Sacramento River
Ecological Flows Tool (SacEFT):
Design & Guidelines (v.2.00)

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Prepared for

The Nature Conservancy
North Central Valley Office
500 Main St.
Chico, CA 95928

Prepared by

ESSA Technologies Ltd.
1765 West 8th Avenue, Suite 300
Vancouver, BC V6J 5C6

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Glossary

ADO.NET - The data-access component of the Microsoft .NET Framework.

Base Class Library (BCL) - An object oriented framework of reusable classes accessible from any .NET language

Binary file - 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.

Binary object – A binary large object (BLOB) is a format of binary data stored in a relational database.

Business validation rules - 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.

CALSIM II - A state-wide planning model which simulates operations of SWP and CVP facilities, under a Coordinated Operations Agreement, on a monthly time-step.

Cascade delete and update - A process that causes an action to be taken on rows in a database when another row is deleted.

Class - 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.

COM components - A set of specification and services that facilitates a developer to create reusable objects and components for running various applications.

Compatibility list - 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.

Data instance - A SacEFT database concept for tracking imported datasets and their metadata using a unique identifier. Also used to tag information on non-imported (i.e., local) generic rules/parameter values for focal species (i.e., also used as a scenario identifier).

Database engine - The part of the database manager that provides the base functions and configuration files that are needed to use the database.

Desktop centered architecture – The majority of software application code is installed on individual workstations rather than accessed from a centralized server computer.

HEC-5Q – alternate name for USBR Temperature Model.

IEM - 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.

Metadata - The set of characteristics that describe the underlying assumptions and other major properties of a dataset or model.

NWIS - USGS National Water Information System.

OOD - 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.

RM – 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 Chipps Island.

R/Y/G – The Red/Yellow/Green 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.

SacEFT – Sacramento River Ecological Flows Tool.

SOAP - 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.

SQL Server 2005 Express - A free, redistributable version of SQL Server 2005 designed for building simple data-driven applications.

Structured error handling – An approach for signaling and responding to unexpected problems while a software program is running.

Thick-client architecture – Where application-specific code runs on and processes data on the client, rather than merely rendering data which has been processed by a server.

TUGS – The Unified Gravel-Sand model.

USBR Temperature Model – occasionally referred to as USBR TMS/HEC-5Q or HEC-5Q; and more recently the USBR Upper Sacramento River Temperature Model.

Windows event log - 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.

Wrapper - A program or script that sets the stage and makes possible the running of another, more important program.

1. Decision Analysis Tool: Overview

1.1 Background

This document describes how SacEFT v.1 will be refined to generate SacEFT v.2.

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.delta.dfg.ca.gov/erp/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. The SacEFT allows: 1) the evaluation of ecosystem responses to alternative scenarios of discharge, water temperature, gravel augmentation, and channel revetment 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 (+SRWQM and USRDOM), that evaluate statewide water management operations. SacEFT is now fully operational, and herein we describe refinements to its utility to Sacramento River water management planning processes.

One of the main tasks of the SacEFT v.1 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 minimal. Ecological considerations were limited to meeting minimal in-stream flows, meeting basic temperature requirements, or limiting periods of pumping during times when sensitive species are present. Although these considerations are among the highest management priorities, they are often focused on single species management. 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 focal species and their habitats. 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 assessing ecological trade-offs.

In addition to integrating disparate sources of information, the second challenge we overcame in constructing SacEFT v.1 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).

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.

Building a tool that will make accurate predictions of ecosystem behavior is challenging and usually not possible in complex, open natural systems (Oreskes et al. 1994). SacEFT's main purpose will be 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 CBDA, water resource managers and stakeholders converge on options that best strike a balance among a variety of conflicting objectives.

1.1.1 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 ERP ecoregion) prior to expanding efforts to other ERP ecoregions. We now have a significant foundation of existing work to build upon in light of progress with the DRERIP process, BDCP process, new OCAP BiOPs, PPIC initiatives and POD research. The timing and information sources are now 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 ecoregions of the Sacramento River and Delta.

Extending the SacEFT software in order to incorporate Delta targets and management actions will 1) better unite ecological water operations planning by allowing for inter- and intra-regional ecological trade-off evaluations within and between the Sacramento and Delta systems, 2) take advantage of previously awarded CALFED ERP funds, and 3) achieve economies of scale by applying the same approach utilized to construct the SacEFT architecture.

In addition to building on the investment in SacEFT, the Delta Ecological Flows Tool – DeltaEFT – will build upon the substantial body of recent scientific research conducted to inform the ongoing planning efforts listed earlier. Our vision for DeltaEFT (presented in depth in the DeltaEFT Design Document (in prep.)) is to create a software tool that makes it easy for non-specialists to expand the ecological considerations and science foundation used to evaluate Delta water management alternatives, keeping the technical details "under the hood" for managers and other stakeholders, but still accessible to technical specialists. Another goal is to use DeltaEFT to strengthen current water planning efforts in both the Delta and Sacramento Basin. Our premise is that this can occur by clearly analyzing comprehensive restoration strategies that better account for multiple ecosystem components in multiple locations. DeltaEFT will explicitly link upstream (Sacramento River) ecological responses evaluated with SacEFT to ecosystem responses in the Delta evaluated with DeltaEFT. The software architecture will be constructed such that managers and decision makers may choose to evaluate ecological responses to management actions in upstream geographies (the Middle Sacramento River), downstream geographies (the Delta), or both.

DeltaEFT will use the common interfaces and design principles of SacEFT, to become "Sac DeltaEFT".

