The Delta Ecological Flows Tool: Record of Design (v.1.1)

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Prepared for

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Executive Summary

> *"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)*

The Ecological Flows Tool (EFT) is a decision support system that demonstrates how changes in flow management (and other actions) result in changes to the physical habitats for multiple species within the Sacramento River and the San Francisco Delta. This document provides the as-built Record of Design for the focal species and habitat indicators developed for version 1 of the Delta Ecological Flows Tool (DeltaEFT) branch of EFT. The Record of Design for the Sacramento Ecological Flows Tool (SacEFT) version 2 branch of EFT is documented separately (see: ESSA 2011a). Between 2004 and 2008 The Nature Conservancy (TNC) conducted the Sacramento River Ecological Flows Study in which TNC and its project partners developed a decision analysis tool that incorporates physical models of the Sacramento River with biophysical habitat models for six Sacramento River species. The resultant tool, SacEFT, links flow management actions to focal species outcomes on the mainstem Sacramento River (see ESSA 2011a for details). Building on the success of SacEFT, this software architecture was extended starting in 2008 to include a range of Delta specific ecological indicators and management actions through construction of version 1 of the DeltaEFT branch of the software. Version 1 of DeltaEFT, the subject of this document, was completed in September 2012. Importantly, completion of DeltaEFT now provides the ability to explicitly link upstream (Sacramento River) ecological responses evaluated with SacEFT to ecosystem responses in the Delta evaluated with DeltaEFT. "SacEFT" and "DeltaEFT" are collectively referred to as "EFT".

EFT works by integrating a range of representative functional ecological response indicators with key physical variables obtained from widely used hydrologic models (*e.g.*, CalSim, DSM2, USRDOM). EFT more transparently relates multiple attributes of the flow regime to multiple species' life history needs, contributing to an effective understanding of flow and non-flow (gravel augmentation, rip-rap removal, levee set-back) restoration actions on *multiple* focal species and their habitats. The hallmark of the EFT approach is integration and clear communication of ecological trade-offs associated with different water operation alternatives. This capability has been illustrated in recent applications of EFT to EIS/R investigations for North of Delta Off-stream Storage (NODOS; TNC and ESSA 2011) and the Bay Delta Conservation Plan (BDCP; ESSA 2011b and see BDCP Plan documents[1]).

EFT is structured as an 'ecological plug-in' to existing physical models that are commonly used for water planning in the Central Valley. Rather than reinventing models, EFT utilizes output data sets from daily disaggregations of CalSim, DSM2 and other models that are used to investigate water delivery and other standards set for the CVP and SWP water system. EFT utilizes these data and adds ecological calculations (algorithms) to evaluate effects of water re-operation and conveyance and storage project changes on multiple ecosystem targets.

Extensive scientific understanding of the Sacramento River and Delta ecosystem's likely response to changes in flow management has been developed over the past twenty years. Development of DeltaEFT

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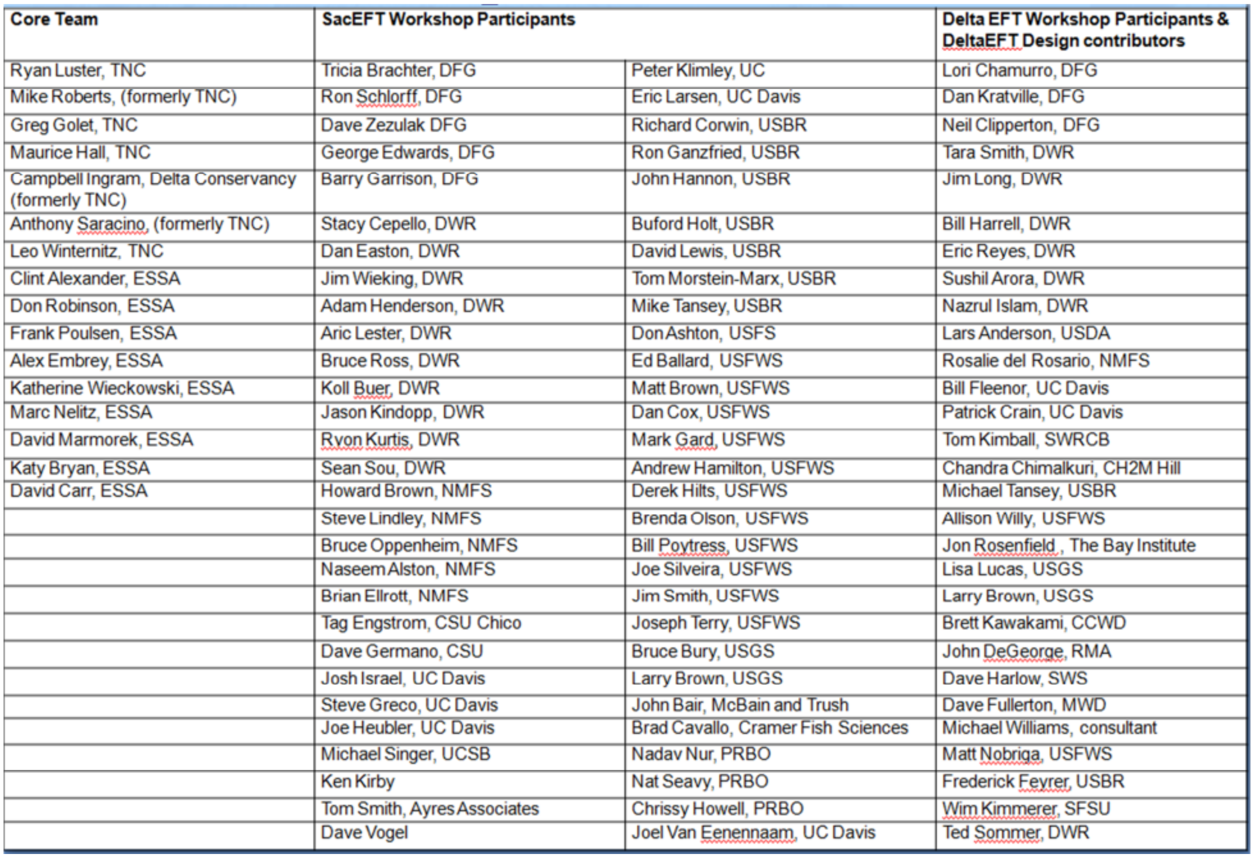
[1] http://baydeltaconservationplan.com/Library/DocumentsLandingPage/BDCPPlanDocuments.aspx (last accessed November 2012).

and SacEFT was not conducted in a vacuum that ignored this evolution in scientific understanding. The functional relationships and indicators that are encapsulated into the decision support tool reflect the collective thoughts of **more than seventy (70) scientists** from state and federal agencies, consulting firms, and academic research institutions. These experts either participated in our workshops, wrote primary papers on which the relationships are based, or were individually consulted during design and development of EFT. Prior to EFT, much of this important information existed in a multitude of separate reports, independent conceptual models, and unconnected modeling tools. EFT has helped to synthesize a wide range of disparate information, linking ecological submodels to existing physical planning models, to provide a major advance in the region's capabilities for assessing ecological tradeoffs. Furthermore, the EFT framework has been developed so that it is relatively easy to "swap in" (or remove) indicators as the state of scientific knowledge evolves. We are very grateful for the strong collaborative relationships we were able to form during the development of EFT (including experts working in the domains of hydrology, hydrodynamics, aquatic ecology, wetland and riparian ecology, fish sciences, fluvial geomorphology and sediment transport), which were essential for the successes achieved to date.



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In addition to integrating disparate sources of information, a challenge overcome by EFT's design is translating information into easily understandable results for water operation managers. Practical synthesis and integration is challenging when considering multiple ecological targets, complex physical models, and multiple audiences (*i.e.*, high level managers as well as technical level staff). In keeping with a core design principle of making it easy for non-specialists to understand the model's results, EFT creates output that can span the range from high-overview to daily and location specific detail. The output interface makes extensive use of a "traffic light" paradigm that juxtaposes performance measure (PM) results and scenarios to provide an intuitive overview of whether a given year's PMs are healthy (**green**), of some concern (**yellow**), or of serious concern/poor (**red**).

EFT contributes to a more comprehensive understanding of how proposed changes to water operations infrastructure and management (and future climate conditions) effect target species and 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. As illustrated in this Record of Design, DeltaEFT's output interface, reports and data visualizations make it clear how actions implemented for the benefit of one area or focal species may affect (both positive and negative) another area or focal species. For example, we can show how altering Sacramento River flows to meet export pumping schedules in the Delta affects focal species' performance measures both in the Sacramento River and the Delta.

The tool is also useful for developing functional ecological flow guidelines. Because of the multi-species approach, EFT helps communicate how to prioritize and trade-off amongst ecological objectives and adjust these priorities based on emerging conditions (*e.g.*, water year types) and the ability to realize different objectives over time. One of the biggest challenges in the practical development of ecological flow regime guidelines is the wide range of objectives, focal species and habitat types that need to be considered. EFT has brought into focus how these various objectives cannot all be simultaneously met. In nature, conditions often benefit one target or species to the potential detriment of another in any given year. Fortunately, flow characteristics that benefit the various ecological targets investigated are usually required on a periodic basis and not every single year. EFT studies simplify communication of these trade-offs, and catalyze definition of state-dependent management practices that promote the development of needed flexibility in the water management system.

Ecological effects analyses informed by EFT have the following strengths:

1. **More representative**: multiple focal species & habitats.
2. **Rapid scenario comparison**: trade-offs in one framework.
3. **Eco-regions linked: Sacramento & Delta.**
4. Broad **synthesis of science & advice** of experts.
5. Ability to **evaluate multiple actions** (gravel, channel migration, floodplain activation, conveyance, operations) and deliver **functional flow guidelines**.
6. **Intuitive outputs simplify communication**.
7. **Speed / agility** – EFT effects analyses can be run in "days" and "weeks" (rather than months/years).
8. **Plug-in** to any hydrodynamic / water quality model.
9. **Extensible**. Improve/add performance indicators as science evolves. Design anticipates being refined over time.
10. **"Goldilocks" level of detail.** Less data hungry (and assumption laden) as detailed single species life-cycle models.

EFT Reader software is publically available and free to download at: http://essa.com/tools/eft/download. The EFT Reader links with a centralized copy of the EFT database located on a remote server. The public EFT Reader database currently contains a suite of fully configured scenarios, derived from the Sacramento River Ecological Flows Study and from test scenarios supplied by DWR and project partners. Future versions of the EFT Reader database will include results for simulations based on other effects analysis investigations, as they move into the public domain.

An on-line users guide describing the features of the EFT graphical user interface can be found here: http://eft-userguide.essa.com/.

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Glossary

AIC	Akaike information criterion.
BDCP	Bay Delta Conservation Plan.
BiOp	Biological Opinion.
BOD	Biological oxygen demand.
CALFED	CALFED Bay-Delta Program (program as originally conceived retired ~2010). In August of 2000, the CALFED Record of Decision and an accompanying memorandum of understanding executed by the then 13 state and federal implementing agencies was finalized. The program has now transitioned from the CALFED Bay-Delta Program to the Delta Stewardship council (which includes a narrower mandate, focused on the San Francisco Bay Delta).
CalSimII	CalSim is a generalized water resources simulation model for evaluating operational alternatives of large, complex river basins. See: http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSimII/
CALVIN	University of California Davis Statewide Economic-Engineering Water Model. See: http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/
CDEC	California Data Exchange Center. See: http://cdec.water.ca.gov/
CDFG	California Department of Fish and Game.
CEQA	California Environmental Quality Act.
COA	Coordinated Operation Agreement.
CVP	Central Valley Project.
DCC	Delta Cross Channel.
DeltaEFT	Delta Ecological Flows Tool (an eco-region branch of the larger Ecological Flows Tool). DeltaEFT, SacEFT and EFT are all functionally the same software product.
DEM	Digital Elevation Model
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DRERIP	The Delta Regional Ecosystem Restoration Implementation Plan
DSM2	Delta Simulation Model 2. A one-dimensional hydrodynamic model developed by DWR.
DSS	Proprietary, binary file format used to manage large time series datasets in a number of US Army Corp of Engineers modeling tools (*e.g.*, HEC-RAS), including CalSim, DSM2.
DWR	(California) Department of Water Resources.
EC	Electroconductivity, a measure of water salinity.
EHW	Extreme high water.
EFT	The Ecological Flows Tool (which at the time of writing consists of SacEFT and DeltaEFT).
E:I	San Francisco Delta Export (at southern pumping facilities): Import (natural freshwater inflow from Sacramento River and east-side tributaries) ratio
EIS/ EIR	Environmental Impact Statement (EIS) is required for certain types of projects and activities under NEPA (National Environmental Policy Act). An Environmental Impact Report (EIR) is required for certain types of projects and activities under CEQA (The California Environmental Quality Act).
ERP	Ecosystem Restoration Program
FMWT	Fall Midwater Trawl. See: http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT
HEC	Hydrologic Engineering Center. See: http://www.hec.usace.army.mil/
HEC-EFM	Hydrologic Engineering Centers Ecosystems Functions Model. See: http://www.hec.usace.army.mil/software/hec-efm/index.html
HEC-RAS	Hydrologic Engineering Centers River Analysis System. See: http://www.hec.usace.army.mil/software/hec-ras/
IHA	Indicators of Hydrologic Alteration. See:

	www.conservationgateway.org/ConservationPractices/Freshwater/EnvironmentalFlows/MethodsandTools/IndicatorsofHydrologicAlteration/Pages/indicators-hydrologic-alt.aspx
IOS	Interactive Object-Oriented Simulation Model for winter run chinook salmon. See: http://www.fishsciences.net/projects/ios.php
LiDAR	Light detection and ranging.
LOM	Looking Outward Matrix.
MTL	Mean tide level.
NEPA	National Environmental Policy Act.
OCAP	Operational Criteria and Plan
OMR	Old- and Middle River area of San Francisco Delta.
PM	Performance Measures
POD	Pelagic Organism Decline
PTM	Particle Tracking Model.
PPIC	Public Policy Institute of California
PTM	(Ref DSM2) Particle Tracking Model
QUAL	(Ref DSM2) Simulation of temp, EC, DO, DOC
RM	River Mile
RMA	Resource Management Associates, often used synonymously to refer to this companies numerical model representing the Bay-Delta system from its tidal boundary seaward of the Golden Gate to the limits of tidal influence on the Sacramento and San Joaquin rivers.
RPA	Reasonable and Prudent Alternatives
RYG	EFT uses “Red” – “Yellow” – “Green” summary rollup ratings for annual performance for each focal species/habitat performance indicator. Red = poor: Yellow = fair: Green = good.
SacEFT	Sacramento River Ecological Flows Tool (an eco-region branch of the larger Ecological Flows Tool). DeltaEFT, SacEFT and EFT are all functionally the same software product.
SALMOD	Salmonid Population Model. See: http://www.fort.usgs.gov/products/Publications/pub_abstract.asp?PubID=4046
SRWQM	The Upper Sacramento River Water Quality Model. (Also referred to as USRWQM).
SWP	State Water Project.
SWRCB	State Water Resource Control Board. See: http://www.swrcb.ca.gov/
TMS	Temperature Modeling System.
TNC	The Nature Conservancy.
TUGS	The Unified Gravel-Sand sediment transport model.
UNTRIM	The UnTRIM San Francisco Bay-Delta model (UnTRIM Bay-Delta model) is a three-dimensional hydrodynamic model of San Francisco Bay and the Sacramento-San Joaquin Delta. See: http://www.deltamodeling.com/untrimbaydeltamodel.html
USBR	US Bureau of Reclamation.
USRDOM	US Reclamation Daily Operations Model.
X2	Distance (in kms) up the axis of the estuary from the Golden Gate Bridge to where the tidally averaged bottom salinity is 2%.

1. DeltaEFT Synopsis

This document describes the final as-built design of the Delta Ecological Flows Tool (DeltaEFT) **version 1**, a decision support project led by The Nature Conservancy, with technical execution from ESSA Technologies, to model the effects of water management actions on a suite of ecological indicators in California's San Francisco Delta region. This multi-year project has resulted in an integrated cross-disciplinary tool to characterize ecological trade-offs that result from the implementation of alternative water management programs (*e.g.*, new proposed conveyance infrastructure, changes to Sacramento River operations, Delta export pumping levels). Our approach builds upon extensive work already completed in the creation of the Sacramento River Ecological Flows Tool (SacEFT; ESSA 2011a and see: www.dfg.ca.gov/ERP/signature_sacriverecoflows.asp). Building on our Sacramento River ecological flow study efforts to incorporate Delta targets and management actions: 1) better unites ecological water operations planning by allowing for inter- and intra-regional ecological trade-off evaluations within and between the Sacramento and Delta systems; 2) takes advantage of previously awarded CALFED ERP funds; and 3) achieves economies of scale by applying the same approach successfully completed in developing SacEFT.

DeltaEFT's paradigm takes a bottom-up, process-based view of how flow and related aquatic habitat variables are tied to key species life-stages and ecosystem functions. The DeltaEFT framework is designed to take into account new scientific knowledge and lines of reasoning (mainly from process-based research) over time. Our multi-species, multi-indicator paradigm provides a "portfolio" approach for assessing how different flow, habitat restoration and Delta configuration combinations suit the different life stages of desired species (and inhibit invasive species). We use detailed reviews of peer reviewed literature, expert workshops and reviews of our submodels to identify key ecosystem function indicators. Considerable effort has been made to ensure that these design steps were insulated from political influences.

Construction of DeltaEFT has leveraged a substantial body of scientific research. This research was elicited starting in 2008 when we began a comprehensive background literature search that included review of thematically related efforts, such as the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP), Pelagic Organism decline (POD) research, the Delta Solutions Program led by UC Davis, State Water Resource Control Board (SWRCB) Delta Flow Criteria workshops and related submissions, and the Bay Delta Conservation Plan (BDCP). Having reviewed these and related bodies of research, our team prepared a Backgrounder report outlining candidate features, submodels and indicators of the Delta Ecological Flows Tool (ESSA 2008b). This Backgrounder was provided to participants prior to the DeltaEFT design workshop in January 2009.

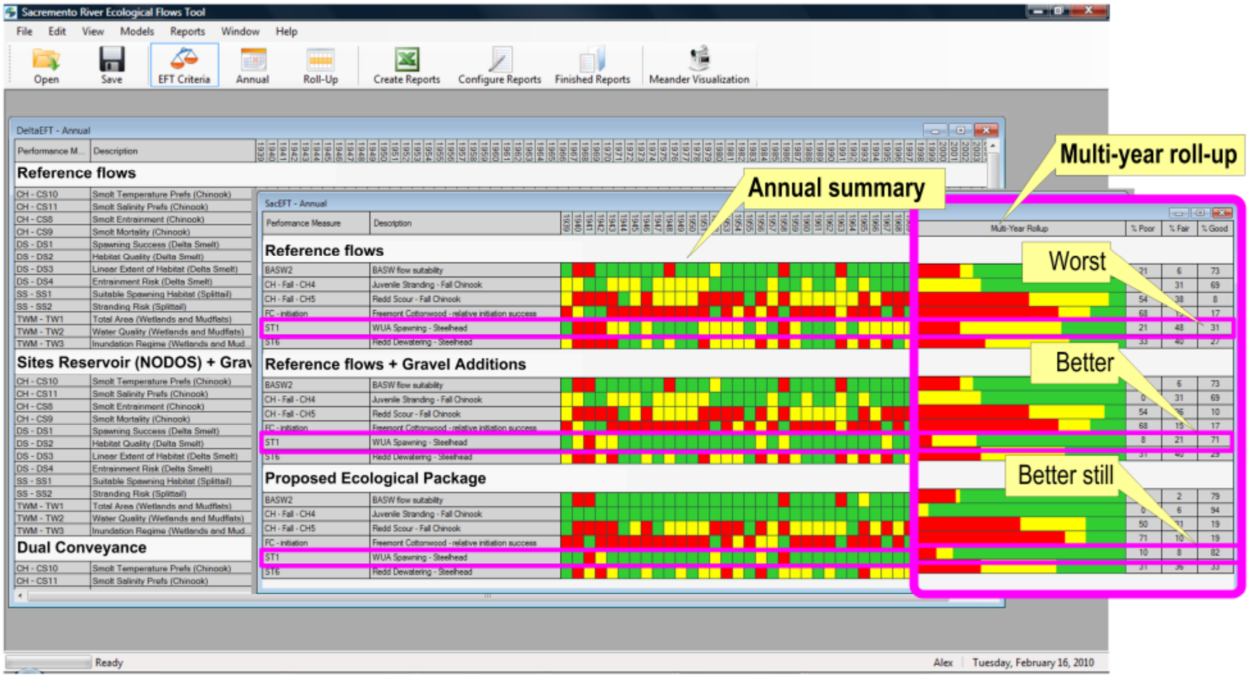
On January 27 and 28 2009, ESSA Technologies Ltd., in partnership with The Nature Conservancy, held a model Design Workshop to evaluate a preliminary conceptual design of DeltaEFT. About 3 dozen scientists and other technical experts, each having expertise with one of the focal species or physical submodels in the Delta were invited to attend the workshop to discuss and *prioritize* aspects of these submodels. A Backgrounder on the DeltaEFT tool was provided to workshop participants which described the candidate submodels that would be evaluated at the workshop (ESSA 2008b). The 2-day DeltaEFT Model Design Workshop objectives were structured to elicit the essential information needed to:

1. window in on the priority candidate focal habitats and species indicators, and their functional relationships;

2. develop a common understanding of the key relationships between Delta inflow, hydrodynamics, salinity, stage and water temperature on habitat requirements for these in-Delta focal habitat and species indicators;
3. consult with technical experts on potential submodel components and their integration across submodels, looking for mutual synergies across thematically related research efforts;
4. further define the candidate management scenarios to apply in DeltaEFT (an iterative exercise);
5. narrow the geographic scope to be considered, by identifying representative geographical index locations within the Delta for the candidate model performance indicators, and determine the ability of physical driving models to supply necessary outputs at these locations; and
6. decide on next steps for refining components and their integration (who, what, when).

Conceptual models were developed and presented during our Design Workshop, and specific impact pathways and algorithms developed for inclusion in DeltaEFT. Workshop participants met in plenary to review the project background, learn about the intended scope and use of the model, and consider 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 and outcome was to identify a small subset of priority performance measures per focal species to integrate into DeltaEFT.

Following the January 2009 Design Workshop for the Delta Ecological Flows Tool (DeltaEFT), ESSA Technologies prepared a draft summary of the workshop which reflected our study of relevant background material prior to the workshop combined with a synthesis of the workshop plenary and subgroup discussions. The project was subsequently put on hold December 23 2009 as a result of the California financial meltdown, and was restarted October 2009. With the focus provided by the January 2009 Design Workshop, our team continued to review evolving research and continued to work to further prioritize, quantify and strengthen important linkages amongst important physical variables, models and selected focal habitats and species. We implemented model algorithms for the representative performance measures for selected key species (not just listed fish), including habitat measures that serve as proxies for species of concern. DeltaEFT database and software development then proceeded in earnest between 2011 - 2012 (a large fraction of our teams effort in 2010 was spent refining SacEFT version 1, culminating in the completion of SacEFT version 2). **Describing these DeltaEFT focal habitat and species indicators (and their assumptions) is the focus of this document.**



Practical synthesis and integration is challenging when considering multiple ecological targets, complex physical models, and multiple audiences (*i.e.*, high level managers as well as technical level staff). In keeping with a core design principle of making it easy for non-specialists to understand the model's results, EFT creates output that can span the range from high-overview to daily and location specific detail. DeltaEFT uses proven interfaces and design principles from the SacEFT to effectively communicate results. The output interface makes extensive use of a "traffic light" paradigm that juxtaposes performance measure (PM) results and scenarios to provide an intuitive overview of whether a given year's PMs are healthy (**green**), of some concern (**yellow**), or of serious concern/poor (**red**). EFT's output interface and reports for trade-off analyses make it clear how actions implemented for the benefit of one area or focal species may have both positive and negative consequences for other areas and/or focal species.

There have been *many* challenges to address in the development of a scientifically credible decision support tool of this scale. Under the sustained leadership of TNC beginning in 2002, the EFT project team has emphasized close collaboration across disciplines and periodic peer review to refine EFT and build-in new science. This collaboration, sustained funding, and our acknowledgement of the need to adaptively update EFT over time has been critical to the success of this effort. We have and continue to work to identify mutual opportunities and synergies, work to complement ongoing modeling and research, and to capitalize on past research investments (including SacEFT). Likewise, we have and will continue to work actively to establish close ties with investigators participating in Delta solutions research, and other Delta-centered research efforts. We continue to welcome feedback that enhances the credibility of this effort.

1.1 Vision - What is DeltaEFT for?

The vision for EFT is to link physical models to a representative sampling of *multiple* ecosystem components in a cross-disciplinary synthesis tool for evaluating *multiple* ecosystem trade-offs of different conveyance and water operation alternatives both in the Delta and Sacramento River. Our goal with this work is to facilitate the inclusion of a broader suite of ecological considerations into water-planning exercises and to catalyze clearer communication of new ecological flow targets and guidelines, and remove obstacles to routinely taking these targets into account during assessment of conveyance and water (re-)operation investigations. We choose representative ecological indicators that capture the *essence* of existing scientific understanding. We believe we have approximated a "Goldilocks" level of detail in EFT. While some EFT indicators can be quite sophisticated and others relatively simplistic, generally, we have worked hard to balance credibility and level of detail. This was a conscious design decision in order to avoid detailed data hungry single-species focused models that while comprehensive in their representation of life-history processes, sometimes suffer from a statistical challenge just as problematic as claims of model over-simplification — *equifinality* [2].

1.1.1 How is DeltaEFT used?

DeltaEFT is intended to provide an integration framework that leverages existing tools focused on the human need aspects of water deliveries in northern California by taking outputs from external physical models as inputs (*e.g.*, CalSim II, DSM2, HEC-RAS, USRDOM). DeltaEFT users are able to download the model from the internet (http://essa.com/tools/eft/download), and immediately work with pre-defined scenarios built upon these widely accepted physical planning models. In water gaming environments, DeltaEFT will combine outputs generated by existing water planning models (like DSM2) with others to illuminate the anticipated ecological tradeoffs. DeltaEFT users are able to quickly review the assumptions embedded in its physical submodels and ensure these components are *sufficiently* consistent with one another.

For new scenarios, a qualified DeltaEFT database administrator is required to import external datasets that have been verified for compatibility, which are then run through DeltaEFT's ecological submodels to give immediate feedback on ecological performance and tradeoffs. The efficiency of EFT gaming exercises depends on how quickly external physical submodels can be configured and run, and their results delivered to the DeltaEFT administrator. **We have found that the primary velocity limit is sharing of physical hydrosystem modelling products**, which typically owes to confidentiality and non-disclosure arrangements that deter open data exchange[3].

Once external datasets are provided (the hard part), imported and configured, and DeltaEFT focal species submodels run, DeltaEFT trade-off analysis are nearly instantaneous[4].

An on-line users guide describing the features of the EFT graphical user interface can be found here: http://eft-userguide.essa.com/.

1.1.2 Need for integrating ecological issues

Many water planning efforts to balance demands on the mainstem of the Sacramento River and Delta do not explicitly account for enough critical ecosystem components. Current attention focuses primarily on maintaining minimum in-stream flow (including export pumping restrictions based on I:E ratios), temperature and salinity (X2) requirements at a limited number of locations to support listed endangered fish species, and Delta Cross Channel Gate operations. Incorporating additional attributes of the flow regime, and the manner in which they maintain the ecological function of the Sacramento River and Delta

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[2] It is endemic to mechanistic modelling 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 behaviour 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 numeric *detail*. This is a significant concern when different (equally plausible) parameter sets produce *different* future trajectories.

[3] Even though as a taxpayer, one may have already paid for it, rendering it technically public domain. The development of consistent rules for reporting provenance and data citation (including proper citation of draft material) have been confused with a need to lock data down. This kind of approach violates open sharing and comes at the expense of improved frontiers of discovery and progress. (Search "Linked Data" "Open Data" TED talks by visionaries Tim Berners-Lee* and Hans Rosling). *"[You do your bit, share your data so it can be linked up, allowing others to do theirs. When you connect data together, let it out of your clutches, encourage re-use, we get power that can't happen when data is left locked in silos.]"

[4] When data is supplied in a format that matches the provided EFT data specification, a new DeltaEFT scenario can be imported, configured, run and analyzed in a week or two. A 66 year daily DeltaEFT model run can be completed in a few hours.

result in more effective ecosystem water management and restoration strategies. An important first step is to develop a more complete understanding of multiple species' requirements, so as to identify the critical attributes of the flow regime (and related water quality characteristics) necessary to maintain ecosystem function. We note that identifying and working to improve "critical attributes" is not to be confused with an attempt to "naturalize" Delta inflows from the Sacramento River and Delta hydrodynamics.

There has also grown a vast disparity in the number of (continuously funded) tools for evaluating ecological consequences relative to assessing physical factors. Tools *like* CalSim, USRDOM, CALVIN, HEC, DSM2, RMA, UNTRIM not to mention numerous water temperature models will have received orders of magnitude more funding than for tools *like* EFT, HEC-EFM, IHA, SAM, SALMOD or IOS and other life-cycle model descendants. The force of analysis dominance on out of stream beneficial uses explains this disparity. While considerable attention in recent years has been paid to ecological needs in the Delta, this research has been isolated and siloed amongst different investigators and institutions and rarely translated into agile decision support tools that can be easily applied by water resource managers. We agree both with past CALFED Science Panels as well as more recent Delta Flow Criteria panels convened by the SWRCB on the practical need to better integrate ecological requirements into a single framework that does a better job of communicating ecological needs.

1.2 Scope and Bounding

1.2.1 Summary of ecological objectives and performance measures

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. The EFT study team recognized that it is unrealistic to eliminate large-scale confounding influences that surround flow-related modeling in the Delta: *e.g.*, changing oceanographic conditions, changes in food web structure, seismic threats, progression of invasive species regimes or to account for potential release of contaminants from newly restored wetlands. To avoid paralysis there was a practical need to constrain our modeling efforts to a domain well inside the universe of "all things that might matter". Details on the formal focal habitat/species filtering and screening criteria (vetting process) used for DeltaEFT are provided in **Appendix A.**

On January 27 and 28 2009, The Nature Conservancy and ESSA Technologies Ltd. held a model Design Workshop to evaluate a preliminary conceptual design of the Delta Ecological Flows Tool (DeltaEFT). Workshop participants met in plenary to review the project background, learn about the intended scope and use of the model, and consider 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 measures per focal species to integrate into DeltaEFT.

Complex decisions and associated trade-offs are easier when structured using formal approaches to evaluate management alternatives. **Ecological objectives** are statements describing the desired condition or state of the system that decision makers want to achieve. Clear objectives are needed to evaluate **alternative management scenarios** and help distinguish which among them is the best alternative. The purpose of DeltaEFT is to evaluate management alternatives on the basis of *fundamental objectives*: what do managers want to achieve? – not *means objectives*: how do decision makers plan to achieve it? With the list of fundamental objectives in mind, we then attribute consequences caused by various alternative actions through representative **performance measures** (PMs) (or if you prefer "indicators" or "targets").

DeltaEFT's priority objectives and performance indicators are discussed in detail later in this document and summarized below in Table 1.1.

Table 1.1: Ecological objectives and performance measures for DeltaEFT version 1.

Focal Species	Ecological Objectives	Performance Measures
Chinook salmon & steelhead trout	Promote smolt weight gain by providing enhanced rearing in Yolo Bypass	CS7 –weight gain, especially in Yolo Bypass (% weight change)
	Reduce non-entrainment mortality through flow management in Bay-Delta	CS9 – smolt mortality exposure (days)
	Provide preferred temperature range for resident smolts	CS10 – smolt temperature stress (absolute degree-days)
Delta smelt	Provide cold water spawning habitat	DS1 – temperature index
	Provide appropriate adult abiotic environment	DS2 – Index of habitat suitability
	Reduce entrainment risk through effect of flow on X2 location	DS4 – entrainment risk (index)
Splittail	Provide extensive period for spawning	SS1 – extent of spawning (days)
Freshwater and brackish tidal wetlands	Provide productive habitat for ecosystem	TW1 – Tidal wetland area brackish
	Provide appropriate abiotic environment	TW2 – Tidal wetland area freshwater
Invasive species deterrence	Suppress invasive aquatic vegetation	ID1 – Brazilian waterweed suppression
	Suppress invasive clams	ID2,3 – invasive clam larvae and recruit suppression

Relationships between physical datasets, submodels and focal species PMs are summarized in Table 1.2.

Table 1.2: Physical data types necessary for each focal species or focal habitat performance in DeltaEFT. **T** = Tidally filtered daily discharge (flow); **D** = Daily average; **H** = Hourly. The physical datasets indicated in this table span all the PMs for each focal species and habitat. Requirements for individual PMs can be found in Section 2.2.

Focal Species and Performance Measures		Physical Datasets											
		Flow			Stage			Temperature			Salinity		
		T	D	H	T	D	H	T	D	H	T	D	H
Invasive species deterrence													
ID1	Brazilian waterweed suppression											●	
ID2	Overbite clam suppression											●	
ID3	Asiatic clam suppression											●	
Chinook & Steelhead													
CS7	Smolt Development & Growth		●						●				
CS9	Smolt predation risk	●[1]	●[1]										
CS10	Smolt Thermal Stress	●[1]	●[1]						●				
Delta smelt													
DS1	Index of spawning success								●			●	
DS2	Index of habitat suitability											●	
DS4	Index of risk of entrainment		●										
Splittail													
SS1	Spawning habitat extent		●										
Tidal wetlands													
TW1	Tidal wetland area brackish						●[2]						
TW2	Tidal Wetland Area Freshwater						●[2]						

[1] Hourly data (instantaneous top of hour values) are tidally filtered at stations where tidal effects exist (< ~3m elevation of mean sea level); otherwise non-filtered.

[2] Top of hour values are used.

Out of scope considerations

While the Delta is a continuum of habitats, we can also legitimately isolate portions of it for simulation modeling (Healey *et al.* 2008). As shown in Appendix A, we have adopted a vetting procedure designed to help us scope and keep our effort focused on critical flow-modulated indicators. This does not mean we are ignorant of the reality that trends in population abundance (*e.g.*, such as POD species) are often due to multiple causes. Instead, we are focused in the DeltaEFT effort on flow-related linkages that are believed to be the most scientifically credible in helping reverse undesirable trends, stabilize and restore conditions that support resilience and recovery. For example, estuarine-dependent species abundance has been shown to increase with lower values of X2 (*i.e.*, higher freshwater inflows to the Delta) (Kimmerer 2002), but the strength of this relationship changed after invasive benthic clams became dominant. Despite ever evolving shifts in nutrient and food web dynamics, freshwater inflow and export pumping management – all else equal – remain *one* important tool manager's can work with to lessen cumulative pressures on desired species. Excluding indicators because a species might have some potential or unknown ability to (periodically) overcome losses through compensatory dynamics in other phases of its life-cycle while convenient, only delays plausible steps that support a species resilience and recovery.

Given our focus, the following considerations are out of scope for the DeltaEFT version 1 effort:

- *Full population level consequences*: We intentionally avoid attempts to model all life-history phases, density dependent interactions, growth, explicit life-history movement of cohorts or individuals, ocean conditions, competition and predation, and detailed multi-species physio-chemical food web dynamics. Attempting to model the entire ecosystem and its physical drivers would lead to excessive complexity, eroding communications with managers, and defeat this project's goals. Also significant, the data required to calibrate and initialize these models are not available future gaming scenarios, which sometimes limits detailed applications to historic datasets. Other single species life-cycle models are becoming available to attempt to understand detailed life-stage survival and production associated with different management strategies (noting our warnings related to equifinality).
- *Fate and effects of toxic contaminant mixtures*: Water quality in the Delta is impaired due to chemical mixtures resulting from agriculture, industry, historic gold mining activities, sewage run-off, shipping, automobiles and urban storm water run-off. However, the sources, fates and ecological consequences of these toxic mixtures are poorly understood and at the forefront of active research. Due to our focus we do not include toxics in DeltaEFT version 1.
- *Propagation of uncertainty from linked sets of models*: Accounting for process uncertainty is a very important issue in any modeling exercise. However, due to the scale of work involved with linking models and developing representative indicators, and the size of the datasets involved (gigabytes per scenario), we expect to be limited to a sensitivity analysis approach, rather than more comprehensive techniques (*e.g.*, Monte Carlo, neural network or Bayesian methods).
- *Consequences of a major seismic event*: A major earthquake in the San Francisco region would have devastating effects on the integrity of some of the levees in the Delta. DeltaEFT does not address the most appropriate emergency response measures that would need to be taken in the face of a major seismic event.

1.2.2 Water management alternatives addressed by DeltaEFT

The primary emphasis of DeltaEFT is to provide ecological trade-off information and recommend ecological flow criteria for alternative water storage, conveyance and operation alternatives. The January 2009 DeltaEFT physical subgroup identified a **"4 box" conceptual framework** for communicating DeltaEFT scenarios (Figure 1.1). The conceptual framework is made up of 1) external climate forcing (historical or future) and human population demands 2) Sacramento River operations 3) Delta conveyance (*e.g.,* Fremont weir, new proposed conveyance pipes), cross channel gates and pumping operations and 4) operational criteria for the Sacramento River and Delta (*e.g.,* D1641 with other Biological Opinions or priority rule sets). Each of these boxes in effect can contain multiple "levers" that can be changed, any of which can impact conditions in the Sacramento River and Delta.

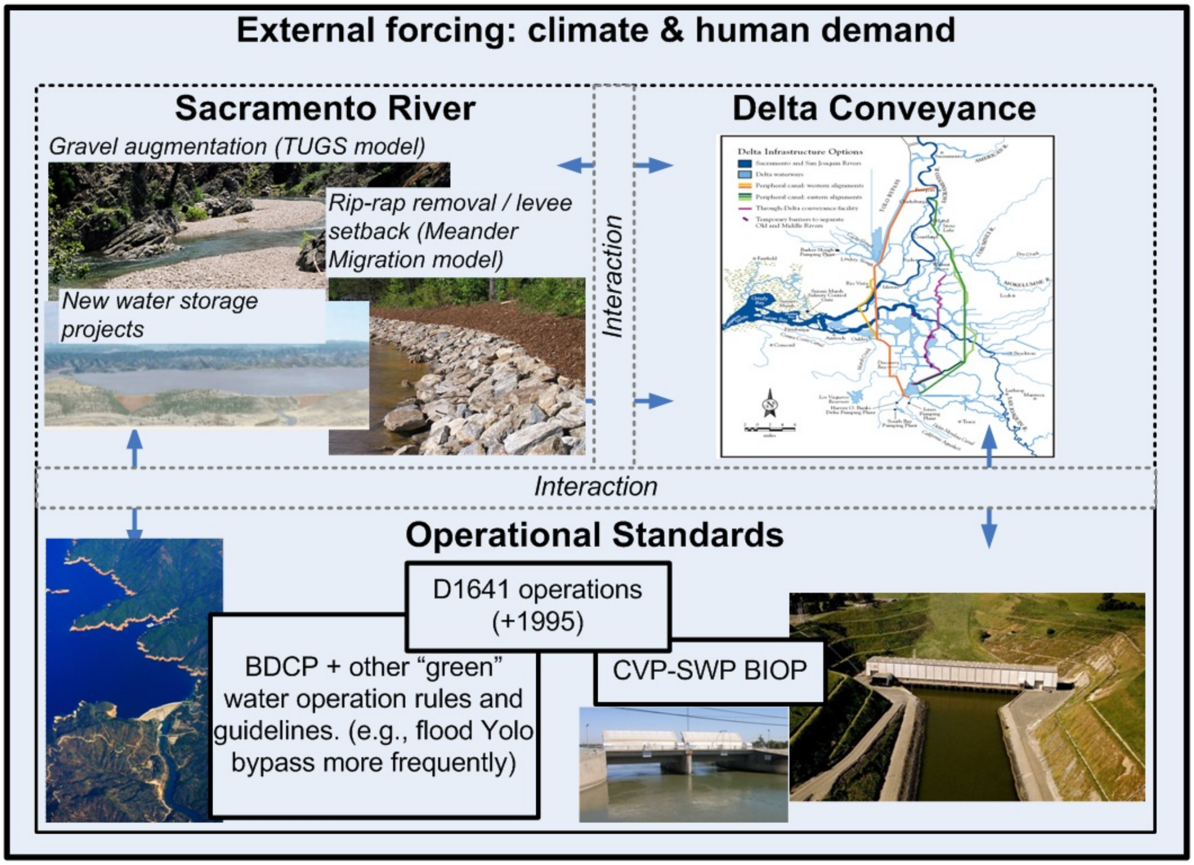

Figure 1.1: "4 box" conceptual framework for DeltaEFT scenarios identified at the January 2009 DeltaEFT Design Workshop. Note: other tributary rivers beyond the Sacramento River could be considered in future versions of DeltaEFT (*e.g.*, San Joaquin, Mokelumne, *etc.*).

Different rules for these "boxes" ultimately translates into different flow regimes (Figure 1.2).

Typically, the range of available scenarios is defined by investigations underway with the CalSim and DSM2 modelling platforms. To date DeltaEFT has been applied to North of Delta Offstream Storage and Bay Delta Conservation Plan scenarios. We note that SacEFT also includes "internal" scenario options, specifically the ability to: i) evaluate the impacts of alternative gravel augmentation and sediment transport effects on spawning conditions for chinook and steelhead; and ii) explore effects of rip rap removal or levee set-back on channel migration and nesting conditions for bank swallows.

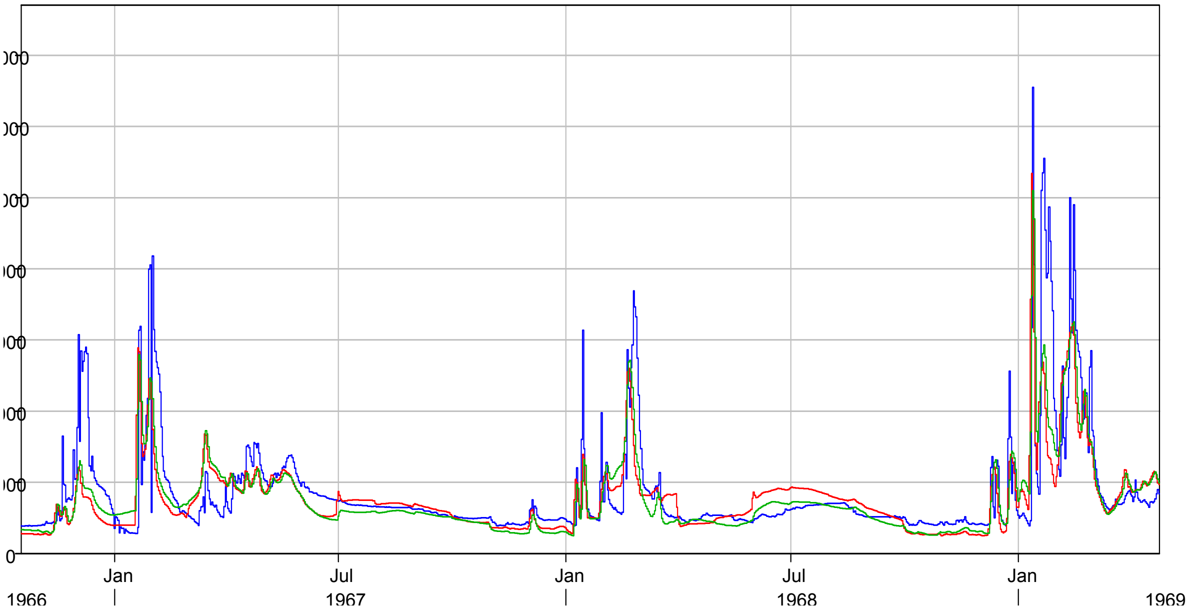

Figure 1.2: Different climate forcing, operational standards, or conveyance properties of the Sacramento River and/or San Francisco Delta translate into alternate flow regimes.

1.2.3 Spatial extent

The spatial extent of DeltaEFT includes to the north the entrance to Yolo Bypass and the mainstem Sacramento River at Sacramento downstream and westward to the inlet of Suisun Marsh near Martinez. To the south, DeltaEFT extends to the Harvey Banks and Jones pumping plants exiting the Clifton Court Forebay including the eastern Delta (without explicit representation of the San Joaquin River and other major eastside tributaries) (Figure 1.3). Specific locations identified in DeltaEFT were chosen based on three factors:

1. their biological importance (*e.g.*, what is the current or historic range for a focal species?);
2. the areas where we have reliable *biological* relationships (focal species models); and
3. the feasibility of obtaining or producing the *physical* driving variables required for focal species submodels at these biologically relevant sites.

The overlap between these three considerations determines the spatial resolution of performance measures throughout DeltaEFT's study area.

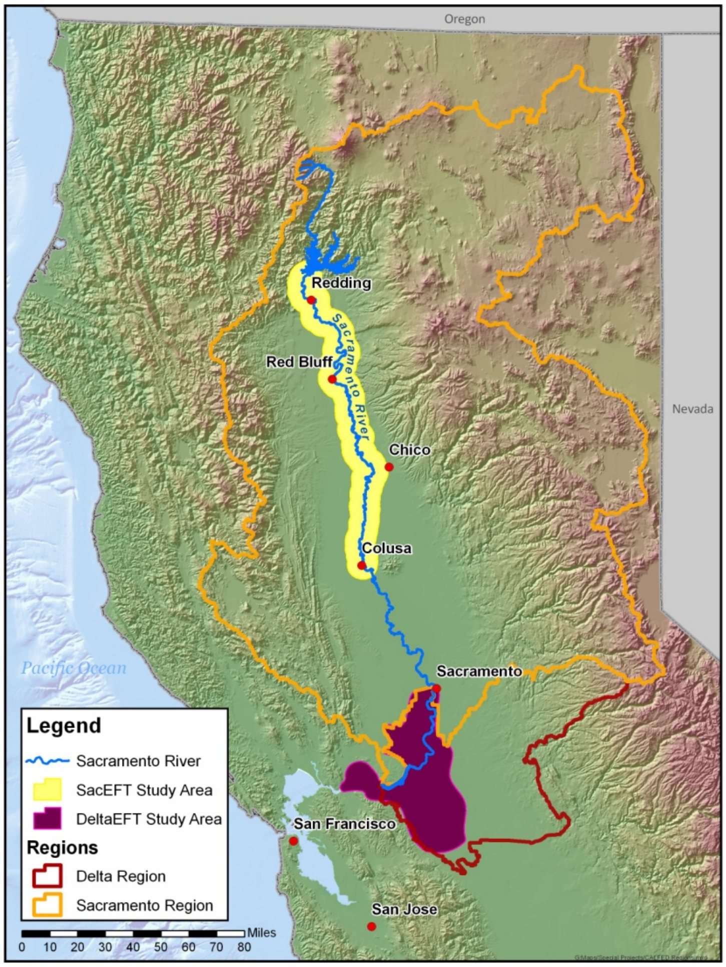

Figure 1.3: SacEFT and DeltaEFT study areas – linked eco-regions evaluated jointly or separately. Sacramento River (SacEFT) study area – from Keswick Dam (RM 301) to Colusa (RM 143). DeltaEFT shown in purple.

1.2.4 Spatial resolution

DeltaEFT makes use of several spatial concepts to describe specific locations:

- points (arcs and nodes);
- cross-sections;
- linear segments;
- routes, and
- data regions (*i.e.*, sets of points, cross-sections or linear segments inside a polygon area).

A concrete example of a variable linked to a point would be a stream gauge. An example of a variable or relation associated with a cross-section is a stage-discharge relationship. The length of newly eroded bank at a particular river bend is well represented using the concept of a segment (*e.g.*, RM *X* to *Y*). Certain variables in the Delta are taken as a weighted average throughout a region of importance.

Currently, for future simulations the physical driving data leveraged by DeltaEFT version 1 are derived from DSM2. Thus, the DSM2 grid and common output locations dictate DeltaEFT's spatial resolution. As

DeltaEFT is "agnostic" to choice of driving physical model, other physical models and their spatial network could be imported and used in the future.

Table 1.3 lists the *historical* stream gauge records are imported into the DeltaEFT database, including all physical variables: flow, temperature, electro-conductivity and stage. The temporal resolution used for the physical variables are provided in Table 1.2. Table 1.4 shows the simulated locations used from DSM2.

DeltaEFT treats locations as fixed throughout model simulations for purposes of generating focal species performance measures.

Table 1.3: **Historical** gauge locations included in DeltaEFT. LocationID refers to the internal location-numbering system of DeltaEFT. DSM2 and CDEC codes are include along with USGS gauge names. Columns to the right of the CDEC column show where Flow (T), Temperature (T), Electroconductivity (E) and Stage (S) locations are required for each Indicator. Cells with a dot (●) denote locations where historical data is available for some years. Shaded cells without a dot are locations of interest for the indicator, but they have no historical data.

LocationID	Name	RM	RKI	DSM2	CDEC	CS7		CS9	CS10		DS1		DS2	DS4	SS1	TW1	TW2		ID1	ID2	ID3
						F	T	F	F	T	T	E	E	F	F	S	E	S	E	E	E
39	KNIGHTS LANDING (using SACRAMENTO R A BUTTE CITY CA)	168			KNL	●	●														
414	SACRAMENTO R A VERONA CA				VON	●	▨														
84	SACRAMENTO R A SACRAMENTO CA	59.5	178	RSAC178	IST	●	▨														
86	SACRAMENTO R A FREEPORT CA		155	RSAC155	FPT	●	▨														
389	SACRAMENTO RIVER AT HOOD		142	RSAC142	SRH			▨	▨	●											
308	SACRAMENTO R AB DELTA CROSS CHANNEL CA		128	RSAC128	SDC	●	▨	●	●	▨											
307	SACRAMENTO R BL GEORGIANA SLOUGH CA		123	RSAC123	GSS	●	▨	●	●	▨	▨	▨									
300	SACRAMENTO R A RIO VISTA CA		101	RSAC101	RVB,RIV	●	●	●	●	●	●	●							●	●	●
461	CACHE SLOUGH A RYER ISLAND			CACHE_RYER		▨	▨				▨	▨									
357	EMMATON (USBR)		92	RSAC092	EMM	▨	▨				▨	●	●						●	●	●
325	COLLINSVILLE ON SACRAMENTO RIVER		81	RSAC081	CSE	▨	●	▨											●	●	●
335	SUTTER BYPASS AT RD 1500 PUMP			SUT_US_MIN	SBP				▨	▨											
473	Steamboat Slough			STMBT_S					▨	▨											
426	SAN FRANCISCO BAY A PITTSBURG CA		77	RSAC077	PTS						●	●	●						●	●	●
324	SUISUN BAY A MALLARD IS CA		75	RSAC075	MAL	▨	●	▨	▨	●	●	●	●							●	
463	Delta Cross Channel			DCC					▨	▨						▨	▨	▨			
311	GEORGIANA SLOUGH NR SACRAMENTO R	50		GEORG_SL	GGS				▨	▨	▨	▨									
85	**FREMONT WEIR SPILL TO YOLO BYPASS NR VERONA CA**		**244**	**RSAC244**	**FRE**	●	▨								●						
316	**SACRAMENTO WEIR SPILL TO YOLO**		**182**	**RSAC182**		●	▨								●						
424	N MOKELUMNE NR WALNUT GROVE CA		19	RMKL019					▨	▨	▨	▨									
390	LITTLE POTATO SLOUGH NR TERMINOUS CA		8	RSMKL008	STI				▨	●	●	●									
381	PORT CHICAGO		64	RSAC064	PCT						●	●	●			▨	▨	▨		●	

LocationID	Name	RM	RKI	DSM2	CDEC	CS7		CS9	CS10		DS1		DS2	DS4	SS1	TW1	TW2		ID1	ID2	ID3
						F	T	F	F	T	T	E	E	F	F	S	E	S	E	E	E
302	SAN JOAQUIN R A JERSEY POINT CA		18	RSAN018	JER						●	●									
338	SAN JOAQUIN R A ANTIOCH CA		7	RSAN007	ANH						●	●							●	●	●
374	MIDDLE RIVER AT TRACY BLVD		63	RSAN063	MTB																
385	ROUGH AND READY ISLAND		58	RSAN058	RRI																
371	CARQUINEZ STRAIT A MARTINEZ CA		54	RSAC054	MRZ						●	●	●							●	
326	SAN JOAQUIN R A VENICE ISLAND - TIDE GAGE CA		43	RSAN043	VNI																
386	SAN ANDREAS LANDING		32	RSAN032	SAL				●	●	●	●							●	●	●
305	OLD R A BACON ISLAND CA		24	ROLD024	OBI									●							
459	MIDDLE R AT BORDEN HWY NR TRACY CA		23	RMID023	VIC						●	●									
301	SAN JOAQUIN R BL GARWOOD BRIDGE A STOCKTON CA		27	RMID027	SJG																
309	MIDDLE R AT MIDDLE RIVER CA		15	RMID015	MDM									●							
365	HOLLAND CUT NR BETHEL ISLAND CA		14	ROLD014	HLL						●	●									
330	BELDON LANDING		11	SLMZU011	BDL							●				●		●		●	
437	DWR-CD 1479		11	SLSBT011																	
358	FARRAR PARK		9	SLDUT007	FRP						●	●							●	●	●
345	BARKER SLOUGH PUMPING PLANT (KG000000)		2	SLBAR002	BKS												●				
344	BETHEL ISLAND		3	SLPPR003	BET														●	●	●
319	GOODYEAR SLOUGH		3	SLGYR003	GYS															●	
327	SUNRISE CLUB		2	SLCBN002	SNC															●	
331	NATIONAL STEEL		25	SLMZU025	NSL															●	
333	VOLANTI		12	SLSUS012	VOL															●	

Table 1.4: **Modeled** gauge locations included in DeltaEFT (from DSM2). Locations in red are provided as boundary conditions or are created through the synthetic combination of other gauges. LocationID refers to the internal location-numbering system of DeltaEFT. DSM2 and CDEC codes are include along with USGS gauge names. Columns to the right of the CDEC column show where Flow (T), Temperature (T), Electroconductivity (E) and Stage (S) locations are required for each Indicator. Cells with a dot (●) denote locations where historical data is available for some years. Shaded cells without a dot are locations of interest for the indicator, but they have no historical data.

LocationID	Name	RM	RKI	DSM2	CDEC	CS7		CS9	CS10		DS1		DS2	DS4	SS1	TW1	TW2		ID1	ID2	ID3
						F	T	F	F	T	T	E	E	F	F	S	E	S	E	E	E
39	KNIGHTS LANDING	168			KNL	●	●														
414	SACRAMENTO R A VERONA CA				VON	●	▨														
84	SACRAMENTO R A SACRAMENTO CA	59.5	178	RSAC178	IST	●	▨														
86	SACRAMENTO R A FREEPORT CA		155	RSAC155	FPT	●	▨														
389	SACRAMENTO RIVER AT HOOD		142	RSAC142	SRH			●	●	▨											
308	SACRAMENTO R AB DELTA CROSS CHANNEL CA		128	RSAC128	SDC	●	●	●	●	●											
307	SACRAMENTO R BL GEORGIANA SLOUGH CA		123	RSAC123	GSS	●	●	●	●	●	●	●									
300	SACRAMENTO R A RIO VISTA CA		101	RSAC101	RVB,RIV	●	▨	●	▨	▨	●	●							●	●	●
461	CACHE SLOUGH A RYER ISLAND			CACHE_RYER		▨	▨				●	●									
357	EMMATON (USBR)		92	RSAC092	EMM	●	●		●	●	●	●	●						●	●	●
325	COLLINSVILLE ON SACRAMENTO RIVER		81	RSAC081	CSE	●	●	●											●	●	●
335	SUTTER BYPASS AT RD 1500 PUMP			SUT_US_MIN	SBP				●	▨											
473	Steamboat Slough			STMBT_S					●	▨											
426	SAN FRANCISCO BAY A PITTSBURG CA		77	RSAC077	PTS						●	●	●						●	●	●
324	SUISUN BAY A MALLARD IS CA		75	RSAC075	MAL	●	●	●	●	●	●	●	●							●	
463	Delta Cross Channel			DCC					●	●						●	●	●			
311	GEORGIANA SLOUGH NR SACRAMENTO R	50		GEORG_SL	GGS				●	●	●	●									
85	FREMONT WEIR SPILL TO YOLO BYPASS NR VERONA CA		244	RSAC244	FRE	●	▨								●						
316	SACRAMENTO WEIR SPILL TO YOLO		182	RSAC182		●	▨								●						
424	N MOKELUMNE NR WALNUT GROVE CA		19	RMKL019					●	●	●	●									
390	LITTLE POTATO SLOUGH NR TERMINOUS CA		8	RSMKL008	STI				●	●	●	●									
381	PORT CHICAGO		64	RSAC064	PCT						●	●	●			●	●	●		●	

LocationID	Name	RM	RKI	DSM2	CDEC	CS7		CS9	CS10		DS1		DS2	DS4	SS1	TW1	TW2		ID1	ID2	ID3
						F	T	F	F	T	T	E	E	F	F	S	E	S	E	E	E
302	SAN JOAQUIN R A JERSEY POINT CA		18	RSAN018	JER						●	●				●	●	●			
338	SAN JOAQUIN R A ANTIOCH CA		7	RSAN007	ANH						●	●							●	●	●
374	MIDDLE RIVER AT TRACY BLVD		63	RSAN063	MTB						●	●									
385	ROUGH AND READY ISLAND		58	RSAN058	RRI						●	●									
371	CARQUINEZ STRAIT A MARTINEZ CA		54	RSAC054	MRZ						●	●	●							●	
326	SAN JOAQUIN R A VENICE ISLAND - TIDE GAGE CA		43	RSAN043	VNI						●	●									
386	SAN ANDREAS LANDING		32	RSAN032	SAL				●	●	●	●							●	●	●
305	OLD R A BACON ISLAND CA		24	ROLD024	OBI						●	●		●							
459	MIDDLE R AT BORDEN HWY NR TRACY CA		23	RMID023	VIC																
301	SAN JOAQUIN R BL GARWOOD BRIDGE A STOCKTON CA		27	RMID027	SJG						●	●									
309	MIDDLE R AT MIDDLE RIVER CA		15	RMID015	MDM						●	●		●			●				
365	HOLLAND CUT NR BETHEL ISLAND CA		14	ROLD014	HLL						●										
330	BELDON LANDING		11	SLMZU011	BDL						●	●				●	●	●		●	
437	DWR-CD 1479		11	SLSBT011					●	●	●	●									
358	FARRAR PARK		9	SLDUT009	FRP							●							●	●	●
345	BARKER SLOUGH PUMPING PLANT (KG000000)		2	SLBAR002	BKS											●	●	●			
344	BETHEL ISLAND		3	SLPPR003	BET																
319	GOODYEAR SLOUGH		3	SLGYR003	GYS																
327	SUNRISE CLUB		2	SLCBN002	SNC															●	
331	NATIONAL STEEL		25	SLMZU025	NSL															●	
333	VOLANTI		12	SLSUS012	VOL															●	

1.2.5 Temporal horizon

DeltaEFT is based on a paradigm of evaluating ecological responses over multi-decadal time scales. In order to compare the overall long-run performance of alternative scenarios they need to be evaluated under a range of water year types and conditions. This is best achieved using simulations of at least 16 or more years in duration. SacEFT scenarios typically run for 66 years. In practice, the temporal horizon available depends on available external physical model simulations (*e.g.,* CalSim, USRWQM, DSM2).

1.2.6 Temporal resolution

The temporal resolution will be dictated by the life history timing of each focal species indicator (in the form of biological distributions which weight the relative importance of causal relationships through these time windows) and the key index locations most relevant to each indicator. The default temporal resolution of calculations in DeltaEFT is defined in Table 1.2.

