000 cfs. However, based on the flow recommended by Fleenor (ref.), an even lower minimum flow of 5,000 cfs actually confers greater potential for growth by increasing residency time from about 26 to 33 days. There is a trade-off between the cost of providing water, the benefit to individual juveniles at 5,000 cfs and aggregate benefit to a larger portion of the year-cohort at higher flow.	

Timing

O	N	D	J	F	M	A	M	J	J	A	S	
							X	X				Spring
					X	X	X	X				Fall
	X	X	X	X	X	X						Late-fall
			X	X	X	X						Winter
					X	X	X	X				Steelhead

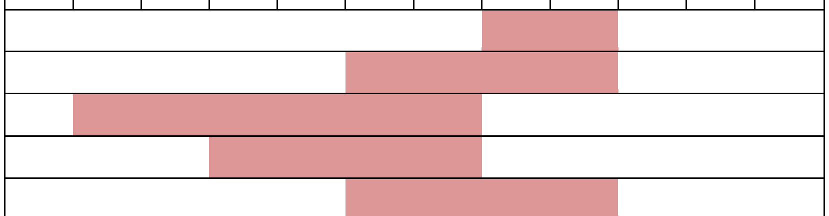
Joint Timing

O	N	D	J	F	M	A	M	J	J	A	S	
					5	5	5					Q_{min} kcfs
												Q_{max} kcfs

San Joaquin-Sacramento Delta		
Chinook & Steelhead		
Indicator	CS9	Predation Risk (mainstem)
Objective & Rationale	Juvenile salmonids migrating downstream they may experience mortality from bass. Juvenile passage time was selected as index to this predation risk. (DeltaEFT Design Document Section 2.2.1, pp. 54-60.)	
Timing		
Location	Hood (SACRAMENTO RIVER AT HOOD, RSAC142, 382205121311300)	
Variable & Condition	Q_{avg} > 11,000 cfs (between Q_{avg} R/Y)	Spring
	Q_{avg} > 17,000 cfs (between Q_{avg} R/Y)	Fall Late-fall Winter Steelhead
Joint Timing		
Other Triggers	Not in conflict with CS7 goal	
Recurrence	1 out of 3 years (based on non-conflict with 2-out-of-3-years CS7 goal)	
Potential conflicts & trade-offs	Inversely correlated with Juvenile rearing habitat (CS7); should ***not*** attempt to concurrently achieve CS7 and CS9 flows in same year and same run-type. DCC preferably closed to avoid exposure to interior Delta. Even if DCC open, mainstem velocity generally fast enough to result in fast transit times.	
References	Bartholow and Heasley (2006)	

Joint Timing:

O	N	D	J	F	M	A	M	J	J	A	S	
	17	17	17	17	17	17	17	17				Q_{min} kcfs
												Q_{max} kcfs