1.1.2 Need for assessing ecological issues

Many water planning efforts to balance demands on the mainstem of the Sacramento River do not explicitly account for enough critical ecosystem components. Current attention focuses primarily on maintaining minimum in-stream flow and temperature requirements for the upper reaches to support listed fish species, or treating the Sacramento River as a conduit to control relationships between flow and salinity in the Delta. Incorporating additional attributes of the flow regime, and the manner in which they maintain the ecological function of the Sacramento River, could result in more effective water management and ecosystem restoration strategies. An important first step is to develop 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. Identifying and working to improve "critical attributes" is not to be confused with a naive attempt to "naturalize" Sacramento River hydrosystem operations.

There is also a disparity in the number of (actively funded) tools for evaluating ecological consequences relative to assessing physical factors. Figure 1-1 illustrates the large number of tools and studies available on the Sacramento River to address social and economic considerations relative to ecological consequences. Panel "a" (top) in Figure 1-1 lists some of the more important factors taken into account, while panel "b" (bottom) illustrates the relative emphasis and weight of analysis traditionally devoted to these issues.

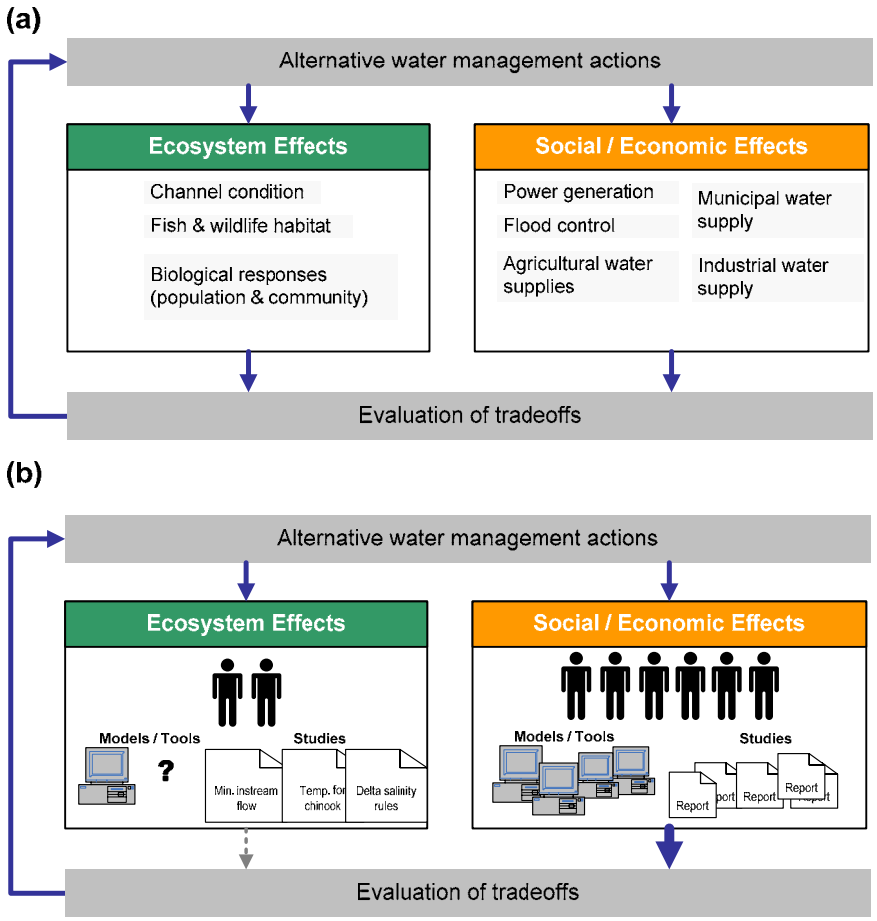

Figure 1-1. Water management on the mainstem Sacramento River affects both ecosystem and socioeconomic issues. Panel (a) lists some of the issues, while panel (b) shows the larger emphasis and number of tools/studies traditionally brought to bear on the evaluation of socioeconomic factors.

SacEFT will expand the consideration given to ecological targets in water management decisions on the Sacramento River by leveraging many of the same planning models used in existing socioeconomic evaluations. While the SacEFT tool could later be linked to socioeconomic models, this was not a focus of this project. To reduce the shortfall in ecological evaluation capability, SacEFT includes ecological objectives and a series of habitat/biological performance measures for various focal species. Following testing and threshold calibration SacEFT will:

- *Improve the basis for evaluating flow alternatives.* A number of potential water development projects are on the horizon in northern California, including a north of Delta off-stream storage reservoir (NODOS), raising Shasta Dam, water transfers, conjunctive use strategies, and an updated Operations, Criteria, and Plan (OCAP). Currently, water planners and managers only have limited information related to potential ecological impacts and responses to evaluate when considering making changes within the water management system. This information is primarily minimum in-stream flows, since temperature targets and pumping schedules in the Delta have affected how these projects are developed and operated. Most of these instream flows have been derived based on a very narrow focus on a few species (mostly salmon and smelt). SacEFT will enable evaluation of strategies from a multiple species point of view by focusing on some key physical - habitat linkages. Routine incorporation of this information in a more balanced, proactive approach should reduce future listing of species that leads to costly regulatory actions.
- *Synthesize an array of information in different formats and scales in one place.* In addition to bringing together *data*, SacEFT will serve as an "eco plug-in" compatible with major water planning *models*, namely the CALSIM-SRWQM-HEC5Q modeling complex.
- *Improve interdisciplinary communications.* SacEFT will allow physical and natural scientists to integrate their knowledge and better test current beliefs (hypotheses) about key inter-relationships between river flows and ecological conditions.
- *Catalyze exploration of new alternatives* and promote the development of needed flexibility in the water management system.
- *Focus future monitoring and adaptive management experiments research on critical uncertainties that affect ecosystem response.*
- *Simplify communication of ecological flow recommendations to non-experts.*

SacEFT uses habitat attributes obtained from physical submodels (e.g., flow, water, temperature, substrate composition), as well as biological responses (or habitat surrogates for such responses) obtained from focal species submodels. These models involve a mix of spatial and temporal scales, and a mix of performance measures that vary widely in levels of reliability. Standardized metadata is included in SacEFT to help gauge the level of reliability of its component datasets and rules.