2. DeltaEFT Submodels: Functional Details

2.1 Hydrologic Foundation

Figure 2.1 shows the currently "recognized" external physical modeling system for which DeltaEFT serves as an ecological effects "plug-in". Some of these models generate results for the Sacramento River eco-region, others for the Delta eco-region (or both). The physical data sets used as DeltaEFT's foundation originate from several high-profile planning models. Our intent is to leverage the extensive existing efforts made in these systems to supply key inputs necessary to calculate focal species performance measures. In addition to these models, select gauging records will be used for river discharge, stage, salinity and water temperatures. Using data from models and stream gauges permits mixed prospective and retrospective analyses.

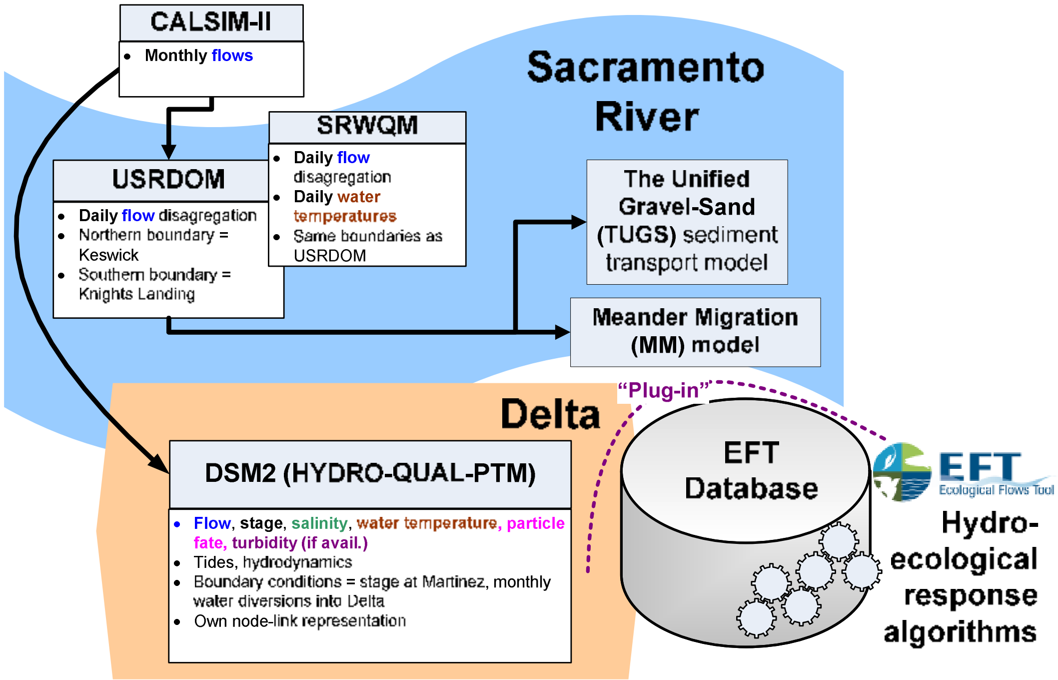

Figure 2.1: DeltaEFT hydrologic foundation ("recognized" physical models). Note: physical models used in DeltaEFT are not necessarily limited to those shown here. Where it is feasible and practical to obtain outputs ***at a daily resolution for multi-decadal simulations***, other models can be "swapped in" if they are deemed a better representation of the physical variables of interest.

The primary output format for most models will be DSS files [from USRDOM/SRWQM→Sac and DSM2 modules→Delta] for each scenario. The ecological response indicators currently incorporated into DeltaEFT are driven by the following physical variables, which are all closely linked to flow:

- Flow ($ft^3\ s^{-1}$) [incld. direction of flow]
- Stage (ft above mean sea level); Godin filtered
- Salinity (EC; μMhos cm^{-1})
- Water temperature (°C)

These variables are taken from DSS files created by CalSim II/SRWQM for the Sacramento River downstream to Colusa; and from DSS files created by DSM2 for locations downstream from Sacramento.

2.1.1 Metadata standards used to maintain provenance and scenario compatibility

By design, DeltaEFT requires no pre-requisite knowledge or experience in the operation of CalSim, USRDOM, SRWQM or DSM2. All of these models are complex, requiring highly specialized expertise to configure and implement. Rather than become CalSim – SRWQM – DSM2 experts, the DeltaEFT user (or more commonly the consultant configuring model scenarios) is tasked with aligning external model assumptions between a given imported dataset and the other "downstream" related physical models (*e.g.*, TUGS, Meander Migration in the case of SacEFT). This requires the ability to quickly summarize the key embedded assumptions, inputs, and other important characteristics of a CalSim – SRWQM – DSM2 DSS database in a form non-experts can understand. To achieve this, we apply the metadata standard shown in Figure 2.2 to all physical submodel datasets that are imported into DeltaEFT.

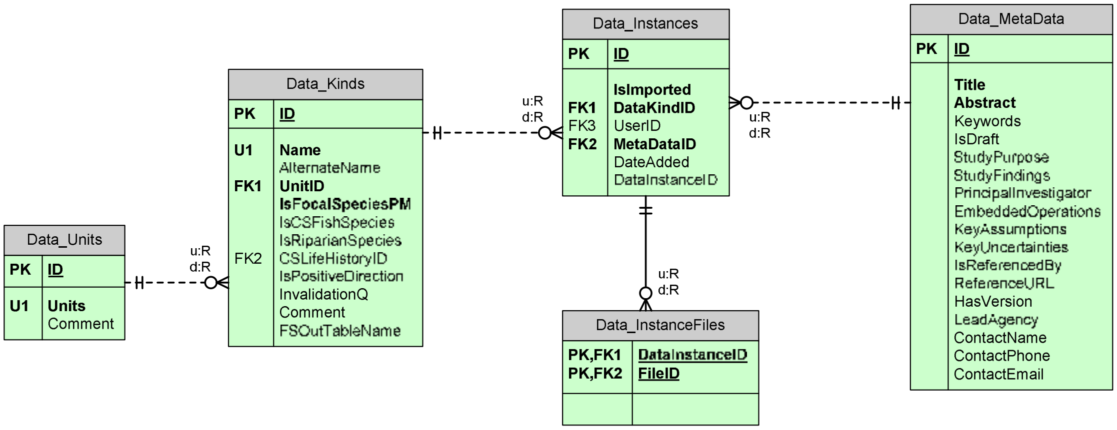

Figure 2.2: Underlying database design showing how each imported DSS file from CalSim (and any other data from an external physical model) is associated with a DataInstance and a set of Metadata.

Note: **This metadata standard (Figure 2.2) is also applied to focal species submodels in DeltaEFT**. In other words, the concept of a DataInstance refers both to *imported data sets*, as well as *resident generic rules* for a particular focal species submodel. For example, a riparian submodel scenario may use a different tap-root growth rate from that of another. While this will not require nearly as great a level of detail in metadata documentation as a DSM2 DataInstance, the rationale for one growth rate over another is the kind of information that can be tracked using the DeltaEFT metadata standard.

In short, there are two files to import when incorporating a CalSim – SRWQM – DSM2 output dataset in DeltaEFT: (1) the output DSS file, and (2) the associated summary metadata.

2.2 Focal Habitat and Species Submodels

2.2.1 Chinook salmon & steelhead trout

The salmonid conceptual model includes run-types and populations which originate from the Sacramento River and its tributaries only, and is shown in Figure 2.3.[5] Readers are referred to ESSA (2008b) for further details on the development of this model and the decisions that led to its current structure. The candidate Performance Measures and numbered pathways presented in ESSA (2008b) were discussed in subgroup and the appropriate tables were updated as shown below in Table 2.1. PMs and pathways accepted for version 1 are highlighted in blue.

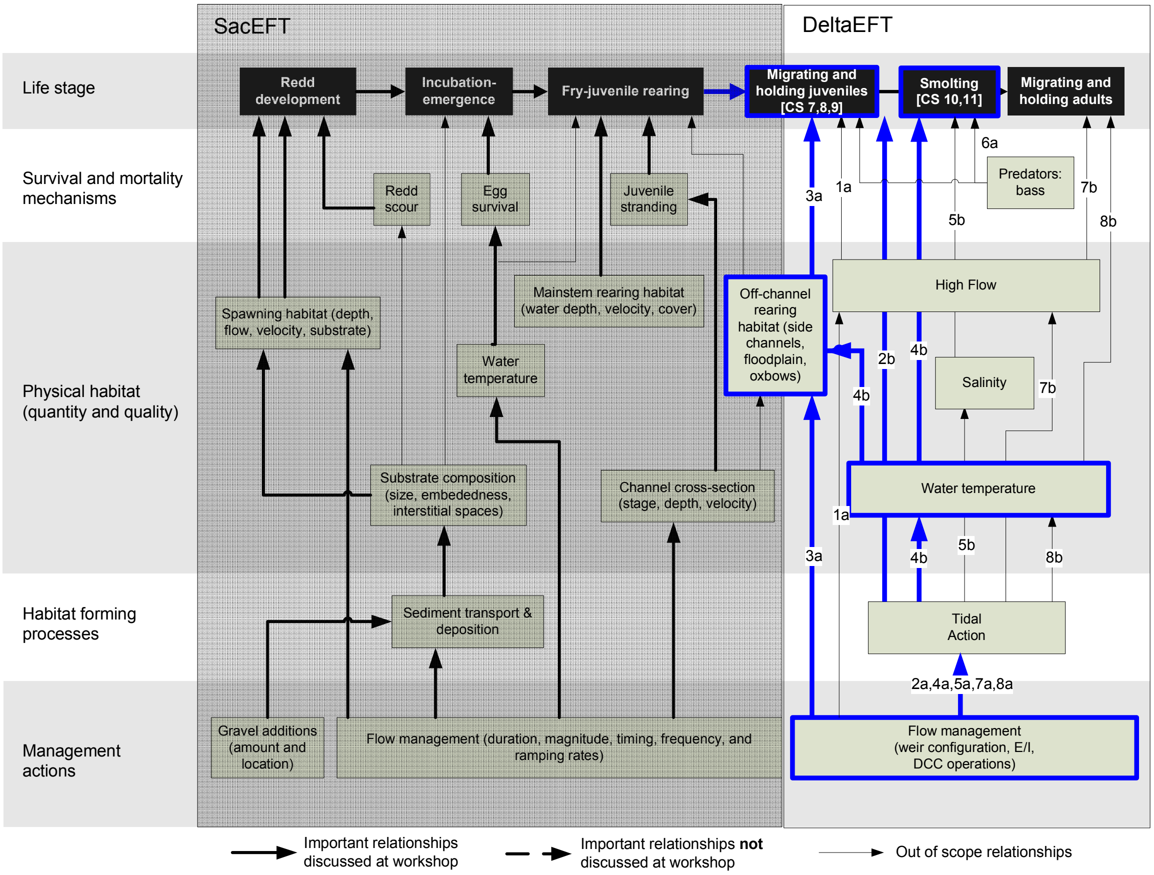

Figure 2.3: The salmonid conceptual model. Relationships developed for SacEFT version 1 are shown in simplified form at left. Linkages and components shown with blue outlining are included in DeltaEFT version 1.

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[5] The scope for salmonid run-types included in Version 1 is limited to run-types of the Upper Sacramento River because of the large effort required to integrate flow, temperature and habitat data from other salmon-bearing rivers and streams in the model.

Table 2.1: Performance measures for Chinook salmon and steelhead trout.

Performance Measure	Synonyms	PM code
Smolt development & growth		CS7
Smolt predation exposure	Passage Time	CS9
Smolt temperature stress		CS10

CS7 – Smolt Development & Growth

Rationale

As juvenile salmonids migrate downstream they continue to feed and grow. With increased size comes improved probability of survival as they enter the estuary and then move out to the open ocean (Beamish and Mahnken 2001). During some sustained high flow events, Yolo Bypass provides a high quality environment for extended rearing and enhanced growth (Benigno and Sommer 2009; Sommer *et al.* 2001). Although short-term benefits of floodplain connectivity exist, these benefits become greater for juvenile Chinook and steelhead the longer those juveniles are able to take advantage of the productive insect and zooplankton 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 more time for growth, or a temperature environment that is closer to the optimum.

Juvenile Development

Growth of migrating juveniles is interpolated from the ration-temperature-growth relationship for sockeye smolts (Brett *et al.* 1969) shown in Figure 2.4. Based on laboratory studies from a related species, the relationship is consistent with values provided at the workshop (ESSA 2008b) for Chinook smolts. We prefer the Brett relationship to the one provided by Baker *et al.* (1995) and employed by Cavallo *et al.* (2008) for the IOS model, for which there is no penalty for cold water. The dome-shaped curve provides a functional response that is more in line with enzyme kinetics and in times of very high water temperature can even result in weight loss for juveniles.

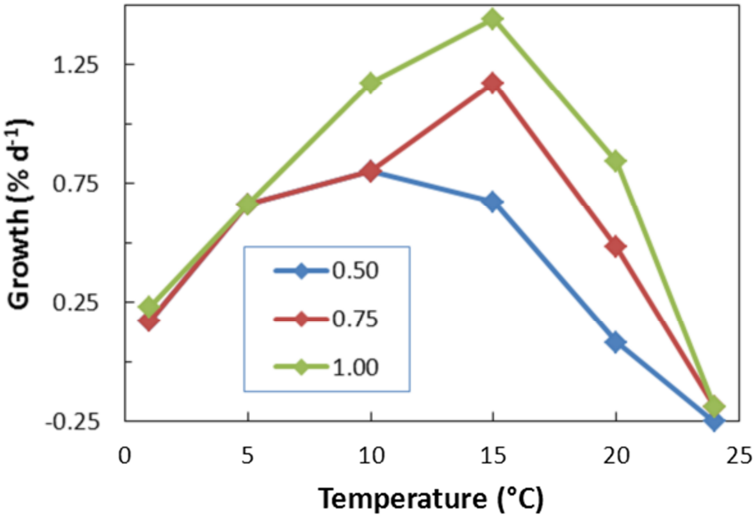

Figure 2.4: The relationship between daily weight gain and temperature for 7-12 month sockeye smolts (Brett *et al.* 1969, Figure 11 and Table 3) for three levels of daily ration. A ration of 6% of body weight/day is assigned as ration level of 1.00, and lower rations are expressed in relation to this level.

Juveniles are assumed to receive a daily food ration that is 0.60 of the maximum reported by Brett. However, when Yolo Bypass has been inundated for 14 or more days, the food ration for day-cohorts present in the Bypass is increased to 0.80 of the maximum, in keeping with the findings of Benigno and Sommer (2009). The 14-day threshold can be configured, as can the 0.60 and 0.80 food ration assumptions and the initial weight of 6.0 grams for all run-types (estimated from McFarlane 2010). The actual Performance Measure is reported as percent weight change, but the absolute and percentage measurements are easily interchangeable through a simple calculation.

Daily water temperatures are based on historical or simulated gauge data, as shown in Table 2.3. Juveniles migrating in the Sacramento River experience the temperatures recorded (or simulated) at the gauge linked to the leading node of each segment. Those that migrate through Yolo Bypass experience temperatures based on water temperature at Fremont Weir and Sacramento Weir, which are combined based on the proportion of flow from each source. This pooled temperature is further modified by the relationship shown in Figure 2.5, based on three years of empirical data proved by Ted Sommer (CDWR, *pers. comm.*).

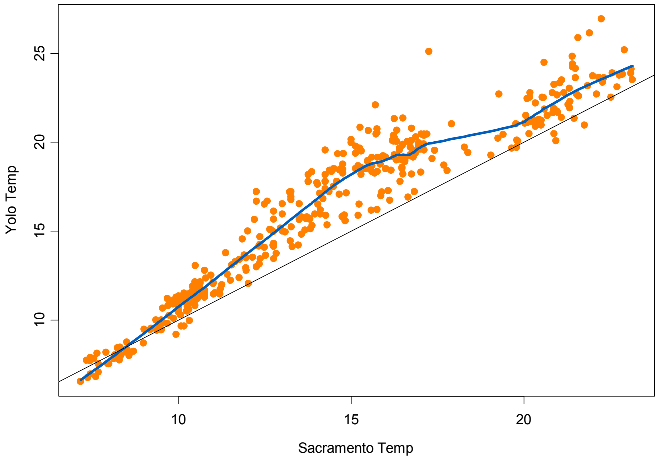

Figure 2.5: The relationship between water temperature in Yolo Bypass and water temperature in the Sacramento River at Fremont Weir. Based on the smoothing line, Yolo temperature is slightly greater than the mainstem river temperature. Data provided by T. Sommer.

Migration Timing

Outmigration of juveniles is modeled using Knights Landing (RM91) as a temporal datum. Beginning from this point and proceeding downstream, day-cohorts of juveniles migrate into a network that can vary from simple to complex. The migration calendar shown in Table 2.2 is synthesized from Fisher (1994), McEwan (2001), Moyle (2002), Williams (2006a) and Yoshiyama *et al.* (1996). The CS7 Performance Measure begins at Knights Landing, but CS9 and CS10 (described below) begin further downstream at Hood (RM49) and, based on typical flows and IOS model predictions, are advanced by 17 days from the calendar based on Knights Landing.

Migration Speed

As juveniles out-migrate from their natal streams toward the estuary and ocean, they are faced with a variety of different flow and temperature regimes, as well as different migration routes. The migration of each day-cohort is based on historical or simulated gauges associated with each node in the migration network. As migration proceeds, the flow environment of each route segment affects the distance travelled by the day-cohort each day, and ultimately determines how long the day-cohort will spend before it arrives at the end of each route. For migration routes within the main river system, we use a flow-migration relationship borrowed from the IOS model (Cavallo *et al.,* 2008:16, Figure 2.6), which parameterizes fry migration rates (Giorgi *et al.* 1997)[6] using a logistic relationship to predict migration rate, S_f (km d^{-1}), with the following parameters: minimum fry migration rate S_0 = 1.84 km d^{-1} at zero flow, asymptotic maximum migration rate K = 6 km d^{-1}, r = 0.00025, Q = ft^3 s^{-1} flow:

$$S_f = \frac{K\,S_0\,e^{rQ}}{K - S_0\left(1 - e^{rQ}\right)} \qquad \text{Eqn 2.1}$$

The migration of smolts travelling through Yolo Bypass incorporates a flow-velocity relationship shown in Figure 2.7, created from three years of inundation data provided by Ted Sommer (CDWR, *pers.*

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[6] Cavallo *et al.* (2008) cite Giorgi *et al.* (1997) for a study of Columbia River salmonids: fry (40-58 mm at 1.84 km d^{-1}; parr (58-78 mm at 4.75 km d^{-1}) and smolts (78-150 mm at19.71 km d^{-1}).

comm.) calibrated to reproduce the range of 30-50 day passage time observed by Sommer. As juveniles move from the Sacramento River into Yolo Bypass and out again (by two possible routes), their movement dynamics change accordingly.

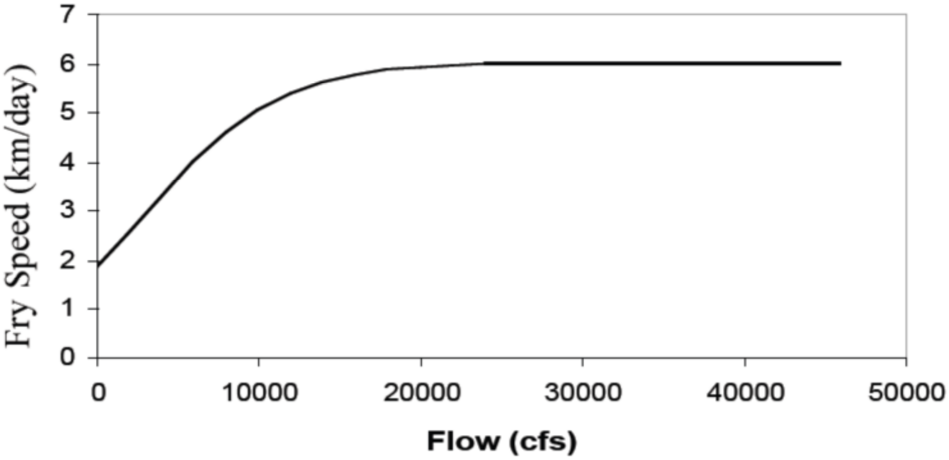

Figure 2.6: Migration speed (km d^{-1}) as a function of flow (f^3 s^{-1}), as defined by the IOS model (taken from Cavallo *et al.* 2008:16).

Table 2.2: Distribution of juvenile migration time from Knights Landing.

Run-type	Proportion	Start	End
Spring	0.75	01-Dec	19-May
	0.25	20-May	30-Jun
Fall	1.00	01-Mar	30-Jun
Late-fall †	1.00	11-Sep	10-May
Winter †	0.25	11-Sep	31-Jan
	0.50	01-Feb	30-Mar
	0.25	01-Apr	10-Apr
Steelhead	0.25	01-Jan	30-Mar
	0.50	01-Apr	10-Jun
	0.25	11-Jun	30-Jul

† Late-fall and winter-run Chinook span the WY boundary and are accounted for in the ending WY.

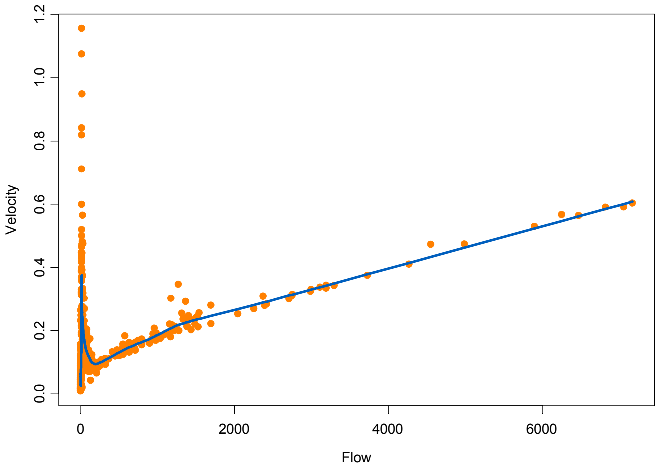

Figure 2.7: Water velocity (m s^{-1}) as a function of flow (m^3 s^{-1}) in Yolo Bypass. Data provided by Ted Sommer.

Routing Logic

Depending on the branching and complexity of the migration network, juveniles can be faced with a variety of pathways in their outmigration. Migration is represented as the traversal of a network containing nodes and segments and is best visualized in terms of a Lagrangian coordinate system. Each node is associated with a flow and temperature gauge, and has a length derived from the physical location of the node, as measured by a freehand line drawn along the river segment with a Google Maps tool. Some nodes and segments are treated in special ways, using either a Junction-flag or a Weir-flag (Table 2.3) as described below.

Up to two gauges can be provided for a node, as detailed in Table 2.3. At the beginning of each simulation year, the database is queried for flow and temperature data from the preferred first gauge. Following that query, gaps of up to 10 days are filled using linear interpolation within the gap. Gaps longer than 10 days are counted, and if more than 20% of a run-type's total days are missing from these longer gaps, the gauge is rejected as being too sparse and the second gauge is tried. If both gauges are too sparse, the simulation is not attempted for that year. Nodes marked with a Weir-flag are treated as a special case, with gaps treated simply as zero-flow days. Nodes marked with a Junction-flag are a second kind of special case, and require no corresponding gauge. Instead, the upstream gauges (Fremont Weir and Sacramento Weir in the case of Yolo Bypass) are used to provide a pooled daily flow and flow-weighted temperature, respectively. Finally, node numbers, which are assigned arbitrary but internally consistent StartPointID and EndPointID numbers in Table 2.3, use a special negative value (–101) to denote that they represent Yolo Bypass. In this case, site-specific flow-velocity and temperature relationships are used, and replace the relationships used in the mainstem Sacramento River.

The movement of day-cohorts of juveniles along different possible routes is based on Perry *et al.* (2010), in which juveniles were observed to "go with the flow," based on the proportional division of flow in a particular route (Figure 2.8). When routes split, flow at the two (in the case of a two-way split) downstream gauges is used to determine the proportion of flow among the routes, and each day-cohort of juveniles is divided in proportion to the relative flow in each route. With fluctuating flow, proportions change dynamically from day to day, and each day-cohort that begins at Knights Landing will be divided among routes that are unique to the flow history it experiences as the cohort migrates downstream.

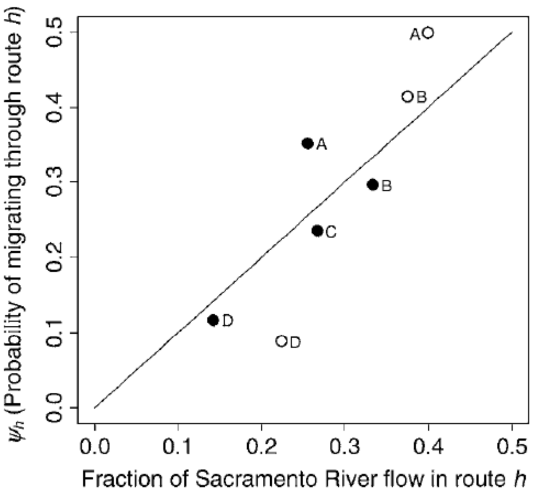

Figure 2.8: "The probability of migrating through route *h* as a function of the proportion of total river flow in route *h* for late-fall juvenile Chinook salmon... The 45° reference line shows where the fraction migrating through a particular route is equal to the proportion of flow in that route." (Perry *et al.* 2010, Figure 4).

The route traversal logic allows for cases where smolts divide at a branch, as described above. The logic also allows flow and temperature from multiple branches to recombine, as in the case of the multiple inputs to Yolo Bypass from Fremont Weir and Sacramento Weir. When merges occur, each migrating day-cohort remains individually accounted for, so that spatially overlapping cohorts can be distinguished from one another. Finally, the logic also allows for situations in which flow is discontinued in a route, as when flow over one of the weirs stops. In these cases, flow and temperature conditions on the last day-of-flow are used to estimate migration conditions until the day-cohort exits the route or rejoins a positive-flow segment of the route. When this occurs, this simple rule may lead to some unreasonable measures, as discussed later.

The specific routes that are simulated for CS7 incorporate Yolo Bypass and the mainstem of the Sacramento River, and allow the evaluation of differences in growth between the different routes. These are shown in Figure 2.9 and Table 2.3.

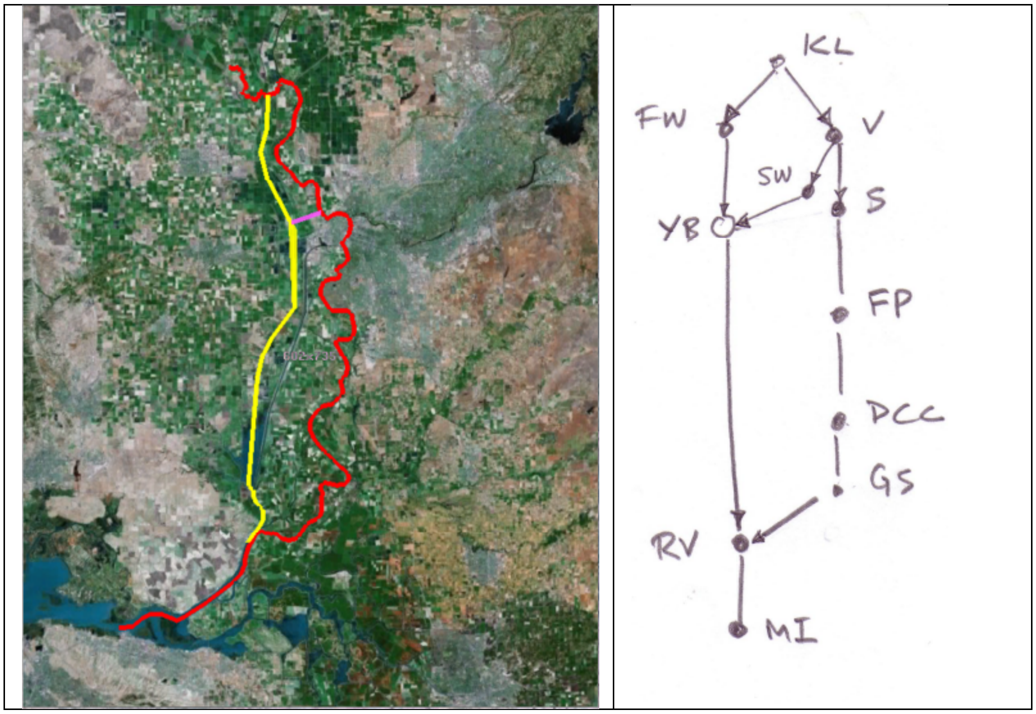

Figure 2.9: The CS7 Performance Measure includes three routes from Knights Landing to Mallard Island. In the left panel, the unique portion of the yellow route passes (during flooding periods) over Fremont Weir through Yolo Bypass. The unique portion purple route passes over Sacramento Weir through Yolo Bypass during flood periods. The red route passes along the mainstem of the Sacramento River. A schematic view of the routes is shown at right. Route splitting logic governs the division of day-cohorts of migrating juveniles and route pooling logic governs the aggregation of flow in Yolo Bypass. ***Node abbreviations:*** KL=Knights Landing; FW=Fremont Weir; V=Verona; YB=Yolo Bypass; SW=Sacramento Weir; S=Sacramento; FP=Freeport; DCC=Delta Cross Channel; GS=Georgiana Slough; RV=Rio Vista; MI=Mallard Island.

Table 2.3: Parameters of the 3 routes used for CS7 Performance Measure: Smolt Development and Growth. This table represents the content of the EFT database table: dbo.Spatial_Route. Columns marked F-1, T-1, FT-1 *etc.* denote EFT gauge location identifiers for Flow, Temperature and combined Flow-Temperature, respectively. '1' gauges are preferred but '2' gauges will be used if data are sparse or missing from the '1' gauge. A limited number of simulation gauges were available for fitting the Version 1 model, as noted in the table footnote. Node abbreviations in the first column are provided in Figure 2.9.

Route & Nodes	ID	Seq.	Start Link	End Link	Length (km)	Junction	Weir	Historical F-1	Historical F-2	Historical T-1	Historical T-2	Simulated FT-1	Simulated FT-2
SR: KL – V	901	1	1	3	18.30			39	414	389		39	
SR: V – S		2	3	5	30.59			414		389		414	308
SR: S – FP		3	5	6	21.40			308		389		308	307
SR: FP – DCC		4	6	7	29.30			308		389		308	307
SR: DCC – GS		5	7	8	2.86			308		389		308	307
SR: GS – RV		6	8	9	21.60			307	308	389		307	300
SR: RV – MI		7	9	10	26.00			300		300	357	357	324
FW: KL – FW	902	1	1	2	11.70			39	414	39		39	40
FW: FW – YB		2	2	-101	20.40		(1) Yes	85		39		(2) 85	308
FW: YB – RV		3	(3) -101	9	51.20	(4) Yes							
FW: RV – MI		4	9	10	26.00			300		300	357	357	324
SW: KL – V	903	1	1	3	18.30			39	414	389		39	
SW: V – SW		2	3	4	24.30			308		389		414	308
SW: SW – YB		3	4	-101	4.77		Yes	316		389		316	308
SW: YB – RV		4	-101	9	51.20	Yes							
SW: RV – MI		5	9	10	26.00			300		300	357	357	

[1] The Weir flag is used internally to denote a node that is allowed missing days without causing the data source to be rejected during data consistency checks.

[2] The absence of simulation data at Fremont Weir and Sacramento Weir will prevents applying the model to Yolo Bypass.

[3] A link with negative sign is used internally to denote Yolo Bypass, triggering site-specific calculations for flow and temperature.

[4] The Junction flag is used internally to denote a "virtual gauge" that uses upstream flow and temperature to produce combined input. Junctions are used for pools only.

Calibration

Calibration criteria for CS7 were not available following the Design Workshop. In the absence of specific guidance, DeltaEFT uses discontinuities in the annual rollup distribution to divide the distribution of percent-weight-change into upper, middle and lower groups that are then used to assign a R/Y/G score. We initially used a 6 year period of Historical data (WY 2002-2007), but upon review determined that this period has an excess of wet year types, in addition to being of short duration. To try to provide a more balanced mixture of year types, we added more observations from the 16-year span of the BDCP No Action Alternative (NAA) scenario (WY1976-1991; refer to BDCP EIR-EIS documentation on No Action Alternative[7]). These two sources are shown by red (Historical) and blue (NAA-Current) points in Figure 2.10. The figure columns show the distributions at three different time scales, but the thresholds themselves are based on the distribution of the Year rollup in the right-most column and are held constant across the time scales. The Day distribution (left-most column) shows the percent gain for each day-cohort without weighting the day-cohort, and clearly indicates that some rare day-cohorts experience very high weight gain. The Route distribution uses weighted day-cohorts within each route, and the Year calibration combines both day- and route-weights into a weighted percent gain. Calibration values are shown in Table 2.4. As the time-scale is lengthened and the totality of the annual cohort is factored into the weighted result, the wide range of the distribution is narrowed considerably. The rows show the distribution of observations for each of the five run-types.

Table 2.4: Breakpoints for the CS7 Smolt Development and Growth indicator. Units are percent weight gain and larger values are better

	Daily		Route		Annual	
Run-type	**Good-Fair**	**Fair-Poor**	**Good-Fair**	**Fair-Poor**	**Good-Fair**	**Fair-Poor**
Spring	≥32	≤24	≥32	≤24	≥32	≤24
Fall	≥23	≤16	≥23	≤16	≥23	≤16
Late-fall	≥32	≤24	≥32	≤24	≥32	≤24
Winter	≥32	≤24	≥32	≤24	≥32	≤24
Steelhead	≥23	≤16	≥23	≤16	≥23	≤16

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[7] The NEPA Baseline for assessing environmental effects, including cumulative effects, of the Proposed Project and alternatives is defined as the No Action Alternative. The No Action Alternative also demonstrates the future consequences of not meeting the need of the Proposed Project. Under NEPA, the No Action Alternative describes the future conditions if the Proposed Project were not approved and there was no change from current management direction or level of management intensity. The No Action Alternative may include reasonably foreseeable future actions that are not consistent with existing plans, infrastructure, or services if the actions are consistent with existing management direction or level of management.

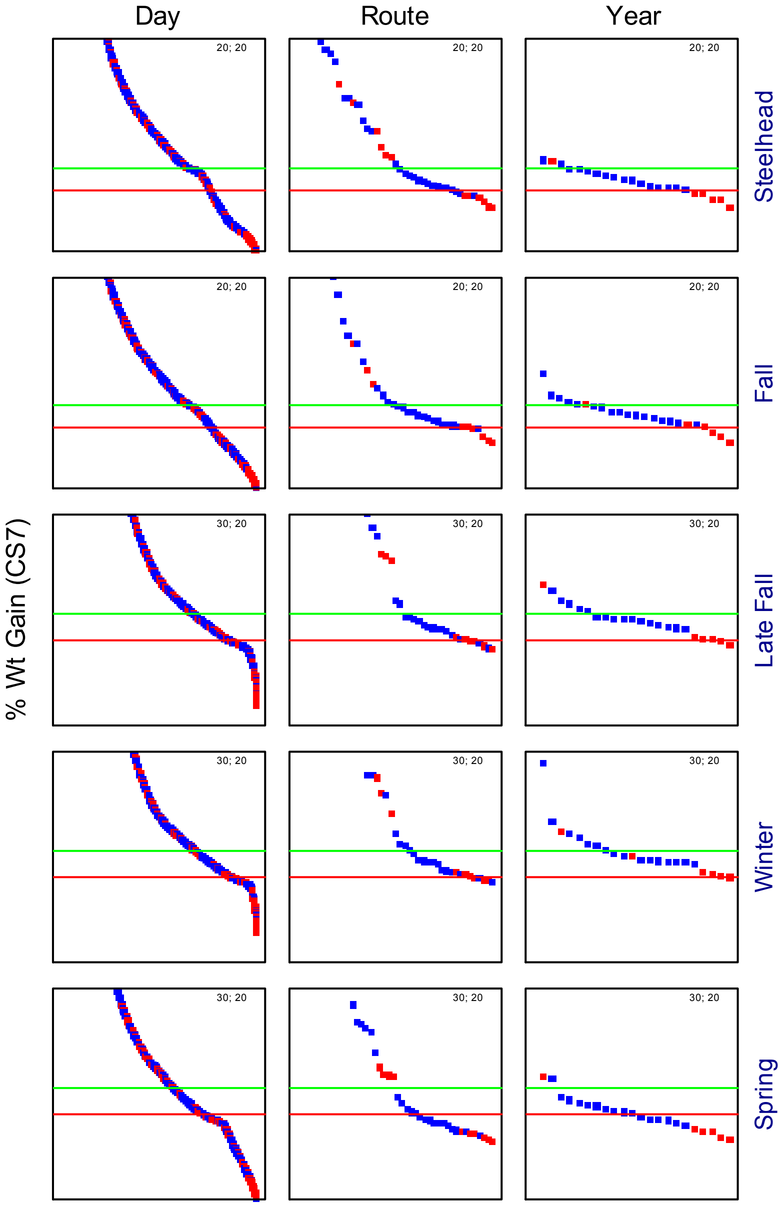
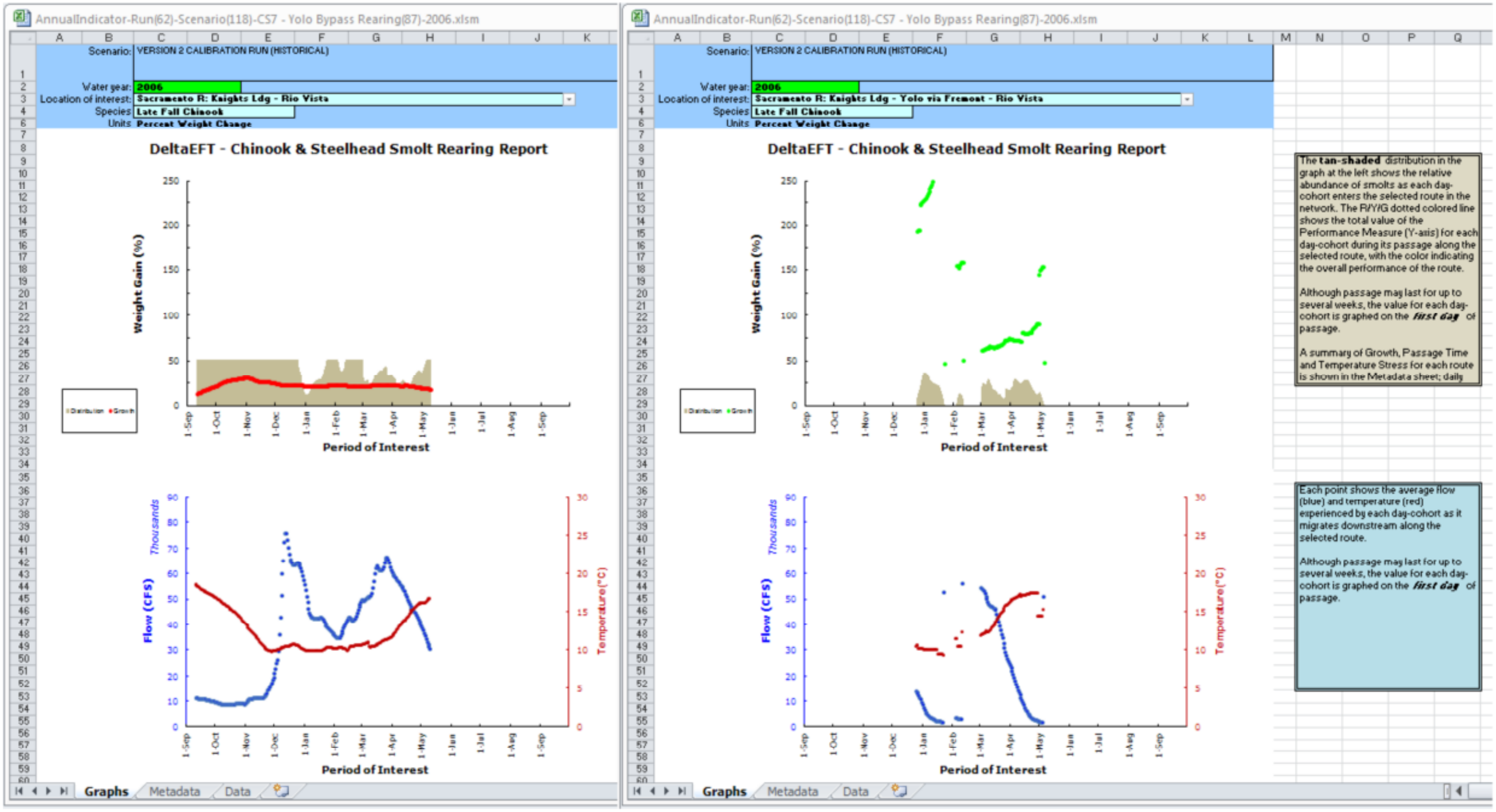


Figure 2.10: The CS7 Performance Measure calibration is based on the distribution of percent weight gain simulated using Historical (red) flow and temperature data, augmented by the NAA-Current simulation (blue), and is made at three temporal scales (columns) for five run-types (rows). The Day-calibration is unweighted; the Route-calibration incorporates day-cohort weights based on the migration timing distribution; and the Year-calibration incorporates weights based on the proportion of juveniles migrating through each route.

Excel Reports

Excel reports and metadata are available for the annual rollup of CS7. An example is shown below in Figure 2.11 and in Figure 2.12.



Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)
Water year: 2006
Location of interest: Sacramento R: Knights Ldg - Rio Vista
Species Late Fall Chinook
Units Percent Weight Change

DeltaEFT - Chinook & Steelhead Smolt Rearing Report

Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)
Water year: 2006
Location of interest: Sacramento R: Knights Ldg - Yolo via Fremont - Rio Vista
Species Late Fall Chinook
Units Percent Weight Change

DeltaEFT - Chinook & Steelhead Smolt Rearing Report

The **tan-shaded** distribution in the graph at the left shows the relative abundance of smolts as each day-cohort enters the selected route in the network. The R/Y/G dotted colored line shows the total value of the Performance Measure (Y-axis) for each day-cohort during its passage along the selected route, with the color indicating the overall performance of the route.

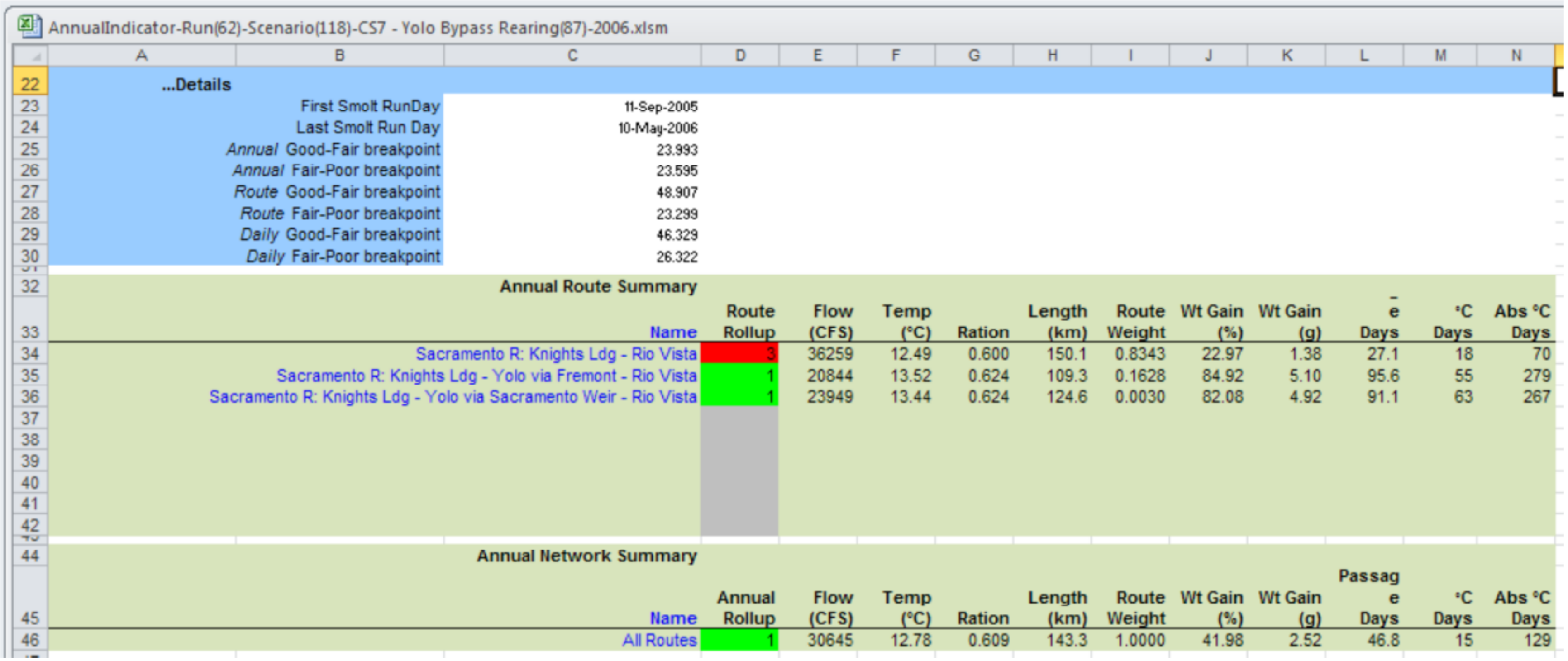
Although passage may last for up to several weeks, the value for each day-cohort is graphed on the ***first day*** of passage.

A summary of Growth, Passage Time and Temperature Stress for each route is shown in the Metadata sheet; daily

Each point shows the average flow (blue) and temperature (red) experienced by each day-cohort as it migrates downstream along the selected route.

Although passage may last for up to several weeks, the value for each day-cohort is graphed on the ***first day*** of passage.

Figure 2.11: An example of screen captures from the Annual Rollup report for CS7: Smolt Development and Growth. This example shows Late-fall Chinook WY2006 from two routes in the Historical calibration run. Note that the tan day-cohort distributions of the Sacramento (left) and Yolo route (right) are complementary and that in this year the Sacramento route is ranked Red while the Yolo route is ranked Green due to higher weight gain.



AnnualIndicator-Run(62)-Scenario(118)-CS7 - Yolo Bypass Rearing(87)-2006.xlsm

...Details

First Smolt RunDay	11-Sep-2005
Last Smolt Run Day	10-May-2006
Annual Good-Fair breakpoint	23.993
Annual Fair-Poor breakpoint	23.595
Route Good-Fair breakpoint	48.907
Route Fair-Poor breakpoint	23.299
Daily Good-Fair breakpoint	46.329
Daily Fair-Poor breakpoint	26.322

Annual Route Summary

Name	Route Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	e Days	°C Days	Abs °C Days
Sacramento R: Knights Ldg - Rio Vista	🟥 3	36259	12.49	0.600	150.1	0.8343	22.97	1.38	27.1	18	70
Sacramento R: Knights Ldg - Yolo via Fremont - Rio Vista	🟩 1	20844	13.52	0.624	109.3	0.1628	84.92	5.10	95.6	55	279
Sacramento R: Knights Ldg - Yolo via Sacramento Weir - Rio Vista	🟩 1	23949	13.44	0.624	124.6	0.0030	82.08	4.92	91.1	63	267

Annual Network Summary

Name	Annual Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passag e Days	°C Days	Abs °C Days
All Routes	🟩 1	30645	12.78	0.609	143.3	1.0000	41.98	2.52	46.8	15	129

Figure 2.12: An example of the metadata provided for CS7 based on the simulation shown in Figure 2.11. Each route is assigned a route-based rollup score and the year is assigned an overall rollup score. Metrics provided in route summary represent the weighted average experienced by all day-cohorts in each route; those in the Annual Network Summary day- and route-weighted averages and thus represent the entire year-cohort. In this year and for this run-type, 83% of the year-cohort migrates along the mainstem, 16% migrates through Yolo via Fremont Weir, and 0.3% migrates through Yolo via Sacramento Weir. Juveniles migrating through Yolo have a higher average ration of 62% of maximum, spend longer migrating (95 days vs. 27 days) and gain more weight (85% weight gain vs. 23% weight gain).

Spatial Reports

Spatial reports are available for the route rollup of CS7. These include R/Y/G coloring for the route ranking and variable line width to reflect the weight of the route. An example is shown below in Figure 2.13.

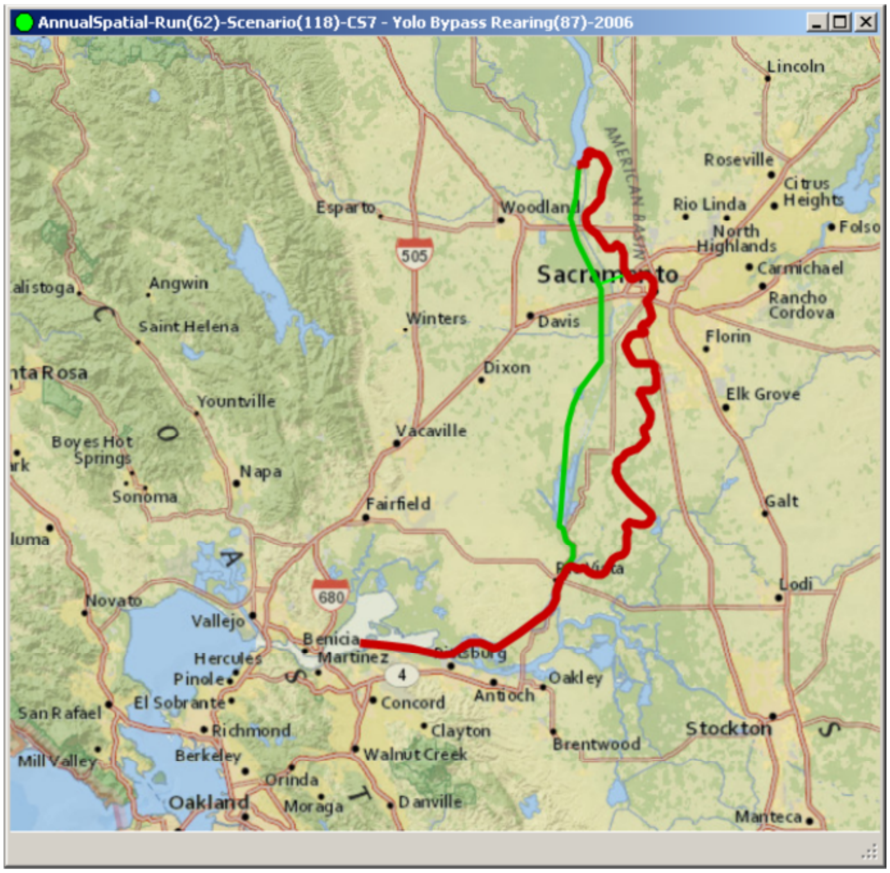


Figure 2.13: An example of the Spatial route rollup for CS7, showing the route-weighted R/Y/G score for Late-fall Chinook in WY2006 from the Historical simulation. Line width is based on the route-weight (see Figure 2.12). The Annual rollup value is shown by the green dot at the upper left corner.

PM Uncertainties and Overall Reliability

Our hypothesis that smolts “go with the flow” is based on the most recent observations, but it is possible that juveniles perceive additional cues that could affect route choice at different times or in different locations.

Two additional sources of uncertainty remain. First, our choice of 60% default ration and 80% ration in Yolo Bypass after 14 days of inundation are both arbitrary. Both assumptions could probably be improved through comparison with observed weight gain along the different migration routes. Secondly, although the representation of routes is strictly one-dimensional, it reproduces the range of observed passage times reasonably well. However, when flow over Fremont or Sacramento Weir is declining toward cessation, some day-cohorts become “computationally stranded” in the Bypass with no flow or velocity to move them downstream to the next segment. As a short-term solution, the flow on the previous non-zero day is used to simulate migration until they reach the end of the segment, and flow once again becomes non-zero. However, last-day flow is likely to be very low and can lead to very long predicted passage times in the Bypass; this is something that can be seen in some Annual Rollup graphs.

We do not think that a detailed hydrologic and bathymetric model of Yolo Bypass is called for, but that future model development should consider some rules-of-thumb which result in plausible passage times and growth for these "stranded" day-cohorts.

Finally, it is possible to link migration timing with the (upstream) juvenile rearing Performance Measures simulated with the Sacramento EFT model. Currently a fixed calendar is used, but if SacEFT is actively simulating rearing in the natal headwaters, it should be possible to use the time that pre-smolts leave the headwaters to more directly simulate their arrival at Knights Landing or other locations.

CS9 – Smolt Predation Risk

Rationale

As juvenile salmonids migrate downstream they may experience mortality from bass (Figure 2.3). During the Design Workshop it became apparent that directly modeling such predation was not feasible due to the complexity of predator-prey dynamics, which would probably require an additional model of predator population dynamics, including density-dependence. As a simpler solution, juvenile passage time was selected as an index of predation risk. If the CS9 Predation Risk index were compared against CS7 in the same location, it would be negatively correlated, since the benefit of additional growth creates the risk of additional mortality. Such is life.

Migration Speed and Timing

Migration speed is simulated using the flow-distance relationship described for CS7, which is ultimately based on Cavallo *et al.* 2008 (see Figure 2.6). Similarly, the timing of migration uses the same Knights Landing temporal datum, shifted later in time by 17 days to account for the passage time required to travel from Knights Landing (RM91) to Hood (RM49), which is the upstream starting point for the Performance Measure.

Routing Logic

The CS9 PM uses the very simple linear route shown in Figure 2.14 and Table 2.5. The route traversal logic and rules are identical to those used for CS7.

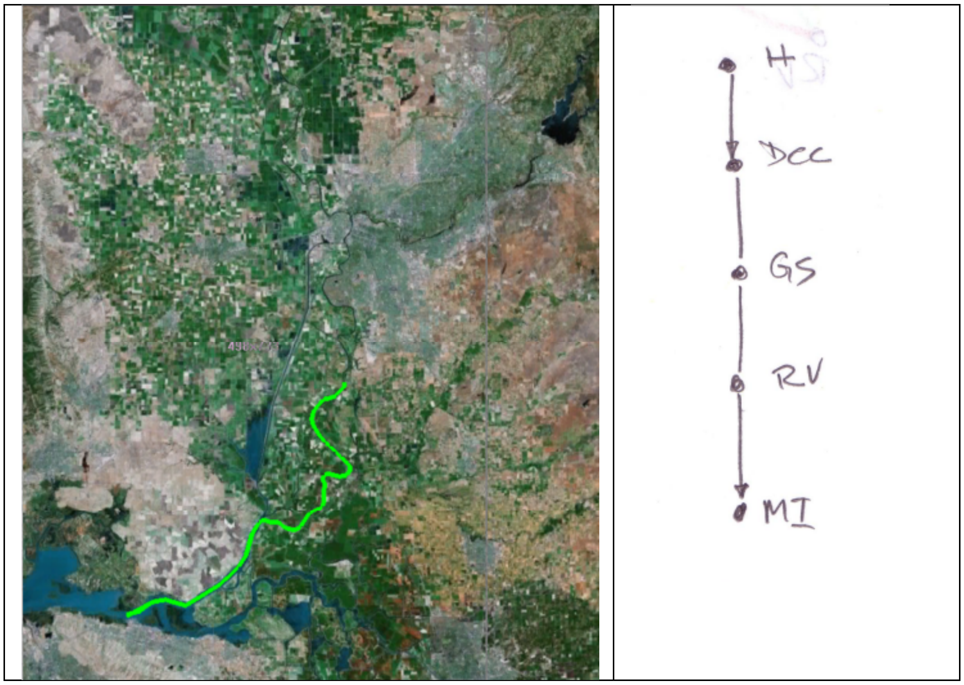


Figure 2.14: The CS9 Performance Measure includes a single route from Hood to Mallard Island. The left panel shows the route as draw from Google Earth. A schematic view of the route is shown at right. ***Node abbreviations:*** H=Hood; DCC=Delta Cross Channel; GS=Georgiana Slough; RV=Rio Vista; MI=Mallard Island.

Table 2.5: Parameters of the route used for CS9 Performance Measure: Smolt Predation Risk. This table represents the content of the EFT database table: dbo.Spatial_Route. Columns marked F-1, T-1, FT-1 *etc.* denote EFT gauge location identifiers for Flow, Temperature and combined Flow-Temperature, respectively. '1' gauges are preferred but '2' gauges will be used if data are sparse or missing from the '1' gauge. A limited number of simulation gauges were available for fitting the Version 1 model, leading to repeated use of some gauges. Node abbreviations in the first column are provided in Figure 2.14.

Route & Nodes	ID	Seq.	Start Link	End Link	Length (km)	Junction	Weir	Historical				Simulated	
								F-1	F-2	T-1	T-2	FT-1	FT-2
SR: H – DCC	904	1	1	2	16.80			308		389		389	307
SR: DCC – GS		2	2	3	2.86			308		389		308	307
SR: GS – RV		3	3	4	21.60			307	308	389		307	
SW: RV – MI		4	4	5	26.00			300		300	357	357	300

Calibration

Calibration criteria for CS9 were not available following the Design Workshop. In the absence of specific guidance, DeltaEFT uses discontinuities in the annual rollup distribution to divide the distribution of passage days into upper, middle and lower groups that are then used to assign a R/Y/G score. We initially used a 6 year period of Historical data (WY 2002-2007), but upon review determined that this period has an excess of wet year types, in addition to being of short duration. To try to provide a more balanced mixture of year types we added more observations from the 16-year span of the NAA-Current scenario (WY1976-1991; refer to BDCP EIR-EIS documentation on No Action Alternative[8]) to try to provide a better mixture of year types. These two sources are shown by red (Historical) and blue (NAA-Current) points in Figure 2.15. The figure columns show the distributions at three different time scales, but the thresholds themselves are based on the distribution of the Year rollup in the right-most column and are held constant across the time scales. The Day distribution (left-most column) shows the passage time for each day-cohort without weighting the day-cohort, and clearly indicates that some rare day-cohorts experience very short passage times. The Route distribution uses weighted day-cohorts within each route, and the Year calibration combines both day- and route-weights into a weighted passage time. Calibration values are shown in Table 2.6. As the time-scale is lengthened and the totality of the annual cohort is factored into the weighted result, the wide range of the distribution is narrowed considerably. The rows show the distribution of observations for each of the five run-types. While larger values are better for CS7, smaller values are better for CS9.

Table 2.6: Breakpoints for the CS9 smolt predation risk indicator. Units are passage time days and smaller values are better.

	Daily		Route		Annual	
Run-type	**Good-Fair**	**Fair-Poor**	**Good-Fair**	**Fair-Poor**	**Good-Fair**	**Fair-Poor**
Spring	≤12	≥16	≤12	≥16	≤12	≥16
Fall	≤12	≥16	≤12	≥16	≤12	≥16
Late-fall	≤12	≥16	≤12	≥16	≤12	≥16
Winter	≤12	≥16	≤12	≥16	≤12	≥16
Steelhead	≤12	≥16	≤12	≥16	≤12	≥16

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[8] The NEPA Baseline for assessing environmental effects, including cumulative effects, of the Proposed Project and alternatives is defined as the No Action Alternative. The No Action Alternative also demonstrates the future consequences of not meeting the need of the Proposed Project. Under NEPA, the No Action Alternative describes the future conditions if the Proposed Project were not approved and there was no change from current management direction or level of management intensity. The No Action Alternative may include reasonably foreseeable future actions that are not consistent with existing plans, infrastructure, or services if the actions are consistent with existing management direction or level of management.