<table>
<tr><td colspan="14">San Joaquin-Sacramento Delta</td></tr>
<tr><td colspan="14">Chinook & Steelhead</td></tr>
<tr><td>Indicator</td><td colspan="2">CS10</td><td colspan="11">Thermal stress (eastern delta)</td></tr>
<tr><td>Objective & Rationale</td><td colspan="13">The approach quantifies the absolute value of the difference between daily temperature and the optimum-growth temperature at the peak of a dome-shape rate-of-gain function. Even though Delta water temperatures are largely driven by weather and this stress cannot currently be managed, future management actions could conceivably result in changes to location preferences which could reduce temperature stress. The indicator includes six routes through the eastern Delta. (DeltaEFT Design Document Section 2.2.1, pp. 61-70.)</td></tr>
<tr><td rowspan="2">Timing</td><td>O</td><td>N</td><td>D</td><td>J</td><td>F</td><td>M</td><td>A</td><td>M</td><td>J</td><td>J</td><td>A</td><td>S</td><td></td></tr>
<tr><td colspan="12"></td><td>Spring
Fall
Late-fall
Winter
Steelhead</td></tr>
<tr><td>Location</td><td colspan="13">Above Delta Cross Channel (SACRAMENTO R AB DELTA CROSS CHANNEL CA, RSAC128, 11447890)</td></tr>
<tr><td rowspan="5">Variable & Condition</td><td colspan="12">May: Q_{avg} > 7,000 cfs (between R/Y)</td><td>Spring</td></tr>
<tr><td colspan="12">Apr: Q_{avg} > 15,000 cfs (between R/Y)</td><td>Fall</td></tr>
<tr><td colspan="12">Mar: Qavg > 27,000 (between R/Y)</td><td>Late-fall</td></tr>
<tr><td colspan="12">Apr: Q_{avg} > 15,000 cfs (between R/Y)</td><td>Winter</td></tr>
<tr><td colspan="12"></td><td>Steelhead</td></tr>
<tr><td rowspan="3">Joint Timing</td><td>O</td><td>N</td><td>D</td><td>J</td><td>F</td><td>M</td><td>A</td><td>M</td><td>J</td><td>J</td><td>A</td><td>S</td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>27</td><td>15</td><td>7</td><td></td><td></td><td></td><td></td><td>Q_{min} kcfs</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>Q_{max} kcfs</td></tr>
<tr><td>Other Triggers</td><td colspan="13">Not in conflict with CS7 goal</td></tr>
<tr><td>Recurrence</td><td colspan="13">1 out of 3 years (based on non-conflict with 2-out-of-3-years CS7 goal)</td></tr>
<tr><td>Potential conflicts & trade-offs</td><td colspan="13">Inversely correlated with Juvenile rearing habitat (CS9); should not attempt to concurrently achieve CS7 and CS9 flows in same year and same run-type. DCC preferably closed to avoid exposure to interior Delta. Even if DCC open, mainstem velocity generally fast enough to result in fast transit times.</td></tr>
<tr><td>References</td><td colspan="13">Shelbourn et al. (1973), Perry et al. (2010)</td></tr>
</table>

San Joaquin-Sacramento Delta	
Splittail	
Indicator	SS1 — Spawning habitat extent (Yolo)
Objective & Rationale	Providing adequate spawning and rearing habitat is key to the long-term conservation of splittail (Moyle *et al.* 2004); consequently maintaining flow regimes that result in periodic inundation of riparian and floodplain habitat during winter and spring is important for splittail viability. When flooded, the majority of splittail spawning habitat is located in Yolo bypass, consequently inundation of the floodplain plays a large role in determining the extent of available spawning habitat. Inundation is defined as a depth of water <2m (Sommer *et al.* 2002). Total inundated area of the floodplain <2m deep is an index of the amount of shallow water spawning habitat. The proportion of spawners on a given day was estimated by fitting a normal distribution to spawn date data from Feyrer *et al.* (2006) using the year 1998. (DeltaEFT Design Document Section 2.2.3, pp. 100-105.)
Timing	O N D J F M A M J J A S (Feb 21)
Location	Fremont Weir (FREMONT WEIR SPILL TO YOLO BYPASS NR VERONA CA, RSAC155, 11391021)
Variable & Condition	$100 < Q_{avg} < 2000$ cfs for at least 75% of the period shown (approx. four weeks within this period)
Other Triggers	
Recurrence	4 out of 10 years
Potential conflicts & trade-offs	Notching Fremont Weir should provide habitat
References	Sommer *et al.* (2002), Feyrer *et al.* (2006)

San Joaquin-Sacramento Delta		
Delta Smelt		
Indicator	DS1	Index of spawning success
Objective & Rationale	Spring water temperature affects spawning success, and extended periods with cool water typically result in more spawning events and larger cohorts (Bennett 2005). A longer spawning period is made possible by an earlier spawning start date, which increases the probability of reaching spawning maturity in that year and of spawning multiple times in a single season. Adults spawn in freshwater during late winter and spring months, with the majority occurring from March – April (Moyle 2002). Peak occurrence of ripe females occurs at 12-16°C (Nobriga, pers. comm.), with highest hatch success at about 15°C. Delta smelt distribution is closely tied to the low salinity zone and tidal freshwater areas of the Delta, with over 90% occurring at < 6‰ (Bennett 2005) and salinities > 19‰ being lethal. (Design Document Section 2.2.2, pgs. 71-81.)	
Timing	O N D J F M A M J J A S	
Location	Suisun Bay at Mallard Island (RSAC075, MAL, 11185185)	
Water Year Types	≥ Normal WY	
Variable & Condition	$X2_{avg}$ is ≤ 74km	
Other Triggers	≥ Normal WY; 54°F< T_{avg}< 61°F.	
Recurrence	Every other year	
Potential conflicts & trade-offs	Requires high Delta outflow, which can impact reservoir storage and exports	
References	Bennett (2005)	