1.2 SacEFT vision

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. SacEFT is structured as an "ecological plug-in" to existing models that are commonly used for water planning in the Central Valley. Rather than reinventing models, SacEFT utilizes output data sets from CALSIM II and other models that are already addressing water supply and other demands on the water storage and delivery system. SacEFT utilizes these data sets, which typically emphasize human demands on the system, and adds ecological calculations to evaluate effects on various ecosystem targets. Specifically, SacEFT uses predictions of change in habitat attributes from these water management planning models (e.g., flow, water, temperature, substrate composition), to generate biological responses using functional relationships for a

select group of representative focal species of the Sacramento River ecosystem (chinook salmon, steelhead, green sturgeon, Fremont cottonwoods, western pond turtle, and bank swallows). These functional relationships were vetted through a multi-disciplinary workshop process; the findings of a second technical review workshop are the focus of this document. SacEFT uses these biological inferences as performance measures against which to evaluate alternative water management scenarios. Collectively, the constituent focal species "submodels" provide over 35 performance measures which vary in spatial scale, temporal scale, and levels of reliability. Multi-year rollups 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 (i.e., implementation of ideas in this document), the decision analysis tool will provide the ability to:

1. improve the basis for evaluating flow alternatives on the Sacramento River from Keswick to Colusa (e.g., North-of-Delta Off-Stream Storage Investigation, or Sites Reservoir, Shasta Lake Water Resources Investigation, or enlarged Shasta Dam, and new 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 six 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 detail functional relationships and transparent assumptions for review by technical experts;
4. leverage existing systems and data sources (CALSIM, 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.

To meet this vision, the system will continue to leverage existing physical datasets and models rather than reinventing wheels, and selectively fills in ecological gaps. Use of existing models is a key aspect of the system; this includes both common water planning tools like CalSim II as well as various ecologically oriented models such as the meander migration model developed by researchers at UC Davis. In the case of focal species, SacEFT typically "builds-in" select functional relationships from external models or studies when generating habitat/biological performance measures.

The long-range goal is for SacEFT to reliably evaluate the ecological impacts of alternative water delivery projects. However, this does not mean SacEFT should grow into a gargantuan information system that tries to do everything. Over time its scope may grow, but in the first instance, the solution will focus on ecological performance for a representative set of focal species.

1.2.1 Features

Water planners, decision-makers and scientists of moderate computer sophistication will be the main users of SacEFT. The system is not built for "power-users" or highly sophisticated technophiles. Each SacEFT technology component will be designed with this in mind. Because initial efforts emphasize demonstration of the integrated trade-off evaluation framework, the system will most readily meet this usability goal when users work with existing scenarios. In the v.2.00 release, manual effort and steps are required to import datasets, configure metadata and new scenarios.

SacEFT centralizes specific datasets and rules inside a relational database that supports multi-objective and multi-disciplinary gaming and evaluation of Sacramento River water management decisions. This is made possible by a unified data model and a unique, simple user interface that allows users to pick different scenarios and obtain a rapid assessment of overall performance by indicator and year. The

software allows more sophisticated users to "window in" on key performance measures to obtain details for locations and time periods of interest.

To be useful for non-specialists, results are displayed in a simplified grid showing "traffic light" performance by indicator and year. Through metadata and user feedback, SacEFT will also track the relevance and applicability of various performance measures over the different spatial and temporal scales of its component submodels. Longer range forecasts are less certain.

Table 1.1 summarizes the system's other major features.

Table 1.1. Summary of planned features for SacEFT. The IT concepts listed in this table are explained later in this document.

Feature set	Description
(1) Spatial harmonization	▪ Unique spatial identification for all sites of interest (initial demonstration emphasizes the river mile concept) ▪ Tracked as georeferenced points, segments and cross-sections ▪ Locations of interest to focal species identified in this context (initially treated as fixed) ▪ Some sites may have additional spatial detail (e.g., channel centerline from meander migration model), but for needs of focal species, can be managed in a "fixed zonal" context
(2) Import of external datasets, rules and associated metadata	▪ Tracked through *data instances* ▪ Manual import templates can be provided: requires familiarity with SacEFT db to import and configure. ▪ Automated data import routines for pre-defined, SacEFT compatible models and templates are not available in the v.2.00 release. ▪ Identification of kind/type of dataset (e.g., flow from gauge or CalSim II DOM, generic rule for riparian submodel) ▪ Date imported ▪ *Metadata standard for evaluation of embedded assumptions, uncertainties, external references, etc.* ▪ Optional storage of original source file objects
(3) User dataset/data instance reviews	▪ User-based reviews of dataset/data instance applicability, relevance and rigor ▪ Based on inspection of metadata accompanying data instance
(4) Compatibility management	▪ Inspection of metadata and user reviews to build "compatibility lists" -- a listing of imported physical model data instances that are allowed to be grouped together, based on having sufficiently similar embedded assumptions (i.e., same flows in USBR Upper Sacramento River Temperature Model and meander migration model and TUGS). This mechanism is used to encourage apples and apples datasets across models – At present, this is completed manually by SacEFT database administrator – Up-front choreography is needed to ensure independent models use identical flow datasets.
(5) Windows desktop application with easy to use interface	▪ Windows®-based rich client application. ("Rich client" means the user interface provides a variety of common controls and interactivity on the user's desktop). ▪ Tree and grid based controls; emphasizing "traffic light" displays of scenario x indicator x year performance. ▪ Developed in Visual Studio .NET 2005 (.NET Framework v.2.0)