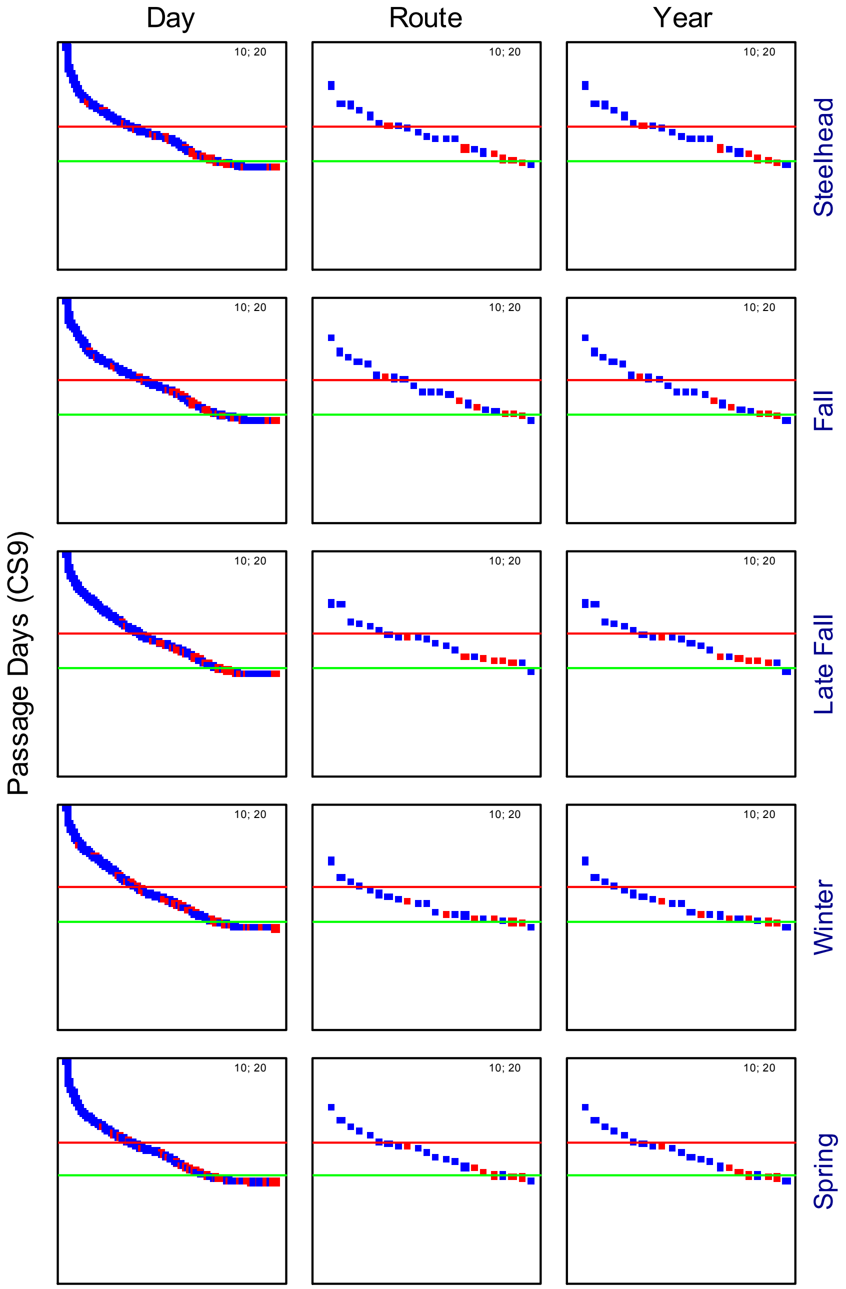
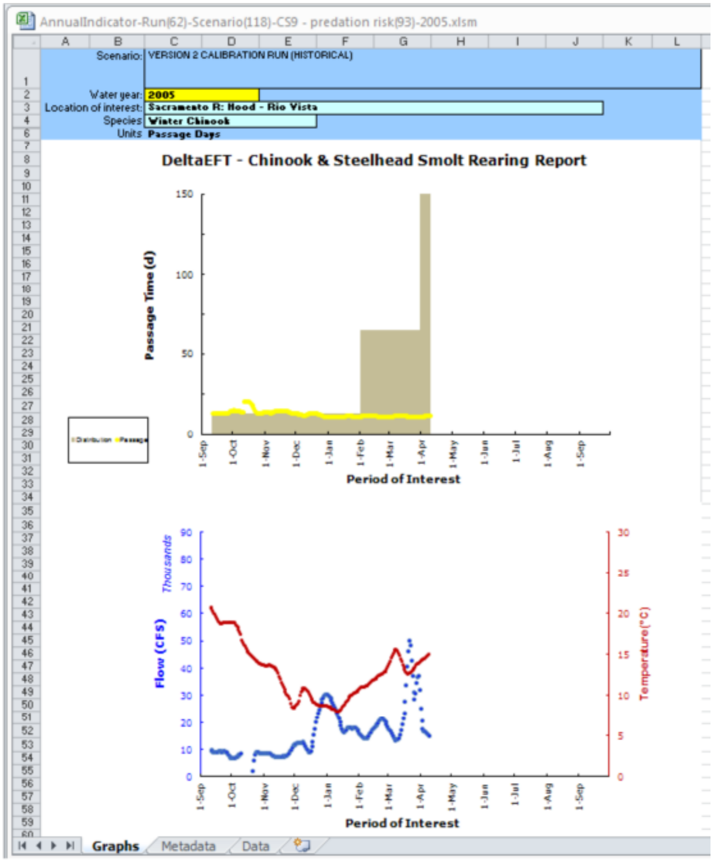


Figure 2.15: The CS9 Performance Measure calibration is based on the distribution of passage days simulated using Historical (red) flow data, augmented by the NAA-Current simulation (blue), and is made at three temporal scales (columns) for five run-types (rows). The Day-calibration is unweighted; the Route-calibration incorporates day-cohort weights based on the migration timing distribution; and the Year-calibration incorporates weights based on the proportion of juveniles migrating through each route. Route and Year calibrations are identical for CS9 because only 1 route is defined.

Excel Reports

Excel reports and metadata are available for the annual rollup of CS9. An example is shown below in Figure 2.16.



AnnualIndicator-Run(62)-Scenario(118)-CS9 - predation risk(93)-2005.xlsm

Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)
Water year: 2005
Location of interest: Sacramento R: Hood - Rio Vista
Species: Winter Chinook
Units: Passage Days

Figure 2.16: An example screen capture from the Annual Rollup report for CS9: Smolt Predation Risk. This example shows winter-run Chinook in WY2005 from the Historical calibration run.

Spatial Reports

Spatial reports are available for the route rollup of CS9. These include R/Y/G coloring for the route ranking and variable line width to reflect the weight of the route. An example is shown below in Figure 2.17.

Figure 2.17: An example of the spatial route rollup for CS9 for Winter Chinook in WY2005 from the Historical simulation. The Annual rollup value is shown by the yellow dot at the upper left corner. Since there is only one route for CS9, the route- and annual-rollups are identical.

PM Uncertainties and Overall Reliability

Many of the uncertainties described for CS7 apply to CS9. Because the route currently defined for CS9 does not include the complex hydrology of Yolo Bypass in which zero-flow over the weirs can cause “computational stranding,” that particular weakness is not an issue for the current route.

CS10 – Smolt Thermal Stress

Rationale

Following outmigration from their natal streams in the Sacramento River, juvenile salmonids rear in the Bay-Delta, growing and becoming adapted to marine conditions. During this residency period they must balance needs that include environmental variables as oxygen, temperature, salinity, turbidity, food resources and predation risk. Many of these requirements are ultimately linked to the physiological costs of growth, maintenance and respiration; processes that are summarized through growth rate (Williams 2006b; Shelbourn *et al.* 1973). We assume that the temperature which provides the highest rate of weight gain minimizes temperature stress for a given food supply, and therefore use the maximum value from this dome-shaped relationship as a measure of temperature stress (Figure 2.4).

Water temperature in the Bay-Delta is chiefly driven by ambient air temperature and is likely to vary in future climate scenarios simulated with DeltaEFT. The PM can demonstrate differences in temperature stress among historical and simulated future years as well as differences driven by climate change. 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 result in reduced temperature stress. The PM has the additional benefit of being easy to measure and simulate, relative to many other indicators of physical stress.

The approach is related to the method used for measuring daily weight change already described for CS7. In this case however, we use the difference between the measured daily temperature and the optimum temperature at the peak of the dome-shape function. The departure is measured two ways using the relationship shown in Figure 2.4. First, we measure using positive degree-days when the ambient temperature is above the optimum and negative degree-days when the ambient temperature is below the optimum. We also measure using the absolute value. The absolute-value degree-days measurement is used as the unit of the PM, since it circumvents the cancellation that occurs when positive and negative units are added, which would otherwise understate the true amount of thermal stress. We considered but did not include a direct mortality model such as the one developed by Baker *et al.* (1995, Figure 4), since the survival curve for the direct mortality model shows a very similar shape to the growth-rate curve of Brett, but is limited to warmer water (>16°C), while the Brett relationship also includes colder temperature.

Migration Speed and Timing

Migration speed is simulated using the flow-distance relationship described for CS7. Similarly, the timing of migration uses the same Knights Landing temporal datum, shifted later in time by 17 days to account for the passage time required to travel from Knights Landing (RM91) to Hood (RM49), which is the upstream starting point for the Performance Measure.

Routing Logic

The CS10 PM uses a fairly complex 6-path route shown in Figure 2.19 and Table 2.7. The route traversal logic and rules are identical to those used for CS7 and CS9. The 6 paths are derived from the 4 routes selected by Perry *et al.* (2010, Figure 1), which include the Sacramento River (A), Sutter and Steamboat Slough (B), Delta Cross Channel (C) and Georgiana Slough (D). Because of the way in which routes are defined and processed internally, the EFT system of routes required a further subdivision of two of Perry's routes to account for additional large waterways.

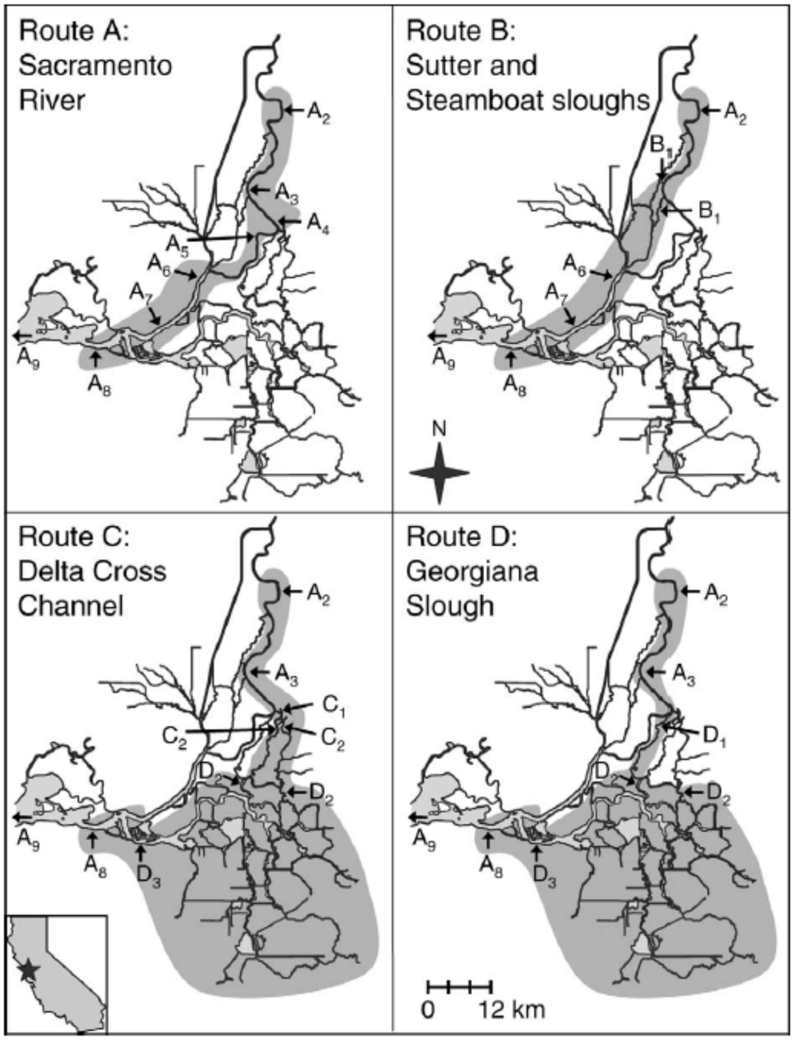


Figure 2.18: Figure 1 of Perry *et al.* (2010), showing their choice of important migration route pathways taken by juvenile Chinook salmon. Key points along the four migration routes are denoted by letters A-D, all of which are included in CS10.

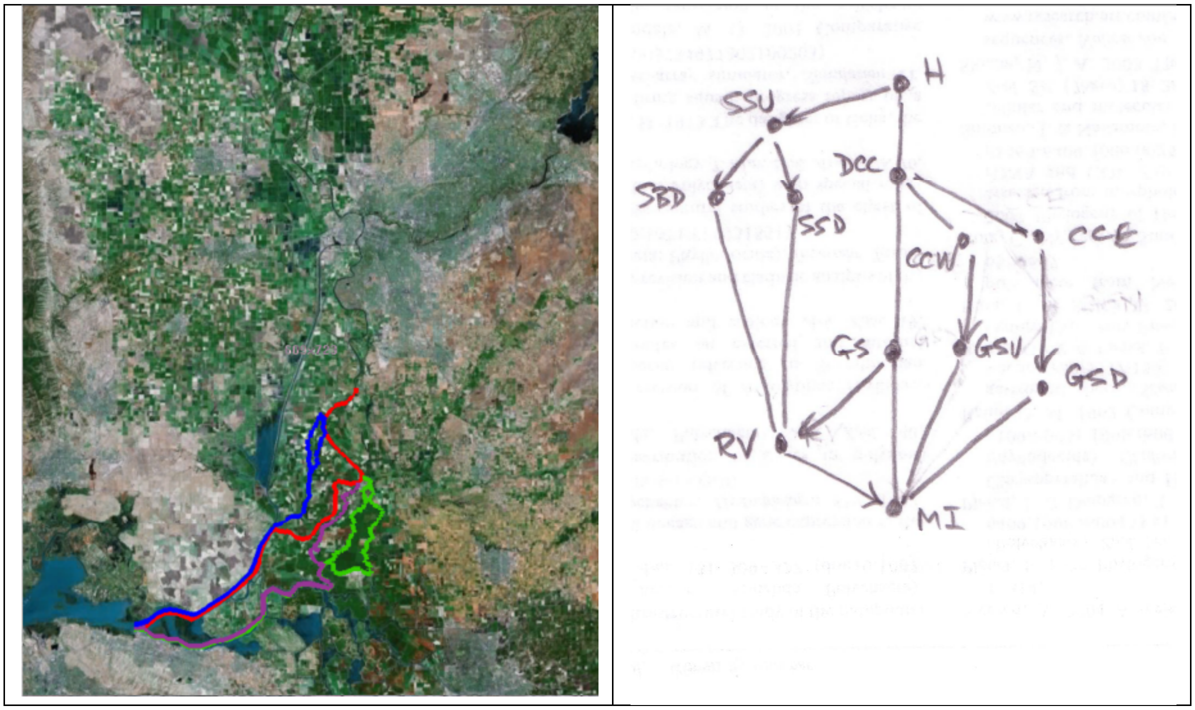


Figure 2.19: The CS10 Performance Measure includes six routes through the eastern Delta, from Hood to Mallard Island. In the left panel, the two blue paths extend through Steamboat and Sutter Sloughs; the red path follows the Sacramento River; the green path follows two paths downstream from the Delta Cross Channel gate, and the purple path follows Georgiana Slough. A schematic view of the routes is shown at right. Route splitting logic governs the division of day-cohorts of migrating juveniles. ***Node abbreviations:*** H=Hood; SSU=Sutter Slough Upstream; SSD=Sutter Slough Downstream; SBD=Steamboat Slough Downstream; DCC=Delta Cross Channel; CCE=Cross Channel East; CCW=Cross Channel West; GS=Georgiana Slough; GSU=Georgiana Slough Upstream; GSD=Georgiana Slough Downstream; RV=Rio Vista; MI=Mallard Island.

Table 2.7: Parameters of the 3 routes used for CS10 Performance Measure: Smolt Thermal Stress. This table represents the content of the EFT database table: dbo.Spatial_Route. Columns marked F-1, T-1, FT-1 *etc.* denote EFT gauge location identifiers for Flow, Temperature and combined Flow-Temperature, respectively. ‘1’ gauges are preferred but ‘2’ gauges will be used if data are sparse or missing from the ‘1’ gauge. A limited number of simulation gauges were available for fitting the Version 1 model, leading to repeated use of some gauges. Node abbreviations in the first column are provided in Figure 2.19.

								Historical				**Simulated**	
Route & Nodes	**ID**	**Seq.**	**Start Link**	**End Link**	**Length (km)**	**Junction**	**Weir**	**F-1**	**F-2**	**T-1**	**T-2**	**FT-1**	**FT-2**
SS: H – SSU	905	1	1	7	7.17			308		389		389	307
SS: SSU – SSD		2	7	8	10.50			310	308	389		389	437
SS: SSD – RV		3	8	5	14.50			310	300	389		389	437
SS: RV – MI		4	5	6	26.00			300		300	357	357	300
SB: H – SSU	906	1	1	7	7.17			308		389		389	307
SB: SSU – SBD		2	7	9	9.92			310	308	389		389	437
SB: SBD – RV		3	9	5	14.50			310	300	389	300	389	437
SB: RV – MI		4	5	6	26.00			300		300	357	357	300
SR: H – DCC	907	1	1	2	7.00			308		389		389	307
SR DCC – GS		2	2	4	12.07			308	307	389		308	307
SR: GS – RV		3	4	5	22.10			307	300	389	300	307	311
SR: RV – MI		4	5	6	26.00			300		300	357	357	300
CC1: H - DCC	908	1	1	2	7.00			308		389		389	307
CC1: DCC – CCE		2	2	3	12.81			308	307	389		308	307
CC1: CCE – GSD		3	3	10	27.50			308	307	390	389	307	307
CC1: GSD – MI		4	10	6	40.80			300	308	386	302	307	311
CC2: H – DCC	909	1	1	2	7.00			308		389		389	307
CC2: DCC – CCW		2	2	3	12.81			308	307	389		308	307
CC2: CCW - GSU		3	3	11	17.90			308	307	390	389	307	307
CC2: GSU – MI		4	11	6	41.90			300	308	386	302	307	311
GS: H – DCC	910	1	1	2	7.00			308		389		309	307
GS: DCC – GS		2	2	4	12.07			308	307	389		308	386
GS: GS – MI		3	4	6	40.80			300	308	386	302	386	302

Calibration

Calibration criteria for CS10 were not available following the Design Workshop. In the absence of specific guidance, DeltaEFT uses discontinuities in the annual rollup distribution to divide the distribution of accumulated degree-days into upper, middle and lower groups that are then used to assign a R/Y/G score. We initially used a 6 year period of Historical data (WY 2002-2007), but upon review determined that this period has an excess of wet year types, in addition to being of short duration. To try to provide a more balanced mixture of year types we added more observations from the 16-year span of the NAA-Current scenario (WY1976-1991; refer to BDCP EIR-EIS documentation on No Action Alternative[9]) to try to provide a better mixture of year types. These two sources are shown by red (Historical) and blue (NAA-Current) points in Figure 2.20. The figure columns show the distributions at three different time scales, but the thresholds themselves are based on the distribution of the Year rollup in the right-most column and are held constant across the time scales. The Day distribution (left-most column) shows degree-days for each day-cohort without weighting the day-cohort, and clearly indicates that some rare day-cohorts experience very high accumulated thermal stress. The Route distribution uses weighted day-cohorts within each route, and the Year calibration combines both day- and route-weights into a weighted passage time. Calibration values are shown in Table 2.8. As the time-scale is lengthened and the totality of the annual cohort is factored into the weighted result, the wide range of the distribution is narrowed considerably. The rows show the distribution of observations for each of the five run-types. While larger values are better for CS7, smaller values are better for CS10.

Table 2.8: Breakpoints for the CS10 smolt thermal stress indicator. Units are degree-days (°C-d) departure from optimal growth temperature and smaller values are better.

	Daily		Route		Annual	
Run-type	**Good-Fair**	**Fair-Poor**	**Good-Fair**	**Fair-Poor**	**Good-Fair**	**Fair-Poor**
Spring	≤68	≥100	≤68	≥100	≤68	≥100
Fall	≤68	≥100	≤68	≥100	≤68	≥100
Late-fall	≤39	≥53	≤39	≥53	≤39	≥53
Winter	≤39	≥53	≤39	≥53	≤39	≥53
Steelhead	≤68	≥100	≤68	≥100	≤68	≥100

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[9] The NEPA Baseline for assessing environmental effects, including cumulative effects, of the Proposed Project and alternatives is defined as the No Action Alternative. The No Action Alternative also demonstrates the future consequences of not meeting the need of the Proposed Project. Under NEPA, the No Action Alternative describes the future conditions if the Proposed Project were not approved and there was no change from current management direction or level of management intensity. The No Action Alternative may include reasonably foreseeable future actions that are not consistent with existing plans, infrastructure, or services if the actions are consistent with existing management direction or level of management.

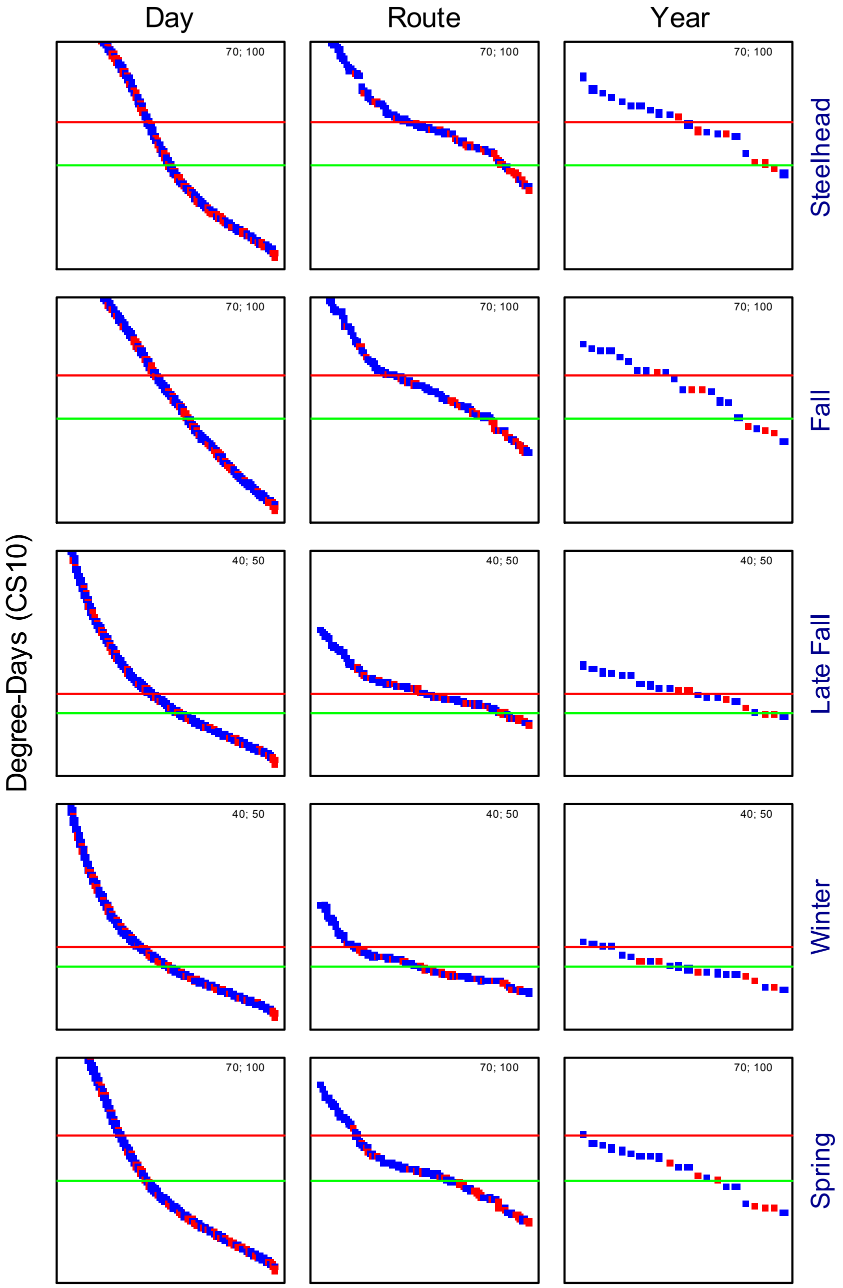
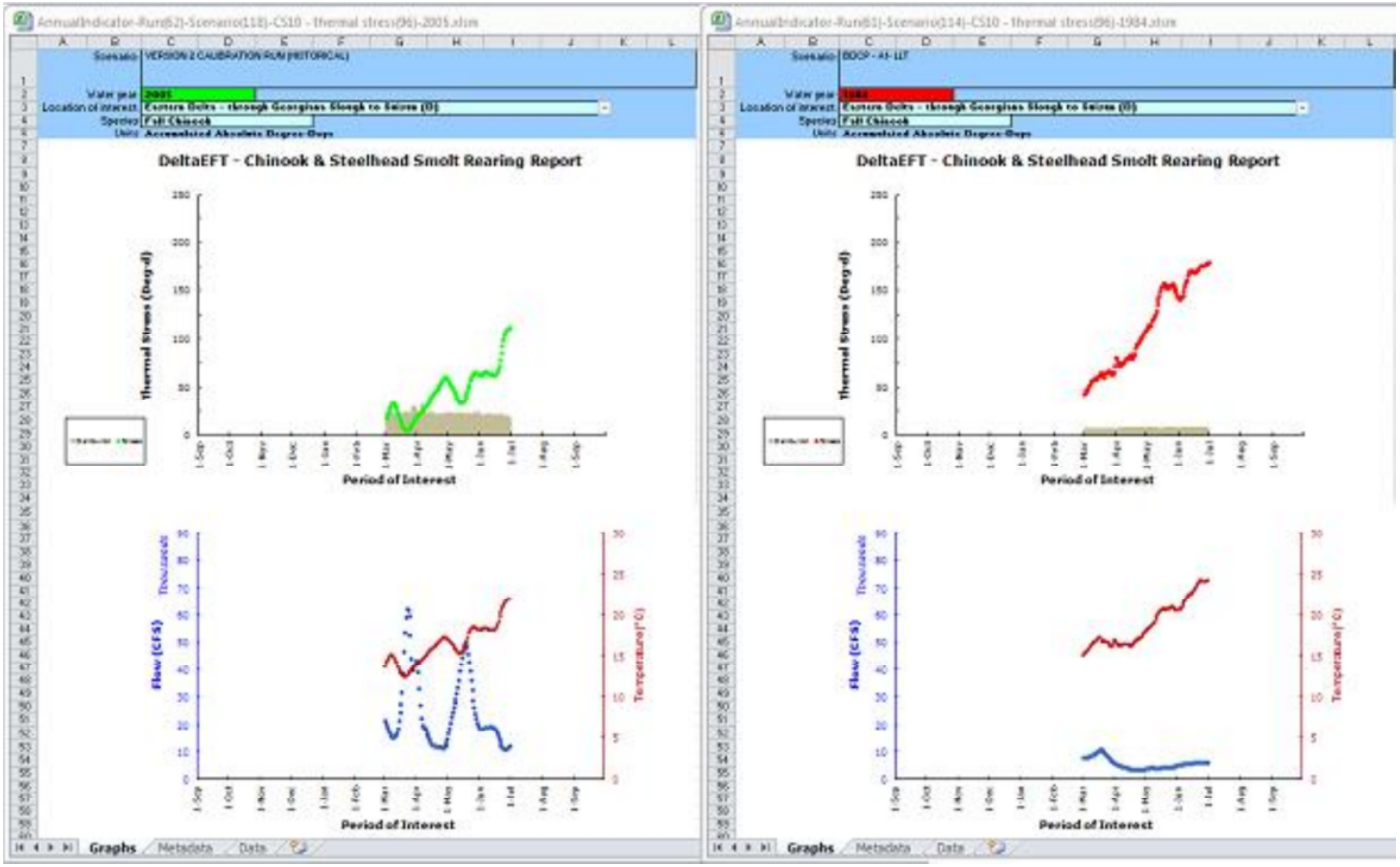


Figure 2.20: The CS10 Performance Measure calibration is based on the distribution of accumulated degree-days of thermal stress simulated using Historical (red) flow and temperature data, augmented by the NAA-Current simulation (blue), and is made at three temporal scales (columns) for five run-types (rows). The Day-calibration is unweighted; the Route-calibration incorporates day-cohort weights based on the migration timing distribution; and the Year-calibration incorporates weights based on the proportion of juveniles migrating through each route.

Excel Reports

Excel reports and metadata are available for the annual rollup of CS10. An example is shown below in Figure 2.21 and Figure 2.22 for Fall-run Chinook migrating through the Georgiana Slough route. Comparing these two reports shows the difference between a Good year (2005) for the Historical simulation, and a Poor Year (1984) for a scenario called "A1-LLT." This A1-LLT scenario simulates future hydrosystem dynamics for a 2060 climate regime, including the effects of climate change and water allocation changes. The tan histograms on the two upper panels show that the proportion of the total year-cohort migrating along the Georgiana Slough route is reduced in the A-LLT scenario to about one quarter of the Historical scenario. Water temperature is also higher and flow is lower, compared to the Historical scenario, which shows two high storm flow events. Route and system summaries are shown in Figure 2.22, which shows how route rankings are linked with flow conditions.



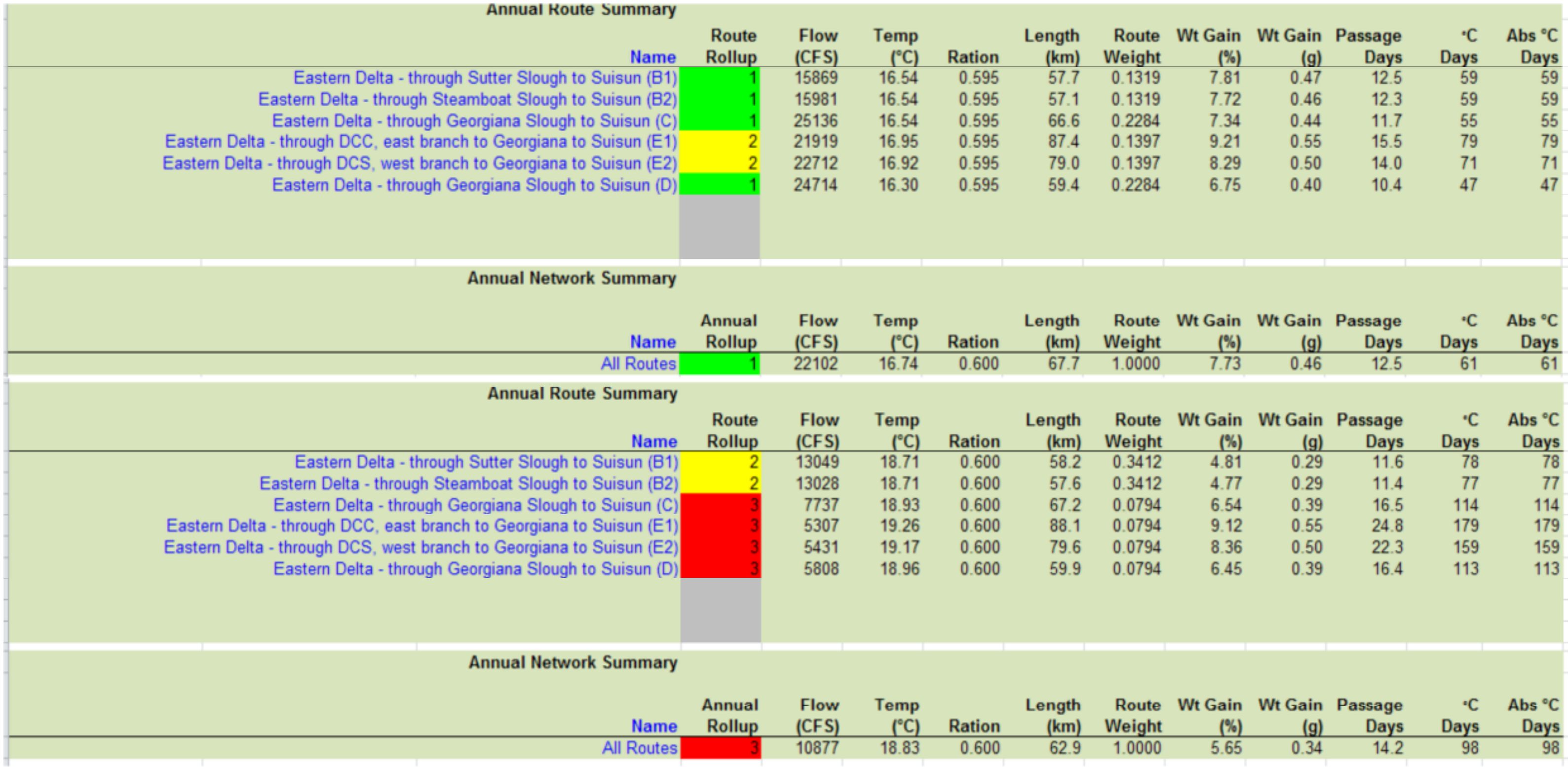
AnnualIndicator-Run(62)-Scenario(118)-CS10 - thermal stress(96)-2005.xlsm

Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)
Water year: 2005
Location of interest: Eastern Delta - through Georgiana Slough to [illegible]
Species: Fall Chinook
Units: Accumulated Absolute Degree Days

AnnualIndicator-Run(61)-Scenario(114)-CS10 - thermal stress(96)-1984.xlsm

Scenario: BDCP - A1-LLT
Water year: 1984
Location of interest: Eastern Delta - through Georgiana Slough to [illegible]
Species: Fall Chinook
Units: Accumulated Absolute Degree Days

Figure 2.21: Example screen captures from the Annual Rollup report for CS10: Smolt Thermal Stress. This example shows Fall-run Chinook from WY2005 (Historical scenario) and WY1984 (A1-LLT scenario) along the Georgiana Slough route. Note the steady lower flow in the A1-LLT simulation compared to the higher pulsing flow in the Historical simulation.



Annual Route Summary

Name	Route Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
Eastern Delta - through Sutter Slough to Suisun (B1)	1	15869	16.54	0.595	57.7	0.1319	7.81	0.47	12.5	59	59
Eastern Delta - through Steamboat Slough to Suisun (B2)	1	15981	16.54	0.595	57.1	0.1319	7.72	0.46	12.3	59	59
Eastern Delta - through Georgiana Slough to Suisun (C)	1	25136	16.54	0.595	66.6	0.2284	7.34	0.44	11.7	55	55
Eastern Delta - through DCC, east branch to Georgiana to Suisun (E1)	2	21919	16.95	0.595	87.4	0.1397	9.21	0.55	15.5	79	79
Eastern Delta - through DCS, west branch to Georgiana to Suisun (E2)	2	22712	16.92	0.595	79.0	0.1397	8.29	0.50	14.0	71	71
Eastern Delta - through Georgiana Slough to Suisun (D)	1	24714	16.30	0.595	59.4	0.2284	6.75	0.40	10.4	47	47

Annual Network Summary

Name	Annual Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
All Routes	1	22102	16.74	0.600	67.7	1.0000	7.73	0.46	12.5	61	61

Annual Route Summary

Name	Route Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
Eastern Delta - through Sutter Slough to Suisun (B1)	2	13049	18.71	0.600	58.2	0.3412	4.81	0.29	11.6	78	78
Eastern Delta - through Steamboat Slough to Suisun (B2)	2	13028	18.71	0.600	57.6	0.3412	4.77	0.29	11.4	77	77
Eastern Delta - through Georgiana Slough to Suisun (C)	3	7737	18.93	0.600	67.2	0.0794	6.54	0.39	16.5	114	114
Eastern Delta - through DCC, east branch to Georgiana to Suisun (E1)	3	5307	19.26	0.600	88.1	0.0794	9.12	0.55	24.8	179	179
Eastern Delta - through DCS, west branch to Georgiana to Suisun (E2)	3	5431	19.17	0.600	79.6	0.0794	8.36	0.50	22.3	159	159
Eastern Delta - through Georgiana Slough to Suisun (D)	3	5808	18.96	0.600	59.9	0.0794	6.45	0.39	16.4	113	113

Annual Network Summary

Name	Annual Rollup	Flow (CFS)	Temp (°C)	Ration	Length (km)	Route Weight	Wt Gain (%)	Wt Gain (g)	Passage Days	°C Days	Abs °C Days
All Routes	3	10877	18.83	0.600	62.9	1.0000	5.65	0.34	14.2	98	98

Figure 2.22: An example of the metadata provided for CS10 based on the two simulations shown in Figure 2.21. Each route is assigned a route-based rollup score and the year is assigned an overall rollup score. Metrics provided in route summary represent the weighted average experienced by all day-cohorts in each route; those in the Annual Network Summary are day- and route-weighted averages and thus represent the entire year-cohort.

Spatial Reports

Spatial reports are available for the route rollup of CS10. These include R/Y/G coloring for the route ranking and variable line width to reflect the weight of the route. An example is shown below in Figure 2.23.

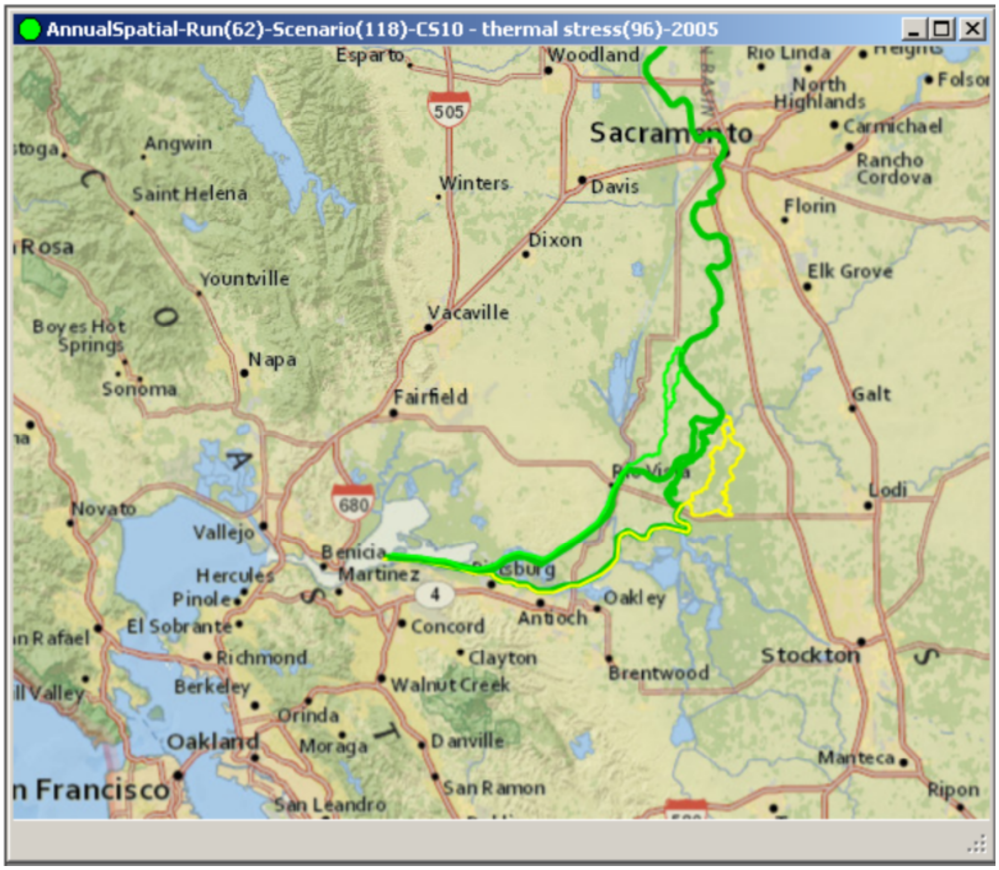


Figure 2.23: An example of the spatial route rollup for CS10 for Fall-run Chinook in WY2005 from the Historical simulation. The Annual rollup value is shown by the green dot at the upper left corner.

PM Uncertainties and Overall Reliability

Our hypothesis that smolts "go with the flow" is based on the most recent observations, but it is possible that juveniles perceive additional cues that could affect route choice at different times or in different locations.

As in the case of CS9, it is possible to link migration timing with the (upstream) juvenile rearing Performance Measures simulated with the Sacramento EFT model. Currently a fixed calendar is used, but if SacEFT is actively simulating rearing in the natal headwaters, it should be possible to use the time that pre-smolts leave the headwaters to more directly simulate their arrival at Knights Landing or other locations.

Empirical and theoretical studies of foraging behavior (Webster and Dill 2006; Webster *et al.* 2007) show that physiological optimality (to temperature in this case) does not completely describe salmonid preferences. In the case of Chinook, behavioral temperature preferences are cooler than the optimal physiological (minimum energy expenditure) temperature, possibly because the fish are conservative in the face of predator risk and select cooler habitats even though they are acting against their physiological best interest. If this is true for Sacramento stocks, then the measurement of degree-days may be using a datum (the physiological optimum) that is higher than the one actually used by juveniles. Since above-optimum temperature is much more common than below-optimum, this would result in an understatement of the total absolute degree-days of behavior-based optimum. However, the rankings of results would remain unchanged.

2.2.2 Delta smelt

The Delta smelt conceptual model is shown in Figure 2.24.

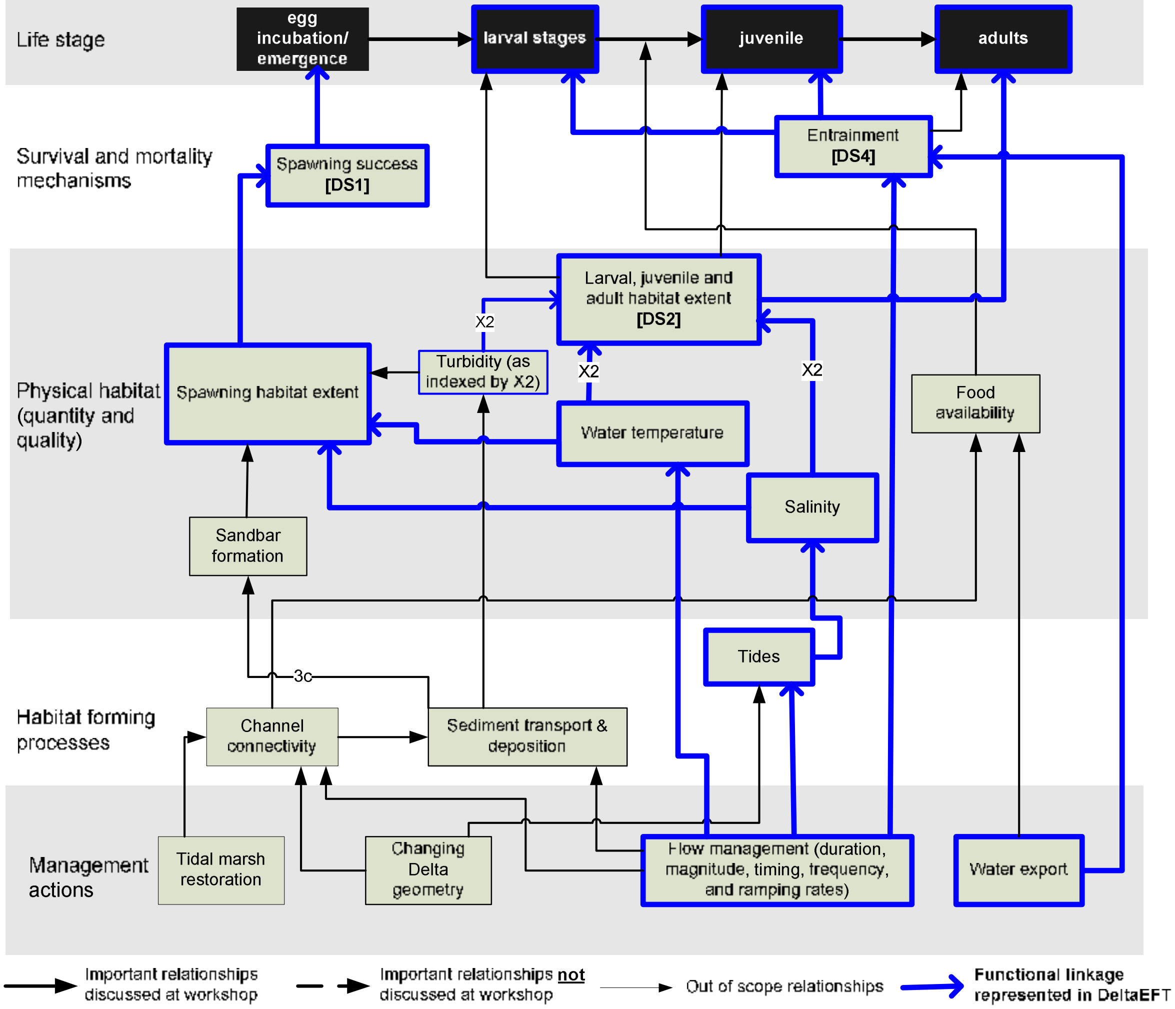


Figure 2.24: The conceptual model representing the links between management actions and Delta smelt, as mediated by changes in habitat forming processes. Heavy blue lines show the processes and linkages that are included in DeltaEFT.

DeltaEFT includes 3 PMs that describe changes in the physical habitat available to Delta smelt (Table 2.9).

Table 2.9: Performance measures for Delta smelt.

Performance Measure	Synonyms	PM code
Index of spawning success		DS1
Index of habitat suitability		DS2
Risk of entrainment	Entrainment	DS4

The approach and data we used are largely based on studies published in the primary literature.

DS1 – Index of spawning success

Rationale

Empirical evidence suggests that spring water temperature affects the spawning success of the population (Bennett 2005), *i.e.*, the number of fish that successfully spawn. Extended periods with cool water in spring typically result in more spawning events, and thus more abundant cohorts produced (Bennett 2005). For example, fish that are spawned late in the cool year may not reach reproductive maturity by the time water temperatures reach 20°C in the following warm year, thus decreasing the number of spawners in the warm year. A longer spawning period, which is made possible by an earlier spawning start date, increases the probability of all fish reaching spawning maturity in that year (Bennett 2005). Additionally, Delta smelt can be iteroparous, meaning they can spawn multiple times in a single season (Bennett 2005; Wang 2007). A longer spawning season increases the probability of this occurring, further adding to increased spawning success.

Water temperature is only one of many factors affecting spawning success. Exposure to other factors affecting spawning success (*e.g.*, occurrence with food supply, predators, pulses of toxic chemicals) is not taken into consideration in this PM.

Performance measure

Adults spawn in freshwater during late winter and spring months, with the majority of spawning occurring in March through April (Moyle 2002). The spawning period typically spans from late February through to May, however spawning can extend into June if water temperatures are favorable (Delta smelt BiOp 2008). For the purposes of this PM, the spawning season is defined as February 1st to June 1st, assuming Delta smelt will spawn in this interval if the conditions are favorable.

The majority of spawning occurs at temperatures between 7 and 15°C (Moyle 2002), with peak occurrence of ripe females at 12-16°C (Nobriga, pers. comm.). Hatch success is highest at about 15°C, and decreases at lower and higher temperatures (temperatures < 10°C and > 20°C result in very poor hatch success; Bennett 2005).

Delta smelt distribution is closely tied to the low salinity zone (centered at 2‰; Kimmerer 2002) and tidal freshwater areas of the Delta, with over 90% occurring at < 6‰ (Bennett 2005). Salinities > 19‰ are lethal to Delta smelt (Swanson *et al.* 2000).

The daily habitat suitability indices for spawning are based on salinity and temperature thresholds (Figure 2.25 and Figure 2.26).

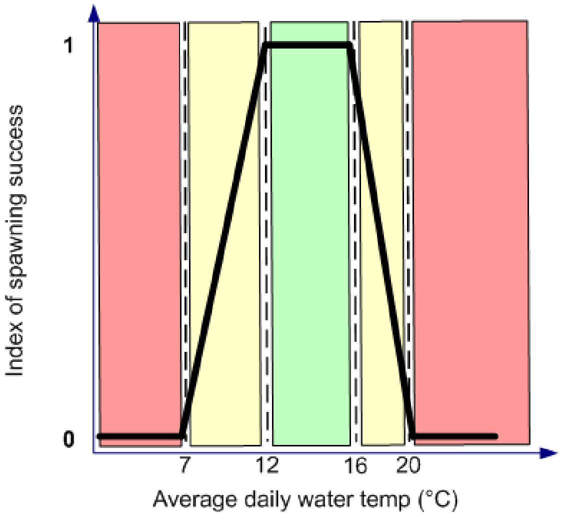


Figure 2.25: Daily temperature thresholds for spawning success. Temperature of 12-16°C are ideal for successful spawning success (green), temperatures of 7-12°C and 16-20°C are moderately good (yellow), and temperature <7°C and >20°C result in poor recruitment success (red).

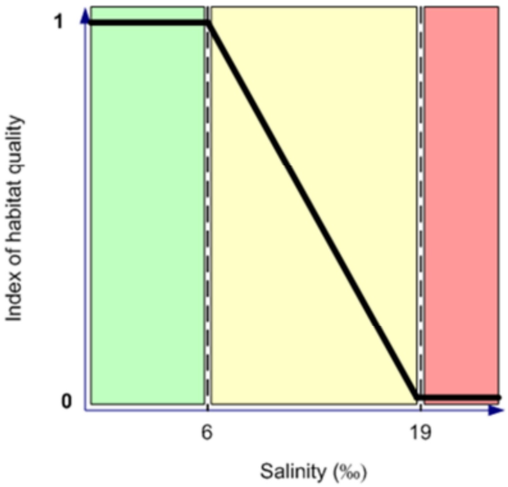


Figure 2.26: Daily salinity thresholds for spawning success. Salinities of < 6‰ are preferable (green), salinities between 6 and 19 ‰ are tolerable (yellow), and salinities > 19 ‰ are lethal (red).

The daily Habitat Suitability for spawning ($HS_{i,j}$) on location i, on day j is a function of the Habitat Suitability for Temperature ($HST_{i,j}$) and Habitat Suitability for Salinity ($HSS_{i,j}$):

$$HS_{i,j} = HST_{i,j} + 2 \cdot HSS_{i,j} \qquad \text{Eqn 2.2}$$

where salinity is twice as influential in determining habitat suitability compared to temperature. The rationale for weighting salinity more heavily than temperature is based on work by Feyrer *et al.* (2007), who found that temperature only explained 0.1% of the total deviance in their model, whereas salinity explained 18.6%.

The Habitat Suitability for Temperature (HST) is a function of average water temperature $\left(\overline{T}\right)$ for location i, on day j:

$$HST_{i,j} = \begin{cases} 0 \quad when\ (7°C \geq \overline{T}_{i,j} \leq 20°C) \\ \dfrac{\overline{T}_{i,j} - 7}{5} \quad when\ (7°C < \overline{T}_{i,j} < 12°C) \\ 1 \quad when\ \left(12°C \leq \overline{T}_{i,j} \geq 16°C\right) \\ 1 - \left(\dfrac{\overline{T}_{i,j} - 16}{4}\right) \quad when\ (16°C < \overline{T}_{i,j} < 20°C) \end{cases} \qquad \text{Eqn 2.3}$$

and the Habitat Suitability for Salinity (HSS) is a function of average water temperature $\left(\overline{S}\right)$ for location i, on day j:

$$HSS_{i,j} = \begin{cases} 0 \quad when\ (\overline{S} \geq 19\,psu) \\ 1 - \left(\dfrac{\overline{S} - 6}{13}\right) \quad when\ \left(6\,psu < \overline{S} < 19\,psu\right) \\ 1 \quad when\ \left(\overline{S} \leq 6\,psu\right) \end{cases} \qquad \text{Eqn 2.4}$$

The PM for Delta smelt Spawning (DS1) is based on the number of consecutive days of optimal habitat ($CDOP_{i,j}$), which is defined as:

$$CDOP_{i,j} = \begin{cases} CDOP_{i-1,j} + 1 \ \ if\ HS_{i,j} = 1 \\ 0 \ \ if\ HS_{i,j} < 1 \end{cases} \qquad \text{Eqn 2.5}$$

The cumulative daily PM is the maximum number of consecutive days with optimal habitat ($HS_{i,j} = 1$) before or on a given day i:

$$DS1_{i,j} = \begin{Bmatrix} DS1_{i-1,j} \ \ if\ CDOP_{i,j} \leq DS1_{i-1,j} \\ CDOP_{i,j} \ \ if\ CDOP_{i,j} > DS1_{i-1,j} \end{Bmatrix} \qquad \text{Eqn 2.6}$$

The annual PM for a location j ($DS1_j$) is the cumulative daily PM on the final day I of the spawning period,

$$DS1_j = DS1_{I,j} \qquad \text{Eqn 2.7}$$

and the annual rollup PM is calculated by assigning a weighting to each location (w_i),

$$DS1 = \sum_{j=1}^{J} DS1_j \cdot w_j \qquad \text{Eqn 2.8}$$

As very little is currently known about where Delta smelt spawn, we currently weight locations uniformly:

$$w_j = \frac{1}{J} \qquad \text{Eqn 2.9}$$

where J is the number of locations. More research and information on spawning may allow future stratification of the Delta using a weighting scheme based on preferred Delta smelt spawning areas.

Locations of interest

Spawning locations are unknown and inferred from catches of very young larvae and adult fish as they transition from fecund to spawned (Bennett 2005). In years of low flows, most fecund females and yolk-sac larvae are found in the Sacramento River, particularly around Prospect Island and the Barker-Lindsey slough complex. In years of high flow, spawning is more broadly distributed across most of the Delta, Suisun Marsh channels, and the Napa River.

Since spawning locations are unknown, DS1 locations of interest were selected to be representative of the entire San Francisco Delta, see Table 2.10. Note that not all locations were used for calibrating the PM.

Table 2.10: Locations of interest for Delta smelt Index of spawning success (DS1). Note that only locations marked with a "Yes" in the last column are used for calibration based on historical data.

Location Name	IEP ID	CDEC ID	River	River Kilometer	Used in calibration
Martinez	RSAC054	MRZ	Sacramento	54	No
Port Chicago	RSAC064	PCT	Sacramento	64	Yes
Mallard Island	RSAC075	MAL	Sacramento	75	Yes
Pittsburg	RSAC077	PTS	Sacramento	77	Yes
Emmaton	RSAC092	EMM	Sacramento	92	Yes
Rio Vista	RSAC101	RVB	Sacramento	101	No
Sacramento River Below Georgiana Slough	RSAC123	GES	Sacramento	123	No
Antioch	RSAN008	ANC	San Joaquin	8	Yes
Jersey Point	RSAN018	JER	San Joaquin	18	No
San Andreas Landing	RSAN032	SAL	San Joaquin	32	Yes
Venice Island	RSAN043	VNI	San Joaquin	43	No
Rough and Ready Island	RSAN058	RRI	San Joaquin	58	No
Holland Cut	ROLD014	HLL	Old	14	Yes
Bacon Island	ROLD024	OBI	Old	24	No
Middle River at Middle River	RMID015	MDM	Middle	15	No
Borden Hwy near Tracy	RMID023	VIC	Middle	23	Yes
Middle River at Tracy Blvd.		MTB	Middle		No
Little Potato Slough near Terminous	RSMKL008	STI	South Mokelumne	8	Yes
Walnut Grove	RMKL019	NMR	North Mokelumne	19	No
Farrar Park	SLDUT009	FRP	Dutch Slough	9	Yes
Beldon Landing	SLMZU011	BDL	Montezuma Slough	11	No
Steamboat Slough below Sutter Slough	SLSBT011	SSS	Steamboat Slough	11	No
Cache Slough at Ryer Island		RYI	Cache Slough		No
Georgiana Slough near Sacramento River		GSS	Georgiana Slough		No

Calibration

Calibration criteria were not available following the Design Workshop. In the absence of any guidance for DS1, DeltaEFT Version 1 adopts a tercile-based calibration approach in which the upper, middle and lower thirds of the DS1 PM values are used to assign a R/Y/G score, based on a simulation using daily historical temperature and salinity data, see Figure 2.27 and Table 2.11.

Although this method provides an internally consistent way to compare results (*i.e.,* it will always provide a consistent ranking of which water management scenarios are "better" than others), it does not provide any concrete inferences about the biological significance of the three categories. For example, it is possible that a year that ranks as "Good" (Green) with this method may still be biologically suboptimal. Conversely, a year that ranks as "Poor" (Red) may be biologically insignificant.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years with Good or Poor performance. It is possible that good and bad years can be identified based on field observations, however it would be difficult to separate physical habitat effects from other effects, such as prey availability. At the time of this report, we are not aware of a suitable processed dataset.

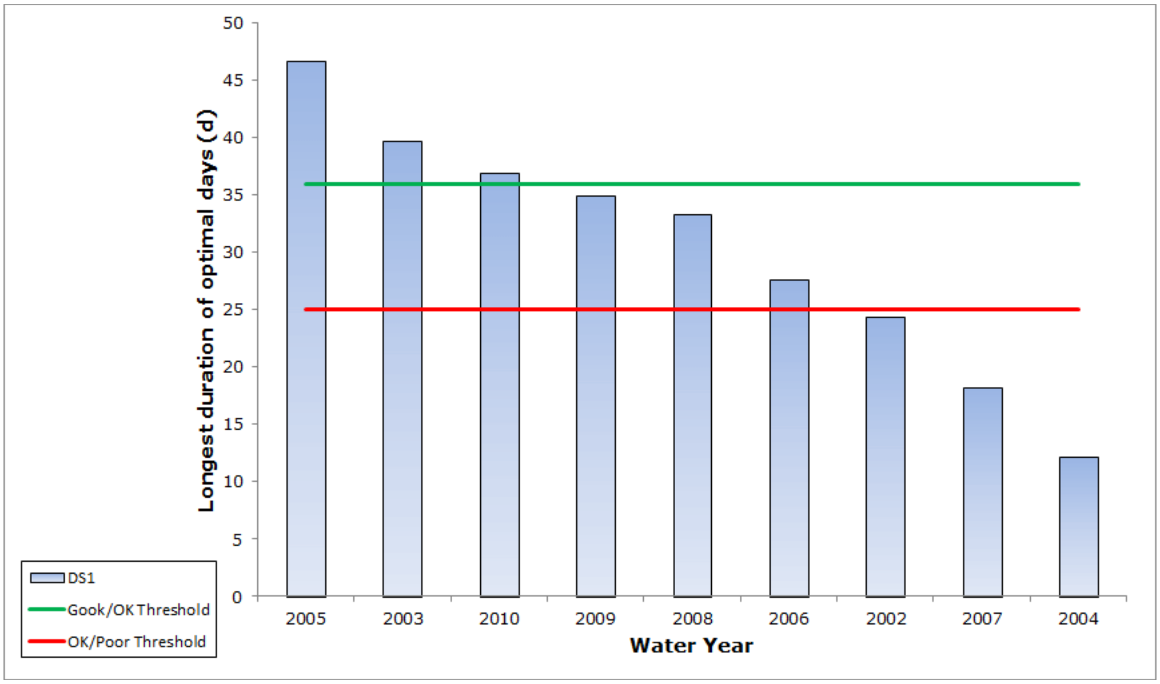


Figure 2.27: Calibration results for DS1. Thresholds are based on terciles for a historical simulation from WY 2002 to WY 2010 for 10 locations. Threshold values are 36 and 25 days.

