



**Sacramento River  
Ecological Flows Tool (SacEFT):  
Record of Design (v.2.00)**

# Sacramento River Ecological Flows Tool (SacEFT): Record of Design (v.2.00)

Prepared for



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May 2011 Revision

Citation: **ESSA Technologies Ltd.** 2011. 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.

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## Glossary

|                                      |  |
|--------------------------------------|--|
| <b>ATU</b>                           | Accumulated Thermal Unit.  |
| <b>ADO.NET</b>                       | The data-access component of the Microsoft .NET Framework.   |
| <b>Base Class Library (BCL)</b>      | An object oriented framework of reusable classes accessible from any .NET language.  |
| <b>BDCP</b>                          | Bay Delta Conservation Plan.   |
| <b>Binary file</b>                   | A file containing information that is in machine-readable form that can only be interpreted by a program that understands in advance exactly how it is formatted.  |
| <b>Binary object</b>                 | A binary large object (BLOB) is a format of binary data stored in a relational database.   |
| <b>Business validation rules</b>     | A step or set of steps in a process or procedure or guide (algorithmic or heuristic) used by a customer for doing its business, work, or function, and often embodied in whole or in part in the software of a system.   |
| <b>CalSim II</b>                     | A state-wide planning model which simulates operations of State Water Project and Central Valley Project facilities, under a Coordinated Operations Agreement, on a monthly time-step.   |
| <b>Cascade delete and update</b>     | A process that causes an action to be taken on rows in a database when another row is deleted.   |
| <b>CDWR</b>                          | California Department of Water Resources.  |
| <b>Class</b>                         | A template code file that can be used to create objects with a common definition and common properties, operations, and behavior. An object is an instance of a class.   |
| <b>COM components</b>                | A set of specification and services that facilitates a developer to create reusable objects and components for running various applications.   |
| <b>Compatibility list</b>            | A listing of imported physical model data instances that are allowed to be grouped together, based on having sufficiently similar embedded assumptions. Unless a data instance is part of the same “compatibility family”, users cannot add it to a model scenario. This is the mechanism used to encourage use of apples and apples data instances. |
| <b>Data instance</b>                 | A SacEFT database concept for tracking imported datasets and their metadata using a unique identifier. Also used to tag information on non-imported ( <i>i.e.</i> , local) generic rules/parameter values for focal species ( <i>i.e.</i> , also used as a scenario identifier).   |
| <b>Database engine</b>               | The part of the database manager that provides the base functions and configuration files that are needed to use the database.   |
| <b>Desktop centered architecture</b> | The majority of software application code is installed on individual workstations rather than accessed from a centralized server computer.   |
| <b>DOM</b>                           | Daily Operations Model; a subsystem of CalSim which produces daily location-specific estimates of flow and temperature, while preserving the attributes of the monthly timestep model.   |
| <b>ERP</b>                           | Ecological Restoration Program.  |
| <b>HEC-5Q</b>                        | Alternate name for USBR Temperature Model.   |
| <b>IEM</b>                           | Import/Export Manager – an envisioned SacEFT component for importing external datasets to the SacEFT relational database, using a combination of Excel templates, wrapper code for COM components that may be provided by USACE HEC programmers (for DSS files) and web services.  |
| <b>Metadata</b>                      | The set of characteristics that describe the underlying assumptions and other major properties of a dataset or model.  |

|                                  |  |
|----------------------------------|--|
| <b>NODOS</b>                     | North of Delta Offstream Storage.  |
| <b>NWIS</b>                      | USGS National Water Information System.  |
| <b>OOD</b>                       | Object-Oriented Design. OOD is a design method in which a system is modeled as a collection of cooperating objects and individual objects are treated as instances of a class within a class hierarchy.                          |
| <b>PM</b>                        | Performance Measure.   |
| <b>RBDD</b>                      | Red Bluff Diversion Dam.   |
| <b>RM</b>                        | River Mile; a historical (but not rigorously quantitative) system of assigning locations along the Sacramento River Ecol according to early survey work. The benchmark location for RM is located at Chippis Island.             |
| <b>R/Y/G</b>                     | The <b>Red/Yellow/Green</b> categorical indicator rating system used by EFT. It may sometimes be referred to by the values that define the breakpoints between categories: Hazard Thresholds or Indicator Breakpoints.           |
| <b>SacEFT</b>                    | Sacramento River Ecological Flows Tool.  |
| <b>SOAP</b>                      | A lightweight, XML-based protocol for exchanging information in a decentralized, distributed environment. SOAP can be used to query and return information and invoke services across the Internet.                              |
| <b>SQL Server 2005 Express</b>   | A free, redistributable version of SQL Server 2005 designed for building simple data-driven applications.  |
| <b>SRWQM</b>                     | Sacramento River Water Quality Model; a subsystem of the CalSim model which predicts water temperature (among other variables).  |
| <b>SSURGO</b>                    | Soil Survey Geographic.  |
| <b>Structured error handling</b> | An approach for signaling and responding to unexpected problems while a software program is running.   |
| <b>Thick-client architecture</b> | Where application-specific code runs on and processes data on the client, rather than merely rendering data which has been processed by a server.  |
| <b>TNC</b>                       | The Nature Conservancy.  |
| <b>TUGS</b>                      | The Unified Gravel-Sand model.   |
| <b>USBR Temperature Model</b>    | Occasionally referred to as USBR TMS/HEC-5Q or HEC-5Q; and more recently the USBR Upper Sacramento River Temperature Model.  |
| <b>USFWS</b>                     | United State Fish and Wildlife Service.  |
| <b>USGS</b>                      | United States Geological Survey.   |
| <b>USRDOM</b>                    | Upper Sacramento River Daily Operations Model.   |
| <b>USRWQM</b>                    | Upper Sacramento River Water Quality Model; a subsystem of the CalSim model which predicts water temperature (among other variables).  |
| <b>Windows event log</b>         | The event logs contain the most important information for diagnosing application and operating system failures, determining the health and status of a system and verifying that system and applications are operating properly. |
| <b>Wrapper</b>                   | A program or script that sets the stage and makes possible the running of another, more important program.   |
| <b>WUA</b>                       | Weighted Usable Area.  |

# 1. Decision Analysis Tool: Overview

## 1.1 Background and Goals

With over 50 years of international concern about the effects of flow alteration on ecosystems, the continued advancement of scientifically based tools to quantify the ecological effects of flow regulation and river channel alterations has become a prominent research activity (*e.g.*, Stalnaker 1994; Bunn and Arthington 2002; Annear *et al.* 2004; Veldkamp and Verburg 2004; Arthington *et al.* 2006; Poff *et al.* 1997; Petts 2009; Poff and Zimmerman 2010). Process-based models constitute one powerful and efficient tool for comparing the effects of alternative flow and river channel change scenarios. The Sacramento River Ecological Flows Tool (SacEFT) is a decision support tool emphasizing clear communication of trade-offs for key ecosystem targets associated with alternative conveyance, water operations and climate futures in the Sacramento River eco-region. The vision for SacEFT, one we believe we have achieved, is to create software that makes it easy for non-specialists to expand the ecological considerations and science foundation used to evaluate water management alternatives on the Sacramento River.

Practical integration of multi-species, multi-habitat needs in the evaluation of water operation scenarios is challenging. In SacEFT, we more transparently relate additional attributes of the flow regime to multiple species' life-history needs, thereby contributing to a more effective understanding of water operations on representative sets of focal species and their habitats (Chinook salmon, steelhead, green sturgeon, bank swallows, channel erosion/migration, Fremont cottonwoods, and large woody debris recruitment). Scientifically, SacEFT takes a bottom-up, process-based approach to the relationship between flow and related aquatic habitat variables, and looks at how these variables are tied to key species life-stages and ecosystem functions. Our work and the input of many expert contributors develops a more complete understanding of the flow regime and its relation to natural processes and species' requirements, so as to identify the critical attributes of the flow regime necessary to maintain ecosystem function. The multi-species, multi-indicator paradigm provides a "portfolio" approach for assessing how different flow and habitat restoration combinations suit the different life stages of desired species. In so doing, SacEFT transparently relates additional attributes of the flow regime to multiple species' life-history needs in an overall effort at careful organization of representative functional flow needs. This provides a robust scientific framework to focus the definition of ecological flow guidelines and contribute to the understanding of water operation effects on focal species and their habitats.

The performance indicators and functional relationships built into SacEFT were vetted through two multi-disciplinary workshops and numerous design document reviews. The recommendations of these technical design workshops and subsequent peer reviews provide the basis for the indicators and models described in this document. Collectively, the constituent focal species "submodels" provide twelve (12) performance measures which vary in spatial scale, temporal scale, and levels of reliability. Multi-year roll-ups allow users to quickly zoom in on the much smaller set of performance measures which differ significantly across management scenarios. With the completion of SacEFT v.2, the decision analysis tool provides the ability to:

1. improve the basis for evaluating flow alternatives on the Sacramento River from Keswick to Colusa (*e.g.*, Bay-Delta Conservation Plan flows, North-of-Delta Off-Stream Storage Investigation, Shasta Lake Water Resources Investigation, and other future diversions and water transfers);
2. evaluate a variety of management actions' affects (*e.g.*, gravel augmentation and bank protection alternatives) on ecosystem targets for the five Sacramento River focal species;

3. provide multiple levels of communication of information ranging from simplified formats for managers and decision-makers to in-depth displays of detailed functional relationships and transparent assumptions for review by technical experts;
4. leverage existing systems and data sources (CalSim /USRWQM/USRDOM, historical gauging station records, the Meander Migration Model, and TUGS, a new sediment transport model); and
5. catalyze exploration of new alternatives as data sets become available (e.g., climate change) and help promote the development of needed flexibility in the water management system.

By leveraging many of the same planning models used in existing socioeconomic evaluations in California (e.g., CalSim, USRDOM, USRWQM), SacEFT provides an “eco plug-in” for water operation studies based on use of these physical hydrologic/water balance models. SacEFT advances and enables ecological flow (e-Flow) science by linking these physical models to a representative set of individual ecosystem components inside an overall compressed, cross-disciplinary synthesis tool for evaluating conveyance operation alternatives in the Sacramento River eco-region.

Lastly, SacEFT’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 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 in the Upper and Middle Sacramento River. One of the biggest challenges in the practical implementation of ecological flow guidelines is the wide range of objectives, focal species and habitat types that need to be considered. Our work to date 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.

Building a tool that makes accurate future predictions of ecosystem behavior is challenging and usually not possible in complex, open natural systems (Oreskes *et al.* 1994). SacEFT’s main purpose is to characterize and explore important ecological trade-offs and inform managers and decision makers about the relative impacts of various flow management alternatives. The system can also act as a catalyst for exploring deliberate or opportunistic adaptive management experiments (Murray and Marmorek 2003) that assess actual ecological responses on a variety of spatial/temporal scales. This approach (model exploration of management alternatives and adaptive management experiments) will ultimately help water resource managers and stakeholders converge on options that best strike a balance among various of conflicting objectives.

### **1.1.1 History**

Between 2004 and 2008 the Sacramento River Ecological Flows Study team developed a decision analysis tool that incorporates physical models of the Sacramento River with biophysical habitat models for six Sacramento River species (see: [www.dfg.ca.gov/ERP/signature\\_sacriverecoflows.asp](http://www.dfg.ca.gov/ERP/signature_sacriverecoflows.asp)). The resultant tool, the Sacramento River Ecological Flows Tool (SacEFT), is a database-centered software system that links flow management actions to focal species outcomes on the mainstem Sacramento River. SacEFT allows: (1) the evaluation of ecosystem responses to alternative scenarios of discharge, water temperature, gravel augmentation, and channel revetment (rock removal) actions, and (2) water operations managers to significantly expand their ecological considerations when evaluating water management projects for the Sacramento River. The SacEFT software leverages considerable previous investment by utilizing data sets from commonly used models, such as CalSim II, USRWQM and

USRDOM, which evaluate statewide water management operations. SacEFT v.2 is now fully operational, and herein we describe its focal species performance indicators and its utility to Sacramento River water management planning processes.

One of the main tasks of the SacEFT project was to create an integrated cross-disciplinary tool to characterize ecological trade-offs that result from the implementation of alternative water management scenarios. We undertook the Sacramento River Ecological Flows Study after noting challenges facing management agencies within existing water management planning efforts for the Central Valley that if addressed could greatly enhance these efforts. First, upon reviewing Sacramento River planning efforts, we noted that ecological considerations included in water management planning were generally narrow in scope and detail (esp. prior to 2008). Ecological considerations were limited to meeting some static minimum in-stream flow targets, meeting basic temperature requirements, or limiting periods of pumping (in the Delta) during times when sensitive species are present. Although these considerations are among the highest management priorities, they are often focused on single species management.

Prior to SacEFT, much of the important information on focal species existed in stacks of separate reports, independent conceptual models, and unconnected modeling tools. SacEFT has synthesized much of this disparate information, linking ecological submodels to existing physical planning models, and providing a major advance in the region's capabilities for rapidly assessing ecological trade-offs. In addition to integrating disparate sources of information, the second challenge we overcame in constructing SacEFT was translating analyses of this information into easily understandable results for 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 the design principle of making it easy for non-specialists to understand the model's results, SacEFT creates output that can span the range from high-overview to high-resolution. 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).

## DECEMBER 2005 INITIAL DESIGN WORKSHOP (SACEFT v.1)

On December 5 and 6 2005, ESSA Technologies Ltd., in partnership with The Nature Conservancy and Stillwater Sciences, held a model design workshop to evaluate a preliminary conceptual design of the Sacramento River Ecological Flows Tool (SacEFT). Forty scientists and other technical experts (see Appendix A), each having expertise with one of the focal species or physical submodels on the Sacramento River, were invited to attend the workshop to discuss and *prioritize* aspects of these submodels. Prior to their attendance a backgrounder on the SacEFT tool was provided to workshop participants which described the candidate submodels that would be evaluated at the workshop (ESSA Technologies Ltd. 2005).

Four criteria guided the technical review and prioritization of indicators **for SacEFT v.1**. First, experts assessed whether proposed indicators were directly *relevant* to the Sacramento River – *i.e.*, whether relationships were derived from data on the focal species or physical habitat attribute of interest, or whether indicators were developed using data collected within the study area during recent conditions. Second, scientists evaluated the *clarity* of functional relationships to ensure that they are not contested or confounded by other information. To the extent possible, we wanted to avoid functional relationships predicting species responses to flow that may be confounded by other factors not modeled in SacEFT (*e.g.*, changes in adjacent land uses). Third, participants discussed the level of *rigor* underlying functional relationships. That is, whether the evidence supporting a functional relationship was either: (1) well established, generally accepted, or from peer reviewed empirical studies; (2) strong but not fully conclusive; (3) theoretical support with some evidence; or (4) hypothesized based purely on theory and

professional judgment. Finally, recognizing our inability to “include everything”, we facilitated a discussion regarding the *feasibility* of integrating the proposed performance measures, ensuring SacEFT reflects both a reasonable level of breadth and depth across the five focal species present in SacEFT v.1.

### **DECEMBER 2008 REVIEW WORKSHOP (SACEFT v.1 → SACEFT v.2)**

Building a software system of this magnitude is an iterative process. Previous steps included preparation of a workshop background document (ESSA Technologies Ltd. 2005), holding a technical design workshop on December 5 and 6 2005 in Davis, CA, and developing and applying SacEFT v.1. Usually, the first iteration of a decision support tool has data and conceptual gaps that are filled by estimates. To improve on the initial version of SacEFT, on October 7 and 8 2008, ESSA Technologies Ltd., in partnership with The Nature Conservancy, held a model review workshop to improve Version 1 of the Sacramento River Ecological Flows Tool. This technical workshop had two goals:

1. Through peer review, ensure credibility in SacEFT’s existing focal species’ indicators; and
2. Ensure the model’s outputs remain clear and directly relevant to water managers.

Over 30 experienced biologists and water managers participated in discussions on how to improve the Sacramento River Ecological Flows Tool (see Appendix A). During the technical review workshop we solicited feedback (both in plenary and subgroups) on the following topics to help define improvements to the initial version of SacEFT:

- i) A peer review of critical uncertainties in existing SacEFT functional relationships.
- ii) A peer review of SacEFT hazard thresholds. (While SacEFT calculates performance measures in their native units, it uses a tri-state “traffic light” system of **R/Y/G** zones to rapidly communicate the desirability of flow/temperature/sediment transport outcomes. In the current version of SacEFT, the hazard threshold boundaries between **Red/Yellow** and **Yellow/Green** and are based on tercile break points determined by sorting performance measure values from our default water operation scenario based on the 66-year historical time series (1939-2004).)
- iii) Discussion of additional/new indicators for SacEFT v.2.
- iv) A discussion of how to enhance Excel report model output to show the assumptions associated with each model run.
- v) Water manager advice was sought on SacEFT’s key synthesis concept of “target and avoidance flow envelopes”. This output concept is promising for translating SacEFT’s “green” (good) traffic light results emerging from the model into multi-species flow operating rules for dam operators. However, while it may be desirable to satisfy certain ecological objectives every year (*e.g.*, temperature criteria) other objectives may only be satisfied occasionally (*e.g.*, cottonwood recruitment every 5-10 years). Technical discussions were held on how to convert SacEFT target and avoidance flows for multiple focal species into water year specific criteria and constraints to support the vision that this information feed back into other planning tools as new constraints and improved formulations in tools such as CalSim.

Table 1.1 summarizes the priority performance indicators that were identified by workshop participants, and distinguishes indicators developed for SacEFT v.1 that are unchanged in SacEFT v.2 from new indicators or existing indicators that received a significant overhaul in Version 2. The intention was to



identify a finite number of priority performance measures per focal species to integrate into SacEFT v.2. *Ideally*, performance measures should be directly relevant to the Sacramento River conditions, very clear and uncontested by technical or non-technical audiences, be supported by a high level of evidence, and manageable to implement. Of course, few performance measures will meet all of these criteria. Four criteria guided the technical review and prioritization of indicators **for SacEFT v.2** (Table 2.3). These revised criteria were based on lessons learned in the subsequent development of design guidelines for DeltaEFT (ESSA Technologies Ltd. 2008b). This updated indicator classification and prioritization system (Table 2.3) is used from this point forwards in this document.

Table 1.1 Summary of the performance measures (PMs), selection criteria ratings (H = High, M = Moderate, L = Low), and priorities following the SacEFT v.2 model design workshop. Note the following PM abbreviations: CS – Chinook salmon or Steelhead trout, GS – green sturgeon, BASW – bank swallow, FC – Fremont cottonwood, and LWD – large woody debris. PMs marked with a red dot in the ver. 2 column are pre-existing indicators that were not significantly modified as a consequence of the December 2008 SacEFT v.1 review workshop. Those marked in green are pre-existing indicators that have been significantly changed; those marked in blue are new indicators created for SacEFT Version 2. Definitions of relevance, clarity, rigor and feasibility are provided later in Table 2.3.

| Focal species and performance measure                    | Relevance | Clarity | Rigor | Feasibility | Priority | Ver. 2 | Comments  |
|--|-----------|---------|-------|-------------|----------|--------|---|
| <b>CS = Chinook/Steelhead</b>                            |           |         |       |             |          |        |   |
| <u>CS1</u> - Area of suitable spawning habitat           | Direct    | H       | H     | H           | H        | ●      | 5 aggregate reaches, 4 run types, side channel included; gravel augmentation-sediment requires additional data  |
| <u>CS2</u> - Area of suitable rearing habitat            | Direct    | H       | H     | H           | H        | ●      | 3 aggregate reaches, 4 run types  |
| <u>CS3</u> - Egg-to-fry survival rate                    | Direct    | H       | L     | H           | H        | ●      | 5 reaches, Bureau of Reclamation model  |
| <u>CS4</u> - Index of juvenile stranding                 | Direct    | H       | H     | H           | H        | ●      | Daily flow; relationships from Gard (United States Fish and Wildlife Service (USFWS))   |
| <u>CS5</u> - Redd scour                                  | Direct    | M       | L     | H           | M        | ●      | Max flow during incubation  |
| <u>CS6</u> - Redd dewatering                             | Direct    | M       | M     | H           | M        | ●      | Stage recession during incubation   |
| <u>GS1</u> – Green Sturgeon Egg-to-larvae survival rate  | Direct    | M       | M     | H           | H        | ●      | Laboratory studies for temperature tolerance  |
| <u>BASW1</u> – Bank swallow habitat potential            | Direct    | H       | M     | M           | H        | ●      | Only considering length of suitable banks within appropriate soils. Not feasible to assess suitability relative to other variables: bank height and bank slope.                   |
| <u>BASW2</u> – Ramping rates during bank swallow nesting | Direct    | M       | M     | M           | H        | ●      | Used findings in Linkages report to develop an indicator of bank sloughing due to flows during nesting  |
| <u>FC1</u> – Successful cottonwood initiation            | Direct    | H       | H     | M           | H        | ●      | Highly relevant issue, box model has been developed, and data are available at 3 locations. Relevant data (stage-discharge and x-sections) are not available for other locations. |
| <u>FC2</u> – Cottonwood seedling scour                   | Direct    | M       | H     | M - L       | H        | ●      | Highly relevant PM to FC. If seedlings are scoured out in year 2 and 3, actions taken in year 1 (FC1) become moot.  |
| <u>LWD1</u> – Large Woody Debris recruitment             |           | M       | M     | L/M         | L/M      | ●      | Data may not be available; not feasible   |

### **1.1.2 Related component in development: DeltaEFT**

Early in the project development phase of SacEFT, the project team specifically excluded Delta considerations when bounding the limits of the SacEFT decision analysis tool. We sought to first achieve proof of concept in one location (*e.g.*, the Sacramento River eco-region) prior to expanding efforts to other CALFED Ecological Restoration Program (ERP) eco-regions. We now have a significant foundation of existing work to build upon in light of progress with the Delta Regional Ecosystem Restoration Implementation Plan process, the Bay Delta Conservation Plan (BDCP) process, new Operations Criteria and Plan biological options, Public Policy Institute of California initiatives, State Water Resource Control Board criteria development efforts, and Pelagic Organism Decline research. As of 2010, the timing and information sources were significantly more appropriate to address Delta specific needs in a similar fashion. Incorporation of Delta considerations into the existing EFT framework will provide managers with the ability to better inform Delta management actions for ecological affects, as well as evaluate a management action's affects in the two inseparable ERP eco-regions of the Sacramento River and Delta.

Under the grant ERP-07D-P06 - DFG# E0720044, ESSA Technologies Ltd., in continuing partnership with The Nature Conservancy, is developing the Delta Ecological Flows Tool, which is expected to be completed in the late fall of 2011.

### **1.1.3 How it will be used**

EFT is intended to provide a framework for collaboration and integration that leverages existing tools focused on the human need aspects of water deliveries in northern California (*e.g.*, CalSim II). EFT users are able to download the model from the internet ([www.essa.com/tools/EFT/download.html](http://www.essa.com/tools/EFT/download.html)) and immediately work with pre-defined scenarios. In the context of specific water gaming environments, EFT combines outputs generated by existing water planning models with others to illuminate the anticipated ecological tradeoffs. Prior to these gaming sessions, EFT users can verify that the assumptions embedded in its physical submodels (*e.g.*, meander migration, TUGS) are *sufficiently* consistent with those in the primary water planning tools (*e.g.*, CalSim II, USBR Upper Sacramento River Temperature Model). Once a qualified EFT database administrator has imported external datasets and verified submodel compatibility, EFT scenarios can then be configured and run to give immediate feedback on ecological performance and tradeoffs. The efficiency of gaming exercises depends largely on how quickly EFT's external physical submodels can be configured and run, and their results imported into EFT. Once external datasets are imported and configured, and focal species submodels run, gaming and trade-off analysis are instantaneous.

EFT can provide valuable results to two groups of users. Scientists can supply their core data and metadata to EFT for ecological evaluation. Managers and decision makers are able to quickly review "traffic light" (dashboard) summary reports that illuminate the overall balance of performance across ecological indicators. Advanced tools also exist within the EFT relational database to perform further diagnostic and summary level analyses (*e.g.*, identify target and avoidance flows, exceedance plots, *etc.*).

## 2. Scope and Bounding

### 2.1 Ecological objectives and performance measures

Complex decisions and associated trade-offs are easier when structured using formal approaches to evaluate management alternatives. SacEFT encourages a PrOACT approach (Hammond *et al.* 1999) to evaluate trade-offs among different ecological objectives and help managers choose amongst water management alternatives. PrOACT is a simplified form of multi-objective decision analysis that provides a framework for decision making in the face of a large number of objectives and uncertainties. PrOACT is a five-step process: (1) define the **P**roblem; (2) determine the **O**bjectives; (3) develop **A**lternative actions; (4) assess the **C**onsequences associated with each alternative across the set of objectives; and (5) evaluate **T**radeoffs across alternatives and the range of objectives being considered. This framework is described in more detail in ESSA's (2005) workshop backgrounder. SacEFT is designed with this framework in mind, and can be useful for completing most aspects of PrOACT, particularly steps 4 & 5.

**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 SacEFT 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 predictive performance measures (PMs).

SacEFT v.2's priority objectives and performance indicators – discussed in detail later in this document – are listed in Table 2.1.

Table 2.1 Ecological objectives and performance measures found in EFT Version 2. PMs marked in green have been significantly modified from Version 1; those marked in blue are new PMs.

| Focal Species                        | Ecological Objectives   | Performance Measures   |
|--------------------------------------|---|--|
| Fremont cottonwood (FC)              | Maximize areas available for riparian initiation, and rates of initiation success at individual index sites.  | <u>FC1</u> – Successful Fremont cottonwood initiation (incidence of cottonwoods initiated along a given cross section, at end of seed dispersal period)<br><u>FC2</u> – Cottonwood seedling scour. Following years that have fair to good initiation success, evaluate the risk of seedling scour during the first year following successful initiation. |
| Bank swallow (BASW)                  | Maximize availability of suitable nesting habitat   | <u>BASW1</u> – Habitat potential/suitability.<br><u>BASW2</u> – Risk of nest inundation and bank sloughing during nesting  |
| Western pond turtle (WPT)            | Maximize availability of habitat for foraging, basking, and predator avoidance  | <u>LWD1</u> – Index of old vegetation recruited to the Sacramento River mainstem.  |
| Green sturgeon (GS)                  | Maximize quality of habitat for egg incubation  | <u>GS1</u> – Egg-to-larvae survival  |
| Chinook salmon, Steelhead trout (CS) | Maximize quality of habitat for adult spawning<br>Maximize quality of habitat for egg incubation<br>Maximize availability and quality of habitat for juvenile rearing | <u>CS1</u> – Area of suitable spawning habitat (ft <sup>2</sup> )<br><u>CS3</u> – Egg-to-fry survival (proportion)<br><u>CS5</u> – Redd scour (Red/Yellow/Green hazard zones)<br><u>CS6</u> – Redd dewatering (proportion)<br><u>CS2</u> – Area of suitable rearing habitat (ft <sup>2</sup> )<br><u>CS4</u> – Juvenile stranding (index)                |

Relationships between physical datasets (described in section 4.1), submodels and focal species PMs are summarized in Table 2.2.

Table 2.2. Physical datasets that potentially impact focal species and focal habitat performance in SacEFT. Only those species and habitats that are currently expected to be included in SacEFT Version 2 are shown.

| Focal Species<br>Performance Measures   | Physical datasets and submodels |                      |             |                       |                      |
|---|---------------------------------|----------------------|-------------|-----------------------|----------------------|
|   | Flow                            | Stage -<br>Discharge | Temperature | Sediment<br>Transport | Meander<br>Migration |
| Fremont cottonwood (FC)                 | •                               | •                    |             |                       |                      |
| Bank swallow (BASW)                     | •                               |                      |             |                       | •                    |
| Green sturgeon (GS)                     |                                 |                      | •           |                       |                      |
| Chinook, steelhead (CS)                 | •                               |                      | •           | • <sup>1</sup>        |                      |
| Large Woody Debris (LWD)<br>recruitment | •                               |                      |             |                       | •                    |

<sup>1</sup> Certain indicators only. The linkage between channel bed conditions and Chinook and steelhead is restricted to weighted useable area for spawning. According to source data from Mark Gard (USFWS), rearing habitat is unaffected by substrate conditions. We relate substrate suitability curves taken from *River-2D* with substrate conditions predicted by the TUGS sediment transport model.

### 2.1.1 Revised indicator classification and prioritization

Keeping in mind the criteria and priorities stated above, the ecological objectives and performance measures proposed in the backgrounder were reviewed at the December 2005 model design workshop. In SacEFT v.1, these Performance Measures were prioritized based on relevance, clarity, rigor and technical feasibility. Using lessons learned in the subsequent development of design guidelines for DeltaEFT (ESSA Technologies Ltd. 2008b), these categories have been updated so that they are more consistent with the classification scheme used for DeltaEFT (Table 2.3). The updated indicator classification and prioritization system is used from this point forwards in this document.

Table 2.3 Classification and prioritization concepts employed for the evaluation of SacEFT v.2 performance measures. Tables showing the strengths and weaknesses of PMs (Section 4.3) refer to these classification criteria using “I”, “U”, “R” and “F” to label each class.

| Label   | Explanation  | Levels   |
|---|--|--|
| <b>I</b><br><b>Importance</b>                   | The degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome. | <p><b>4 = High:</b> 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.</p> <p><b>3 = Medium:</b> Expected sustained minor population effect or effect on large area or multiple patches of habitat.</p> <p><b>2 = Low:</b> Expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial or temporal habitat effects.</p> <p><b>1 = Minimal:</b> Conceptual model indicates little or no effect.</p> |
| <b>U</b><br><b>Understanding</b><br>(“Clarity”) | The degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s).             | <p><b>4 = High:</b> Understanding is high and nature of outcome is largely unconstrained by variability in ecosystem dynamics, other confounding external factors.</p> <p><b>3 = Medium:</b> Understanding is high but nature of outcome is moderately dependent on other variable ecosystem processes or uncertain external confounding factors.</p> <p><b>2 = Low:</b> 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.</p> <p><b>1 = Minimal:</b> Understanding is lacking. Mainly subject of active ongoing primary research.</p>   |

This table continues on the next page.

| Label   | Explanation  | Levels  |
|---|--|---|
| <p><b>R</b><br/><b>Rigor</b><br/>("Predictability")</p> | <p>The degree to which the scientific evidence supporting our understanding of a cause-effect relationship (linkage) is contested or confounded by other information.</p>  | <p><b>4 = High:</b> 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.</p> <p><b>3 = Medium:</b> 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.</p> <p><b>2 = Low:</b> 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.</p> <p><b>1 = Minimal:</b> 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.</p>  |
| <p><b>F</b><br/><b>Feasibility</b></p>                  | <p>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.</p> | <p><b>4 = High:</b> 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.</p> <p><b>3 = Medium:</b> 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 falls within project budget subject to prioritization decisions elsewhere that remove some other indicators from consideration.</p> <p><b>2 = Low:</b> 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.</p> <p><b>1 = Minimal:</b> 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> |
| <p><b>P</b><br/><b>Priority</b></p>                     | <p>Initial Priority Ranking</p>  |   |

## 2.2 Spatial extent and temporal horizon

The spatial extent of SacEFT includes the mainstem Sacramento River at RM 301 (Keswick) downstream to RM 143 (Colusa) (Figure 2.1). Specific locations identified in SacEFT are 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* variables required for focal species submodels at these biologically relevant sites (*e.g.*, where have stage-discharge relations and channel cross-section profiles been developed?).

The overlap between these three considerations determines the spatial extent of performance measures throughout SacEFT's 158 mile study area.

The temporal horizon of SacEFT varies by submodel, ranging from specific events occurring at daily resolution (*e.g.*, changes in flow and stage) to performance measures that obtain their meaning when viewed over annual and longer time scales. In practice, we anticipate that the temporal horizon for a given SacEFT model run will be limited by the "weakest" (*i.e.*, shortest) dataset or submodel responsible for supplying inputs to other models. Depending on the purpose of a simulation, the *maximum* temporal horizon of a given SacEFT model run is expected to be in the neighborhood of 60 years.

## 2.3 Spatial and temporal resolution

Three **spatial** elements are used in SacEFT to describe specific locations:

- **points;**
- **cross-sections;** and
- **segments.**

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*).

At the December 2005 model design workshop, considerable discussion occurred over the fact that the spatial localization and identification of certain variables changes over time. For example, a river center line determines river mile demarcations, and the center line of a river changes over time. On the Sacramento River, river miles (abbreviated "RM") have acquired a "cultural" significance, with many scientists/managers referring to river mile demarcations that are based on surveys performed decades ago (1950s). Today, these river miles are no longer technically accurate, but they are still commonly used and can be useful for clarifying which discharge or temperature gauge is closest to a biologically significant point or segment.

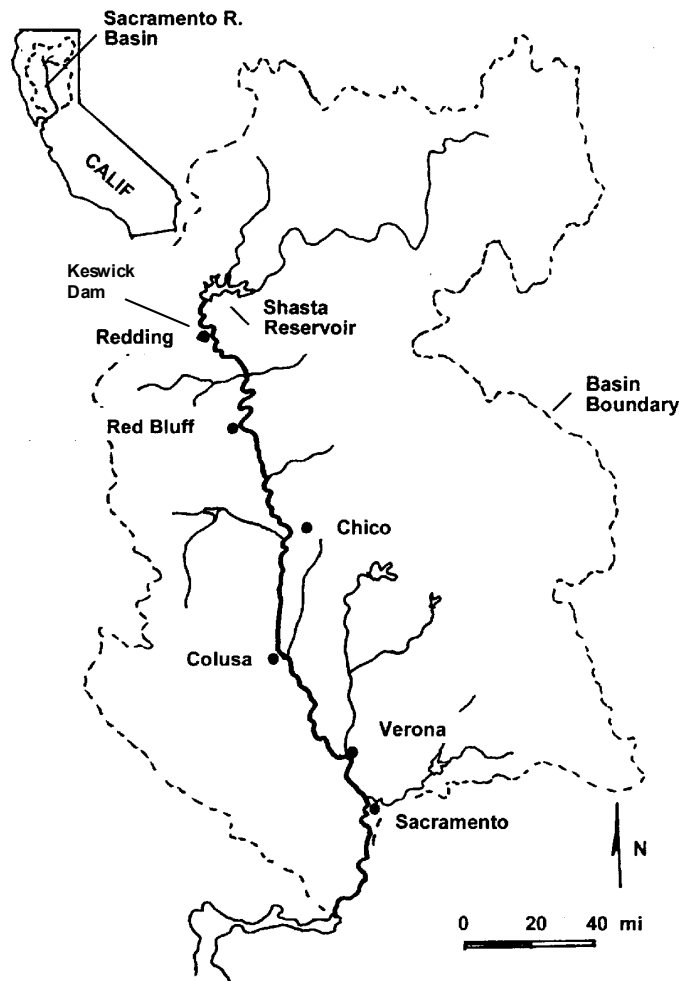


Figure 2.1. Map of the Sacramento River watershed and study area over which the SacEFT Version 2 can be applied – from Keswick Dam (RM 301) to Colusa (RM 143) (source of map: CALFED Bay-Delta Program 2000).

The underlying design of the SacEFT relational database supports spatial definition of points, cross sections and segments. However, focusing on the data needs of focal species and recognizing the relative predictive errors between physical and focal species submodels, SacEFT treats locations as being fixed over the course of a multi-decadal simulation. Conceptually, this introduces what we call a “zonal notion” of points and segments. For example, bank swallow colonies may exist between RM 202 and 183, and we may have a calibrated Meander Migration Model to provide information on the length of newly eroded bank in suitable soils in this region. Let’s assume the river miles just mentioned were based on a 2004 river centerline survey. If the Meander Migration Model is run forward for 50 years (assuming some flow regime for that period), then the precise spatial location of the river miles on the landscape will shift. However, for purposes of determining the suitability of banks swallow nesting habitat, the locations of the individual bends of interest will still be in *approximately* the same zones. A dynamic bend at RM 191—while now technically at (say) RM 186.84—is still in *the same overall zone of interest to bank swallows*. The overall amount of suitable nest habitat for bank swallows is of interest, not its precise location. On this basis, SacEFT foregoes the costly overhead of precisely tracking fine spatial details such as these when this does not interfere with generating and interpreting focal species performance measures.

While SacEFT treats locations as fixed throughout model simulations for purposes of generating and summarizing focal species performance measures, certain inherently dynamic processes like center line



change (from the Meander Migration Model output) are still being handled in a spatially explicit fashion. External simulations of centerline change using the Meander Migration Model are summarized and loaded into SacEFT according to the appropriate fixed zonal notion.

The **temporal** horizon of SacEFT varies by submodel, ranging from specific events at the daily scale, to longer duration events (*e.g.*, egg maturation) that may require months, to annual-scale events like channel migration. As well, there are some time periods within a year that are of greater interest for a focal species due to the life-history timing of specific biological processes. Differences in spatial and temporal resolution have implications on the way information is aggregated across the study area and presented to users for evaluation of alternative management actions. Table 2.4 summarizes both the spatial and temporal resolution of performance measures in SacEFT.

Table 2.7 summarizes the life-history timing that is relevant to the various focal species performance measures. In the case of Chinook and steelhead spawning time, closely follows the timing and spread used by Bartholow and Heasley (2006) for the SALMOD model; a distribution which is in turn based on Vogel and Marine (1991). When timing information was provided as a 3-part proportional distribution, the leading and trailing shoulders were each assigned one quarter of the spawning proportion, and the middle third of the distribution was assigned one half of the spawning proportion, divided over the number of days in the period.

Table 2.4. Summary of the spatial location and extent of physical datasets, linked models and performance measures for the *non-salmonid* focal species. Performance measures (PMs) for the species are summarized in Table 2.1. Vertical bars denote PMs that are simulated for river segments; dots denote those that are simulated (measured in the case of gauges) at points along the river. Q = river discharge. T = water temperature. Annotation details are listed in Table 2.6.

|     |                  | Physical Driving Variables |                    |                            | Linked Models     |                   | Biological Models  |              |                    |                |
|-----|------------------|----------------------------|--------------------|----------------------------|-------------------|-------------------|--------------------|--------------|--------------------|----------------|
|     |                  | Historical <sup>1</sup>    | NODOS <sup>2</sup> | BDCP Analysis <sup>6</sup> | TUGS <sup>3</sup> | Meander Migration | Fremont Cottonwood | Bank Swallow | Large Woody Debris | Green Sturgeon |
| RM  | Name             | Q                          | T                  | Q                          | T                 | Q                 | T                  | 1            | 2                  | RM             |
| 301 | Keswick          | •                          | •                  | •                          | •                 | •                 | •                  |              |                    | 301            |
| 298 | ACID Dam         |                            | •                  |                            |                   |                   |                    |              |                    | 298            |
| 293 | ACID Intake      |                            |                    | •                          |                   |                   |                    |              | •                  | 292            |
| 289 | Clear Creek      | •                          | •                  | •                          | •                 | •                 | •                  |              |                    | 289            |
| 281 | Stillwater Creek |                            | •                  | •                          |                   |                   |                    |              |                    | 281            |
| 280 | Cow Creek        | •                          | •                  | •                          | •                 | •                 | •                  |              |                    | 280            |
| 278 | Bear Creek       |                            | •                  | •                          |                   |                   |                    |              |                    | 278            |
| 277 | Ball's Ferry     | •                          |                    | •                          | •                 | •                 | •                  |              |                    | 277            |
| 275 | Anderson Creek   | •                          |                    | •                          |                   |                   |                    |              |                    | 275            |
| 273 | Cottonwood Creek | •                          | •                  | •                          | •                 | •                 | •                  |              |                    | 273            |
| 272 | Battle Creek     | •                          | •                  | •                          |                   |                   |                    |              |                    | 272            |
| 267 | Jelly's Ferry    | •                          | •                  | •                          | •                 | •                 | •                  |              |                    | 267            |
| 260 | Bend Bridge A    | •                          | •                  | •                          | •                 |                   |                    |              |                    | • 260          |
| 258 | Bend Bridge B    |                            |                    |                            |                   |                   |                    |              |                    | 258            |
| 252 |                  |                            |                    |                            |                   |                   |                    |              |                    | 252            |
| 243 | Red Bluff        | •                          |                    | •                          | •                 | •                 |                    |              |                    | 243            |
| 243 | Red Bluff DD     |                            |                    | •                          | •                 | •                 |                    |              |                    | 243            |
| 230 | Mill Creek       |                            | •                  | •                          |                   |                   |                    |              |                    | 230            |
| 218 | Vina             | •                          | •                  | •                          |                   |                   |                    |              |                    | 218            |
| 208 |                  |                            |                    |                            |                   |                   |                    |              |                    | 208            |
| 207 | GCID Pump        |                            |                    |                            |                   |                   |                    | •            |                    | 207            |
| 201 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 201            |
| 199 | Hamilton City    | •                          | •                  | •                          | •                 | •                 | •                  | •            |                    | • 199          |
| 197 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 197            |
| 196 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 196            |
| 192 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 192            |
| 190 | Stony Creek      |                            |                    |                            |                   |                   |                    | •            |                    | 190            |
| 185 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 185            |
| 183 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 183            |
| 182 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 182            |
| 172 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 172            |
| 170 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 170            |
| 168 | Butte City       | •                          | •                  | •                          |                   |                   |                    | •            |                    | 168            |
| 165 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 165            |
| 164 |                  |                            |                    |                            |                   |                   |                    | •            |                    | 164            |
| 159 | Moulton Weir     |                            | •                  | •                          |                   |                   |                    | •            |                    | 159            |
| 143 | Colusa           | •                          | •                  | •                          |                   |                   |                    |              |                    | 143            |



Table 2.6. Annotations for Table 2.4 and Table 2.5.