Feature set	Description
(6) SQL Server 2005 Express relational database	▪ Desktop deployable relational database with the enterprise capabilities of SQL Server (security model, triggers, stored procedures, XML integration, .NET integration, 4Gig storage limit excluding log space) ▪ Capability to easily move to SQL Server Enterprise (e.g., if centralize to internet accessible multi-user application or need more than 4 Gig) at some future date.
(7) "Traffic light" and more detailed output reports in Excel	▪ Standardize ALL performance measures on green, yellow, red system to remove disparate and otherwise non-comparable units ▪ Account for value judgments ▪ Progressively disclose more detailed outputs for more sophisticated users ▪ Reports in MS Excel in support of the widely held Office application suite and make it easy to customize
(8) Web site for deployment files	▪ Install steps and files available from the web, eliminating CD media / access limitations: www.essa.com/SacEFT ▪ *User name and password required ▪ Installation of pre-requisites requires internet connectivity

1.2.2 How it will be used

SacEFT is intended to provide a collaboration and integration framework that leverages existing tools focused on the human need aspects of water deliveries in northern California (e.g., CalSim II). SacEFT users will be able to download the model from the internet, and immediately work with pre-defined scenarios. In context specific water gaming environments, SacEFT will combine outputs generated by existing water planning models with others to illuminate the anticipated ecological tradeoffs. Prior to these gaming sessions, SacEFT users will 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 SacEFT database administrator has imported external datasets and verified submodel compatibility, SacEFT scenarios can then be configured and run to give immediate feedback on ecological performance and tradeoffs. The efficiency of gaming exercises will depend largely on how quickly SacEFT's external physical submodels can be configured and run, and their results imported into SacEFT. Once external datasets are imported and configured, and focal species submodels run, gaming and trade-off analysis are instantaneous.

SacEFT will provide valuable results to two groups of users. Scientists will be able to supply their core data and metadata to SacEFT for ecological evaluation. Managers and decision makers will be able to quickly review "traffic light" (dashboard) summary reports, that illuminate the overall balance of performance across ecological indicators.

1.3 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 2005).

Four criteria guided the technical review and prioritization of submodels for SacEFT v.1. First, experts assessed whether proposed submodels 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 submodels 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 six focal species.

Table 1.2 summarizes the priorities resulting from the December 2005 workshop. The intention was to identify one or two priority performance measures per focal species to integrate into SacEFT. *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.

1.4 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 December 5-6 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 green, yellow and red zones to rapidly communicate the desirability of flow/temperature/sediment transport outcomes. In the current version of SacEFT, the hazard threshold boundaries between green/yellow and yellow/red 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) Suggestions for a small set of sensitivity analyses on alternative forms of critical functional relationships.

iv) Discussion of additional/new indicators for SacEFT v.2.

v) A discussion of how to enhance Excel report model output to show the assumptions associated with each model run.

vi) 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.

This document formalizes the feedback received at this workshop.

1.4.1 Summary of priority performance indicators for SacEFT v.2

Table 1.2 summarizes the priority performance indicators that were identified by workshop participants, and distinguishes indicators selected for inclusion in SacEFT v.2 after considering the (historic) selection criteria. This table also differentiates existing indicators that are unchanged in SacEFT v.2 from those that are to receive a significant overhaul.

Table 1.2. Summary of the performance measures, evaluation criteria, and priorities following the SacEFT model design workshop. Note the following abbreviations: CS – Chinook salmon or Steelhead trout, GS – green sturgeon, BASW – bank swallow, WPT – western pond turtle, and FC – Fremont cottonwood, FAD – floodplain age diversity, OFI – off-channel inundation, LWD – large woody debris, ISDF1 – invasive species deterrence. PMs marked in **red** in the Ver. 2 column are indicators that are still included in Version 2, but have not been significantly modified; those marked in **green** are pre-existing indicators that will be **significantly changed**; those marked in **blue** are **new** candidate indicators for Version 2. Text above defines our meaning of relevance, clarity, rigor and feasibility.

Focal species and performance measure	Relevance	Clarity	Rigor	Feasibility	Priority	Ver. 2	Comments
CS1 - 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
CS2 - Area of suitable rearing habitat	Direct	H	H	H	H	●	3 aggregate reaches, 4 run types
CS3 - Egg-to-fry survival rate	Direct	H	L	H	H	●	5 reaches, Bureau of Reclamation model
CS4 - Index of juvenile stranding	Direct	H	H	H	H	●	Daily flow; relationships from Gard (USFWS)
CS5 - Redd scour	Direct	M	L	H	M	●	Max flow during incubation
CS6 - Redd dewatering	Direct	M	M	H	M	●	Stage recession during incubation
CS98 – Juvenile gain	Direct	H	M	H	M/H	●	Rate of Juvenile weight gain
CS99 – Redd superimposition	Direct	H	L	L	L		Requires population for all years and scenarios; not feasible
GS1 - Egg-to-larvae survival rate	Direct	M	M	H	H	●	Laboratory studies for temperature tolerance
BASW1 – Length of channel bank with suitable nesting	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.
BASW2 – Ramping rates	Direct	M	M	M	H	●	Used findings in Linkages report to develop an indicator of bank sloughing due to flows during nesting
WPT1 – Area / connectivity of off-channel habitats	Direct	L	H	H	H		Area of orphaned channel habitat (m^2). Detailed modeling of connectivity – dependent on stage-discharge and x-sectional data – not feasible.
FC1 – Successful riparian 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.
FC2 – Riparian 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.
FAD1 – Riparian areas		M	M	M/H	M	●	Possible; not yet finalized
OFI1 – flooding pattern		L/M	M	L/M	L/M		Understanding is low; not feasible
LWD1 – recruitment		M	M	L/M	L/M		Data may not be available; not feasible
ISDF1 – Invasive deterrence		M	M	M	M ?	●	Possible; not yet finalized