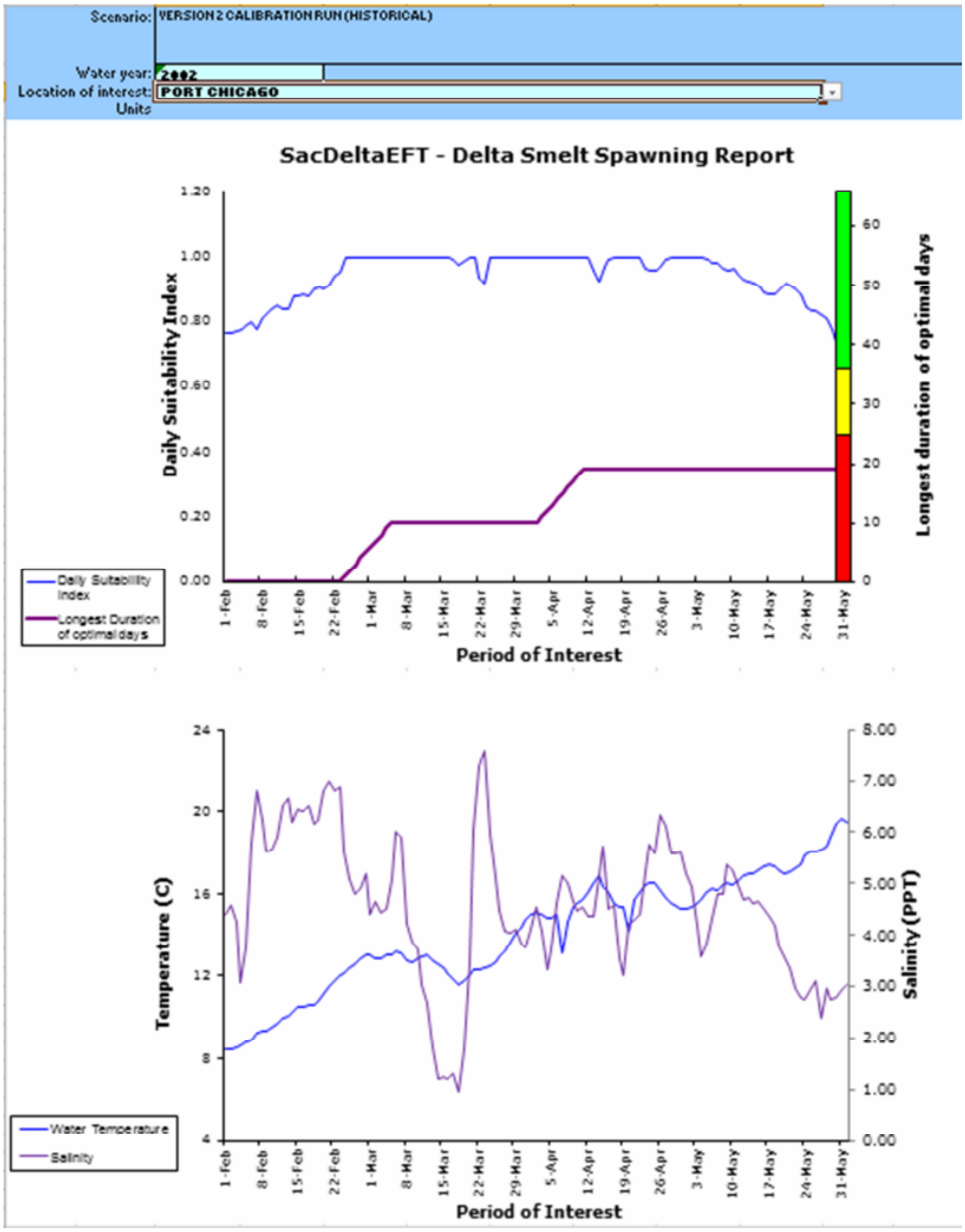
Table 2.11: DS1 – Index of spawning success indicator rating breakpoints. Units are days.

	Daily		Rollup		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
DS1 – Index of spawning success	N/A	N/A	36	25	• Criteria: terciles, "more" is better • Units: days • No daily estimate

The DS1 PM requires continuous data during the spawning period, and historical data from gauges were evaluated to determine the best dataset of temperature and salinity. There are inherent trade-offs between the number of gauges available and the length of the datasets, so that you can either choose a dataset with a long record and few gauges, or many gauges with a shorter record. For the purpose of calibrating the DS1 PM, we decided to use 10 gauges with continuous data from WY2002 to 2010 for calibration (see Table 2.10).

Excel Reports

An example of the annual rollup Excel report for DS1 is shown below in Figure 2.28. The report shows two graphs: the upper panel shows the daily spawning habitat suitability in blue and the cumulative DS1 PM in purple. The performance of a given location for the year can be found by comparing the cumulative DS1 value on the last day of the spawning period with the vertical R/Y/G bar. The lower graph shows daily water temperature and salinity values. The x-axes are identical and span the potential spawning period for Delta smelt.



Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)

Water year: 2002

Location of interest: PORT CHICAGO

Units

Figure 2.28: An example of screen captures from the Annual Rollup report for DS1: Delta smelt success index. This example shows performance in 2002 for the Port Chicago location for the Historical calibration. Note that in this case, there are multiple periods with optimal spawning conditions, breaking up the longest duration and resulting in poor performance.

Spatial Reports

There are 2 types of spatial reports available for DS1: Annual spatial reports and multi-year rollup reports. The annual spatial report displays an R/Y/G dot for each location of interest (see Figure 2.29). The color of each dot represents the annual location-specific performance based on the calibration thresholds described previously. PM Summary information and time-series for water temperature and salinity can also be displayed for each location by selecting it with the Select tool, see Figure 2.30.

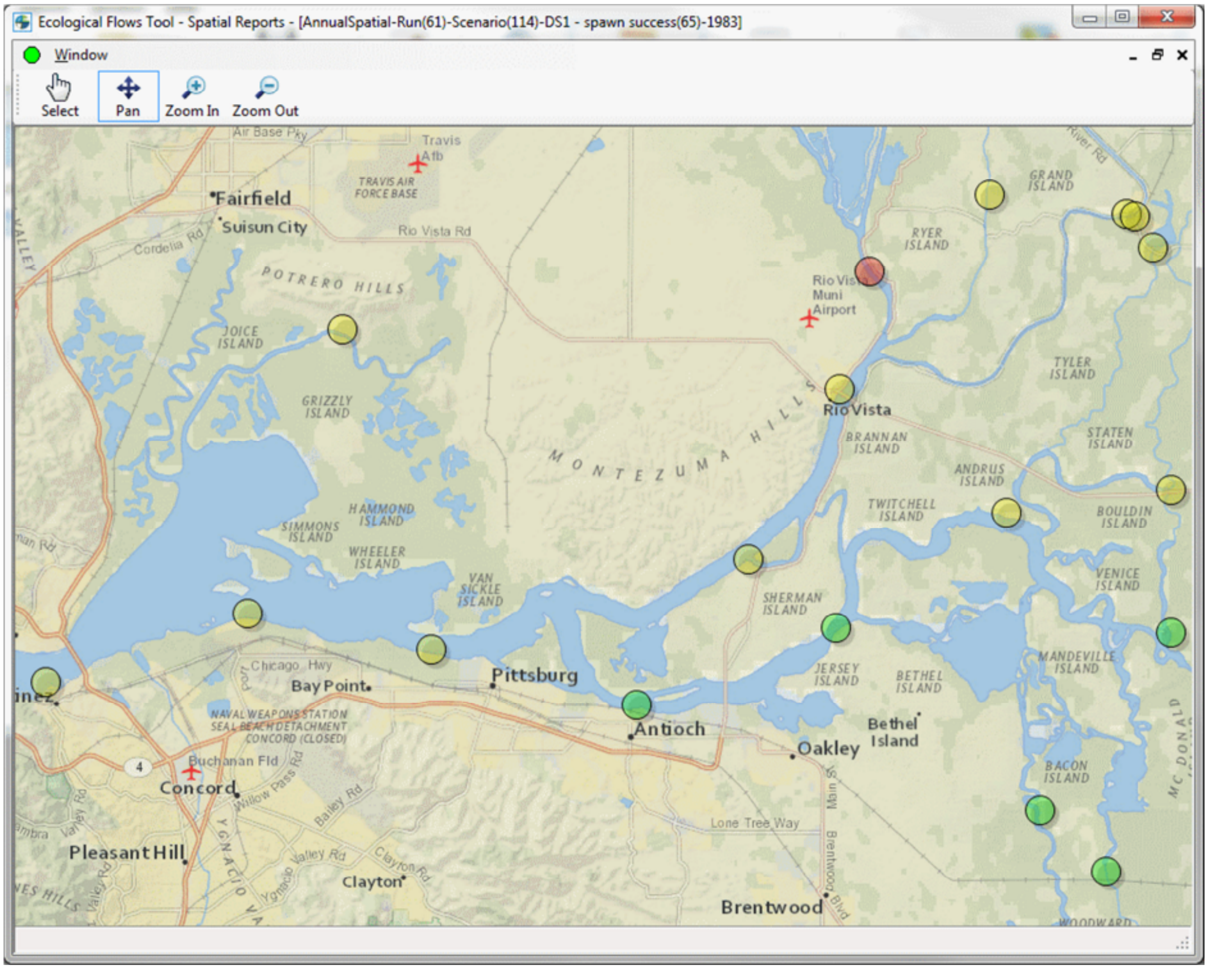
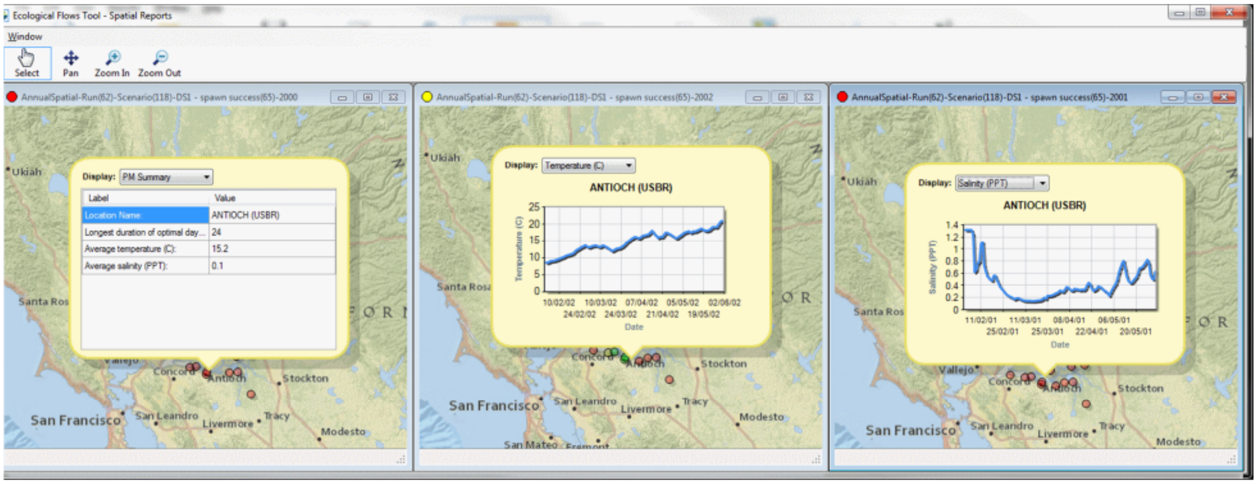


Figure 2.29: An example of a screen capture from the Annual Spatial report for DS1: Delta smelt success index. This example shows the performance for each location for a year with good performance. The color for each location is based on the same thresholds described in the calibration section.



Label	Value
Location Name:	ANTIOCH (USBR)
Longest duration of optimal day...	24
Average temperature (C):	15.2
Average salinity (PPT):	0.1

Figure 2.30: An example of a screen capture of location-specific information for DS1: Delta smelt success index. This example shows the PM Summary, water temperature and salinity time-series for the Antioch location for 3 different years.

The multi-year rollup spatial report displays an R/Y/G colored pie-chart for each location of interest (see Figure 2.31). Each pie-slice represents the number of years the location was assigned a Good, Fair or Poor performance. This report is useful for quickly finding spatial patterns in performance, *e.g.,* localized effects or downstream gradients in performance. A location-specific breakdown for number of years in each category can be displayed by selecting the location with the Select tool.

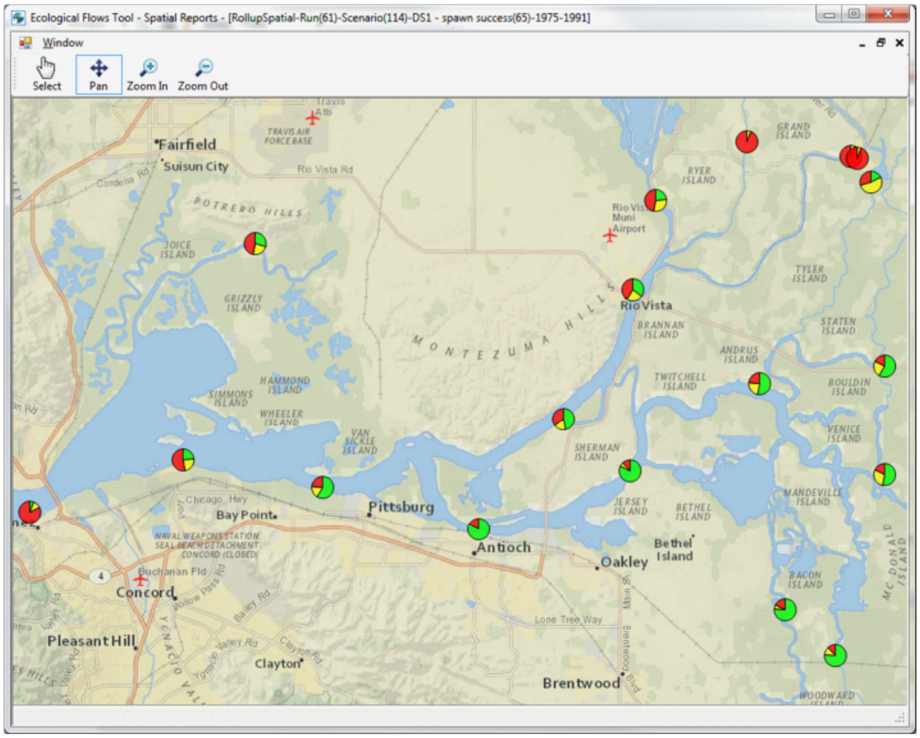


Figure 2.31: An example of a screen capture of multi-year rollup spatial report for DS1: Delta smelt success index. This example shows the percentage of good/fair/poor years for each location of interest for 17 years. Note that in this example, locations to the west and north have more poor years than other locations. A location-specific breakdown for number of years in each category can be displayed by selecting the location with the Select tool.

PM uncertainties and overall reliability

There is uncertainty around Delta smelt spawning locations (*i.e.*, spawning events have not been observed in the field, nor have any egg clusters been found). As a result, we plan to uniformly weight all locations in the Delta where spawned females have been found or where spawning is believed to occur. Because of the high degree of uncertainty around spawning locations, it is possible that DS1 will under- or over-estimate spawning success simply by virtue of it not taking into account the true spawning distribution. Resolving this source of uncertainty is perceived to more critical to DS1 reliability than that of turbidity. On-going efforts by the Delta smelt working group on spawning locations will hopefully identify spawning locations more clearly to allow for a more realistic weighting scheme.

Recently, the duration of water temperatures suitable for spawning has been used as a potential factor in 3 life-cycle models. Only one model (MacNally *et al.* 2010) found a clear positive relationship between duration of water temperatures suitable for spawning and Delta smelt abundance, whereas this factor was not found to be significant in models by Thompson *et al.* 2010 and Maunder and Deriso 2011. The latter model did however select average water temperature for April–June as the first factor based on AIC. It is unknown how much the 2 factors are correlated, but high temperatures in April and June are likely to lead to fewer days with temperatures between 12 and 16 degrees. While research into the importance of water temperatures for Delta smelt spawning and abundance continues, this PM continues to be valuable.

Several different approaches to defining water temperatures suitable for Delta smelt spawning exist. For example, Bennett 2005, MacNally *et al.* 2010 and Thompson *et al.* 2010 use a temperature interval of 15-20 °C and Maunder and Deriso 2011 uses a wider interval of 11-20 °C. We decided to use the water temperatures associated with peak occurrence of ripe females (12-16 °C) because it is based on observations of Delta smelt biology instead of a statistical relationship. Furthermore, these different variations of spawning success metrics are likely highly correlated and would result in similar classifications of good/fair/poor years.

DS2 – Index of habitat suitability

Rationale

Habitat for Delta smelt largely consists of open water, away from shorelines and vegetated inshore areas, except during spawning (Delta smelt BiOp 2008). This includes areas such as Suisun Bay and the deeper areas of many larger channels in the Delta. However, Delta smelt habitat is most strongly determined by water quality, *i.e.*, salinity, turbidity, and temperature, with salinity being a key defining variable (Bennett 2005). As a result, freshwater flow into the estuary strongly influences Delta smelt habitat location and extent. Other factors such as low contaminant levels and prey production are also important, but beyond the scope of this PM.

Delta smelt habitat extends from the tidal freshwater reaches of the Delta seaward to 19 psu salinity at water temperatures lower than 25°C (Bennett 2005). The volume and shape of this habitat is determined by climate, freshwater discharge, tidal forcing, and bathymetry. In general, the larger the habitat volume the better it is for Delta smelt because it reduces crowding and provides opportunities to avoid localized sources of mortality. Unger (1994) showed that the overall surface area of habitat bounded by 0.3 to 1.8 psu is maximized when X2 is located in Suisun Bay. That being said, unlike many other species in the Delta, the relationship of Delta smelt abundance is not easily explained by X2. In general, Delta smelt recruitment is poor in high and low flow years and highly variable in intermediate flow years when low salinity habitat is located in Suisun Bay (Moyle *et al.* 1992).

Performance measure

The abiotic habitat requirements for Delta smelt are commonly defined by salinity, turbidity and temperature. Unfortunately, data and modeling constraints do not permit us to create a habitat suitability index similar to the DS1 performance measure that incorporates turbidity at the present time. To avoid creating a performance measure of Delta smelt habitat that does not include turbidity, we decided to use a model by Feyrer *et al.* (2011) that incorporates temperature, salinity and turbidity measurements. This model has also been used in the Delta smelt BiOp (2008) to specify targets for water exports.

Feyrer *et al.* (2011) developed a Generalized Additive Model (GAM) based on a mid-water trawl survey with samples from approximately 100 stations in the Delta. The stations were sampled once a month from September to December beginning in 1967 with missing or incomplete data in 1974, 1976 and 1979. They define the abiotic habitat of Delta smelt as:

$$\pi_{y,m,s} = f(temp, Secchi, cond) + \varepsilon_{y,m,s}, \qquad \text{Eqn 2.10}$$

where the probability of occurrence of Delta smelt (π) for a given year (y), month (m), and sampling station (s) is a function of water temperature (temp; °C), Secchi depth (Secchi; m, a surrogate for turbidity), and specific conductance (cond; µS cm^{-1}, a proxy for salinity).

They used the GAM to develop an annual habitat index (H_y) that combines habitat quality and quantity for a subset of 73 stations as follows:

$$H_y = \sum_{1}^{73} \left[A_s \frac{1}{4} \sum_{m=sep}^{dec} \hat{\pi}_{y,m,s} \right], \qquad \text{Eqn 2.11}$$

where A_s is the surface area attributed to station s, m is the month (September to December) and $\hat{\pi}_{y,m,s}$ is an estimate of the probability of occurrence.

Finally, Feyrer *et al.* used locally-weighted-regression scatterplot smoothing (LOESS regression) to develop a data-driven relationship between the habitat index (H_y) and the location of the 2ppt bottom salinity in kilometers from the Golden Gate Bridge ($X2_y$):

$$H_y = f_2(X2_y) + \varepsilon_y, \qquad \text{Eqn 2.12}$$

where *X2* is a metric that is often used as an indicator of outflow in the Delta. To be consistent with the sample data, the annual $X2_y$ is the average X2 for the September to December period. Feyrer *et al.* (2011) report that the LOESS smooth defining the X2-habitat index relationship has an r^2 of 0.85 (see Figure 2.32).

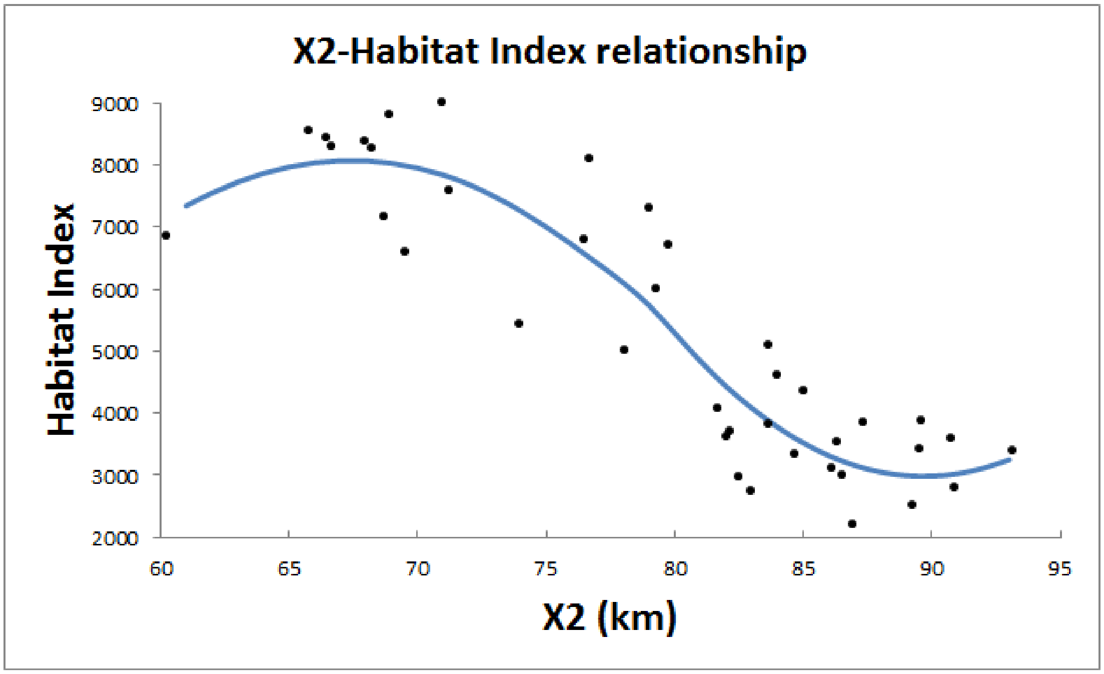


Figure 2.32: The X2-Habitat index relationship developed by Feyrer *et al.* (2011). The blue line shows LOESS regression with an r^2 of 0.85, the black dots are Habitat Index values for individual years. Note that the curve has a noticeable steep portion between approximately 74 and 86 km, where the Habitat Index more than doubles.

The DS2 - Index of habitat suitability PM is defined as the annual habitat index (H_y):

$$DS2_y = H_y, \qquad \text{Eqn 2.13}$$

The daily location of X2 for the PM is estimated based on historical and modeled data from 5 salinity stations in the Sacramento River between river kilometers 54 and 92 (see Table 2.12). The salinity gradient between stations is assumed to be linear and the location of the 2ppt concentration is found by interpolating between stations:

$$X2_d = \begin{cases} 54 \ \ if \ S_{54} \le 2 \\ 54 + 10\dfrac{S_{54} - 2}{S_{54} - S_{64}} if \ S_{64} \le 2 \\ 64 + 11\dfrac{S_{64} - 2}{S_{64} - S_{75}} if \ S_{75} \le 2 \\ 75 + 2\dfrac{S_{75} - 2}{S_{75} - S_{77}} if \ S_{77} \le 2 \\ 77 + 15\dfrac{S_{77} - 2}{S_{77} - S_{92}} if \ S_{92} \le 2 \\ 92 \ \ if \ S_{92} > 2 \end{cases}, \qquad \text{Eqn 2.14}$$

The annual X2 values are defined as the average location of X2 for all days between September 1st (D1) and December 31st (D2):

$$X2_y = \frac{1}{N} \sum_{d=D_1}^{D_2} X2_d \ , \qquad \text{Eqn 2.15}$$

where N is the number of days between September 1st and December 31st.

Locations of interest

The locations of interest for this PM are the 5 salinity stations necessary to estimate the daily location of X2 (see Table 2.12). If more salinity stations become available in the Sacramento River between river kilometers 54 and 92, they can be used to improve the accuracy of the X2 estimate by reducing the distance between stations.

Table 2.12: Locations of interest for Delta smelt Index of habitat suitability (DS2).

Location Name	IEP ID	CDEC ID	River	River Kilometer
Martinez	RSAC054	MRZ	Sacramento	54
Port Chicago	RSAC064	PCT	Sacramento	64
Mallard Island	RSAC075	MAL	Sacramento	75
Pittsburg	RSAC077	PTS	Sacramento	77
Emmaton	RSAC092	EMM	Sacramento	92

Calibration

The DS2 – Index of habitat suitability indicator rating breakpoints are based on sections of rapid change in the X2-Habitat Index relationship, see Figure 2.32. A steep portion of the curve occurs between approximately 74 and 86 km, where the habitat index more than doubles. The Delta smelt BiOp (2008) uses the rapid change in the Habitat Index to developed a RPA (Component 3: Improve Habitat for Delta smelt Growth and Rearing) that includes providing sufficient Delta outflow to maintain X2 lower than 74 km for wet years and 81 km for above-normal years. The 81 km target was selected as it provides about 50% more of the abiotic habitat benefits than maintaining X2 at 86 km. We chose habitat index values of 7261 (equivalent to 74 km) and 4835 (equivalent to 81km) as the thresholds for this indicator (see Figure 2.33 and Table 2.13).

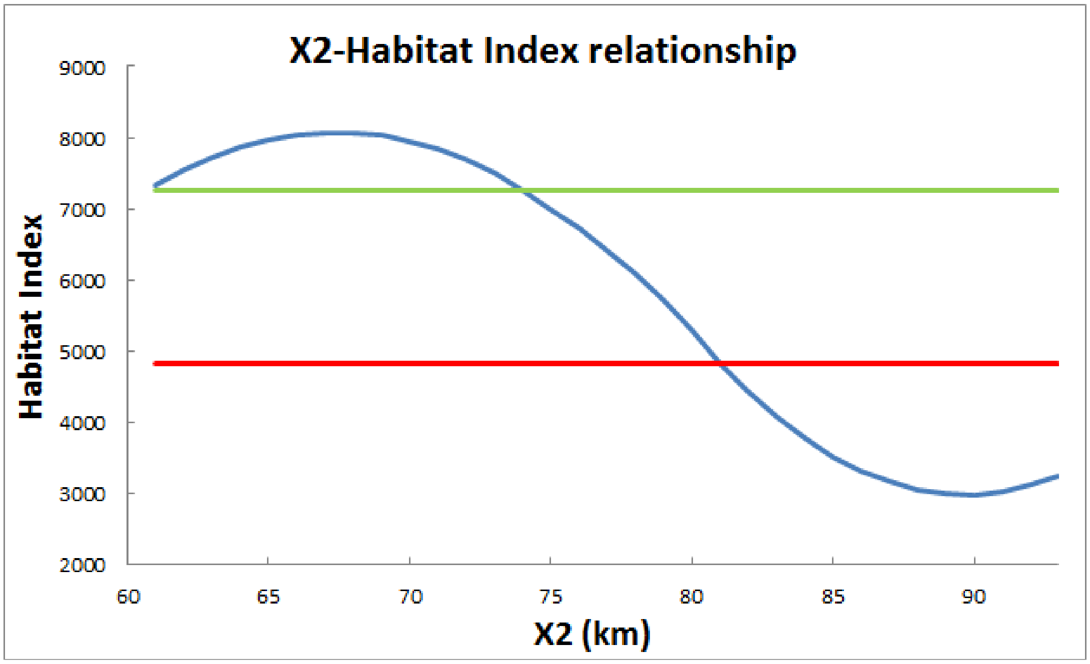


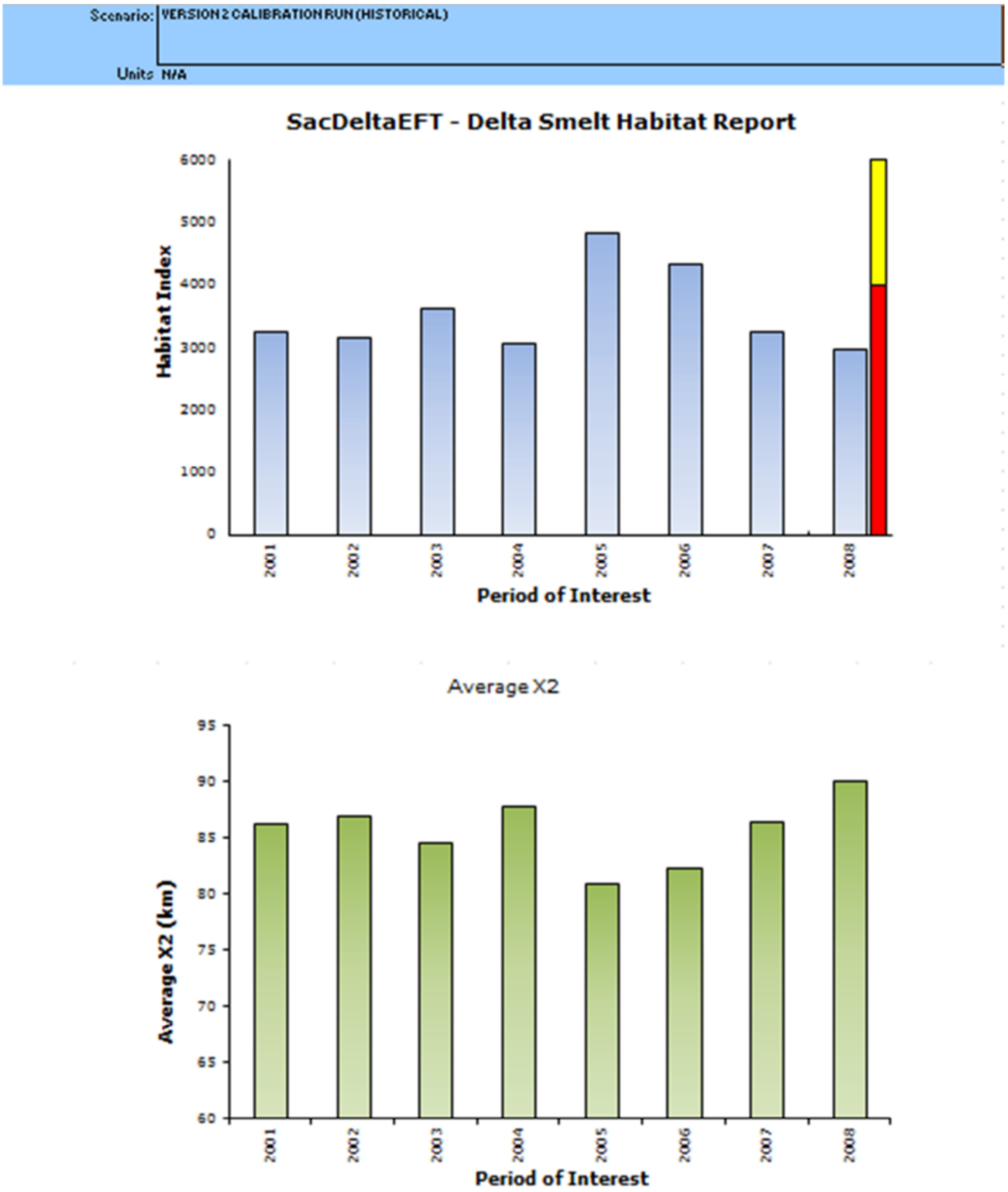
Figure 2.33: Calibration results for DS2. The blue line shows the X2-Habitat Index relationship developed by Feyrer *et al.* 2011, the green and red lines are the Good-Fair and Fair-Poor thresholds. The breakpoints are set at 7261 and 4835 respectively, equivalent to the X2 targets of 74 and 81 km described in the Delta smelt BiOp (2008).

Table 2.13: DS2 – Index of habitat suitability indicator rating breakpoints.

	Daily		Rollup		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
DS2 – Index of habitat suitability	N/A	N/A	7261	4835	• Criteria: Based on X2 targets in the Delta smelt BiOp (2008). • Units: n/a • No daily estimate

Excel Reports

An example of the multi-year rollup report for DS2 is shown below in Figure 2.34. The report shows two graphs: the upper panel shows the annual habitat index and the lower graph shows the average annual X2 location measured in km from the Golden Gate Bridge. Note that a low average X2 value results in a high habitat index (see Figure 2.32). Valid X2 values range from 54 to 92 km. The performance for a given year can be found by comparing the annual habitat index value with the vertical R/Y/G bar.

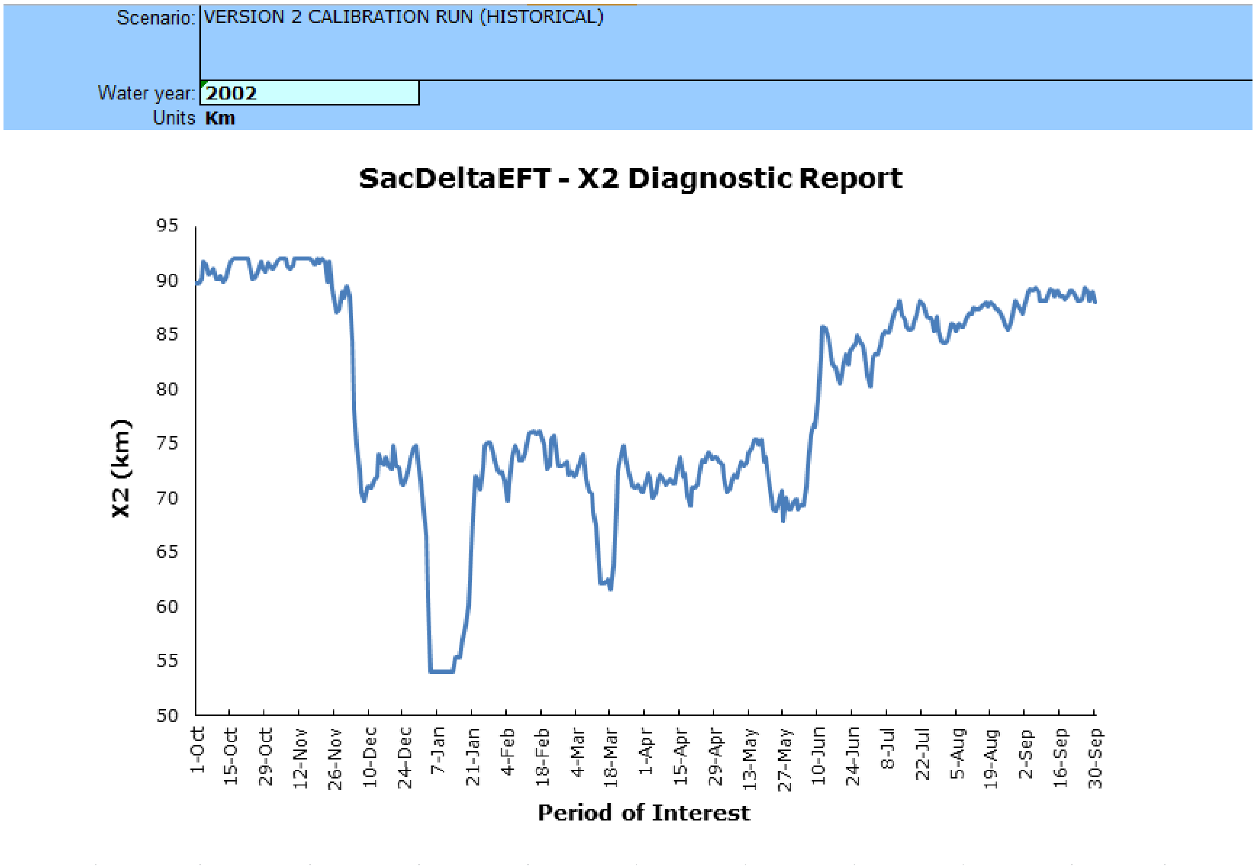


Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)

Units N/A

Figure 2.34: An example of screen captures from the multi-year rollup report for DS2: Index of habitat suitability. This example shows performance from 2002 to 2008 for historical data. Low average X2 value results in a high habitat index. Note that there are no good years in this time period, so no green bar is showing.

More information is available for X2 in the X2 Diagnostic Report, see Figure 2.35. The report shows the daily location of X2 for the entire water year (October 1st to September 30th). Note that the X2 values are bound by 54 and 92 km.



Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)

Water year: 2002

Units Km

Figure 2.35: An example of a screen capture from the X2 Diagnostic Report. This example shows the daily location of X2 for WY 2002 (October 1st 2001 to September 30th 2002) for historical data. Note that X2 values are bound by 54 and 92 km.

Spatial Reports

There are no spatial reports available for DS2 - Index of habitat suitability, as the PM does not have an associated location. The daily location of X2, used to calculate this PM, can be viewed in the X2 spatial diagnostic report (see Figure 2.36). The report displays either a time-series animation of the daily location of X2 or the user can view the location on a specific date using the date selection control below the report. Reports for multiple years can be synchronized to compare the daily X2 location for different years.

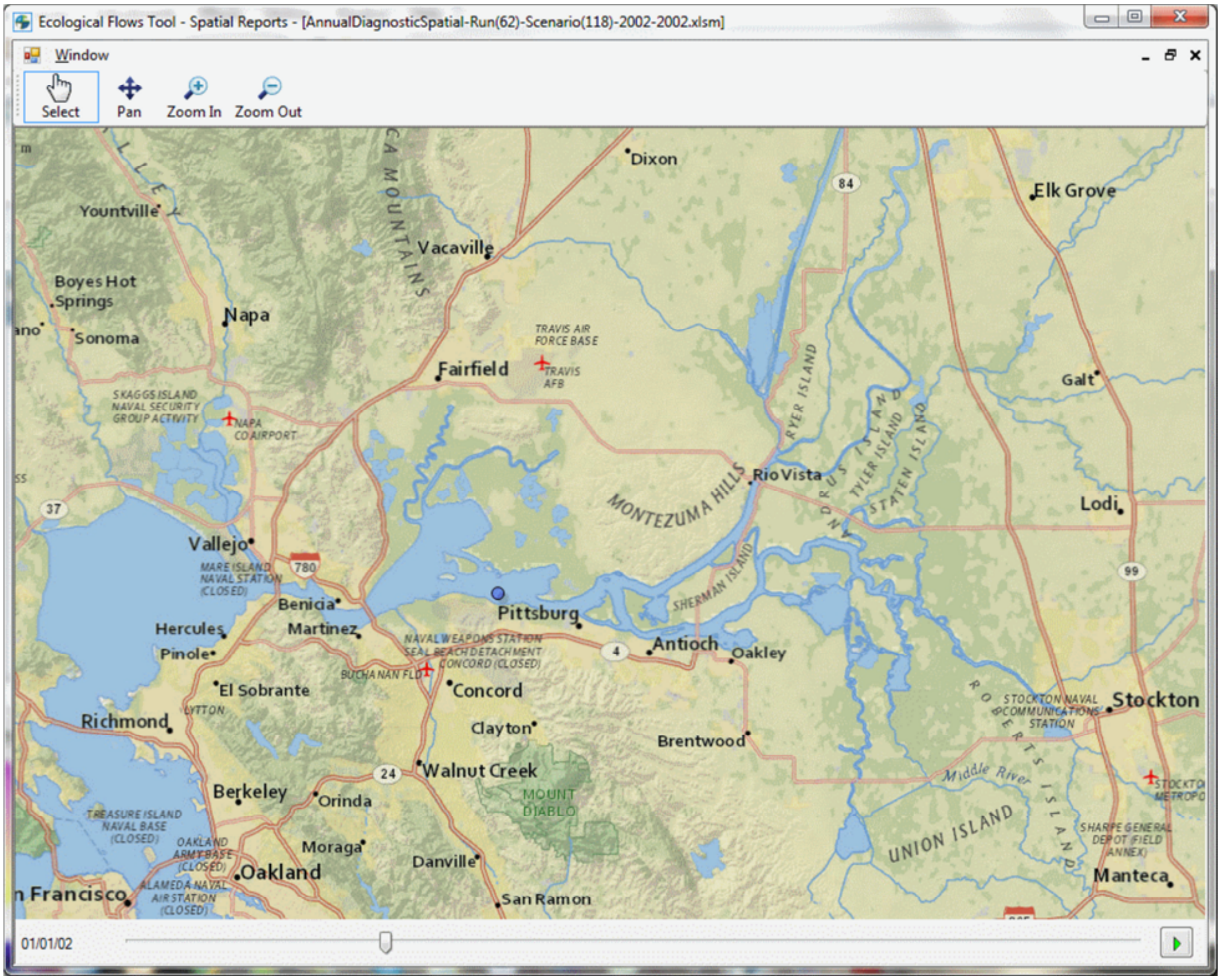


Figure 2.36: X2 spatial diagnostic report for 2002 historical data. The blue dot shows the location of X2 on any given day of the water year, in this example for January 1st 2002.

PM uncertainties and overall reliability

Although the X2-Habitat Index relationship developed by Feyrer *et al.* (2011) is widely used (*e.g.,* Delta smelt BiOp 2008), there is still significant discussion about the impact of abiotic habitat on Delta smelt abundance.

In August 2011, Judge Oliver W. Wanger reviewed the X2 target of 74 km in wet years specified as a RPA in the Delta smelt BiOp (2008), a target based on the Feyrer *et al.* (2011) model. He concluded that "there is essentially no biological evidence to support the necessity of the specific 74 km requirement" and changed the X2 Fall target to 79 km to reduce the impact to water supply from an estimated 300,000 AF to 90,000 AF (Wanger 2008). A significant part of Judge Wanger's critique is based on 3 life-cycle models that were all published after the 2008 BiOP. All 3 models concluded that the location of X2 in the fall does not have a statistically significant effect on Delta smelt abundance. Furthermore, the model was also criticized during the trial for not considering smelt populations residing in the Cache Slough Complex. Feyrer *et al.*'s model is based on data from the Fall Midwater Trawl (FMWT) up until 2008, which didn't include stations in the Cache Slough Complex; however Feyrer argues that including them "would simply add a constant number of units to the habitat index, which would not affect the shape of the X2-habitat index relationship." (Wanger 2008).

Although the X2-Habitat Index relationship has its limitations, it is still currently the best metric for Delta smelt abiotic habitat and continues to be widely used by agencies and scientists in the Delta.

DS4 Index of risk of entrainment

Rationale

The risk of entrainment to Delta smelt varies seasonally and among years. Low flow years historically have higher incidences of entrainment than high flow years because the distribution of fish is closer to the points of diversion in low flow years and a higher proportion of juveniles rear in the Delta (Moyle *et al.* 1992; Sommer *et al.* 1997). The greatest entrainment risk of Delta smelt by CVP and SWP export operations is hypothesized to occur during winter (between December and April) when pre-spawning adults migrate into the Delta in preparation for spawning (Moyle 2002). Investigations by the Pelagic Organism Decline (POD) support this hypothesis and show that increased water export in winter results in higher losses of adult smelt, particularly early spawning fish and their offspring, a result that has a particularly negative effect on Delta smelt populations (Baxter *et al.* 2008). Juvenile Delta smelt are also vulnerable to entrainment, with the majority of juvenile salvage occurring from April to July with a peak in May-June (Nobriga *et al.* 2001). Little is known about the effect that entrainment has on the larval life stages because larvae are not sampled effectively at the fish screening facilities. A model of particle tracking with survey results to estimate larval entrainment suggest that entrainment losses of Delta smelt larvae could exceed 50 percent of the population under some low flow and high export conditions, depending on the spawning distribution (Kimmerer and Nobriga 2008).

Kimmerer (2008) estimated that on average 13% of the larval and juvenile Delta smelt were entrained annually between 1995 and 2005 with losses up to 25% in dry years. Miller (2011) later revisited the assumptions underlying Kimmerer's calculations and concluded that 8 out of 10 assumptions had an upward bias. A significant bias is introduced because the 20-mm survey used by Kimmerer did not begin to sample the Cache Slough Complex or the Sacramento Deep Water Ship Channel until 2008. These locations have since been found to have significant concentrations of larval and juvenile Delta smelt. In a later paper, Miller and others (2012) reduced Kimmerer's entrainment estimates by 40% to account for this bias. In a response by Kimmerer (2011) he acknowledges that Miller raises some valuable points, but argues that it does not change his overall conclusion that losses to Delta smelt are substantial in some years.

Performance measure

The DS4 - Index of risk of entrainment PM is based on Particle Tracking Model (PTM) results by Kimmerer and Nobriga (2008). The model simulates the fate of particles released at 20 sites in the Delta under a range of inflows and outflows (see Figure 2.37). Delta smelt entrainment is simulated as the proportion of particles which ultimately end up at the CVP or SWP water export facilities. In order to utilize the results from the PTM, which simulates passive, neutrally buoyant particles, it is important to apply it only to life-stages with limited mobility. For this reason, this PM focuses on **larval and juvenile Delta smelt**.

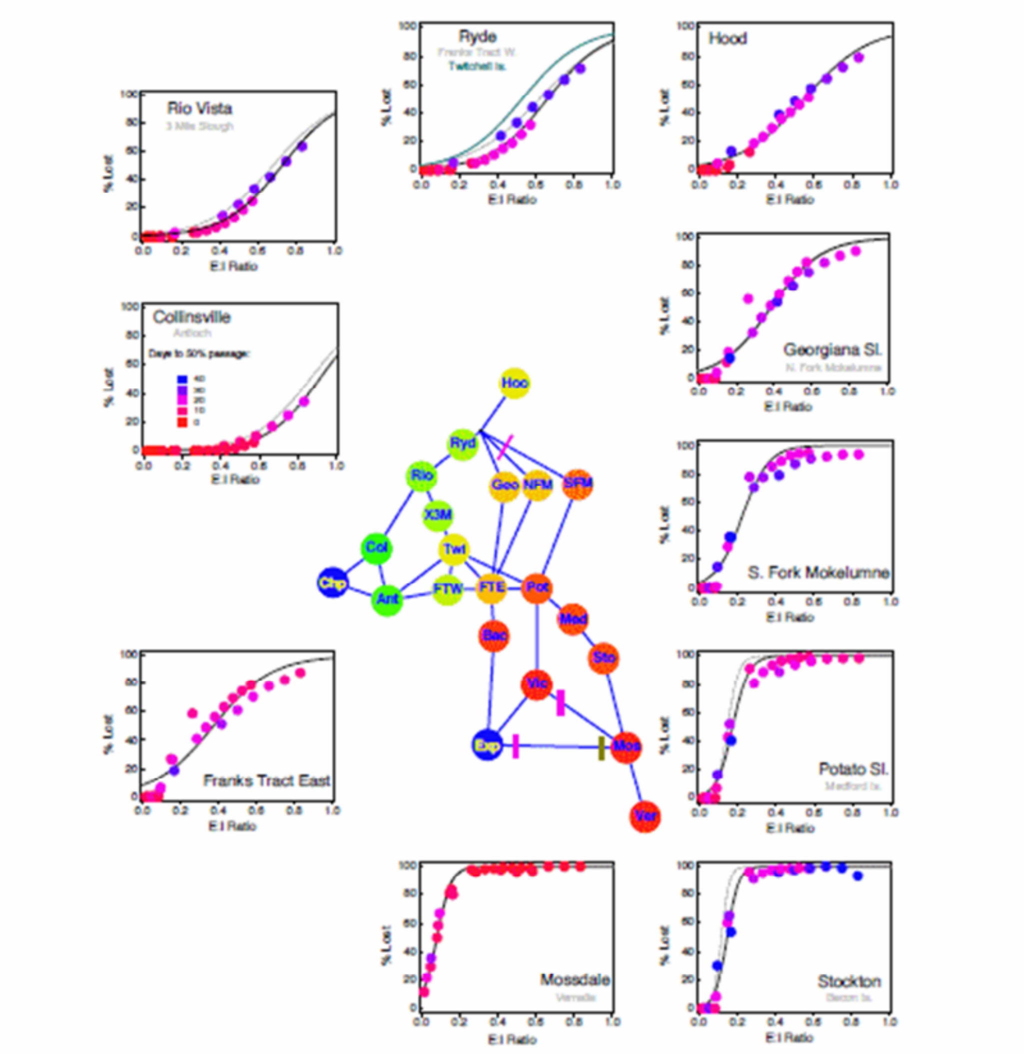


Figure 2.37: Percent of particles lost to export pumps for spring tide runs with no agricultural diversions and 24 combinations of inflow and export flow. Data are shown for selected release sites, color-coded by the time needed for 75% of particles to leave the Delta. Lines are logistic functions fit to the data, and are dark for selected sites and light gray for other sites with similar responses. Central diagram is a schematic arrangement of the sites with principal links between sites. Short lines represent barriers including the DCC in the northern Delta, the Head of Old River barrier in the south Delta (dark yellow), and south Delta agricultural barriers (pink). Reproduced from Figure 7 in Kimmerer and Nobriga (2008).

The proportion of Delta smelt larvae and juveniles entrained ($DS4_j$) from each location j is estimated from the percentage of particles lost as a function the water export:import ratio (E:I). The relationship is fitted using a logistic regression with location-specific coefficients a_j and b_j:

$$DS4_j = \frac{e^{a_j + b_j \cdot EI}}{1 + e^{a_j + b_j \cdot EI}}, \qquad \text{Eqn 2.16}$$

where E:I is estimated from a logarithmic regression fitted to historic data (see Figure 2.38):

$$EI_y = 0.1198 \cdot e^{-0.002 \cdot OMR_y} \qquad \text{Eqn 2.17}$$

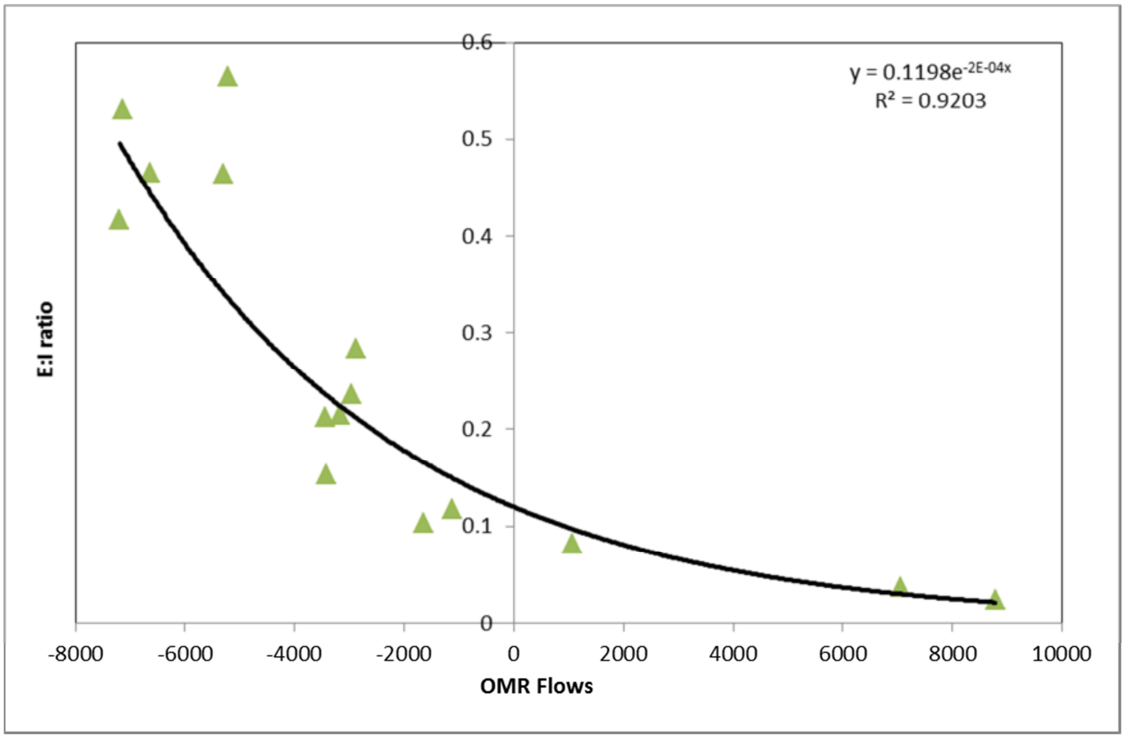


Figure 2.38: Logarithmic regression for Export:Import ratio as a function of OMR flows. Data are from the DAYFLOW program from 1987 to 2002 based on average values from April 1st to May 15th. Green triangles are data points for each year and the black curve shows the data predicted by the regression.

The annual weighted Old and Middle River flow is the daily Old and Middle River flow multiplied by the daily weight:

$$OMR_y = \sum_{i=1}^{I} OMR_i \cdot w_i \qquad \text{Eqn 2.18}$$

where the Old and Middle River flows ($Q_{OMR,u}$) for a given day i is the sum of the flow for the Old River ($Q_{old,i}$) and the Middle River ($Q_{mid,i}$):

$$Q_{OMR,i} = Q_{old,i} + Q_{mid,i} \qquad \text{Eqn 2.19}$$

Daily weights (w_i) were developed based on data from the 20mm survey from 1995 to 2011 (see Figure 2.39). The data were filtered to only include observations of larval and juvenile Delta smelt (fork length < 10 mm). All surveys dates were grouped into 24 time periods of approximately 15 days. The spawning period for a given year was defined as any time period where at least one larval or juvenile Delta smelt was observed at any station. Each time period was then assigned a probability of spawning occurring based on how many years spawning was observed. Finally, the daily weights were normalized to sum to 1 over the year.

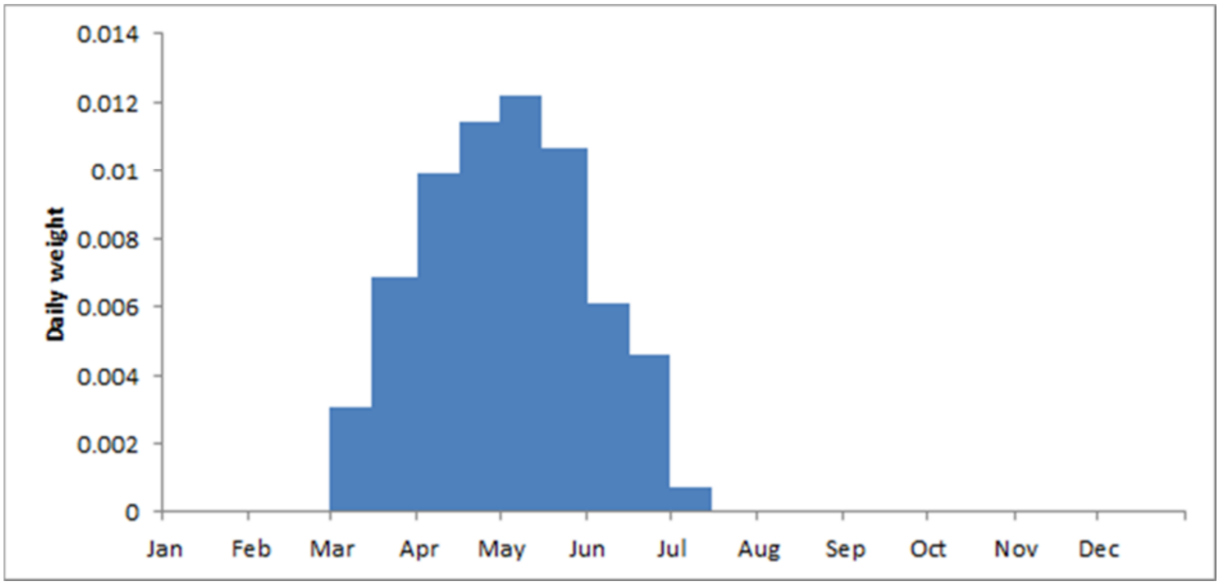


Figure 2.39: Daily weights for OMR flows. The daily weights sum to 1 over the year. The spawning peaks the first 2 weeks of May, where juveniles were observed in 16 out of 17 years.

The annual PM for DS4 is the sum of the local entrainment ($DS4_j$) multiplied by a location-specific weight (w_j):

$$DS4 = \sum_{j=1}^{J} DS4_j \cdot w_j \qquad \text{Eqn 2.20}$$

The spatial weights are based on data from the 20-mm survey for 2009 and 2010. First, the data was filtered for Delta smelt with a fork length < 10 mm. Years before 2008, when surveying of the Cache Slough Complex and the Deep Water Ship Channel began, were excluded to avoid introducing a spatial bias (see Miller 2011). Data from 2008 was excluded, because there were only 3 observations, and 2010 was the last year available at the time of analysis. In total, 45 observations in 2009 and 2010 were used to assign spatial weights. Each survey station received a weight equivalent to the number of fish observed, *i.e.*, location weights are independent of observed fork length. Each survey station was associated with the nearest downstream PTM release location except for 2 locations downstream of Chipps Island, that were assumed not to experience entrainment. Spatial weight for each PTM release location was defined as the sum of all survey station weights associated with it. Only 8 out of 20 PTM locations were assigned a non-zero weight (see Figure 2.40).

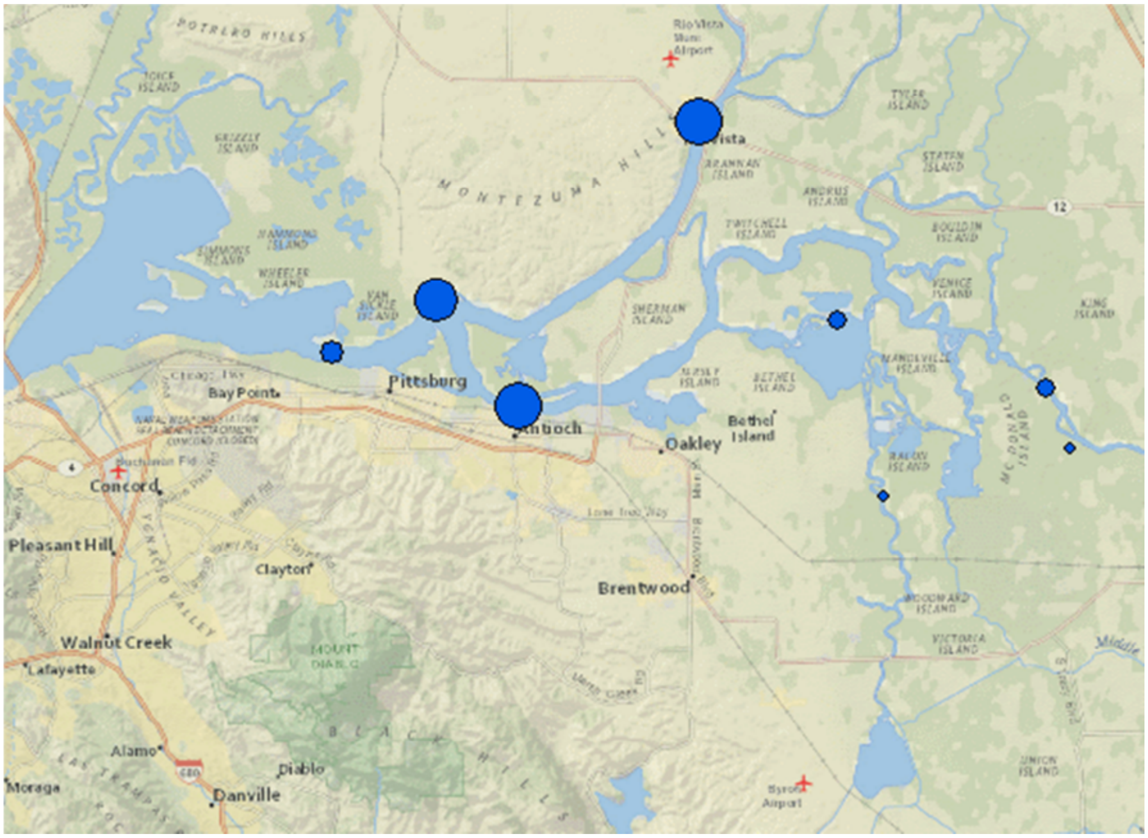


Figure 2.40: Spatial weights for DS4 - Index of risk of entrainment. Generally, locations further away from the water export facilities had higher weights. Only 8 out of 20 PTM release sites are shown, as the sites with zero weights are not displayed.