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<sup>1</sup> The common time span of Historic discharge (Q) data is 1-Oct-1938 to 30-Sep-2004. The common time span of Historic temperature (T) data is 1-Jan-1970 to 31-Dec-2001.

<sup>2</sup> The common time span of the NODOS scenario analyses performed in April 2011 include discharge (Q) and temperature (T) data between 1-Oct-1921 to 30-Sep-2003.

<sup>3</sup> TUGS simulations (Cui 2007) shown in red actually comprise 5 distinct reaches between RM 301 and RM 289. TUGS results are not available downstream from Cow Creek but are necessary for linkage to Chinook and Steelhead spawning Weighted Usable Area (WUA) (CS1). TUGS relationships for these downstream segments (pink) are mapped from the nearest upstream location, as described in Section 4.2.3.

<sup>4</sup> Chinook and Steelhead *spawning* WUA relationships shown in pale blue are mapped from the closest downstream segment, as described in Section 4.2.3. Spring Chinook habitat preferences are assumed to follow those of fall Chinook. Chinook *rearing* WUA relationships shown in pale blue are mapped from the closest upstream section, as described in Section 4.2.4.

<sup>5</sup> The BDCP analysis performed in June of 2010 included a subset of PMs: Chinook, Steelhead and green sturgeon in the region from Keswick to Hamilton City only.

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Table 2.7. Summary of the life-history timing information relevant to the SacEFT focal species. Only those performance measures requiring information on life history timing are included here. Abbreviations of performance measures (PMs) are described in Table 2.1. Time intervals marked with heavy color denote periods of greater importance to focal species. In the case of the spawning PMs (CS-1), heavily shaded regions denote for each salmonid run-type/species the period between the 25<sup>th</sup> and 75<sup>th</sup> percentile, when half the spawning takes place. In the case of the other salmonid PMs, the heavily shaded regions denote the period between the 25<sup>th</sup> and 75<sup>th</sup> percentile of the population are present. Specific timing of CS-2, 3, 4, 5, 6 depends on ambient water temperature and varies with discharge scenario and year. Juvenile residency is defined by a fixed 90 day period following emergence for Chinook and a 365 day period for steelhead. This table is based on SALMOD (Bartholow and Heasley 2006, ultimately Vogel and Marine 1991). Salmonid timing values shown here are typical and may shift by as much as five days earlier or later, depending on year and reach. Timing values for green sturgeon, cottonwood and bank swallow are based on workshop discussions, and all values are under user control.

| Performance Measure & Timing Relevance            | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| CS - 1 <b>Spring Chinook Spawning</b>             |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 3,5,6 Egg Development Period                 |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 2,4 Juvenile Period                          |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 1 <b>Fall Chinook Spawning</b>               |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 3,5,6 Egg Development Period                 |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 2,4 Juvenile Period                          |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 1 <b>Late fall Chinook Spawning</b>          |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 3,5,6 Egg Development Period                 |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 2,4 Juvenile Period                          |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 1 <b>Winter Chinook Spawning</b>             |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 3,5,6 Egg Development Period                 |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 2,4 Juvenile Period                          |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 1 <b>Steelhead Spawning</b>                  |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 3,5,6 Egg Development Period                 |     |     |     |     |     |     |     |     |     |     |     |     |
| CS - 2,4 Juvenile Period                          |     |     |     |     |     |     |     |     |     |     |     |     |
| GS1 <b>Green Sturgeon Spawning</b>                |     |     |     |     |     |     |     |     |     |     |     |     |
| FC1 <b>Fremont Cottonwood Seed Viability Date</b> |     |     |     |     |     |     |     |     |     |     |     |     |
| BASW1 <b>Bank Swallow Habitat</b>                 |     |     |     |     |     |     |     |     |     |     |     |     |
| BASW2 <b>Ramping Rates</b>                        |     |     |     |     |     |     |     |     |     |     |     |     |

Table 2.8. Summary of the spatial and temporal resolution of performance measures. Abbreviations of performance measure are described in Table 2.1. Physical submodels are abbreviated as: FLOW – Historical flow records and CalSim-USRWQM/USRDOM, STAGE – stage-discharge relations, TEMP – historical water temperatures and USBR Upper Sacramento River Temperature Model (HEC-5Q), TUGS – The Unified Gravel-Sand model, MEANDER – Meander Migration Model. Units describing spatial resolution are after Pasternack *et al.* (2004).

| Spatial resolution     |  | Temporal resolution |                       |          |                           |         |
|------------------------|--|---------------------|-----------------------|----------|---------------------------|---------|
|                        |  | Event-based         | Daily                 | Seasonal | Annual                    | Decadal |
| <b>Hydraulic unit</b>  | <u>Point or cross-section:</u> micro habitat, 0.1 to 1 channel width | FC2<br>BASW2        | FLOW<br>STAGE<br>TEMP | FC1      |                           |         |
| <b>Geomorphic unit</b> | <u>Segment:</u> meso-habitat, 10 channel widths (100s feet - miles)  |                     |                       |          | TUGS<br>BASW1<br>LWD1     | MEANDER |
| <b>Reach unit</b>      | <u>Segment:</u> 100 to 1,000 channel widths (10 - 60 miles)          |                     | CS1-6<br>GS1          |          | MEANDER<br>BASW1<br>BASW2 |         |

## 2.4 Management actions

The primary emphasis of SacEFT is to provide ecological trade-off information for alternative **flow operation alternatives** in water planning forums. Changes in flow will affect all focal species performance measures, either directly by influencing availability or suitability of physical habitats, or indirectly as mediated by outcomes from the physical submodels. Two classes of **channel actions** can be examined using SacEFT: (i) gravel augmentation, and (ii) channel revetment states (*e.g.*, rip-rap (rock) removal). Gravel augmentation and sediment transport will affect substrate conditions for spawning for Chinook salmon and steelhead. The revetment scenarios affect the amounts of new bank created annually, and thus can affect bank swallow nesting success.

### 3. SacEFT Solution

#### 3.1 Design principles

A main design aim for SacEFT is to allow exploration of trade-offs amongst key ecological components in a way that is clear to non-specialists. The main technical product is an integrated database, model engine, and user interface for presenting these ecological trade-offs for a defined set of management scenarios. Over time, this database, as well as the information management and reporting that it supports, will provide a foundation upon which additional scenarios can be configured and additional submodels added as new relationships are developed. Table 3.1 outlines some of the principles that underlie the design of SacEFT.

Table 3.1. SacEFT design principles. Various technical terms are defined in the glossary.

|   |   |
|---|---|
| Prioritize, avoid being a jack of all trades, master of nothing | <b>Focus initially on a tight set of key ecosystem attributes.</b> Considering the scale of the mainstem Sacramento River, the many habitat units it encompasses, and the many species that it supports, it is necessary to focus on the most critical priority ecosystem attributes first. This allows the team to demonstrate how SacEFT can be used to identify and visualize key ecological trade-offs instead of spending all resources cataloguing the entire ecosystem and attempting to integrate everything. The 'integrate everything' approach usually results in having very little to show at the end in terms of actual scientific/management results because all resources will have been spent in data inventory activities.  |
| Do not reinvent existing functionality                          | <b>Capitalize on existing tools and models.</b> To the extent possible, integrate existing quantitative models (including water operation planning tools such as the CalSim, USRWQM and USRDOM), followed by existing qualitative models or other decision support tools. Selectively analyze existing data to build new models (e.g., regression relationships) for focal species, habitats, or habitat forming processes where appropriate and feasible.<br><br>This principle also includes not spending effort coding custom graphical output controls. Instead, SacEFT leverages MS Excel, a widely held application with powerful graphing and analysis capabilities, when summarizing tabular and graphical outputs.   |
| Generic, flexible relational data model                         | <b>Develop a custom relational database as the "glue" holding all submodel data together.</b> Linking together existing models with new ones to evaluate trade-offs for different scenarios requires a substantial level of planning. Given the large number of sites, variables and scenarios to be evaluated for a system as large as the mainstem Sacramento River, we need an infrastructure to organize and manage the large volume of data and to enable subsequent automation of trade-off analyses. This not only involves fundamental bookkeeping of the required information, but also supports core needs such as having a common way of defining locations and time-steps, linking output for submodels that are in common with a given point-of-interest, archiving metadata and running scenarios to give key output in a useable format. To achieve these and other needs, and to significantly reduce the likelihood of errors, a relational database is essential. The SacEFT database is the backbone of the software and it supports an information management engine used to automate ecological trade-off analysis to the greatest degree possible. Metadata on imported datasets are essential in the interpretation of model output. |
| Flexible, object-oriented design (OOD)                          | <b>Use a flexible model architecture and object-oriented design.</b> SacEFT incorporates software development strategies that maximize adaptability and ease of revision. The system architecture follows a tiered design that separates the database (first tier) from submodel logic (middle tier) and any user interface (third tier) components (e.g., user reports). It also uses object-oriented design (OOD) within each of these components, which maximizes the reliability and flexibility of software development. However, SacEFT also relies on output from other models which may not have such flexible structures.  |
| User friendly   | <b>SacEFT should be designed for users of low to moderate computer literacy.</b> This includes the kinds of users who are comfortable building spreadsheets with formulas. The tool does not require power user skills, such as coding, or database design. For example, output reports are generated in Excel, a widely held application familiar to most users of computer models. Further, reporting in Excel typically reduces development costs associated with the alternative of tedious programming/customizing of third party reporting products.  |

|   |   |
|---|---|
| Number of users   | The solution provides a desktop software application connected to a remote centralized database. Multiple users can interact with this central database simultaneously. In the future, individual users may obtain copies of the master database for their own analyses.            |
| Database  | SQL Server 2005 leveraging ADO.NET Version 2.0.   |
| Client software   | Windows®-based rich client application developed in Visual Studio .NET 2005 (.NET Framework v.2.0).   |
| Use error handling and logging                          | Invisible to users, SacEFT application code uses structured error handling (Try...Catch) and by default log all moderate and severe errors to the Windows Event Log. This simple practice has been shown from experience to greatly simplify debugging and maintenance.             |
| Role of Internet  | SacEFT uses a thick-client, desktop centered architecture built around an internet accessible central database. Deployment needs and system help access web resources.  |
| Avoid COM components and 3 <sup>rd</sup> party controls | Use .NET Framework components in user interface to simplify deployment and maintenance. Consider COM components only if functionality cannot be reproduced by a .NET Framework component.<br>The exception in SacEFT is MS Excel.   |
| Installation, accessibility                             | Deployment needs are currently supported via: <a href="http://www.essa.com/tools/EFT/download.html">www.essa.com/tools/EFT/download.html</a><br>The deployment model uses standard MSI and .EXE install packages generated by two Visual Studio 2005 setup and deployment projects. |

### 3.1.1 Integration with external systems and data sources

A critical feature of SacEFT identified early in project planning was the need to leverage existing systems and data sources. Millions of dollars have already been spent developing and applying models like CalSim II, USRWQM and USRDOM. As most of these are road tested, commonly used and generally accepted tools, SacEFT does not reinvent their functionality. The Upper Sacramento River Daily Operations Model (USRDOM) was developed to simulate reservoir operations and hydrologic stream routing in the upper Sacramento River from Keswick Dam to Knights Landing on a daily timescale. The simulated daily flows from USRDOM can be used as inputs to SacEFT. The Upper Sacramento Water Quality Model (USRWQM) was developed to simulate daily temperature conditions in the Sacramento River based on the daily flow conditions. The geographical extent of the model is similar to the USRDOM. The simulated daily water temperatures from USRWQM are used as inputs to SacEFT.

Rather than attempt to replicate this functionality, SacEFT instead makes it easy to link with and import external datasets and enter critical summary metadata. Thus, SacEFT's database contains a mix of imported datasets derived from external models while other components—usually its focal species algorithms—are embedded within SacEFT software itself. Importing of external datasets is performed manually though one-time data preparation and import. As much as possible, we attempt to make use of pre-defined Excel templates to streamline this process. Future versions of SacEFT may provide automated import routines for external data sources (*e.g.*, DSS output files).

In addition to analyzing alternative (CalSim/USRDOM) flow and water temperature (USRWQM) regimes, SacEFT enables comparisons of gravel augmentation and rock removal restoration actions. SacEFT requires annual estimates of the gravel grain size-distribution at each of 5 river segments in order to calculate the weighted useable area available for spawning (ST1/CH1). This habitat estimate is then used as one of the inputs to calculate subsequent performance measures for egg maturation, survival, and juvenile rearing. In the absence of gravel data, no calculations are possible for these linked components. SacEFT was designed to leverage grain-size specific sediment transport results from The Unified Gravel & Sand (TUGS) model (Cui 2007). TUGS simulates changes in grain size of the river by accounting for how its sediment flux interacts with sediment in both the surface and subsurface of the channel bed. Results of a default historical sediment scenario analysis are described in Stillwater Sciences (2007).

Likewise, SacEFT studies can also evaluate alternative bank erosion modeling, *e.g.*, for (a) the existing channel armoring and (b) selected rip-rap (rock) removal scenarios. Bank erosion modeling is informed



by the Meander Migration model developed by Eric Larsen and associates at UC Davis (see Larsen 2007). Channel armoring conditions have a direct bearing on riparian model performance measures (bank swallows and LWD recruitment). Conversely, these assumptions do not influence SacEFT’s aquatic performance measure results. SacEFT results including the label “NoRipRapRemoval” refer to the existing 2004 channel and existing 2004 revetment (no change to bank protection) while scenarios with the label “RipRapRemoval” refer to selected removal of rock at specific locations (Larsen 2007).

### 3.1.2 Indicator thresholds and rating system

The SacEFT 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 experiencing favorable conditions (**Green**), are performing only fairly (**Yellow**), or are experiencing unfavorable conditions (**Red**). For all twelve (12) performance measures, annual cumulative weighted performance measure values are calculated for our default historical water operation scenario based on the 66-year historical time series of observed flows and water temperatures from 1938 to 2003. These “annual roll-up” values for each performance measure (e.g., average over days and locations with applicable biological distributions) are then assigned a “Good” (**Green**), “Fair” (**Yellow**) or “Poor” (**Red**) performance measure rating (e.g., Figure 3.1). The *default* threshold boundaries between **Yellow/Green** and **Red/Yellow** are based on tercile break points determined by sorting the annual weighted performance measure values from the default historical water operation scenario.

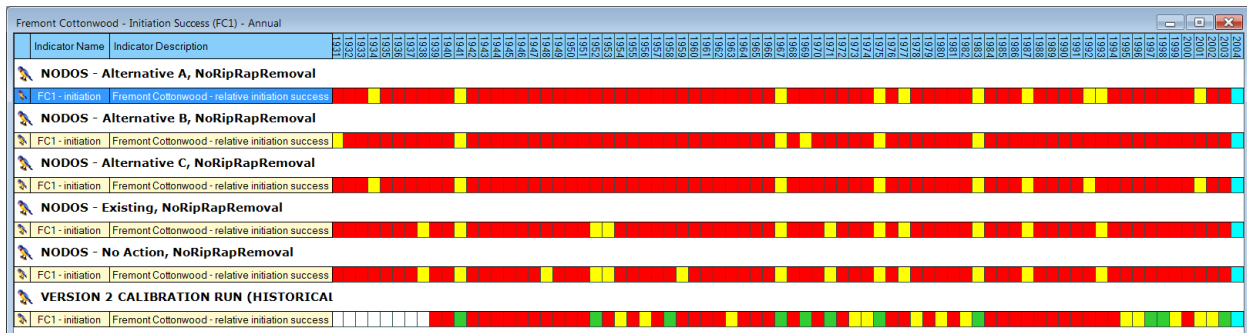


Figure 3.1: Typical SacEFT output showing annual roll-up results for the Fremont cottonwood initiation (FC1) performance measure. Analogous plots are available for all of the tools’ focal species and performance measures.

These annual performance measure ratings are based on thresholds<sup>1</sup> defined by sorting cumulative annual results produced by SacEFT for historic observed flows and water temperatures between calendar years 1938 and 2003 (e.g., Figure 3.2). The “units” of these plots vary with the performance measure. *In this way, historic observed flows/temperatures provide the de facto “calibration scenario” for SacEFT’s twelve (12) focal species performance measures.*

<sup>1</sup> Indicator thresholds in SacEFT are fully configurable via settings found in the SacEFT relational database.

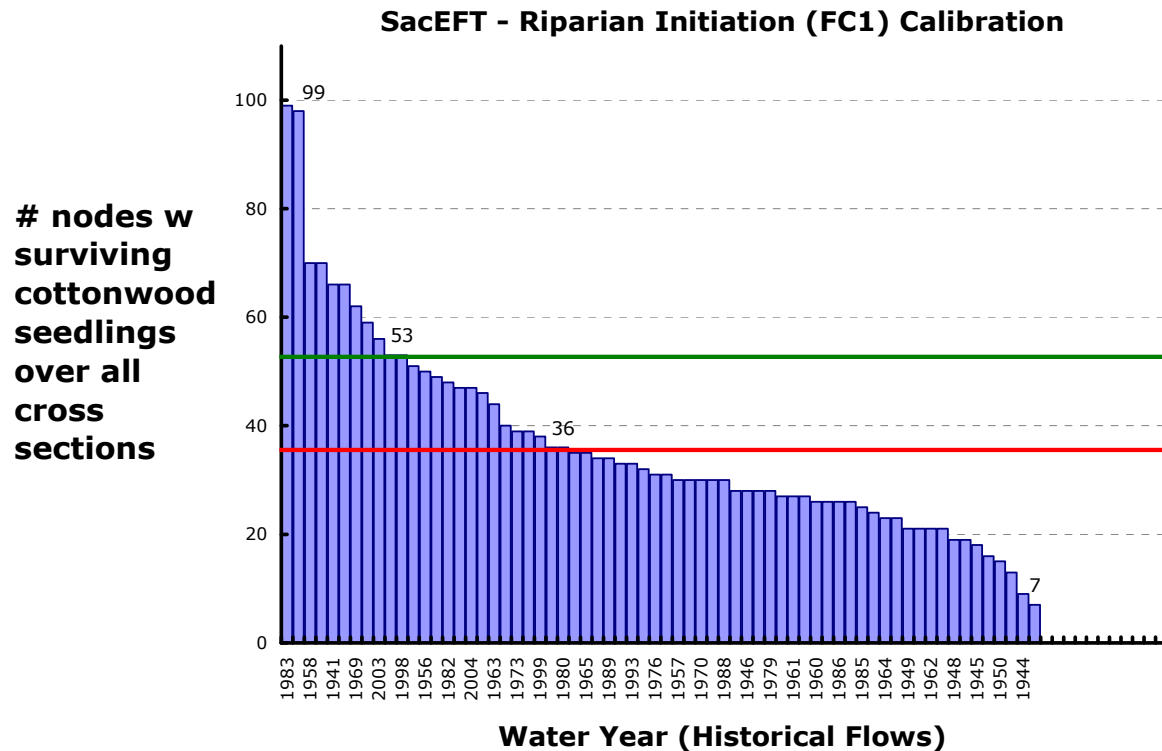


Figure 3.2: Annual roll-up results for the SacEFT Fremont cottonwood initiation (FC1) performance measure run using historic observed flows (1938–2003). This calibration also takes into consideration comparisons with aerial photographs of historically strong Cottonwood recruitment at study sites vs. model results.

Our concept of indicator threshold calibration in SacEFT focuses on historical data (rather than a future no action alternative or an existing condition based on present or future constraints). From an ecological standpoint, aquatic and riparian species are adapted to a historical range and frequency of variations in their habitats. Taken to the extreme, historical conditions would ideally include pre-settlement (natural) flows/water temperatures that represented ‘typical’ conditions experienced over evolutionarily significant windows of time. The closest flow/temperature time series that we have available to this evolutionarily representative condition is the range of variation in historical observed flows/temperatures (approx. 66 years). It is recognized that during 1938–2003 the Sacramento River experienced a number of waves of human and structural development and operational changes to the hydrosystem. Nevertheless, these flows and temperatures, derived from measurements, actually occurred in recent history and encompass repeat episodes of multiple water year types. Calibrating SacEFT indicator thresholds to a future no action or ‘existing’ scenario that includes a fixed set of hydrosystem features, constraints, operating regulations and assumed human demands would create a “self-fulfilling prophecy” inconsistent with SacEFT’s underlying natural flow regime science foundation.

The highest level synthesis concept in SacEFT is that of a “multi-year roll-up”. This is the percentage of years in the simulation having favorable (Green), fair (Yellow), and poor (Red) conditions (*e.g.*, Figure 3.3).

| Fremont Cottonwood - Initiation Success (FC1) - Roll-Up |                  |  |                          |                   |        |           |        |
|---|------------------|--|--------------------------|-------------------|--------|-----------|--------|
| ScenarioID  | Indicator Name   | Indicator Description                            | Create Report            | Multi-Year Rollup | % Poor | % Worn... | % Good |
| <b>NODOS - Alternative A, NoRipRapRemoval</b>           |                  |  |                          |                   |        |           |        |
| 136   | FC1 - initiation | Fremont Cottonwood - relative initiation success | <input type="checkbox"/> |                   | 85     | 15        | 0      |
| <b>NODOS - Alternative B, NoRipRapRemoval</b>           |                  |  |                          |                   |        |           |        |
| 139   | FC1 - initiation | Fremont Cottonwood - relative initiation success | <input type="checkbox"/> |                   | 91     | 9         | 0      |
| <b>NODOS - Alternative C, NoRipRapRemoval</b>           |                  |  |                          |                   |        |           |        |
| 140   | FC1 - initiation | Fremont Cottonwood - relative initiation success | <input type="checkbox"/> |                   | 88     | 12        | 0      |
| <b>NODOS - Existing, NoRipRapRemoval</b>                |                  |  |                          |                   |        |           |        |
| 132   | FC1 - initiation | Fremont Cottonwood - relative initiation success | <input type="checkbox"/> |                   | 87     | 13        | 0      |
| <b>NODOS - No Action, NoRipRapRemoval</b>               |                  |  |                          |                   |        |           |        |
| 134   | FC1 - initiation | Fremont Cottonwood - relative initiation success | <input type="checkbox"/> |                   | 83     | 17        | 0      |
| <b>VERSION 2 CALIBRATION RUN (HISTORICAL)</b>           |                  |  |                          |                   |        |           |        |
| 118   | FC1 - initiation | Fremont Cottonwood - relative initiation success | <input type="checkbox"/> |                   | 63     | 20        | 17     |

Figure 3.3: Typical SacEFT output showing multi-year roll-up results for the Fremont cottonwood initiation (FC1) performance measure. Analogous plots are available for all of the tools' focal species and performance measures.

The preferred method for calibrating the indicator thresholds is to identify historical years for each performance measure that were known (in nature) to have experienced 'good' or 'poor' performance. Unfortunately, our repeat survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.* 2011; Matt Brown, USFWS, *pers. comm.* 2011) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT v.1 review workshop revealed there are no known synoptic studies of this kind for many of the indicators in SacEFT. Because of this gap and the hesitancy of experts to reveal their opinions, we instead defaulted to the distribution of sorted weighted annual results and selected tercile break-points (the lower-, middle- and upper thirds of the sorted distribution) to categorize results into "Good" (Green), "Fair" (Yellow) or "Poor" (Red) categories. **While this method provides a fully internally consistent method of comparing scenario results (i.e., will always provide an accurate picture of which water management scenarios are "better" than another), it does not necessarily provide a concrete inference about the biological significance of being a "Poor" (Red) or "Good" (Green) category.** 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 (i.e., not biologically 'unacceptable'). In the focal species/habitat performance indicator calibration summary tables in section 4.3 we flag cases where there are major gradients in performance indicator thresholds.

The challenge of identifying "acceptable" and "unacceptable" changes in habitat conditions or focal species performance measures confronts all biological effects analysis methods. SacEFT makes these inherent value judgments explicit in the model's summary outputs. Future analyses using SacEFT look forward to ecological effects analysis experts themselves providing clearer guidance on the (readily configurable) thresholds in the SacEFT modeling system.

## 3.2 Application overview

SacEFT uses a thick-client architecture driven by a desktop relational database. The goal is to combine external model datasets and focal species rules/hypotheses in a single client database that facilitates generation of focal species performance measures (via the SacEFT Analysis Engine) over time and space to evaluate ecological trade-offs associated with alternative flow, water temperature, gravel augmentation and channel revetment scenarios.

Snapshots of external data are imported into the SacEFT database where they are stored in an integrated system of related tables that standardize the spatial definition of variables and capture key metadata. Likewise, focal species rules/parameter values/hypotheses are stored in their own system of related tables.

At the time of data import or focal species rule specification, available metadata is specified according to a pre-defined standard. In addition to standard metadata, each imported data instance is allowed to have one or more binary objects (files) associated with it. This allows further flexibility for associating metadata with each dataset. Binary fields can be used for single files (*e.g.*, source reports in Word or PDF), digital images, or even WinZip archives containing a set of model input or configuration parameters.

To carry out ecological trade-off analyses, end users install the client SacEFT software and database on their desktop computers. At the time of writing, the software is available from:

<http://www.essa.com/tools/EFT/download.html>.

### 3.2.1 Technology platform

SacEFT uses the Microsoft .NET Framework (Version 2.0) as its software development platform. .NET is a Microsoft technology that allows cross-language development and provides a very large standard library of components and functionality. The .NET Framework includes a Base Class Library (BCL) of types and classes available to all languages which encapsulate a large number of common functions such as file reading and writing, graphic rendering, database interaction, XML document manipulation, and so forth. The BCL is much larger than other libraries, and provides a very large breadth of functionality in one package. The .NET platform also greatly simplifies deployment. For these and other reasons, the majority of future Microsoft-based development will have a .NET foundation, ensuring SacEFT will be supportable well into the future.

The specific .NET Framework 2.0<sup>1</sup> technologies that are used in SacEFT Version 2 include:

- **Windows Forms:** the portion of the .NET Framework that provides managed wrappers for the user interface controls contained in the existing Win32 API.
- **VB.NET 2005:** a fully object-oriented computer language backed by the .NET Framework some view as an evolution of Microsoft's Visual Basic (VB6) though with significant changes that ultimately render it a new language.
- **ADO.NET:** the primary relational data access model for Microsoft .NET-based applications. It is used to access data sources for which there is a specific .NET Provider, or via a .NET Bridge Provider.

The database platform chosen is Microsoft SQL Server 2005. The master EFT database is hosted on a central server, and remote connections from the EFTReader software ([www.essa.com/tools/EFT/download.html](http://www.essa.com/tools/EFT/download.html)) are supported. SQL Server 2005 provides high-value database functionality including: stored procedures, triggers, transact-SQL (which supports conditional logic, such as if/then and case blocks), integrated XML and an integrated security model.

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<sup>1</sup> The EFT development team plans to upgrade the application to the .NET Framework 3.x later in 2011.

### 3.3 System architecture

SacEFT's component architecture is illustrated in Figure 3.4 and described in the sections that follow.

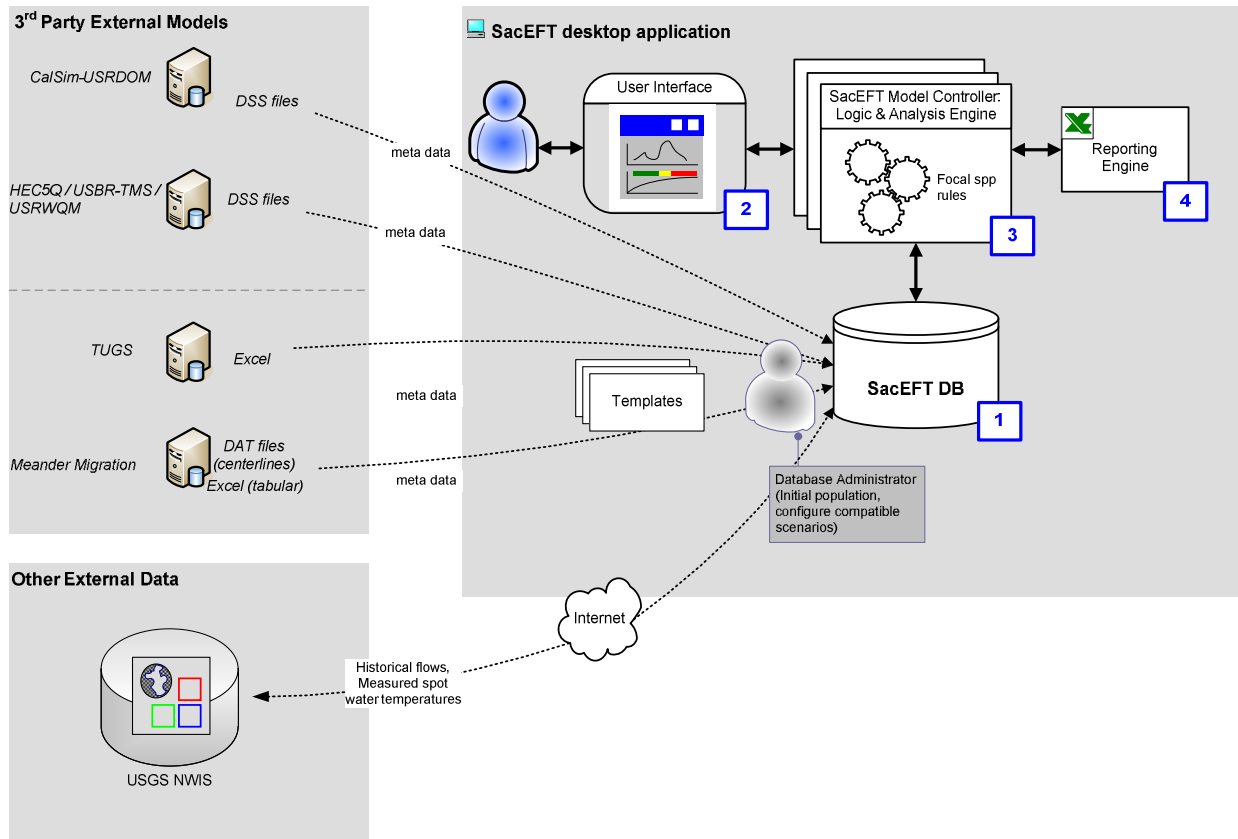


Figure 3.4. SacEFT component architecture.

#### 3.3.1 External physical submodels

The physical input variables required by SacEFT's focal species submodels are derived from several external models or systems (see Figure 3.4, "3<sup>rd</sup> Party External Models"). These models vary in terms of sophistication, physical location, data formats and documentation. Many of them depend on the same kinds of input data. For example, the temperature simulation component of the US Bureau of Reclamation's Water Quality Model (USRWQM) depends on many of the same hydro system operation assumptions that are central configuration properties of CalSim II, as does a sediment transport model (TUGS) and a Meander Migration Model (because these assumptions affect Sacramento River flow). The datasets of results from these models must be accessed and imported to the SacEFT database. In so doing, **SacEFT addresses two issues at the time of data import:**

1. Identifying output variables (daily average flows, daily average water temperatures, sediment transport variables, river bend erosion variables) within a common spatial identification system.
2. Tagging imported data instances with key metadata that allows non-specialist users to: (a) determine whether that given instance should be combined with a dataset that was imported from another related model; and (b) understand a model run's assumptions and limitations.

Spatial harmonization is simply managed through the common concept of river miles. This includes making assumptions about the river segment that a particular node link in CalSim-USRWQM represents,

*even though it is recognized* that as a node link it has no *precise* spatial meaning. We nevertheless must make explicit all the assumptions required to link different models together. The linkage process requires maturity surrounding the relative errors between physical and focal species submodels as well as a realization that even though a high level of detail may be possible, it is not always useful. As stated earlier, SacEFT is not an attempt to make precise predictions of ecosystem behavior or outcomes. The main purpose is to characterize and explore important ecological trade-offs and inform managers and decision makers about the *relative* impacts of various flow management alternatives.

Details of external physical models are described in more detail in Section 4.

### 3.3.2 Database

SacEFT is built around a single master relational database (Blue box labeled “1” in the upper right portion of Figure 3.4). The SacEFT Graphical User Interface (Box “2” in Figure 3.4), Model Controller & Analysis Engine (Box “3” in Figure 3.4) and Excel Reporting Service (Box “4” in Figure 3.4) connect to and interact with this database.

The SacEFT database contains seven important classes of related tables (Table 3.2). The SacEFT v.2 relational database schema is illustrated in Figure 3.5.

Table 3.2. The seven major classes of SacEFT database table, and their general role.

| Table Family           | Role  |
|------------------------|---|
| (1) Spatial_           | <ul style="list-style-type: none"> <li>Tables under the Spatial namespace are responsible for holding all information related to the spatial definition of locations. This information is managed as points, cross-sections and segments.</li> </ul>  |
| (2) Data_Instances     | <ul style="list-style-type: none"> <li>The key generic concept for tracking imported datasets and their metadata</li> <li>Also used to (optionally) tag information on non-imported (<i>i.e.</i>, local) generic rules/parameter values for focal species.</li> </ul>   |
| (3) Data_MetaData      | <ul style="list-style-type: none"> <li>Data.Metadata provide a standard set of fields to capture metadata for all submodels. This information, along with optional model reviews, would be inspected by users when building compatibility lists for structuring unified, “apples and apples” SacEFT model runs.</li> </ul>  |
| (4) Data_Review        | <ul style="list-style-type: none"> <li>Further comments, opinions regarding Data_Instances and model results can be provided by data reviews, which characterize applicability, relevance and rigor, and allow for general comments.</li> </ul>   |
| (5) ModelRun_          | <ul style="list-style-type: none"> <li>Tables under the ModelRun namespace unify the concept of a model scenario, identifying all the associated data instances (imported data sets to be used, and focal species submodel rules) that are to be used within a single model run.</li> </ul>   |
| (6) DataImport.<Model> | <ul style="list-style-type: none"> <li>The DataImport namespace is used to structure how data imported from external physical models are stored. Typically, the variables of interest are arrayed by a DataInstanceID, a LocationID and a date (at the appropriate temporal resolution).</li> <li>These tables store the physical data itself – the streamflow, water temperatures, model results, <i>etc.</i></li> </ul> |
| (7) FS_ and FSOut_     | <ul style="list-style-type: none"> <li>This family of tables hold the lookup data, rules and parameter values for focal species and their associated model results generated internally by SacEFT code.</li> </ul>  |

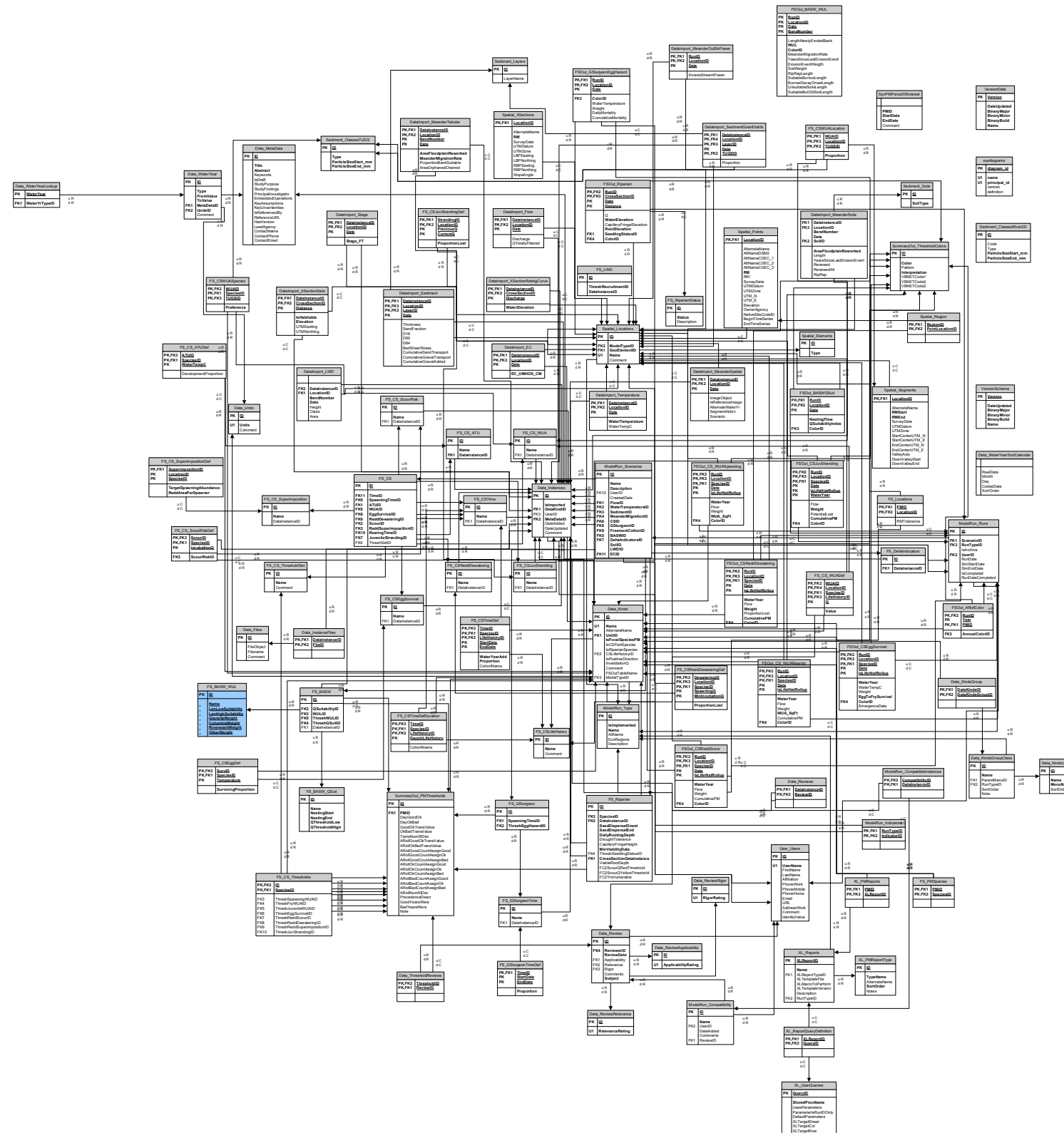


Figure 3.5. SacEFT v.2 relational database entity relationship diagram. DeltaEFT database components are also included in the same master database. PK = part of the primary key. FK = foreign key. U = unique index (values cannot repeat in the table). C = cascading referential action (delete and updates). Not shown are dozens of stored procedures, functions and views that leverage these user tables. (Note: This diagram has not been layout- or print-optimized).

## **DATABASE CONFIGURATION**

As discussed above, a critical feature of SacEFT is the need to leverage existing systems and data sources. This requires import of components of these datasets from these external models, into the SacEFT database. Presently in v.2.00, a database administrator who understands the SacEFT database schema is required to populate the SacEFT database.

## **DATAMASTER**

Data-driven applications require a considerable amount of interaction with their underlying data store(s). Code is required to move data from the physical database tables to: a) the presentation layer (user interface), and b) in-memory datasets, arrays and variables used by indicator algorithms. Different commands are needed to retrieve, add, delete and update.

This functionality is the responsibility of SacEFT's DataMaster project, an ADO.NET wrapper for encapsulating all connection and command-based operations vs. SacEFT's SQL Server 2005 database. The DataMaster also interacts with a wide range of calculation specific SQL functions and stored procedures stored in the SacEFT database.

### **3.3.3 Model controller and analysis engine**

#### **FOCAL SPECIES SUBMODELS (PERFORMANCE INDICATOR ALGORITHMS)**

This is the component of the system that is of the most interest to biologists. Unlike external physical submodels, the SacEFT code base is largely comprised of *in-situ* focal species rules and algorithms for the tool's various indicators. This includes, in several cases, porting lookup tables and even code from other studies or external models where this is efficient. These classes house all of the logic necessary to take physical inputs, and translate them into various focal species performance measures.

#### **COMPATIBILITY LISTS AND SCENARIOS**

Before a model run, the database administrator must have ensured physical datasets and focal species rules are internally consistent and compatible. This includes review of metadata and user reviews (optional) for the candidate data instances.