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 will encourage 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 **Pr**oblem; (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 will 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. Candidate ecological objectives and performance measures. PMs marked in **green** have been significantly modified from Version 1; those marked in **blue** are new candidate PMs. Only those species and habitats that are currently expected to be included in SacEFT Version 2 are shown.

Focal Species	Ecological Objectives	Performance Measures
Fremont cottonwood (FC)	Maximize areas available for riparian initiation, and rates of initiation success at individual index sites.	FC1 – Successful riparian initiation (incidence of cottonwoods initiated along a given cross section, at end of seed dispersal period)
Bank swallow (BASW)	Maximize availability of suitable nesting habitats	BASW1 – Length of newly eroded banks with suitable soil texture for nesting (m) BASW2 – Indicator of bank sloughing during nesting (Red/Yellow/Green hazard zones)
Western pond turtle (WPT)	Maximize availability of habitats for foraging, basking, and predator avoidance	WPT1 – Area of orphaned channel habitat (m^2)
Green sturgeon (GS)	Maximize quality of habitats for egg incubation	GS1 – Egg-to-larvae survival
Chinook	Maximize quality of habitats for adult spawning	CS1 – Area of suitable spawning habitat (ft^2)

Focal Species	Ecological Objectives	Performance Measures
salmon, Steelhead trout (CS)	Maximize quality of habitats for egg incubation	CS3 – Egg-to-fry survival (proportion) CS5 – Redd scour (Red/Yellow/Green hazard zones) CS6 – Redd dewatering (proportion)
	Maximize availability and quality of habitats for juvenile rearing	CS2 – Area of suitable rearing habitat (ft^2) CS4 – Juvenile stranding (index) CS98 – Weight gain during juvenile residence (g)
FAD	Range of floodplain ages results in greater seral diversity for a variety of species	FAD1 – riparian floodplain age diversity (index)
ISDF	Flush side channels to favor local species	ISDF1 – invasive deterrence

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 Performance Measures	Physical datasets and submodels				
	Flow	Stage-Discharge	Temperature	Sediment Transport	Meander Migration
Fremont cottonwood (FC)	●	●			
Bank swallow (BASW)	●				●
Green sturgeon (GS)	●		●		
Chinook, steelhead (CS)	●		●	●[1]	
floodplain age diversity (FAD1)	●				●
Invasive deterrence (IDSF1)	●		●		

[1] 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 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 concepts employed for the evaluation of the 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
I **Importance**	The degree to which a linkage (functional relationship) controls the outcome relative to other drivers and linkages affecting that same outcome.	4 = High: Expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population's natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics. 3 = Medium: Expected sustained minor population effect or effect on large area or multiple patches of habitat. 2 = Low: Expected sustained effect limited to small fraction of population, addresses productivity and diversity in a minor way, or limited spatial or temporal habitat effects. 1 = Minimal: Conceptual model indicates little or no effect.
U **Understanding** ("Clarity")	The degree to which the performance indicator can be predicted from the defined linkage (functional relationship) and its driver(s).	4 = High: Understanding is high and nature of outcome is largely unconstrained by variability in ecosystem dynamics, other confounding external factors. 3 = Medium: Understanding is high but nature of outcome is moderately dependent on other variable ecosystem processes or uncertain external confounding factors. 2 = Low: Understanding is moderate or low and/or nature of outcome is greatly dependent on highly variable ecosystem processes or other external confounding factors. Many important aspects are subject of active ongoing research. 1 = Minimal: Understanding is lacking. Mainly subject of active ongoing primary research.
R **Rigor** ("Predictability")	The degree to which the scientific evidence supporting our understanding of a cause-effect relationship (linkage) is contested or confounded by other information.	4 = High: Is generally accepted, peer reviewed empirical evidence, strong predictive power and understanding, evidence not contested or confounded. Data in support of the functional relationship is derived from direct Bay-Delta field observations. 3 = Medium: Strong evidence but not conclusive, only medium strength predictive power, some evidence for competing hypotheses and/or confounding factors. Data in support of the functional relationship is derived from direct Bay-Delta field observations OR from field observations outside the Bay-Delta estuary. 2 = Low: Theoretical support with some evidence, semi-quantitative relationships, several alternative hypotheses and/or confounding factors. Data in support of the functional relationship is derived from lab or theoretical studies without field evidence. 1 = Minimal: Hypothesized based on theory and/or professional judgment, purely qualitative predictions, many alternative hypotheses and/or confounding factors. Support for the functional relationship is largely hypothetical and based on first principles.