Locations of interest

The locations of interest relevant to this PM are the hydrodynamic footprint of Old and Middle Rivers (see Table 2.13).

Table 2.14: Locations of interest for Delta - Index of risk of entrainment (DS4).

Location Name	IEP ID	CDEC ID	River	River Kilometer
Middle River	RMID015	MDM	Middle	15
Bacon Island	ROLD024	OBI	Old	24

Calibration

Calibration criteria were not available following the Design Workshop. In the absence of any guidance for DS4, natural breakpoints in DS4 PM values are used to assign a R/Y/G score, based on a simulation using daily historical flows in the Old and Middle River (see Figure 2.41 and Table 2.15).

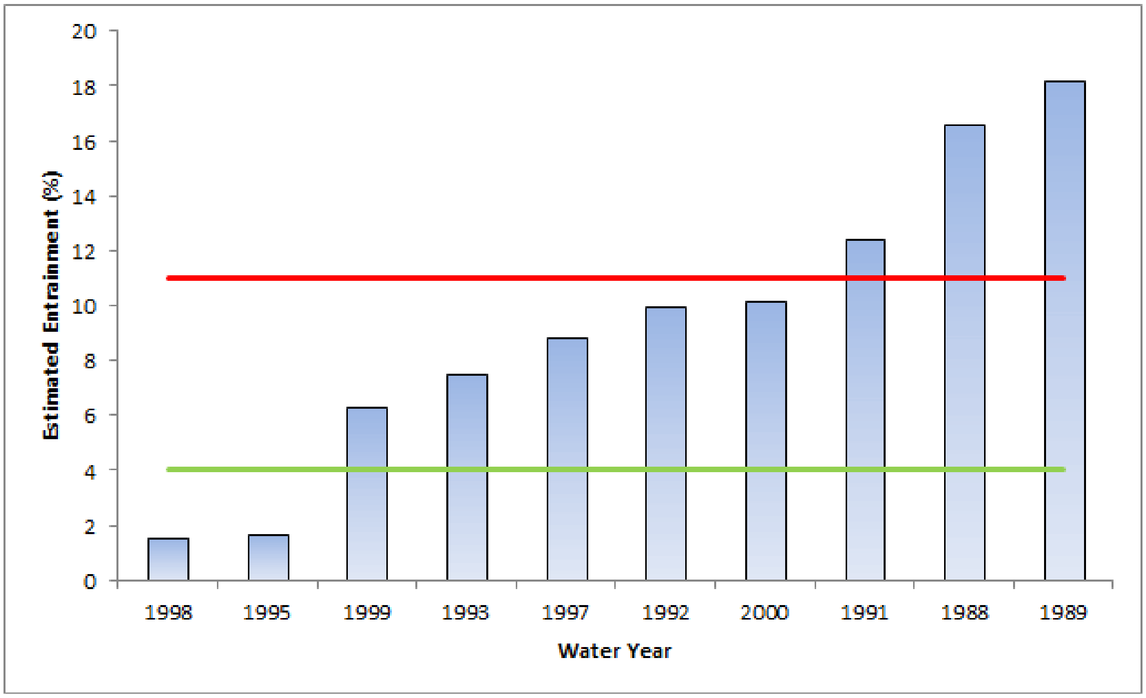


Figure 2.41: Calibration results for DS4. Thresholds are based on terciles for a historical simulation from WY1988 to WY2000. Data were not available for calibration in WY1990, 1994 and 1996. Note that lower estimated entrainment is better. Threshold values are 4 and 11 % estimated entrainment.

Table 2.15: DS4 – Index of risk of entrainment indicator rating breakpoints. Units are percent.

	Daily		Rollup		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
DS4 – Index of risk of entrainment	N/A	N/A	4	11	• Criteria: Natural breakpoints, “less” is better • Units: Percent • No daily estimate

Although this method provides an internally consistent way to compare results (*i.e.,* it will always provide a consistent ranking of which water management scenarios are “better” than others), it does not provide any concrete inferences about the biological significance of the three categories. For example, it is possible that a year that ranks as “Good” (Green) with this method may still be biologically suboptimal. Conversely, a year that ranks as “Poor” (Red) may be biologically insignificant.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years with Good or Poor performance. Entrainment of adult Delta smelt can be estimated from salvage data from the state and federal water export facilities, but salvage data cannot be used to estimate entrainment of Delta smelt larvae, as fish smaller than 20mm are generally not counted (Kimmerer 2008). We compared the DS4 Index of risk of entrainment to results published in two other papers (Kimmerer 2008 and Miller *et al.* 2012) and found good correspondence in terms of year with good/fair/poor entrainment (see Table 2.16).

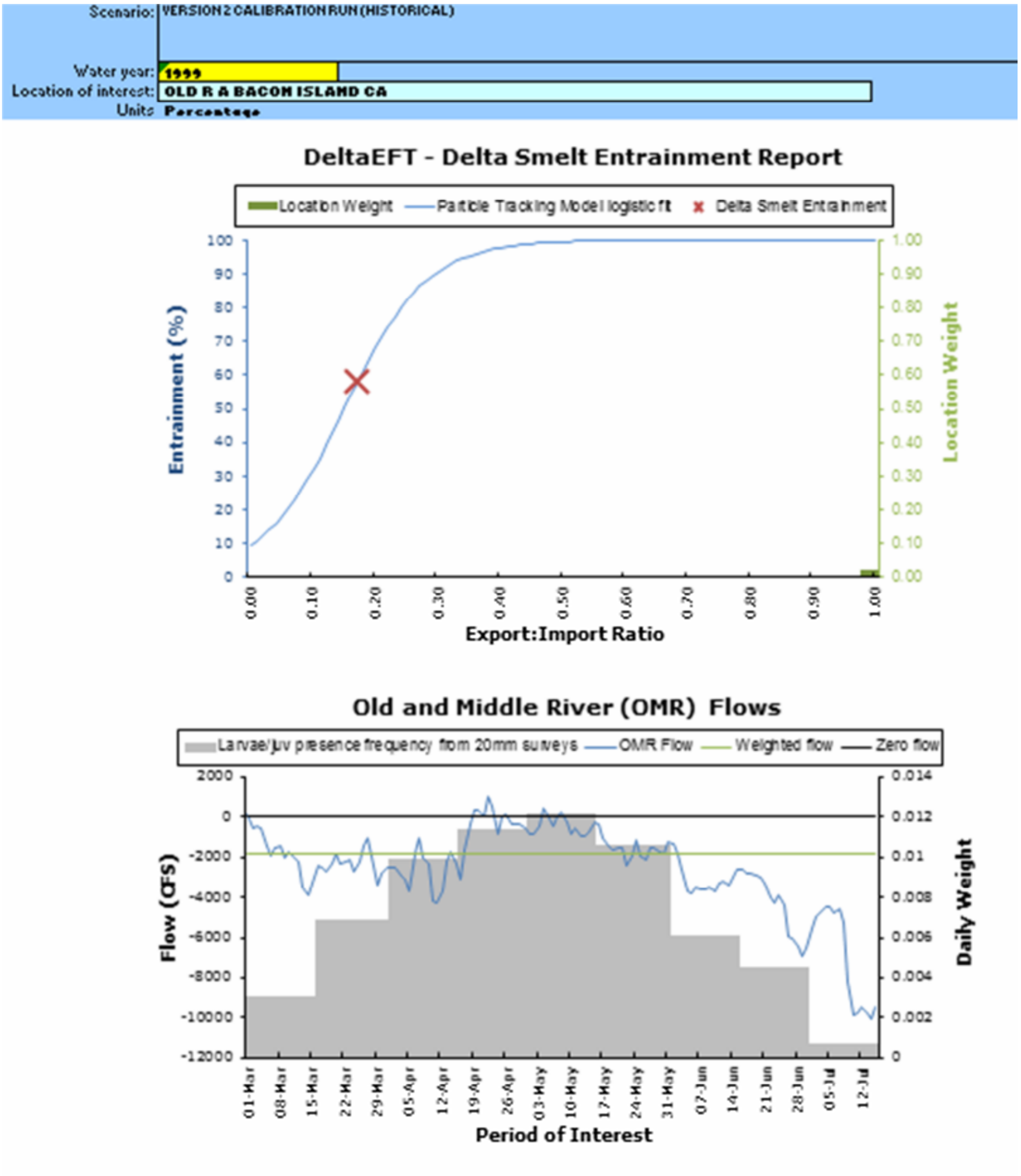
Table 2.16: Annual estimates of larval-juvenile Delta smelt entrainment.

		Proportional entrainment (%)		
Year	**DS4 Performance**	**DS4**	**Kimmerer 2008**	**Miller *et al.* 2012**
1988	Poor	17		28
1989	Poor	18		22
1990		n/a		27
1991	Poor	12		23
1992	Fair	10		20
1993	Fair	8		12
1994		n/a		14
1995	Good	2	0	6
1996		n/a	1	2
1997	Fair	9	14	9
1998	Good	2	0	0
1999	Fair	6	7	5
2000	Fair	10	13	10

Excel Reports

An example of the annual rollup Excel report for DS4 is shown below in Figure 2.42. The report shows two graphs: the upper panel shows the estimated entrainment for a particular location as a function of the Export:Import ratio (blue line) based on a logistic fit the Particle Tracking Model results by Kimmerer and Nobriga (2008), as well as the value for this particular year (marked with a red X). The weight for each location is shown on the right Y-axis (green bar). Note that locations with high entrainment may have a low spatial weight and vice-versa.

The lower graph shows daily flow in the Old- and Middle River (OMR) combined (blue line), daily temporal weight based on probability of spawning on a given day (grey bars) and the weighted OMR flows for the period of interest (green line). Negative OMR flows denote water flowing towards the CVP and SWP water export facilities.



Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)

Water year: 1999

Location of interest: OLD R A BACON ISLAND CA

Units: Percentage

Figure 2.42: An example of a screen capture from the Annual Rollup report for DS4: Index of risk of entrainment. This example shows performance in 1999 for the Old River at the Bacon Island location for the Historical calibration. Note that this location has a high entrainment (shown by the red X), and a low spatial location weight (show by the green bar to the right).

Spatial Reports

There are 2 types of spatial reports available for DS4: Annual spatial reports and multi-year rollup reports. The annual spatial report displays an R/Y/G dot for each location of interest (see Figure 2.43). The color of each dot represents the annual location-specific performance based on the calibration thresholds described previously. PM Summary information can also be displayed for each location by selecting it with the Select tool (see Figure 2.44).

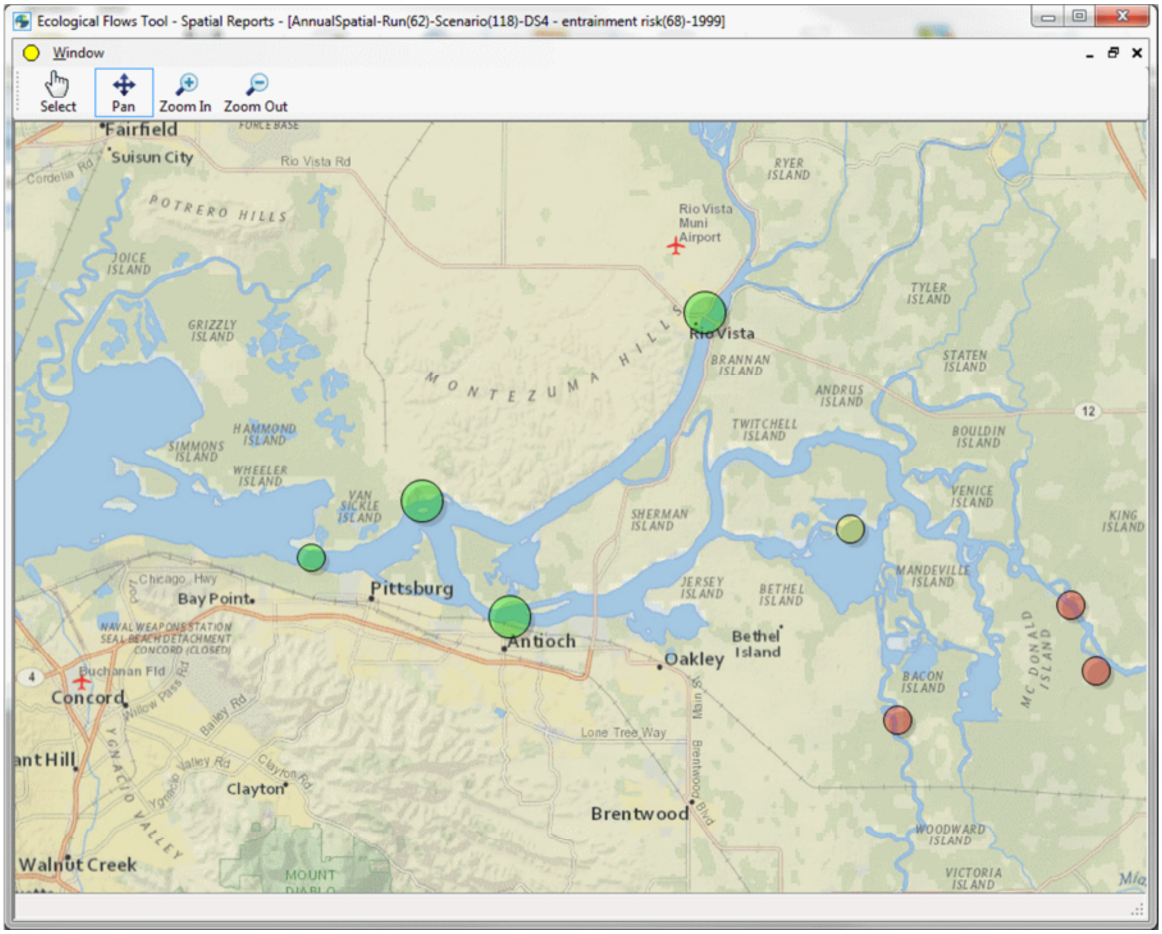
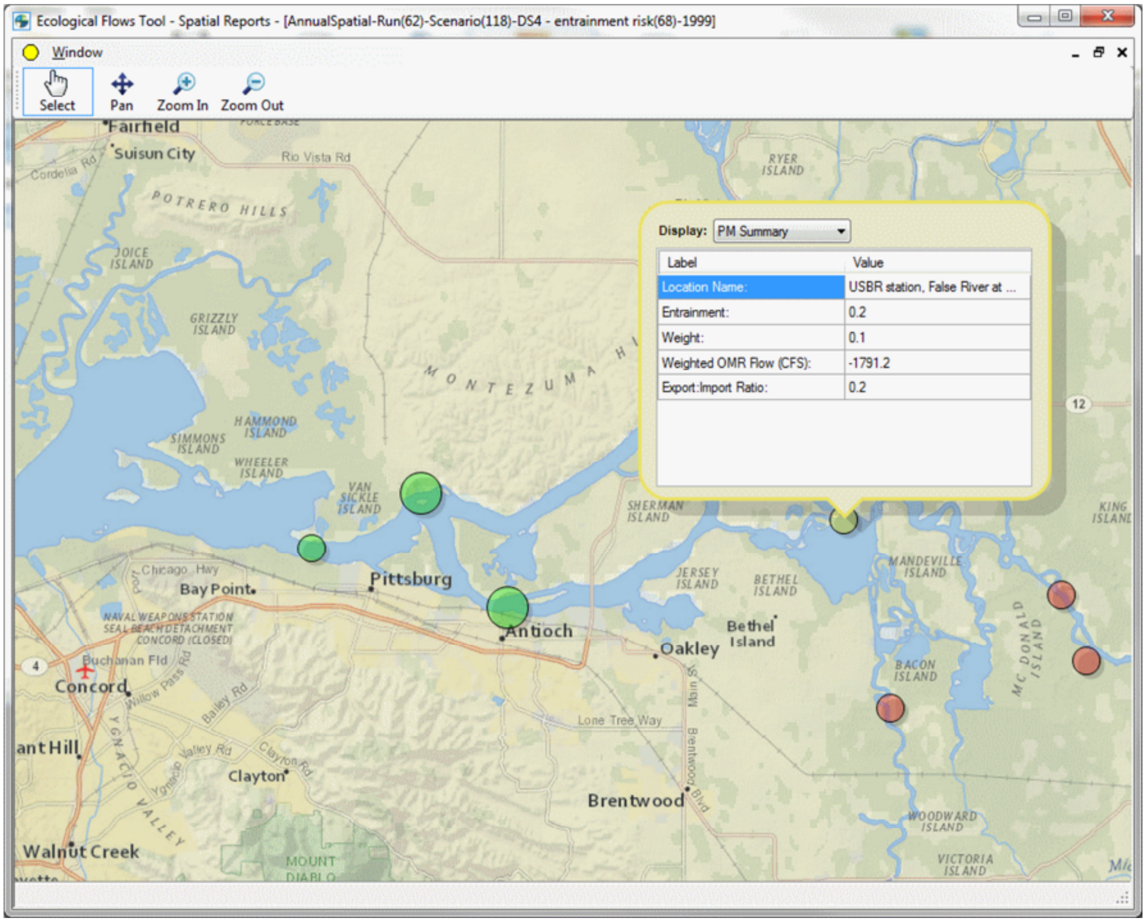


Figure 2.43: An example of a screen capture from the Annual Spatial report for DS4: Index of risk of entrainment. This example shows the performance for each location for a year with fair performance. Dots are colored based on their entrainment. Green dots are less than 5%, yellow dots are 5 – 25% and red dots are more 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.



Display: PM Summary

Label	Value
Location Name:	USBR station, False River at ...
Entrainment:	0.2
Weight:	0.1
Weighted OMR Flow (CFS):	-1791.2
Export:Import Ratio:	0.2

Figure 2.44: An example of a screen capture of location-specific information for DS4: Index of risk of entrainment. This example shows the PM Summary False River at the Webb Tract location. In this case, the location has fair performance (entrainment: 0.2) and low weight (weight: 0.1).

The multi-year rollup spatial report displays an R/Y/G colored pie-chart for each location of interest (see Figure 2.45). Each pie-slice represents the number of years the location was assigned a Good, Fair or Poor performance. This report is useful for quickly finding spatial patterns in performance, for example localized effects or downstream gradients in performance. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

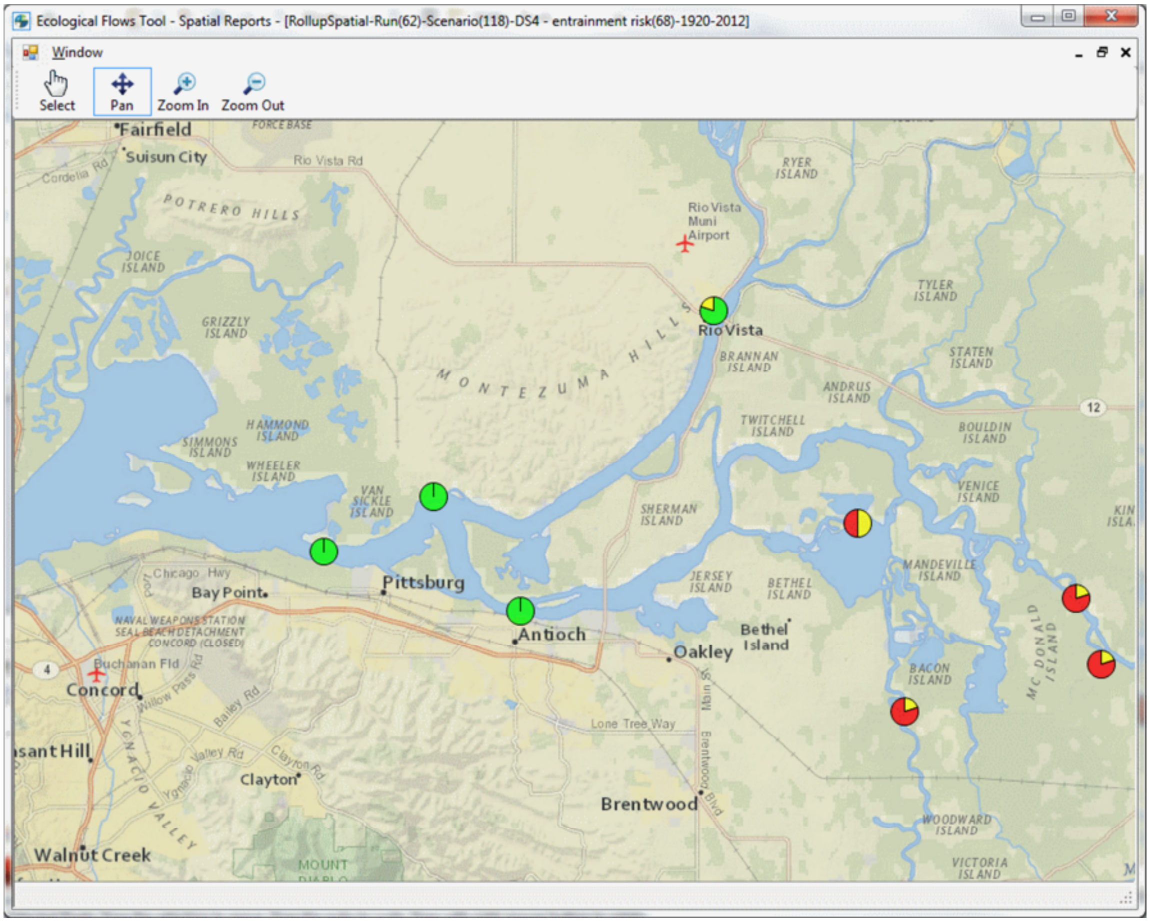


Figure 2.45: An example of a screen capture of multi-year rollup spatial report for DS4: Index of risk of entrainment. This example shows the percentage of good/fair/poor years for each location of interest for 10 years. Note that in this example, locations to closer to the CVP and SWP water export facilities have more poor years than other locations. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

PM uncertainties and overall reliability

> "The issue of whether entrainment of adults or larvae/juveniles has "population-level" impacts is hotly contested. It is essentially a classic fisheries management issue in which fishing pressure (water exports) has increased over time, but productivity has decreased over time, and the degree of compensatory density-dependence the population has to absorb the increased mortality is unknown – and where it exists statistically, it cannot be cleanly separated from declining habitat suitability – some of which is due to water management effects on flow and thus abiotic aspects of habitat suitability."
>
> -Matt Nobriga, pers. comm., 2010

The Delta smelt has been modelled by four different life-cycle models between 2010 and 2012, and they all have different measures of entrainment as a potential factor. Both Thomson *et al.* (2010) and MacNally *et al.* (2010) found that the magnitude of winter export was an important factor in their models, but only the latter study found spring exports to be important. Entrainment of adults, as measured at the pump salvage stations, was found to be important by Maunder and Deriso (2011) when their models included density dependence from the adult to the larvae stage. Adjusted entrainment estimates based on Kimmerer (2008) were found statistically significant in explaining fall-to-summer survival by Miller *et al.* (2012), but they didn't find it significant in explaining fall-to-fall (life-cycle) survival. The weight of evidence from these four models indicates that entrainment can have a population-level effect, although they is no agreement between models on the importance.

An important uncertainty regarding the proportion of Delta smelt that are entrained relates to distribution. Since the Cache Slough Complex and the Deep Water Shipping Channel were first regularly surveyed in 2008, the understanding of the current Delta smelt distribution has changed (*e.g.,* Miller 2011), and there are even some indications that a non-migratory population may exist at the flooded Liberty Island (Sommer *et al.* 2009). Only 45 observations of larvae and juvenile Delta smelt were available to develop the spatial weights for this PM at the time of implementation of DeltaEFT version 1, and there is still significant disagreement regarding the most appropriate weighting scheme (*e.g.,* Miller 2011 and Kimmerer 2011). A revised spatial weighting scheme could be integrated into future versions of this tool as more observations and research into the distribution of Delta smelt becomes available.

2.2.3 Splittail

The splittail conceptual model is shown in Figure 2.46.

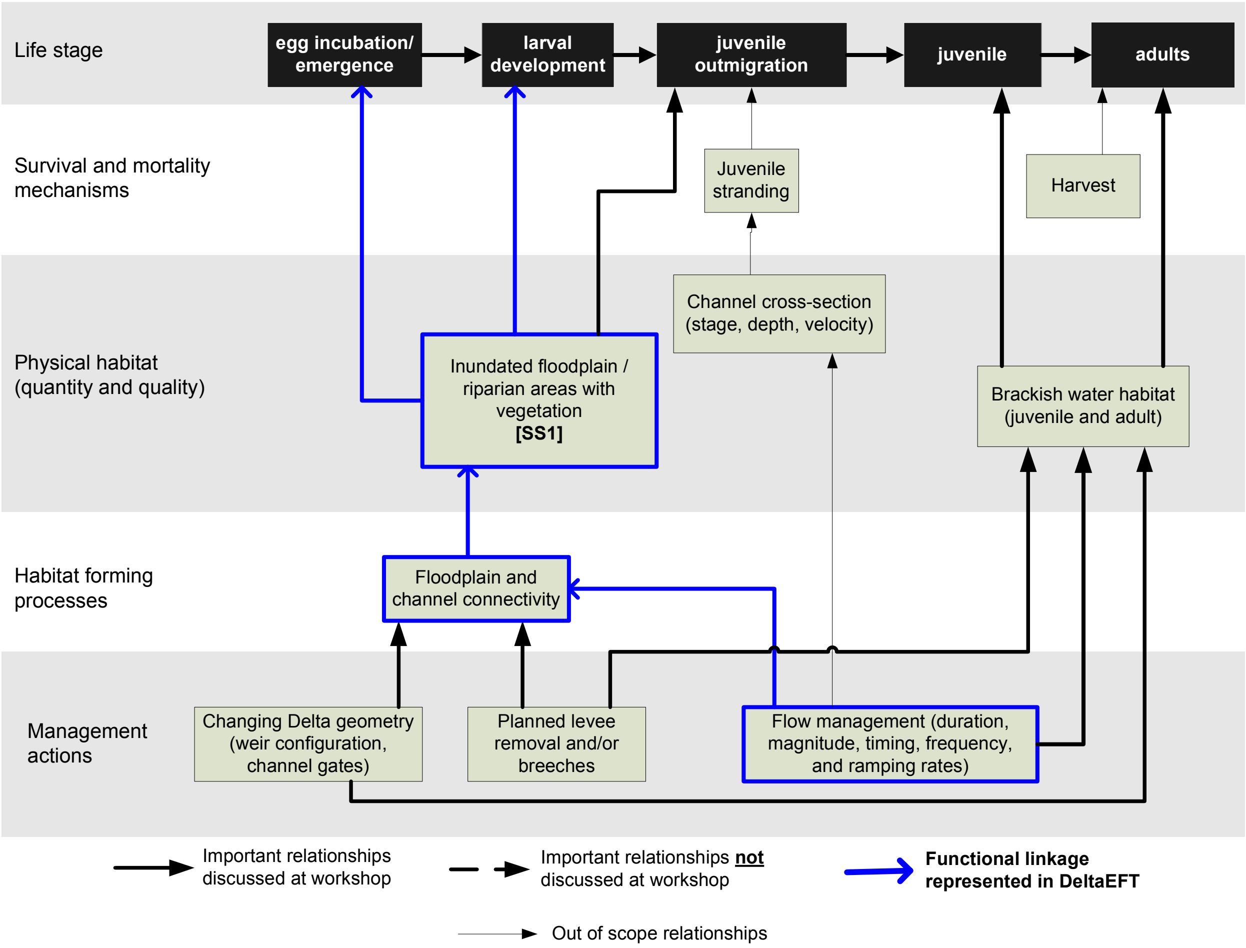


Figure 2.46: The conceptual model representing the links between management actions and splittail, as mediated by changes in habitat forming processes. Heavy blue lines show the processes and linkages that are included in DeltaEFT.

DeltaEFT includes 1 PM that describe changes in the physical habitat available to splittail (Table 2.8). We focus on habitat requirements for spawning and rearing because these are believed to be the habitat limited lifestages for splittail. Splittail are tolerant of a wide range of salinities and temperatures as adults may occupy brackish water environments. We chose not to develop a PM specific to brackish water habitat for splittail because we felt they would be redundant with other PMs in DeltaEFT, *i.e.*, DS2. Delta smelt are more sensitive to water quality parameters (*i.e.*, salinity, turbidity, and temperature) than splittail, consequently conditions that are satisfactory for Delta smelt will be satisfactory for splittail.

Table 2.17: Performance measures for splittail.

Performance Measure	Synonyms	PM code
Spawning habitat extent in Yolo bypass		SS1

The approach and data we used are largely based on studies published in the primary literature.

SS1 Spawning habitat extent

Rationale

Historically, splittail were among the most abundant estuarine species in the Sacramento-San Joaquin estuary and were found throughout the Delta (Caywood 1974 in Young and Cech 1996). Splittail abundance has decreased over time as a result of habitat destruction and alteration (Moyle *et al.* 2004). Modification of lowland floodplain habitat and riparian areas is one of the major stressors on splittail as they are dependent on these areas for spawning and rearing. Much of the historical floodplain habitat and river edge used for spawning has been converted for agricultural and urban developments and this limits splittail populations (Moyle *et al.* 2004). Spawning habitat is characterized by the presence of dense vegetation (perennial and/or annual plants), in water with detectable flow, shallow depth (< 1.5m), low temperature and high clarity (Moyle *et al.* 2004).

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. In addition to floodplains along the two primary tributaries in the Delta, substantial spawning also occurs in smaller tributaries such as the Petaluma River, Napa River, and Butte Slough (Feyrer *et al.* 2006). Splittail are opportunistic spawners, meaning that some level of spawning occurs in all years regardless of water year type. Active management of flow in dry years could increase the total area of inundated floodplain for spawning purposes. Flow management options that are beneficial to this species have been hindered to a degree because it is not known what characteristics of the flood pulse (timing and magnitude) are best for spawning and rearing (Feyrer *et al.* 2006; Moyle *et al.* 2004). Several studies suggest that manipulation of flows into Yolo Bypass such that floodplain inundation is maximized between January and June is likely to provide the greatest overall benefit to the splittail population, as well as other fish populations, particularly in dry years when overall production is low (Lehman *et al.* 2008; Feyrer *et al.* 2006; Sommer *et al.* 2001).

Performance measure

The foundation for this PM is the relationship between flow and inundation of Yolo bypass. Currently, the flow necessary to top Fremont weir at the top of Yolo bypass is 58,000cfs. Water entering Yolo bypass initially flows through a perennial channel on the east edge of the basin before spilling onto the floodplain when discharge in this small channel exceeds 3530cfs. 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. The rationale for focusing on this bypass is that it is one of the few areas in the Delta where inundation regimes can be directly manipulated using Fremont weir.

The spawning period typically spans from March to early May; however, it is highly variable and depends on water year and associated conditions (Moyle *et al.* 2004). For this PM, we assume that length of spawning period is a function of inundation (*i.e.*, the length of time that Yolo bypass is inundated). 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. We used a relationship between flow thru Yolo bypass (this is the sum across both the Freemont and Sacramento weirs) and area inundated <2m in Yolo derived from data collected by Ted Sommer (Figure 2.47).

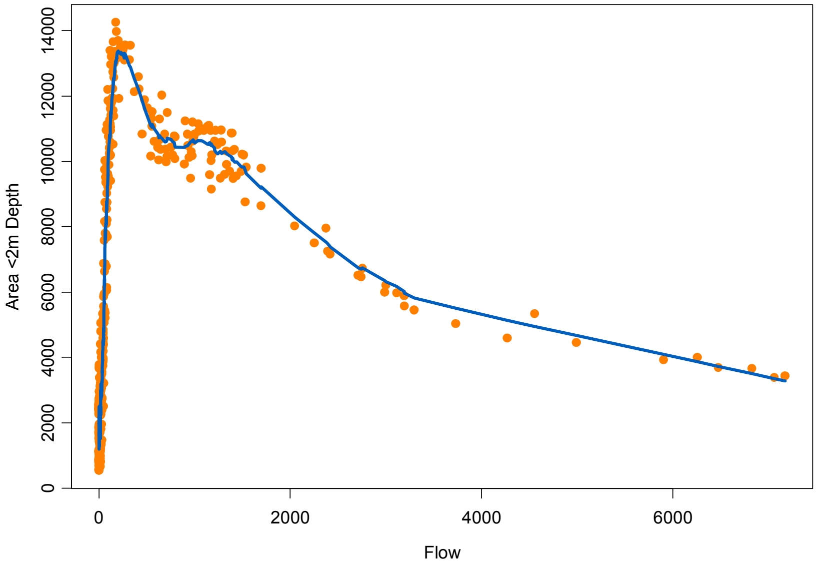


Figure 2.47: Area less than 2m depth as a function of flow in Yolo Bypass. The smoothing span was set to 0.03 for this example, instead of the default cross-validation smoother. This better captures the curve at large flows. Sommer also computed total area, which is not included in this document.

The annual PM (SS1) is a function of the number of days that floodplains are inundated (based on depth criteria) between February through to early May:

$$SS1 = \sum_{j=1}^{J} \left(\underset{i=j}{\overset{i=j+s}{Min}} \left(\frac{A_i}{A_{\max}} \right) \bullet p_j \right) \qquad \text{Eqn 2.21}$$

Where $j=1$ is the first spawn date in the period of interest; J is the number of spawning days; i is the day post spawn date in the development of an individual; s is the minimum duration of inundation from spawn date to the point where an individual is mobile enough to avoid entrapment or being swept away (15 days); Ai is the area inundated (<2m) on day i; Amax is the maximum possible inundated area (<2m); and

p_j is the proportion of the egg population spawned on day j. The proportion of spawners, p_j, on a given day was estimated by fitting a normal distribution to spawn date data from Feyrer *et al.* (2006) using the year 1998. This was the favorable year for splittail in their data set and is assumed to be the best indicator of spawn date distribution.

Calibration

This indicator is dimensionless and the cumulative value represents the proportion of maximum potential spawning habitat extent for the population. R/Y/G breakpoints are derived from historic data of catch per unit effort for rotary screw trap data (Feyrer *et al.* 2006) such that 1998 and 2000 are considered to be good years, 1999 is considered to be a fair year and 2001-2004 are considered to be poor years (see Table 2.18).

Table 2.18: SS1 – Spawning habitat extent. Units are dimensionless.

	Daily		**Rollup**		**Notes**
	Good-Fair	**Fair-Poor**	**Good-Fair**	**Fair-Poor**	
SS1 – Spawning habitat extent	N/A	N/A	0.05	0.02	• Criteria: Based on historical good/fair/poor years • Units: N/A • No daily estimate

Excel Reports

Excel reports and metadata are available for the annual rollup of SS1. An example is shown below in Figure 2.48.

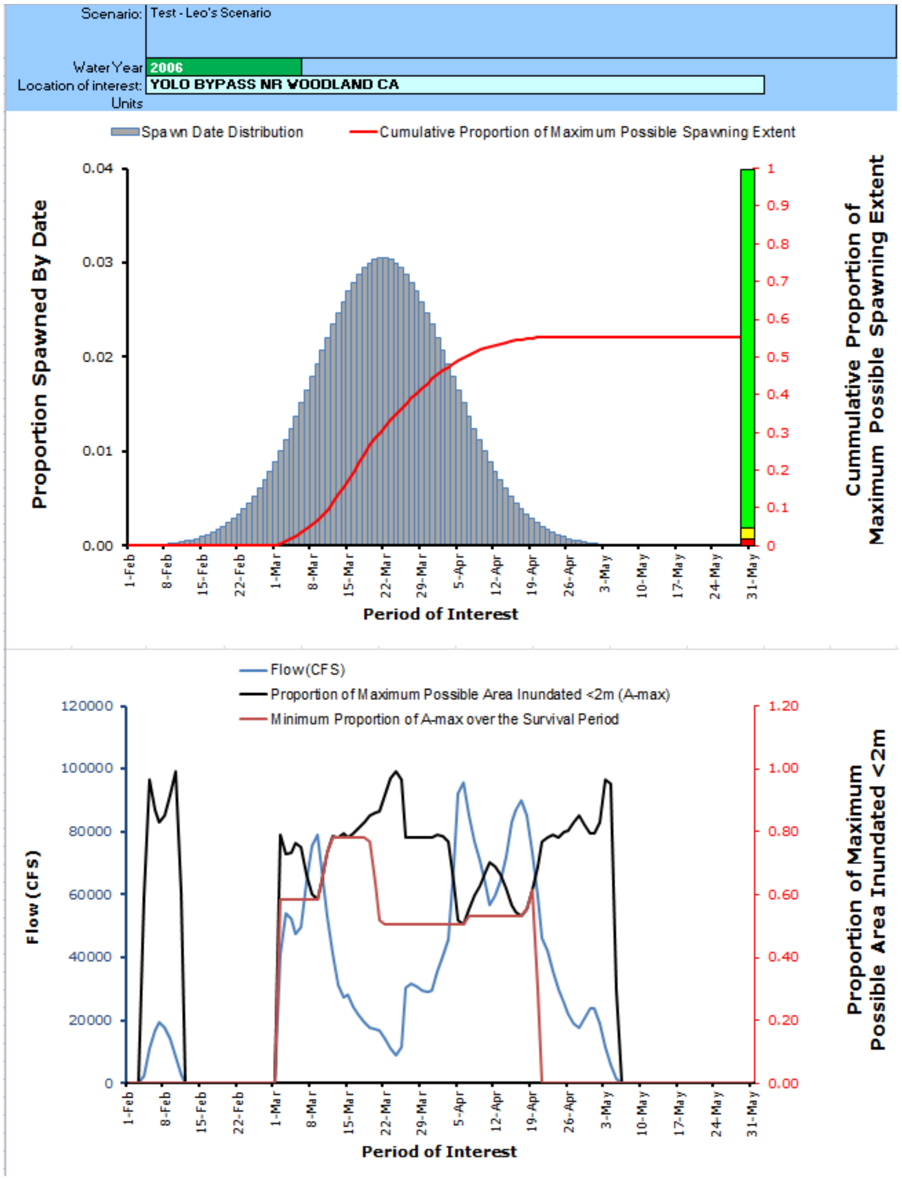


Figure 2.48: Sample excel report for SS1. The bottom graph shows flow in blue, the resulting area inundated by less than 2m of water in Yolo bypass and the minimum area inundated experience over the survival period by a cohort of splittail spawned on a specific day. Areas are expressed as a proportion of the maximum possible. The top graph shows the spawn date distribution and the cumulative proportion of the maximum possible spawning extent.

Spatial Reports

There is no spatial report defined for this Indicator.

Locations of interest

The primary location of interest for this PM is Yolo bypass. There are other areas in the estuary where spawning does occur; however, the relationship between stage and flow for these floodplains has not to our knowledge been documented. We will include additional areas where this relationship has been established and the supporting data can be extracted from DSM2 (see Table 2.23).

Table 2.19: Locations of interest for Splittail spawning habitat extent (SS1).

Location Name	IEP ID	CDEC ID	River	River Kilometer
Fremont weir spill to Yolo Bypass	RSAC244	FRE	Sacramento River	244
Sacramento Weir Spill to Yolo Bypass	RSAC182		Sacramento River	182

PM uncertainty and overall reliability

The relationship between inundation period and splittail spawning habitat is well established in the literature (Feyrer *et al.* 2006). There is some source of uncertainty regarding the minimum inundation depth at which splittail spawn. We did not have a way to model minimum depth criteria so we assumed that all levels of inundation >0.0 m and <2.0m resulted in suitable habitat for splittail.

2.2.4 Fresh & Brackish Tidal Wetlands

The fresh and brackish tidal wetlands conceptual model is shown in Figure 2.49.

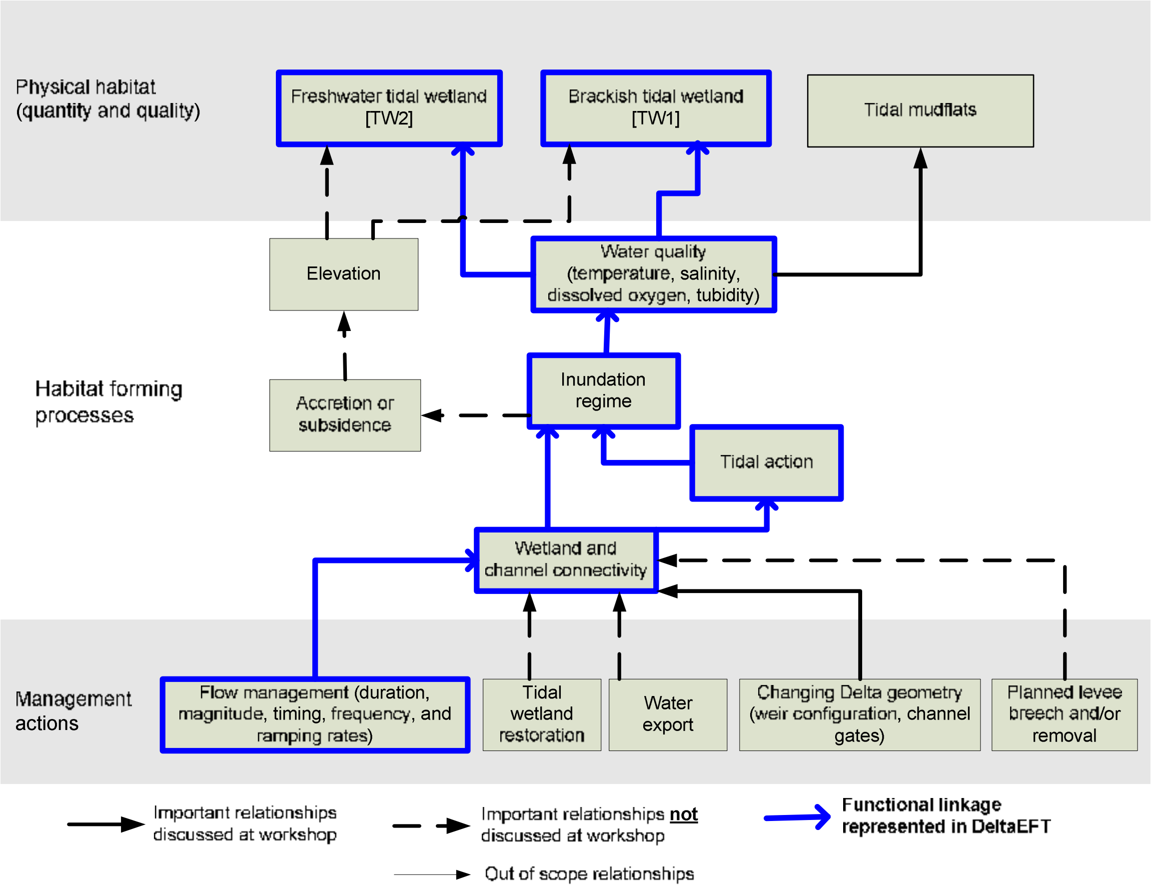


Figure 2.49: The conceptual model representing the links between management actions and fresh and brackish wetlands, as mediated by changes in habitat forming processes. Heavy blue lines show the processes and linkages that are included in DeltaEFT.

DeltaEFT includes 2 PMs that describe changes in the tidal wetlands (brackish and freshwater) condition (Table 2.20).

Table 2.20: Performance measures for fresh and brackish wetlands.

Performance Measure	Synonyms	PM code
Tidal wetland area brackish		TW1
Tidal wetland area freshwater		TW2

TW1 Tidal wetland area brackish

Rationale

Tidal wetlands are very productive ecosystems with high nutrient output (source of detritus which forms the base of the food chain in tidal wetlands). Areas that border on or lie beneath tidal waters (*e.g.*, banks, bogs, salt marshes, swamps, meadows, flats, or other low lands subject to tidal action) whose surface is at or below an elevation of 0.3m above local extreme high water are typically classified as tidal wetlands. The loss of ~ 90% of the estuary's wetlands since 1850 has placed increased importance on the remaining 125km^2 of wetlands which continue to be threatened by development, erosion, pollution, and rising sea level (Nichols et al. 1986). Loss of wetlands has led to reduction in habitat available for associated fish and wildlife species (*e.g.*, waterfowl and wading birds, Chinook, splittail, garter snakes, *etc.*; CALFED 2000). Channelization, levee-building, removal of vegetation to stabilize levees, and upstream flood control have reduced the extent of tidal wetlands, altered their ecological function through changes to flooding frequency, inundation duration, rates of alluvial material deposition, and resulted in rapid rates of subsidence of Delta islands (Lund *et al.* 2007; Nichols *et al.* 1986).

Performance measure

Wetlands are often defined by their inundation regime and the salinity of the water inundating the area. Brackish wetlands typically experience daily water level fluctuations because of tidal influences and are only inundated during parts of any given day. Freshwater wetlands, in contrast, are more likely to experience seasonal inundation, *e.g.,* during the spring freshet or other types of high freshwater flows. The inundation regime influences the plants that are able to grow in an area. The flora of a salt marsh is differentiated into levels according to the plants' individual tolerance of salinity and water table levels, and the tide creates a vertical zonation.

For the purpose of this indicator, we define the wetland zone to encompass low-, mid- and high-marsh areas between the mean tide level and the extreme high tide see Figure 2.50. This is consistent with what US Fish and Wildlife Service classifies as intertidal emergent vegetation characterized by erect, rooted, herbaceous hydrophytes, excluding mosses and lichens. The area between the extreme low tide and mean tide level is considered mudflats.

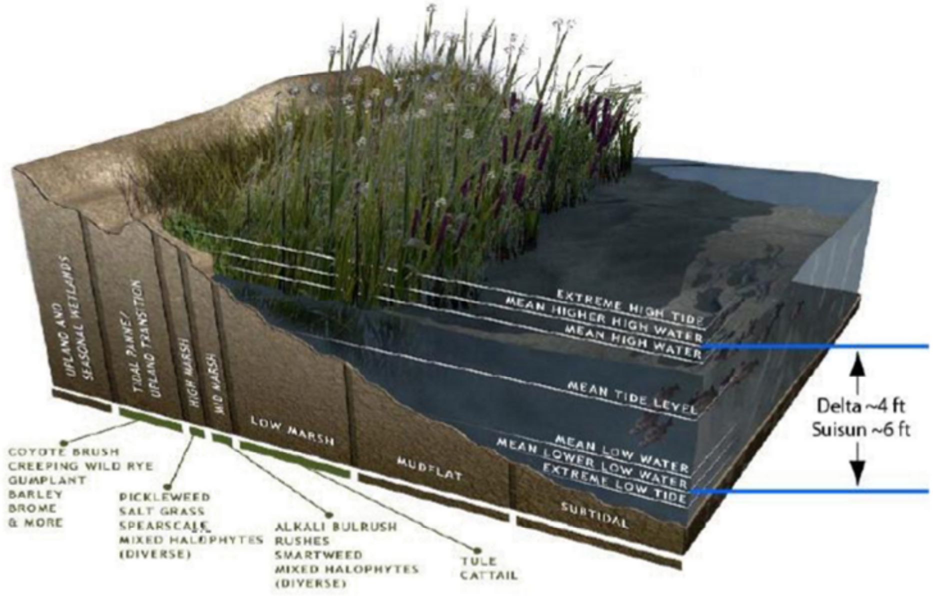


Figure 2.50: Perspective view of a tidal brackish marsh profile (*e.g.,* Suisun Marsh) with adjacent uplands and open waters. DeltaEFT considers low-, mid- and high-marsh areas between the mean tide level and the extreme high tide as wetlands. Reproduced from Siegel 2007.

The San Francisco Estuary has mixed, semi-diurnal tides, meaning twice-daily tides with differing elevations for successive low and high tides (Siegel *et al.* 2005). The DSM2 models are simulating the stage in the delta under current and future sea level rise (SLR) condition. Based on DSM2 stage data for a location, we can determine the Extreme High Water (EHW) and the Mean Tide Level (MTL), see Figure 2.51.

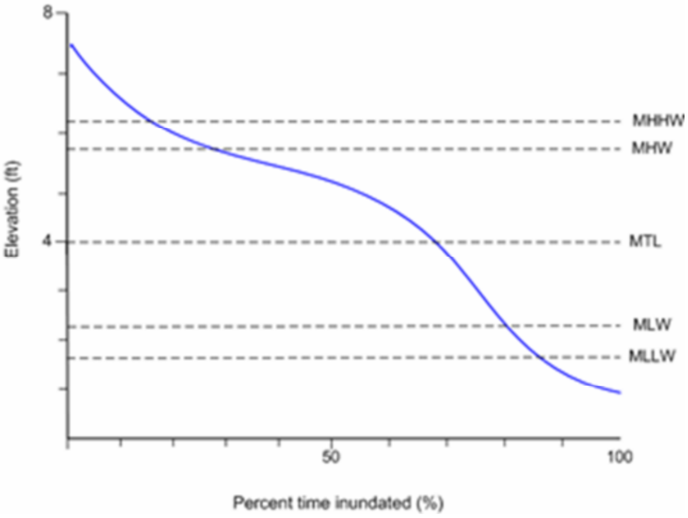


Figure 2.51: Example of tide elevation profile illustrating MTL and EHW. EHW is the highest elevation observed in the period of interest, *i.e.,* the elevation is never exceeded.

Extreme High Water is calculated for a location *i* as:

$$EHW_i = \max(Stage_i) \qquad \text{Eqn 2.22}$$

and Mean Tide Level for location *i* is calculated as:

$$MTL_i = \frac{1}{N}\sum Stage_i \qquad \text{Eqn 2.23}$$

where N is the number of observations.

The area of low-, mid- and high-marsh between the mean tide level and the extreme high tide can be estimated from a Digital Elevation Model (DEM). LiDAR (Light Detection And Ranging) have been used to develop a 1x1m grid (DEM) for the study area with an estimated vertical accuracy of 10cm. Figure 2.52 shows an example of a DEM with elevation bands classified as above EHW (terrestrial), between MTL and EHW (wetland) and below MTL (mudflats).

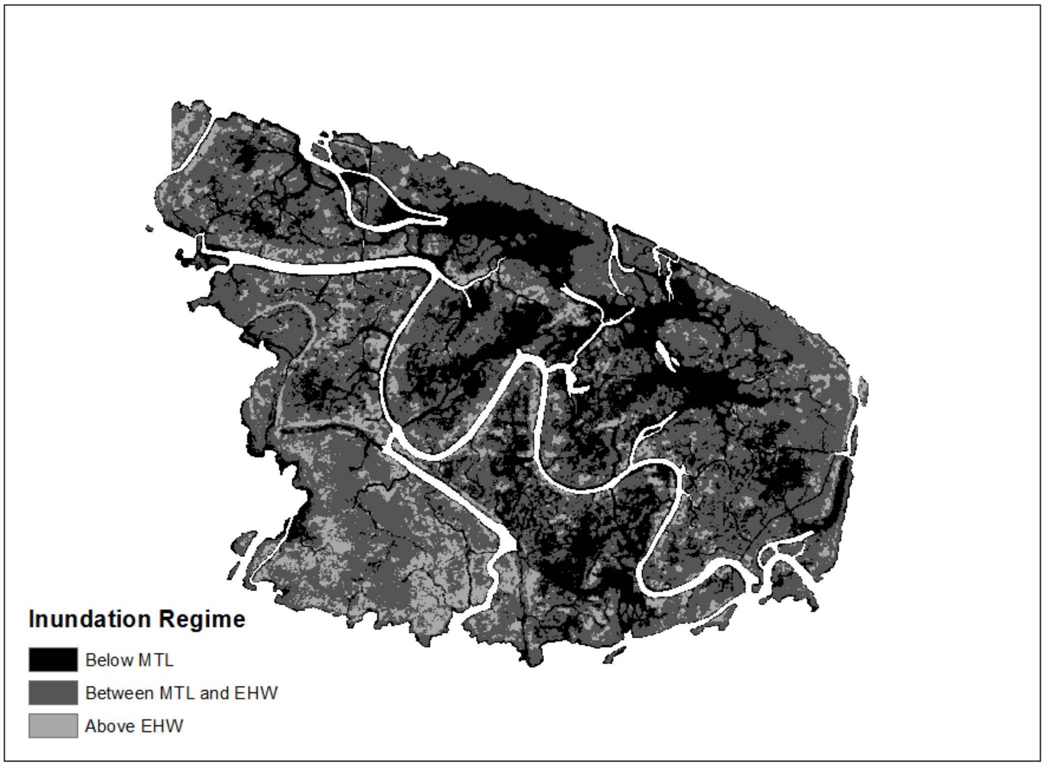


Figure 2.52: Example of a DEM for Ryer Island with elevation bands classified as above EHW (terrestrial), between MTL and EHW (wetland) and below MTL (mudflats)**.**

The DEM data can be used to develop an elevation profile for each of our locations of interests, see Figure 2.53.

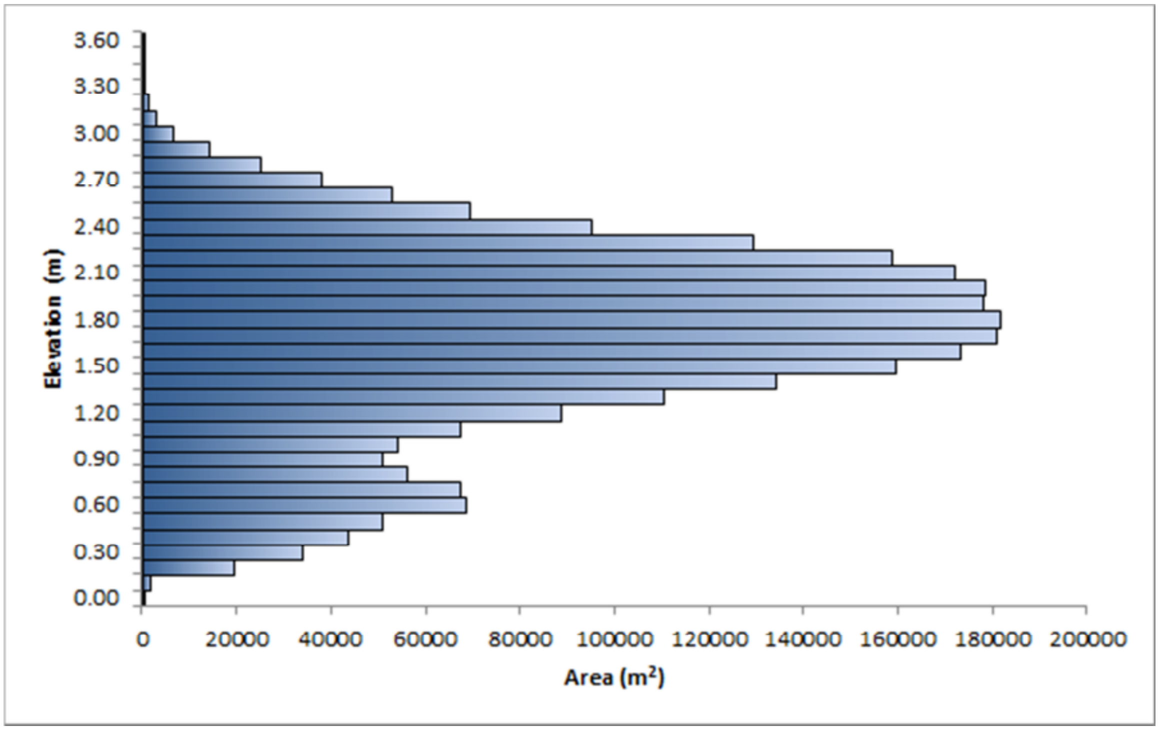


Figure 2.53: Example elevation profile for Ryer Island based on DEM data. Each band is 10cm.

The elevation profile can then be used to estimate the wetland area for a location *i* by summing up all area between the MTL and EHW:

$$TW1_{i,y} = \sum_{z=MTL_{i,y}}^{EHW_{i,y}} A_{i,z} \qquad \text{Eqn 2.24}$$

The annual PM for TW1 is the sum of wetland area for all locations:

$$TW1_{y} = \sum TW1_{i} \qquad \text{Eqn 2.25}$$

Locations of interest

Locations of interest were selected so they would represent different BDCP Restoration Opportunity Areas (ROAs[10]), however, all potential index sites for brackish wetlands are located in the Suisun ROA. Wetland areas were then mapped using the U.S. Fish and Wildlife Service's National Wetlands Inventory and filtered according to the wetlands and deepwater habitats classification, so only emergent wetlands we selected, *e.g.,* no managed wetlands or farmed areas. Finally, the nearest gauge with stage date was located. The locations of interest relevant to this PM are 3 brackish wetland index sites, see Table 2.21 and associated figures.

The selected process resulted in 3 index sites, of which 1 site is an island and the other 2 are diked. We assume that in the case of sea-level rise, the dikes will be heightened, so the water will not cross the dike,

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[10] Maps of BDCP ROAs can be found at: http://baydeltaconservationplan.com/BDCPPlanningProcess/BackgroundDocuments/Maps.aspx. Accessed on January 21, 2013.

which means that all 3 sites area constrained by outside boundaries. This server to constrained the DEM to a fixed area.

Table 2.21: Locations of interest for TW1 - tidal wetlands area brackish.

Location Name	Wetland Area (ac)
Roe Island	600
Grizzly Bay	460
Montezuma Slough	1,150

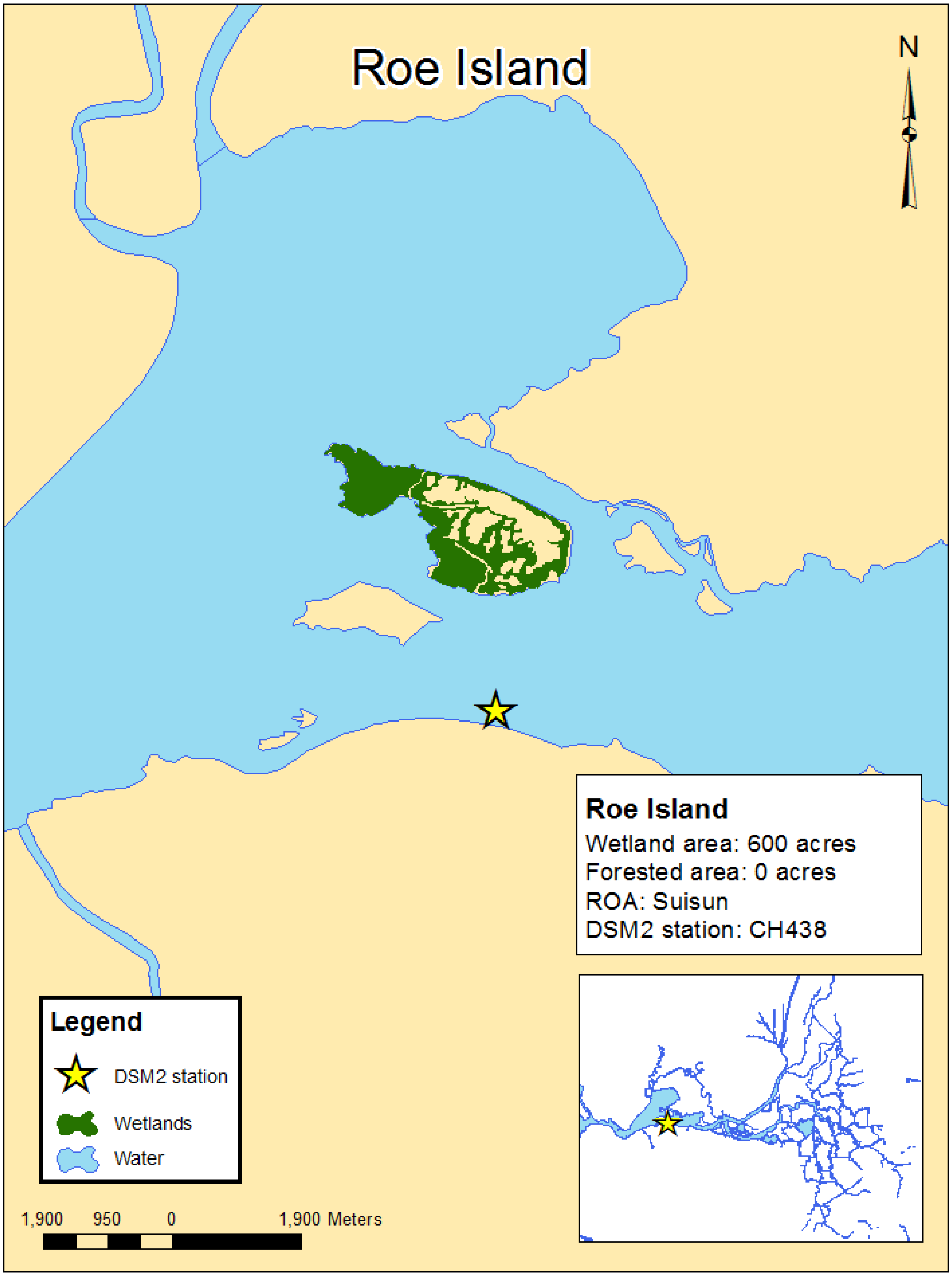


Figure 2.54: Overview map of Roe Island location of interest.