#### **ANALYSIS ENGINE**

The final job of the ModelController occurs at run-time, once a compatible scenario is established and run. During a SacEFT model run, the ModelController organizes calls to physical and focal species components in the required sequence, ensures that variables are packaged correctly for transfer between submodels. In essence, the ModelController is the thing that ensures performance measures are calculated in an orderly, sensible manner and the appropriate outputs written to the SacEFT database.

When combined with ADO.NET data transfer responsibilities in the DataMaster, the ModelController and focal species components make up the bulk of code in SacEFT.



### 3.3.4 Excel reporting

As identified earlier, SacEFT uses MS Excel for reporting detailed outputs in tabular and graphical format. MS Excel is a well-established software tool widely used at one time or another by the majority of scientists and planners in the field of water operation planning. SacEFT's Excel Reporting engine involves designing Excel templates, and using them in a "just in time" fashion as the target of a specific set of stored procedure calls. For example, an Excel template may have a "flow" and "temperature" worksheet, and two embedded line graphs that expect this data in a specific location and format. Excel macros (VBA code) are optionally used to further extend the features of these reports.

The unique and intuitive manner in which this reporting feature is integrated into the SacEFT User Interface is highly extensible and customizable.

### 3.3.5 User interface

Figure 3.6, Figure 3.7 and Figure 3.8 illustrate three of the main screens or views provided by SacEFT v.2.00. This user interface was developed using Windows Forms with Visual Studio 2005 and the Visual Basic 2005 programming language.

SacEFT v.2.00 emphasizes display of output rather than dialogue-intensive database editing features. In our experience, it is more important to demonstrate results and iterate on how this is best presented before investing resources in a user interface for editing and configuring all aspects of the underlying database. Typically, database editing capability and the associated myriad of dialogue forms required eats up considerable time without fundamentally enabling users to access modeling results or appreciate the merits of the system.

Readers are referred to the EFTReader on-line User Guide for operational details on the SacEFT user interface, see: [www.essa.com/tools/EFT/Help/index.html](http://www.essa.com/tools/EFT/Help/index.html).

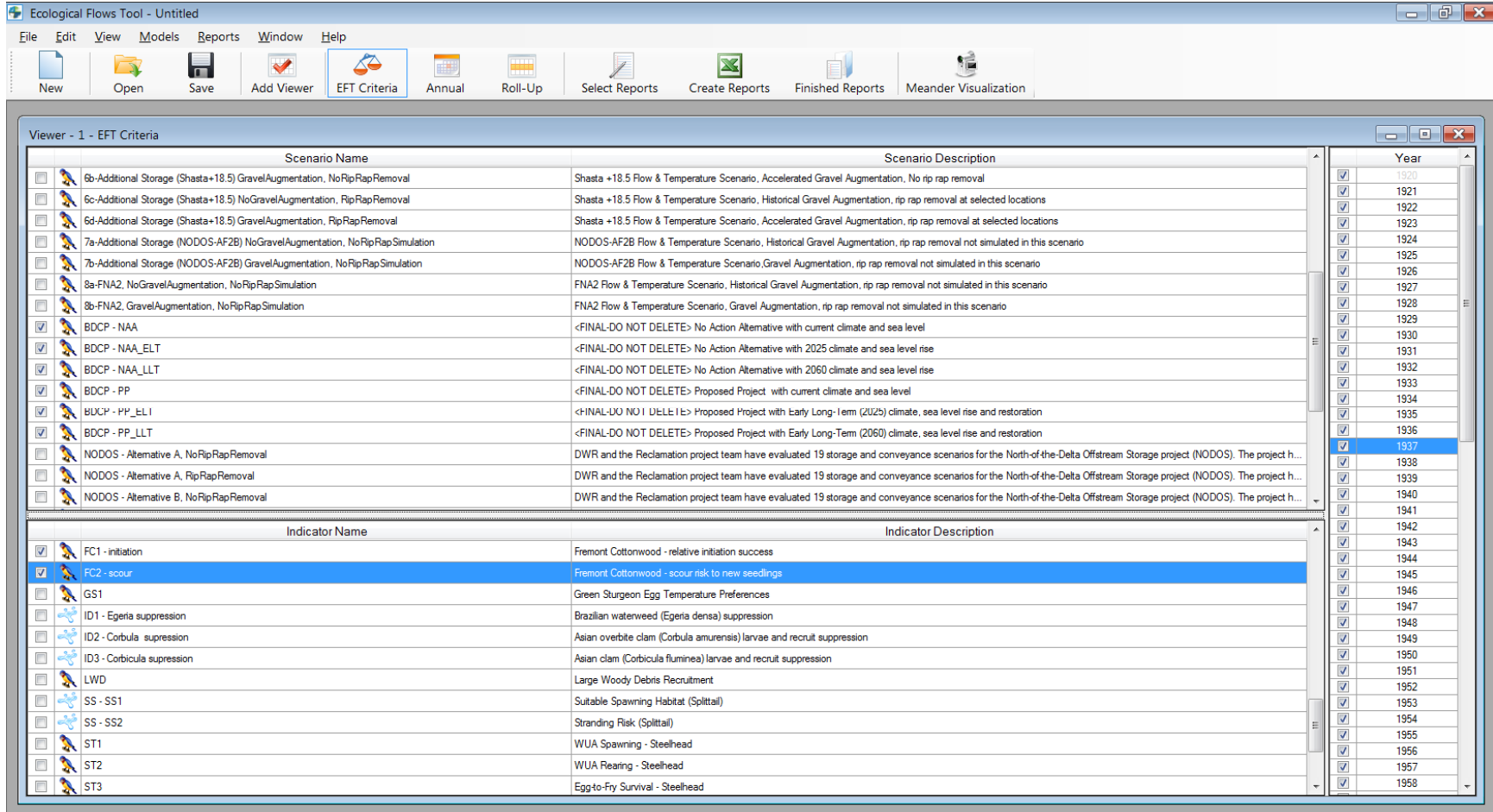


Figure 3.6: EFT’s main screen, showing the Criteria selection dialogue used for choosing scenarios, indicators and simulation years.

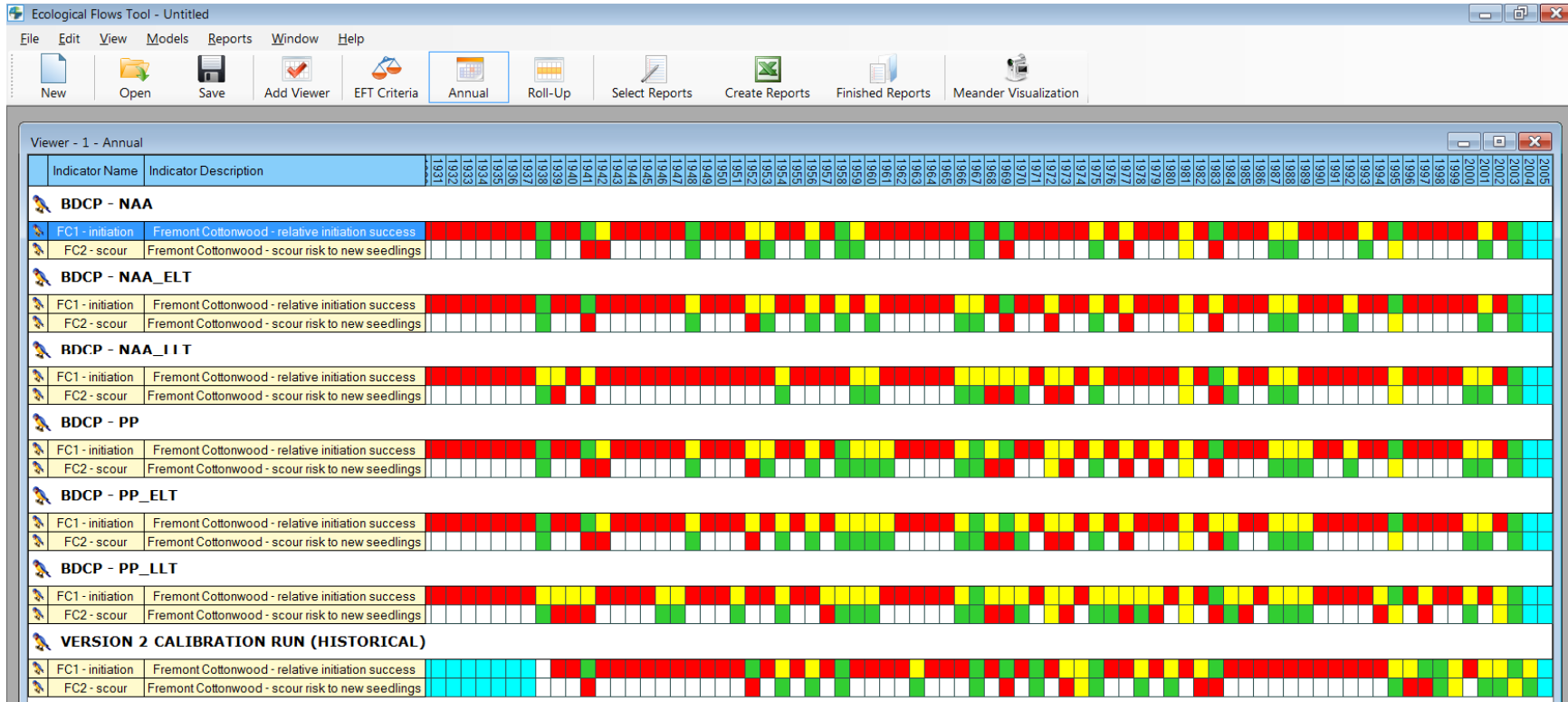


Figure 3.7: An example of EFT’s Output Viewer screen in Annual View, showing a multi-scenario comparison for two performance measures and the tool’s signature “traffic light” hazard assessment or indicator rating system over multiple years. The hazard assessment tool provides a rapid visual summary of a scenarios’ overall ecological performance, and can be used as a navigational aid to drill into the details.

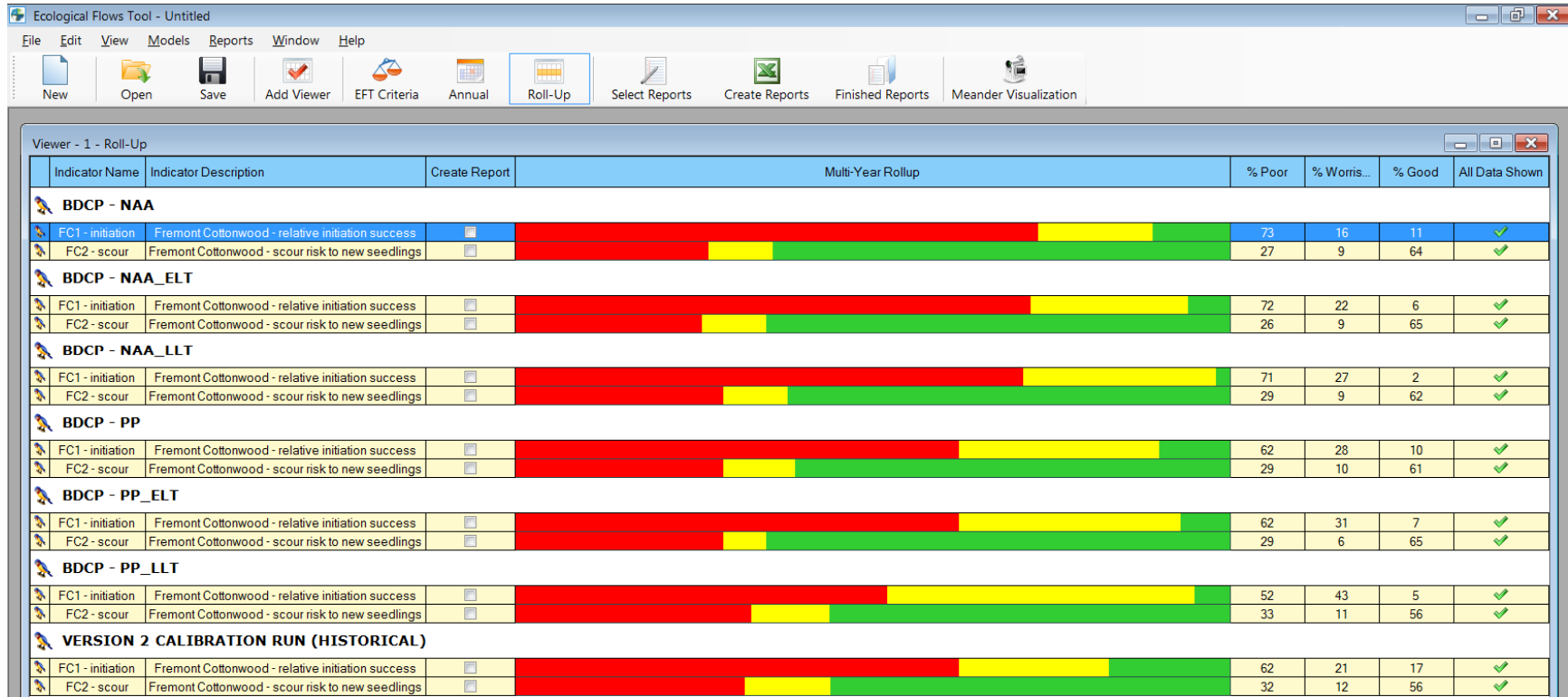


Figure 3.8: An example of EFT’s Output Viewer screen, showing the same information as Figure 3.7, but in multi-year Rollup View. This is the best view for quickly assessing the relative differences in performance among scenarios.

**EXCEL OUTPUT REPORTS**

MS Excel graphs and tables serve as the primary method for delivering detailed outputs. An example of SacEFT’s v.2.00 Fremont Cottonwood initiation model is given in Figure 3.9.

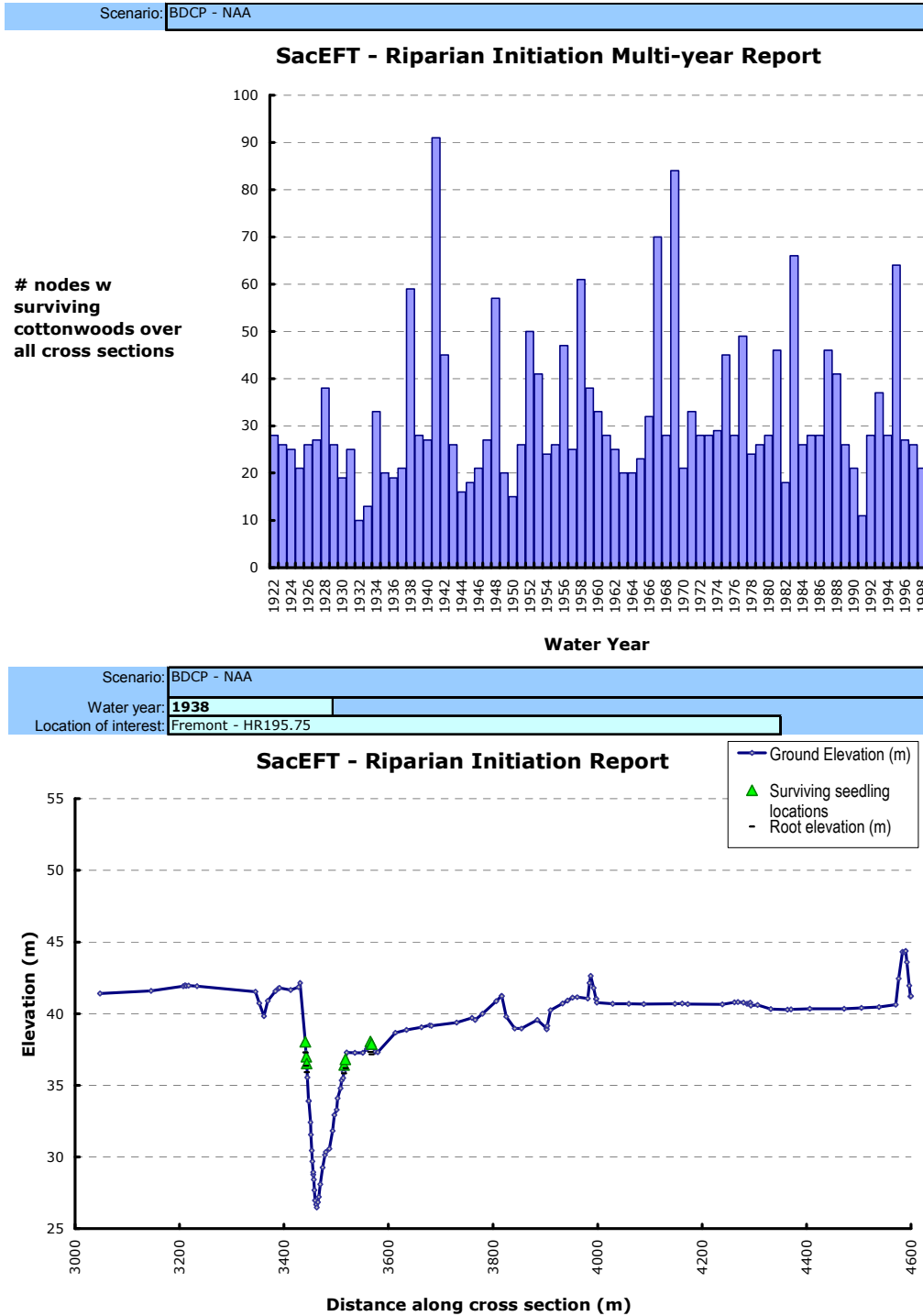


Figure 3.9: EFT provides detailed output on a scenario × year × performance measure basis in Excel. Refer back to Figure 3.7 for context.

## SCENARIO DETAILS AND METADATA

SacEFT provides a Scenario Details and Reviews feature to allow users to find additional information on a given scenario or model component (Figure 3.10).

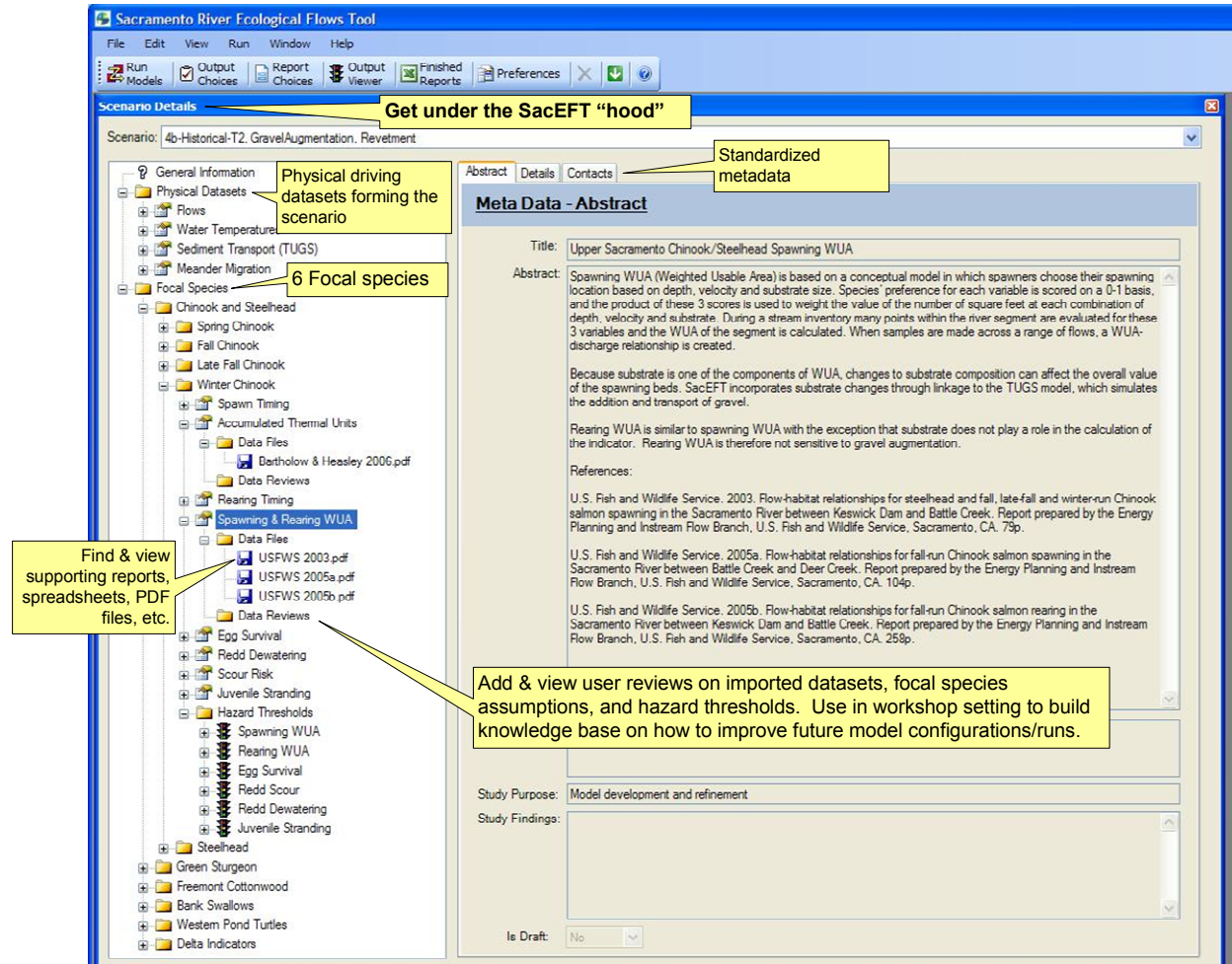


Figure 3.10: EFT’s Scenario Details and Reviews dialogue for learning more about imported datasets and focal species assumptions.

## 4. SacEFT Submodels: Functional Details

### 4.1 Physical driving submodels

The physical data sets used by SacEFT originate with several high-profile planning models. The intent of SacEFT is to leverage the extensive existing efforts made to develop, maintain and calibrate these systems, to supply key inputs necessary to calculate focal species performance measures. In addition to these models, selected mainstem Sacramento River gauging records have been used for river discharge and water temperatures. Using data from both models and stream gauges permits a mix of prospective and retrospective analyses.

#### 4.1.1 Flow / hydrology

##### HISTORICAL/ACTUAL FLOWS: STREAM GAUGES

Table 4.1 lists the *historical* Sacramento River stream gauge records that have been imported into the SacEFT database. The finest temporal resolution of these historical records is the daily average.

Table 4.1. An example of the mainstem Sacramento River United States Geological Survey (USGS) stream gauges included in SacEFT. These gauges were selected because each provides a lengthy and complete or nearly-complete record of average daily flow. *Source:* The USGS surface water data web site ([waterdata.usgs.gov/usa/nwis](http://waterdata.usgs.gov/usa/nwis)) and related web service ([river.sdsc.edu/NWISTS/nwis.asmx](http://river.sdsc.edu/NWISTS/nwis.asmx)).

| Native Site Code | Name  | UTM Zone | UTM Datum | UTM_N         | UTM_E       | RM  | Elev (ft) | Owner Agency |
|------------------|---|----------|-----------|---------------|-------------|-----|-----------|--------------|
| 11370500         | SACRAMENTO R A KESWICK CA                   | 10T      | NAD27     | 4,494,415.947 | 547,098.993 | 301 | 479.8     | USGS         |
| 11377100         | SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA | 10T      | NAD27     | 4,459,898.695 | 569,229.379 | 260 |           | USGS         |
| 11378000         | SACRAMENTO R NR RED BLUFF CA                | 10T      | NAD27     | 4,443,331.523 | 569,713.045 | 243 | 253.6     | USGS         |
| 11383730         | SACRAMENTO R A VINA BRIDGE NR VINA CA       | 10S      | NAD27     | 4,417,891.359 | 577,616.258 | 218 | 197.0     | USGS         |
| 11383800         | SACRAMENTO R NR HAMILTON CITY CA            | 10S      | NAD27     | 4,400,469.206 | 586,147.110 | 199 | 145.0     | USGS         |
| 11389000         | SACRAMENTO R A BUTTE CITY CA                | 10S      | NAD27     | 4,367,853.628 | 586,631.562 | 168 |           | USGS         |
| 11389500         | SACRAMENTO R A COLUSA CA                    | 10S      | NAD27     | 4,340,812.116 | 586,405.165 | 143 |           | USGS         |

Approximately 66 years of daily historical records were gathered in this manner and used in retrospective and calibration scenarios. This historical gauging data includes use of pre-existing data files supplied by project contributors.

**Note:** an extensive survey of the NWIS web service showed a total of 28 stations with some data, but many of these had incomplete time series. Even the 10 gauges with reasonably complete series (Table 4.1) had some gaps in daily average flow. Two missing data segments at VINA (1/Oct/1938 to 12/Apr/1945; 1/Oct/1978 to 30/Sep/2004) were interpolated by linear regression of the incomplete “SACRAMENTO R A VINA BRIDGE NR VINA CA” vs. complete “SACRAMENTO R AB BEND

BRIDGE NR RED BLUFF CA”: (1.2459 x BendBridge – 1364.5) (Yantao Cui, Stillwater Sciences, *pers. comm.*). Three missing data segments at this station (1/Oct/1938 to 20/Apr/1945; 15/Jan/1956 to 18/Jun/1956; 3/Oct/1980 to 30/Sep/2004) were interpolated by linear regression of incomplete “SACRAMENTO R NR HAMILTON CITY CA” vs. complete “SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA”: (1.2047 x BendBridge – 1987.4) (Yantao Cui, Stillwater Sciences, *pers. comm.*). Finally, numerous winter gaps (typically Nov–May; 1921–1940) in COLUSA R A COLUSA CA were imputed using a nonlinear relationship with SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA discharge, even though that station is >100mi upstream. The best predictive relationship obtained for Colusa discharge day on day  $t$  was found to be given by Bend Bridge on day  $t-1$  (*i.e.*, a 1 day lag). Loess smoothing with a span of 2.5% was used to develop a fairly smooth predictive relationship, which was applied to the missing Colusa dates.

With these gaps filled, the available historical flow data span a continuous common period from 1/Oct/1938 to 30/Sep/2004: Water Years 1939-2004, a minimum of 24,107 historical records for each location.

### **FUTURE/PROSPECTIVE FLOWS AND WATER TEMPERATURES: UPPER SACRAMENTO WATER QUALITY MODEL (USRWQM) / UPPER SACRAMENTO RIVER DAILY OPERATIONS MODEL (USRDOM)**

SacEFT prospective daily flow datasets are dependent on the input data provided to them. The Upper Sacramento River Daily Operations Model (USRDOM) was developed to simulate reservoir operations and hydrologic stream routing in the upper Sacramento River from Keswick Dam to Knights Landing on a daily timescale. The simulated daily flows from USRDOM can be used as inputs to several biological and habitat models. Upper Sacramento Water Quality Model (USRWQM) was developed to simulate daily temperature conditions in the Sacramento River based on the daily flow conditions. The geographical extent of the model is similar to the USRDOM. The simulated daily temperatures from USRWQM can be used as inputs to biological and habitat models. Both of these models depend on CalSim.

CalSim is a generalized water resource planning tool developed jointly by CWDR and the US Bureau of Reclamation Mid-Pacific Region. The primary purpose of the CalSim II model is to evaluate the performance of Central Valley Project (CVP) and State Water Project (SWP) at current and prospective future levels of water supply and demand. A mass balance model, CalSim is used as a framework to evaluate water delivery scenarios associated with expansion of project facilities as well as changes in hydrosystem operation criteria. Water routing and operational decisions are formalized into algorithms that include subjective judgments, rules and weights on various objectives. Explicit operating rules define what action is to be taken at each time-step given the state of the hydrosystem.

### **METADATA NEEDED TO DEVELOP SCENARIO COMPATIBILITY LISTS**

By design, SacEFT requires no pre-requisite knowledge or experience in the operation of CalSim, USRDOM and USRWQM. Rather than become CalSim – USRDOM – USRWQM experts, SacEFT users are tasked with aligning model assumptions between a given imported dataset and other related physical models (TUGS, Meander Migration). This requires the ability to quickly summarize the key embedded assumptions, inputs, and other important characteristics of a CalSim – USRDOM – SRWQM DSS database in a format that non-CalSim experts can understand. To achieve this, we apply the metadata standard shown in Figure 4.1 to all physical submodel datasets that are imported into SacEFT.



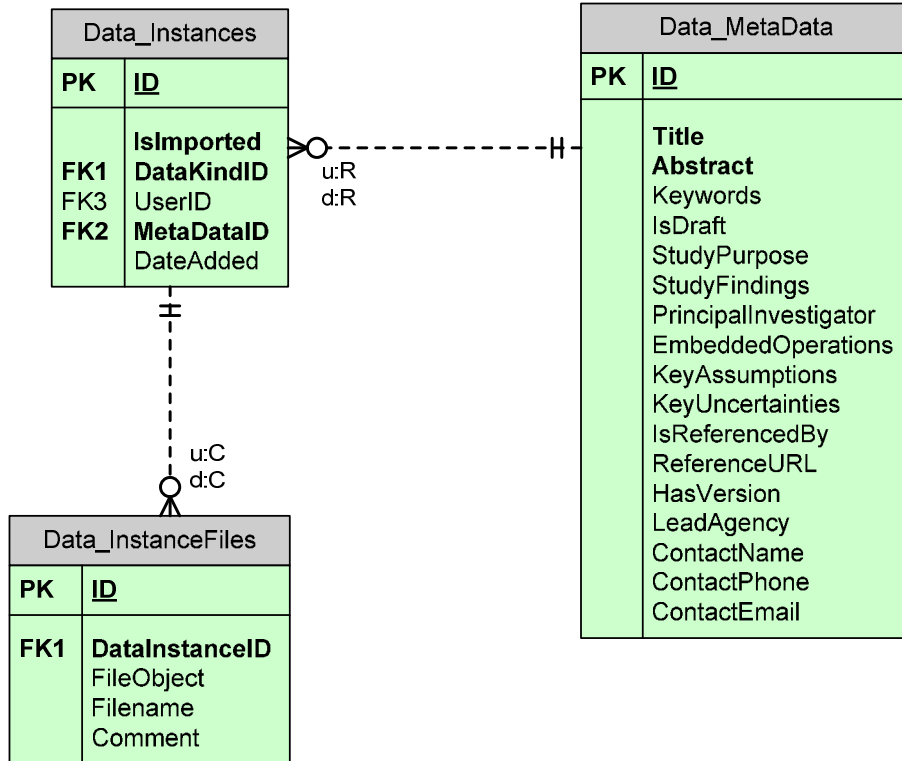


Figure 4.1. Underlying database design showing how each imported DSS file from CalSim (and any other data from an external physical model) is associated with a DataInstance and a set of MetaData. A considerable number of the fields in Data\_MetaData are optional.

**Note: The metadata standard shown in Figure 4.1 is also applied to focal species submodels in SacEFT.** 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, one riparian submodel scenario may use a different tap-root growth rate from another riparian scenario. While this does not require nearly as great a level of detail in metadata documentation as a CalSim DataInstance, the rationale for one growth rate over another is the kind of information that can be tracked using the metadata standard.

## 4.1.2 Water temperature

### HISTORICAL/ACTUAL WATER TEMPERATURES: GAUGES

The same USGS stream gauges listed in Table 4.1 were polled for water temperature information. These records can also be accessed using the [NWIS web service](#), using a method call along the following lines:

```
oNWIS.GetWQValues(sUSGSStatCode, sWaterTempCode1, "1880-01-01", "2008-11-25")
```

We attempted to use this data source to gather historical water temperature records but found that the existing historical temperature records are ephemeral. There are no temperature data corresponding to the

<sup>1</sup> The parameter code for water temperature in NWIS is: "00010"

long continuous records available for discharge. Instead, Table 2.4 shows the 10 gauge locations (themselves modeled) between Bend Bridge and Keswick (RM 260-301) over the period 1-Jan-1970 to 31-Dec-2001.

### SPATIAL RESOLUTION AND INTERPRETATION OF NODE LINKS

SacEFT treats USRWQM water temperatures as adequately representative of defined segments using a fixed river mile start and end value. Of the approximately 159 mile mainstem Sacramento River study area, the USBR model provides 10 nodes/arcs of interest (Table 4.2). The approximate river miles shown in the table are based on the U.S Army Corps of Engineers (1991). Additional nodes of interest can be provided, requiring only minor modifications to the software.

Table 4.2. USBR Temperature Model spatial nodes of interest on mainstem Sacramento River.

| USBR Temperature Model Node / Arc Name | River mile |
|--|------------|
| KESWICK                                | 301        |
| SAC_AT_COW_CR                          | 280        |
| BALLS_FERRY                            | 277        |
| JELLYS_FERRY                           | 267        |
| BEND_BR                                | 260        |
| RED_BLUFF                              | 243        |
| WOODSON_BR                             | 218        |
| HAMILTON_CITY                          | 199        |
| BUTTE_CITY                             | 168        |
| COLUSA                                 | 143        |

### METADATA NEEDED TO DEVELOP SCENARIO COMPATIBILITY LISTS

As with CalSim – USRDOM results, SacEFT users must align model assumptions between a given USRWQM run and other related physical models (USRDOM, TUGS, Meander Migration). This requires the ability to quickly summarize the key embedded assumptions, inputs, and other important characteristics of a USBR Temperature Model DSS database in a form that non-USBR experts can understand. As described earlier in Section 4.1.1, we apply a metadata standard to document the context for all imported data (see Figure 4.1).

#### 4.1.3 Stage-discharge

Some focal species submodels require information on water surface elevation (stage) at specific points along a cross-section, as a function of river discharge. These stage-discharge relationships are site specific and dependent on numerous variables that govern hydraulic behavior. Cross-sections themselves, that is – ground surface elevation profiles as a function of distance along a transect – are typically surveyed in the field by some means of bathymetric observation. The process of collecting this information from direct field measurement is time consuming, and often the flows of interest are not presented in a timely or predictable fashion. For these reasons, hydraulic simulation models have become widely used, especially tools developed by the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC).

A variety of groups have used HEC software or UNET models on the Sacramento River (*e.g.*, California Department of Water Resources Comprehensive Study, U.S. Geological Survey, U.S. Fish and Wildlife Service, Ayers and Associates consultants, and The Nature Conservancy. Unfortunately, many of these

studies only consider large flood recurrence discharges (50-, 100-, and 200-year events) and largely ignore lower-magnitude discharges needed to study in-channel and near-bank dynamics. Other academic researchers have developed detailed elevation models that provide stage-elevation and wetted area relations, but the output of these models is not readily available.

It is important to understand that in SacEFT, this information **is only needed where**:

1. A focal species submodel needs to know this information; and
2. Where geometric data and HEC (or other model) implementations already exist or can readily supply the ground surface profile and an in-channel stage-discharge relationship.

## **SITES OF INTEREST AND SPATIAL RESOLUTION**

Cottonwood initiation is currently the only consideration in SacEFT driving the choice of matched stage-discharge and ground surface elevation data. During our reconnaissance leading up to the model design workshop in December 2005, three sites at RM 172, 183 and 192 – examined during the 2003 Beehive Bend study (Roberts *et al.* 2002, Roberts 2003) met the two criteria above. These sites were assumed to be representative of the Colusa to Red Bluff section of the Sacramento River, and SacEFT’s riparian initiation submodel is therefore applied to these 3 sites. In subsequent development work additional locations have been added, so that Version 2 contains cross sections from these 10 locations: RM 164, 165, 172, 183, 185.5, 192, 195.75, 199.75, 206 and 208.25.

## **METADATA NEEDED**

As with any other dataset in SacEFT, these manually imported data are tagged with a DataInstance ID, which allows key background information to be tracked using SacEFT’s metadata standard.

### **4.1.4 Sediment transport and bed composition**

Stillwater Sciences has developed The Unified Gravel-Sand (TUGS) model to simulate how bed mobilization and scour affect grain size distribution, including the fraction of sand in both the surface and subsurface layers. The model can be used to assess the effects of different management scenarios (*e.g.*, gravel augmentation, flow releases to increase the frequency of bed mobilization and scour, reduction in fine sediment supply) on salmonid spawning habitat.

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

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

- a) the surface-based bedload equation of Wilcock and Crowe (2003);
- b) a combination of the backwater equation and the quasi-normal flow assumption for flow;
- c) Exner equations for sediment continuity on a fractional basis, including both gravel and sand, and the process of gravel abrasion;

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

The Wilcock and Crowe (2003) sediment transport equation calculates the transport rate of both coarse sediment (gravel and coarser) and sand based on the surface grain size distribution and on local shear stress. The Wilcock and Crowe equation assumes no relationship among surface, subsurface, and bedload grain size, which limits the application of the equation to field conditions. However, the research of Toro-Escobar *et al.* (1996) and Hoey and Ferguson (1994) identified a correlation among subsurface, surface, and bedload grain size distributions for coarse sediment, and Cui and Parker (1998) showed that the subsurface sand fraction is strongly correlated with the standard deviation of the grain size distribution of the coarse sediment. It is therefore possible to hypothesize a relation among the subsurface, surface, and bedload grain size distributions, and to combine these relations with the Wilcock and Crowe sediment transport equation to develop a numerical model that can be applied to field conditions. The hypothetical surface-subsurface sand transfer function is structured so that the subsurface sand fraction increases with the increase in the surface sand fraction and decreases with the increase in the subsurface gravel geometric standard deviation. Comparison with field data from several rivers indicates that the hypothetical surface-subsurface sand transfer function produces estimates of subsurface sand fraction within the general range measured in the field. Simulation of the Sandy River produced reasonable trend for surface/subsurface sand fractions under various hypothetical management scenarios.

The TUGS model was developed using a dataset developed in the Sandy River in Oregon. It is a one-dimensional model that predicts reach-average channel bed elevation and grain size distribution variations. A reach is defined as a length equal to a few channel widths. Because of limitations in current sediment transport modeling theories and techniques, TUGS model cannot simulate grain size distributions at the scale of local channel features, such as alternate bars or pool-riffle sequences. As with any sediment transport model, TUGS model results are most useful for comparing different management alternatives to assess their effectiveness in achieving defined goals (*e.g.*, increasing gravel deposition, reducing fine sediment, *etc.*). The model also uses existing cross-sections developed by the Army Corps of Engineers and CDWR as part of the Comprehensive Study.

### **SPATIAL HORIZON AND RESOLUTION**

The TUGS model can be applied to any reach of the Sacramento River for which channel cross-sections and surface and subsurface grain size data are available, and has been calibrated for the Sacramento River using existing bulk sampling data collected by CDWR in 1980, 1984, and 1994. Stillwater Sciences has added to the dataset by collecting new bulk samples in the upper and middle Sacramento River in 2005, at locations sampled previously by CDWR. Table 4.3 displays the river miles where the CDWR bulk samples and Stillwater 2005 bulk samples were collected. Generally, sediment transport and routing models including TUGS require a very high initial effort to calibrate.

Table 4.3. Bulk sampling sites in the Sacramento River where surface and subsurface grain size distribution data are available.

| Upper Sacramento River |                        | Middle Sacramento River |                           |
|------------------------|------------------------|-------------------------|---------------------------|
| RM                     | Site Name              | RM                      | Site Name                 |
| 298.3                  | Caldwell Park          | 242.7                   | Red Bluff Diversion Dam   |
| 296.9                  | Turtle Bay Upstream    | 240.4                   | Above Blackberry Island   |
| 292.7                  | Golf Course            | 238.5                   | Above Todd Island         |
| 291.3                  | Below Tobiasson        | 236.1                   | Below Todd Island         |
| 289.1                  | Clear Creek confluence | 233.0                   | Oat Creek                 |
| 288.1                  | Above I-5 embankment   | 228.3                   | Tehama                    |
| 287.3                  | At I-5 embankment      | 225.6                   | Thomes Creek              |
| 286.3                  | n/a                    | 221.2                   | Copeland Bar              |
| 282.6                  | Anderson outfall       | 218.6                   | Woodson Bar               |
| 281.1                  | Stillwater Creek       | 215.3                   | Above Cutoff              |
| 280.2                  | Cow Creek              | 211.6                   | Upstream of Foster Island |
| 279.1                  | Below Cow Creek        | 208.9                   | Upstream of Shaded Slough |
| 278.3                  | Above Bear Creek       | 201.8                   | McIntosh Landing          |
| 275.7                  | Anderson Creek         | 197.9                   | Upstream of Pine Creek    |
| 273.3                  | Cottonwood Creek       | 163.5                   | Princeton                 |

**FORM OF TUGS OUTPUT TO BE ACCESSED AND IMPORTED: EXCEL**

TUGS is capable of providing a variety of grain size specific transport estimates for gravel and sand, and of tracking these two classes of sediment by their proportions in surface and subsurface layers. The current output format for the model is shown in Figure 4.2.