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Label	Explanation	Levels
F **Feasibility**	The degree to which input data necessary to calculate the proposed performance measure can be delivered in a timely fashion (without external bottlenecks) and the amount of effort (relative to other possible indicators) needed to implement the cause-effect linkage in a computer model.	4 = High: Input data currently exists in a format easy to disseminate, can be delivered readily and the effort (time) associated with implementing the cause-effect linkage easily falls within project budget without sacrificing other indicators. 3 = Medium: Input data currently exists (or can readily be generated by new model runs), and while it might need some additional formatting, can be delivered readily. The effort (time) associated with implementing the cause-effect linkage will fall within project budget subject to prioritization decisions elsewhere that remove some other indicators from consideration. 2 = Low: Input data does not currently exist, but can be generated through additional analyses or external model runs. The time before this external work could be completed is or may be uncertain. The effort (time) associated with implementing the cause-effect linkage could be accommodated within the project budget, but a number of other indicators would need to be eliminated from consideration. 1 = Minimal: Input data does not currently exist, and it is not clear if it can be generated through additional analyses or external model runs. The time before this external work could be completed is unacceptably long. The effort (time) associated with implementing the cause-effect linkage would take up a disproportionately high amount of the project budget, and the majority of other indicators would need to be eliminated.
P **Priority**	Initial Priority Ranking	

2.2 Spatial extent and temporal horizon

Note: unchanged from SacEFT v.1

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

Note: unchanged from SacEFT v.1

Three spatial elements will be 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.

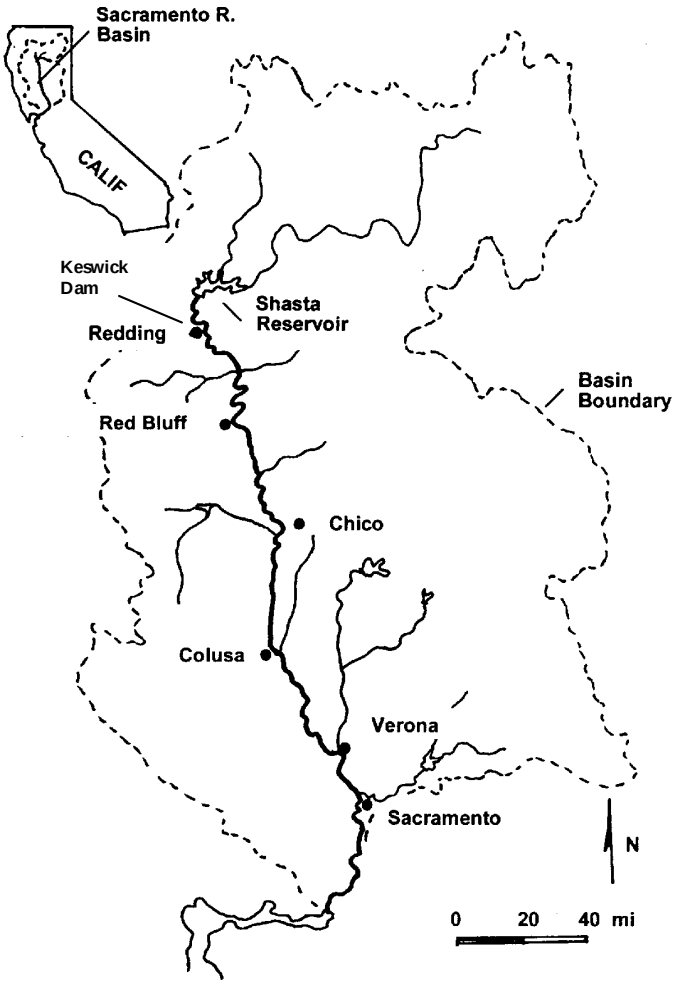

Figure 2-1. Map of the Sacramento River watershed and study area over which the SacEFT will be applied – from Keswick Dam (RM 301) to Colusa (RM 143) (source of map: CALFED Bay-Delta Program 2000).

The underlying design of the SacEFT relational database supports dynamic 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 will treat locations as being fixed over the course of a 66 year simulation. Conceptually, this introduces what we call a "zonal notion" of points and segments. For example, bank swallow colonies may exist between RM 202 to 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 50 years (assuming some flow regime for that period, etc.), the precise spatial locations of these 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 187.84—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 tracking fine spatial details over time 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 focal species performance measures, certain inherently dynamic processes like center line change (from the Meander Migration Model output) may still be handled in a more spatially explicit fashion. Initially, we will assign highly spatial outputs like river center lines to spatial output tables for visualization, while tabular summary outputs that pass variables to focal species will be managed using the fixed zonal notion. 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. As SacEFT will not reproduce or advanced GIS functionality, we emphasize georeferenced tabular data. Sophisticated spatial manipulations or dynamic displays will be left up to SacEFT's source models and other GIS platforms. (**Note**: DeltaEFT may include spatial output visualizations – design in progress).

There are much more important issues related to non-stationarity in variables over long simulations. For instance, stage discharge relationships are generally invalidated following large floods that re-shape a channel. Since our current understanding and tools make it impossible to predict these changes, future versions of SacEFT will use threshold rules related to flows that prevent the continued application of relationships that depend on this kind of information. We envision an approach in the future whereby certain performance measures become unavailable ("grayed out") following a large flood or other threshold event.

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 will be 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.

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.