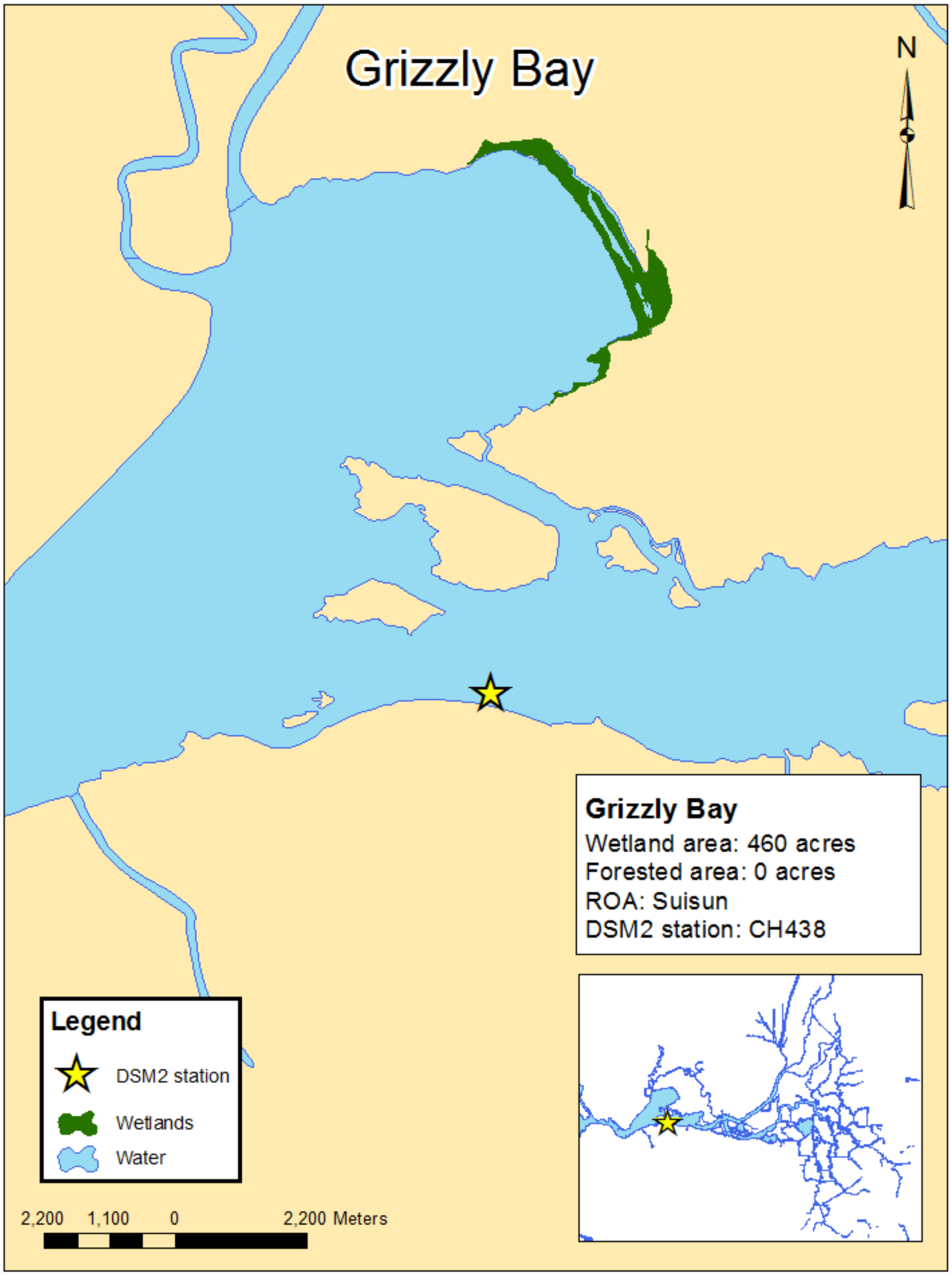


Figure 2.55: Overview map of Grizzly Bay location of interest.

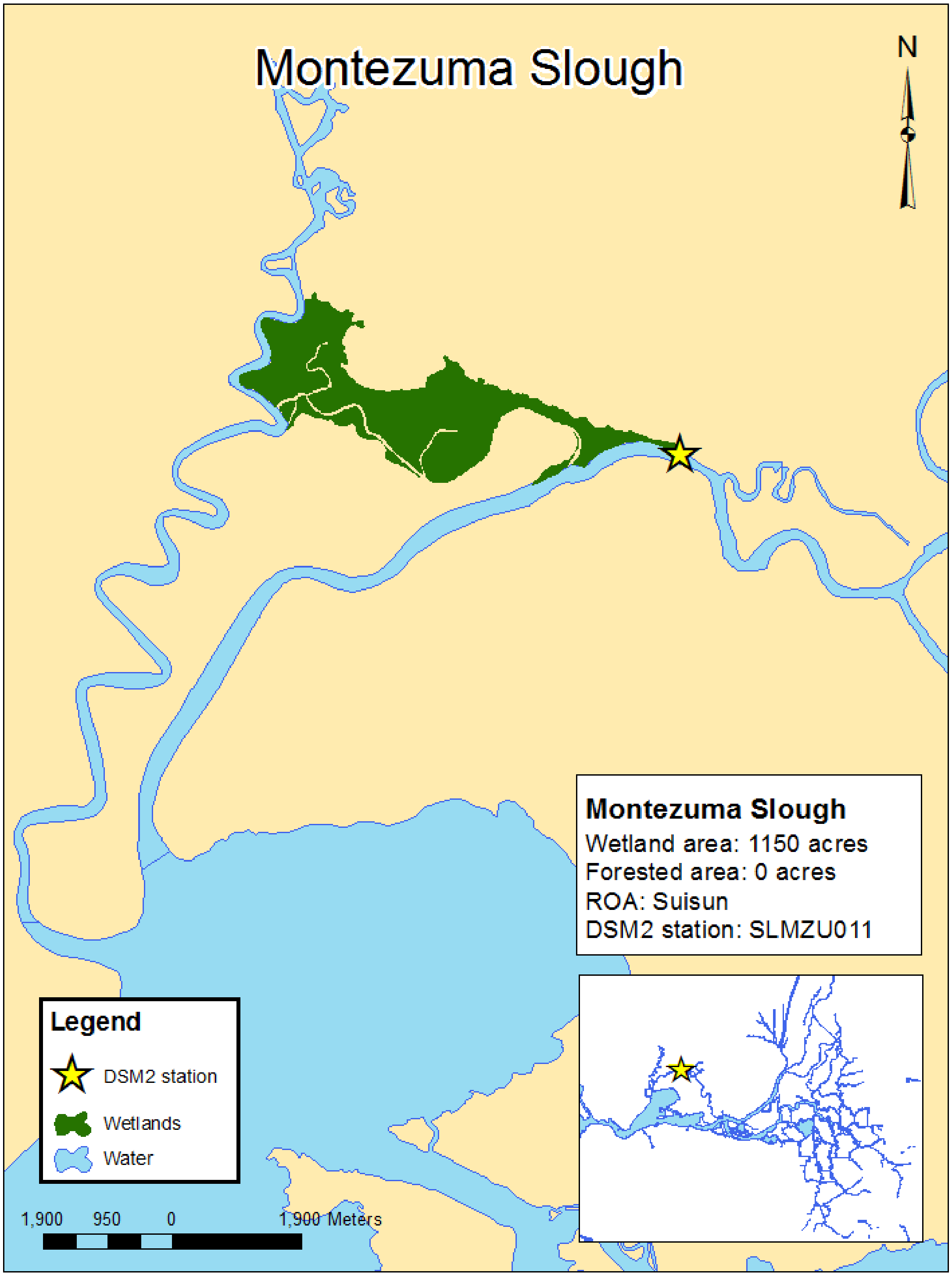


Figure 2.56: Overview map of Montezuma Slough location of interest.

Calibration

Calibration criteria were not available following the Design Workshop. In the absence of any guidance for TW1, natural breakpoints in TW1 PM values are used to assign a R/Y/G score, based on a simulation using current conditions, see Figure 2.57 and Table 2.22.

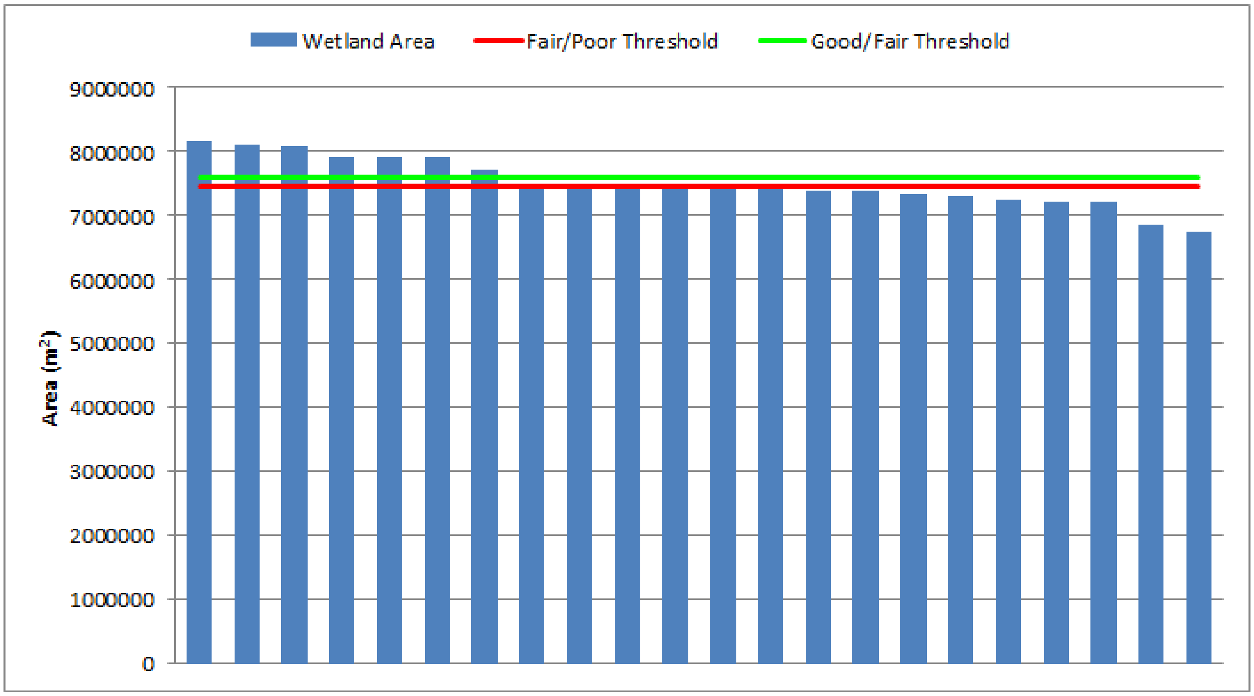


Figure 2.57: Calibration results for TW1. Thresholds are based on natural breaks for historical and simulated data Note that due to low variation between years, thresholds are very close. Threshold values are 7600000 and 7450000 m^2 wetland area.

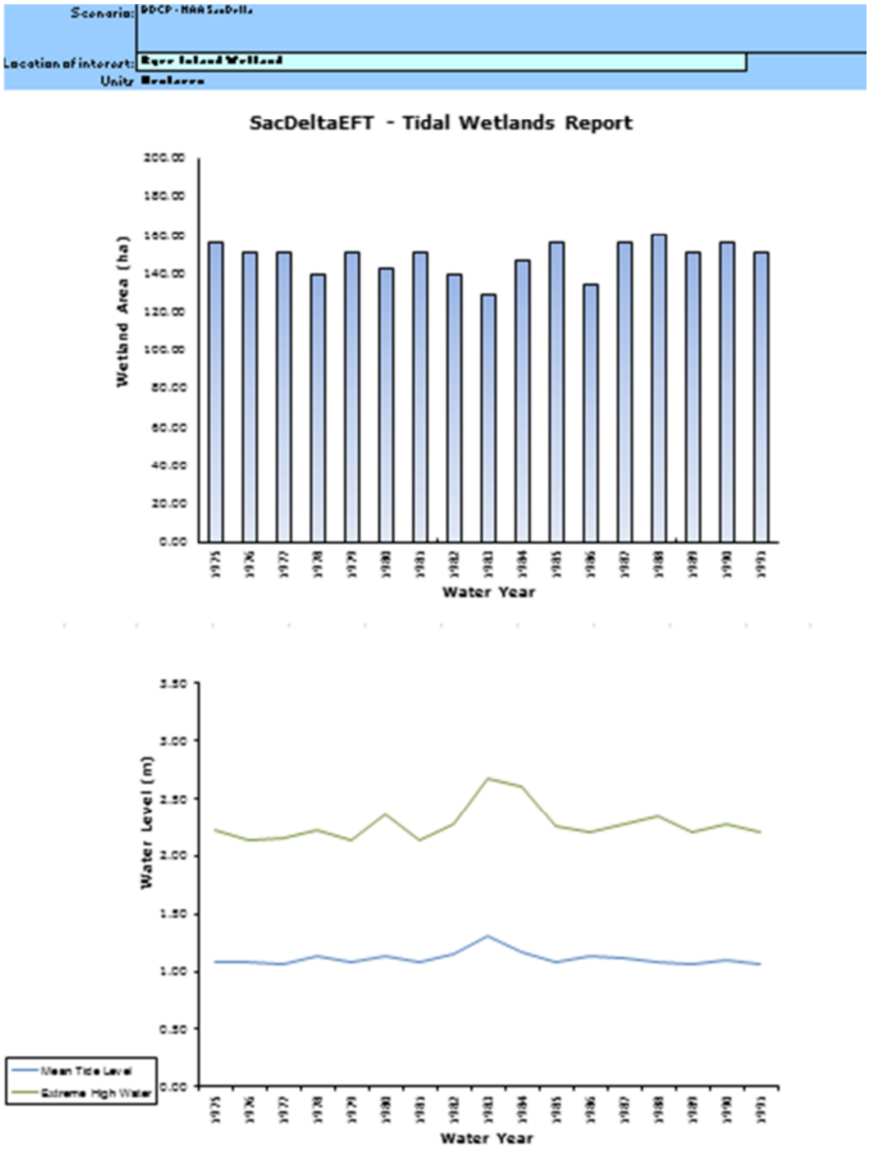
Table 2.22: TW1 – tidal wetland area brackish. Units are m^2.

	Daily		Rollup		Notes
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	
TW1 –tidal wetland area brackish	N/A	N/A	7600000	7450000	• Criteria: natural breakpoints, "more" is better • Units: m^2 • No daily estimate

Although this method provides an internally consistent way to compare results (*i.e.*, it will always provide a consistent ranking of which water management scenarios are "better" than others), it does not provide any concrete inferences about the biological significance of the three categories. For example, it is possible that a year that ranks as "Good" (Green) with this method may still be biologically suboptimal. Conversely, a year that ranks as "Poor" (Red) may be biologically insignificant.

Excel Reports

An example of the multi-year rollup Excel report for TW1 is shown below in Figure 2.58. The report shows two graphs: the upper panel shows the estimated wetland area for a particular location and the lower graph shows the annual Mean Tide Level and Extreme High Water.



Scenario: BDCP - NAA SacDelta
Location of interest: Ryer Island Wetland
Units: Hectares

Figure 2.58: An example of a screen capture from the Multi-year Rollup report for TW1: tidal wetland area brackish. This example shows performance for the Ryer Island location for the calibration data. Note that there is not a lot of variation between years.

Spatial Reports

There are 2 types of spatial reports available for TW1: Annual spatial reports and multi-year rollup reports. The annual spatial report displays an R/Y/G area for each location of interest, see Figure 2.59. The color of each area represents the annual location-specific performance. PM Summary information can also be displayed for each location by selecting it with the Select tool.

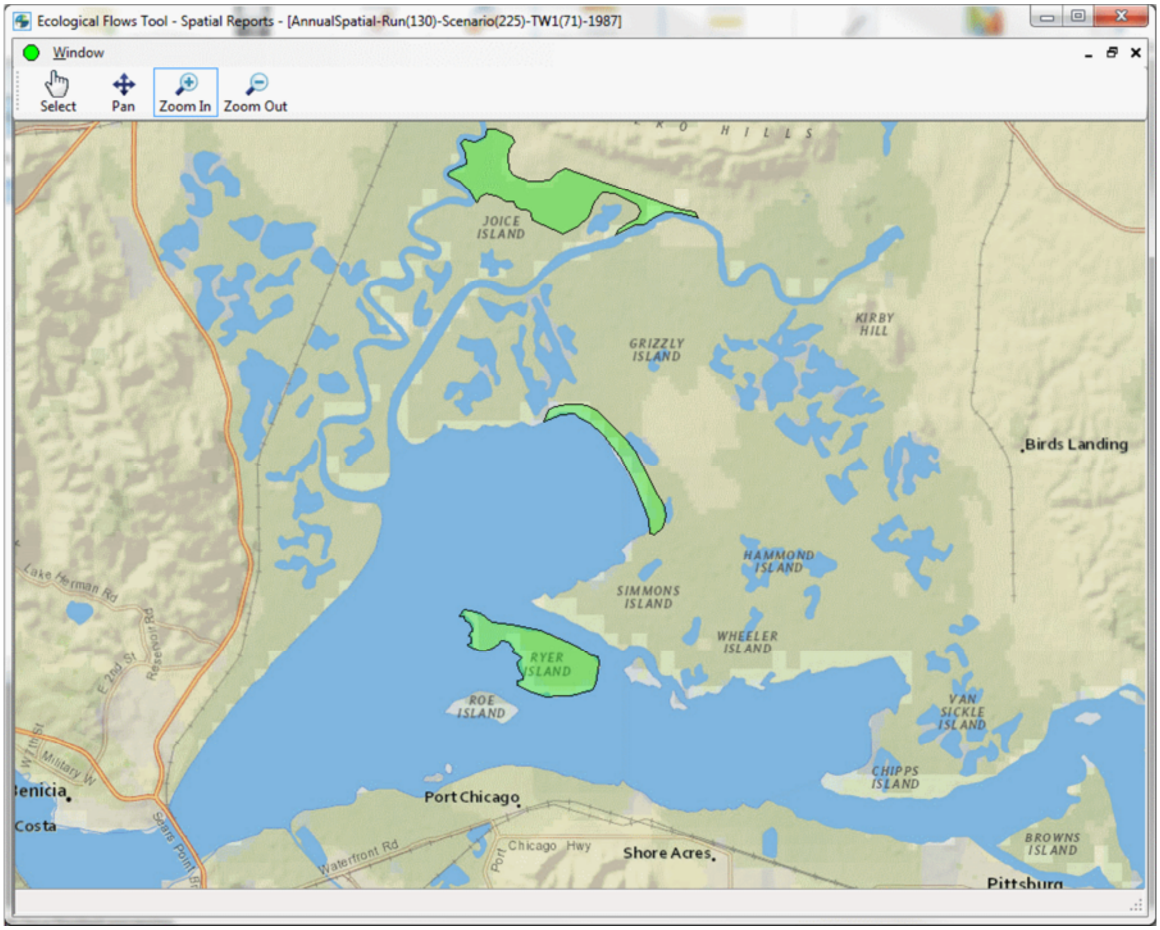


Figure 2.59: An example of a screen capture from the Annual Spatial report for TW1: tidal wetland area freshwater. This example shows the performance for each location for a year with good performance. Areas are colored based on their area relative to current conditions.

The multi-year rollup spatial report displays an R/Y/G colored pie-chart for each location of interest, see Figure 2.63. Each pie-slice represents the number of years the location was assigned a Good, Fair or Poor performance. This report is useful for quickly finding spatial patterns in performance, for example localized effects. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

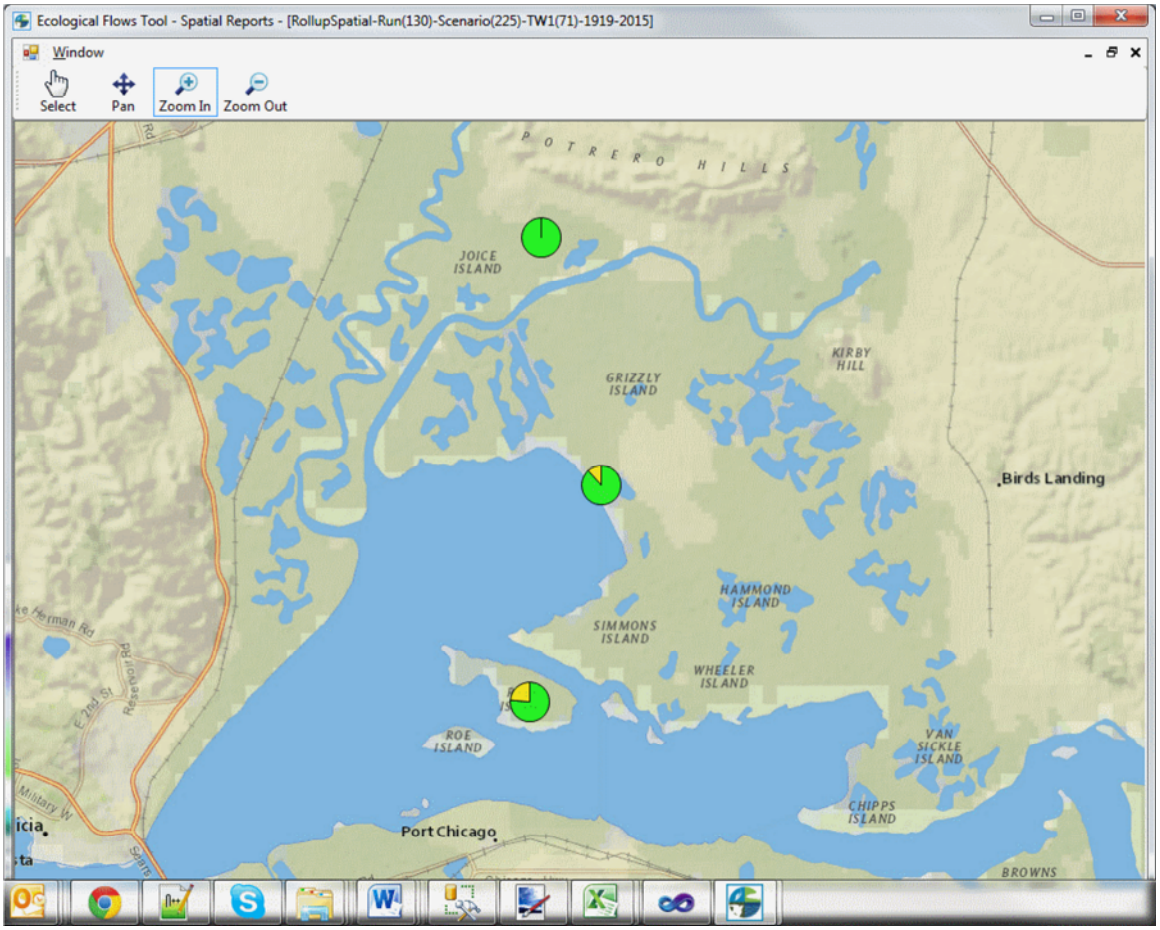


Figure 2.60: An example of a screen capture of multi-year rollup spatial report for TW1: tidal wetland area brackish. This example shows the percentage of good/fair/poor years for each location of interest for 17 years. Note that in this example, locations in Suisun Bay have more fair years than the Montezuma Slough location. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

PM uncertainties and overall reliability

TW1 is reliant on GIS spatial analysis to quantify area of tidal wetland for baseline and for each modeled scenario. Management actions that result in increased or decreased wetland area will require new GIS layers with updated polygons demarcating wetland areas. The premise behind TWI is that if areas classified as wetlands are not inundated they aren't actually functioning as a wetland at that point in time. Consequently, TW1 is only as good as the GIS and inundation regime inputs that we are able to access. The PM may over estimate wetland area because it only takes into account area inundated in polygons identified as tidal wetland and does not take into account vegetation structure and/or presence. Likewise, TW1 could under estimate total wetland area if the GIS layer informing the PM is not comprehensive and up to date.

TW2 Tidal Wetland Area Freshwater

Rationale

TW2 is similar to TW1 but focuses on freshwater tidal wetlands instead.

Performance measure

The TW2 PM is calculated similarly to TW1, but is defined for different index locations.

Locations of interest

Locations of interest were selected so they would represent different BDCP Restoration Opportunity Areas (ROAs[11])Wetland areas were then mapped using the U.S. Fish and Wildlife Service's National Wetlands Inventory and filtered according to the wetlands and deepwater habitats classification, so only emergent wetlands we selected, *e.g.,* no managed wetlands or farmed areas. Finally, the nearest gauge with stage date was located.

The selected process resulted in 5 potential index sites, one for each ROA except Suisun (*i.e.,* Cosumnes/Mokelumne, South Delta, West Delta, East Delta and Cache Slough ROA). Unfortunately, LiDAR data wasn't available for the index site in the Cosumnes/Mokelumne and South Delta ROA. Furthermore, initial result from classifying wetlands in the Cache Slough ROA was not promising, so only 2 freshwater index sites were selected. We decided to include the Shin Kee tract index sites even though the nearest gauge with stage data is more than 10km from the wetland area. Both remaining index sites are bordering dikes, and we assume that in the case of sea-level rise, the dikes will be heightened, so the water will not cross the dike, which means that all both sites constrained by outside boundaries. This serves to constrain the DEM to a fixed area.

The locations of interest relevant to this PM are 2 freshwater wetland index sites, see Table 2.22 and associated figures.

Table 2.23: Locations of interest for TW2 - tidal wetlands area freshwater.

Location Name	**Wetland Area (ac)**
Shin Kee Tract	320
Big Break	350

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[11] Maps of BDCP ROAs can be found at: http://baydeltaconservationplan.com/BDCPPlanningProcess/BackgroundDocuments/Maps.aspx. Accessed on January 21, 2013.

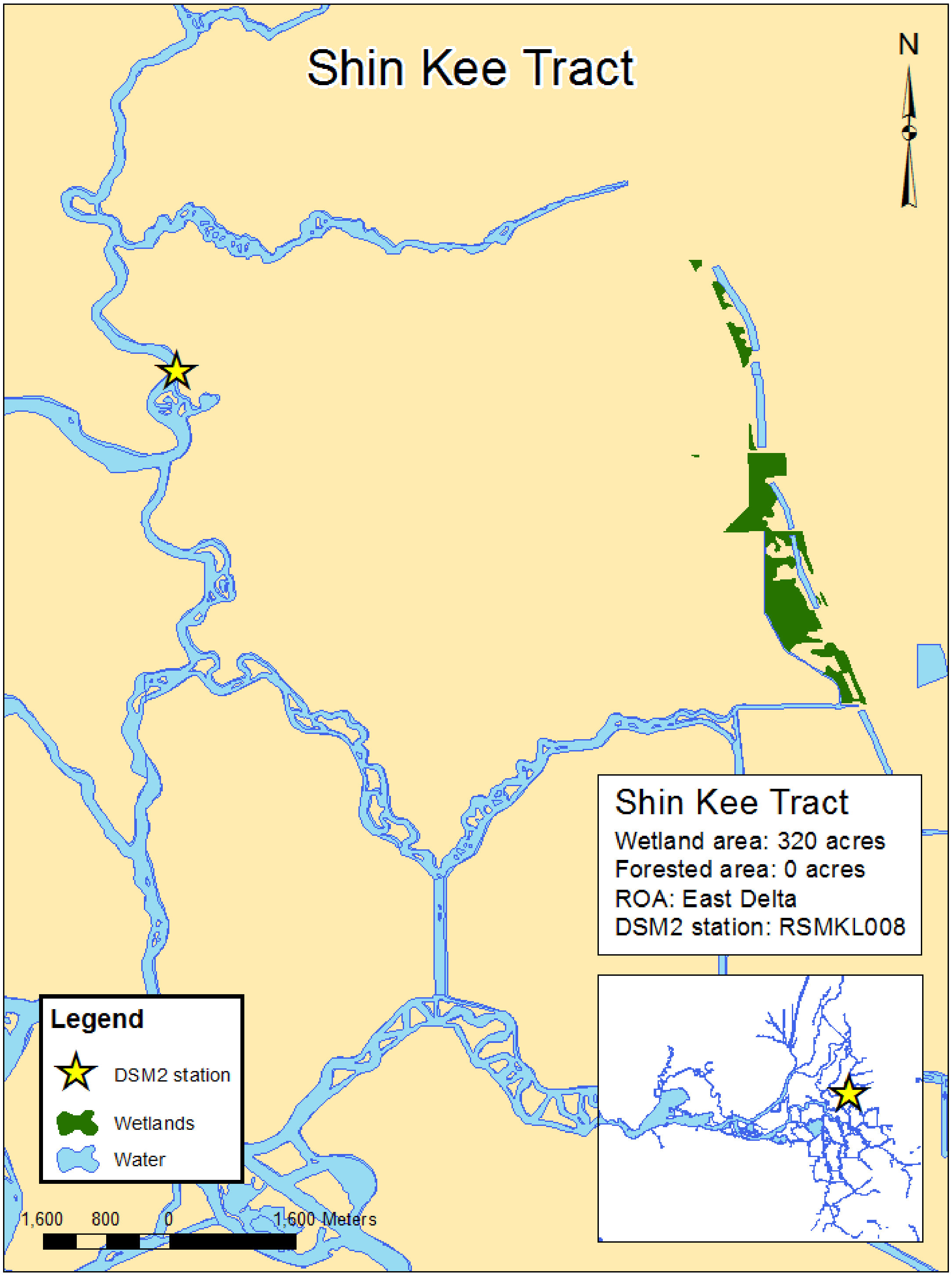


Figure 2.61: Overview map of Shin Kee Tract location of interest.

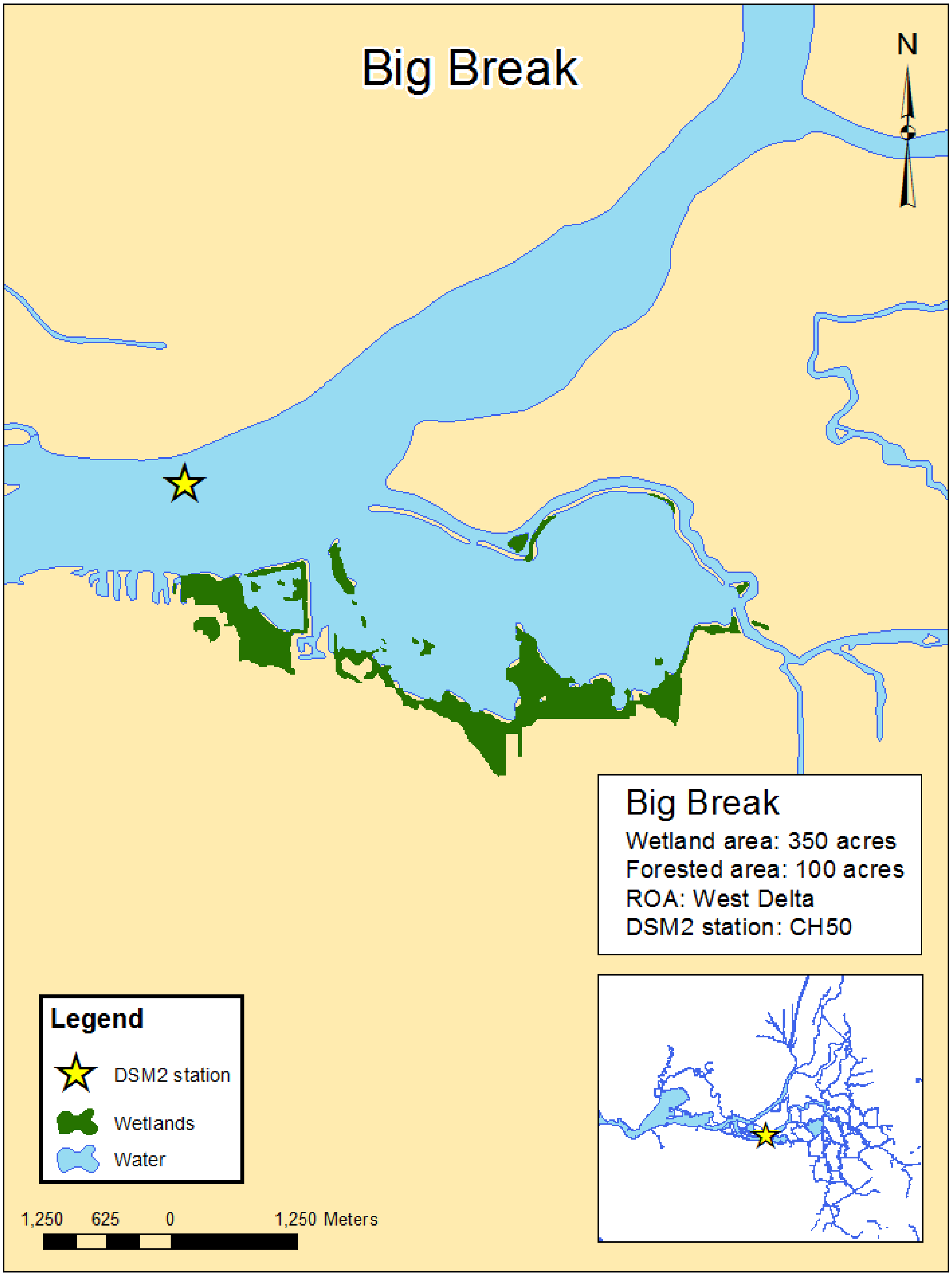


Figure 2.62: Overview map of Big Break location of interest.

Calibration

Calibration criteria were not available following the Design Workshop. In the absence of any guidance for TW2, natural breakpoints in TW2 PM values are used to assign a R/Y/G score, based on a simulation using current conditions, see Figure 2.63 and Table 2.24.

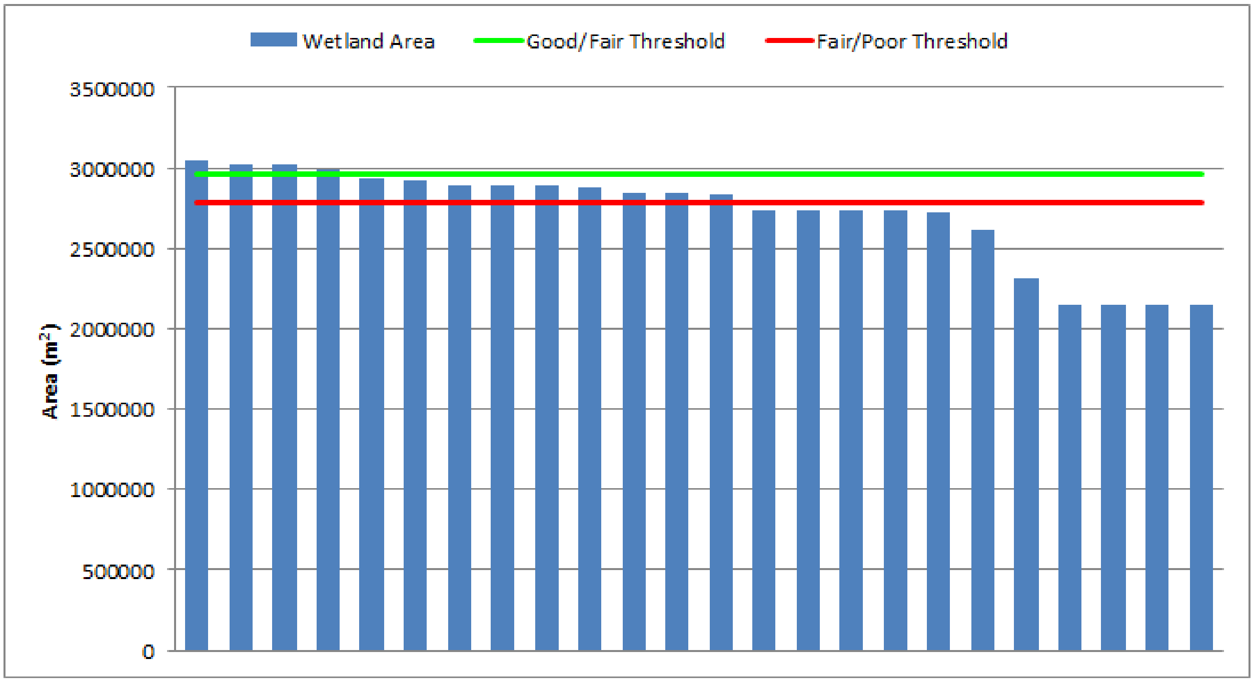


Figure 2.63: Calibration results for TW2. Thresholds are based on natural breaks for historical and simulated data. Note that due to low variation between years, thresholds are very close. Threshold values are 2960000 and 2780000m^2 wetland area.

Table 2.24: TW2 – tidal wetland area freshwater. Units are m^2.

	Daily		Rollup		Notes
	Good-Fair	**Fair-Poor**	**Good-Fair**	**Fair-Poor**	
TW2 –tidal wetland area freshwater	N/A	N/A	2960000	2780000 m2	• Criteria: natural breakpoints, "more" is better • Units: m^2 • No daily estimate

Although this method provides an internally consistent way to compare results (*i.e.*, it will always provide a consistent ranking of which water management scenarios are "better" than others), it does not provide any concrete inferences about the biological significance of the three categories. For example, it is possible that a year that ranks as "Good" (Green) with this method may still be biologically suboptimal. Conversely, a year that ranks as "Poor" (Red) may be biologically insignificant.

PM uncertainties and overall reliability

TW2 has the same uncertainties and overall reliability as TW1.

2.2.5 Invasive species deterrence

The San Francisco Bay–Delta may be the most invaded estuary, and possibly the most invaded aquatic ecosystem in the world (Cohen and Carlton 1998). Cohen and Carlton (1998) identified approximately 234 exotic species (164 in salt/brackish water and 84 in freshwater) established in the ecosystem including plants, protists, invertebrates, and vertebrates. Based on their analysis of the raw data, 55.2% of the total number of invasions were recorded after 1960 (Figure 2.64), showing that about half of all invasions over the past 165 years have occurred in the past 35 years. This is equal to a rate of about 1 new introduction every 14 weeks.

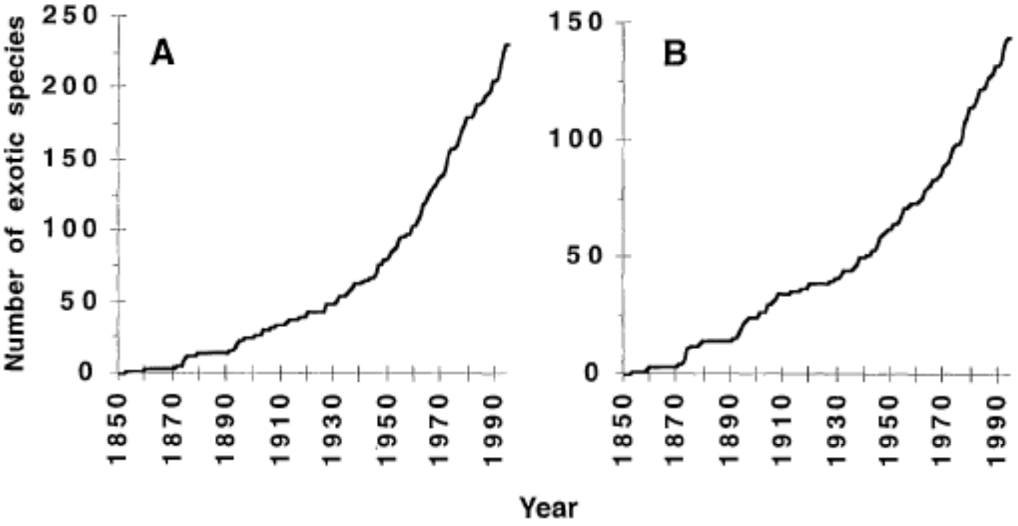


Figure 2.64: Cumulative number of exotic species established in the San Francisco Estuary. A) raw data, the total number of invasive species found; B) modified data, excludes each record in the raw data for which the year of planting, observation, or collection could not be determined. Source: Cohen and Carlton 1998.

Invasive species establishment has resulted in changes in species composition at all trophic levels, which have in turn significantly altered food web productivity via altered trophic linkages (Feyrer *et al.* 2003). In particular, the introduction of two clams from Asia, the overbite clam (*Corbula amurensis*) and the Asian clam (*Corbicula fluminea*), have resulted in substantial changes to ecosystem dynamics in the Delta. These clams are considered ecosystem modifiers because of their wide ranging effects on the aquatic ecosystem and native species. Both are highly efficient filter feeders that reduce phytoplankton and zooplankton in the water column. For example, the invasive overbite clam (*Corbula amurensis*) appropriates most of the primary production in Suisun Bay, starving pelagic fish such as the Delta smelt of zooplankton through their affect on phytoplankton (Healey *et al.* 2008).

Unfortunately, the evidence for a simple food web linkage from phytoplankton to pelagic fish like Delta smelt is weak. For instance, phytoplankton and Delta smelt trends are not correlated (Jassby *et al.* 1995; Kimmerer 2002; Jassby 2008). Kimmerer (2008) in his Figure 17 shows a loose correlation among copepod biomass and Delta smelt survival. Bennett (2005) in his Figure 29 shows chronically smaller Delta smelt size (~ 5 mm) beginning a few years after the overbite clam invasion. While there is a linkage between planktonic production and pelagic fish in the Delta, Delta smelt seem to be quite a bit more sensitive to abiotic habitat constraints. For example, factors such as spring-summer water temperature, turbidity, and outflow during fall set their caloric demand and, at high temperatures, affect their ability to even achieve it (similar to CS10 for salmon). All of this leads to a ‘messier’ conceptual model of how Delta smelt functionally respond to variation in the estuary’s pelagic food web.

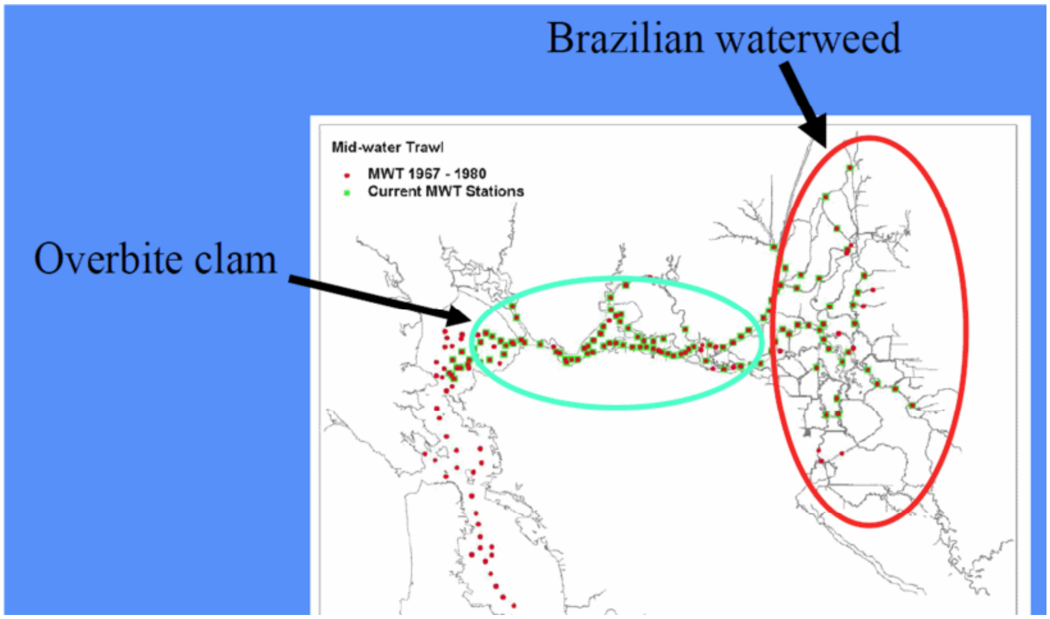


Figure 2.65: Zones of overbite clam (*Corbula amurensis*) and Brazilian waterweed invasions in the Bay-Delta. Source: slide by Peter Moyle. Note: current *Corbula* distribution extends through south bay.

A simplified conceptual model for invasive species deterrence linkages are given in Figure 2.66.

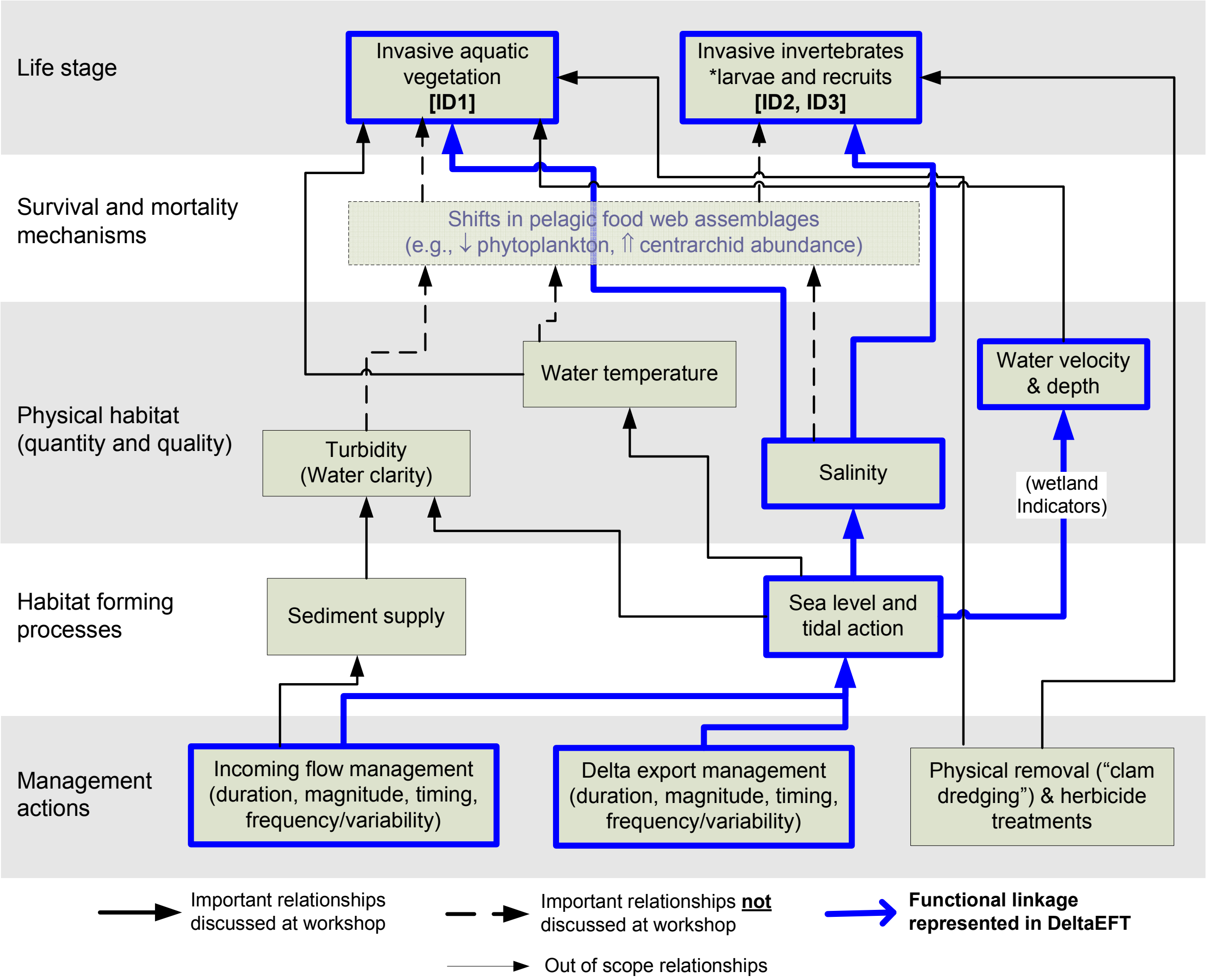


Figure 2.66: Conceptual model for invasive species deterrence. Heavier blue lines and boxes indicate cause-effect linkages included in DeltaEFT.

Table 2.25: Performance measures for DeltaEFT invasive species deterrence.

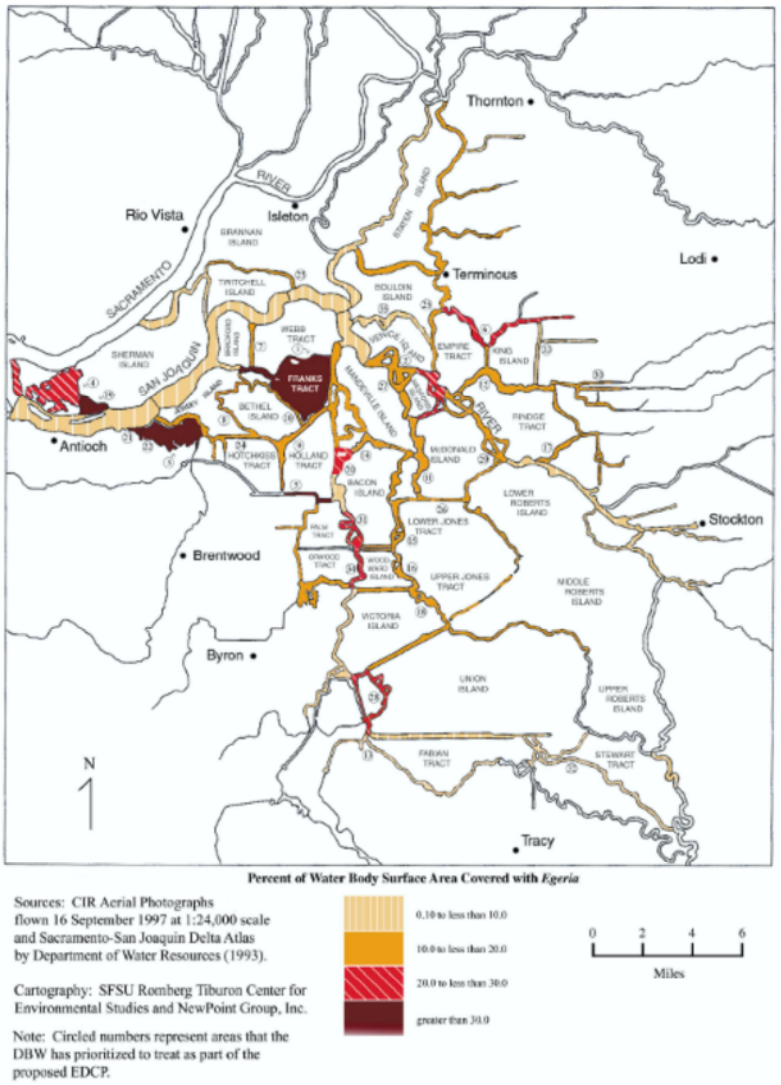
Performance Measure	Synonyms	PM code
Brazilian waterweed (*Egeria densa*) suppression	Invasive aquatic vegetation suppression	ID1
Asian overbite clam (*Corbula amurensis*) larvae and recruit suppression	Brackish water invasive clam suppression	ID2
Asian clam (*Corbicula fluminea*) larvae and recruit suppression	Freshwater invasive clam suppression	ID3

ID1 – Brazilian waterweed suppression

Rationale

Brazilian waterweed (*Egeria densa*) is a very hardy and persistent species that has established itself throughout the Delta; infesting approximately 6,000 surface acres, or twelve percent of the Delta (CCWD 2010). Its date of introduction to the Delta is unknown, but was abundant enough to become a boating nuisance by the late 1980s. *E. densa* is a highly competitive plant that is capable of rapid growth and spread, resulting in the displacement of native species, reduction in biodiversity, decreased water quality and flow, and disruption to vessel navigation and recreation (Grimaldo and Hymanson 1999). Once established, *E. densa* can form thick mats on the water's surface that restrict light penetration to the complete exclusion of native plants (MDEM 2002).

Egeria Infestation Levels and Locations of Proposed Treatment Sites in the Sacramento-San Joaquin Delta



Percent of Water Body Surface Area Covered with *Egeria*

▥	0.10 to less than 10.0
🟧	10.0 to less than 20.0
▨	20.0 to less than 30.0
🟫	greater than 30.0

Sources: CIR Aerial Photographs flown 16 September 1997 at 1:24,000 scale and Sacramento-San Joaquin Delta Atlas by Department of Water Resources (1993).

Cartography: SFSU Romberg Tiburon Center for Environmental Studies and NewPoint Group, Inc.

Note: Circled numbers represent areas that the DBW has prioritized to treat as part of the proposed EDCP.

Figure 2.67: A map showing the percent of water body surface area covered with the invasive *Egeria densa*. Source: CCWD 2010.

Flow restoration and export reduction would push the estuary toward a more variable and presumably more productive ecosystem, or at least one with higher abundance of desired species.

Performance Measure

ID1 would be calculated as a categorical indicator of the relative likelihood of suppressing *E. densa* based on multi-year assessment of variation in net Delta outflow and salinities in eastern Suisun Bay and the western-interior Delta.

In mesocosm experiments, Hauenstein and Ramirez (1986) noted a dramatic decrease in Brazilian waterweed growth at salinities >4‰ and no growth of roots or stems at ≥10‰. They did not find Brazilian waterweed at field sites where salinity was >5‰.

Fleenor *et al.* 2010 suggested experimentally reducing net Delta outflow to 8,000 cfs for 2 months (July-August) in 3 of 10 years in order to suppress the Brazilian waterweed. These flows would allow the western and parts of the central Delta to become much more saline and unimpaired flow data indicate that these low flows would have occurred in 28% of the years.

Table 2.26 shows the functional salinity rules for ID1. The salinity thresholds are based on Hauenstein and Ramirez (1986), and the Net Delta outflow values are estimated from Fleenor *et al.* 2010, assuming the suggested experimental flow results in moderate suppression. The period of interest is also based on Fleenor *et al.*'s work, but extended 2 month earlier and later. The function rules for ID were reviewed by experts at a workshop in January 2009.

Table 2.26: Functional salinity rules for suppression of Brazilian waterweed (ID1).

Category score	Net Delta outflow†	Salinity$^{\phi}$	Recurrence frequency
1 = negligible suppression likelihood	≤ 15,000 cfs	< 5‰ (parts per thousand)*	2 or fewer of 10 years
	for 1 or more months (May – October)*		
2 = moderate suppression likelihood	≤ 8,000 cfs	≥ 5‰ (parts per thousand)*	3 of 10 years or more
	for 2 or more months (May – October)*		
3 = high suppression likelihood	≤ 4,000 cfs	≥ 10‰ (parts per thousand)*	4 of 10 years or more
	for 3 or more months (May – October)*		

$^{\phi}$ = Primary criteria

* These values would be taken as the average flow and salinities during target intervals of 1, 2, 3, and 4 months.

† Estimated flow values to achieve salinity targets in western and parts of the central Delta. Values to be refined to deliver the target salinity based on Delta operations, sea-level, etc)

Under current Delta conveyance, these flows are only likely in **dry years**.

Suddenness of salinity change:

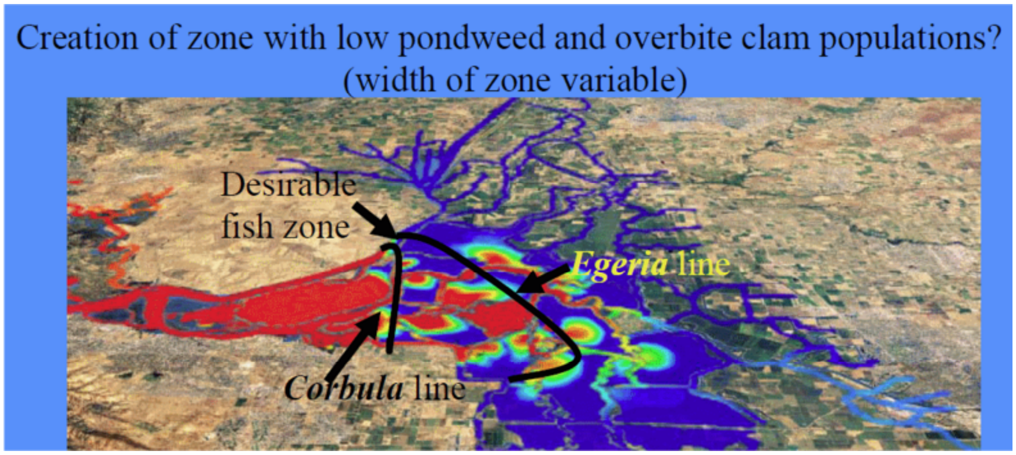
A secondary feature of salinity associated with ID1 will be, within the target period, calculation of whether salinity moves from a) <3‰ to ≥5‰ ***in 4 or fewer days***, and b) <3‰ to ≥10‰ ***in 5 or fewer days***. When "a" occurs category 1 suppression scores will be elevated to a category 2 score. When "b" occurs, category 2 suppression scores will be elevated to category 3 scores. Likewise, when "b" occurs the duration required for a category 3 suppression score will be dropped to 2 or more months (instead of 3 or more months).

The suddenness component of the model will be an option that can be turned “on/off”. Some experts questioned the evidence in support of this “suddenness” component, and believe that the duration of the salinity regime is more important than the suddenness of change (Janet Thompson, pers. comm., 2010).

The suppression category is calculated for a region (see Locations of Interest) based on the average salinity from multiple gauges (see Table 2.27). In the case of Brazilian Waterweed, the region from Chipps Island to Oakley is considered more important than the region from Oakley to the interior Delta, so the annual PM category is assigned the same suppression category as the Chipps Island to Oakley region.

Locations of interest

This PM will be calculated sequentially for a set of 2 regions starting with: i) Chipps Island to Oakley; and ii) Oakley to the interior Delta seaward of USGS 11313452 Old River at Franks Tract near Terminous CA (Figure 2.68). The westernmost distribution of any substantive infestation of *Egeria densa* is the Broad Slough/Sherman Lake area at the confluence of the Sacramento and San Joaquin rivers. The data exist to interpolate the salinity (EC) at this location by using a downstream sensor and the one at Collinsville. Table 2.27 shows the locations used to calculate the average salinity for a region.



Creation of zone with low pondweed and overbite clam populations?
(width of zone variable)

Figure 2.68: Regional extent for targeting *Egeria densa* suppression. Slide: Peter Moyle.

Table 2.27: Locations of interest for Brazilian waterweed suppression (ID1). Each location belongs to one of the 2 regions of interest.