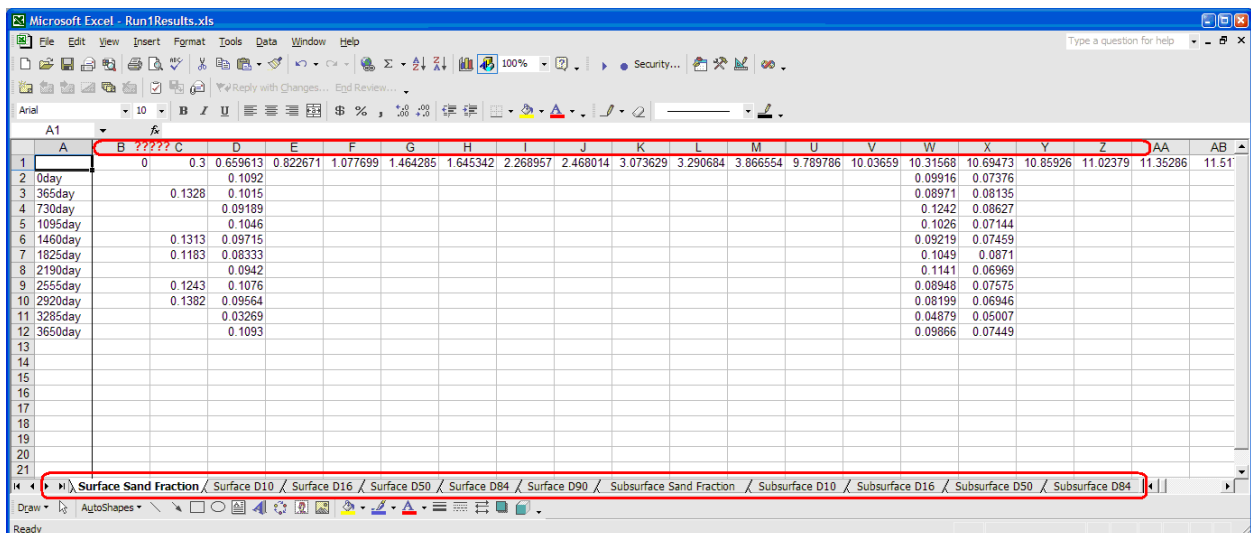


Figure 4.2. Current raw output from TUGS model. Numerous worksheets contain results for specific performance measures. As shown, it is not always clear what distance (location) or time period is associated with a particular value. An Excel template was developed to better organize and streamline this information for orderly import into the SacEFT database.

With the benefit of a new Excel template, TUGS output is bulk loaded into SacEFT’s database in the relational form shown in Figure 4.3.

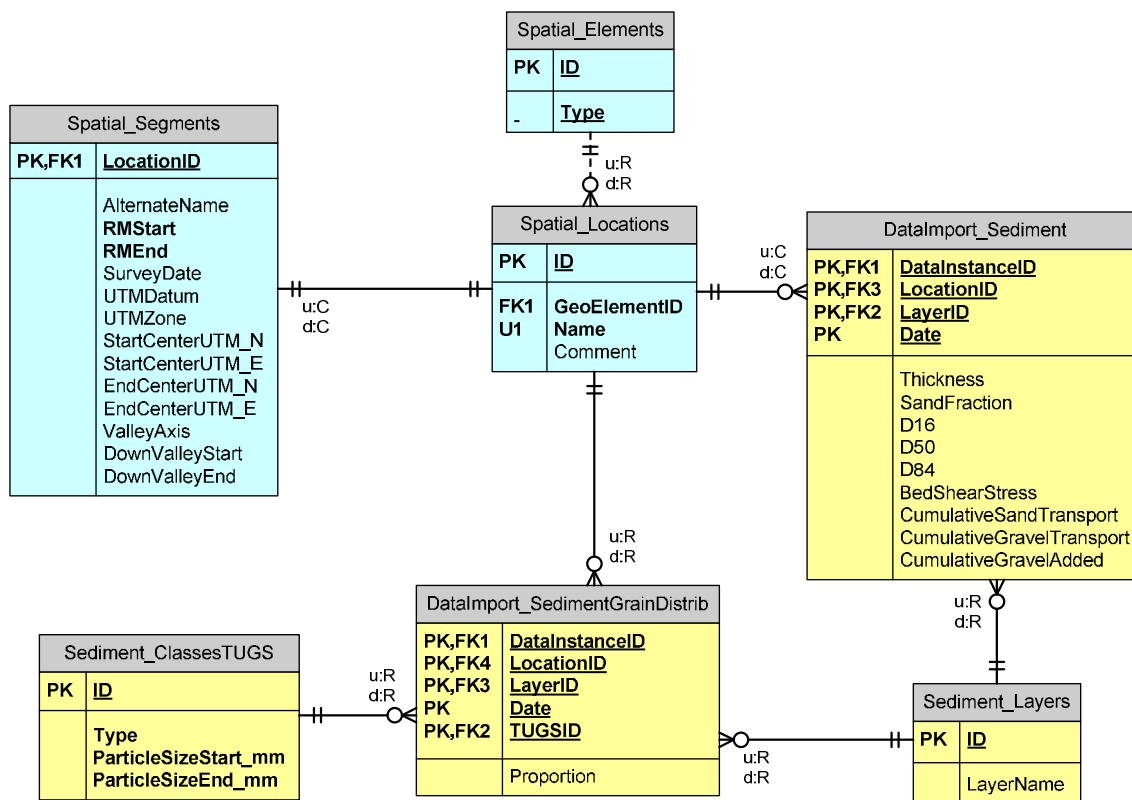


Figure 4.3. Relational database design used by SacEFT for storing TUGS model output.

After consultations between Stillwater Sciences and TNC, two scenarios were incorporated into SacEFT for v.2.00: a “No Gravel” scenario that assumes no gravel injection to the rivers, although small amounts of natural sand and gravel are present. The second scenario “Gravel Injection” contains a single gravel injection in Water Year 1940, with no subsequent additions. The scenarios were simulated using historical, NODOS and Shasta discharges at Keswick (RM 301) and implemented over 5 reaches as shown in Table 4.4. The results of the TUGS scenarios are incorporated into the calculation of Spawning WUA (Weighted Usable Area) for Chinook and steelhead, as described in Section 4.2.5.

Table 4.4. Location of TUGS simulation segments and amount of supplementary gravel added for “Gravel Injection” scenarios.

| Upper RM | Lower RM | Gravel Injection (m <sup>3</sup> )<br>(when present) |
|----------|----------|--|
| 301.956  | 299.800  |  |
| 299.800  | 297.000  | 179,423 <sup>δ</sup> (234,677 yd <sup>3</sup> )      |
| 297.000  | 295.600  |  |
| 295.600  | 292.400  | 188,662 <sup>δ</sup> (246,760 yd <sup>3</sup> )      |
| 292.400  | 289.375  |  |

<sup>δ</sup> These are bulk amounts, assuming a gravel porosity of 0.4.

*Note:* As part of the TUGS calibration process a third “zero gravel” scenario was also developed using historical flow at Keswick and *historical* gravel additions from 1981-2006.

#### 4.1.5 Meander migration

UC Davis researchers have developed a Meander Migration Model (Larsen 1995, Larsen and Greco 2002, Larsen *et al.* 2006b) using MATLAB software, that calculates channel migration using a simplified form of equations for fluid flow and sediment transport developed by Johannesson and Parker (1989). One version of the Meander Migration Model predicts meander migration as a function of a single, representative, geomorphically effective discharge (“characteristic discharge”). The model has been modified to consider the effects of a variable hydrograph on meander migration rates. This is believed to provide a more accurate depiction of the conditions in which meander migration occurs. The underlying hypothesis is that the bank migration rate, when thresholds are excluded, in a specified time interval is linearly related to the sum of the cumulative excess stream power in the same time interval (Larsen *et al.* in review).

The meander migration MATLAB code that is used to assess ecological flows is similar to the code used in other applications (*i.e.*, Larsen and Greco 2002) but incorporates a variable flow, where channel migration in yearly time steps is a function of annual flow rates, through the measure of scaled annual cumulative excess stream power (Larsen *et al.* 2006a).

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

Conceptually, the Meander Migration Model produces a temporal series of channel centerlines that are imported into ArcInfo where bends and lateral change polygons are defined and studied for movement in terms of progressive migration (Larsen and Greco 2002, Larsen *et al.* 2006). GIS tools are used to automate the spatially explicit measurements.

#### SPATIAL HORIZON AND RESOLUTION

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

The finest unit of resolution of interest in SacEFT is **a bend**. We apply a fixed zonal concept based on segments, using the locally well-known concept of river miles to reference these bends. While we recognize the channel alignment has changed significantly since the U.S. Army Corps of Engineers 1964 centerline survey, the critical consideration is that these locations be “well-known” and consistent across

SacEFT's submodels. This in no way inhibits the spatial accuracy of meander migration calculations, just simplifies the manner in which specific bends are identified. As described earlier, for purposes of determining the suitability of bank swallow nesting habitat, the exact locations of individual bends of interest is still in *approximately* the same zones whether at RM 191 or RM 208. Knowing *exactly* where it is does not help us answer questions about bank swallow nesting habitat.

While SacEFT treats locations as fixed throughout model simulations for purposes of generating focal species performance measures, variables like centerline change, which are inherently spatial, may still be handled in a fully spatially explicit fashion. The distinction we draw is one of a need for "visualization" vs. an empirical summary performance measure that is transferred to a submodel of lower resolution and precision. Highly visual, dynamic map-based outputs usually require spatially explicit treatment; other variables do not.

#### 4.1.6 Bank erosion model

ESSA has developed a GIS-based erosion model that allows users to combine the predictions from the Meander Migration Model with other spatial information, such as soil and vegetation information. Each year, the model simulates the location of the river channel, the area of eroded banks and the location of the banks at the end of the year. The location of the river channel is calculated from the centerline using two simplifying assumptions regarding the river channel: (1) that it is symmetrical around the centerline; and (2) that the local channel width for a given section of the river is unchanged during the simulation. The eroded area for each year is defined as the channel area overlapping the previous year's banks. The river banks at the end of the year are calculated by subtracting the eroded area from the banks at the start of the year. Figure 4.4 shows an example of change of centerlines simulated by the Meander Migration Model over a period of 56 years.

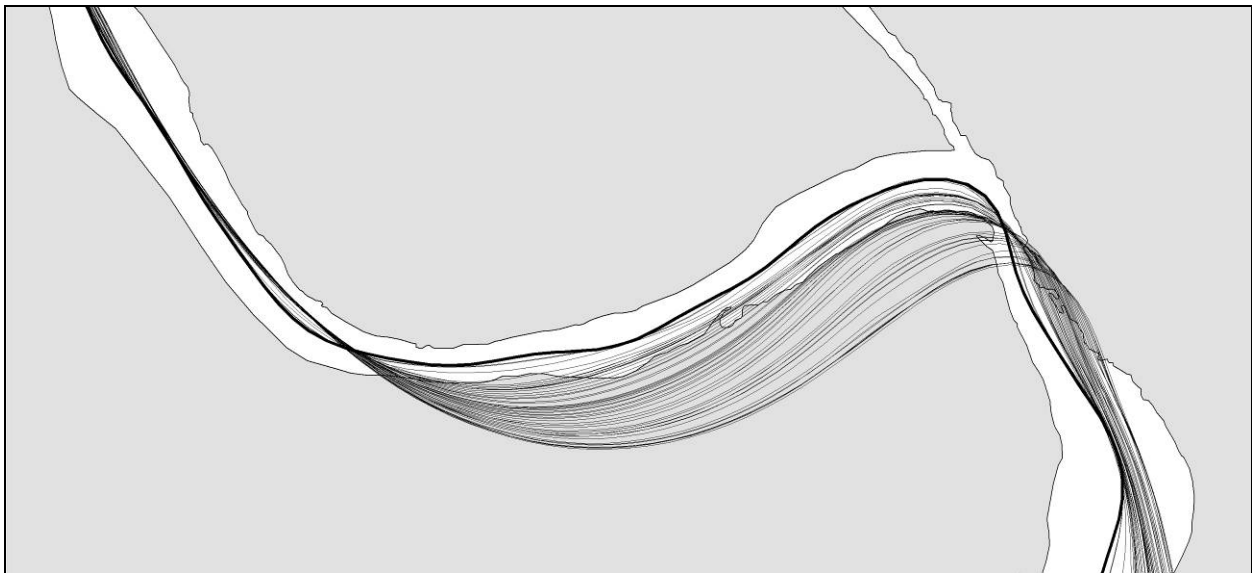


Figure 4.4. Example of centerlines for 56 years for one scenario.

The initial simplified channel is based on the measured location of banks in 2004. The centerline was divided into segments and the local channel was determined as the distance to the nearest bank. Then, a simplified channel was created by buffering each centerline segment by the local channel width (Figure 4.5).





Figure 4.5. Simplified channel for initial conditions.

Each future channel is simulated based on the previous centerline and on the local channel width for each centerline segment. The new centerline is then divided into segments based on the proximity to the segment of the previous year's centerline. Next, the channel for the year is created by buffering the new centerline by the channel width for the closest location matching the previous year's centerline. Finally, the locations of eroded bank are defined as the area of the new channel that overlap the previous year's bank. Finally, the new bank locations are used to calculate the next year's erosion.

#### **FORM OF EROSION OUTPUT TO BE ACCESSED AND IMPORTED: SHAPE FILE AND EXCEL**

The erosion model produces three outputs: (1) GIS layers with eroded area for each year, (2) the vegetation for the eroded areas and (3) the soil composition of the eroded areas. The soil composition is divided into 4 types based on bank swallow preference and prevalence in the eroded areas. The eroded areas are overlaid on the amalgamated Soil Survey Geographic (SSURGO) soil data to derive soils data for the bank swallow model (Figure 4.6). The eroded areas are also overlaid on vegetation data to provide input to the large woody debris indicator (Figure 4.7).

The screenshot shows an Excel spreadsheet with the following data:

|    | A              | B          | C          | D              | E      | F                      |
|----|----------------|------------|------------|----------------|--------|------------------------|
| 1  | DataInstanceID | LocationID | BendNumber | Date           | SoilID | AreaFloodplainReworked |
| 2  | 36             | 101        | 1          | 10/1/1947 0:00 | 1      | 5255.658903            |
| 3  | 36             | 101        | 1          | 10/1/1947 0:00 | 2      | 1056.642774            |
| 4  | 36             | 101        | 1          | 10/1/1947 0:00 | 4      | 229.973208             |
| 5  | 36             | 101        | 1          | 10/1/1947 0:00 | 3      | 1007.852746            |
| 6  | 36             | 101        | 2          | 10/1/1947 0:00 | 1      | 2180.507031            |
| 7  | 36             | 101        | 2          | 10/1/1947 0:00 | 2      | 1439.139418            |
| 8  | 36             | 101        | 2          | 10/1/1947 0:00 | 4      | 1357.752306            |
| 9  | 36             | 101        | 2          | 10/1/1947 0:00 | 3      | 6637.248507            |
| 10 | 36             | 101        | 3          | 10/1/1947 0:00 | 1      | 420.436605             |

Figure 4.6. Example of soil composition data for eroded areas in Excel.

The screenshot shows an Excel spreadsheet with the following data:

|    | A              | B          | C          | D              | E      | F     | G          |
|----|----------------|------------|------------|----------------|--------|-------|------------|
| 1  | DataInstanceID | LocationID | BendNumber | Date           | Height | Class | Area       |
| 2  | 36             | 101        | 1          | 10/1/1947 0:00 | 3      | BE    | 682.933553 |
| 3  | 36             | 101        | 1          | 10/1/1947 0:00 | 3      | BW    | 604.263007 |
| 4  | 36             | 101        | 1          | 10/1/1947 0:00 | 4      | CS    | 245.582267 |
| 5  | 36             | 101        | 1          | 10/1/1947 0:00 | 4      | CW    | 790.193086 |
| 6  | 36             | 101        | 1          | 10/1/1947 0:00 | 4      | RS    | 93.85927   |
| 7  | 36             | 101        | 1          | 10/1/1947 0:00 | 5      | RS    | 312.373066 |
| 8  | 36             | 101        | 1          | 10/1/1947 0:00 | 3      | VO    | 244.089725 |
| 9  | 36             | 101        | 1          | 10/1/1947 0:00 | 4      | VO    | 732.928372 |
| 10 | 36             | 101        | 2          | 10/1/1947 0:00 | 3      | BW    | 40.240858  |

Figure 4.7. Example of vegetation data for eroded areas in Excel.

## 4.2 Integration of physical data, linked models and SacEFT submodels

### 4.2.1 Water year conventions for simulations and outputs

By convention, SacEFT uses the Water Year (WY) as its annual simulation framework. Each Water Year ( $y$ ) begins on October 1 of calendar year ( $y-1$ ) and ends on September 30 of calendar year ( $y$ ). Spring-run Chinook salmon spawn across the ( $y-1$ ):( $y$ ) boundary, and are accounted for with the run-types spawning in WY  $y$ .

### 4.2.2 Matching physical variables to focal species locations of interest

The model underlying each PM is designed to accommodate the temporal framework of its input data: daily for flow and temperature and annual for TUGS and Meander Migration data. SacEFT accepts inputs

that may be point-based (*e.g.*, discharge and temperature) or segment-based (*e.g.*, TUGS data). It links these inputs to PMs that may themselves be point-based (*e.g.*, GS1 – Green Sturgeon spawning locations) or segment-based (*e.g.*, CS1 – Chinook spawning WUA).

The guiding principle for this linkage is to first fill gaps that may be present in the input data. The second principle is to use the input data that are nearest to the location where the PM is modeled. To do this, SacEFT uses the concept of a neighbor zone: any input data located within a user-defined river mile tolerance zone are considered a perfect match. Failing a match within the tolerance zone, the nearest upstream data are usually selected. In some cases, such as the riparian initiation submodel, flows are interpolated based on the nearest available upstream and downstream source of flow data for the cross-section of interest.

Some matches require overlaying segment-based data from multiple sources (*e.g.*, TUGS data and salmonid spawning segments). When this occurs, segments that are completely-contained and segments that overlap are weighted by the proportion of their length contained in the common segment. For example, if a short TUGS segment is completely contained in a longer spawning segment along with an adjacent TUGS segment that is half in the spawning segment, the sediment data from the first segment are given a weight of 1.0 and the data from the second segment a weight of 0.5.

In the unique case of salmonid rearing habitat, there are some rearing-reaches without spawning and therefore without any natural way to predict the egg-emergence that eventually follows spawning and marks the initiation of rearing. In these cases, the average emergence of the *upstream* segments is used to create an egg-emergence distribution for the downstream rearing segment.

Finally, in cases where there are multiple data sources within a salmonid reach segment for flow or temperature, those data are averaged to provide a single pooled estimate for the reach-based calculations.

### **4.2.3 Extending TUGS locations to Chinook and steelhead locations**

The initial surface substrate conditions for TUGS simulations consisted of the substrate size categories in two river segments (see Section 4.2.5). Changes to these initial distributions were then modeled over time with the two gravel scenarios.

When applying TUGS data for Chinook and steelhead spawning WUA, it was generally necessary to apply annual location-based TUGS results to portions of the river that are outside the area where TUGS was calibrated (compare red and pink segments in Table 2.5). In accordance with our nearest-neighbor principle, the predicted substrate composition of the most downstream of the five TUGS simulation segments (near RM 289) is mapped to the downstream segments used by the Chinook and steelhead submodels each year for each of the combinations of flow scenarios and gravel scenarios. In the case of fall Chinook, the most distant segment can extend downstream over 70 miles to Vina (RM 218), implying that the distribution of surface substrate size classes (sand through boulder) is comparable across this entire range. It also assumes that gravel injection simulations at upstream locations can be plausibly extended at the downstream locations. The further the spatial extrapolation, the more tenuous this assumption becomes. The solution to this extrapolation problem can be resolved by obtaining TUGS simulation results calibrated and tested for these more downstream reaches of the Sacramento River.

#### 4.2.4 Extending Chinook and steelhead WUA relationships across locations and run-types

Chinook and steelhead spawning and rearing WUA performance measures (CS1, CS2) are parameterized for three upstream reaches only. The detailed empirical substrate information required to estimate site-specific spawning WUA (and its relationship to gravel injection) is not available at the 2 downstream segments. This is shown graphically in Table 2.5 where parameterized reaches are shown in dark blue and mapped reaches in light blue. The parameterization methodology developed and applied at the 2 downstream reaches is described more fully in Section 4.2.5.

Similarly, spawning and rearing WUA relationships (when they exist) have been parameterized for steelhead and for fall-, late fall- and winter- Chinook run-types. Habitat preferences for spring Chinook are not available and we assumed they follow those of fall Chinook (Mark Gard, USFWS, *pers. comm.*).

#### 4.2.5 Linking Chinook and steelhead WUA relationships to TUGS substrate classes

The Chinook and steelhead spawning Weighted Usable Area (WUA) models are based on Gard's habitat preference models (U.S. Fish and Wildlife Service 2003, 2005a, 2005b). These models assume that spawners prefer habitats with optimal combinations of depth, velocity and gravel size, and that given an environment in which all three of the characteristics vary, their overall preference can be empirically modeled as the product of 0-1 preferences for each of these 3 variables. When one square foot of habitat is optimal (1.0) for all 3 preferences, it has a weighted usable area (WUA) of 1.0 ft<sup>2</sup>; otherwise it has some smaller value. Gard's results are based on the River-2D hydrodynamic model (Steffler and Blackburn 2002, U.S. Fish and Wildlife Service 2006a), a 2-dimensional hydrodynamic simulation of river segments. River-2D takes as input discharge at the upstream segment transect and surface elevation at the downstream transect, along with empirical measurements of the river bottom topography and composition, and estimates the velocity field over the points of the segment's triangular irregular network (TIN), producing an estimate of WUA for each node of the TIN. When these TIN nodes are summed up, an estimate for the reach is produced and finally, when the reaches are summed in proportion to their presence in the entire segment, an overall segment WUA is obtained.

Using original data provided by Gard, we re-ran all the River-2D analyses and used raw River-2D output to determine  $a_s$ , the proportional area contribution of each of the 11 substrate size categories in each river reach, across a range of discharges. When  $A_i$  is the absolute area in any substrate size class,  $a_s$  is:

$$a_s = \frac{A_s}{\sum_{s=1}^{11} A_i}$$

The  $a_s$  vector was found to be fairly insensitive to discharge, and we therefore took the average  $a$ -vector across the full range of flows (3,250 to 31,000 cfs), allowing us to develop a relationship that was independent of discharge. This calculation implicitly collapses two-dimensional information about substrate size categories across each reach into a one-dimensional summary. To provide a consistent set of size categories, the  $a_s$  vector calculated by River-2D was transformed to the 8 size categories ( $a_8$ ) used by TUGS by linear interpolation between overlapping size classes. After this operation, the  $a_8$  vector was provided as an initial condition for the TUGS simulations.

In SacEFT model runs, along with the actual surface substrate size distribution  $a^*$ , predicted annually by TUGS gravel augmentation scenarios, the reference size distribution vector  $a_s$  is combined with substrate preference  $p_{r,s}$  to modify Gard's reference spawning discharge relationship  $WUA_{r,q}$  for each species  $r$ . The

actual WUA available each day to spawners  $WUA_{r,Q}^*$  is computed by the ratio of the reference conditions (denominator) to the current conditions (numerator), making WUA sensitive to changes in substrate:

$$WUA_{r,Q}^* = WUA_{r,Q} \times \frac{\sum_{s=1}^8 p_{r,s} a_s^*}{\sum_{s=1}^8 p_{r,s} a_s}$$

### 4.3 Focal species submodels

#### 4.3.1 Chinook salmon & steelhead trout

The salmonid conceptual model is shown in Figure 4.8. Readers are referred to ESSA Technologies Ltd. (2005) for details on the development of this model and the decisions that led to its current structure.

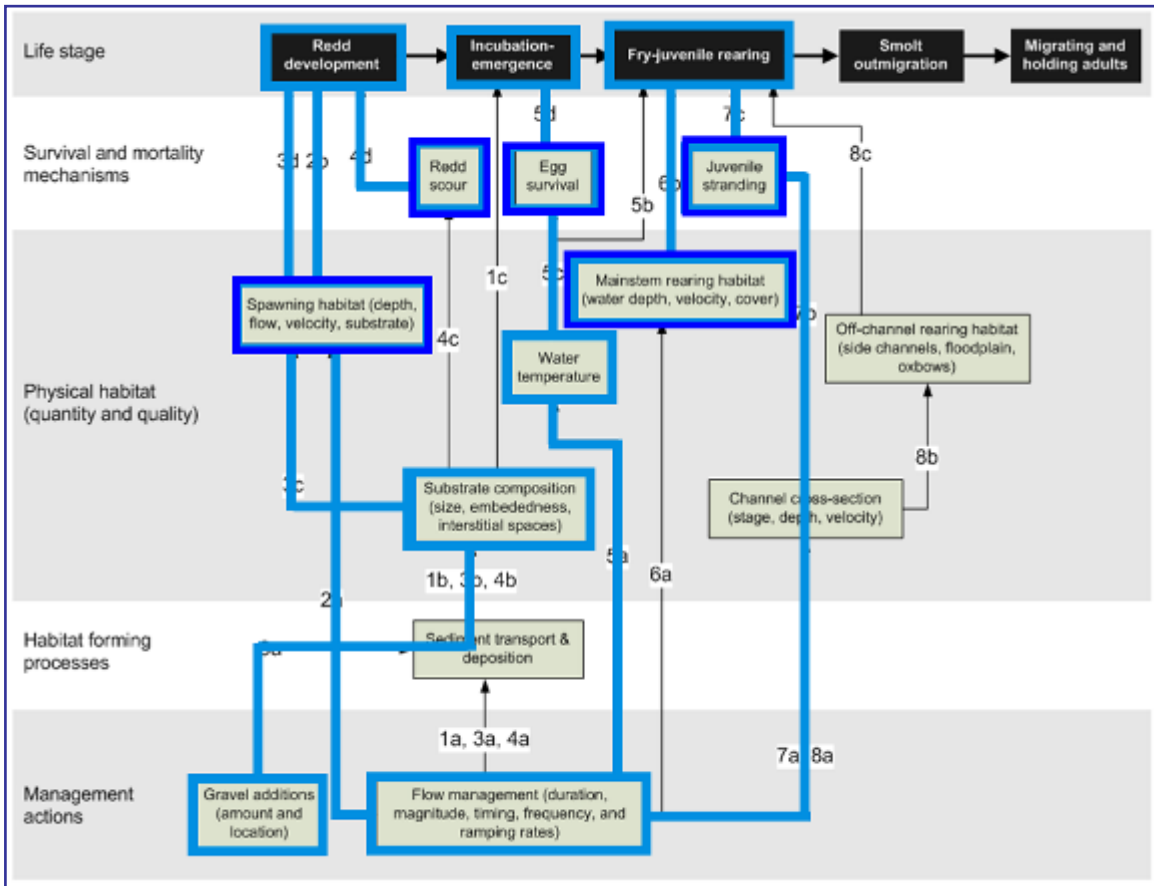


Figure 4.8. The salmonid conceptual model. Heavy lines show the processes and linkages that are currently implemented. See ESSA Technologies Ltd. (2005) for additional context and detail on processes and linkages shown here.

SacEFT includes six performance measures (PMs) that describe changes in the physical habitat available for salmonid spawning and rearing. These performance measures are shown in Table 4.5.

Table 4.5. Performance Measures (PMs) for Chinook salmon and steelhead trout.

| Performance Measure               | Synonyms     | PM code | Units           |
|-----------------------------------|--------------|---------|-----------------|
| Weighted Usable Area for Spawning | Spawning WUA | CS1     | Square feet     |
| Redd Dewatering                   |              | CS6     | Proportion      |
| Redd Scour Potential              |              | CS5     | Hazard category |
| Egg-to-Fry Thermal Mortality      | Egg Survival | CS3     | Proportion      |
| Weighted Usable Area for Rearing  | Rearing WUA  | CS2     | Square feet     |
| Juvenile Stranding Potential      |              | CS4     | Index           |

Steelhead trout and four Chinook salmon run-types are modeled using the common modeling framework described in this section. Our approach and data are largely based on research results provided by Mark Gard of the U.S. Fish and Wildlife Service in Sacramento (U.S. Fish and Wildlife Service 2003, 2005a, 2005b). As described below, additional temperature-emergence and temperature-mortality data have been provided from relationships published for the SALMOD model (Bartholow and Heasley 2006) and by Crisp (1981).

The salmonid performance measures broadly cover key features of the spawning and rearing portions of the juvenile life history, and are simulated in up to 5 segments of the mainstem, as shown in Table 2.5 and Table 4.5. Because parameterized relationships were not always available for every location and PM, relationship mapping was carried out by assuming that relationships parameterized for a run-type or location could be applied to another run-type or location (Mark Gard, USFWS, *pers. comm.*).<sup>1</sup> For example, based on U.S. Fish and Wildlife Service (1995), the distribution of rearing habitat for *spring-run* Chinook is almost entirely concentrated below Battle Creek but uses *fall-run* rearing WUA relationships. Likewise, rearing WUA relationships are not available for locations *downstream* from Battle Creek, and currently make use of *upstream* WUA relationships.

SacEFT presents the results for each PM at up to 3 scales. First, at the system-wide resolution (which we term the *rollup*), each annual PM is evaluated by comparing the results against those of a benchmark historical run scenario (historical flow and temperature, no gravel augmentation, no bank revetment). The distribution range of the benchmark annual PM is used, employing obvious discontinuities in the distribution to create a heuristic **R/Y/G** classification called the *Indicator Rating*. (If there are no obvious discontinuities, the tercile points – measurements taken at the 1/3 and 2/3 points of the sorted PM distribution – are used to assign the Indicator Rating.) At the *Annual* scale (not graphed in v.2.00) the terciles of the annual average for the PM are used to create indicator ratings. At the *Daily* scale, the indicator rating is represented using horizontal color bars on some Excel reports. This scale of indicator uses the terciles of the *daily* historic flow and temperature to assign a daily **R/Y/G** indicator rating.

Although each model operates internally on the basis of a daily cohort, the distributional and cumulative results shown on the Excel report often portray the cumulative (summed) distribution of all day-cohorts each day. This way it is possible to see daily changes to the entire population in the face of fluctuations in flow and temperature, even though internally, each day-cohort is tracked separately.

<sup>1</sup> One reviewer of Version 1 documentation noted that “the conventional wisdom is that rearing above Battle Creek is insignificant” and that “in-river rearing for all four named varieties of Chinook extends at least down to Ord Bend.” (Andrew Hamilton, *pers. comm.*). If additional rearing WUA estimates are available for downstream locations, they can easily be accommodated in subsequent versions.

Table 4.6. Reaches with calibrated or mapped spawning (CS1) and rearing (CS2) WUA relationships. Spawning WUA-substrate relationships for some reaches (light blue) are based on parameterizations (dark blue) from the nearest segment. Rearing relationships downstream from Battle Creek are based on WUA-Flow relationships from the nearest upstream segment (abstracted from Table 2.5).

| Upstream     | Downstream   | Spawning PMs |      |           |        |           | Rearing PMs |      |           |        |           |   |
|--------------|--------------|--------------|------|-----------|--------|-----------|-------------|------|-----------|--------|-----------|---|
|              |              | Spring       | Fall | Late Fall | Winter | Steelhead | Spring      | Fall | Late Fall | Winter | Steelhead |   |
| Keswick      | ACID         |              | █    | █         | █      | █         |             | █    | █         | █      | █         | █ |
| ACID         | Cow Creek    | █            | █    | █         | █      | █         | █           | █    | █         | █      | █         | █ |
| Cow Creek    | Battle Creek | █            | █    | █         | █      | █         | █           | █    | █         | █      | █         | █ |
| Battle Creek | Red Bluff    |              | █    |           |        |           | █           | █    | █         | █      |           |   |
| Red Bluff    | Deer Creek   |              | █    |           |        |           | █           | █    | █         | █      |           |   |

In developing the initial design for SacEFT, our intention was that each PM be a measure of habitat suitability *only*, and that for consistency with the PMs of other species, we try to avoid designs where one PM depended on another and which can therefore resemble population-based models. In general we have adhered to this principle; but where the linkage between closely related PMs seemed robust, we have in one case allowed WUA Spawning (CS1) to affect a subsequent indicator.

In addition to modeling each PM at specific locations, each species spawns according to a timing-relationship developed at the design workshop (Table 2.7). The duration and amounts shown in this table strongly resemble the timing relationships used by SALMOD (Figure 3 in Bartholow and Heasley (2006), derived from Vogel and Marine (1991)). Rearing relationships were originally part of the design, but these became superfluous once we incorporated temperature-based egg maturation from SALMOD. As a result of this emergence relationship, eggs from each day-cohort remain in the gravel until the temperature-driven emergence relationship predicts their maturation. The relationship we adopted is not strictly egg-maturation, but covers the period to free swimming emergence.

The six performance measures described here are necessarily simplistic and generally do not attempt to account for interactions that naturally occur. For example, redd dewatering, temperature-driven egg mortality and redd scour risk all occur during the incubation period and the processes together would predict a different outcome than each process taken alone. Additionally, the cross-sectional data used to parameterize the models of WUA-based performance measures are a snapshot in time of conditions in the mainstem, and mainstem habitat locations may change slowly or episodically as a result of meanders. Habitat is therefore assumed to be in an equilibrium state in which the spatial arrangement of particular habitats may change, but the segment-wide non-spatial proportions do not.

### Calibrating the Chinook and Steelhead Models

To calibrate SacEFT Version 2 we used the same historical data used for the Version 1 calibration: empirically measured historical flow data and a mix of empirical and modelled upstream temperature data. These provide about 30 years (WY 1971-2003) of paired observations that are required to calibrate all the models, some of which depend on temperature (the shorter time series) which drives the timing of egg maturation for later life history PMs.



Using these empirical historical data, up to 3 calibration measures are computed for some CS1, CS3, CS4 and CS6 (Spawning and Rearing WUA, Juvenile Stranding and Redd Dewatering) indicators:

1. **Daily Indicator Rating** – Daily ratings are computed separately for each run-type, making use of daily values from all reaches and years for the run-type. The PM values are then sorted from largest to smallest (*e.g.*, the population-proportion weighted square feet of Rearing WUA on each day in the case of CS2). Values that define the upper third and lower thirds of the sorted values are termed daily Hazard Threshold boundaries and are shown as horizontal **R/Y/G** lines on some of the Excel Reports. They give a system-wide daily comparison of how the PM score compares to other days and reaches. Consistently high (**Green**) days in a reach show that the reach contributes strongly to the PM’s performance in a given year. Daily indicator ratings are never weighted across multiple reaches. Because they are close to raw measurements, intrinsic differences between reaches need to be considered when looking at daily ratings. For example, a reach may have intrinsically low Rearing WUA simply because it is shorter than another reach, and could show a lower (**Yellow** or **Red**) daily rating compared to a reach with higher Rearing WUA.
2. **Annual Indicator Rating** – Annual summaries of the PM are computed separately for each run-type, pooling the daily values into combinations of year and reach for the reach-type. These values are sorted from largest to smallest and the terciles computed. This provides each reach with a Hazard Threshold boundary; a ranking of its PM relative to other reaches and years. These ranking data are stored as output, **but are not currently used**.
3. **Annual Rollup Indicator Rating** – Annual summaries of the PM are computed separately for each run type, taking the average value of all reaches within the year. These data are sorted and then graphed to create a cumulative distribution. Generally the distributions are fairly uniform and taking terciles is a reasonable default approach. In some situations there may be a marked discontinuity in the distribution and in these cases the discontinuity may be used as an alternative breakpoint. These alternative distributions can be seen by examining the annual roll-ups for the calibration data sets. In cases that use the tercile approach, the **R/Y/G** bars are evenly divided (or nearly so, given round-off). In cases that use discontinuities, the division is not even. In both cases however, comparison across matched scenarios (*e.g.*, calibration versus a management scenario) will show differences in the distribution of years. These differences can be used to infer changes in the system, relative to the calibration.

An example of the approach for the Annual Rollup Indicator is shown below (Figure 4.9) for steelhead CS6 – Redd Dewatering. The sorted distribution of the annual average of all reaches shows a fairly even slope with the possibility of some discontinuities. However, the terciles have been used to select the Indicator Rating boundaries.

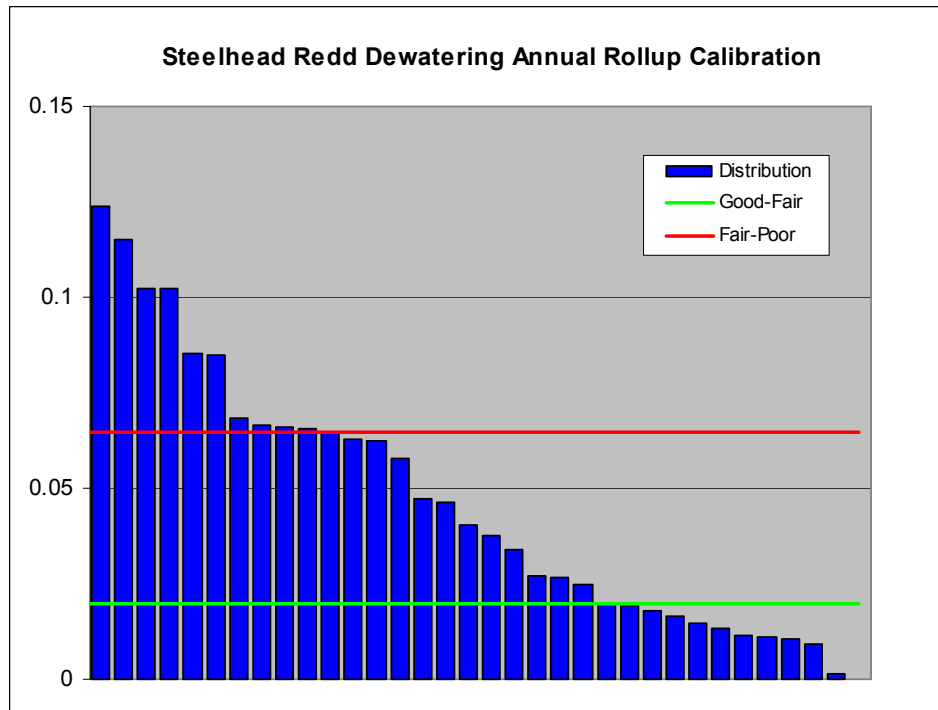


Figure 4.9. An example showing the distribution of the Redd Dewatering (CS6) index for steelhead trout based on the average annual value for all reaches, sorted by year from largest to smallest value. Similar graphs are created for all 3 temporal resolutions (daily, annual, and annual rollup) for 5 salmonid run-types for CS1, CS2 and CS6, a total of 60 graphs. Note that for this PM a lower value indicates a better condition: the green line is lower than the red line. For some PMs “more is better” and the lines are reversed.

Calibration of the CS3 and CS5 (Egg-to-Fry Thermal Mortality and Redd Scour) indicators follows a slightly different logic than the calibration of Spawning and Rearing WUA, Juvenile Stranding and Redd Dewatering. CS3 and CS5 are based on fixed Indicator Threshold boundaries such as % survival or 1-in-10 year flood flows. These differences are noted below in the descriptions of the individual PMs.

The calibration exercise affects the interpretation of all SacEFT outputs and assumes that the calibration period is the norm for the Sacramento system. While it provides a necessary benchmark, it should be borne in mind that if the calibration period is somehow abnormal (“very good”, “very bad” “a time of extreme change,” *etc.*), conclusions based on the benchmark will need to be critically examined. For PMs which are cued to absolute values like % survival, a poor benchmark causes fewer problems than PMs like redd dewatering which are often analyzed in a comparative way that hinges on the correct interpretation of changes in relative distributions.

## CS1 – WEIGHTED USABLE AREA FOR SPAWNING

Spawning WUA is calculated using daily cohorts of spawners for each run-type and river segment. The historical or simulated gauges provide daily average flow ( $Q$ ) over the spawning period  $D$  for each location ( $l$ ) and run-type ( $r$ ) combination<sup>1</sup>.

<sup>1</sup> ‘Run-types’ are sometimes referred to as ‘races.’ We recognize four Chinook run-types and Steelhead trout as separate salmonid species.

The *daily* performance measure is computed each day by interpolating the WUA-flow relationship – possibly modified by changes in substrate size composition from the TUGS model –  $f(l,r,Q^*)$  to predict Weighted Usable Area (WUA, square feet). The PM accounts for spawning area only, and subsequent exposure to thermal mortality or redd dewatering is not included. Linear interpolation is used to calculate WUAs between the tabular values found in Gard’s studies of spawning WUA (U.S. Fish and Wildlife Service 2003, 2005a).

The *rollup* PM is computed by averaging across all locations ( $L$ ). It uses a  $1/L$  average rather than a sum, so that system-wide thresholds are more meaningful should the number of locations vary across years and/or run-types, based upon the availability of the underlying flow and water temperature data.

$$CSI_r = \frac{1}{L} \sum_{l=1}^L \left( \frac{1}{D} \sum_{d=1}^D f(l,r,Q_d^*) w_d \right)$$

During the model review leading up to the release of Version 2, we considered using empirically driven measures of reach-usage (see “Field” columns in Table 4.7) to add further realism to the rollup. But a re-reading of U.S. Fish and Wildlife Service (2005b) makes it clear that this is not necessary: reach-weights from U.S. Fish and Wildlife Service (2003) were *already* incorporated in the study which produced WUA Spawning estimates for SacEFT Version 1. Moreover, estimates shown in Table 4.7 are based on 1989-1994 redd counts that preceded two very high flood events, and the WUA estimates developed by Gard (U.S. Fish and Wildlife Service 2005b) represent post-flooding conditions that changed substantially in the more downstream reaches, with downgraded habitat availability below Battle Creek.