These 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 2.4. 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 [1]		NODOS [2,3]		BDCP Analysis[6]		TUGS[4]	Meander Migration	Fremont Cottonwood	Bank Swallow		Western Pond Turtle	Green Sturgeon	
RM	Name	*Q*	*T*	*Q*	*T*	*Q*	*T*				1	2			RM
301	Keswick	●	●	●	●	●	●								301
298	ACID Dam		●												298
292												●			292
289	Clear Creek		●	●	●	●	●								289
280	Cow Creek		●	●	●	●	●								280
277	Ball's Ferry		●	●	●	●	●								277
275	Anderson Creek		●												275
273	Cottonwood Cr		●	●	●	●	●								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
228	Tehama														228
218	Vina	●													218
207	GCID Pump			●	●										207
201															201
199	Hamilton City	●		●	●	●	●							●	199
197												●			197
192										●					192
190	Stony Creek			●	●										190
185															185
183										●					183
182															182
172										●					172
170															170
168	Butte City	●		●	●							●			168
143	Colusa	●		●	●										143

Table 2.5. Summary of the spatial location and extent of physical datasets, linked models and performance measures for the ***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 [1]		NODOS [2,3]		BDCP Analysis [6]		TUGS [4]	Meander Migration	Chinook & Steelhead Spawning & Egg Stage PMs [5]					Chinook Steelhead Juvenile Rearing Stage PMs				
										Spring	Fall	Late Fall	Winter	Steelhead	Spring	Fall	Late Fall	Winter	Steelhead
RM	**Name**	*Q*	*T*	*Q*	*T*	*Q*	*T*												
301	Keswick	●	●	●	●	●	●												
298	ACID Dam		●																
292																			
289	Clear Creek		●	●	●	●	●												
280	Cow Creek		●	●	●	●	●												
277	Ball's Ferry		●	●	●	●	●												
275	Anderson Creek		●																
273	Cottonwood Cr		●	●	●	●	●												
272	Battle Creek		●																
267	Jelly's Ferry		●	●	●	●	●												
260	Bend Bridge A	●	●	●	●														
258	Bend Bridge B																		
252																			
243	Red Bluff	●		●	●	●	●												
243	Red Bluff DD			●	●	●	●												
228	Tehama																		
218	Vina	●																	
207	GCID Pump			●	●														
201																			
199	Hamilton City	●		●	●	●	●												
197																			
192																			
190	Stony Creek			●	●														
185																			
183																			
182																			
172																			
170																			
168	Butte City	●		●	●														
143	Colusa	●		●	●														

Table 2.6. Annotations for Table 2.4 and Table 2.5.

[1] 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**.

[2] The common time span of the NODOS scenario discharge (Q) and temperature (T) data is **31-Oct-1921 to 30-Sep-1994**.

[3] The Common Assumptions team has agreed that the daily disaggregation results for these discharge and temperature scenarios are flawed and that results from SRWQM **below Red Bluff Diversion Dam** are in error. Hence, this scenario is to be used for model demonstration purposes only and DWR has released these data to TNC with the understanding they are for test use in SacEFT.

[4] TUGS simulations 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 WUA (CS1). TUGS relationships for these downstream segments (pink) are mapped from the nearest upstream location, as described in Section 4.3.1.

[5] Chinook and Steelhead *spawning* WUA relationships shown in pale blue are mapped from the closest downstream segment, as described in Section 4.3.1. 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 describe in Section 4.3.1.

[6] The BDCP analysis includes a subset of PMs: Chinook, Steelhead and green sturgeon in the region from Keswick to Hamilton City only.

Table 2.7. Summary of the life-history timing information relevant to the focal species performance measures being integrated into SacEFT. 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 race/species the period between the 25th and 75th percentile, when half the spawning takes place. In the case of the other salmonid PMs, the heavily shaded regions denote the period between the 25th and 75th 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 90day period following emergence for Chinook and a 365 day period for steelhead. The values shown here are typical and may shift by as much as five days earlier or later, depending on year and reach. This table is based on SALMOD (Bartholow and Heasley 2006, ultimately Vogel and Marine 1991).