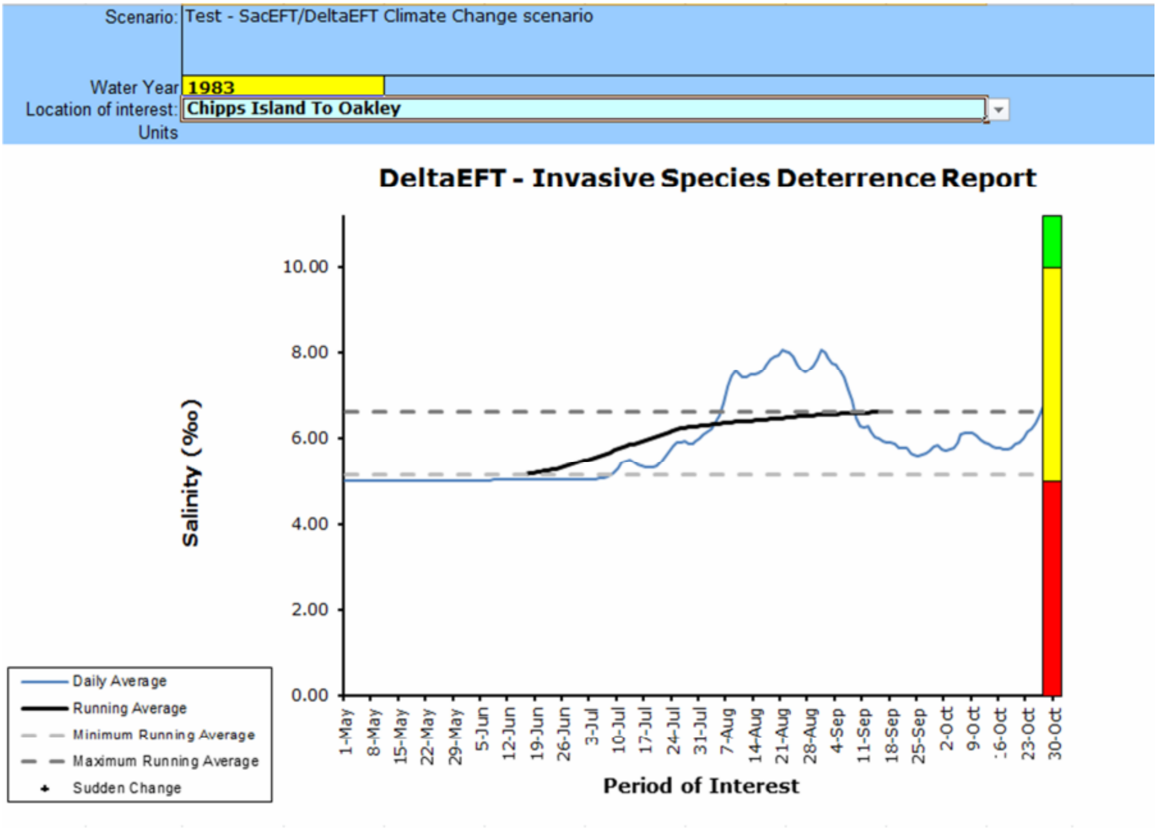
Location Name	IEP ID	CDEC ID	River	River Kilometer	Region
Pittsburg	RSAC077	PTS	Sacramento	77	Chipps Island to Oakley
Collinsville	RSAC081	CSE	Sacramento	81	Chipps Island to Oakley
Emmaton	RSAC092	EMM	Sacramento	92	Oakley to the interior Delta
Rio Vista	RSAC101	RVB	Sacramento	101	Oakley to the interior Delta
Antioch	RSAN008	ANC	San Joaquin	8	Chipps Island to Oakley
San Andreas Landing	RSAN032	SAL	San Joaquin	32	Oakley to the interior Delta
Farrar Park	SLDUT009	FRP	Dutch Slough	9	Oakley to the interior Delta

Calibration

The Brazilian waterweed suppression is not calibrated, as the annual performance follow directly from Table 2.26. The suppression category is used to assign a R/Y/G score for each year, with High Suppression yielding a Good score and Negligible Suppression yielding a Poor score.

Excel Reports

An example of the annual rollup Excel report for ID1 is shown below in Figure 2.69. The report shows the daily (blue line), running average (black line) and minimum/maximum running (grey stippled lines) average salinity for the region. The performance of a given location for the year can be found by comparing the maximum running average salinity value with the vertical R/Y/G bar.



Scenario: Test - SacEFT/DeltaEFT Climate Change scenario

Water Year 1983

Location of interest: Chipps Island To Oakley

Units

Figure 2.69: An example of screen captures from the Annual Rollup report for ID1: Brazilian waterweed suppression. This example shows performance in 1983 for the Chipps Island to Oakley region. The blue line shows the daily average salinity for the region based on multiple gauges. The black line shows the 2- or 3-month running average, depending on whether the region has a fair or good performance (see Table 2.26). In this example, the region is assigned a fair suppression because the Maximum Running Average (dark grey stippled line) is above 5ppt, but below 10ppt. The vertical R/Y/G bar to the right shows the indicator thresholds. Note that there are no days with Sudden Change, which is marked with a diamond symbol.

Spatial Reports

There are 2 types of spatial reports available for ID1: Annual spatial reports and multi-year rollup reports. The annual spatial report displays an R/Y/G polygon for each region (see Figure 2.70). The color of each region represents the annual location-specific performance. PM Summary information and a chart of the daily salinity can also be displayed for each region by selecting it with the Select tool (see Figure 2.71).

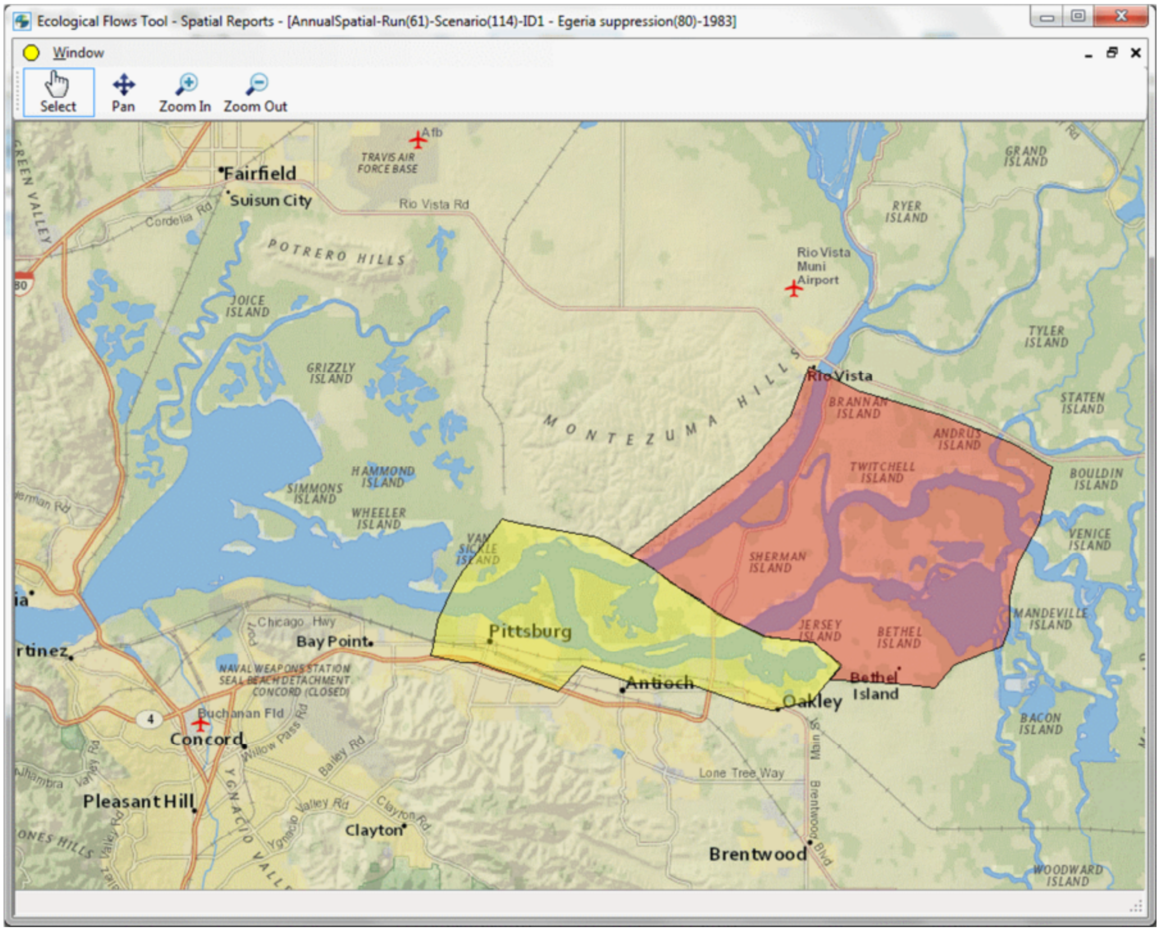
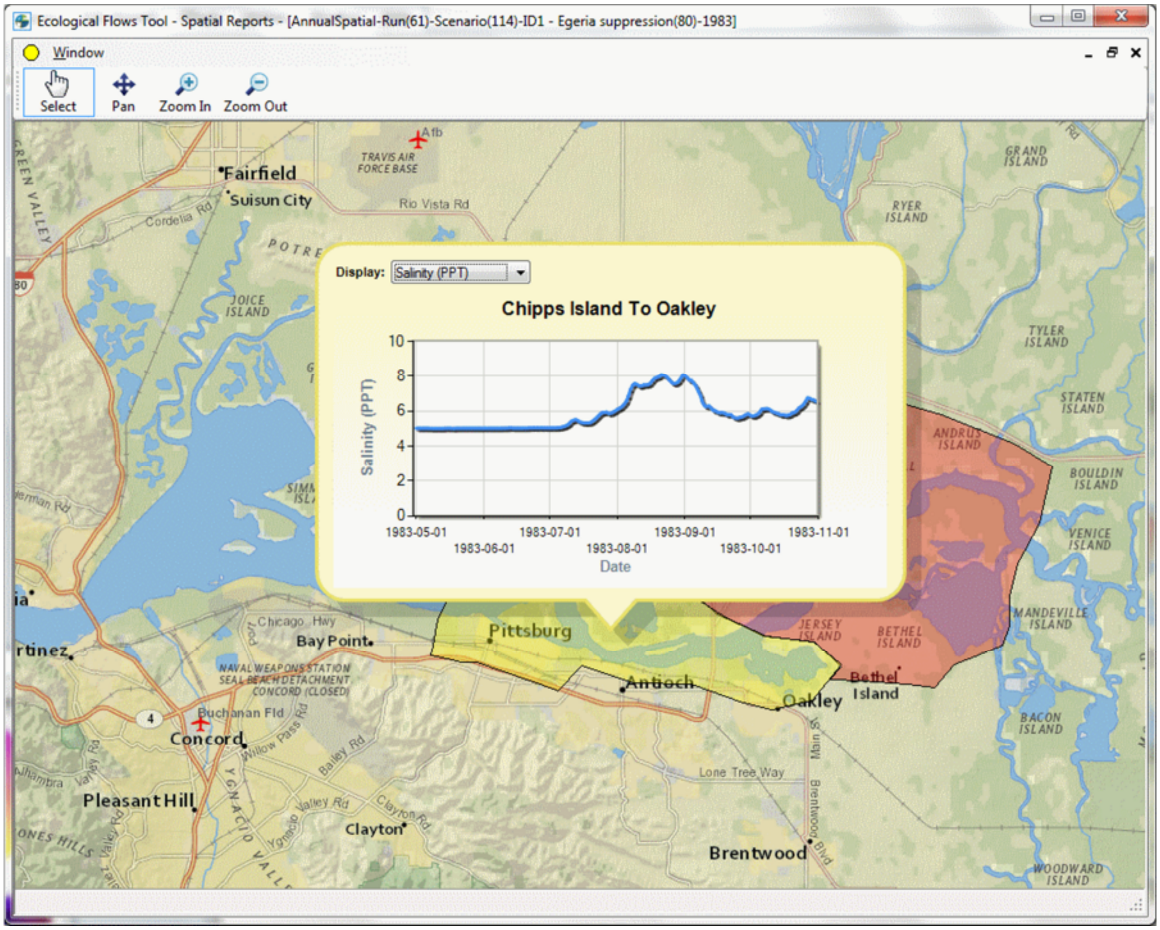


Figure 2.70: An example of a screen capture from the Annual Spatial report for ID1: Brazilian waterweed suppression. This example shows the performance for each region for a year with fair performance. Regions are colored based on their suppression.



Display: Salinity (PPT)

Figure 2.71: An example of a screen capture of location-specific information for ID1: Brazilian waterweed suppression. This example shows the daily salinity for the Chipps Island to Oakley region.

The multi-year rollup spatial report displays an R/Y/G colored pie-chart for each region (see Figure 2.72). Each pie-slice represents the number of years the location was assigned a Good, Fair or Poor performance. This report is useful for quickly finding spatial patterns in performance, for example localized effects or downstream gradients in performance. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

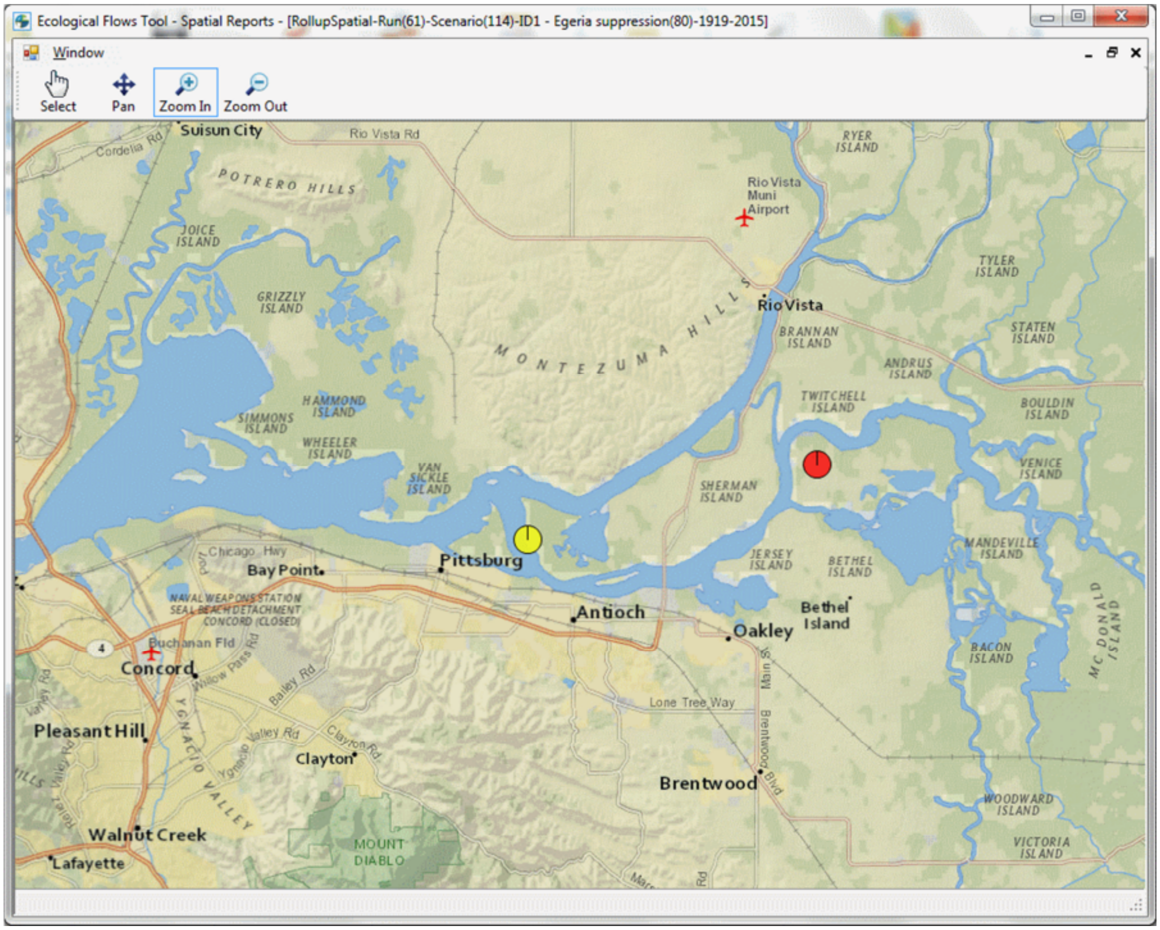


Figure 2.72: An example of a screen capture of multi-year rollup spatial report for ID1: Brazilian waterweed suppression. This example shows the percentage of good/fair/poor years for each region. Note that in this example, the western location always has fair suppression, whereas the eastern region always has poor suppression. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

PM uncertainties and overall reliability

There is a high degree of uncertainty around the specific salinity ranges and salinity rules in this indicator. There is strong scientific support for testing the effectiveness of experimental flows in discouraging freshwater organisms in the western Delta. Some studies have suggested that Delta outflow would need to be reduced to near zero for 4-5 months in order to increase central Delta salinity to 10‰. This magnitude of flow is well outside the historical norm and there is not a good understanding of the unintended biological effects of such a flow/salinity regime.

The indicator is using average salinities for a region with potentially a lot of spatial heterogeneity. The regions could be disaggregated to provide more insight into the area where suppression would occur.

ID2 – Brackish water invasive overbite clam suppression

Rationale

Since 1987, the overbite clam (*Corbula amurensis*), which is tolerant of a wide range of salinities, has been the dominant clam species in the brackish water regions of the estuary. Starting about 1987-1988, there have also been major step-declines observed in the abundance of phytoplankton and certain zooplankton species. There was also a major step-decline in mysid shrimp in 1987-1988, likely due to competition with overbite clam for phytoplankton (Orsi and Mecum 1996). The mysid shrimp had been an extremely important food item for larger fishes like longfin smelt and juvenile striped bass; its decline resulted in substantial changes in the diet composition of these species (Feyrer *et al.* 2003).

The overbite clam, a brackish water species, is most successful between 5‰ and 15‰ (Cohen 2011).

The hypothesis associated with ID2 is based on whether flow restoration and export reduction could be conducted to push the estuary toward a more variable and presumably more productive ecosystem, or at least one with higher abundances of desired species.

Performance Measure

ID2 would be calculated as a categorical indicator of the relative likelihood of suppressing *C. amurensis* based on multi-year assessment of variation in net Delta outflow and salinities in Suisun Bay and the western-interior Delta.

One of the few identified environmental limits on *Corbula*'s reproduction and thus potentially on its distribution, is the salinity limit (5-25) at which spawning and fertilization can occur (Thompson and Parchaso 2010). Nicolini and Penry (2000) found animals did not spawn at salinities below 2ppt and above 32ppt, but did not test salinities >2 and <5, and salinities >25 and <32.

Fleenor *et al.* 2010 suggested using an experimental high Delta net outflow of 120,000 cfs to freshen the western Delta and Suisun Marsh and Bay and suppress the overbite clam. They target 3 months (January-March) for 3 of 10 years and estimate it would have occurred in 11% of years according to unimpaired flow data.

Table 2.28 shows the functional salinity rules for ID2. The salinity thresholds for moderate suppression are from Thompson and Parchaso (2010). We assume that thresholds for high suppression are in the interval not tested by Nicolini and Penry (2000). The Net Delta outflow values are estimated from Fleenor *et al.* 2010, assuming the suggested experimental flow results in high suppression. The period of interest is also based on Fleenor *et al.*'s work, but extended 1 month earlier and later. The function rules for ID were reviewed and refined by experts at a workshop in January 2009.

Table 2.28: Functional salinity rules for suppression of overbite (*Corbula*) clam larvae and recruits (ID2).

Category score	Net Delta outflow[†]	Minimum Salinity[ϕ]	Maximum Salinity[ϕ]	Recurrence frequency
1 = negligible suppression likelihood	< 75,000 cfs	≥ 5‰ (parts per thousand)*	≤ 25‰ (parts per thousand)*	2 or fewer of 10 years
	for 1 or more months (December – April)*			
2 = moderate suppression likelihood	≥ 75,000 cfs	< 5‰ (parts per thousand)*	> 25‰ (parts per thousand)*	3 of 10 years or more
	for 2 or more months (December – April)*			
3 = high suppression likelihood	≥ 120,000 cfs	< 3‰ (parts per thousand)*	≥ 30‰ (parts per thousand)*	4 of 10 years or more
	for 3 or more months (December – April)*			

[ϕ] Primary criteria

* These values would be taken as the average flow and salinities during target intervals of 1, 2, 3, and 4 months.

[†] Estimated flow values to achieve salinity targets in the western Delta and Suisun Marsh and Bay. Values to be refined to deliver the target salinity based on Delta operations, sea-level, etc)

Suddenness of change:

A secondary feature of salinity associated with ID2 will be, within the target period, calculation of whether salinity moves from a) ≥ 10‰ to < 3‰ ***in 5 or fewer days***, and b) ≥ 5‰ to < 3‰ ***in 4 or fewer days***. When "b" occurs category 1 suppression scores will be elevated to a category 2 score. When "a" occurs, category 2 suppression scores will be elevated to category 3 scores. Likewise, when "a" occurs, the duration required for a category 3 suppression score will be dropped to 2 or more months (instead of 3 or more months).

The suddenness component of the model will be an option that can be turned "on/off". Most experts believe that the duration of the salinity regime is more important than the suddenness of change (Janet Thompson, pers. comm. 2010).

Under current Delta conveyance, these flows are only likely in very **wet years.**

The suppression category is calculated for a region (see Locations of Interest) based on the average salinity from multiple gauges (see Table 2.29). In the case of overbite clam, the region from 680 Bridge to Chipps Island is considered more important than the other regions, so the annual PM category is assigned the same suppression category as the 680 Bridge to Chipps Island region.

Locations of interest

This PM will be calculated sequentially for a set of 3 regions starting with: i) 680 Bridge to Chipps Island; ii) Chipps Island to Oakley; and iii) Oakley to the interior Delta seaward of USGS 11313452 Old River at Franks Tract near Terminous CA (Figure 2.68). Table 2.29 shows the locations used to calculate the average salinity for a region.

Table 2.29: Locations of interest for overbite clam suppression (ID2). Each location belongs to one of the 2 regions of interest.

Location Name	IEP ID	CDEC ID	River	River Kilometer	Region
Martinez	RSAC054	MRZ	Sacramento	54	680 Bridge to Chipps Island
Port Chicago	RSAC064	PCT	Sacramento	64	680 Bridge to Chipps Island
Mallard Island	RSAC075	MAL	Sacramento	75	680 Bridge to Chipps Island
Pittsburg	RSAC077	PTS	Sacramento	77	Chipps Island to Oakley
Collinsville	RSAC081	CSE	Sacramento	81	Chipps Island to Oakley
Emmaton	RSAC092	EMM	Sacramento	92	Oakley to the interior Delta
Rio Vista	RSAC101	RVB	Sacramento	101	Oakley to the interior Delta
Antioch	RSAN008	ANC	San Joaquin	8	Chipps Island to Oakley
San Andreas Landing	RSAN032	SAL	San Joaquin	32	Oakley to the interior Delta
Farrar Park	SLDUT009	FRP	Dutch Slough	9	Oakley to the interior Delta
Beldon Landing	SLMZU011	BDL	Montezuma Slough	11	680 Bridge to Chipps Island
National Steel	SLMZU025	NSL	Montezuma Slough	25	680 Bridge to Chipps Island
Sunrise Club	SLCBN002	SNC	Chadbourne Slough	2	680 Bridge to Chipps Island
Suisun Slough at Volanti Slough	SLSUS012	VOL	Suisun Slough	12	680 Bridge to Chipps Island

Calibration

The Brackish water invasive overbite clam suppression is not calibrated, as the annual performance follows directly from Table 2.28. The suppression category is used to assign a R/Y/G score for each year, with High Suppression yielding a Good score and Negligible Suppression yielding a Poor score.

Excel Reports

An example of the annual rollup Excel report for ID2 is shown below in Figure 2.73. The report shows the daily (blue line), running average (black line), and minimum/maximum running (grey stippled lines) average salinity for the region. The performance of a given location for the year can be found by comparing the maximum running average salinity value with the vertical R/Y/G bar.

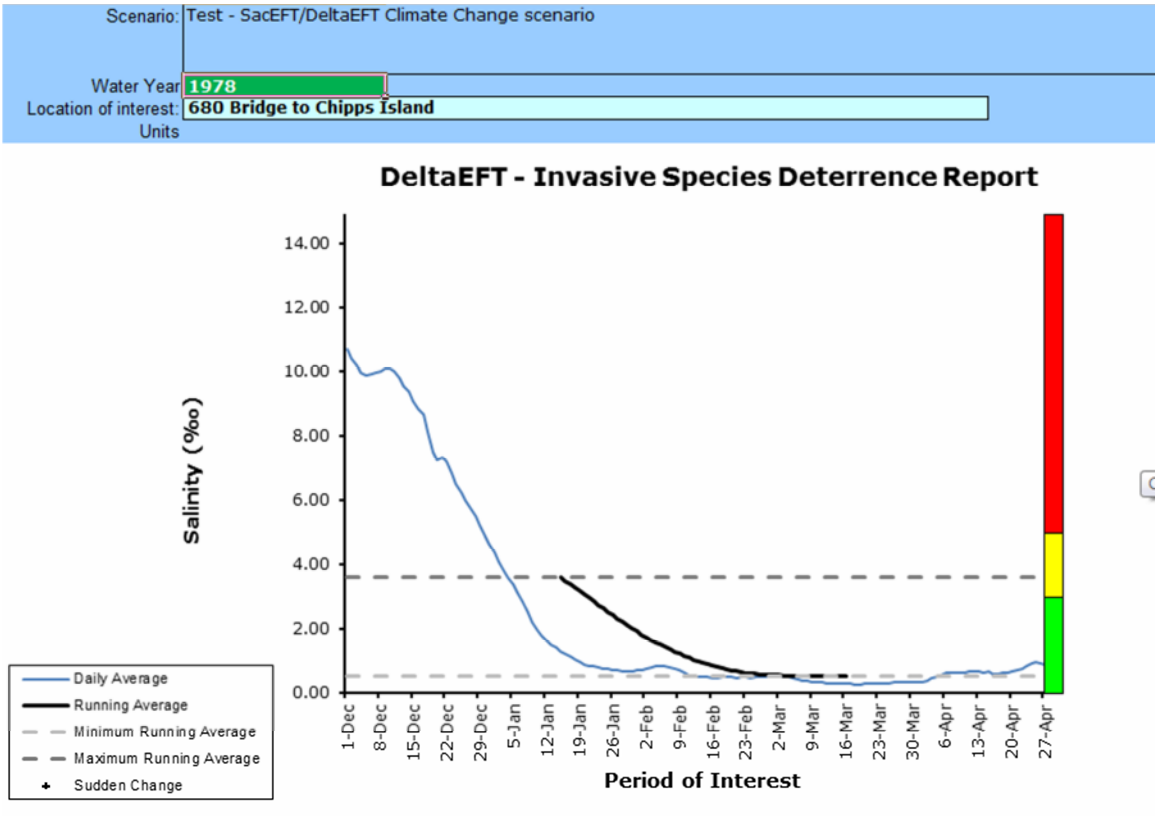

Scenario: Test - SacEFT/DeltaEFT Climate Change scenario
Water Year 1978
Location of interest: 680 Bridge to Chipps Island
Units

Figure 2.73: An example of screen captures from the Annual Rollup report for ID2: Brackish water invasive overbite clam suppression. This example shows performance in 1978 for the 680 Bridge to Chipps Island region. The blue line shows the daily average salinity for the region based on multiple gauges. The black line shows the 2- or 3-month running average, depending on whether the region has a fair or good performance (see Table 2.28). In this example, the region is assigned a good suppression because the Minimum Running Average (light grey stippled line) is below 3ppt. The vertical R/Y/G bar to the right shows the indicator thresholds. Note that there are no days with Sudden Change, which is marked with a diamond symbol.

Spatial Reports

There are 2 types of spatial reports available for ID2: annual spatial reports and multi-year rollup reports. The annual spatial report displays an R/Y/G polygon for each region, see Figure 2.74. The color of each region represents the annual location-specific performance. PM Summary information and a chart of the daily salinity can also be displayed for each region by selecting it with the Select tool, see Figure 2.75.

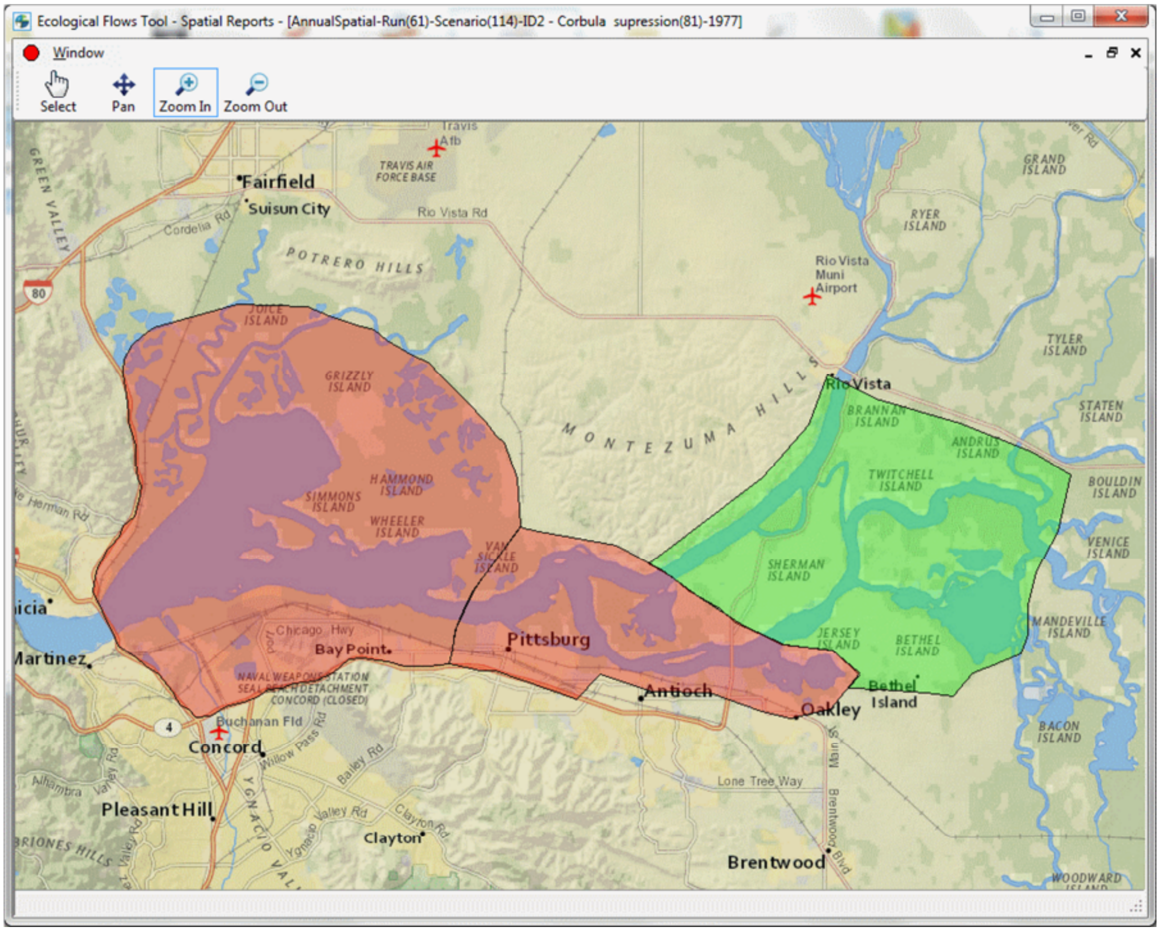
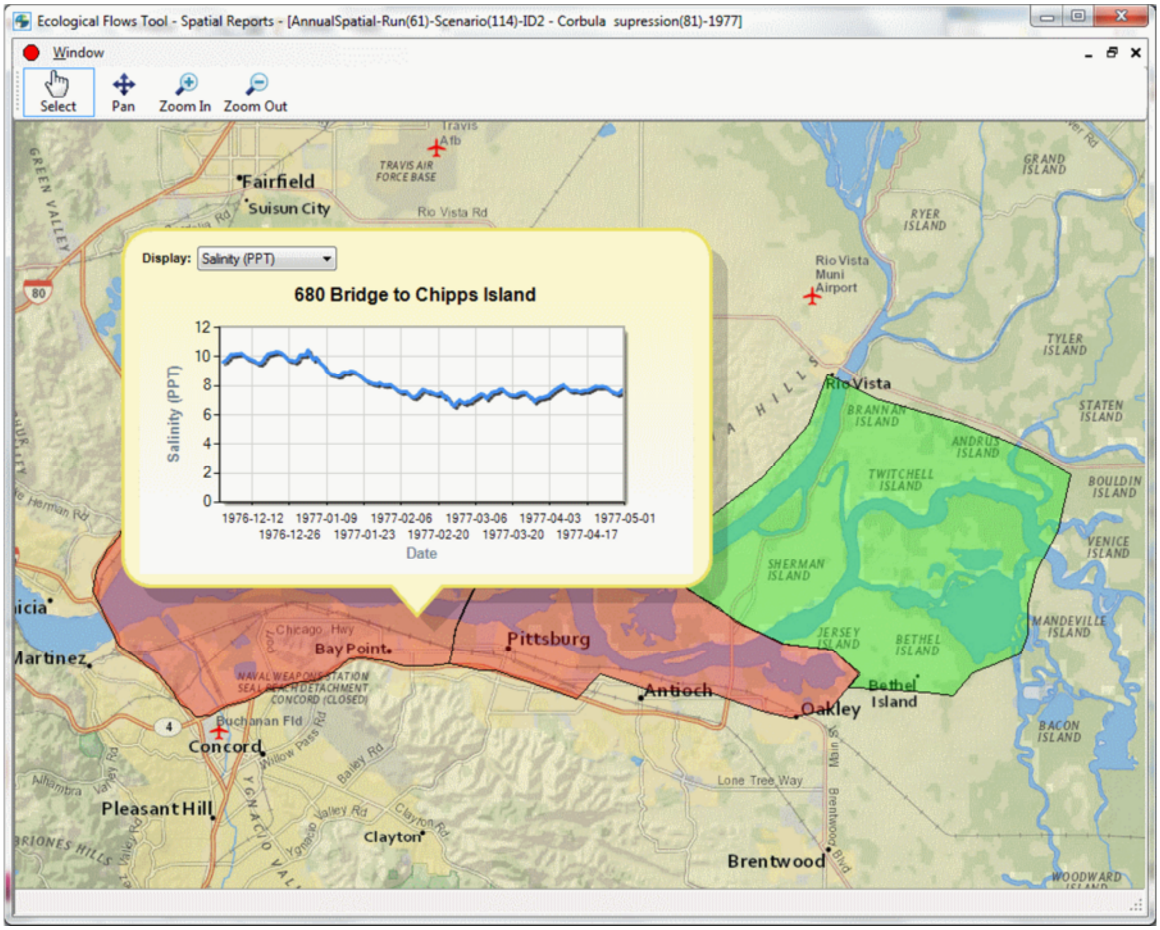


Figure 2.74: An example of a screen capture from the Annual Spatial report for ID2: Brackish water invasive overbite clam suppression. This example shows the performance for each region for a year with poor performance. Regions are colored based on their suppression.


Ecological Flows Tool - Spatial Reports - [AnnualSpatial-Run(61)-Scenario(114)-ID2 - Corbula supression(81)-1977]

Display: Salinity (PPT)

Figure 2.75: An example of a screen capture of location-specific information for ID2: Brackish water invasive overbite clam suppression. This example shows the daily salinity for the 680 Bridge to Chipps Island region.

The multi-year rollup spatial report displays an R/Y/G colored pie-chart for each region (see Figure 2.76). Each pie-slice represents the number of years the location was assigned a Good, Fair or Poor performance. This report is useful for quickly finding spatial patterns in performance, for example localized effects or downstream gradients in performance. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

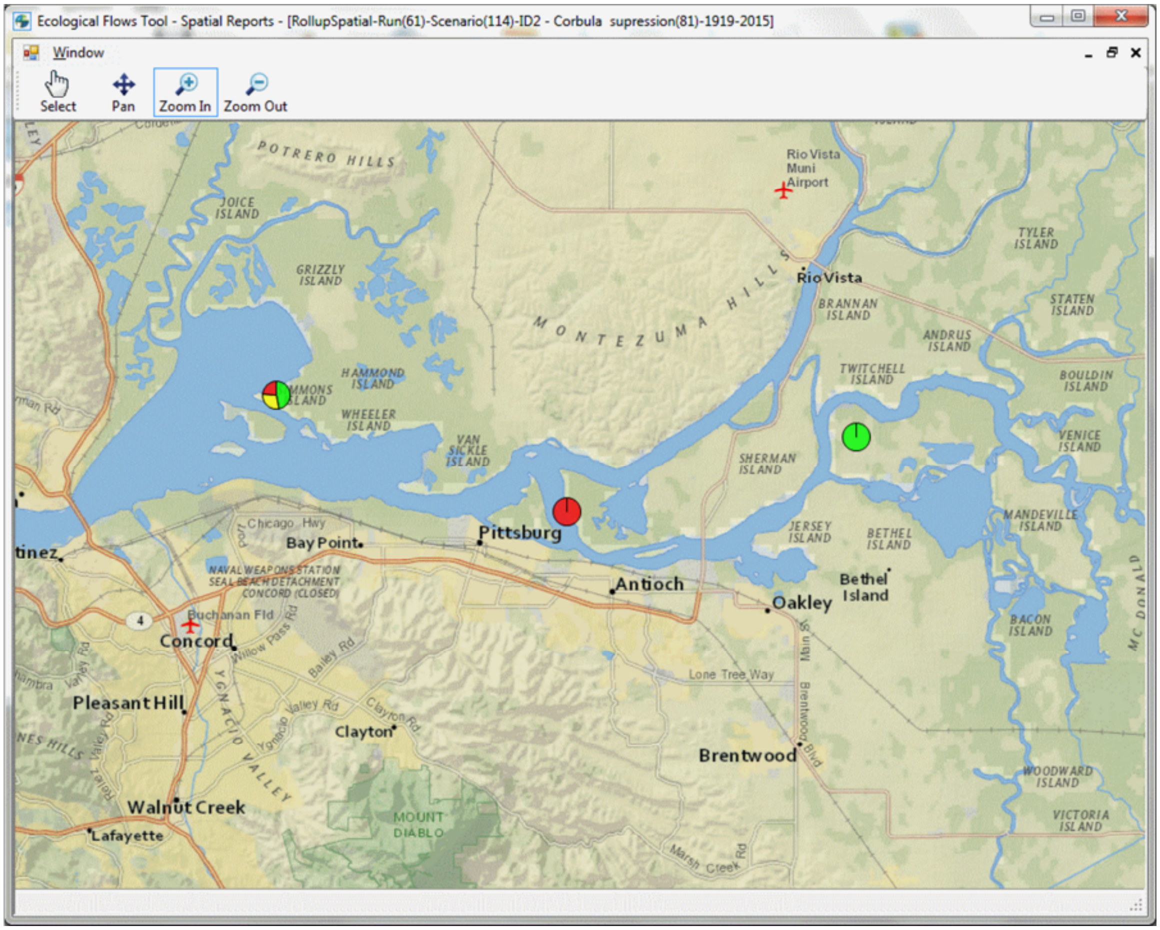


Figure 2.76: An example of a screen capture of multi-year rollup spatial report for ID2: Brackish water invasive overbite clam suppression. This example shows the percentage of good/fair/poor years for each region. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

PM uncertainties and overall reliability

There is a high degree of uncertainty in the specific salinity ranges and salinity rules in this indicator. There is strong scientific support for testing the experimental flow effectiveness in discouraging brackish water organisms in the western Delta.

Our understanding and ability to predict the success of *Corbula* suppression based on salinity patterns is low, with modest amounts of evidence often derived from laboratory studies. There is also a variety of known confounding factors (*e.g.*, near-bed hydrodynamics and currents will be a major determinant of reproductive success and the geographic position of the embryo as it develops into a larva; larval stages have broad salinity tolerances that depend on magnitude and duration of salinity exposure, *etc.*). We recognize that the nature of the real-world outcome is dependent on highly variable ecosystem processes, source-sink meta-population dynamics, and other external confounding factors.

The indicator is using average salinities for a region with potentially a lot of spatial heterogeneity. The regions could be disaggregated to provide more insight into the area where suppression would occur.

ID3 – Freshwater invasive Asiatic clam suppression

Rationale

Flow restoration and export reduction would push the estuary toward a more variable and presumably more productive ecosystem, or at least one with higher abundances of desired species.

Performance Measure

ID3 would be calculated as a categorical indicator of the relative likelihood of suppressing *C. fluminea* based on multi-year assessment of variation in net Delta outflow and salinities in eastern Suisun Bay and the western-interior Delta.

Table 2.30 shows the functional salinity rules for ID3. The salinity threshold for high suppression is based on the maximum salinity for a recruit (between 10 and 14ppt, Janet Thompson, pers. comm. 2010). The salinity threshold for moderate suppression was reviewed by experts at a workshop in 2009, but with limited feedback. The Net Delta outflows are estimated to be consistent with values for ID1 and the period of interest is the same as for ID1. The function rules for ID were reviewed and refined by experts at a workshop in January 2009.

Table 2.30: Functional salinity rules for suppression of Asiatic (*Corbicula*) clam larvae and recruits (ID3).

Category score	Net Delta outflow†	Salinity$^{\phi}$	Recurrence frequency
1 = negligible suppression likelihood	≤ 22,000 cfs	< 7‰ (parts per thousand)*	2 or fewer of 10 years
	for 1 or more months (May – October)*		
2 = moderate suppression likelihood	≤ 11,000 cfs	≥ 7‰ (parts per thousand)*	3 of 10 years or more
	for 2 or more months (May – October)*		
3 = high suppression likelihood	≤ 5,000 cfs	≥ 12‰ (parts per thousand)*	4 of 10 years or more
	for 3 or more months (May – October)*		

$^{\phi}$ Primary criteria

* These values would be taken as the average flow and salinities during target intervals of 1, 2, 3, and 4 months.

† Estimated flow values to achieve salinity targets in western and parts of the central Delta. Values to be refined to deliver the target salinity based on Delta operations, sea-level, etc)

Suddenness of salinity change:

A secondary feature of salinity associated with ID3 will be, within the target period, calculation of whether salinity moves from a) < 4‰ to ≥ 7‰ ***in 4 or fewer days***, and b) < 4‰ to ≥ 12‰ ***in 5 or fewer days***. When "a" occurs category 1 suppression scores will be elevated to a category 2 score. When "b" occurs, category 2 suppression scores will be elevated to category 3 scores. Likewise, when "b" occurs the duration required for a category 3 suppression score will be dropped to 2 or more months (instead of 3 or more months).

The suddenness component of the model will be an option that can be turned "on/off". Most experts believe that the duration of the salinity regime is more important than the suddenness of change (Janet Thompson, pers. comm. 2010).

Under current Delta conveyance, these flows are only likely in **dry years.**

The suppression category is calculated for a region (see Locations of Interest) based on the average salinity from multiple gauges (see Table 2.31). In the case of Asiatic clam, the region from Chipps Island to Oakley is considered more important than the region from Oakley to the interior Delta, so the annual PM category is assigned the same suppression category as the Chipps Island to Oakley region.

Locations of interest

This PM will be calculated sequentially for a set of 2 regions starting with: i) Chipps Island to Oakley; and ii) Oakley to the interior Delta seaward of USGS 11313452 Old River at Franks Tract near Terminous CA (Figure 2.68). Table 2.31 shows the locations used to calculate the average salinity for a region.

Table 2.31: Locations of interest for Asiatic clam suppression (ID3). Each location belongs to one of the 2 regions of interest.

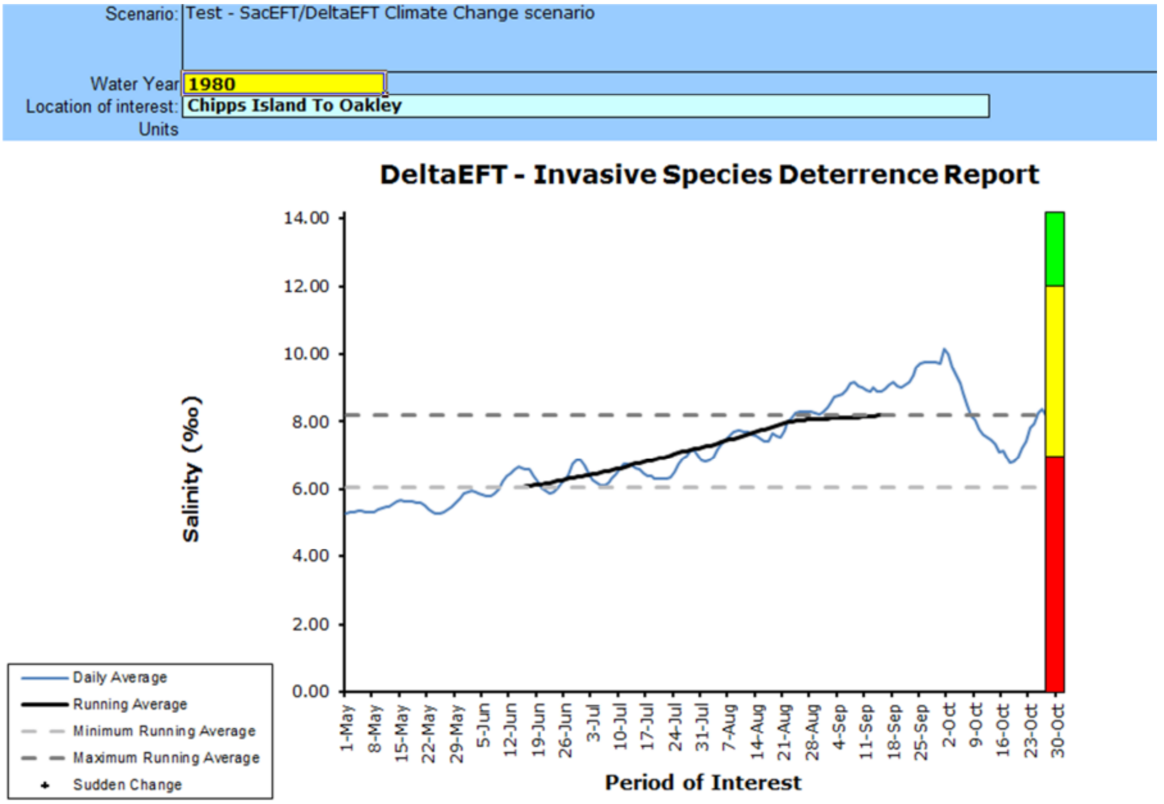
Location Name	IEP ID	CDEC ID	River	River Kilometer	Region
Pittsburg	RSAC077	PTS	Sacramento	77	Chipps Island to Oakley
Collinsville	RSAC081	CSE	Sacramento	81	Chipps Island to Oakley
Emmaton	RSAC092	EMM	Sacramento	92	Oakley to the interior Delta
Rio Vista	RSAC101	RVB	Sacramento	101	Oakley to the interior Delta
Antioch	RSAN008	ANC	San Joaquin	8	Chipps Island to Oakley
San Andreas Landing	RSAN032	SAL	San Joaquin	32	Oakley to the interior Delta
Farrar Park	SLDUT009	FRP	Dutch Slough	9	Oakley to the interior Delta

Calibration

The Brackish water invasive overbite clam suppression is not calibrated, as the annual performance follow directly from Table 2.30. The suppression category is used to assign a R/Y/G score for each year, with High Suppression yielding a Good score and Negligible Suppression yielding a Poor score.

Excel Reports

An example of the annual rollup Excel report for ID3 is shown below in Figure 2.77. The report shows the daily (blue line), running average (black line) and minimum/maximum running (grey stippled lines) average salinity for the region. The performance of a given location for the year can be found by comparing the maximum running average salinity value with the vertical R/Y/G bar.



Scenario: Test - SacEFT/DeltaEFT Climate Change scenario

Water Year: 1980

Location of interest: Chipps Island To Oakley

Units

Figure 2.77: An example of screen captures from the Annual Rollup report for ID3: Freshwater invasive Asiatic clam suppression. This example shows performance in 1980 for the Chipps Island to Oakley region. The blue line shows the daily average salinity for the region based on multiple gauges. The black line shows the 2- or 3-month running average, depending on whether the region has a fair or good performance (see Table 2.30). In this example, the region is assigned a fair suppression because the Maximum Running Average (dark grey stippled line) is above 7ppt but below 12ppt. The vertical R/Y/G bar to the right shows the indicator thresholds. Note that there are no days with Sudden Change, which is marked with a diamond symbol.

Spatial Reports

There are 2 types of spatial reports available for ID3: Annual spatial reports and multi-year rollup reports. The annual spatial report displays an R/Y/G polygon for each region (see Figure 2.78). The color of each region represents the annual location-specific performance. PM Summary information and a chart of the daily salinity can also be displayed for each region by selecting it with the Select tool, see Figure 2.79.

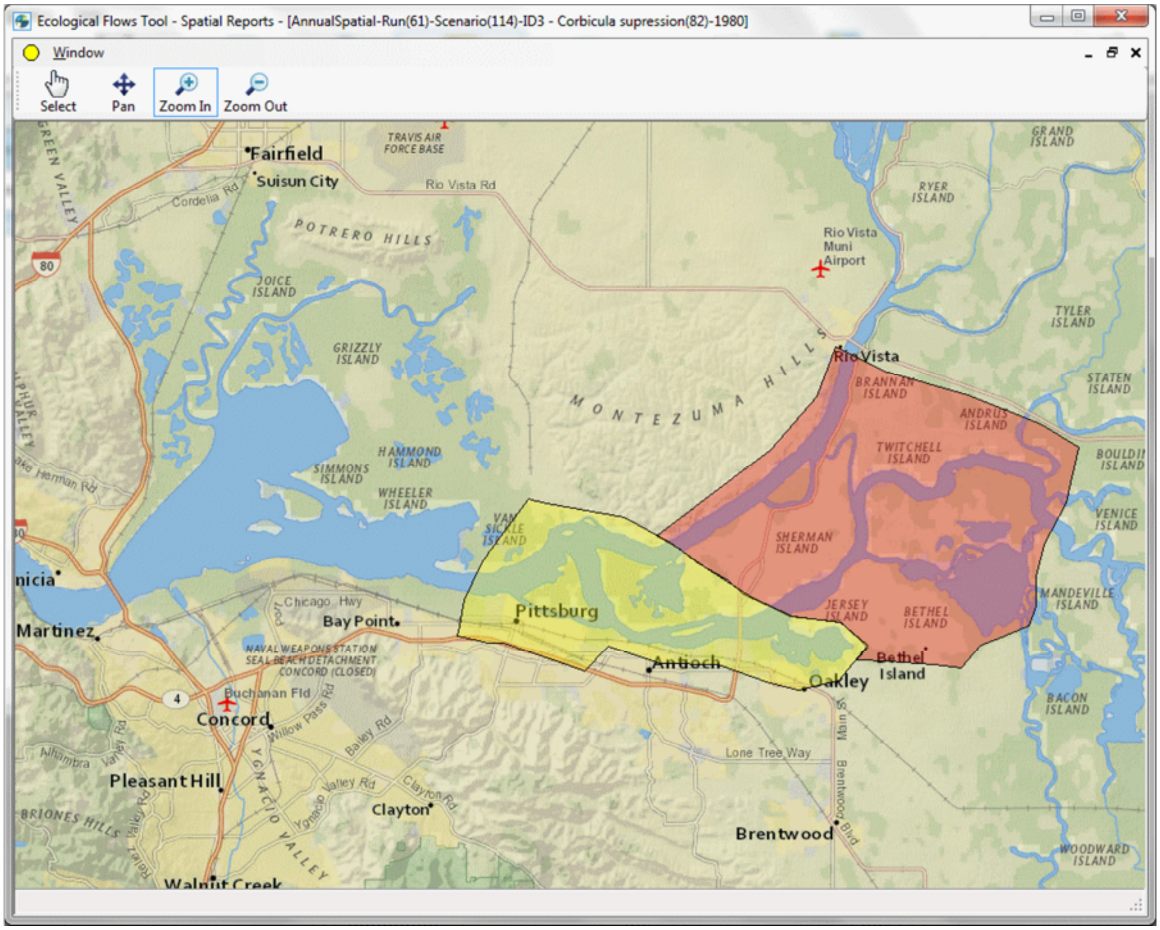
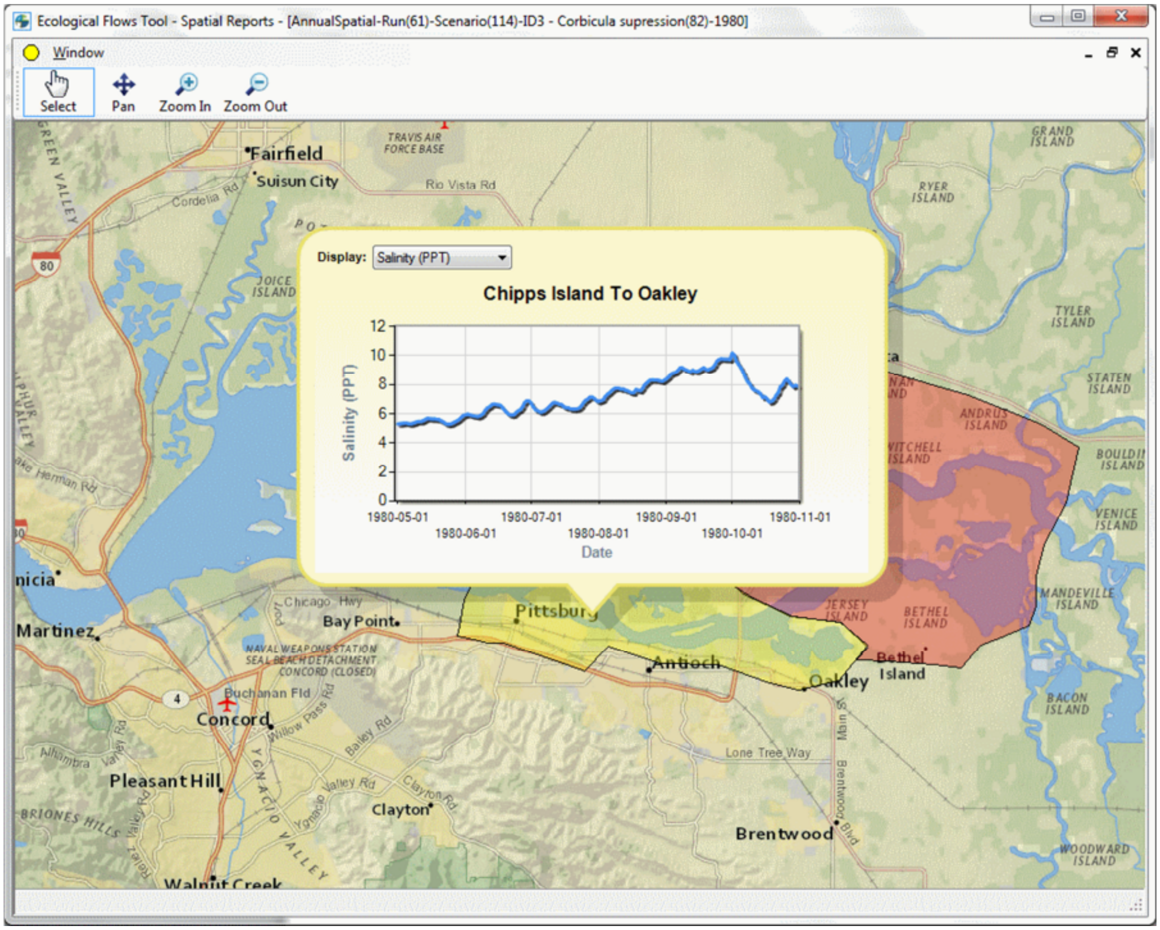


Figure 2.78: An example of a screen capture from the Annual Spatial report for ID3: Freshwater invasive Asiatic clam suppression. This example shows the performance for each region for a year with fair performance. Regions are colored based on their suppression.



Display: Salinity (PPT)

Figure 2.79: An example of a screen capture of location-specific information for ID3: Freshwater invasive Asiatic clam suppression. This example shows the daily salinity for the Chipps Island to Oakley region.

The multi-year rollup spatial report displays an R/Y/G colored pie-chart for each region, see Figure 2.80. Each pie-slice represents the number of years the location was assigned a Good, Fair or Poor performance. This report is useful for quickly finding spatial patterns in performance, for example localized effects or downstream gradients in performance. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

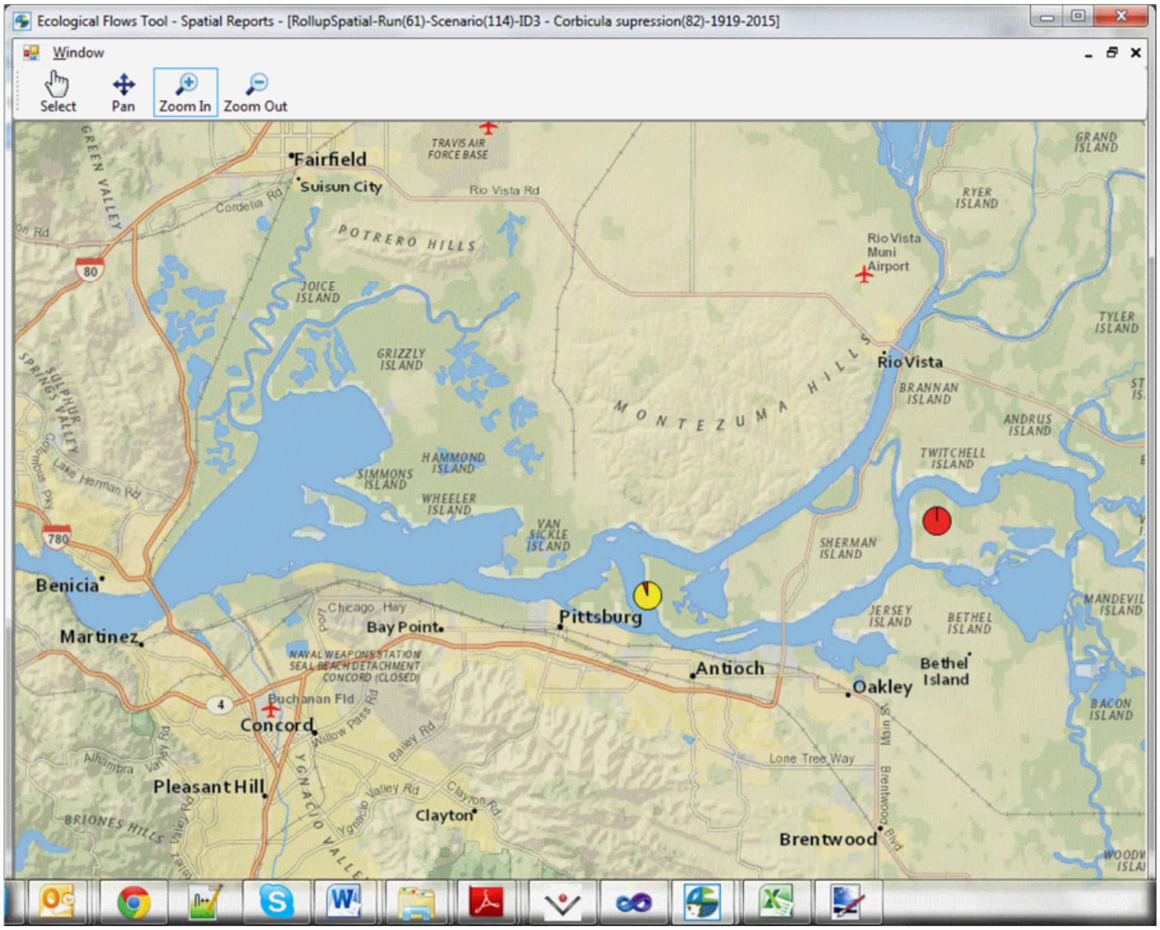


Figure 2.80: An example of a screen capture of multi-year rollup spatial report for ID3: Freshwater invasive Asiatic clam suppression. This example shows the percentage of good/fair/poor years for each region. Note that in this example, the western location almost always has fair suppression, whereas the eastern region always has poor suppression. A location-specific breakdown of number of years in each category can be displayed by selecting the location with the Select tool.