Whichever WUA prediction model is incorporated, SacEFT assumes that WUA predictions are statistically stationary over time, an assumption that loses strength as simulation time periods move away from the time period of the field assessments that generated the underlying WUA curves. A comparison of “Field” and “SacEFT” Spawning WUA for three run-types shown in Table 4.7 shows fair agreement in most situations. SacEFT estimates reflect the dramatic change in available habitat below Battle Creek. No matching estimates are available for Spring Chinook or steelhead.

Table 4.7. 1989-1994 observations of field redd distribution (%) compared to simulated SacEFT Version 2 Spawning WUA (%) for three run-types.

| Segment        |                | Fall (%) |        | Late Fall (%) |        | Winter (%) |        |
|----------------|----------------|----------|--------|---------------|--------|------------|--------|
| Upper boundary | Lower boundary | Field    | SacEFT | Field         | SacEFT | Field      | SacEFT |
| Keswick        | ACID           | 9        | 8      | 24            | 20     | 2          | 25     |
| ACID           | Cow Creek      | 38       | 21     | 52            | 48     | 80         | 62     |
| Cow Creek      | Battle Creek   | 13       | 5      | 8             | 33     | 3          | 12     |
| Battle Creek   | Red Bluff      | 16       | 39     | 7             | -      | 9          | -      |
| Red Bluff      | Deer Creek     | 25       | 27     | 8             | -      | 6          | -      |

Breakpoints for the **R****Y****G** Indicator Ratings are taken using terciles of the sorted river-segment distribution for the daily and annual results, using discontinuities in the annual distribution for the rollup where those exist.

**Indicator Reliability**

The indicator credibility rankings for CS1 are shown in Table 4.8.

Table 4.8. CS1 - Spawning WUA indicator credibility assignments following the workshop.

|                       | Category |   |   |   |     |
|-----------------------|----------|---|---|---|-----|
|                       | I        | U | R | F | P   |
| Winter-run Chinook    |          | H | H | H | H   |
| Spring-run Chinook    |          | M | M | H | M   |
| Fall-run Chinook      |          | H | H | H | H   |
| Late-fall-run Chinook |          | H | H | H | H   |
| Steelhead             |          | M | H | M | M/H |

## Excel Reports

An example of the Version 2 Excel report is shown in Figure 4.10.

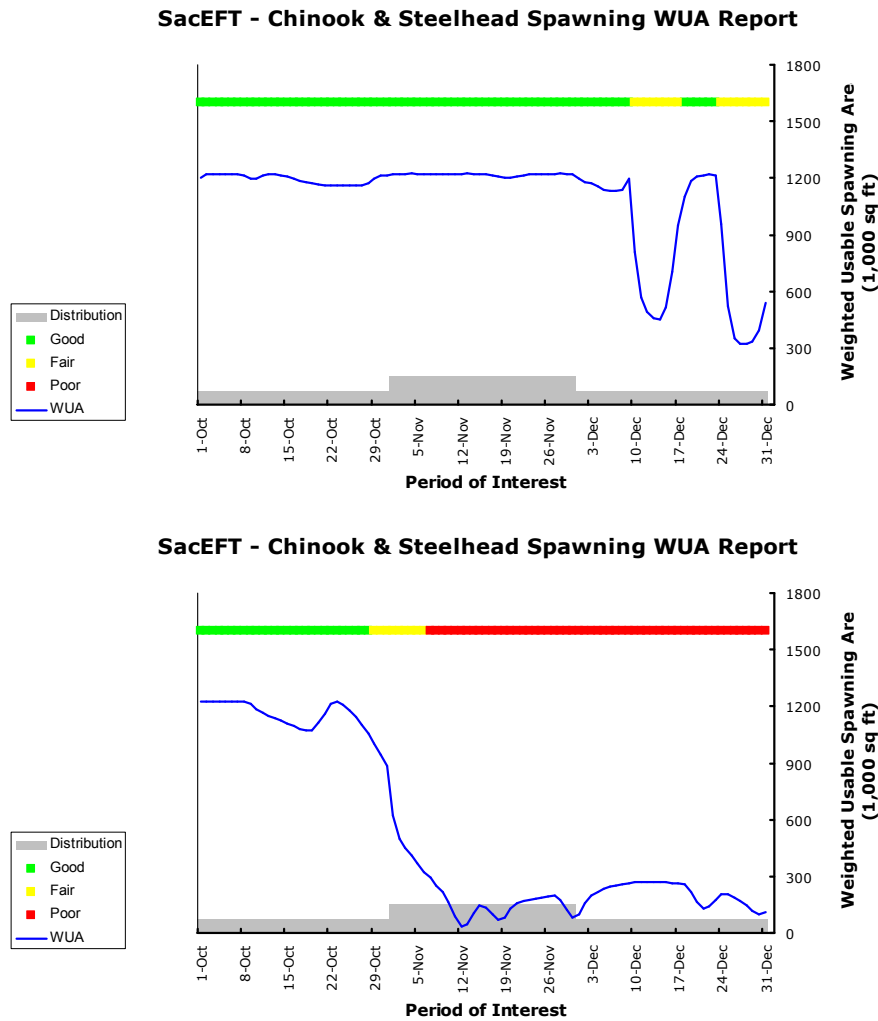


Figure 4.10. The CS1 – Spawning WUA daily Performance Measure as implemented in SacEFT Version 2. The upper and lower panels show results for fall-run Chinook in Reach 2 in 1969 and 1974: Good and Bad years respectively. In each panel, the horizontal **R/Y/G** bar shows the scoring of daily cohorts relative to the distribution of all day-cohorts over all years. To save space, the figure excludes a comparative graph of discharge which is produced as part of the Excel report. It also excludes an additional graph of field data showing redd proportion by reach for the period 1989-1994.

## Indicator Threshold Calibration

Based on model behavior using historical flow and temperature, the indicator rating thresholds for Spawning WUA are shown in Table 4.9. The indicator and its rating calibration have units of square feet of spawning habitat. The breakpoints for the *Daily Indicator* rating for each run-type are based on the estimated daily WUA over all reaches over all days of the spawning period, over all years. Typically, several thousand simulation observations contribute to the sorted daily WUA distribution. Run-types with longer spawning periods have a longer period to accumulate WUA and therefore have more observations and higher breakpoint values, other conditions being equal. The primary *Rollup Indicator* rating is based on a daily average across all reaches over all years, and there are typically a few dozen simulated observations for the distribution of this indicator; one for each simulation year.<sup>1</sup>

In the case of Spawning WUA, differences between the indicator rating breakpoints of the five run-types are notable, and can vary by a factor of 50. Besides differences in flow regime and substrate preferences, this large range is due to differences in the number of reaches and the length of the spawning periods amongst the run-types. The great difference in scales among run-types is part of the rationale for using independent breakpoints for each run. Readers are also reminded that the indicator is a measure of habitat potential (availability) and not a population of spawners or number of redds.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance. However, our repeated survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.*; Matt Brown, USFWS, *pers. comm.*) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for Spawning WUA. Because of this gap and the hesitancy of experts to reveal their opinions, we instead calculated the sorted distribution of weighted annual results and selected terciles (the lower-, middle- and upper thirds of the sorted distribution) as an initial reference to categorize the results.

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. In the last column of Table 4.9 we attempt to flag cases where there are major gradients in performance indicator thresholds.

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<sup>1</sup> We have also defined and calibrated an *Annual Indicator* rating based on calculating an *average* daily value for each reach. This indicator is calculated in SacEFT Version 2 and results are stored in the database, but are not currently presented in any of the output reports. For the Annual Indicator, the contribution of each daily value to the average is weighted by the proportion of the spawning population present on each day. Since a typical spawning period is about 100 days (see Table 2.7 for details), Annual Indicator thresholds for Spawning WUA are about 1% of the Daily Indicator thresholds, and there are typically about 100 simulated observations in the distribution, depending on the number of years and reaches available for simulation. The Annual and Rollup indicator ratings have a similar numerical ranges for each run-type, but are not identical, since the calculated breakpoints use observations of simulation results which are near, but hardly ever exactly identical for the 33% and 67% percentiles of the two sorted distributions.

Table 4.9. CS1 - Spawning WUA indicator rating breakpoints used for Version 2.

|                       | Daily     |           | Rollup    |           | Notes   |
|-----------------------|-----------|-----------|-----------|-----------|---|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |   |
| Winter-run Chinook    | 430060    | 195486    | 2880      | 2475      | <ul style="list-style-type: none"> <li>Criteria: statistical distribution, terciles, "more" is better</li> <li>Units: square feet</li> <li>Flow, spawning period, habitat preferences, affect distribution</li> </ul> |
| Spring-run Chinook    | 607975    | 217913    | 5825      | 4775      |   |
| Fall-run Chinook      | 1006472   | 29967     | 8470      | 5500      |   |
| Late-fall-run Chinook | 520424    | 280581    | 4250      | 2760      |   |
| Steelhead             | 18692     | 13447     | 135       | 106       |   |

## CS2 – WEIGHTED USABLE AREA FOR REARING

Rearing WUA is calculated using daily cohorts of juveniles after emergence, for each run-type and river segment. The historical or simulated gauges provide daily average flow ( $Q$ ) and daily average temperature over the rearing residency period ( $D$ ) for each location ( $l$ ) and run-type ( $r$ ) combination.

Daily juvenile rearing weights are notably different from daily spawning weights. In the case of rearing weight, each day-cohort is the result of the temperature-driven egg-emergence function instead of a deterministic spawning-calendar. This creates a linkage to the spawning performance measures CS1, with a delay between the day on which a cohort of eggs is spawned and the day on which the cohort emerges. Over the year the juvenile distribution is created by adding each daily juvenile cohort ( $c_e$ ) from its date of emergence ( $e$ ) using a run-type-dependent residence period ( $r$ ) after emergence, with the variable  $r$  set to 90 days for all Chinook run-types and 365 days for steelhead. The proportion of juveniles ( $w_d$ ) present on any given day ( $d$ ) is therefore given as the sum of all emerged day-cohorts less than  $r$  days old:

$$w_d = \sum c_e \quad \text{where } (e \leq d), \text{ and } ((e + r - 1) \leq d)$$

The emergence function makes it possible to have multiple spawning day cohorts emerge on the same day, particularly during periods of warming water. After emergence, each juvenile day-cohort is followed for a residency period of  $r$  days, providing an internally consistent way of evaluating both juvenile rearing WUA and juvenile stranding (CS4). Since emergence is driven by Accumulated Thermal Units (ATUs; see the CS3 description on pg. 63 for further information), this distribution will vary across locations and years due to location and temperature variations. After  $r$  days have elapsed, the day-cohort is no longer tracked. SacEFT does not track movement of cohorts between reaches, and during their residence period they are assumed to remain in the reach they were spawned.

The *daily* PM is computed by interpolating the WUA-flow relationship  $f(l,r,Q)$  (which for rearing does *not* vary with substrate composition) to predict Weighted Usable Area for rearing (WUA, square feet). Prior events such as thermal mortality or redd dewatering are not accounted for by this PM, which measures rearing area only. Linear interpolation is used to calculate rearing WUAs between the tabular values found in Gard's studies (U.S. Fish and Wildlife Service 2005b). As already noted, while each model operates internally on the basis of a daily cohort, the distributional and cumulative results shown in the Excel report portray the aggregated juvenile day-cohorts present each day and use that proportion to scale the Indicator Rating assigned to the WUA. This makes it possible to see daily changes to the entire population in the face of fluctuations in flow and temperature (see Figure 4.11), even though internally, each day-cohort is tracked separately.

The *rollup* PM is computed by averaging across all locations ( $L$ ). An average is used rather than a sum, so that thresholds are more meaningful should the number of locations vary across years and/or run-types, based upon the availability of the underlying flow and water temperature data.

$$CS2_r = \frac{1}{L} \sum_{l=1}^L \left( \sum_{d=1}^D f(l,r,Q_d) w_d \right)$$

Breakpoints for the **R****Y****G** Indicator Ratings are taken using terciles of the sorted river-segment distribution for the daily and annual results, and using discontinuities in the annual distribution for the rollup.

**Indicator Reliability**

The indicator credibility rankings for CS2 are shown in Table 4.10.

Table 4.10. CS2 – Rearing WUA indicator credibility assignments following the workshop. These ratings apply to those reaches of the Sacramento River where data have been directly acquired for the indicated run types (*i.e.*, depth, velocity, preference curves). If relationships derived from one reach are applied to another reach, both the U and R scores reduced, since the channel cross-section could lead to different curves of Rearing WUA vs. flow.

|                       | Category |   |   |   |   |
|-----------------------|----------|---|---|---|---|
|                       | I        | U | R | F | P |
| Winter-run Chinook    |          | H | H | H | H |
| Spring-run Chinook    |          | M | M | H | M |
| Fall-run Chinook      |          | H | H | H | H |
| Late-fall-run Chinook |          | H | H | H | H |
| Steelhead             |          | M | M | H | M |



## Excel Reports

An example of the Version 2 Excel report is shown in Figure 4.11. The relative performance of a specific reach year can be compared with the historical range of Rearing WUA, by comparing the purple cumulative PM line to the vertical R/Y/G bar on the right of each graph. The vertical R/Y/G bar shows the distribution of annual rollup values across all years and reaches. The daily distribution is shown by the horizontal R/Y/G bar at the top of each pane.

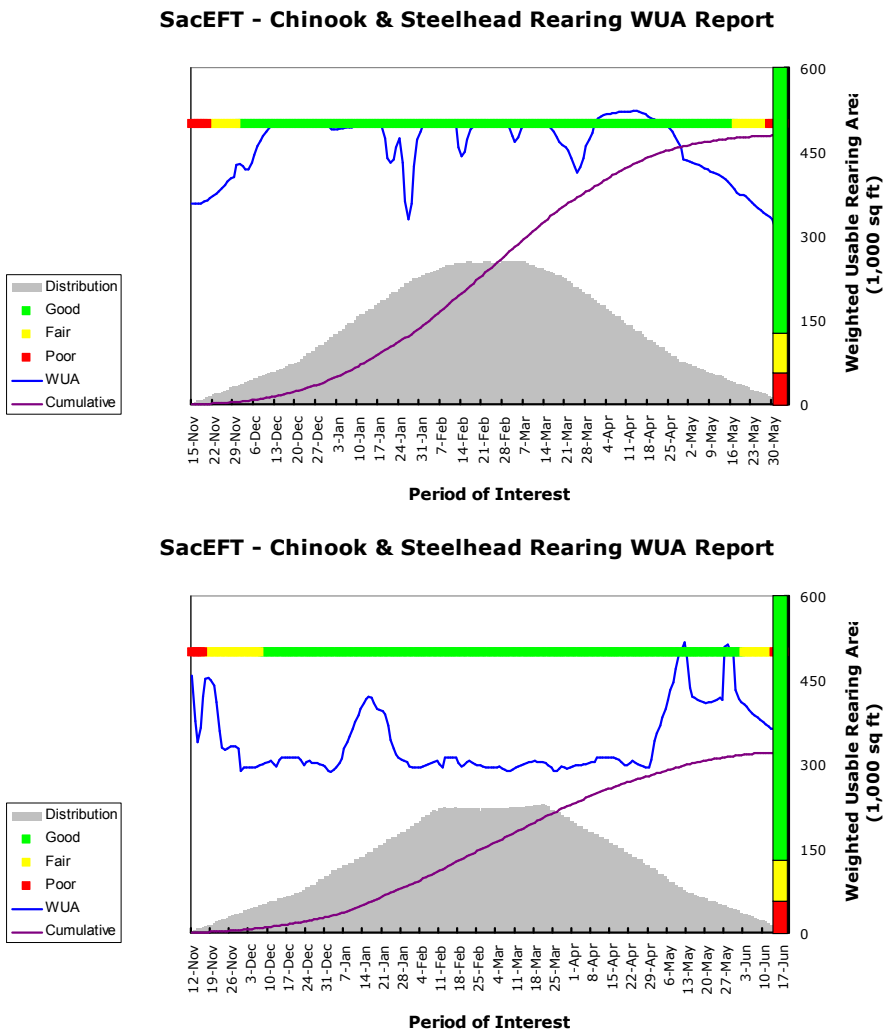


Figure 4.11. An example of the Version 2 Excel report for CS2 – Chinook juvenile rearing WUA using fall-run Chinook from Reach 5 in 1981 and 1982 in the upper and lower panels, respectively. The purple cumulative distribution lines show that Reach 5 receives a Good (Green) ranking relative to all reaches in both years. But because some other reaches scored poorly in one of the two years, *system-wide* 1981 was a Good (Green), while 1982 was a Bad (Red) year. To save space, the figure excludes a comparative graph of discharge which is produced as part of the Excel report.

## Indicator Threshold Calibration

Based on model behavior using historical flow and temperature, the indicator rating thresholds for Rearing WUA are shown in Table 4.11. The indicator and its rating calibration have units of square feet of rearing habitat. The breakpoints for the *Daily Indicator* rating for each run-type are based on the estimated daily WUA over all reaches over all days of the juvenile rearing period, over all years. For Rearing WUA, the observation for each simulation day is weighted by the proportion of the total population present in each day-cohort, meaning that days with more emerging juveniles are given more importance, but longer spawning and residency periods do not contribute to the magnitude of the indicator. Typically, several thousand simulation observations contribute to this sorted daily distribution. The primary *Rollup Indicator* rating has units of “sum of daily square feet” and is based on calculating a *cumulative* daily value for each reach, over the residency period (typically 90 days for Chinook and 365 days for steelhead (see Table 2.7 for details)) for each simulation year, and then taking the average value over all the reaches to produce an annual average value. The practice of using a cumulative total for this indicator leads to much larger indicator values for the Rollup, and there are typically a few dozen simulated observations for the distribution of this indicator; one for each simulation year.

In the case of Rearing WUA, there is about a two-fold range among the breakpoints of the five run-types. These differences are due to differences in the flow regime and number of reaches for each run-type. Difference in scales among run-types is part of the rationale for using independent breakpoints for each run. Readers are also reminded that the indicator is a measure of potential habitat (availability) and not a population of juveniles.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance. However, our repeated survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.*; Matt Brown, USFWS, *pers. comm.*) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for Rearing WUA. Because of this gap and the hesitancy of experts to reveal their opinions, we instead calculated the sorted distribution of weighted annual results and selected terciles (the lower-, middle- and upper thirds of the sorted distribution) as an initial reference to categorize the results.

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. In the last column of Table 4.11 we attempt to flag cases where there are major gradients in performance indicator thresholds.

Table 4.11. CS2 – Rearing WUA indicator rating breakpoints.

|                       | Daily     |           | Rollup    |           | Notes   |
|-----------------------|-----------|-----------|-----------|-----------|---|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |   |
| Winter-run Chinook    | 39675     | 10987     | 10250137  | 9997544   | <ul style="list-style-type: none"> <li>• Criteria: statistical distribution, terciles, “more” is better</li> <li>• Daily units: square feet</li> <li>• Rollup units: cumulative square feet</li> <li>• Flow, number of reaches affect distribution</li> </ul> |
| Spring-run Chinook    | 109294    | 33678     | 24800719  | 19200148  |   |
| Fall-run Chinook      | 51872     | 20539     | 18341766  | 14048587  |   |
| Late-fall-run Chinook | 47481     | 18283     | 13306025  | 11936239  |   |
| Steelhead             | 49501     | 14292     | 18160595  | 16361215  |   |

### CS3 – EGG-TO-FRY THERMAL MORTALITY

Temperature contributes to two opposing processes in SacEFT. Warmer water makes development faster through the temperature-maturation relationship discussed below, reducing the period of exposure to thermal (and other sources of) mortality. At the same time, development in warmer water produces higher thermal mortality.

Maturation is driven by Accumulated Thermal Units (ATUs) calculated from daily temperature. Following the model review workshop we enhanced the ATU calculation originally derived from SALMOD. Based on a review of Myrick and Cech (2010), Version 2 uses Chinook and rainbow trout (*Salmo gairdneri* = *O. mykiss*) relationships developed by Crisp (1981). Besides providing a unique set of steelhead coefficients, the coefficients adopted for Version 2 are also improved for Chinook, since those in Version 1 were interpolated from enlarged drawings found in the SALMOD documentation (Bartholow and Heasley 2006)<sup>1</sup>, and those in Version 2 are taken directly from Crisp’s models, where  $\delta$  is the total days of egg development time at temperature  $T$  (°C) (see Figure 4.12):

$$\log_{10} \delta = -1.8126 \times \log_{10}(T + 6) + 3.9166 \quad \text{Chinook}$$

$$\log_{10} \delta = -2.0961 \times \log_{10}(T + 6) + 4.0313 \quad \text{Steelhead}$$

Proportion maturation per day is then the reciprocal of  $\delta$ . The original SALMOD functions remain in the EFT model and can be used in a run scenario, if desired.

Given a development period determined by temperature, daily egg survival is calculated using daily egg cohorts over their development period ( $\delta$ ) following spawning, for each combination of location ( $l$ ) and run-type ( $r$ ). Survival  $s(T)$  declines at warmer temperature (Table 11, Bartholow and Heasley 2006; see Figure 4.13 ). Chinook and steelhead use a **common** thermal mortality relationship, following Myrick and Cech (2010; see Figure TT.5 and TT.6), who conclude that any notion of run-type-specific mortality for steelhead is more closely related to what they term “genetic strains”, and that the very wide range in mortality makes it very difficult to predict steelhead egg mortality with any precision.

<sup>1</sup> **Note:** Over the course of model development we also evaluated the USBR egg mortality model but later adopted SALMOD models since that model corrected some mathematical errors present in the USBR model we examined.

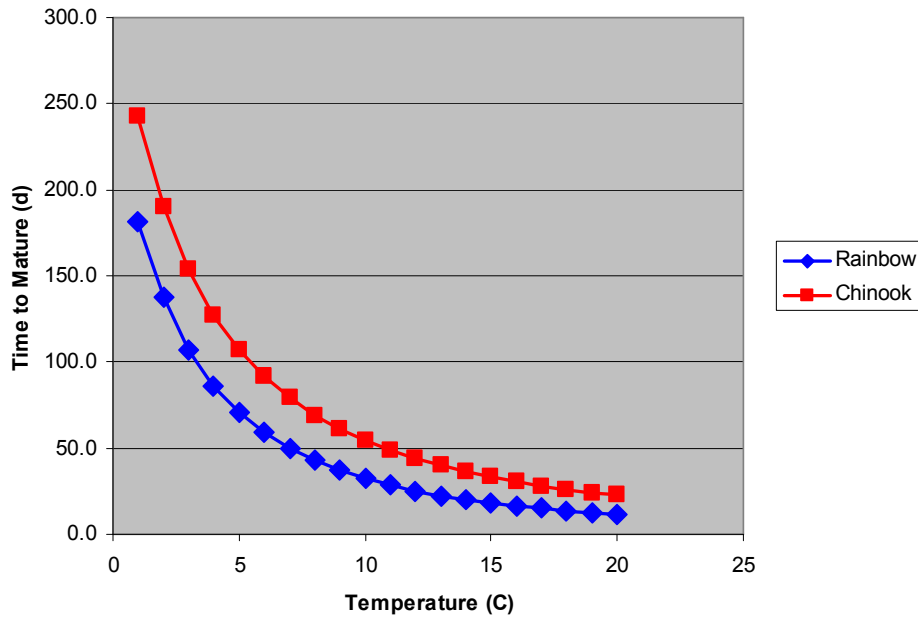


Figure 4.12 Based on relationships developed by Crisp (1981) for Chinook salmon and rainbow trout (= steelhead), eggs at a given temperature will mature in a corresponding number of days. The reciprocal of the number of days is the proportion of maturation occurring over one day, and the maturation period ( $\delta$ ) is complete when the cumulative proportion of daily maturation reaches 1.0.

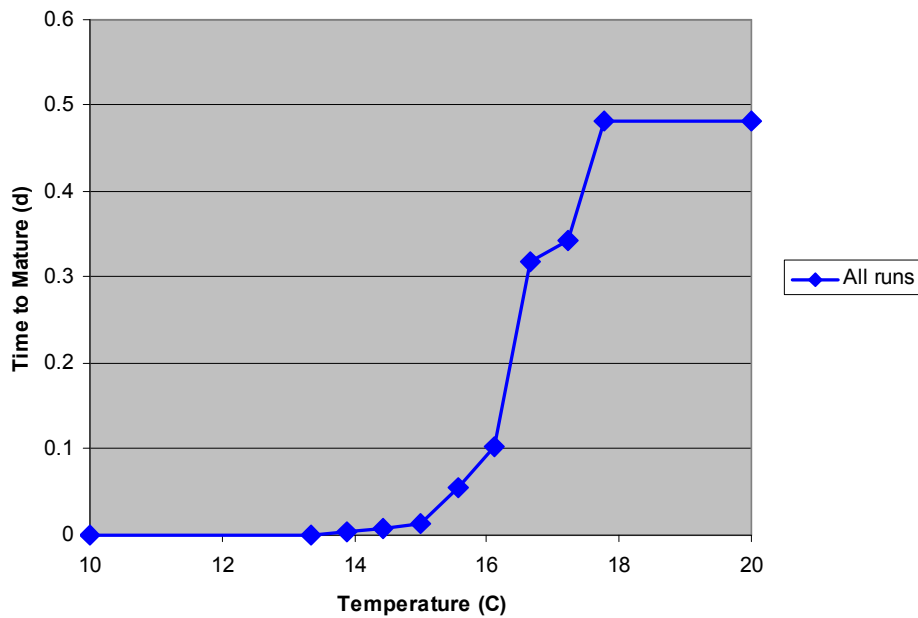


Figure 4.13 Daily thermal mortality is based on SALMOD relationships for all species (Bartholow and Heasley, 2006).

As noted above, longer egg development in colder water also increases the cumulative exposure to other potential mortality sources, a set of processes not accounted for in SacEFT. The influence of each day-cohort is expressed as the proportion ( $w_d$ ) spawning each day over the egg development period. Unlike the Rearing WUA performance measure, which shows relative abundance of rearing salmonids, the Excel

Report for egg survival portrays the spawning-day distribution only and not the relative abundance of in-gravel eggs.

The *daily* PM is calculated by following each spawning day-cohort over the course of its development up to emergence, evaluating its daily survival  $s(T)$  as a function of water temperature and taking the product of daily survival. Exposure to events such as redd dewatering are not accounted for by this PM, which calculates thermal mortality only:

$$CS3_{l,r,d} = \prod_{\delta} s(T)$$

The *rollup* PM is calculated by averaging over all river segments ( $L$ ), weighting each segment by the using the average proportion of total spawning WUA (CS1) for the segment relative to the river-wide average Spawning WUA.

$$CS3_r = \sum_{l=1}^L \left( \frac{CS1_{x,l}}{CS1_x} \right) \left( \sum_{d=1}^D w_d \prod_{\delta} s(T) \right)$$

### Indicator Reliability

The indicator credibility rankings for CS3 are shown in Table 4.12.

Table 4.12. CS3 – Egg thermal mortality indicator credibility assignments following the workshop.

|                       | Category <sup>1</sup> |   |   |   |     |
|-----------------------|-----------------------|---|---|---|-----|
|                       | I                     | U | R | F | P   |
| Winter-run Chinook    |                       | H | H | H | H   |
| Spring-run Chinook    |                       | H | H | H | H   |
| Fall-run Chinook      |                       | H | H | H | H   |
| Late-fall-run Chinook |                       | H | H | H | H   |
| Steelhead             |                       | H | M | H | M/H |

<sup>1</sup> see Table 2.3 for category definitions.

## Excel Reports

The Excel Report for Egg-to-fry Thermal Mortality (CS3) follows the style of the Rearing WUA (CS2) report shown in Figure 4.14, using a vertical bar to show the distribution of the annual rollup for the PM. Note that the orientation of the vertical **R/Y/G** bars are reversed in these two reports, since “more Rearing WUA” is better, but “more Thermal Mortality” is worse. The report shows two graphs. The upper panel shows the spawning-day distribution in gray, the incubation period mortality for each day cohort and the cumulative population mortality across all cohorts. The lower graph shows daily temperatures and R and Y thresholds for daily mortality. The x-axes are identical and span the first day of spawning to the last date of emergence. Note that the incubation period for a day-cohort is typically around 100 days and therefore the mortality for a day-cohort spawned on day  $t$  (and graphed on day  $t$ ) can be high due to increased temperatures and higher mortality at a later date (for example day  $t+50$ ).

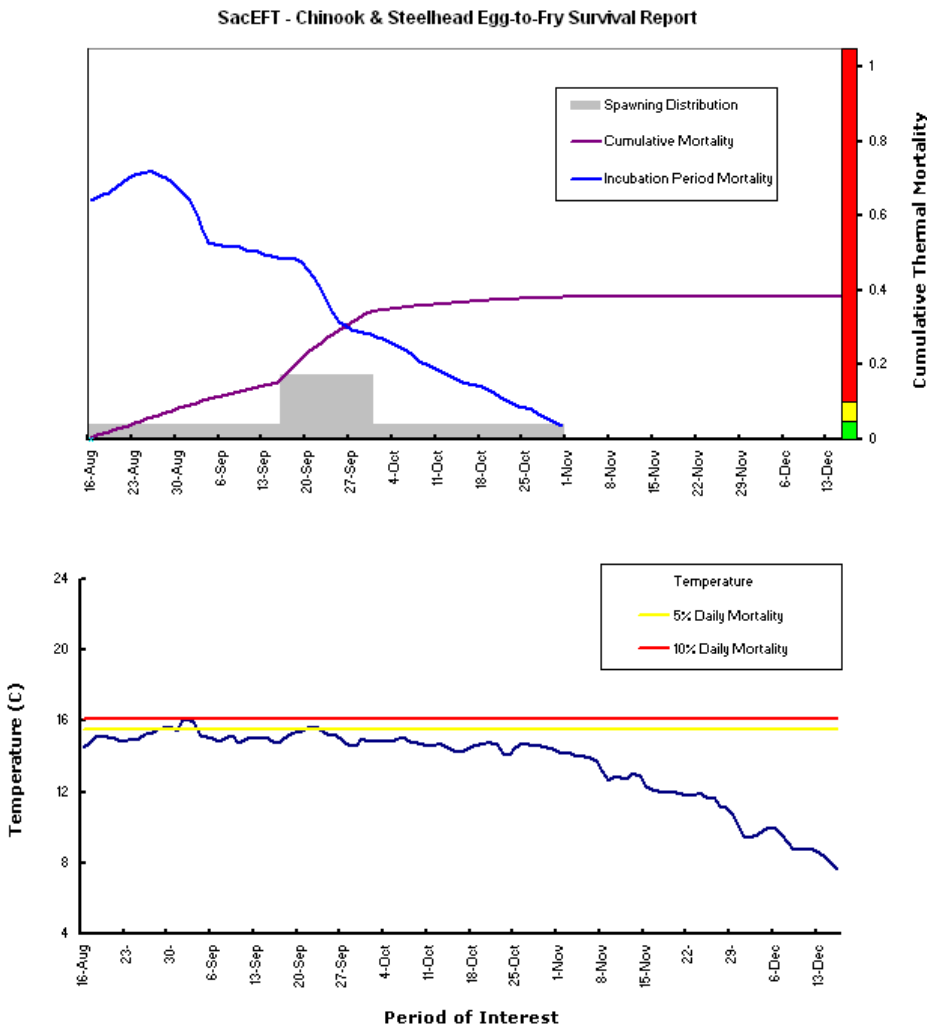


Figure 4.14. An example of the Version 2 Excel Report for CS3 – Egg-to-fry thermal mortality using spring-run Chinook from Reach 4 in 1988. System-wide this year was reported as a **Red** year. To save space, the figure excludes some of the additional explanatory text that accompanies the Excel report.

## Indicator Threshold Calibration

Based on absolute mortality values of 5% and 10%, the Indicator Rating boundaries for Egg-to-fry thermal mortality are shown in Table 4.13. The same units and values are used for *Daily* and *Rollup* indicator ratings. The rationale for this choice of indicator at all scales is that it has an unambiguous meaning, in contrast to other indicators which are either more abstract, or are unit-free indices. Readers should note that 5% mortality at the Daily indicator scale means that 5% of the eggs spawned on that day and in that reach will die because of elevated temperature. At the Rollup level, the same number means that 5% of the entire multi-reach population of eggs will die in that year, due to elevated temperature.

The *Daily* indicator is calculated by accumulating thermal mortality over the egg-development period, which is determined by spawning day and water temperature, and differs for Chinook and steelhead. The *Rollup* indicator has the same units as the Daily rating, goes one step further and calculates an annual average across all reaches, using the relative amount of Spawning WUA in each reach to calculate a weighted average. There are typically a few dozen simulated observations for the distribution of this indicator.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance. However, our repeated survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.*; Matt Brown, USFWS, *pers. comm.*) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for Egg-to-fry thermal mortality. Neither are there universally accepted mortality levels – conceptually similar to LD<sub>50</sub> values for pollutants – for measuring the impact of thermal mortality. Because of this gap and the hesitancy of experts to reveal their opinions, we instead chose arbitrary mortality breakpoints of 5% and 10% as initial reference points to categorize the results.

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. In the last column of Table 4.13 we attempt to flag cases where there are major gradients in performance indicator thresholds.

Table 4.13. CS3 – Egg-to-fry Thermal Mortality indicator rating breakpoints.

|                       | Daily     |           | Rollup    |           | Notes   |
|-----------------------|-----------|-----------|-----------|-----------|---|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |   |
| Winter-run Chinook    | 5         | 10        | 5         | 10        | <ul style="list-style-type: none"> <li>Criteria: absolute values, “less” is better</li> <li>Units: % mortality</li> <li>Common threshold for all run-types</li> </ul> |
| Spring-run Chinook    | 5         | 10        | 5         | 10        |   |
| Fall-run Chinook      | 5         | 10        | 5         | 10        |   |
| Late-fall-run Chinook | 5         | 10        | 5         | 10        |   |
| Steelhead             | 5         | 10        | 5         | 10        |   |

## CS4 – JUVENILE STRANDING

Juvenile stranding is modeled using daily declining changes in discharge ( $Q$ ) over the juvenile rearing period ( $D$ ) for each location ( $l$ ) and run-type ( $r$ ) combination. The daily distribution of rearing juveniles is based on the emergence function and the distribution ( $c_e$ ) derived for juvenile rearing WUA (*i.e.*, from CS2). In the case of juvenile stranding the daily weight ( $w_d$ ) is conditioned on events that take place as the cohort ages through the subsequent juvenile residency period. In particular, a daily cohort may experience losses (as described in the next section) when the flow declines from one day to the next. The cohort weight on a given day  $c_{e,d}$  becomes:

$$c_{e,d} = \begin{cases} c_e & \text{when } (e \leq d < (e+1)) \\ c_e \left( 1 - \sum_{i=e+1}^{d-1} f(l, Q_{i-1}, Q_i) \right) & \text{when } (e < (d-1)) \text{ and } ((e+j-1) \leq d) \\ 0.0 & \text{otherwise, e.g. when } ((e+j-1) < d < e) \end{cases}$$

By definition, no losses occur on the day a cohort emerges. If a drop occurs on the second day the loss is accounted for at the end of the second day, causing the cohort weight to decline on the third day ( $e=1$ ,  $d=3$ ). In SacEFT Version 2, Chinook juveniles reside in their natal reach for 90 days; steelhead for 365 days. Over this residency period, declining flows affect each day-cohort in a cumulative fashion. Based upon the formula above, the weight ( $w_d$ ) for any given day is then assigned to the sum of all the cohort weights that are present on that day:

$$w_d = \sum c_{e,d}$$

The *Daily* indicator uses Gard's juvenile stranding research (U.S. Fish and Wildlife Service 2006b) to estimate the proportional decrease in habitat over the period between juvenile emergence and the end of the juvenile residence period. Mark Gard kindly made his raw results available to us so that his system-level tables could be disaggregated to the reach level used by SacEFT. Gard's results do not include time explicitly. Rather, his model estimates the proportion of rearing WUA lost (if any) at each location ( $l$ ) between the day of emergence and the end of the residency period. Although run-types are modeled separately in SacEFT, they all use a single all-species flow-decline relationship. Based on discussions with Gard, we adapted this relationship in a way that is mathematically consistent with the original results, but which can be disaggregated to the daily scale of the juvenile stranding model. To calculate the daily PM, the model compares the previous day's flow,  $Q_{d-1}$ , and the flow on day  $Q_d$ . If there is a drop, then some proportion of juveniles are potentially stranded:  $f(l, Q_{d-1}, Q_d)$ , and bilinear interpolation is used to calculate proportional losses between the tabular values found in Gard's tables (U.S. Fish and Wildlife Service 2006b).



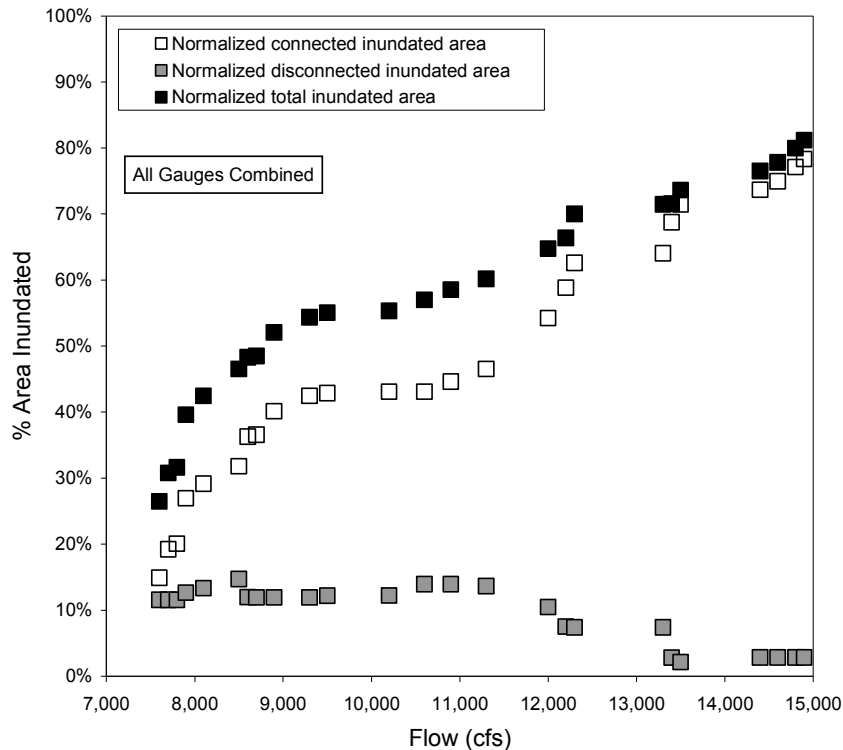


Figure 4.15. Normalized connected (white symbols), disconnected (gray symbols), and total inundated area (black symbols) averaged over all study sites for varying flows on the Sacramento River. Each site is normalized by the maximum potential inundated area, such that they each have equal weight in determining average percent inundated area. The stepped pattern of area versus flow highlights what appears to be a significant river-wide increase in inundated area at about 12,000 cfs. A significant decrease in inundated area appears to occur at roughly 8,500 cfs (Stillwater Sciences 2007; p. 33).

During the Version 1 model review workshop, the salmon sub-group agreed that while the structure of the indicator is good, its usefulness is constrained by the absence of stranding relationships *below Red Bluff Diversion Dam*. Many juveniles are known to rear in these lower portions of the river and it would be useful to have stranding relationships for these locations as well as the more upstream segments. We explored pre-existing datasets from side channel studies described in the Stillwater Sciences (2007) (Figure 4.15). Mark Gard (USFWS, *pers. comm.*) has suggested that these might be adapted to the tabular model structure adopted for the U.S. Fish and Wildlife Service (2006b) report, and that the “normalized disconnected inundated area” from this figure corresponds most closely to the methodology used to estimate stranding at upstream locations. We compared the Stillwater range of data to Gard’s and found that the flows shown in the Stillwater results are much higher than those measured in Gard’s studies. This discontinuity makes it hard to see how downstream locations could be included in a comparable way. Even if this were possible, there is an additional data gap between 3,750 cfs (below which stranding will never be a problem) and 7,500 cfs, the lowest flow value shown in Figure 4.15. Thus, stranding relationships below Red Bluff Diversion Dam remain a model gap.