San Joaquin-Sacramento Delta		
Delta Smelt		
Indicator	DS2	Index of habitat suitability
Objective & Rationale	Habitat largely consists of open water away from shorelines and vegetated inshore areas, except during spawning (Delta Smelt BiOp 2008), including Suisun Bay and the deeper areas of many larger channels. However, habitat is most strongly determined by water quality (salinity, turbidity and temperature), with low salinity being a key variable (Bennett 2005). Therefore, freshwater flow into the estuary strongly influences Delta smelt habitat location and extent. Habitat extends from the tidal freshwater reaches of the Delta seaward to 19‰ salinity with water temperatures <25°C (Bennett 2005). In general, larger habitat volume is better because of reduced crowding and improved opportunities to avoid localized sources of mortality. Unger (1994) showed that the overall surface area of good habitat is maximized when X2 is located in Suisun Bay, although this relationship can be highly variable. (Moyle *et al.* 1992). (Design Document Section 2.2.2, pp. 81-89.)	
Timing	O N D J F M A M J J A S	
Location	Fall X2	
Variable & Condition	≥ Normal WYT: $X2_{avg} \leq 74$km < Normal WYT: $X2_{avg} \leq 81$km	
Other Triggers		
Recurrence	Annually (based on BiOp RPA)	
Potential conflicts & trade-offs	Requires high Delta outflows, which can impact reservoir storage and exports. Inversely correlated with ID1,ID3	
References	Feyrer *et al.* (2011), Moyle *et al.* (1992)	

DS4, Delta smelt entrainment

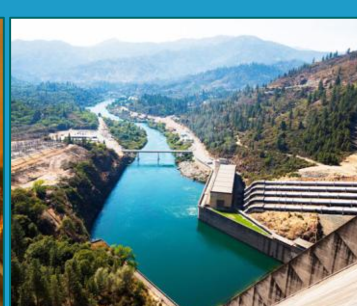
The goal of this action is to minimize entrainment through the management of negative flow in the Old and Middle River.

San Joaquin-Sacramento Delta		
Delta Smelt		
Indicator	DS4	Entrainment index
Objective & Rationale	The indicator simulates entrainment risk from the CVP and SWP export operations. Low flow years historically have higher incidences of entrainment than high flow years because fish are distributed closer to the points of diversion in low flow years, when a higher proportion of juveniles rear in the Delta (Moyle 1992; Sommer *et al.* 1997). The greatest entrainment risk from export operations is thought to occur during winter, but juveniles are also vulnerable; with peak of risk in May-June (Nobriga *et al.* 2001). The indicator is based on the results of a Particle Tracking Model (PTM) experiment (Kimmerer and Nobriga 2008), which simulates the fate of particles released in the Delta under a range of inflows and exports. In order to satisfy the PTM assumptions, the indicator applies only to the larval and juvenile life stages. (Design Document Section 2.2.2, pp. 89-100.)	
Timing	O N D J F M A M J J A S	
		Recommended
		Used in Pilot
Locations	Combined Old + Middle River (OLD R A BACON ISLAND CA, ROLD024, 11313405) + (MIDDLE R AT MIDDLE RIVER CA, RMID015, 11312676)	
Variable & Condition	≤ Normal WYT: Q_{avg} > –2,000cfs > Normal WYT: Q_{avg} > 0cfs	Recommended
	≤ Normal WYT: Q_{avg} > 2,000cfs > Normal WYT: Q_{avg} > 0cfs	Used in Pilot
Other Triggers	Juvenile smelt detected through trawls	
Recurrence	Annually	
Potential conflicts & trade-offs	May conflict with export objectives	
References	Kimmerer and Nobriga (2008)	

Final Report

Environmental & Cumulative Effects Assessment

Climate Change Adaptation & Risk Reduction



Aquatic Species at Risk & Water Resource Management

Terrestrial Ecology & Forest Resource Management