PM uncertainties and overall reliability

There is a high degree of uncertainty in the specific salinity ranges and salinity rules in this indicator. There is strong scientific support for testing the experimental flow effectiveness in discouraging freshwater organisms in the western Delta.

Our understanding and ability to predict the success of *Corbicula* suppression based on salinity patterns is modest. There is also a variety of known confounding factors (*e.g.*, near-bed hydrodynamics and currents will be a major determinant of reproductive success and the geographic position of the embryo as it develops into a larva; larval stages have broad salinity tolerances that depend on magnitude and duration of salinity exposure, *etc.*). We recognize that the nature of the real-world outcome is dependent on highly variable ecosystem processes, source-sink meta-population dynamics, and other external confounding factors.

Other environmental controls on *Corbicula* would not be good for the system. For instance, they are not very resilient (compared to other freshwater bivalves) to anoxic conditions.

The indicator is using average salinities for a region with potentially a lot of spatial heterogeneity. The regions could be disaggregated to provide more insight into the area where suppression would occur.

2.2.6 Longfin Smelt

LS1 – Abundance index

Rationale

The longfin smelt (*Spirinchus thaleichthys*) has experienced a severe decline in the Bay-Delta over the past 40 years (Figure 2.81). Longfin smelt are consistently collected in the monitoring surveys that have been conducted by CDFG as far back as the late 1960s but numbers in the Bay-Delta have declined significantly since the 1980s. In fact, abundance over the last decade is the lowest recorded in the 40-year history of monitoring surveys. Due to the decline and significant threats to the population, the longfin smelt was listed as a threatened species under California's Endangered Species Act in 2009.

The abundance of longfin smelt is heavily influence by freshwater flow. Several authors have confirmed a positive correlation between longfin smelt abundance and freshwater flow noting that abundances of both adults and juveniles were significantly lower during the 1987–1994 drought than during either the pre- or post-drought periods. The U. S. Fish and Wildlife Service (2012) also found that reduced freshwater flows are currently a threat to the Bay-Delta longfin smelt population.

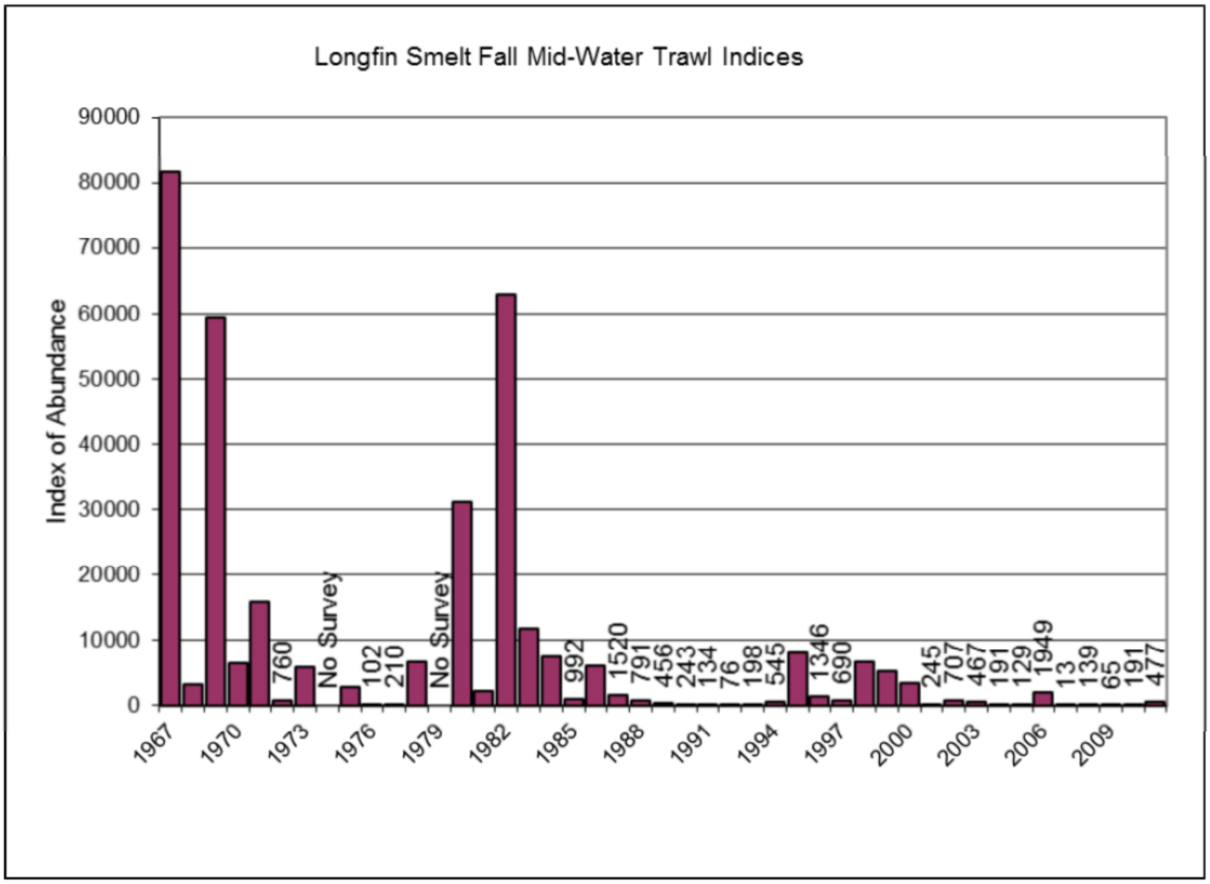


Figure 2.81: Longfin smelt abundance (total across year-classes) as indexed by the Fall Mid-Water Trawl of the Bay-Delta, 1967–2011. The population has experienced a severe decline in the Bay-Delta over the past 40 years.

Performance measure

The longfin smelt performance measure is based on a relationship between the annual index of longfin smelt abundance from the fall midwater trawl survey and the average location of X2 from January to June developed by Mount et. al. (2013). The relationship was defined using the statistical model:

$$\log_{10}\left(LFS_y\right) = a + b \cdot X2_y + \varepsilon_y \qquad \text{Eqn 2.26}$$

Where LFS_y is the annual index of longfin smelt abundance, $X2_y$ is the average location of X2 from January to June and a and b are the parameters that were fitted. The parameters were fitted for 3 time periods: 1967 to 1978 (before introduction of the overbite clam), 1988 to 2002 (before the Pelagic Organism Decline) and 2003 to 2012 (Figure 2.82).

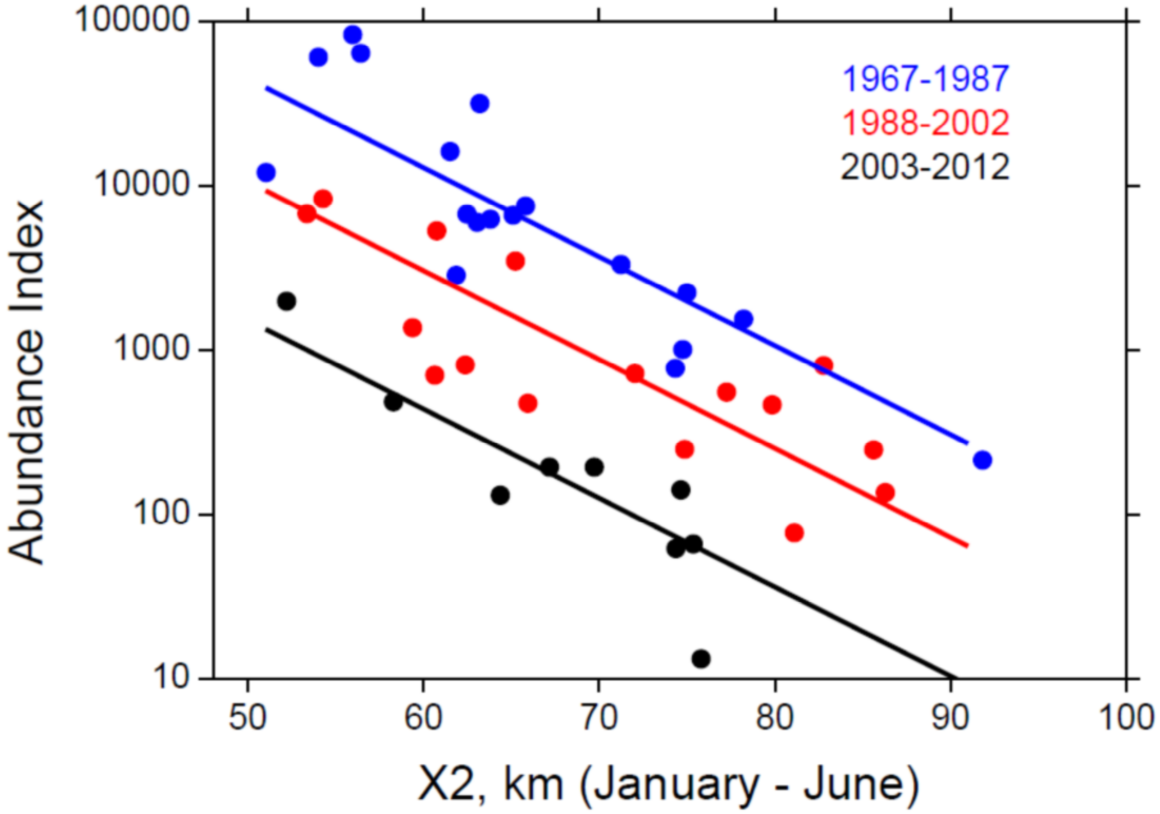


Figure 2.82: Abundance index of longfin smelt vs. X2 averaged over January---June, with step changes between 1987 and 1988 and between 2002 and 2003. Colors of points and lines indicate the time period. Source: Mount et. al. 2013.

For our purpose, we used the post-POD parameters (2003 to 2012 time period) because we are interested in evaluating the longfin smelt abundance response to future flow regimes. The parameters used in the longfin smelt PM can be found in Table 2.32.

Table 2.32: Parameters values for the LS1 – Abundance index PM.

Parameter	Value
a	5.86

b	-0.054

The daily location of X2 for the PM is estimated based on historical and modeled data from 5 salinity stations in the Sacramento River between river kilometers 54 and 92 (see Table 2.33). The salinity gradient between stations is assumed to be linear and the location of the 2ppt concentration is found by interpolating between stations:

$$X2_d = \begin{cases} 54 \;\; if \; S_{54} \le 2 \\ 54 + 10\dfrac{S_{54} - 2}{S_{54} - S_{64}} if \; S_{64} \le 2 \\ 64 + 11\dfrac{S_{64} - 2}{S_{64} - S_{75}} if \; S_{75} \le 2 \\ 75 + 2\dfrac{S_{75} - 2}{S_{75} - S_{77}} if \; S_{77} \le 2 \\ 77 + 15\dfrac{S_{77} - 2}{S_{77} - S_{92}} if \; S_{92} \le 2 \\ 92 \;\; if \; S_{92} > 2 \end{cases}, \qquad \text{Eqn 2.27}$$

The annual X2 values are defined as the average location of X2 for all days between January 1st (D1) and June 30th (D2):

$$X2_y = \frac{1}{N}\sum_{d=D_1}^{D_2} X2_d \;, \qquad \text{Eqn 2.28}$$

where N is the number of days between January 1st and June 30th.

Locations of interest

The locations of interest for this PM are the 5 salinity stations necessary to estimate the daily location of X2 (see Table 2.33). If more salinity stations become available in the Sacramento River between river kilometers 54 and 92, they can be used to improve the accuracy of the X2 estimate by reducing the distance between stations.

Table 2.33: Locations of interest for Longfin Smelt abundance index (LS1).

Location Name	IEP ID	CDEC ID	River	River Kilometer
Martinez	RSAC054	MRZ	Sacramento	54
Port Chicago	RSAC064	PCT	Sacramento	64
Mallard Island	RSAC075	MAL	Sacramento	75
Pittsburg	RSAC077	PTS	Sacramento	77
Emmaton	RSAC092	EMM	Sacramento	92

Calibration

The LS1 – abundance index indicator rating breakpoints are based on historical distribution of flows from 2002-2008 and simulated BDCP NAA-Current flows from 1975 to 1991 for a total of 26 years. The simulated data was used for calibration as data for 7 historical years was not considered a sufficiently long time period for calibration. The thresholds were determined based on natural breakpoints, one reflecting the good performance for the top 3 years and one reflecting the relatively poor performance of the bottom 14 years (see Figure 2.83 and Table 2.34).

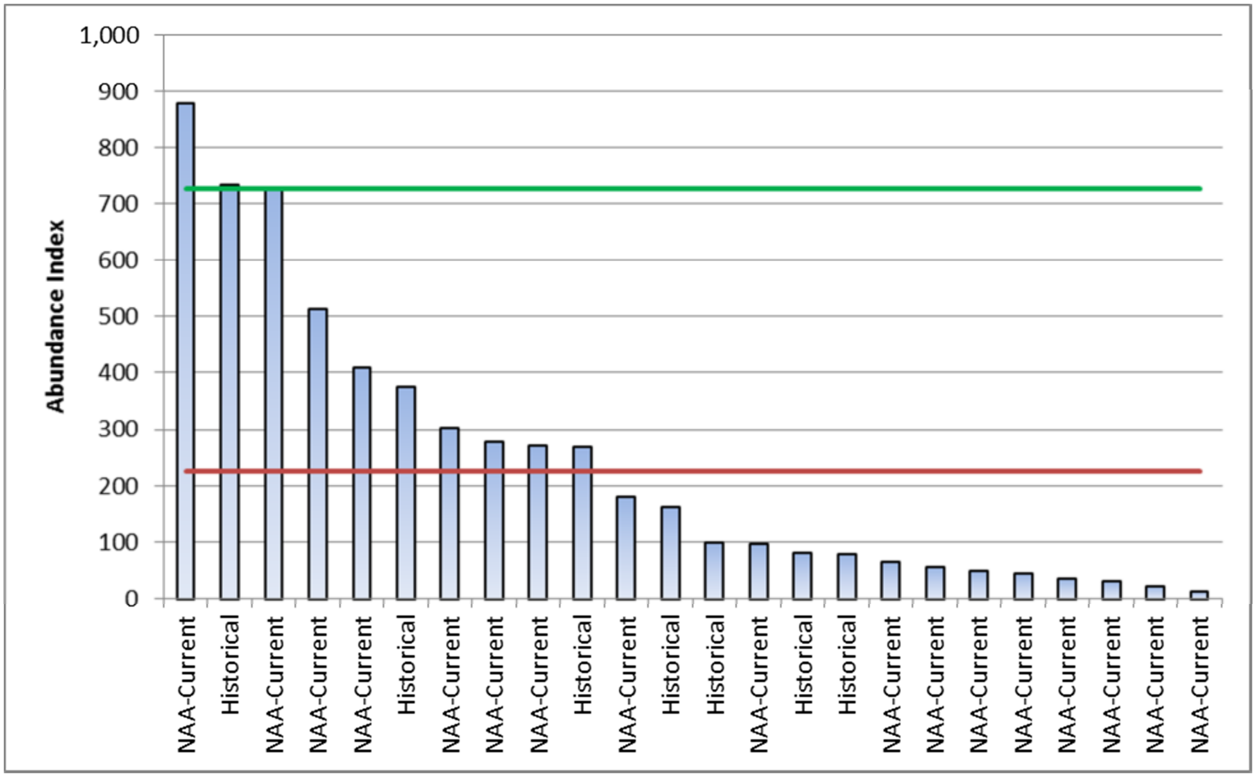


Figure 2.83: Calibration results for LS1. The blue bars show abundance index for each year and the green and red lines are the Good-Fair and Fair-Poor thresholds. The breakpoints are set at 725 and 225 respectively.

Table 2.34: LS1 – Abundance index indicator rating breakpoints.

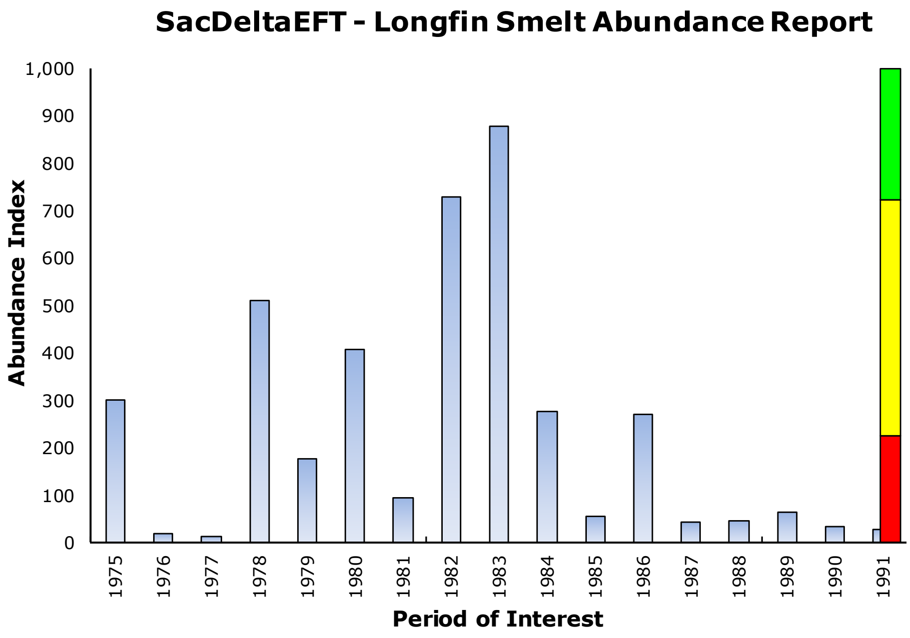
	Daily		**Rollup**		**Notes**
	Good-Fair	**Fair-Poor**	**Good-Fair**	**Fair-Poor**	
LS1 – Abundance index	N/A	N/A	725	225	• Criteria: statistical distribution, terciles, "more" is better • Units: n/a • No daily estimate

Excel Reports

An example of the multi-year rollup report for LS1 is shown below in Figure 2.84. The report shows two graphs: the upper panel shows the annual longfin smelt abundance index and the lower graph shows the average annual X2 location measured in km from the Golden Gate Bridge. Note that a low average X2 value results in a high abundance index. Valid X2 values range from 54 to 92 km. The performance for a given year can be found by comparing the annual habitat index value with the vertical R/Y/G bar.

Scenario: BDCP - NAA-Current SacDelta

Units N/A



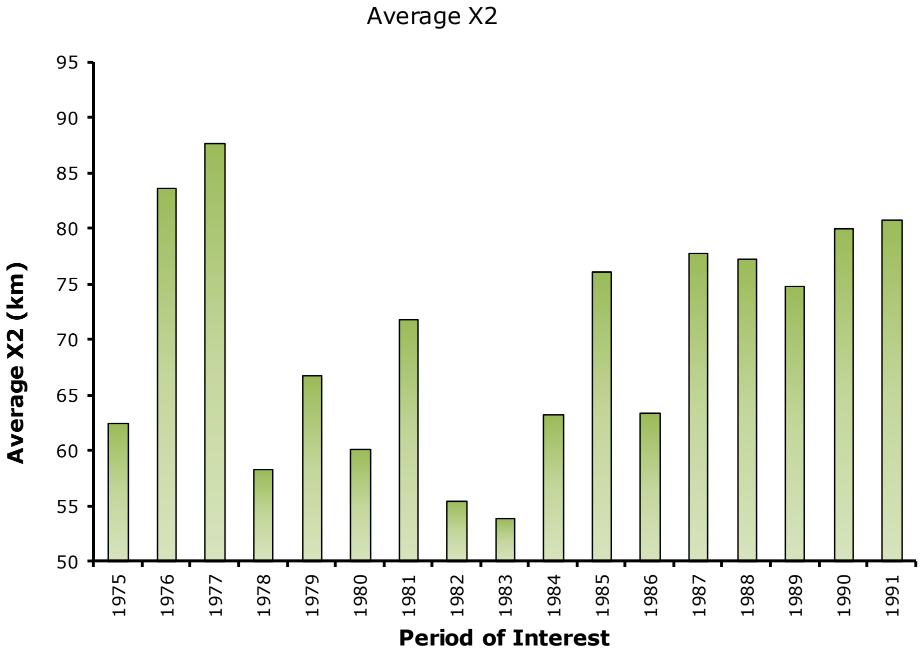
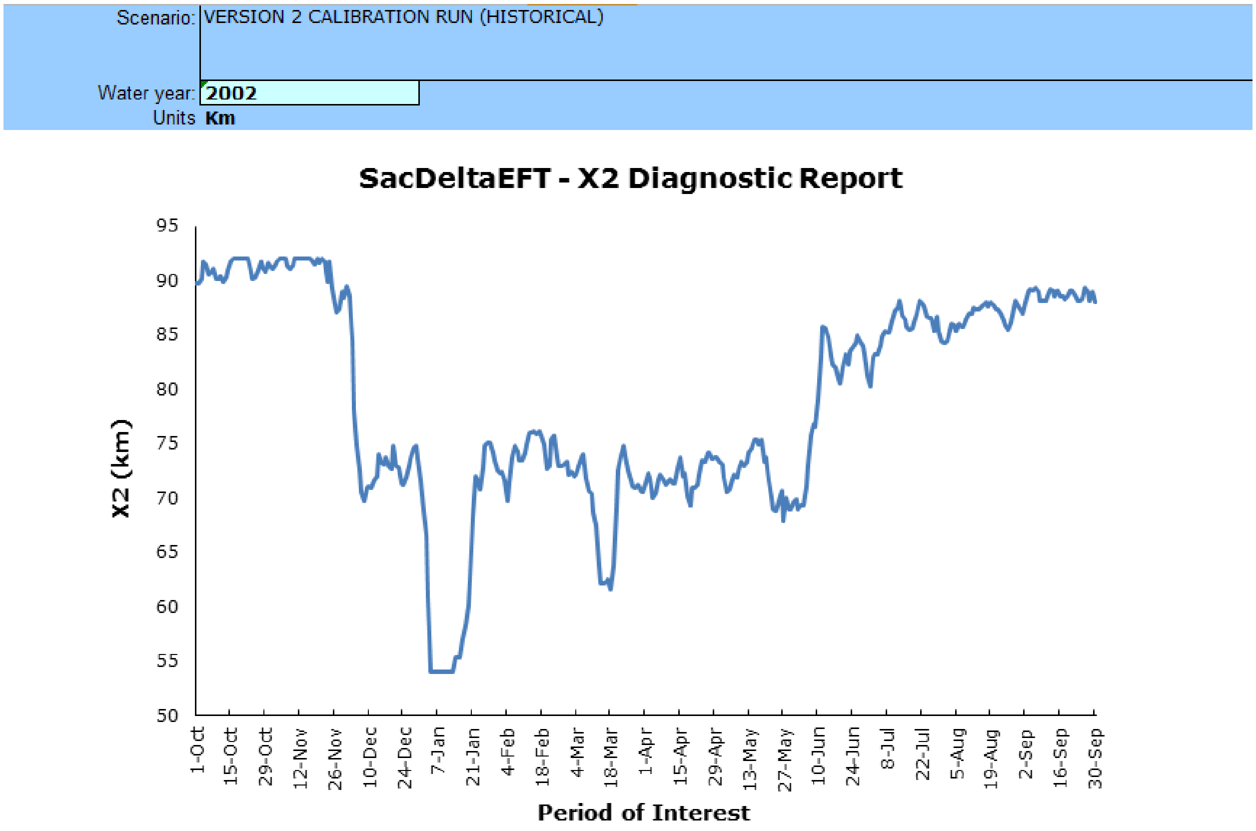


Figure 2.84: An example of screen captures from the multi-year rollup report for LS1: Abundance Index. This example shows performance from 1975 to 1991for modeled data. Low average X2 value results in a high abundance index.

More information is available for X2 in the X2 Diagnostic Report, see Figure 2.85. The report shows the daily location of X2 for the entire water year (October 1st to September 30th). Note that the X2 values are bound by 54 and 92 km.



Scenario: VERSION 2 CALIBRATION RUN (HISTORICAL)

Water year: 2002

Units Km

Figure 2.85: An example of a screen capture from the X2 Diagnostic Report. This example shows the daily location of X2 for WY 2002 (October 1st 2001 to September 30th 2002) for historical data. Note that X2 values are bound by 54 and 92 km.

Spatial Reports

There are no spatial reports available for LS1 – Abundance index, as the PM does not have an associated location. The daily location of X2, used to calculate this PM, can be viewed in the X2 spatial diagnostic report (see Figure 2.86). The report displays either a time-series animation of the daily location of X2 or the user can view the location on a specific date using the date selection control below the report. Reports for multiple years can be synchronized to compare the daily X2 location for different years.

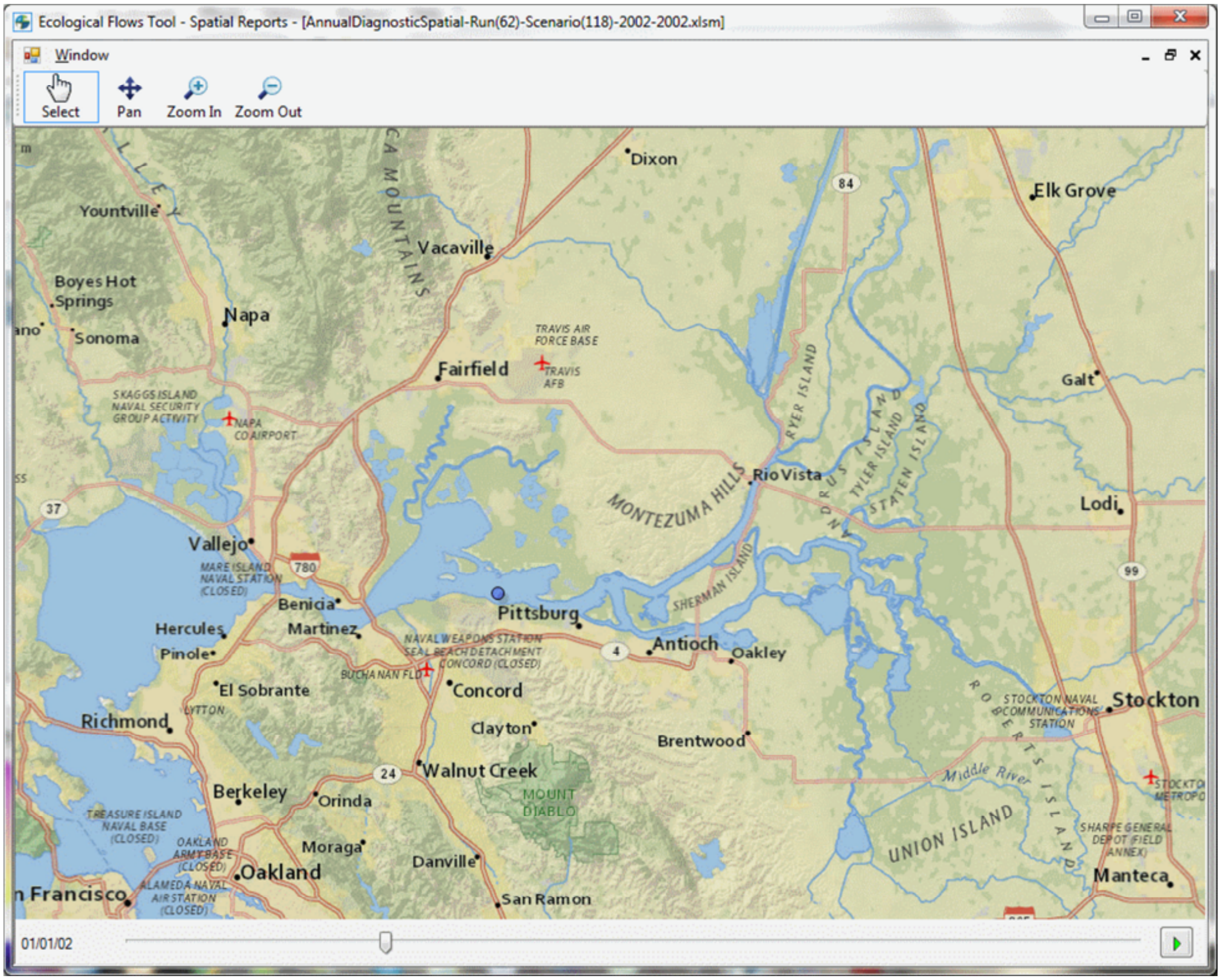


Figure 2.86: X2 spatial diagnostic report for 2002 historical data. The blue dot shows the location of X2 on any given day of the water year, in this example for January 1st 2002.

PM uncertainties and overall reliability

Abundance of longfin smelt has remained very low since 2000, even though freshwater flows increased during several of these years, suggesting that changes in the estuary's food web may have had substantial and long-term impacts on longfin smelt population dynamics (USFWS 2012). Longfin smelt recruitment (replacement of individuals by the next generation) has also steadily declined since 1987, even after adjusting for Delta freshwater flows. The introduction of the overbite clam has impacted zooplankton abundance and species composition by grazing on the phytoplankton that comprise part of the zooplankton's food base. In the Bay-Delta, copepods are the primary prey of longfin smelt during the first few months of their lives and the longfin smelt's diet shifts to include mysids and other small crustaceans as soon as they are large enough to consume these larger prey items. In addition, the food web has also been altered by increased ammonia discharge which has been shown to impair primary productivity (USFWS 2012).

Entrainment was historically a concern for longfin smelt but is no longer considered a major threat because of current regulations (USFWS 2012). Efforts to reduce delta smelt entrainment loss through the implementation of the 2008 delta smelt biological opinion and the listing of longfin smelt under the

CESA have likely reduced longfin smelt entrainment losses. The high rate of entrainment that occurred in 2002 that threatened the Bay Delta longfin smelt population is unlikely to recur, and would no longer be allowed under today's regulations because limits on longfin smelt take would trigger reductions in the magnitude of reverse flows.

3. References and Further Reading

Aldridge, D.W. and R.F. McMahon. 1978. Growth, fecundity, and bioenergetics in a natural population of the freshwater clam, *C. fluminea malinensis* Philippi, from north central Texas. Journal of Molluscan Studies 44: 49-70.

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 - 5th, 2003. 2nd Draft prepared by ESSA Technologies Ltd., Vancouver, BC for McBain and Trush, Arcata, CA. 29 pp.

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. Can. J. Fish. Aquat. Sci. 63: 1142-1156.

Baker, P.F., T.P. Speed and F.K. Ligon. 1995. Estimating the influence of temperature on the survival of Chinook salmon smolts (*Oncorhynchus tshawytscha*) through the Sacramento-San-Joaquin River delta of California. Can J. Fish. Aquat. Sci. 52: 855-863.

Bartholow, J.M. and V. Heasley. 2006. Evaluation of Shasta Dam scenarios using a Salmon production model. Draft Report to U.S.G.S. 110 p.

Baxter, R., R. Breuer, L. Brown, M. Chotkowski, F. Feyrer, M. Gingras, B. Herbold, A. Mueller-Solger, M. Nobriga, T. Sommer and K. Souza. 2008. Pelagic Organism Decline Progress Report: 2007 Synthesis of Results, Sacramento. Available at: http://www.fws.gov/sacramento/es/documents/POD_report_2007.pdf. (Accessed on: November 28, 2008)

Beamish, R.J. and C. Mahnken. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Progress in Oceanography 49:423-437.

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. Available at: http://repositories.cdlib.org/jmie/sfews/vol3/iss2/art1/. (Accessed on: November 20, 2008)

Brett, J.R., J.E. Shelbourn and C.T. Shoop. 1969. Growth rate and body composition of fingerling sockeye salmon, *Oncorhynchus nerka*, in relation to temperature and ration size. Journal of the Fisheries Research Board of Canada 26:2363-2394.

Brown. L.R. 2003. Will tidal wetland restoration enhance populations of native fishes? San Francisco Estuary and Watershed Science 1(1):

CALFED Bay-Delta Program. 2000. Multi-Species Conservation Strategy, Final Programmatic EIS/EIR, Final. July 2000. Available at: http://www.calwater.ca.gov/calfed/library/library_archive_EIS.html.

CALFED Science Advisory Panel. 2008. Workshop on Conveyance Modeling in support of the Delta Vision Blue Ribbon Task Force Summary Findings: Linking Physical and Biological Models for

Ecosystem Prediction, Planning, and Performance. Available at: www.science.calwater.ca.gov/pdf/workshops/Science_Advisor_Panel_Final_Report_5-20-08.pdf

Carlton J.T., J.K. Thompson, L.E. Schemel and F.H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal, Mar Eco Prog Ser 66:81-94.

Cavallo, B., C. Turner and P. Bergman. 2008. North-of-Delta-Offstream-Storage (NODOS) Sacramento River winter run Chinook IOS model. Draft model description and documentation (March 26, 2008). Prepared by Cramer Fish Sciences for California Department of Water Resources, 29 p.

Cech, J.J. Jr., S.I. Doroshov, G.P. Moberg, B.P. May, R.G. Schaffter and D.M. Kohlhorst. 2000. Biological assessment of green sturgeon in the Sacramento-San Joaquin watershed (Phase 1). Project No. 98-C-15, Contract No. B-81738. Final report to CALFED Bay-Delta Program.

Cohen, A.N. and J.T. Carlton. 1998. Accelerating Invasion Rate in a Highly Invaded Estuary. Science 279:555–557.

Cohen, A.N. 2011. The Exotics Guide: Non-native Marine Species of the North American Pacific Coast. Center for Research on Aquatic Bioinvasions, Richmond, CA, and San Francisco Estuary Institute, Oakland, CA. Revised September 2011. Availablt at: http://www.exoticsguide.org. (Accessed on: October 4, 2011).

Contra Costa Water District (CCWD). 2010. Delta Flow Criteria Informational Proceeding, Exhibit CCWD-9, Closing Statement. Available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/docs/closing_comments/ccwd_closing.pdf. Accessed January 22, 2013.

Cui, Y. 2007. The Unified Gravel-Sand (*TUGS*) Model: Simulating Sediment Transport and Gravel/Sand Grain Size Distributions in Gravel-Bedded Rivers, *Water Resour. Res.*, *43*, W10436, doi:10.1029/2006WR005330.

Cui, Y. and G. Parker. 1998. The arrested gravel-front: stable gravel-sand transitions in rivers. Part 2: General numerical solution, *Journal of Hydraulic Research*, 36(2): 159-182.

Davis, J.T. and J.T. Lock. 1997. Largemouth bass: biology and life history. Southern Regional Aquaculture Center. Available at: http://www.aquanic.org/publicat/usda_rac/efs/srac/200fs.pdf.

Delong, L.L., D.B. Thompson and J.K. Lee. 1997. The computer program FOURPT (Version 95.01)—a model for simulating one-dimensional, unsteady, open-channel flow: U.S. Geological Survey Water-Resources Investigations Report 97-4016, 69 pp.

Delta smelt BiOp. 2008. The Sacramento Fish and Wildlife Office's Biological Opinion (BiOp) on the Long-Term Operational Criteria and Plan (OCAP) effects on Delta smelt. December 15, 2008. Available at: http://www.fws.gov/sfbaydelta/documents/SWP-CVP_OPs_BO_12-15_final_OCR.pdf

ESSA Technologies Ltd. 2005. Sacramento River Decision Analysis Tool: Workshop Backgrounder. Prepared for The Nature Conservancy, Chico, CA. 75 p.

ESSA Technologies Ltd. 2008a. Sacramento River Ecological Flows Tool v.1: Candidate Design Improvements & Priorities – Summary of advice & suggestions received at a technical review workshop held October 7–8 2008 in Chico, California. Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 67 p.

ESSA Technologies Ltd. 2008b. Delta Ecological Flows Tool: Backgrounder (Final Draft). Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 121 p.

ESSA Technologies Ltd. 2011a. Sacramento River Ecological Flows Tool (SacEFT): Record of Design (v.2.00). Prepared by ESSA Technologies Ltd., Vancouver, BC for The Nature Conservancy, Chico, CA. 111 p. + appendices.

ESSA Technologies Ltd. 2011b. SacEFT Analysis of the Bay Delta Conservation Plan: Revised Baseline Comparisons [DRAFT]. 52 pp + appendices.

Ferreira, I.C., S.K. Tanaka, S.P. Hollinshead and J.R. Lund. 2005. Musings on a Model: CalSim II in California's Water Community. San Francisco Estuary and watershed Science. 3 (1): Article 1.

Feyrer, F., B. Herbold, S.A. Matern and P.B. Moyle. 2003. Dietary shifts in a stressed fish assemblage: consequences of a bivalve invasion in the San Francisco Estuary. Environmental Biology of Fishes 67:277-288.

Feyrer, F., K. Newman, M. Nobriga and T. Sommer. 2011. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries and Coasts 34: 120-128.

Feyrer, F., M.L. Nobriga and T.R. Sommer. 2007. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Can. J. Fish. Aquat. Sci. 64: 723-734.

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.

U.S. Fish & Wildlife Service (USFWS). 2012. Endangered and Threatened Wildlife and Plants; 12-month Finding on a Petition to List the San Francisco Bay-Delta Population of the Longfin Smelt as Endangered or Threatened. Available from http://www.fws.gov/sfbaydelta/species/longfin_smelt.cfm.

Fisher, F.W. 1994. Past and present status of Central Valley chinook salmon. Conserv. Biol. 8:870-873.

Fleenor, W.E., W.A. Bennett, P.B. Moyle and J.R. Lund 2010. On Developing Prescriptions for Freshwater Flows to Sustain Desirable Fishes in the Sacramento-San Joaquin Delta. Delta Solutions, Center for Watershed Sciences, University of California – Davis. Available from http://deltasolutions.ucdavis.edu.

Fremier, A.K. 2007. Restoration of Floodplain Landscapes: Analysis of Physical Process and Vegetation Dynamics in the Central Valley of California. University of California, Davis. Ph.D. Dissertation. 98p.

Garrison, B.A. 1989. Habitat suitability index model: Bank Swallow (*Riparia riparia*). U.S. Fish and Wildlife Service. Sacramento, California.

Garrison, B.A. 1998. Revisions to wildlife habitats of the California Wildlife Habitat Relationships system. Meeting of the CNPS Vegetation Committee. California Department of Fish and Game, Sacramento.

Garrison, B.A. 1999. Bank Swallow (*Riparia riparia*). *In:* The Birds of North America, No. 414 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, PA.

Giorgi, A.E., T.W. Hillman, J.R. Stevenson, S.G. Hays and C.M Peven. 1997. Factors that influence the downstream migration rates of juvenile salmon and steelhead through the hydroelectric system in the mid-Columbia River base. North American Journal of Fisheries Management. 17: 268-282.

Grimaldo L. and Z. Hymanson. 1999. What is the impact of the introduced Brazilian waterweed Egeria densa to the Delta ecosystem? IEP Newsletter 12:43-45. Available at: http://www.iep.water.ca.gov/report/newsletter

Hammond, J.S., R.L. Keeney and H. Raiffa. 1999. Smart Choices: A practical guide to making better decisions. Harvard Business School Press. Boston, MA.

Hanson, P.C., T.B. Johnson, D.E. Schindler and J.F. Kitchell. 1997. Fish Bioenergetics 3.0. Center for Limnology, University of Wisconsin, Madison.

Haunstein, E. and C. Ramirez. 1986. The influence of salinity on the distribution of *Egeria densa* in the Valdivia River Basin Chile. Archiv Fur Hydrobiologie 107:511–520.

Healey, M.C., M.D. Dettinger and R.B. Norgaard (eds.) 2008. The State of Bay-Delta Science, 2008. Sacramento,

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.

Jassby, A.D., W.J. Kimmere, S.G. Monismith, C. Armor, J.E. Cloern, T.M. Powell, J.R. Schubel and T.J. Vendlinski 1995. Isohaline Position as a Habitat Indicator for Estuarine Populations. Ecological Applications 5(1): 272-280.

Jassby, A. 2008. Phytoplankton in the Upper San Francisco Estuary: Recent Biomass Trends, Their Causes and Their Trophic Significance. San Francisco Estuary and Watershed Science, 6(1): Article 2. Available at: http://escholarship.org/uc/search?entity=jmie_sfews;volume=6;issue=1. (Accessed on: October 3, 2012)

Johannesson, H. and G. Parker. 1989. Linear theory of river meanders. In *River Meandering*, Ikeda S, Parker G (eds). Water Resources Monographs, 12. AGU: Washington; 181–214.

Kimmerer, W.J. 2002. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 242:39-55.

Kimmerer, W.J. 2008. Losses of Sacramento River Chinook salmon and Delta smelt (*Hypomesus transpacificus*) to entrainment in water diversions in the Sacramento-San Joaquin delta. San Francisco Estuary and Watershed Science 6(2): Article 2. Available at: http://escholarship.org/uc/search?entity=jmie_sfews;volume=6;issue=2. (Accessed on: October 3, 2012)

Kimmerer, W.J. 2011. Modeling Delta smelt Losses at the South Delta Export Facilities. San Francisco Estuary and Watershed Science 9:1.

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, Issue 1, Article 4.

Larsen, E.W. 1995. Mechanics and Modeling of River Meander Migration. PhD Dissertation. Civil Engineering. University of California at Berkeley.

Larsen, E.W., A.K. Fremier and S.E. Greco. In review. Cumulative Effective Stream Power and Bank Erosion on the Sacramento River, CA USA. Journal of American Water Resources Association.

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., E. Girvetz and A. Fremier. 2006. Assessing the Effects of Alternative Setback Levee Scenarios Employing a River Meander Migration Model. Environmental Management DOI 10.1007/s00267-004-0220-9 URL dx.doi.org/10.1007/s00267-004-0220-9.

Lehman, P.W., T. Sommer and L. Rivard. 2008. The influence of floodplain habitat on the quantity and quality of riverine phytoplankton carbon produced during the flood season in San Francisco Estuary. Aquatic Ecology 42:363-378.

Lund, J., E. Hanak, W. Fleenor, R. Howitt, J. Mount and P. Moyle. 2007. Envisioning Futures for the Sacramento–San Joaquin Delta, Public Policy Institute of California, San Francisco, California.

McEwan, D. 2001. Central Valley steelhead. *In:* Brown, R.L. (ed.) Contributions to the biology of Central Valley salmonids. Fish Bulletin 179.1. California Department of Fish and Game. p.1-44.

MacFarlane, R.B. 2010. Energy dynamics and growth of Chinook salmon (Oncorhynchus tshawytscha) from the Central Valley of California during the estuarine phase and first ocean year. Can. J. Fish. Aquat. Sci. 67:1549-1565.

MacNally, R., J.R. Thomson, W.J. Kimmerer, F. Feyrer, K.B. Newman, a. Sih, W.A. Bennett, L. Brown, E. Fleishman, S.D. Culberson and G. Castillo. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications, 20(5): 1417–1430

Mahoney, J.M. and S.B. Rood. 1998. Streamflow requirements for cottonwood seedling recruitment-an integrative model. Wetlands 18: 634-645.

Maunder, M.N. and R.B. Deriso. 2011. A state–space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to Delta smelt (Hyposmesus transpacificus). Can. J. Fish. Aquat. Sci. 68(7): 1285-1306.

MDEM. 2002. S. American Waterweed: An Invasive Aquatic Plant. *Egeria* densa. Commonwealth of Massachusetts - Department of Environmental Management. Available at: http://www.mass.gov/dcr/watersupply/lakepond/factsheet/South%20American%20Waterweed.pdf. (Accessed on: October 4, 2012)

Miller, W.J. 2011. Revisiting Assumptions that Underlie Estimates of Proportional Entrainment of Delta smelt by State and Federal Water Diversions from the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 9:1.

Miller, W.J., B.F.J. Manly, D.D. Murphy, D. Fullerton and R.R. Ramey 2012. An Investigation of Factors Affecting the Decline of Delta smelt (Hypomesus transpacificus) in the Sacramento-San Joaquin Estuary. Reviews in Fisheries Science 20:1, 1-19.

Moffatt, K.C., E.E. Crone, K.D. Holl, R.W. Schlorff and B.A. Garrison. 2005. Importance of hydrologic and landscape heterogeneity for restoring bank swallow (*Riparia riparia*) colonies along the Sacramento River, California. Restoration Ecology 13: 391-402

Mount, J. and R. Twiss. 2005. Subsidence, sea level rise, and seismicity in the Sacrament -San Joaquin Delta. San Francisco Estuary and Watershed Science 3: http//repositories.cdlib.org/jmie/sfews/vol3/iss1/art5.

Mount, J., W. Fleenor, B. Gray, B. Herbold and W. Kimmerer. 2013. Panel Review of the Draft Bay Delta Conservation Plan: Prepared for The Nature Conservancy and American Rivers.

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. 2002. Inland fishes of California. Revised edition. University of California Press, Berkeley.

Moyle, P.B., R.D. Baxter, T. Sommer, T.C. Foin and S.A. Matern. 2004. Biology and population dynamics of Sacramento splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science 2(2): Article 3. Available at: http://repositories.cdlib.org/jmie/sfews/vol2/iss2/art3

Murray, C.M. and D.R. Marmorek. 2003. Adaptive Management and ecological restoration. In Ecological Restoration of Southwestern Ponderosa Pine Forests. P. Friederici, ed. Ecological Restoration Institute, Flagstaff, AZ. p. 417-428.

National Marine Fisheries Service (NMFS). 2003. Endangered and threatened wildlife and plants: 12-month finding on a petition to list North American green sturgeon as a threatened or endangered species. Federal Register 68: 4433-4441.

Nichols, F.H., J.E. Cloern, S.N. Louma and D.H. Peterson. 1986. The modification of an estuary. Science 231: 567-573.

Nicolini M.H. and D.L. Penry. 2000. Spawning, fertilization, and larval development of *Potamocorbula amurensis* (Mollusca: Bivalvia) from San Francisco Bay, California. Pacific Science 54:377-388**.**

Nobriga, M.L., T.R. Sommer, F. Feyrer and K. Fleming. 2008. Long-term trends in summertime habitat suitability for Delta smelt, *Hypomesus transpacificus*. San Francisco Estuary and Watershed Science 6: http//repositories.cdlib.org/jmie/sfews/vol6/iss1/art1.

Nobriga, M.L. 2008. Evaluating food limitation in California's Sacramento-San Joaquin Delta: a preliminary comparison of age-0 striped bass and largemouth bass. TAFS. In Press.

Nobriga, M.L. 2009. Bioenergetic modeling evidence for a context-dependent role of food limitation in California's Sacramento-San Joaquin delta. Californai Fish and Game 95:111-121.

Wanger, O.W. 2008. ORDER on Motion for Preliminary Injunction of Fall X2 Action. Court document, August 31, 2011: available from http://www.fws.gov/sfbaydelta/OCAP/index.cfm.

Oreskes, N., K. Schrader-Frechette and K. Belitz. 1994. Verification, validation, and confirmation of numerical models in the earth sciences. Science 263: 641-646.

Orsi, J.J. and W.L. Mecum. 1996. Food limitation as the probable cause of a long-term decline in the abundance of *Neomysis mercedis* the opossum shrimp in the Sacramento-San Joaquin estuary. Pages 375-401 In Hollibaugh, J.T. (ed) San Francisco Bay: the ecosystem. American Association for the Advancement of Science. San Francisco, CA.

Pasternack, G.B., C.L. Wang and J.E. Merz. 2004. Application of a 2D hydrodynamic model to design of reach-scale spawning gravel replenishment on the Mokelumne River, California. River Research and Applications 20:205-225.

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.

RMA. 2003. Upper Sacramento River Water Quality Modeling with HEC-5Q: Model Calibration and Validation. Prepared for: US Bureau of Reclamation. Prepared by: Resource Management Associates, Inc., 4171 Suisun Valley Road, Suite J Suisun City, California 94585.

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.

Rogers, M.W., M.S. Allen and W.F. Porak. 2006. Separating genetic environmental influences on temporal spawning distributions of largemouth bass (*Micropterus salmoides*). Canadian Journal of Fisheries and Aquatic Sciences 63: 2391-2399.

Siegel, S.W., P.A.M. Bachand, J. Lowe, T. Carson, J. Kulpa, S. Avent, C. Toms and D. Gewant. 2005. Physical Processes: Inundation, Datums, Salinity, Channel Geometry. *Poster presentation*. 7th Biennial State of the San Francisco Estuary Conference, October 4-6, 2005. Available at: http://www.irwm.org/files/IRWM-PhysProc-Poster_SciConf_2005-1003trc.pdf

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.

Simon, T.P. and R. Wallus. 2008. Reproductive Biology and Early Life History of Fishes in the Ohio River Drainage: Elassomatidae and Centrarchidae, Volume 6. CRC Press, New York, USA.

Sommer T.R., W.C. Harrell and M.L. Nobriga. 2005. Habitat use and stranding risk of juvenile chinook salmon on a seasonal floodplain. North American Journal of Fisheries Management 25:1493-1504.

Sommer T.R., W.C. Harrell, A.M., Solger, B. Tom and W. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation-Marine and Freshwater Ecosystems 14:247-261.

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.

Sommer, T., B. Harrell, M. Nobriga, R. Brown, P. Moyle, W. Kimmerer and L. Schemel. 2001. California's Yolo Bypass: Evidence that flood control can be compatible with fisheries, wetlands, wildlife, and agriculture. Fisheries 26:6-16.

Sommer, T., K. Reece, F. Mejia and M. Nobriga. 2009. Delta smelt Life-History Contingents: A Possible Upstream Rearing Strategy? IEP Newsletter 22(1). Available from http://www.water.ca.gov/iep/products/newsletter.cfm.

Steffler, P. and J. Blackburn. 2002. River2D – two-dimensional depth averaged model of river hydrodynamics and fish habitat; introduction to depth averaged modeling and user's manual. University of Alberta. 119p.

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.

Swanson, C., T. Reid, P.S. Young and J.J. Cech, Jr. 2000. Comparative environmental tolerances of threatened Delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia 123:384-390.

The Nature Conservancy and ESSA Technologies Ltd. 2011. SacEFT Analysis of the North-of-the-Delta Offstream Storage Investigation. The Nature Conservancy, Chico, CA. 73pp + appendices.

Thompson, J.K. 2005. One estuary, one invasion, two responses: phytoplankton and benthic community dynamics determine the effect of an estuarine invasive suspension feeder. *In:* Olenin S. and R. Dame (eds.). The Comparative Roles of Suspension Feeders in Ecosystems. Amsterdam, Netherlands: Springer, p.291-316.

Thompson J.K., J.R. Koseff, S.G. Monismith and L.V. Lucas. 2008. Shallow water processes govern system-wide phytoplankton bloom dynamics: A field study. J. Mar. Syst. 74:153-166**.**

Thompson J.R., W.J. Kimmerer, L.R. Brown, K.B. Newman, R. MacNally, W.A. Bennett, F. Feyrer and E. Fleishman. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications, 20(5): 1431-1448.

Thompson J.K. and Parchaso F. 2010. *Corbula amurensis* Conceptual Model. USGS. Available from http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/docs/cmnt081712/srcsd/irvine4thompson.pdf. Accessed on January 21, 2013.

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.

Trebitz, A.S. 1991. Timing of spawning in largemouth bass: implications of an individual-based model. Ecological Modelling 59: 203-227.

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.

U.S. Bureau of Reclamation. 2004. Long-term Central Valley Project and State Water Project Operations Criteria and Plan Biological Assessment. USDI Bureau of Reclamation, Mid-Pacific Region, Sacramento, California.

U.S. Fish and Wildlife Service. 1995. Upper Sacramento River IFIM Study Scoping Report –Available Information. USFWS, Sacramento , CA.

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. 79p.

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. 104p.

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. 258p.

U.S. Fish and Wildlife Service. 2006a. Monitoring of the Phase 3A restoration project in Clear Creek using 2-dimensional modeling methodology. Report prepared by the Energy Planning and Instream Flow Branch, U.S. Fish and Wildlife Service, Sacramento, CA. 40p.

U.S. Fish and Wildlife Service. 2006b. 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. 94p.

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. 55p + appendices.

Wang, J.C.S. 2007. Spawning, early life stages, and early life histories of the osmerids found in the Sacramento-San Joaquin Delta in California, Volume 38. Prepared for the US Department of the Interior, Bureau of Reclamation, Mid-Pacific Region. *By* National Environmental Science Inc., Springfield VA.

Watercourse Engineering. 2003. Upper Sacramento Temperature Model Review: Final Report Summary. Prepared for: AgCEL, 900 Florin Road, Suite A, Sacramento, CA 95831. Prepared by: Watercourse Engineering, Inc. 1732 Jefferson Street, Suite 7 Napa, CA 94559

Webster, S.J. and L.M. Dill. 2006. The energetic equivalence of changing salinity and temperature to juvenile salmon. Functional Ecology 20:621-629.

Webster, S.J., L.M. Dill and J.S. Korstrom. 2007. The effects of depth and salinity on juvenile Chinook salmon *Oncorhynchus tshawytscha* (Walbaum) habitat choice in an artificial estuary. Journal of Fish Biology 71:842-851.

Werner I, S.L. Clark and D.E. Hinton. 2003. Biomarkers aid understanding of aquatic organism responses to environmental stressors. California Agriculture 57:110-115.

Wilcock, P.R. and J.C. Crowe. 2003. Surface-based transport model for mixed-size sediment. Journal of Hydraulic Engineering, 129(2): 120-128.

Williams, J.G. 2006a. Life-history conceptual model for Chinook salmon and steelhead. Report prepared for Sacramento-San Joaquin Delta regional ecosystem restoration implementation plan. 75p.

Williams, J.G. 2006b. Central valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4, Issue 3, Article 2.

Young, P.S. and J.J. Cech Jr. 1996. Environmental tolerances and requirements of Splittail. Transactions of the American Fisheries Society 125:664–678

Yoshiyama, R.M., Gerstung, E.R., Fisher, F.W. and P.B. Moyle. 1996.Historical and present distributions of Chinook salmon in the Central Valley drainage in California. In: Sierra Nevada Ecosystem Project. Status of the Sierra Nevada. Volume III. Final Report. p.309-362.

Appendix A – Indicator screening, filtering and 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 (www.dfg.ca.gov/ERP/signature_sacriverecoflows.asp), 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 A.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.

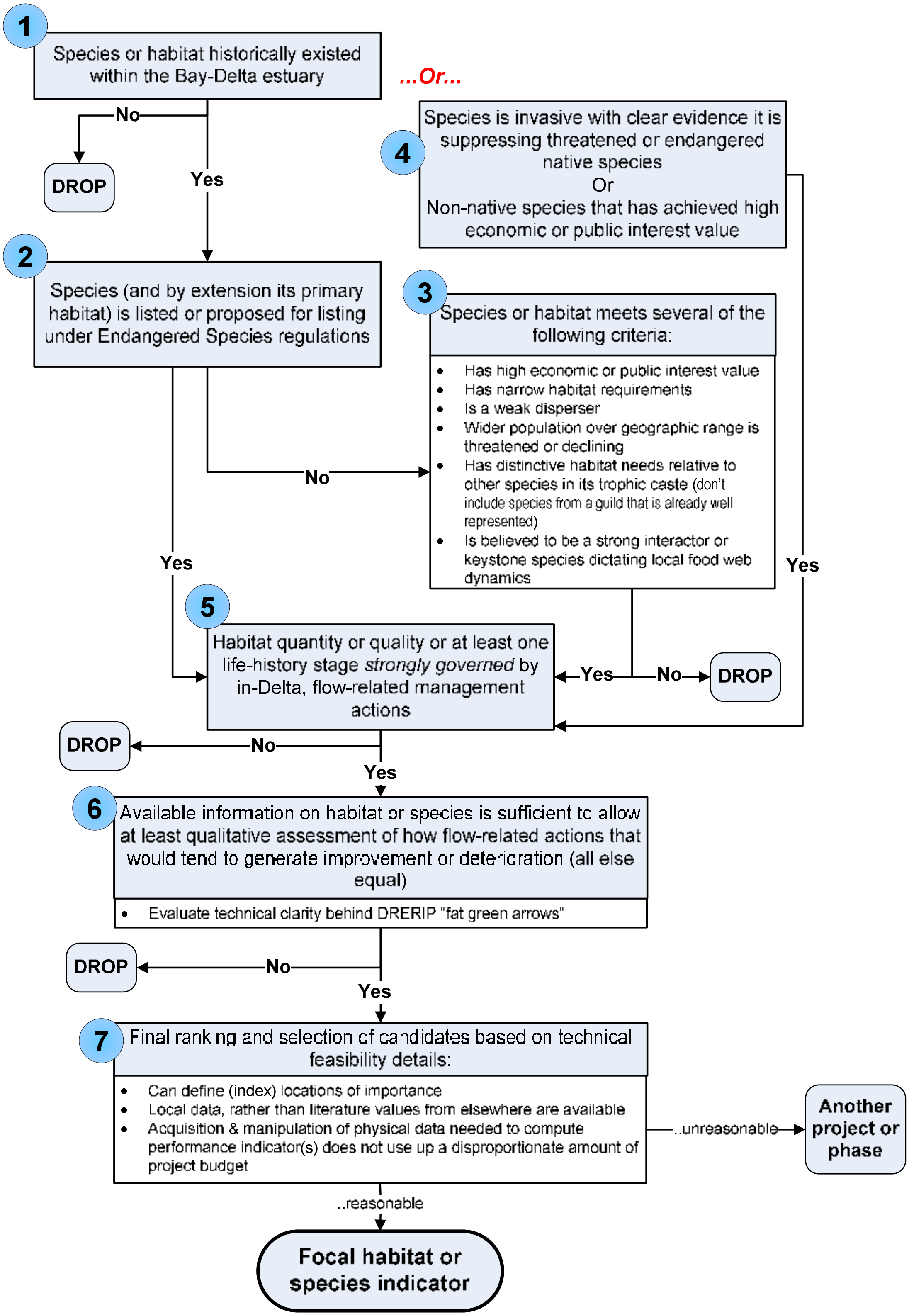


Figure A.1: Focal habitat, species filtering and screening criteria (vetting process) for DeltaEFT version 1.

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 at 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.

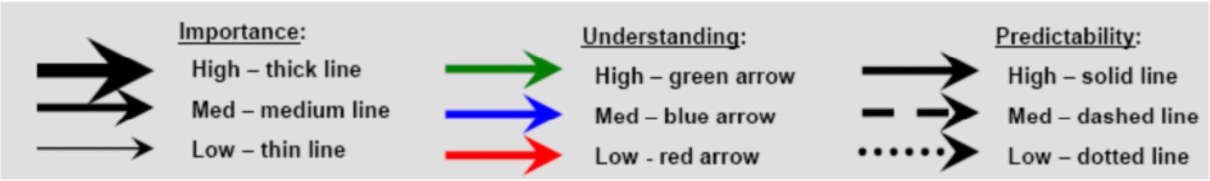
Step 6: Availability of information

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.

A.1 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 A.1).** This indicator classification and prioritization system is used from this point forwards in this document.

Table A.1: Classification concepts employed for the evaluation of the Performance Measures. Tables showing the strengths and weaknesses of PMs (Section 2.2) refer to these classification criteria using "I", "U", "R" and "F" to label each class.

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. **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.

Label	Explanation	Levels
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 measure 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. **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.	