The daily proportional changes to rearing habitat create an *index* of stranding potential which is calculated by using the sum of proportions lost over the residency period, but which is not synonymous with the proportion of the juveniles lost. Because juveniles are mobile and may possess behaviors that help them avoid stranding (unlike eggs in redds), the use of an index of stranding potential is more appropriate, even though the underlying model measures declining fluctuations in rearing WUA.

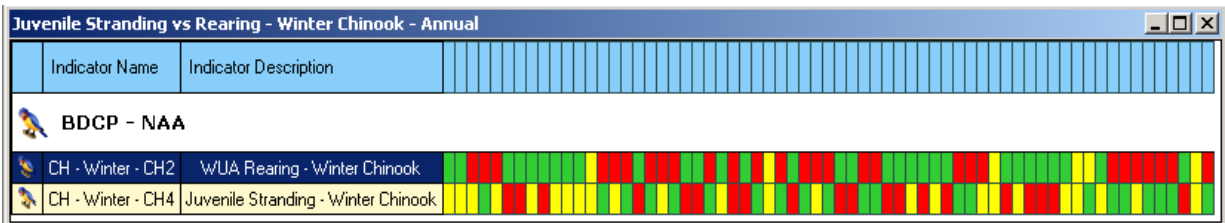
The *Rollup* indicator for juvenile stranding is calculated by taking the average across locations ( $L$ ). An average is used rather than a sum, so that thresholds are more meaningful should the number of locations vary across years and/or run-types, based upon the availability of the underlying flow and water temperature data.

$$CS4_r = \frac{1}{L} \sum_{l=1}^L \sum_{i=1}^D (c_{i,D+1} - c_{i,D})$$

Breakpoints for the **R/Y/G** Indicator Ratings are taken using terciles of the sorted river-segment distribution for the daily and annual results, and using discontinuities in the annual distribution for the rollup.

**Comment on Correlated CS2 and CS4 Behavior**

In a review of 6 BDCP scenarios carried out with Version 2, an apparent negative correlation between juvenile rearing (CS2) and juvenile stranding (CS4) was reported for some run-types:



Our analysis found that the negative correlation arises from the fact that the amount of potential rearing habitat is used as an **input** to weight the impact of juvenile stranding, making it inevitable that as more habitat is created (regardless of the details of the daily flow regime and the exact nature of the flow-stage recession relationship) it exposes proportionally more juveniles to stage-flow recession events when they inevitably occur. Since increased WUA Rearing area results in a **Green** Indicator Rating while an increased Stranding Index results in a **Red** Indicator Rating, the two measures become negatively correlated. A more complete analysis of this negative correlation is found in Robinson (2010).

**Indicator Reliability**

The indicator credibility rankings for CS1 are shown in Table 4.14.

Table 4.14. CS4 – Juvenile stranding indicator credibility assignments following the workshop.

|                       | Category |     |   |   |     |
|-----------------------|----------|-----|---|---|-----|
|                       | I        | U   | R | F | P   |
| Winter-run Chinook    |          | M/H | H | H | M/H |
| Spring-run Chinook    |          | M/H | H | H | M/H |
| Fall-run Chinook      |          | M/H | H | H | M/H |
| Late-fall-run Chinook |          | M/H | H | H | M/H |
| Steelhead             |          | M/H | H | H | M/H |

### Excel Reports

An example of the Version 2 Excel report is shown in Figure 4.16. The relative performance of a specific reach and year can be compared with the historical range of the Juvenile Stranding index, by comparing the purple cumulative PM line to the vertical R/Y/G bar on the right of each graph. The vertical R/Y/G bar shows the distribution of annual rollup Stranding values across all years and reaches. The daily distribution is shown by the horizontal R/Y/G bar at the top of each pane.

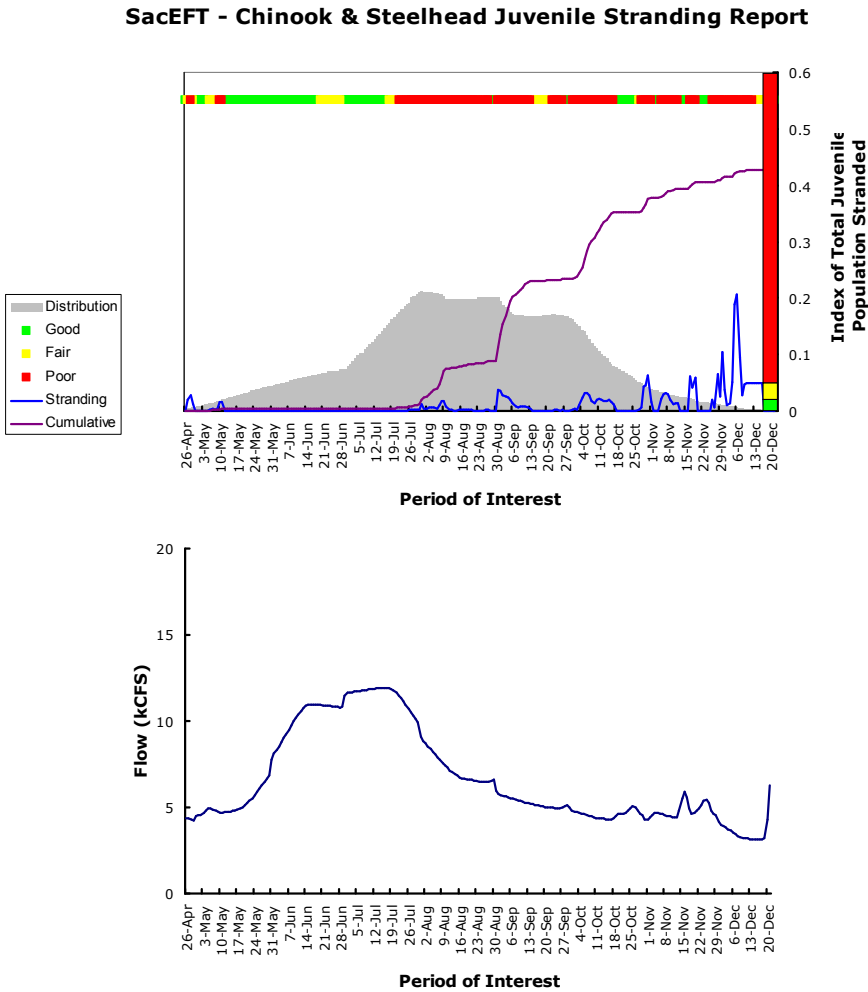


Figure 4.16. Excel Report for CS4 – Juvenile Stranding, showing winter-run Chinook in Reach 5 for 1979. The index is very sensitive to declining changes in flow, even though the discharge is quite low. The upper horizontal bar shows the index R/Y/G score relative to the daily scoring across all reaches and years; the vertical horizontal R/Y/G shows the cumulative distribution of the reach and year relative to the annual rollup distribution. The impact of stranding index upon the juvenile distribution can be seen in the quick declines of the bell-shaped gray distribution that accompany drops in flow, coupled to a sharp jump in the Stranding index.

## Indicator Threshold Calibration

Based on model behavior using historical flow and temperature, the indicator rating thresholds for Juvenile Stranding are shown in Table 4.15. The indicator and its rating calibration are treated as dimensionless index, although technically it is a sum of proportional changes in rearing area. The breakpoints for the *Daily Indicator* rating for each run-type are based on the estimated daily proportional change in rearing area over all reaches over all days of the juvenile rearing period, over all years. Each simulation day's observation is weighted by the proportion of the total rearing population present in each day-cohort, meaning that days with more juveniles are given more importance, with longer residency periods also contributing to the magnitude of the indicator. Typically, several thousand simulation observations contribute to this sorted daily distribution. The primary *Rollup Indicator* rating is also a dimensionless index, and is based on calculating a *cumulative* daily value for each reach, over the residency period (typically 90 days for Chinook and 365 days for steelhead (see Table 2.7 for details)) for each simulation year, and then taking the average value over all the reaches to produce an annual average value. The practice of using a cumulative total for this indicator leads to much larger indicator values for the Rollup, and there are typically a few dozen simulated observations for the distribution of this indicator; one for each simulation year.

In the case of Juvenile Stranding, there is about a two-fold range among the breakpoints of the five run-types. These differences are due to differences in the flow regime and number of reaches for each run-type. There are also some notable differences within run-types. For example, most run-types have lower and upper rollup thresholds that differ by about a factor of two (e.g., 0.08 and 0.16 for winter-run Chinook). But in the case of late-fall Chinook, the difference in thresholds is much smaller (0.06 and 0.08), making the assignment more sensitive to small changes. The biological importance of this difference is unknown: it is simply a measure of the narrower historical range of fluctuations during the late-fall Chinook juvenile residence period. Difference in scales among run-types is part of the rationale for using independent breakpoints for each run. Readers are reminded that the indicator is a measure of potential habitat change (availability) and not a measure of actual stranding.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance. However, our repeated survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.*; Matt Brown, USFWS, *pers. comm.*) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for Juvenile Stranding. Because of this gap and the hesitancy of experts to reveal their opinions, we instead calculated the sorted distribution of weighted annual results and selected terciles (the lower-, middle- and upper thirds of the sorted distribution) as an initial reference to categorize the results.

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. In the last column of Table 4.15 we attempt to flag cases where there are major gradients in performance indicator thresholds.

Table 4.15. CS4 – Juvenile Stranding indicator rating breakpoints.

|                       | Daily     |           | Rollup    |           | Notes  |
|-----------------------|-----------|-----------|-----------|-----------|--|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |  |
| Winter-run Chinook    | 4.517E-05 | 3.528E-04 | 0.0804    | 0.1622    | <ul style="list-style-type: none"> <li>Criteria: statistical distribution, terciles, “less” is better</li> <li>Daily units: index</li> <li>Rollup units: cumulative index</li> <li>Flow, number of reaches affect distribution</li> <li><i>Late-fall-run may be more sensitive-responsive</i></li> </ul> |
| Spring-run Chinook    | 1.483E-04 | 8.852E-04 | 0.1472    | 0.2738    |  |
| Fall-run Chinook      | 1.083E-04 | 5.476E-04 | 0.1299    | 0.2161    |  |
| Late-fall-run Chinook | 6.330E-05 | 2.249E-04 | 0.0654    | 0.0814    |  |
| Steelhead             | 9.964E-05 | 1.202E-03 | 0.1255    | 0.1845    |  |

## CS5 – REDD SCOUR

Redd scour risk is modeled using the daily proportion of eggs present by run type ( $r$ ) and location ( $l$ ) coupled to categorical hazard classes at times when flow exceeds user-configured threshold values. Threshold values that correspond to the 90<sup>th</sup> percentile of 10-year peak flow (75,000 cfs) and 80<sup>th</sup> percentile of 5-year peak flow (55,000 cfs) define the Fair/Poor and Good/Fair thresholds, respectively. The model couples these thresholds to each run-type’s spawning distribution and uses the ATU-driven emergence function (see Figure 4.12) to create an aggregated egg distribution based on day-cohorts. In a final step, the daily weight is scaled by the relative daily proportion of spawning WUA at the given location, as is done for CS3. Thus, the daily proportion of redds ( $w_d$ ) exposed to scour incorporates the joint influence of the original spawning distribution, temperature driven egg-development distribution and the proportion of total spawning WUA available in the reach.

*Daily* indicator values are calculated by multiplying the population-proportion weighted by daily flow. If flow is below the 55,000 cfs threshold, the daily indicator is given a value of zero. If flow exceeds the lower threshold, then the daily indicator is the product of the flow and the value ( $w_d$ ) of the incubation distribution for that day and reach. Annual *Rollup* values are calculated by using a WUA-weighted average of the cumulative sum of daily weights across all reaches, for each simulation year.

### Indicator Reliability

The PM scores shown in are generally lower than other salmonid PMs because they are based on more subjective opinions about scouring flow thresholds with no direct evidence. These scores are themselves only moderately quantitative, and are open to revision.

Table 4.16. CS5 – Redd scour indicator credibility assignments following the workshop.

|                       | Category |     |   |   |   |
|-----------------------|----------|-----|---|---|---|
|                       | I        | U   | R | F | P |
| Winter-run Chinook    |          | L/M | M | H | M |
| Spring-run Chinook    |          | L/M | M | H | M |
| Fall-run Chinook      |          | L/M | M | H | M |
| Late-fall-run Chinook |          | L/M | M | H | M |
| Steelhead             |          | L/M | M | H | M |

### Excel Reports

An example of the Version 2 Excel report is shown in Figure 4.17.

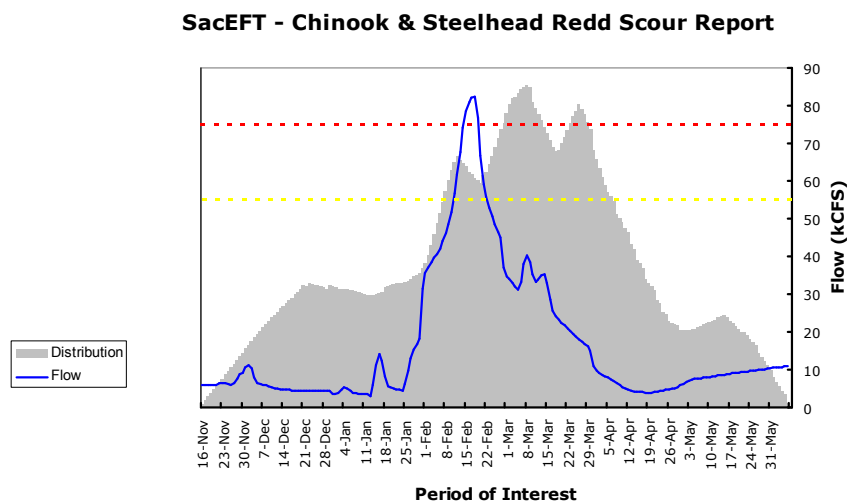


Figure 4.17. Excel Report for CS5 – Redd Scour risk, showing steelhead in Reach 4 for 1986. The Fair/Poor and Good/Fair thresholds are shown by dotted lines. System-wide, 1986 was a Poor year for steelhead scour risk.

### Indicator Threshold Calibration

Based on model behavior using historical flow and temperature, the indicator rating thresholds for Redd scour are shown in Table 4.17. The units of the *Rollup* indicators are flow (cfs)<sup>1</sup>. The calibration process for the Redd Scour indicator is based on critical flow threshold values suggested by the salmonid subgroup at the Version 1 review workshop, of 55,000 cfs and 75,000 cfs. These two flows represent the 80<sup>th</sup> percentile of 5-year peak main stem flow and the 90<sup>th</sup> percentile of 10-year peak main stem flow respectively. When daily flow is less than 55,000 cfs, the indicator is given a value of zero. On days when eggs are present and flows exceed this lower threshold, the daily indicator is the product of the flow and a weight given by the proportion of the total egg population present in each day-cohort. In this way, days with a higher proportion of eggs are given more importance, and longer spawning runs can potentially

<sup>1</sup> A *Daily* indicator is calculated for Redd Scour is calculated and stored in the SacEFT database, but is not currently displayed. This indicator is derived from the terciles of the sorted daily distribution of weighted flow, over all run-types, reaches and years.

expose the run-type to a wider range of flows. Daily weighted flows are subsequently processed using a set of flow-based rules. At the peak of the egg-distribution, a flow event above 75,000 cfs (*i.e.*, with a high daily indicator value from the product of flow and weight) is sufficient to give a **Poor** assignment to the year. In addition, years with more than 2 days of flow between 55,000 and 75,000 cfs are also assigned to the **Poor** class. Years with high flows in the tails of the distribution are assigned as **Fair** years, and all other years are considered **Good**. By iteratively adjusting the thresholds and evaluating the frequency of Bad years, rollup thresholds were set to 5,000 (**Good/Fair**) and 10,000 (**Fair/Poor**) cfs.

| Indicator Name                                | Indicator Description          | Create Report            | Multi-Year Rollup | % Poor | % Worrisome | % Good | All Data Shown |
|---|--------------------------------|--------------------------|-------------------|--------|-------------|--------|----------------|
| <b>VERSION 2 CALIBRATION RUN (HISTORICAL)</b> |                                |                          |                   |        |             |        |                |
| CH - Fall - CH5                               | Redd Scour - Fall Chinook      | <input type="checkbox"/> |                   | 39     | 0           | 61     | ✓              |
| CH - Late Fall - CH5                          | Redd Scour - Late Fall Chinook | <input type="checkbox"/> |                   | 26     | 0           | 74     | ✓              |
| CH - Spring - CH5                             | Redd Scour - Spring Chinook    | <input type="checkbox"/> |                   | 0      | 0           | 100    | ✓              |
| CH - Winter - CH5                             | Redd Scour - Winter Chinook    | <input type="checkbox"/> |                   | 3      | 3           | 94     | ✓              |
| ST5   | Redd Scour - Steelhead         | <input type="checkbox"/> |                   | 22     | 0           | 78     | ✓              |

Figure 4.18. Annual Rollup report for CS5 – Redd Scour risk, showing results for all calibration years (1970-2001) and all run-types.

The Redd Scour risk indicator has no threshold differences among run-types at the Rollup scale. The rationale for this behavior is that scour is a physical process; that run-types which spawn during periods of high flow are likely to experience greater exposure to scour, and that these inherent physical risks should be reflected in the indicator, much the same way that thermal mortality should affect some run-types more than others. Using these thresholds, results for the historical scenario are shown in Figure 4.18. They shows that Spring-run Chinook are intrinsically less sensitive to redd scour compared to Fall-run Chinook, which experience high risk flows about every 3 years. Averaged over all run-types, 81% of years are **Good**, fewer than 1% are **Fair**, and 18% are **Poor**. A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance. However, our repeated survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.*; Matt Brown, USFWS, *pers. comm.*) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for Redd Scour risk. Because of this gap and the hesitancy of experts to reveal their opinions, we instead adopted the heuristic indicator described above, to categorize years with extreme flow events.

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.

Table 4.17. CS5 – Redd scour indicator rating breakpoints.

|                       | Daily     |           | Rollup    |           | Notes  |
|-----------------------|-----------|-----------|-----------|-----------|--|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |  |
| Winter-run Chinook    | N/A       | N/A       | 5000      | 10000     | <ul style="list-style-type: none"> <li>• Criteria: calibrated to 80% Good years, “less” is better</li> <li>• Units: index flow (cfs)</li> <li>• No daily estimate</li> <li>• Common physical threshold for all run-types</li> <li>• <i>Very low risk for spring-, winter-runs</i></li> </ul> |
| Spring-run Chinook    | N/A       | N/A       | 5000      | 10000     |  |
| Fall-run Chinook      | N/A       | N/A       | 5000      | 10000     |  |
| Late-fall-run Chinook | N/A       | N/A       | 5000      | 10000     |  |
| Steelhead             | N/A       | N/A       | 5000      | 10000     |  |

### CS6 – REDD DEWATERING

Redd dewatering is modeled using daily declining changes in discharge ( $Q$ ) over the egg development period for each location ( $l$ ) and run-type ( $r$ ) combination to calculate estimates of proportional redd losses. The dewatering model tracks the daily proportion of spawned eggs based on each spawning day cohort ( $c_s$ ) up to the day of its temperature-driven emergence ( $e$ ). The weight of a spawning day cohort on any day ( $c_{s,d}$ ) is based upon the original spawning cohort weight,  $c_s$ , conditioned on dewatering events that may take place as the egg-cohort matures through the egg development period and as flow may decline from one day to the next. The cohort weight on a given day  $c_{s,d}$  becomes:

$$c_{s,d} = \begin{cases} c_s & \text{when } (s \leq d < (s+1)) \\ c_s (1 - f(l, r, Q_s, Q_{d-1})) & \text{when } (s < (d-1)) \text{ and up to emergence } (d < e) \\ 0.0 & \text{otherwise, e.g. when } (d < s) \text{ or } (d \geq e) \end{cases}$$

By definition, no losses occur on the day an egg cohort is spawned. If a drop occurs on the second day the loss is accounted for at the end of the second day, causing the cohort weight to decline on the third day ( $e=l, d=3$ ). Over the egg-development period, declining flows affect each spawning day-cohort in a cumulative fashion. Based upon this formula above, the river-segment weight ( $w_d$ ) for any given day is the sum of all the cohort weights present on that day:

$$w_d = \sum c_{s,d}$$

In a final step, the daily weight is further scaled by the relative daily proportion of spawning WUA at the given location. Thus, the weight ( $w_d$ ) incorporates the joint influence of the original spawning distribution, temperature driven egg-development distribution and the proportion of total spawning WUA available in the river segment.

The model makes use of Gard’s redd dewatering research (U.S. Fish and Wildlife Service 2006b), which estimates proportional decrease in redds over the period between spawning and the emergence of juveniles. Mark Gard kindly made his raw results available to us so that his system-level tables could be disaggregated to the segment level used by SacEFT. Gard’s results do not include time explicitly. Rather, his model estimates the proportion of spawning redds lost (if any) at each location ( $l$ ) between the time a day-cohort is spawned ( $c_s$ ) and the end of the cohort’s egg development period. Gard’s tabular results include fall- and winter-Chinook salmon and steelhead trout only, and relationships for spring- and late-



fall Chinook salmon are mapped from fall-run Chinook. Based on discussions with Gard, we adapted this relationship in a way that is mathematically consistent with the original results, but which can be disaggregated to the daily scale of the dewatering model. If there is no decline in flow then no loss occurs. To calculate the daily PM, the model compares the previous day’s flow,  $Q_{d-1}$ , and the flow on day  $Q_d$ . If there is a drop, then some proportion of eggs are potentially dewatered:  $f(l, Q_{d-1}, Q_d)$ , and bilinear interpolation is used to calculate proportional loss the tabular values found in Gard’s tables (U.S. Fish and Wildlife Service 2006b).

To calculate a *Daily* performance measure, the model finds the proportion of incubating eggs lost to declines in flow during the egg-development phase of each spawning day cohort, summing all of the cohort’s individual losses occurring on that day:

$$CS6_{l,r,d} = \sum_{i=1}^d (c_{i,d+1} - c_{i,d})$$

Summing losses on previous days gives cumulative losses up to and including day ( $d$ ):

$$CS6_{l,r,d} = \sum_{p=1}^d \sum_{i=1}^d (c_{i,p+1} - c_{i,p})$$

The *Rollup* indicator is based on taking the cumulative loss, summed across locations ( $L$ ). Because of the way that the cohort weight incorporates the proportional spawning WUA, the rollup PM represents the percentage of redds dewatered for all reaches:

$$CS6_r = \sum_{l=1}^L \sum_{p=1}^D \sum_{i=1}^D (c_{i,p+1} - c_{i,p})$$

Breakpoints for the **R****Y****G** Indicator Ratings are taken using terciles of the sorted river-segment distribution for the daily and annual results, sometimes using discontinuities in the annual distribution for the rollup.

### Indicator Reliability

The PM reliability rating for redd dewatering is shown in Table 4.18. The lower rating for spring and late fall Chinook is due to the absence of direct observation for those run-types. Reliability scores are equally high because the data are drawn from studies that have been subject to peer review, and because the functional relationships are being applied within the same reaches, but to different runs.

Table 4.18. CS6 – Redd dewatering indicator credibility assignments following the workshop.

|                       | Category |   |   |   |     |
|-----------------------|----------|---|---|---|-----|
|                       | I        | U | R | F | P   |
| Winter-run Chinook    |          | H | H | H | H   |
| Spring-run Chinook    |          | M | H | H | M/H |
| Fall-run Chinook      |          | H | H | H | H   |
| Late-fall-run Chinook |          | M | H | H | M/H |
| Steelhead             |          | H | H | H | H   |

## Excel Reports

An example of the Version 2 Excel report for Redd Dewatering is shown in Figure 4.19. The amount of dewatering in a specific reach and year can be compared with the historical range of redd dewatering by comparing the purple cumulative PM line to the vertical R/Y/G bar on the right of each graph. The vertical R/Y/G bar shows the distribution of annual rollup values across all years and reaches. The daily distribution is shown by the horizontal R/Y/G bar at the top of each pane.

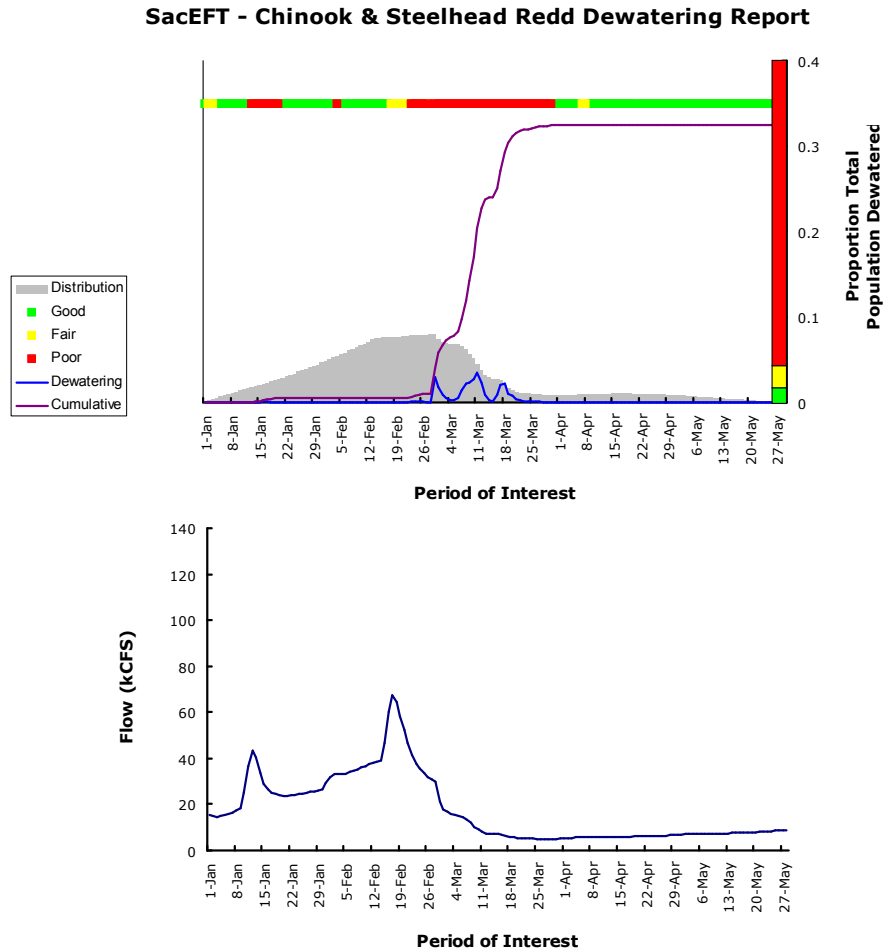


Figure 4.19. Excel Report for CS6 – Redd dewatering showing late-fall-run Chinook in Reach 4 for 1980. The index is sensitive to declining changes in flow. The upper horizontal bar shows the index R/Y/G score relative to the daily scoring across all reaches and years; the vertical horizontal R/Y/G shows the cumulative distribution of the reach and year relative to the annual rollup distribution. The impact of dewatering upon the egg distribution can be seen in the decline of the bell-shaped gray distribution that accompanies drops in flow and the sharp pulse of high dewatering index.

## Indicator Threshold Calibration

Based on model behavior using historical flow and temperature, the indicator rating thresholds for Redd Dewatering are shown in Table 4.19. The indicator and its rating calibration are treated as dimensionless index, although technically it is a sum of proportional changes in spawning area. The breakpoints for the *Daily Indicator* rating for each run-type are based on the estimated daily proportional change in WUA spawning area over all reaches over all days of the egg development period, over all years. Redd dewatering is similar in some ways to juvenile stranding, but because eggs remain fixed in the spawning redd and are not mobile, the details of the calculation of cumulative dewatering differ slightly from the calculation of juvenile stranding (CS4). Each simulation day's observation is weighted by the proportion of the total egg population present in each day-cohort, meaning that days with more developing eggs present are given more importance, with longer spawning periods and development times also contributing to the magnitude of the indicator. Typically, several thousand simulation observations contribute to this sorted daily distribution. The primary *Rollup Indicator* rating is also a dimensionless index correlated with mortality risk, and is based on calculating a *cumulative* daily value for each reach, over the egg development period for each simulation year, and then taking the average value over all the reaches to produce an annual average value. The practice of using a cumulative total for this indicator leads to much larger indicator values for the Rollup, and there are typically a few dozen simulated observations for the distribution of this indicator; one for each simulation year.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance. However, our repeated survey efforts of fisheries experts (e.g., Mark Gard, USFWS, *pers. comm.*; Matt Brown, USFWS, *pers. comm.*) and a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for Redd Dewatering. Because of this gap and the hesitancy of experts to reveal their opinions, we instead calculated the sorted distribution of weighted annual results and selected terciles (the lower-, middle- and upper thirds of the sorted distribution) as an initial reference to categorize the results.

Within run-types, the lower and upper rollup thresholds differ by about a factor of two (e.g., 0.05 and 0.09 for the fall-run Chinook rollup). These differences are due to differences in the flow regime and number of reaches for each run-type. But comparison across run-types shows that there is about a five-fold range among the breakpoints of the five run-types. Comparison across run-types shows an obvious limitation of the statistical approach to creating threshold boundaries. For example, the Good/Fair rollup boundary for winter-run Chinook is about 15% that of steelhead: 0.015 compared to 0.10.

Since the Redd Dewatering indicator is an index that should be highly correlated with potential egg loss, it might be more sensible to establish indicator rating thresholds that are mortality-like and not distributional. Reasonable choices for such boundaries remain an open question, however. Although the distributional 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. In the last column of Table 4.19 we attempt to flag cases where there are major gradients in performance indicator thresholds.

Table 4.19. CS6 – Redd dewatering indicator rating breakpoints. Units are population-proportion-weighted redd dewatering index for Daily resolution; cumulative for the Annual and Rollup scales

|                       | Daily     |           | Rollup    |           | Notes   |
|-----------------------|-----------|-----------|-----------|-----------|---|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |   |
| Winter-run Chinook    | 3.976E-06 | 4.042E-05 | 0.02      | 0.03      | <ul style="list-style-type: none"> <li>• Criteria: statistical distribution, terciles, “less” is better</li> <li>• Daily units: proportion stranded</li> <li>• Rollup units: cumulative proportion stranded</li> <li>• Flow, spawning period, habitat preferences, affect distribution</li> <li>• <i>Very low risk for winter-run</i></li> <li>• <i>Higher sensitivity for Late-fall run Chinook</i></li> </ul> |
| Spring-run Chinook    | 6.184E-05 | 7.333E-04 | 0.07      | 0.13      |   |
| Fall-run Chinook      | 1.597E-05 | 1.910E-04 | 0.05      | 0.09      |   |
| Late-fall-run Chinook | 1.336E-05 | 1.846E-04 | 0.12      | 0.22      |   |
| Steelhead             | 1.181E-05 | 1.428E-04 | 0.10      | 0.17      |   |

### 4.3.2 Green sturgeon

The salmonid conceptual model is shown in Figure 4.20. Readers are referred to ESSA Technologies Ltd. (2005) for details on the development of this model and the decisions that led to its current structure.

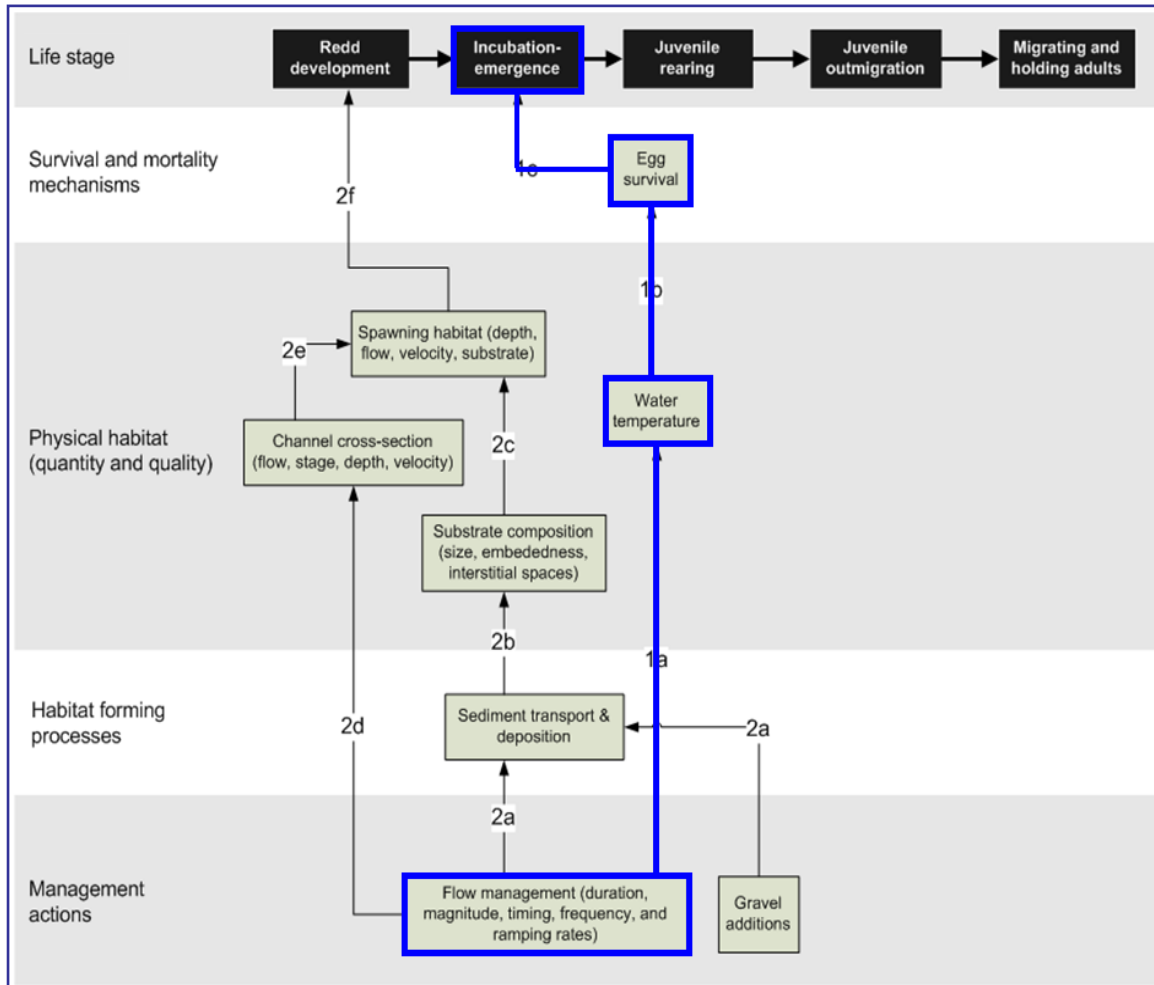


Figure 4.20. The green sturgeon conceptual model. Heavy lines show the processes and linkages that are currently implemented. See ESSA Technologies Ltd. (2005) for additional context and detail on processes and linkages shown here.

The impact of water temperature on green sturgeon eggs is modeled using daily changes in temperature over the egg development period at each location. From the daily average temperature, estimates of exposure to the hazard of warm water are modeled using two temperature breakpoints: 17<sup>0</sup>C and 20<sup>0</sup>C, to mark temperature excursions into zones of moderate and high risk. Each day the model tracks spawned eggs over a fixed development period of 14 days, tracking each day-cohort separately. The simplicity of the model stems from the lack of information about temperature-based mortality and uses the categorical grouping created by Cech *et al.* (2000) to assign “healthy”, “moderate” and “lethal” outcomes. Other measures of green sturgeon life history (*e.g.*, flow-habitat; juvenile entrainment; fishing and poaching, discharge-migration cues) were found to be lacking in quantitative knowledge and therefore are not included in SacEFT v.2.00.

Following the model review workshop the habitat scoring rule was modified so that it approximates a temperature-mortality relationship with full survival below 17°C and complete mortality above 20°C, with linear interpolation between these two temperatures. Daily cohort survival above 95% is scored as Good for the year-cohort; survival between 90-95% is scored as Fair, and survival lower than 90% is ranked as ‘Poor.’ A recommendation that Vina be included as a third possible spawning location was deferred, since simulated temperature data below RBDD were not yet considered reliable.

The *annual* PM at each location is the most frequent outcome for each location, with each day’s Indicator Rating contribution weighted by the spawning distribution weight ( $w_d$ ) for the day.

The *rollup* PM is calculated by combining the daily PMs across all locations over the spawning and development period, with the contribution of each day’s Indicator Rating weighted by the spawning distribution weight ( $w_d$ ) for the day.

### Indicator Reliability

The PM reliability rating for green sturgeon thermal egg mortality is shown in Table 4.20. The low ratings reflect the uncertain linkage between laboratory studies of egg maturation with field observations of larval development.

Table 4.20. GS1 – Green sturgeon indicator credibility assignments following the workshop.

|                             | Category |   |   |   |   |
|-----------------------------|----------|---|---|---|---|
|                             | I        | U | R | F | P |
| GS1 – Thermal Egg Mortality |          | M | M | H | M |

### Excel Reports

The Excel Report for Green Sturgeon thermal egg mortality (GS1) follows the style of the style of the Salmonid thermal mortality (CS3) report, using a vertical bar to show the distribution of the annual rollup for the PM (Figure 4.21). The report shows two graphs: the upper panel shows the spawning distribution in gray, the incubation period mortality for each day-cohort and the cumulative population mortality across all cohorts. The lower graph shows daily temperatures and R and Y thresholds for daily mortality. The x-axes are identical and span the first day of spawning to the last date of emergence.

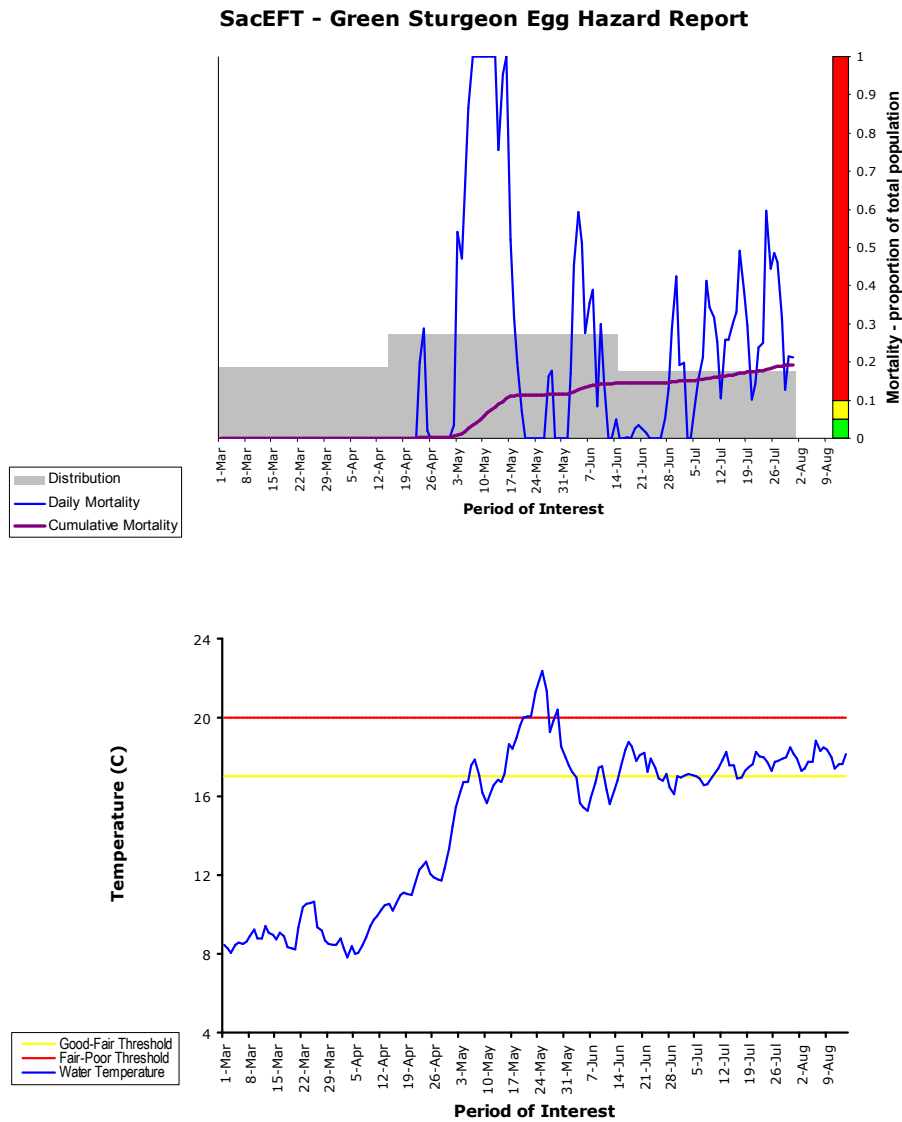


Figure 4.21. Excel Report for GS1 – Green sturgeon egg hazard for location GS1 (Hamilton City) in 1982. The vertical horizontal R/Y/G shows the cumulative mortality. The lower panel shows water temperature with the Good-Fair and Fair-Poor thresholds.

## Indicator Threshold Calibration

Based on absolute mortality values of 5% and 10%, the Indicator Rating boundaries for thermal egg mortality are shown in Table 4.21. The same units and values are used for *Daily* and *Rollup* indicator ratings. The rationale for this choice of indicator at all scales is that it has an unambiguous meaning, in contrast to other indicators which are either more abstract, or are unit-free indices. Readers should note that 5% mortality at the Daily indicator scale means that 5% of the eggs spawned on that day and location will die because of elevated temperature over their 14 day development period. At the Rollup level, the same number means that 5% of the entire multi-reach population of eggs will die in that year, due to elevated temperature.

The *Daily* indicator is calculated by accumulating thermal mortality over the 14 day egg-development period, which is determined by spawning day and water temperature. The *Rollup* indicator has the same units as the Daily rating, goes one step further and calculates an annual average across all reaches, for all simulation years, using the equal weighting for all locations to calculate a weighted average. There are typically a few dozen simulated observations for the distribution of this indicator.

A preferred method for calibrating the indicator and categorizing annual variation across different hydrosystem scenarios is to identify historical years and run-types with Good or Poor performance, or to include robust studies of temperature-based mortality. Our efforts of survey fisheries experts through a questionnaire sent to fisheries biologists prior to the 2008 SacEFT Version 1 review workshop, revealed that there were no known synoptic studies of this kind for green sturgeon thermal mortality. Neither are there universally accepted field mortality levels – conceptually similar to LD<sub>50</sub> values for pollutants – for measuring the impact of thermal mortality. The best information we were able to use is based on *in vitro* studies (Cech *et al.* 2000) of larval development, which we adapted to create a quasi-mortality model in which larvae experience no mortality at temperatures below 17°C and complete mortality at temperatures at and above 20°C. Added to this simple model and the hesitancy of experts to reveal their opinions, we instead chose arbitrary mortality breakpoints of 5% and 10% as initial reference points to categorize the results.

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. In the last column of Table 4.13 we attempt to flag cases where there are major gradients in performance indicator thresholds.

Table 4.21. GS1 – Thermal egg mortality indicator rating breakpoints. Units are % Mortality and are intentionally held constant across all temporal scales. Annual and Rollup scales incorporate population-proportion weights.

|                       | Daily     |           | Rollup    |           | Notes   |
|-----------------------|-----------|-----------|-----------|-----------|---|
|                       | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |   |
| Thermal Egg Mortality | 5         | 10        | 5         | 10        | <ul style="list-style-type: none"> <li>Criteria: absolute values, “less” is better</li> <li>Units: % mortality</li> </ul> |



### 4.3.3 Bank swallow

The bank swallow conceptual model is shown in Figure 4.22 . Readers are referred to ESSA Technologies Ltd. (2005) for details on the development of this model and the decisions that led to its current structure.

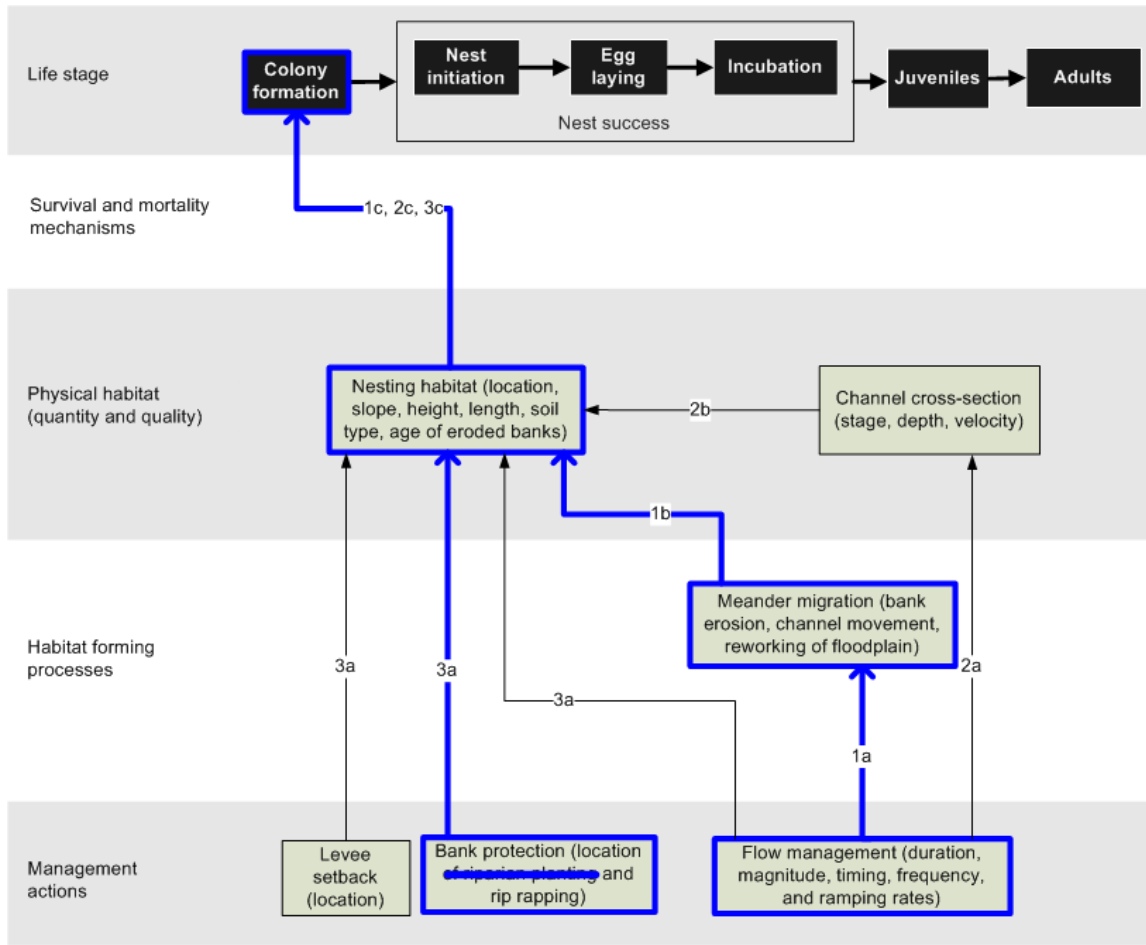


Figure 4.22. The bank swallow conceptual model. Blue heavy lines show the processes and linkages that are currently implemented.

SacEFT includes two performance measures (PMs) that describe changes in the physical habitat available for bank swallow nesting success. Prime bank swallow nesting habitat is limited to friable soils in vertical bank faces (Garrison 1998a, 1999). These bank and soil characteristics render nesting habitat susceptible to collapse when undercut by the river during high flows. Minor bank sloughing can degrade habitat quality by reducing bank slope and creating debris piles below nesting sites. Erosive processes such as lateral river migration are therefore periodically necessary in order to create new nesting habitat with steep slopes and fresh surfaces for new nests (Garrison 1999). Two performance measures describe changes in the physical habitats available for bank swallow. The first of these (BASW1) provides an annual estimate of the weighted useable length of newly eroded bank for nesting. The second of these provides daily estimates of the potential for bank sloughing during the nesting period, with high flows creating a high potential for bank failure (BASW2).

The models used to generate BASW1 and BASW2 are based on Garrison's (1989) habitat suitability index (HSI) model and refinements proposed by Stillwater Sciences (SWS) in its Sacramento River

Linkages Report (Stillwater Sciences 2007). Of the four variables identified in Garrison's model – soil texture, bank slope, bank height, and bank length – and the additional four variables identified by Stillwater Sciences (2007) – distance to nearest grassland, bank age, peak flow during nesting period, and stage increase above base flow during the nesting period – only **newly eroded bank length** and **peak flow during nesting** were available for incorporation into SacEFT v.2.00, and are the key components of the BASW1 and BASW2 performance measures.

Although they reflect the best available information at SacEFT's spatial scale, it is clear that these two PMs are a very simplified picture of the factors affecting the quality and quantity of bank swallow habitat. For example, because the model has no memory of flow over time, the BASW2 indicator is not able to capture the possible cumulative effects of changes in discharge, nor the role of bank height in predicting bank sloughing.

### **BASW1 – BANK SWALLOW HABITAT POTENTIAL/SUITABILITY**

Based on previous studies (*e.g.*, references cited in Stillwater Sciences 2007), the functional relationship for Bank Swallow habitat potential is based on three factors:

1. the length of bank erosion;
2. time since a major erosion event (defined as horizontal erosion  $\geq 1$  m); and
3. the length of this erosion that is in soils of suitable type.

Based on feedback from the Bank Swallow Technical Advisory Committee<sup>1</sup> regarding the observation of bank length of less than 10 m being important habitat, it was decided to model only the second and third factors. Consequently, a weighted useable length (WUL, measured in meters) – or habitat potential – is calculated for each bank segment based on two weighting factors: years since last major erosion event ( $w_e$ ) and soil suitability ( $w_s$ ):

$$WUL_b = w_e \times w_s \times L_b$$

A conceptual example for the BASW1 Habitat Potential indicator is shown in Figure 4.23.

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<sup>1</sup> February 2011 review presentation

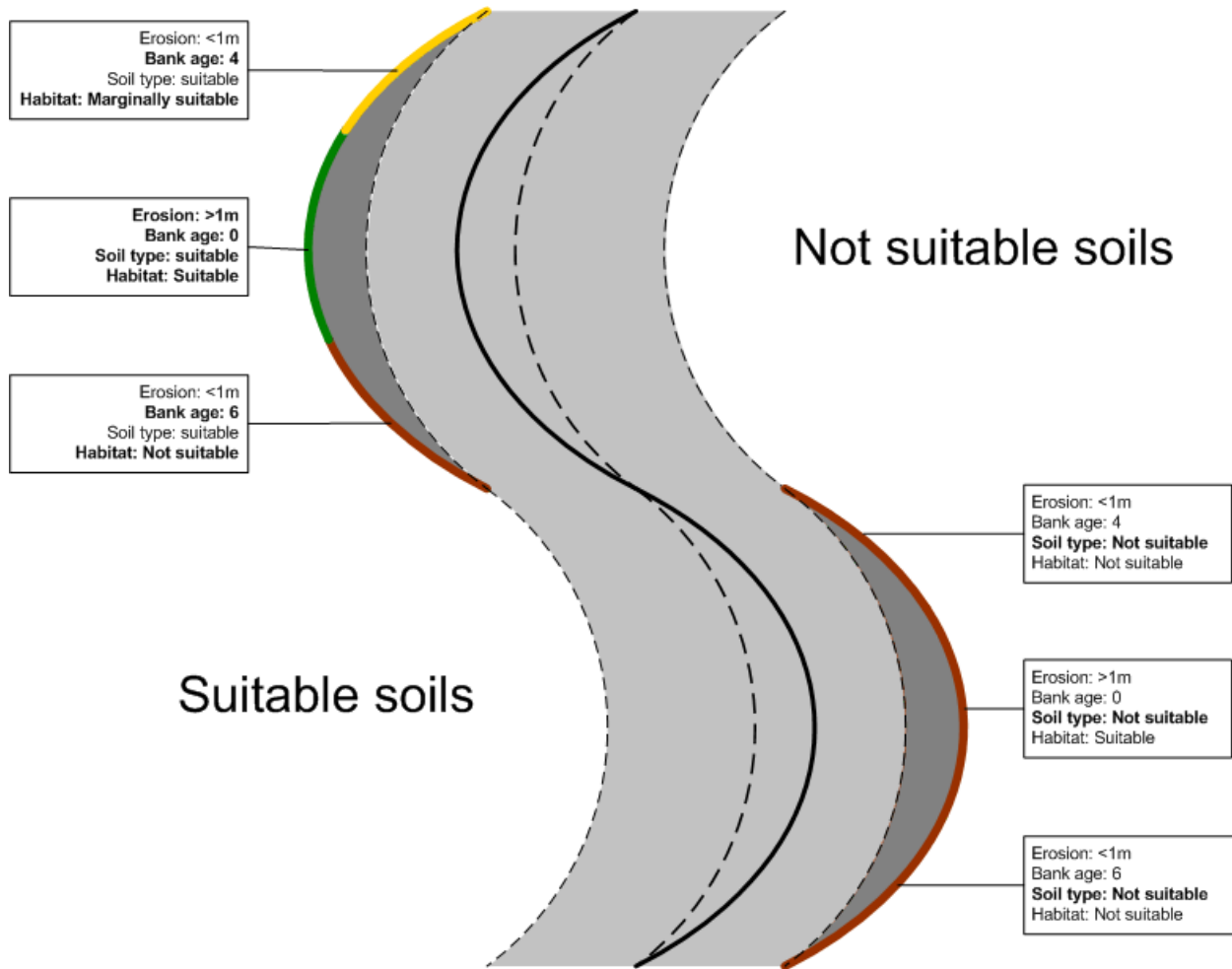


Figure 4.23. Conceptual example for the BASW1 Habitat Potential (or WUL) indicator. Note that all banks on the right hand side are not suitable because of soils, whereas the bank of the left hand side illustrates the effect of different bank ages. See text for details.

Biophysically, the need for periodic renewal of nesting habitat is dictated by the progressive decline in burrow quality due to erosion that reduces bank slopes (and thus provides easier access for predators) and infestation by fleas and other nest ectoparasites. Most of the colonies in the Sacramento valley are used for no more than 7 consecutive years in the absence of a major erosion event (see Stillwater Sciences 2007). After three years, habitat suitability drops rapidly because of high levels of ectoparasites and little room for new nests (Stillwater Sciences 2007). Recent research (Heneberg 2009) suggests that bank swallows will also abandon soils that become too hard to penetrate due to increased soil compactness with age.

The desired frequency of horizontal erosive events  $\geq 1\text{m}$  for habitat renewal is about once every 3 years (*i.e.*, it does not need to occur annually). The SacEFT *BASW1* habitat potential indicator also takes into consideration that burrows can be reused for up to 3 years without significant renewal taking place. Additionally, the model is capable of accounting for cumulative erosion events over multiple years. Based on discussions at the SacEFT refinements workshop (ESSA Technologies Ltd. 2008a), the functional relationship for habitat potential in response to depth of horizontal erosion is a linear decay function where newly eroded banks (*i.e.*, horizontal erosion  $\geq 1\text{m}$ ) receive a habitat suitability index of 1. Habitat potential declines linearly each year until year 3, after which habitat potential/suitability is zero for those bank areas that have not experienced a major erosion event (see Figure 4.24).

A major erosion event is defined as a horizontal erosion depth  $\geq 1\text{m}$ . Erosion less than 1m deep is considered contributing to reduced bank slopes by bank sloughing. The time since last major erosion event ( $t_{erosion}$ ) is defined as the number of years since the bank was eroded to a depth of at least 1m within a single year.

The weighting scheme for the time component reflects habitat degradation in the absence of a major erosion event:

$$w_e = \begin{cases} 1 & \text{when } (t_{erosion} < 3\text{years}) \\ 1 - \frac{t_{erosion} - 3}{2} & \text{when } (3\text{years} \leq t_{erosion} < 5\text{years}) \\ 0 & \text{when } (t_{erosion} \geq 5\text{years}) \end{cases}$$

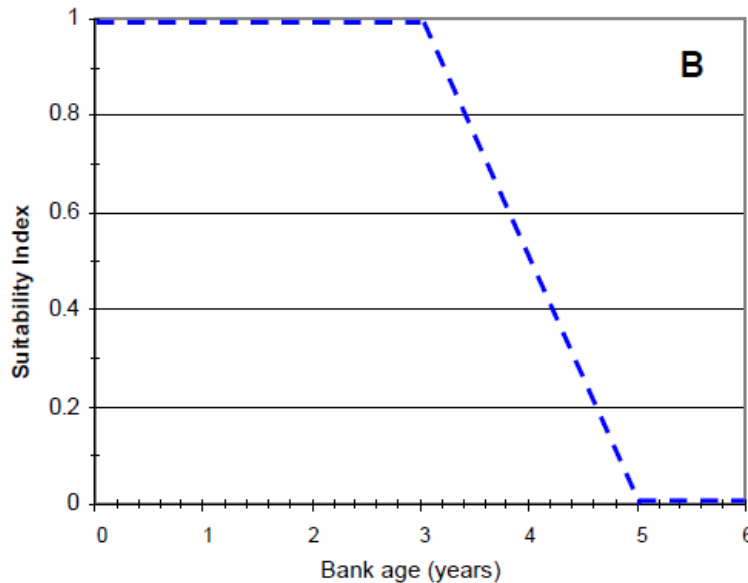


Figure 4.24. Habitat Potential vs. bank age (time since last major bank erosion event). Habitat decreases rapidly after 3 years because of ectoparasites. Most of the colonies in the Sacramento valley are used for no more than 7 consecutive years in the absence of erosion (see Stillwater Sciences 2007).

The bank age ( $t_{erosion}$ ) is calculated based on the location of the current and the previous year's banks as simulated by the bank erosion model (see Section 4.1.6). Any bank segments that are more than 1m away from the previous year's banks are considered renewed in the current year and are assigned a bank age of zero. If the bank segment has not been renewed, the bank age is calculated as the age of the nearest banks from the previous year plus one year (see Figure 4.25 for an example).

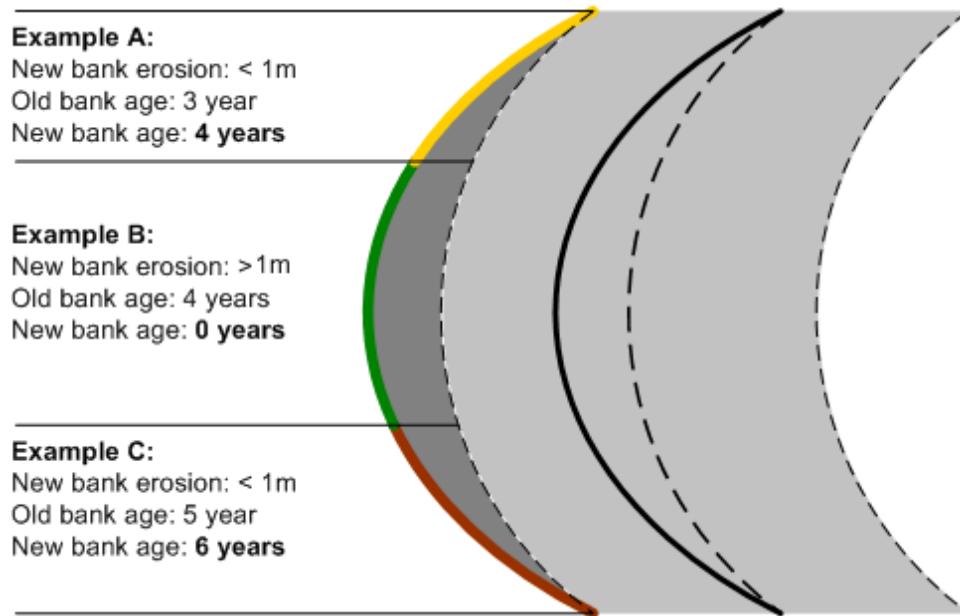


Figure 4.25. Bank age example. If the bank segment has been eroded more than 1m, the new bank age is always 0, see 'B'. If the bank segment has not been eroded this year, the new bank age is calculated as age of the nearest old bank + 1 year, see 'A' and 'C'. Note that the new bank segment in 'A' is now considered marginal habitat according to the weighting scheme, whereas the bank segment in 'C' is no longer suitable.

Not all soils are suitable for bank swallow burrows. Bank swallows prefer banks with soft sand or sandy loam soil (Garrison 1999). Furthermore, recent fieldwork has indicated that Bank swallows may also utilize the local vertical bank stratification to select favorable burrow location, *e.g.*, Bank swallows have been found in the field to burrow into coarse soils between lenses of silt that then function as the 'roof' and 'ceiling' of the burrow (Dean Burkett, Natural Resources Conservation Service, *pers. comm.* 2011). SacEFT's BASW1 soil suitability component is based on SSURGO soil data (Natural Resources Conservation Service 2011). The soils were divided into 4 categories based on the dominant soils near the Sacramento River: Gianella loams, Columbia loam, Riverwash and other soils. Based on communication with Dean Burkett, highlighting some of the limitations in the resolution of SSURGO soil data, it was decided that it is not currently possible to assign different weights to these four soil types with the current data, and it would be preferable to consider only 2 classes: suitable ( $w_s = 1$ ) and unsuitable ( $w_{est} = 0$ ). Based on field observations, Columbia Loam and Gianella Loams are considered suitable ( $w_{Columbia}, w_{Gianella} = 1$ ) and riverwash and other soils are considered unsuitable ( $w_{Riverwash}, w_{Others} = 0$ ). We recognize that soil data give only a snapshot in time, *i.e.*, they represent the river banks in a single year, whereas the bank observations cover almost a decade, during which the river banks have moved.

The length of bank in each soil type is determined in a GIS by overlying the bank locations simulation by the bank erosion model with the soil data (see Figure 4.26).



Figure 4.26. Conceptual example of eroded bank area divided into soil types.

The *annual* PM for BASW1 sums the weighted length of eroded bank across all river segments ( $S$ ) and bends ( $B$ ).

$$BASW1 = \sum_{i=1}^S \sum_{b=1}^B w_e \times w_s \times L_b$$

The *rollup* PM is based on the terciles of total length taken from a historical run with no bank revetment. These terciles determine set the thresholds for performance of BASW1 in any given year (*i.e.*, assignment of **R**/**Y**/**G** to BASW1).

### Indicator Reliability

The indicator credibility rankings for BASW1 are shown in Table 4.22.

Table 4.22. BASW1 – Habitat Potential/Suitability - indicator credibility assignments following the workshop. These ratings apply to those reaches of the Sacramento River where it is possible to have estimates of floodplain area reworked from the Meander Migration Model.

|                                       | Category |   |   |   |   |
|---------------------------------------|----------|---|---|---|---|
|                                       | I        | U | R | F | P |
| BASW1 – Habitat potential/suitability | H        | H | H | M | H |

BASW1 received a score of Medium for feasibility because the performance measure only captures some of the important characteristics with respect to nest habitat suitability.

## Excel Reports

An example of an Excel report for BASW1 is shown in Figure 4.27. The habitat potential (weighted useable length (WUL)) for each year in a specific location is shown in kilometers.

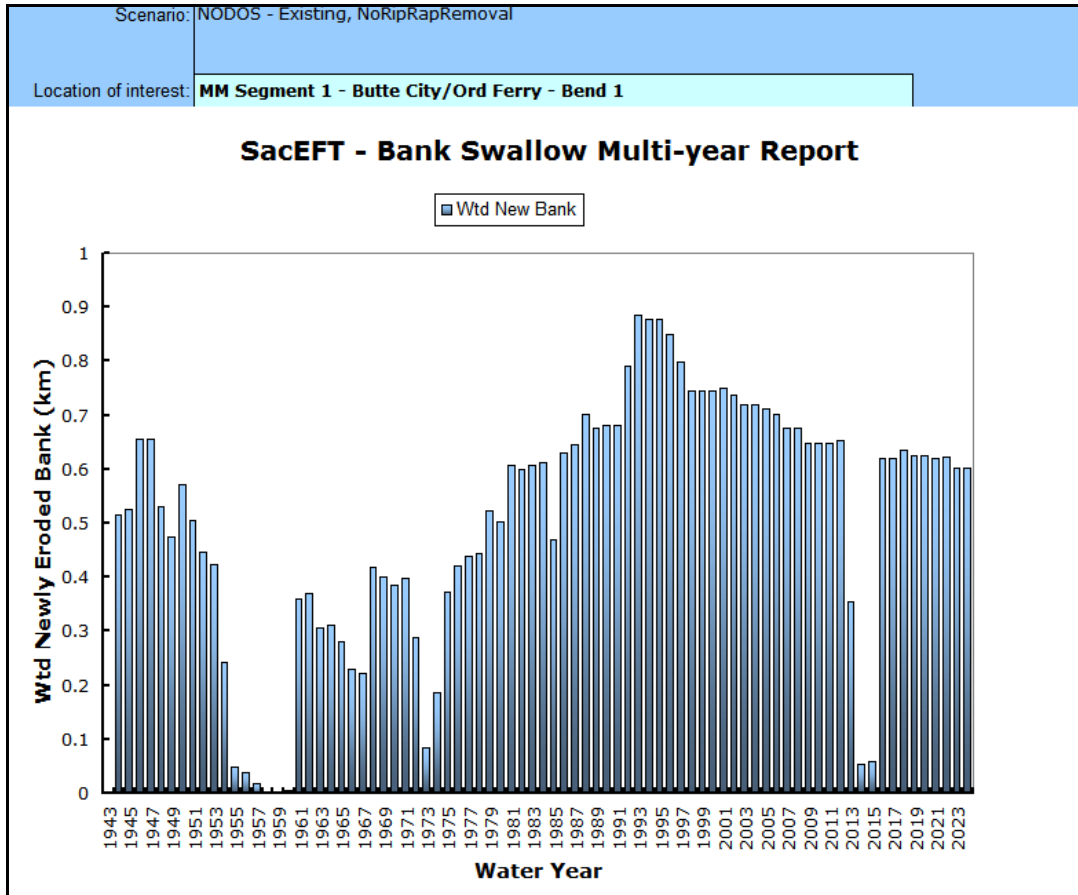


Figure 4.27. An example of an Excel report for BASW1 – Habitat potential/Suitability. This example shows the Weighted Useable Length (WUL; km)) for each year for Bend 1 in the Butte City/Ord Ferry segment.

### Indicator Threshold Calibration

To calibrate the BASW1 indicator, we used empirically measured historical flow data with no rip-rap removal. Annual BASW1 weighted useable length was summed across all locations for each year and the PM values sorted from largest to smallest. Discontinuities (and not exact terciles) of the sorted values were used to establish the roll-up Hazard Threshold boundaries (see Figure 4.28 and Table 4.23).

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 Bank Swallow Experts can create a list of years with Good or Poor performance based on field surveys of bank swallow burrows, including abandoned burrows. However, at the time of this report, we are not aware of a suitable processed dataset.

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.

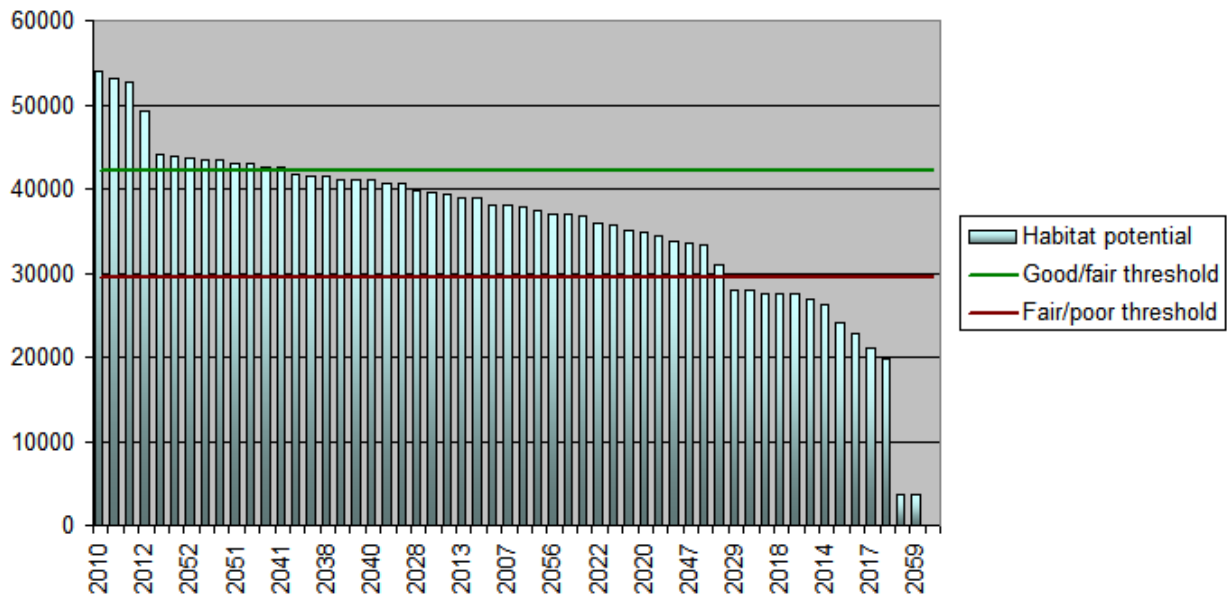


Figure 4.28. Calibration results for BASW1. Bars are the sorted total weighted length of newly eroded bank for each year of the Historical simulation.

Table 4.23. BASW1 – Length of newly eroded bank indicator rating breakpoints. Units are weighted useable length (WUL) in meters.

|                   | Daily     |           | Rollup    |           | Notes   |
|-------------------|-----------|-----------|-----------|-----------|---|
|                   | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |   |
| Habitat potential | N/A       | N/A       | 42200     | 29500     | <ul style="list-style-type: none"> <li>Criteria: statistical distribution using discontinuities, “more” is better</li> <li>Units: meters suitable habitat</li> <li>No daily estimate</li> </ul> |

**BASW2 – PEAK FLOW DURING NESTING PERIOD**

High flows during nesting have the potential to adversely affect bank swallow colonies through two mechanisms: inundation of nests and bank sloughing/collapse (Garrison 1998b; Moffatt *et al.* 2005). The exact magnitude of flow required to initiate bank sloughing is not definitively known. However, growing evidence suggests that flows in the range of 20,000 cfs to 50,000 cfs will typically erode some banks, causing partial collapse. Flows above 50,000 cfs are more than likely to cause widespread erosion leading to widespread colony failure at many sites if breeding swallows are present (Stillwater Sciences 2007).

During the SacEFT refinements workshop we were informed that about half of all nest burrows are located in the upper one quarter of the bank. Hence, the flow that is observed to reach this point should be the natural flow threshold for high risk. Informal observations at Hamilton City suggest that all nests at



that location that are ≤ 3m above a stage of 130.19 feet (flow of 7,250 cfs)<sup>1</sup> would be inundated at 50,000 cfs, which corresponds to a stage of about 139 feet. Extrapolating the Hamilton city rating curve to the larger area between Red Bluff and Colusa, approximately 50% of nests are ≤ 3m above stage (130.19 feet), and would consequently be at least partially inundated at 50,000 cfs. This is likely a conservative estimate because the rating curve at Hamilton City is steeper than at most nesting sites. The specifics of the stage-discharge relationship for other bank swallow nesting sites are still unavailable. Consequently, the current value of 50,000 cfs appears to be a reasonable threshold.

The impact of peak flow during the nesting period is calculated using daily average flow (*Q*) coupled to estimates of exposure to the hazard of bank-sloughing flows in three river segments (see Table 2.4) during the April 15 to July 31 (Table 2.7) nesting period (ESSA Technologies Ltd. 2008a). Hazard is modeled using two flow breakpoints: 20,000 cfs and 50,000 cfs, to provide estimates of risk during flow excursions into zones of moderate and high flow, respectively.

The *daily* performance measure is calculated by an indicator that assigns an influence to the day’s flow at each location, based on the breakpoint values:

$$BASW2 = \begin{cases} 1 & \text{when } (Q < 20kCFS) \\ 1 - \left( \frac{Q - 20}{30} \right) & \text{when } (20kCFS \leq Q < 50kCFS) \\ 0 & \text{when } (Q \geq 50kCFS) \end{cases}$$

The **R/Y/G** Indicator Ratings for BASW2 are based on a heuristic developed from the distribution of the BASW2 indicator, using a historical flow scenario across all river locations. Based on the flow thresholds, *Q* < 20,000 cfs is considered **low risk** and receives a score of 1, whereas *Q* ≥ 50,000 cfs is considered **high risk** and receives a score of 0. BASW2 is calculated at three locations along the river. Because of the fast ramping of flooding flows during the nesting period, days assigned a **Yellow** Indicator rating are infrequent.

**Indicator Reliability**

The indicator credibility rankings for BASW2 are shown in Table 4.24.

Table 4.24. BASW2 – Peak flow during nesting period - indicator credibility assignments following the workshop. These ratings apply to those reaches of the Sacramento River where it is possible to have estimates of floodplain area reworked from the Meander Migration Model.

|  | Category |   |   |   |   |
|--|----------|---|---|---|---|
|  | I        | U | R | F | P |
| BASW2 – Peak flow during nesting periods | H        | M | M | M | H |

With respect to understanding and rigor, BASW2 receives a score of Medium. Although there is strong evidence to support the flow threshold values for moderate and high risk, there remains some uncertainty around the exact magnitude of flow required to initiate substantial bank erosion, and hence bank collapse during nesting periods. Feasibility receives a score of Medium because the input data required to create more representative flow thresholds for high risk are not currently available.

<sup>1</sup> A rating table for Sacramento at Hamilton City showing the relationship between flow and stage is available at: <http://edec.water.ca.gov/rtables/HMC1.html>.

### Excel reports

The Version 2 Excel report is shown in Figure 4.29 using a vertical bar to show the annual rollup for the PM.

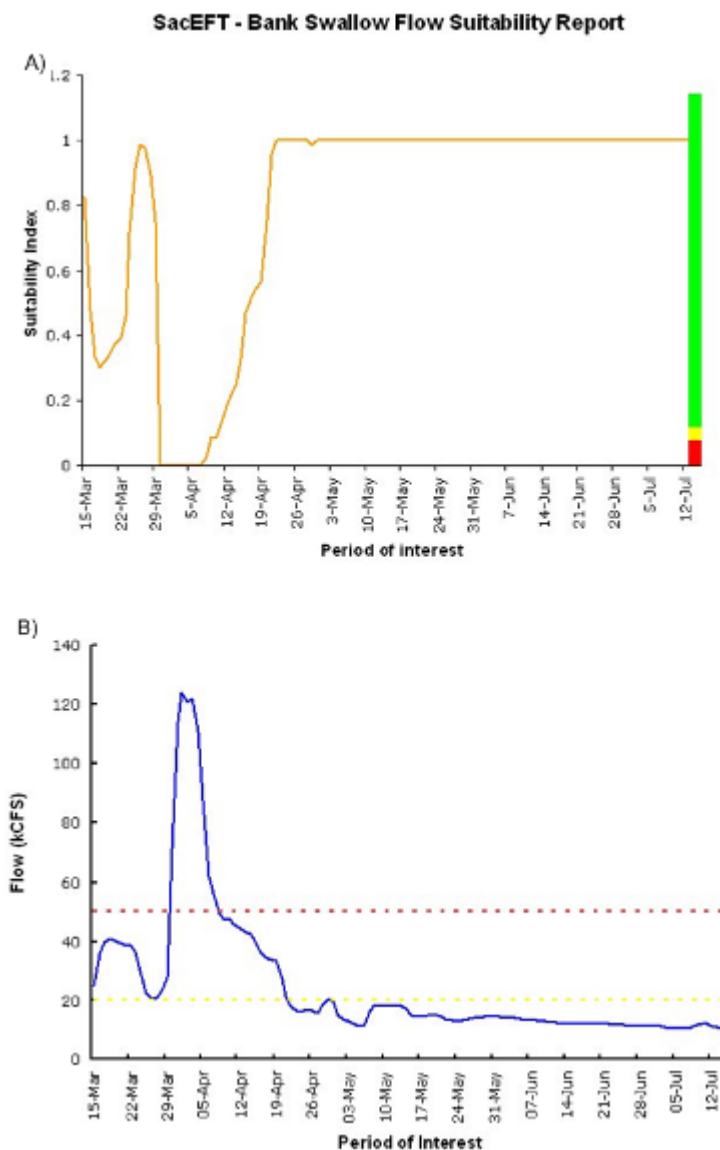


Figure 4.29 A) Daily roll up for BASW2 during the nesting period (April 15 to July 31). A suitability index score  $\geq 0.1$  is ranked as **Good**. A suitability score between 0.01 and 0.1 is ranked as **Fair**, and a suitability score  $\leq 0.01$  is ranked as **Poor**. B) Maximum daily flow during the nesting period. Flows  $\geq 50,000$  cfs (red dashed line) are automatically assigned a suitability index of 0 (**Poor**). Flows  $< 20,000$  cfs are automatically assigned a suitability index of 1 (**Good**).

### Indicator Threshold Calibration

Based on model behavior using historical flow and temperature, the indicator rating thresholds for peak flow during nesting period are shown in Table 4.25. *Daily* suitability indices of BASW2 are assigned based on a heuristic developed from the historical distribution of the BASW2 indicator across all river locations:

$$BASW2 \text{ suitability index} = \begin{cases} \text{green} & \text{when } (BASW2 \geq 0.1; [Q \leq 20k\text{cfs}]) \\ \text{yellow} & \text{when } (BASW2 > 0.01; [20k\text{cfs} < Q < 50k\text{cfs}]) \\ \text{red} & \text{when } (BASW2 \leq 0.01; [Q \geq 50k\text{cfs}]) \end{cases}$$

The *Rollup* PM for BASW2 is based on a similar heuristic that aggregates the annual PM across all locations based on peak flow during nesting. Using the same flow thresholds as the daily indicator, peak flow is used to assign an annual value for each nesting location. The rollup indicator is assigned a **Good** rating if 2 or more locations have a Good indicator rating for the year. The annual rollup is assigned a **Poor** rating if no locations are ranked as Good.

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 Bank Swallow Experts can create a list of years with Good or Poor performance based on field surveys of inundated bank swallow burrows, however at the time of this report, we are not aware of a suitable processed dataset.

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) and is based on discussions at the Version 1 review workshop, 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.

Table 4.25. BASW2 – Peak flow during nesting. Units are flow (cfs), weighted 1 below 20,000 cfs and 0 above 50,000 cfs.

|                   | Daily     |           | Rollup    |            | Notes   |
|-------------------|-----------|-----------|-----------|------------|---|
|                   | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor  |   |
| Nesting Peak Flow | 47000     | 49700     | ≥ 2       | < 1 (zero) | <ul style="list-style-type: none"> <li>• Criteria: flow thresholds based on expert opinion, “less” is better</li> <li>• Daily units: flow (cfs)</li> <li>• Rollup units: count of Good locations</li> </ul> |

### 4.3.4 Fremont cottonwood

The Fremont cottonwood conceptual model is shown in Figure 4.30. Readers are referred to ESSA Technologies Ltd. (2007) or details on the development of this model and the decisions that led to its current structure.

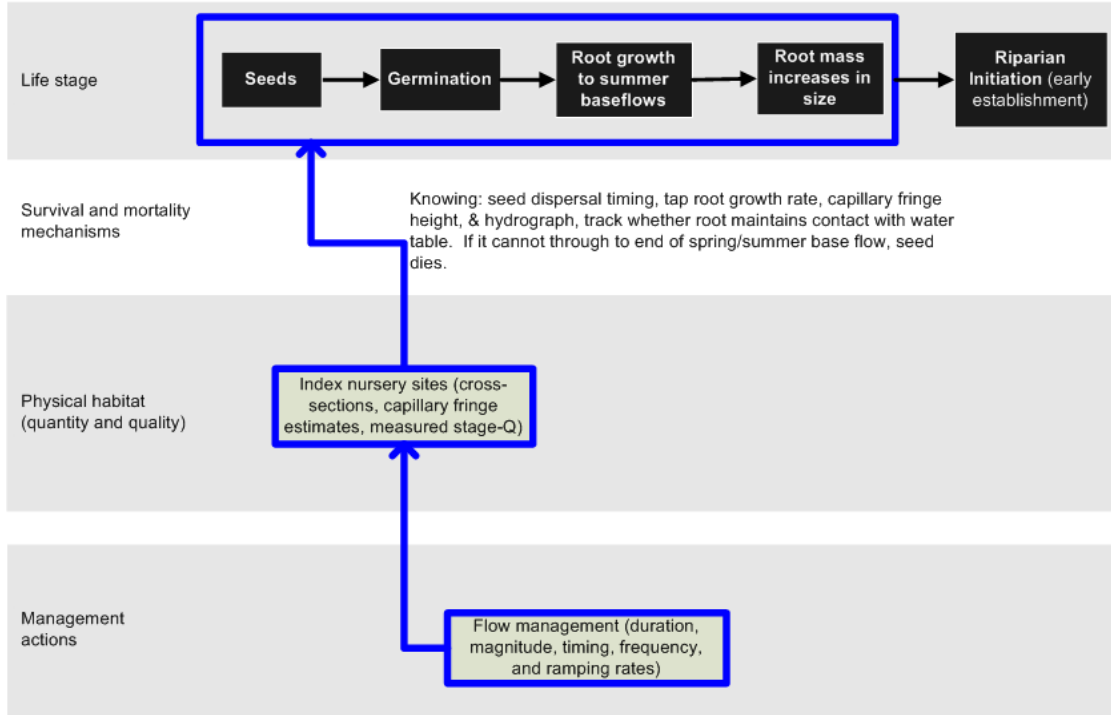


Figure 4.30 The Fremont cottonwood conceptual model. Blue heavy lines show the processes and linkages that are currently implemented.

SacEFT includes one performance measure (PM) that describes the potential for successful Fremont cottonwood initiation, along with a second performance measure designed to capture changes in the physical habitat that could negate successful initiation.

## RIPARIAN INITIATION (FC1)

A single performance measure predicts the biological response of seedling Fremont cottonwood to changes in flow management at eleven (11) index locations along the Sacramento River. The FC1 indicator is based on Mahoney and Rood's (1998) recruitment box model, which predicts the success of riparian initiation as a function of changes in the timing of flows and water surface elevations. Important biological parameters, such as taproot growth rate, seed dispersal timing, capillary fringe, drought tolerance and viable root depths are also integrated. As summarized in Table 4.26, two field studies (Roberts *et al.* 2002; Roberts 2003) provide the bulk of the data necessary to apply this model to eleven index locations on the Sacramento River. These cross sections are located at RM159, 164, 165, 172, 183, 185.5, 192, 195.75, 199.75, 206 and 208.25.

Table 4.26. Data requirements for FC1 – a measure of successful riparian initiation.

| Focal species performance measure  | Required input  | Data source   |  |
|--|---|---|--|
| FC1  | Daily average flow hydrograph                           | Hydrological data from historical discharge and USRDOM                        |  |
|  | Stage-discharge relations                               | Roberts <i>et al.</i> 2002; Roberts 2003 (RM 192, 183, and 172); HEC-RAS      |  |
|  | Channel cross-sections                                  | Roberts <i>et al.</i> 2002; Roberts 2003 (RM 192, 183, and 172); HEC-RAS      |  |
|  | Capillary fringe height = 30 cm                         | FC experts  |  |
|  | Seed dispersal timing (start and end) Apr-15 to 21-June | FC experts  |  |
|  | Seedling tap root growth rate = 22 mm/d                 | Roberts <i>et al.</i> 2002; Roberts 2003 (based on actual field observations) |  |
|  | Drought tolerance = 5 days                              | FC experts  |  |
|  | Viable rooting depth = 50 cm                            | FC experts  |  |
|  | <u>Other assumptions:</u>                               |   |  |
|  | Standard recruitment box model                          |   |  |
| Sampled cross section nodes, if non-uniform, are representative of the overall cross-sectional characteristics.  |   |   |  |
| <ul style="list-style-type: none"> <li>▪ Drought tolerance of 5 days (roots can be out of contact with water table for 5 continuous days without being declared dead)</li> <li>▪ Cottonwood seedlings whose roots reach a depth of 50 cm are assumed to be successful in reaching some type of ephemeral groundwater moisture sufficient to keep them alive through the remainder of their first year (based on dialogue with John Bair, McBain and Trush, <i>pers. comm.</i>).</li> </ul> |   |   |  |
| <b>Note:</b> all these assumptions are fully configurable in the SacEFT database.  |   |   |  |

An adapted version of the TARGETS model (Alexander 2004) is used to determine whether cottonwood seedlings will successfully initiate at a given node along a cross section. Cottonwood seeds are released within a dispersal window (April 15 to June 21, as shown in Table 2.7). Seeds that land on non-inundated ground<sup>1</sup> begin to grow roots downward from the elevation at which they were deposited. While accounting for optional capillary fringe height along the cross section (*e.g.*, 30 cm), the rate of stage decline determines whether the cottonwood's root is able to maintain contact with the water table. As soon as the root depth is above the surface elevation + capillary fringe height, the seedling becomes non-viable (dies). Hence for successful initiation, the rate of stage decline cannot occur at a rate faster than the taproot growth rate (we use a taproot growth rate of 22 mm/day). Cottonwood seedlings whose roots

<sup>1</sup> Seeds/seedlings that are submerged are not declared "dead" but instead the process of tap-root growth is suspended.

reach a depth of 50 cm are assumed to be successful in reaching some type of ephemeral groundwater moisture sufficient to keep them alive through the remainder of their first year. **Note:** All these assumptions are configurable in the SacEFT database.

The cottonwood performance measure tallies the number of initiation successes and failures across years and across the three cross-sections used in the model. Based on inspection of the all year results, counts of successfully initiating nodes are used to assign **R/Y/G** indicator ratings.

The **node concept** is important and sometimes confuses investigators interpreting the model’s cross-section specific results (Figure 4.31). *SacEFT’s riparian initiation model does not provide a count of surviving stems or seedlings. Rather, based on the inherent spatial resolution present for each cross-section dataset, every survey point (whether real or interpolated) is treated as/called a “node”. The model calculates whether a single seedling in the center of each of these “nodes” would or would not survive.* The node count of surviving seedlings is then used as an index of seedling initiation success (more being better). Any change in the number of cross sections evaluated or the resolution of existing cross-sections would result in requiring re-calibration of **R/Y/G** threshold cut-offs.

### Indicator Reliability

The indicator credibility rankings for FC1 are shown in Table 4.27.

Table 4.27. FC1 – Riparian initiation - indicator credibility assignments following the workshop. These ratings apply to those point bars in the Sacramento River that have detailed stage-discharge relationships available.

|                           | Category |   |   |   |   |
|---------------------------|----------|---|---|---|---|
|                           | I        | U | R | F | P |
| FC1 – Riparian initiation | H        | M | H | H | H |

FC1 scores High with respect to rigor because the model is based on field observation data derived for the Sacramento River. Understanding is scored as Medium (“strong evidence but not conclusive, only medium strength predictive power, some evidence for competing hypotheses and/or confounding factors”). Riparian initiation is a site specific process, influenced by local factors such as substrate soil characteristics, presence of ephemeral water and other site specific factors that influence initial seed viability.

Excel reports

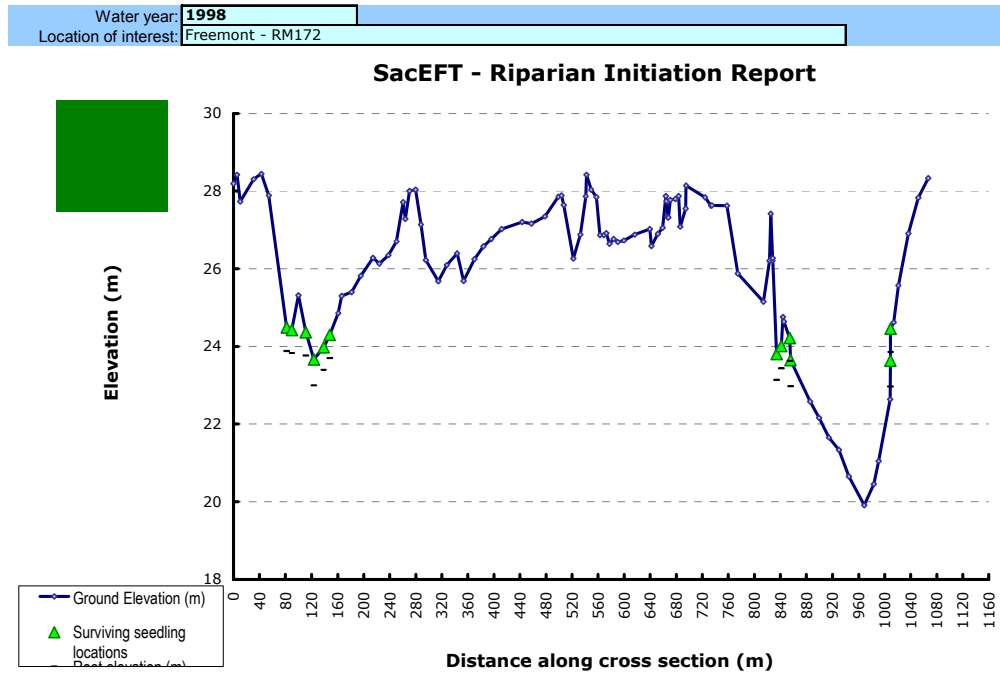
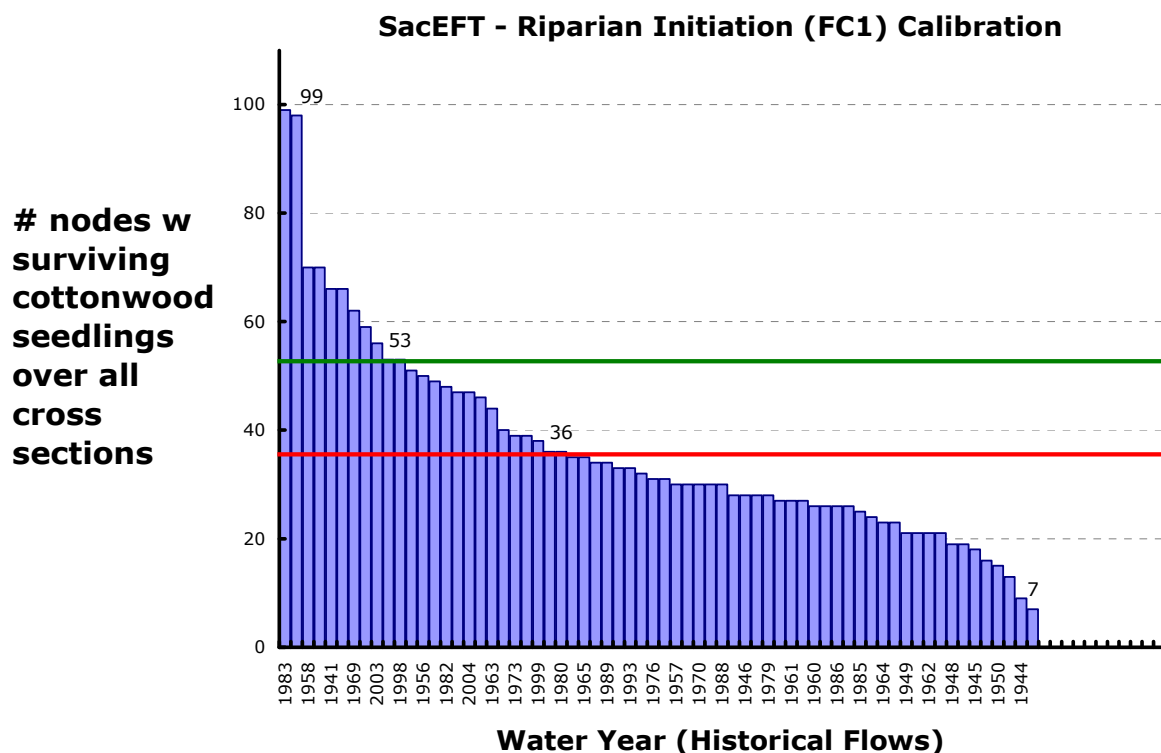


Figure 4.31: SacEFT Fremont Cottonwood seedling initiation success: 1998 (good year).

Indicator Threshold Calibration

The cottonwood performance measure tallies the number of initiation successes and failures across years and across the three cross-sections used in the model. Based on inspection of the all year results, counts of successfully initiating nodes are used to assign R/Y/G indicator ratings. SacEFT’s riparian initiation model calculates whether a single seedling in the center of each of these “nodes” would or would not survive. **The node count of surviving seedlings** is then used as an index of seedling initiation success (more being better).

In making R/Y/G assignments for a particular water year, the value in the *ARollGoodCountAssignGood* field in the SacEFT database (*SummaryOut\_PMThresholds* table) represents a count of cross-sectional nodes, **in the target zone for initiation** (i.e., anything above 8,500 cfs elevation + 3ft), where surviving seedlings were found. At present, with the existing eleven cross-sections, the value 53 was found by visual inspection to represent “good” (i.e., Green) initiation success, from historical flow data sorted descending (best to worst counts for each year) over the 66 year historical record. Likewise, *ARollGoodCountAssignBad* represents the equivalent information, defining the lower bound on successfully initiating nodes before the color Red is assigned (node count ≤ 36) (see Figure 4.32 and Table 4.28).



**Figure 4.32:** Annual roll-up results for the SacEFT Fremont cottonwood initiation (FC1) performance measure run using historic observed flows (1938–2003).

This indicator threshold calibration also takes into consideration comparisons with aerial photographs of historically strong Cottonwood recruitment at study sites vs. model results. At present, years revealed by SacEFT as having the potential for strong riparian initiation success are: 1941, 1952, 1952, 1958, 1967, 1969, 1971, 1975, 1983, 1997, 1999 and 2003 (historical data in SacEFT currently do not extend beyond 2004). However, after considering riparian scour potential (FC2), only **1958, 1967, 1971, 1975, 1999 and 2003** are predicted to show strong initiating cohorts of riparian seedlings (1941, 1952, 1969, 1983, 1997 predicted to suffer high risk of seedling scour following successful initiation).

**Note:** Any change in the number of cross sections evaluated or the resolution of existing cross-sections would result in requiring re-calibration of **R/Y/G** threshold cut-offs.

Table 4.28. FC1 – Riparian initiation success. Units are counts of successful initiation at the index nodes.

|                             | Daily     |           | Rollup    |           | Notes  |
|-----------------------------|-----------|-----------|-----------|-----------|--|
|                             | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |  |
| Riparian Initiation Success | N/A       | N/A       | 53        | 36        | <ul style="list-style-type: none"> <li>Criteria: thresholds based on expert opinion and observation of Good initiation years, “more” is better</li> <li>Units: count of cross section nodes with surviving stems or seedlings.</li> <li>No daily estimate</li> </ul> |



**RIPARIAN SCOUR (FC2)**

Based on recommendations from the SacEFT refinements workshop, a second performance measure has been included in SacEFT v.2 to capture the effects of scour events following riparian initiation. The rationale for including this second performance measure is that gains made after successful riparian initiation are moot if the seedlings are scoured out in the following year, *i.e.*, there is no point expending large volumes of water to achieve riparian initiation, and then wiping out these benefits in year t+1 with a scouring flow (Figure 4.33).

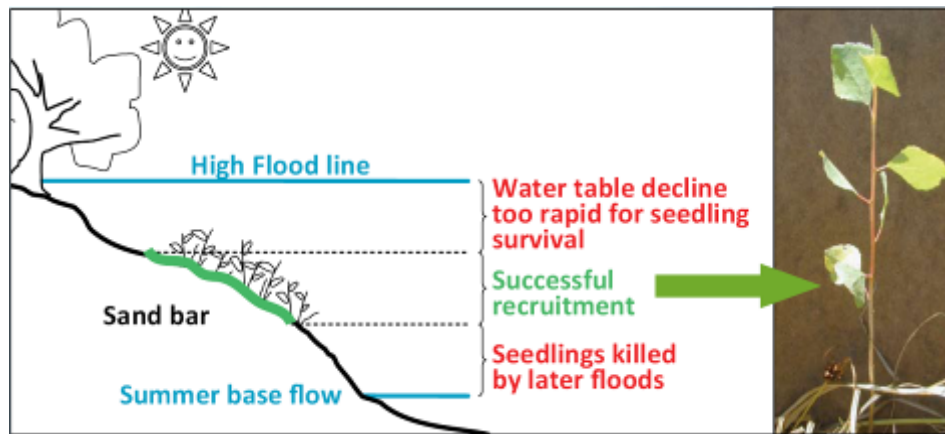


Figure 4.33. Generalized pattern of successful seedling initiation observed for cottonwoods along alluvial rivers. Seedlings that germinate too high on the bank cannot grow roots fast enough to keep up with the receding water table and soil moisture level during the hot summer months, while seedlings that initiate too low on the bank are removed by scour during high flow events during the subsequent winter or spring. Seedlings in the target initiation zone may also be scoured and killed by high flows. *Source:* Stillwater Sciences poster presentation, Calfed Science Conference (2008).

This performance measure is by design only calculated in years following Fair (Yellow) or Good (Green) FC1 initiation success. Considering riparian scour potential (FC2), the following strong initiating cohorts of riparian seedlings (FC1) are predicted to suffer high (Red) rates of scour following successful initiation: 1941, 1952, 1969, 1983, 1997 (*i.e.*, approx. 5 in 11 years successfully initiating cohorts may be wiped out by subsequent high flows).

**Indicator Reliability**

The indicator credibility rankings for FC2 are shown in Table 4.29.

Table 4.29. FC2 – Riparian scour - indicator credibility assignments following the workshop. These ratings apply to those point bars in the Sacramento River that have stage-discharge relationships and scour depth as a function of flow.

|                           | Category |   |     |   |   |
|---------------------------|----------|---|-----|---|---|
|                           | I        | U | R   | F | P |
| FC2 – Riparian scour risk | H        | M | M/L | H | H |

The FC2 indicator scores Medium on understanding because the sensitivity of this measure and its stability across multiple sites is theoretical, and alternative hypotheses and confounding factors will exist.

**Excel Reports**

None.

### Indicator Threshold Calibration

Initial scour thresholds for assignment of **R/Y/G** proposed by riparian subgroup participants were identified as follows. A flow of  $\geq 90,000$  cfs would *ensure* 100% scour mortality of riparian seedlings  $\leq 1$  years (*i.e.*, = **Red** classification), wiping out recruitment success of the previous year. Flows of  $\geq 90,000$  cfs are expected to generate gravel mobilization down to 2 feet or more, based on scour chain observations. Flows of  $\geq 80,000$  cfs (and  $< 90,000$  cfs) are expected to generate gravel mobilization producing a **Yellow** classification risk for seedling scour.

*Note:* these thresholds are readily configurable in the SacEFT database.

Table 4.30. FC2 – Riparian scour risk. Units are threshold flows (cfs) for bank mobilization events.

|                     | Daily     |           | Rollup    |           | Notes  |
|---------------------|-----------|-----------|-----------|-----------|--|
|                     | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |  |
| Riparian Scour Risk | N/A       | N/A       | 80000     | 90000     | <ul style="list-style-type: none"> <li>• Criteria: thresholds based on expert opinion of scour events, “less” is better</li> <li>• Units: flow (cfs)</li> <li>• No daily estimate</li> </ul> |

#### 4.3.5 Large woody debris recruitment to mainstem Sacramento River

Large Woody Debris recruitment (LWD) is a proxy indicator for Western Pond Turtle (WPT) habitat quality. The indicator is based on the assumption provided by professional herpetologists at SacEFT design workshops that recruitment of LWD into the main channel of the Sacramento River will create more hospitable habitat conditions for WPT. To estimate LWD recruitment to the main channel, the area eroded with older forest vegetation is used as a measurement of how much potential large woody debris is recruited each year.

A GIS layer representing mature vegetation was created from the 2007 Riparian vegetation data for the Sacramento River; obtained from the Sacramento River GIS portal<sup>1</sup>. The GIS dataset includes vegetation class and height category. For the purpose of the recruitment of LWD, forests taller than 34 ft (height class 4 or higher) are considered old forest. The vegetation class itself is not used in this version of the LWD model as it is not clear whether WPT would preferentially use different types of LWD. An important simplifying caveat is that the LWD model assumes that the distribution of forest size classes is static during SacEFT simulations, *i.e.*, the vegetation cover map input at the start of the model simulation does not or change in species composition.

The performance measure for this indicator is computed for each location as the area eroded with old vegetation. The area is found in a GIS by overlaying the predicted eroded areas from the bank erosion model (see Section 4.1.6) with the old growth GIS layer (see Figure 4.34). Areas where the eroded area and the old vegetation locations overlap are considered to be the sources of LWD. Finally, the old vegetation areas are divided into 38 bends located in 3 different river segments for reporting purposes.

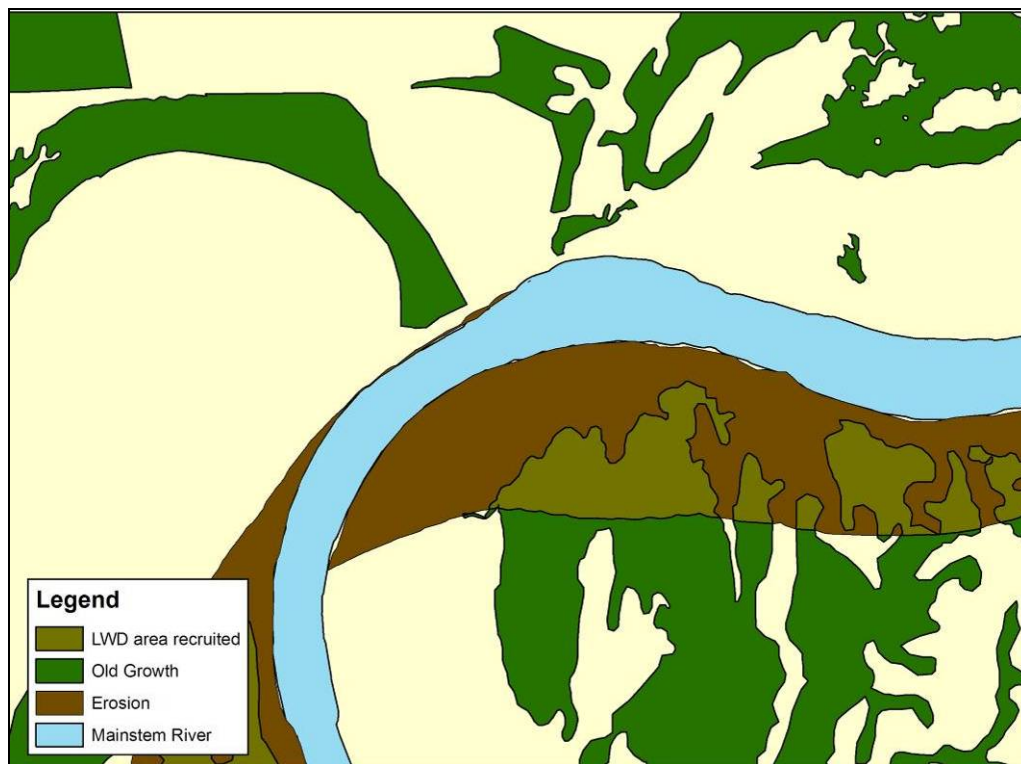


Figure 4.34: Map illustrating vegetation classes used to compute LWD recruitment for SacEFT.

<sup>1</sup> <http://www.sacramentoriver.org/srcaf/index.php?id=data>

The *Rollup* indicator is then computed by summing the area eroded in old growth forest across all locations ( $L$ ):

$$LWD = \sum_{l=1}^L LWD_l$$

### Indicator Reliability

LWD is assigned the reliability shown in Table 4.31. This is a semi-quantitative proxy performance indicator reliant on the results of the Meander Migration Model, which are post-processed to create the Bank Erosion model.

Table 4.31. Credibility assignment for LWD – Large woody debris recruitment.

|                                | Category |   |   |      |     |
|--------------------------------|----------|---|---|------|-----|
|                                | I        | U | R | F    | P   |
| Large woody debris recruitment |          | M | M | L/M? | L/M |

## Excel Reports

An example of a SacEFT v.2 Excel report for LWD is shown in Figure 4.35.

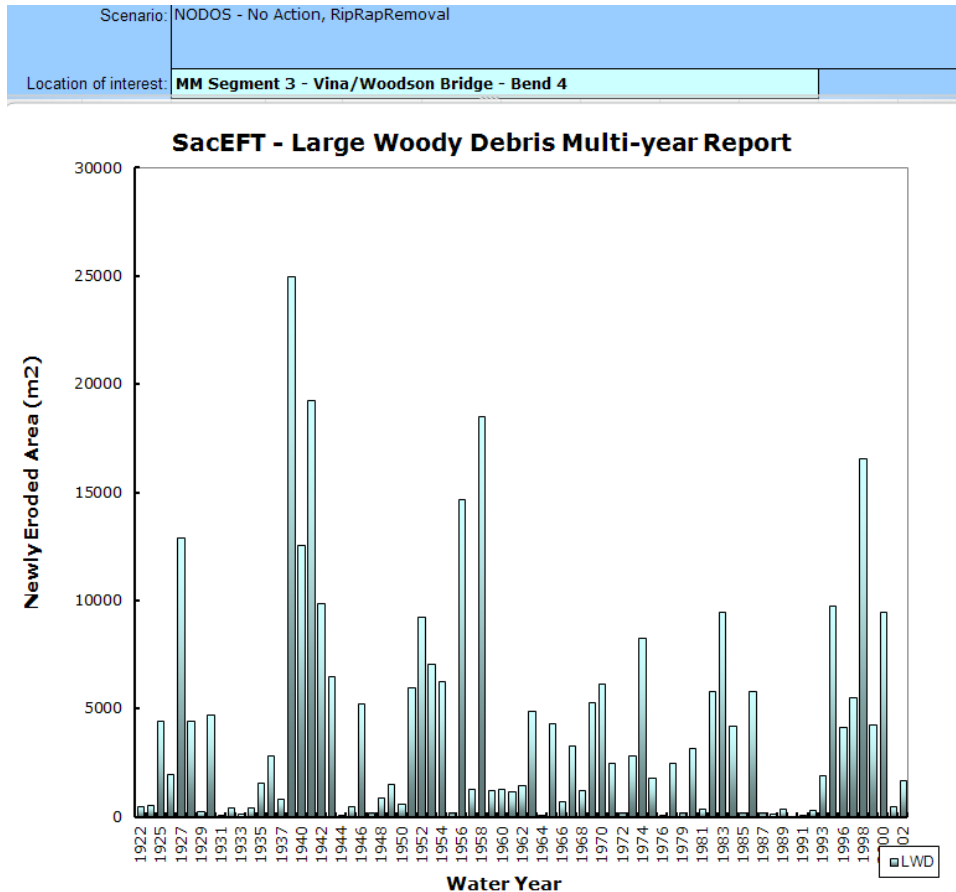


Figure 4.35. An example of an Excel report for LWD – Large Woody Debris recruitment. This example shows the square meters eroded each year for Bend 4 in the Vina/Woodson Bridget segment, as a proxy for WPT habitat.

## Indicator Threshold Calibration

To calibrate the LWD indicator, we used empirically measured historical flow data with no rip-rap removal. LWD areas are summed for all locations for each year and the PM values were sorted from largest to smallest. Values that define the upper-, middle and lower thirds (terciles) of the sorted values are termed roll-up Hazard Threshold boundaries (see Figure 4.36 and Table 4.32).

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. However, to our knowledge, there does not exist a dataset that estimate the amount of LWD recruited to the main-stem Sacramento River, so it is not currently possible to evaluate year with Good or Poor performance.

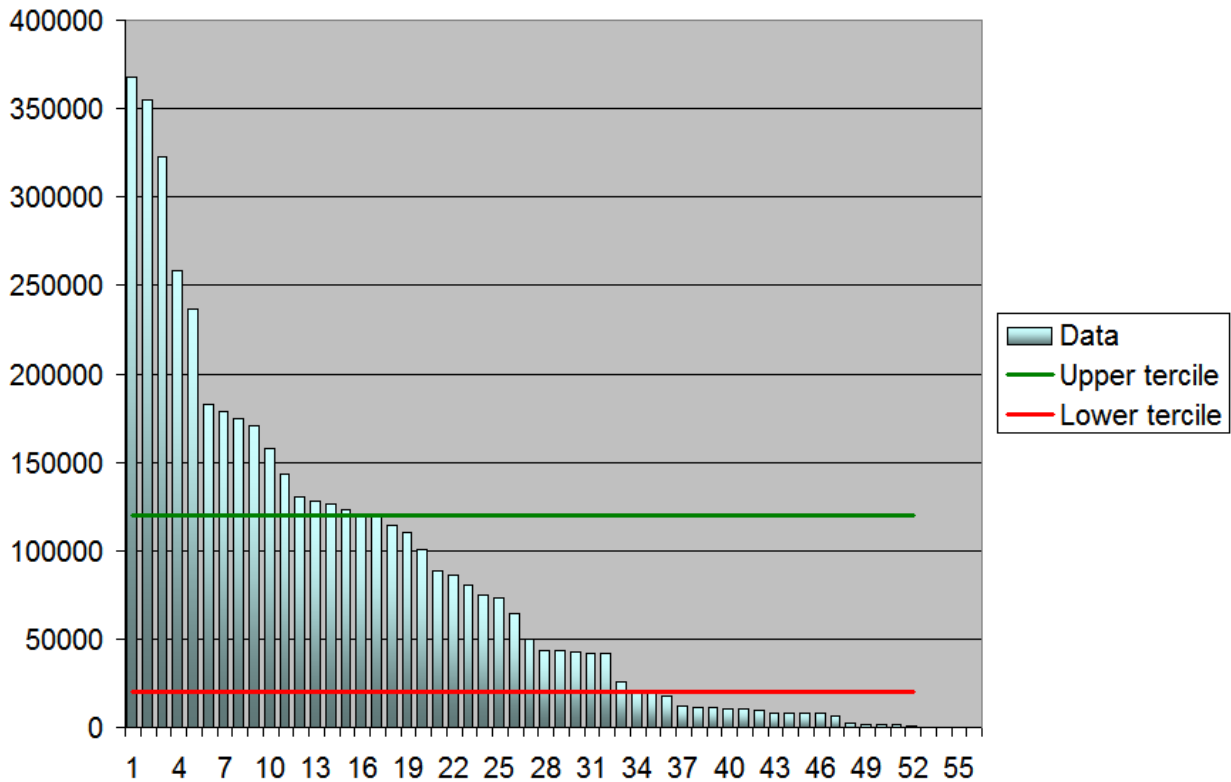


Figure 4.36. Calibration assumptions for LWD. Units on the y-axis are square meters riparian forest eroded to mainstem Sacramento River having forests taller than 34 ft (height class 4 or higher).

Table 4.32. LWD – Large Woody Debris indicator rating breakpoints, in units of square meters.

|                                | Daily     |           | Rollup    |           | Notes  |
|--------------------------------|-----------|-----------|-----------|-----------|--|
|                                | Good-Fair | Fair-Poor | Good-Fair | Fair-Poor |  |
| Large Woody Debris recruitment | N/A       | N/A       | 120000    | 20000     | <ul style="list-style-type: none"> <li>Criteria: statistical distribution, terciles, “more” is better</li> <li>Units: square meters riparian forest eroded to mainstem Sacramento River having forests taller than 34 ft (height class 4 or higher).</li> <li>No daily estimate</li> </ul> |

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## Appendix A – Invited Workshop Participants

### SacEFT v.1 design workshop (Dec. 5-6, 2005 Davis, CA):

| Name              | Subgroup            | Area of Expertise                              | Organization   | Phone / Fax           | Email  |
|-------------------|---------------------|--|--|-----------------------|--|
| Ryan Luster       | Riparian / wildlife | Project Manager / habitat restoration          | The Nature Conservancy   | 530-897-6370 ext 213  | <a href="mailto:rluster@tnc.org">rluster@tnc.org</a>                           |
| Greg Golet        | Riparian / Wildlife | Focal species / functional relationships       | The Nature Conservancy   | 530-897-6370 ext. 212 | <a href="mailto:ggolet@tnc.org">ggolet@tnc.org</a>                             |
| Anthony Saracino  | Physical            | Water Policy                                   | The Nature Conservancy   | 916-449-2850 ext. 22  | <a href="mailto:asaracino@tnc.org">asaracino@tnc.org</a>                       |
| Mike Roberts      | Fish                | Hydrology                                      | The Nature Conservancy   | 801-842-9482          | <a href="mailto:mike_roberts@tnc.org">mike_roberts@tnc.org</a>                 |
| David Marmorek    | Fish                | DA tool, tradeoff evaluations                  | ESSA Technologies  | 604-733-2996          | <a href="mailto:dmarmorek@essa.com">dmarmorek@essa.com</a>                     |
| Clint Alexander   | Physical            | DA Tool construction                           | ESSA Technologies  | 250-860-3824          | <a href="mailto:calexander@essa.com">calexander@essa.com</a>                   |
| Marc Nelitz       | Riparian / Wildlife | DA Tool construction                           | ESSA Technologies  | 604-733-2996          | <a href="mailto:mnelitz@essa.com">mnelitz@essa.com</a>                         |
| Michael Fainter   | Fish                | Focal species info, SOS Report, Field Studies  | Stillwater Sciences  | 510-848-8098 ext. 127 | <a href="mailto:mike@stillwatersci.com">mike@stillwatersci.com</a>             |
| Bruce Orr         | Riparian / Wildlife | Focal species info, SOS Report, Field Studies  | Stillwater Sciences  | 510-848-8098 ext. 111 | <a href="mailto:bruce@stillwatersci.com">bruce@stillwatersci.com</a>           |
| Frank Ligon       | Fish                | Focal species info, SOS Report, Field Studies  | Stillwater Sciences  | 707-822-9607 ext. 213 | <a href="mailto:frank@stillwatersci.com">frank@stillwatersci.com</a>           |
| Yantao Cui        | Physical            | TUGS, Oxbow Cut-off models                     | Stillwater Sciences  | 510-848-8098 ext. 120 | <a href="mailto:yantao@stillwatersci.com">yantao@stillwatersci.com</a>         |
| Eric Larsen       | Physical            | Meander Migration Model                        | UC Davis   | 530-752-8336          | <a href="mailto:ewlarsen@ucdavis.edu">ewlarsen@ucdavis.edu</a>                 |
| Matt Kondolf      | Physical            | Oxbow studies, fluvial geomorphology           | University of California, Berkeley   | 510-644-8381          | <a href="mailto:kondolf@calmail.berkeley.edu">kondolf@calmail.berkeley.edu</a> |
| Rebecca Fris      |                     | CBDA Ecosystem Restoration Program coordinator | CALFED   | 916-445-5031          | <a href="mailto:rebeccaf@calwater.ca.gov">rebeccaf@calwater.ca.gov</a>         |
| Tom Morstein-Marx | Physical            | CalSim II operator                             | USBR   | 916-979-2196          | <a href="mailto:tmorsteinmarx@mp.usbr.gov">tmorsteinmarx@mp.usbr.gov</a>       |
| Dan Easton        | Physical            | CalSim II operator                             | Water Resources Engineer, Department of Water Resources, Bay-Delta Office, Modeling Support Branch | 916-653-7695          | <a href="mailto:deaston@water.ca.gov">deaston@water.ca.gov</a>                 |
| Ken Kirby         | Physical            | Hydrosystem consultant                         | Active Curiosity   | 916-646-4361          | <a href="mailto:kkirby@activecuriosity.com">kkirby@activecuriosity.com</a>     |
| Lisa Micheli      | Physical            | Physical / sediment transport processes        | Sonoma Ecology Center  | 415-264-2018          | <a href="mailto:micheli@vom.com">micheli@vom.com</a>                           |
| Koll Buer         | Physical            | Physical / sediment transport processes        | CDWR (retired)   | 530-527-1417          | <a href="mailto:kollbuer@gmail.com">kollbuer@gmail.com</a>                     |
| Mike Singer       | Physical            | Physical / sediment transport processes        | UC Santa Barbara   | 510-643-2161          | <a href="mailto:bliss@bren.ucsb.edu">bliss@bren.ucsb.edu</a>                   |
| Stacey Cepello    | Physical            | HEC-RAS upper Sac                              | CDWR   | 530-529-7352          | <a href="mailto:cepello@water.ca.gov">cepello@water.ca.gov</a>                 |
| Russ Yaworsky     | Physical            | USBR Upper Sacramento River Temperature Model  | USBR   | 916-978-5099          | <a href="mailto:ryaworsky@mp.usbr.gov">ryaworsky@mp.usbr.gov</a>               |

| <b>Name</b>      | <b>Subgroup</b>     | <b>Area of Expertise</b>                      | <b>Organization</b>                | <b>Phone / Fax</b>   | <b>Email</b>   |
|------------------|---------------------|---|------------------------------------|----------------------|--|
| Tom Smith        | Physical            | HEC-RAS middle Sac                            | Ayres Associates                   | 916-563-7700         | <a href="mailto:smitht@AyresAssociates.com">smitht@AyresAssociates.com</a>                     |
| Harry Rectenwald | Fish                | Chinook salmon                                | CDFG                               | 530-225-2368         | <a href="mailto:hrectenw@dfg.ca.gov">hrectenw@dfg.ca.gov</a>                                   |
| Jim Smith        | Fish                | Chinook salmon                                | USFW, Red Bluff                    | 530-527-3043         | <a href="mailto:Jim_Smith@fws.gov">Jim_Smith@fws.gov</a>                                       |
| Dennis McEwan    | Fish                | Steelhead                                     | CDFG                               | 916-327-8850         | <a href="mailto:dmcewan@dfg.ca.gov">dmcewan@dfg.ca.gov</a>                                     |
| Rob Titus        | Fish                | Steelhead                                     | CDFG                               | 916-227-6399         | <a href="mailto:rtitus@dfg.ca.gov">rtitus@dfg.ca.gov</a>                                       |
| Peter Klimley    | Fish                | Green sturgeon                                | UC Davis                           | 530-752-5830         | <a href="mailto:apklimley@ucdavis.edu">apklimley@ucdavis.edu</a>                               |
| Kurt Brown       | Fish                | Green sturgeon                                | USFWS – Coleman Hatchery           |                      | <a href="mailto:brown_kurtis@fws.gov">brown_kurtis@fws.gov</a>                                 |
| Wim Kimmerer     | Fish                | Chinook salmon modeling                       | San Francisco State Univ.          | 415-338-3515         | <a href="mailto:kimmerer@sfsu.edu">kimmerer@sfsu.edu</a>                                       |
| Mark Gard        | Fish                | PHABSIM, River 2D, juvenile stranding surveys | USFWS                              | 916-414-6600         | <a href="mailto:Mark_Gard@fws.gov">Mark_Gard@fws.gov</a>                                       |
| Dave Germano     | Riparian / Wildlife | Western pond turtle                           | CSU, Bakersfield                   | 661-664-2471         | <a href="mailto:David_Germano@firstclass1.csubak.edu">David_Germano@firstclass1.csubak.edu</a> |
| Bruce Bury       | Riparian / Wildlife | Western pond turtle                           | USGS                               | 541-750-1010         | <a href="mailto:Bruce_Bury@usgs.gov">Bruce_Bury@usgs.gov</a>                                   |
| Tag Engstrom     | Riparian / Wildlife | Western pond turtle                           | California State University, Chico | 530-898-6748         | <a href="mailto:tengstrom@csuchico.edu">tengstrom@csuchico.edu</a>                             |
| Ron Schlorff     | Riparian / Wildlife | Bank swallow                                  | CDFG                               | 916-654-4262         | <a href="mailto:RSchlorf@dfg.ca.gov">RSchlorf@dfg.ca.gov</a>                                   |
| Barrett Garrison | Riparian / Wildlife | Bank swallow                                  | CDFG, Rancho Cordova               | 916-358-2945         | <a href="mailto:bagarris@hq.dfg.ca.gov">bagarris@hq.dfg.ca.gov</a>                             |
| Joe Silveira     | Riparian / Wildlife | Bank swallow                                  | USFWS                              | 530-934-2801         | <a href="mailto:joe_silveira@fws.gov">joe_silveira@fws.gov</a>                                 |
| Naduv Nur        | Riparian / Wildlife | Riparian and songbirds                        | PRBO                               | 415-868-1221 ext 315 | <a href="mailto:nnur@prbo.org">nnur@prbo.org</a>   |
| John Bair        | Riparian / Wildlife | TARGETS                                       | McBain & Trush                     | 707-826-7794         | <a href="mailto:john@mcbaintrush.com">john@mcbaintrush.com</a>                                 |
| Steve Greco      | Riparian / Wildlife | riparian-bird community                       | UC Davis                           | 530-754-5983         | <a href="mailto:segreco@ucdavis.edu">segreco@ucdavis.edu</a>                                   |

**SacEFT v.2 design workshop (October 7-8 2008, Chico CA):**

| <b>Invited water managers for Day 1: October 7</b> |                   |              |
|--|-------------------|--------------|
| Ron Ganzfried                                      | Campbell Ingram   | Sean Sou     |
| Maurice Hall                                       | Aric Lester       | Joseph Terry |
| John Hannon  | Tom Morstein-Marx | Jim Weiking  |
| Derek Hilts  | Steve Roberts     |              |
| Buford Holt  | Anthony Saracino  |              |

| <b>Invited biologists for Days 1 and 2: October 7 and 8</b> |                  |                  |
|---|------------------|------------------|
| Colleen Harvey Arrison                                      | Chris Eilers     | Bruce Oppenheim  |
| Don Ashton  | Tag Engstrom     | Bruce Orr        |
| John Bair   | Mark Gard        | Steve Lindley    |
| Ed Ballard  | Dave Germano     | Keith Marine     |
| Randy Benthin   | Adam Henderson   | Nadav Nur        |
| Mike Berry  | Josh Israel      | Bill Poytress    |
| Tricia Brachter   | Doug Killam      | Bruce Ross       |
| Howard Brown  | Jason Kindopp    | Ron Schlorff     |
| Larry Brown   | Peter Klimley    | Joe Silveira     |
| Matt Brown  | Ryan Kurtis      | Jim Smith        |
| Daniel Burmester  | Eric Larsen      | Alicia Steinholz |
| Bruce Bury  | Alice Low        | Rob Titus        |
| Bradley Cavallo   | Dennis McEwan    | Mike Tucker      |
| Richard Corwin  | Tracy McReynolds | Dave Vogel       |
| Yantao Cui  | Rod McInnis      | Dave Zezulack    |