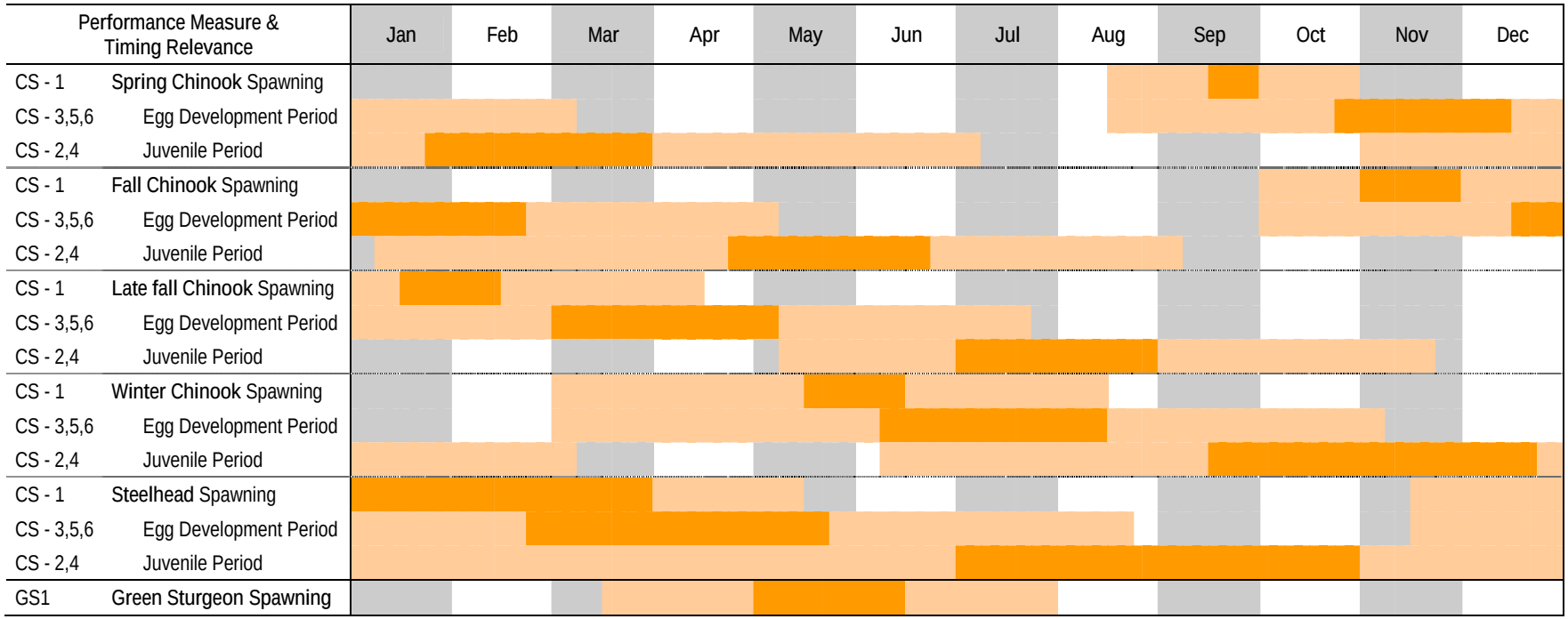

Table 2.8. Summary of the spatial and temporal resolution of performance measures. Abbreviations of performance measure are described in Table 2.1. Physical submodels are abbreviated as: FLOW – Historical flow records and CALSIM-SRWQM, STAGE – stage-discharge relations, TEMP – historical water temperatures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

		Temporal resolution				
Spatial resolution		Event-based	Daily	Seasonal	Annual	Decadal
Hydraulic unit	Point or cross-section: micro habitat, 0.1 to 1 channel width		FLOW STAGE TEMP	FC1		
Geomorphic unit	Segment: meso-habitat, 10 channel widths (100s feet - miles)	OXBOW[δ]			TUGS MEANDER OXBOW BASW1 WPT1	
Reach unit	Segment: 100 to 1,000 channel widths (10 - 60 miles)		CS1-6 GS1		BASW2	
Whole system	Segment: entire study area, RM 142 - 301					

[δ] Not implemented in SacEFT v.2.00.

2.4 Management actions

The primary emphasis of SacEFT is to provide ecological trade-off information for alternative **flow operation scenarios** 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 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

Note: largely unchanged from SacEFT v.1

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 will be 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	Focus initially on a tight set of key ecosystem attributes. 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 will allow 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	Capitalize on existing tools and models. To the extent possible, integrate existing quantitative models (including water operation planning tools such as the CALSIM-SRWQM-HEC5Q modeling complex), 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. This principle also includes not spending effort coding custom graphical output controls. Instead, SacEFT will leverage MS Excel, a widely held application with powerful graphing and analysis capabilities, when summarizing tabular and graphical outputs. Furthermore, SacEFT will not replicate/reproduce GIS functionality. While aspects of SacEFT's underlying data model are spatially explicit, presentation of this information in various dynamic map based views is not a role for SacEFT. Instead, information in SacEFT's database may be extracted and used in external GIS analyses, as/if needed.
Generic, flexible relational data model	Develop a custom relational database as the "glue" holding all submodel data together. 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 will be essential in the interpretation of model output.

Flexible, object-oriented design (OOD)	**Use a flexible model architecture and object-oriented design.** SacEFT will incorporate software development strategies that maximize adaptability and ease of revision. The system architecture will follow 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 will also use object-oriented design (OOD) within each of these components, which maximizes the reliability and flexibility of software development. However, SacEFT will also rely on output from other models which may not have such flexible structures.
User friendly	**SacEFT should be designed for users of low to moderate computer literacy.** 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 will be 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 initial solution provides a desktop software designed for use by one user at a time. The software does allow identification of different users of the same copy of the software, as well as the notion of "user reviews" for individual model components (e.g., in a workshop setting).
Database	SQL Server 2005 Express 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 will use 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. Deployment needs and system help access web resources.
Avoid COM components and 3rd 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. The exception in SacEFT is MS Excel.
Installation, accessibility	Deployment needs are currently supported via: www.essa.com/SacEFT[δ] The deployment model uses standard MSI and .EXE install packages generated by two Visual Studio 2005 setup and deployment projects.

[δ] Note: a user name and password are required to access the installation files. Please contact The Nature Conservancy office at (530).897.6370 for this information.

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. Two background issues set the context. First, water management on the Sacramento River is embedded within a complex array of existing planning and operational models. Millions of dollars have already been spent developing and applying models like CalSim II, SWRWQM and USRDOM. As most of these are road tested, commonly used and generally accepted tools, SacEFT does not reinvent their functionality. Second, it is not feasible for SacEFT to attempt to provide "one-stop flight centre control" for these (and other) external systems. An ecological trade-off analysis tool is not the appropriate system to provide a complex user interface capable of operating/controlling multiple external models in one package. (Not to mention that the cost of doing so is prohibitive). Further, such an approach mistakenly assumes that the expert users of the *external* models would be willing to learn to run their models in some new format. Experience shows this is not realistic.

The implication of these two factors is that SacEFT must make 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 components—are embedded within SacEFT software itself.

For budget reasons importing of external datasets in the initial model 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).

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 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 will install the client SacEFT software and database on their desktop computers. Currently, the software is available from www.essa.com/SacEFT.

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. Installation and deployment of traditional Windows applications has been the bane of many developers' existence (registry settings, file distribution and DLL hell). These hassles are nearly eliminated by new deployment mechanisms in the .NET Framework. 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 technologies that will be used in SacEFT 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 Express. SQL Server 2005 Express is a free, lightweight version of SQL Server 2005. SQL Server Express is free to download and free to redistribute. Built on the SQL Server paradigm, SQL Server 2005 Express 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. SQL Express databases can also be up to 4 GB in size (a limit SacEFT is capable of exceeding if more than 14-16 sets of scenario outputs are stored).

3.3 System architecture

SacEFT's component architecture is illustrated in Figure 3-1 and described in the sections that follow.

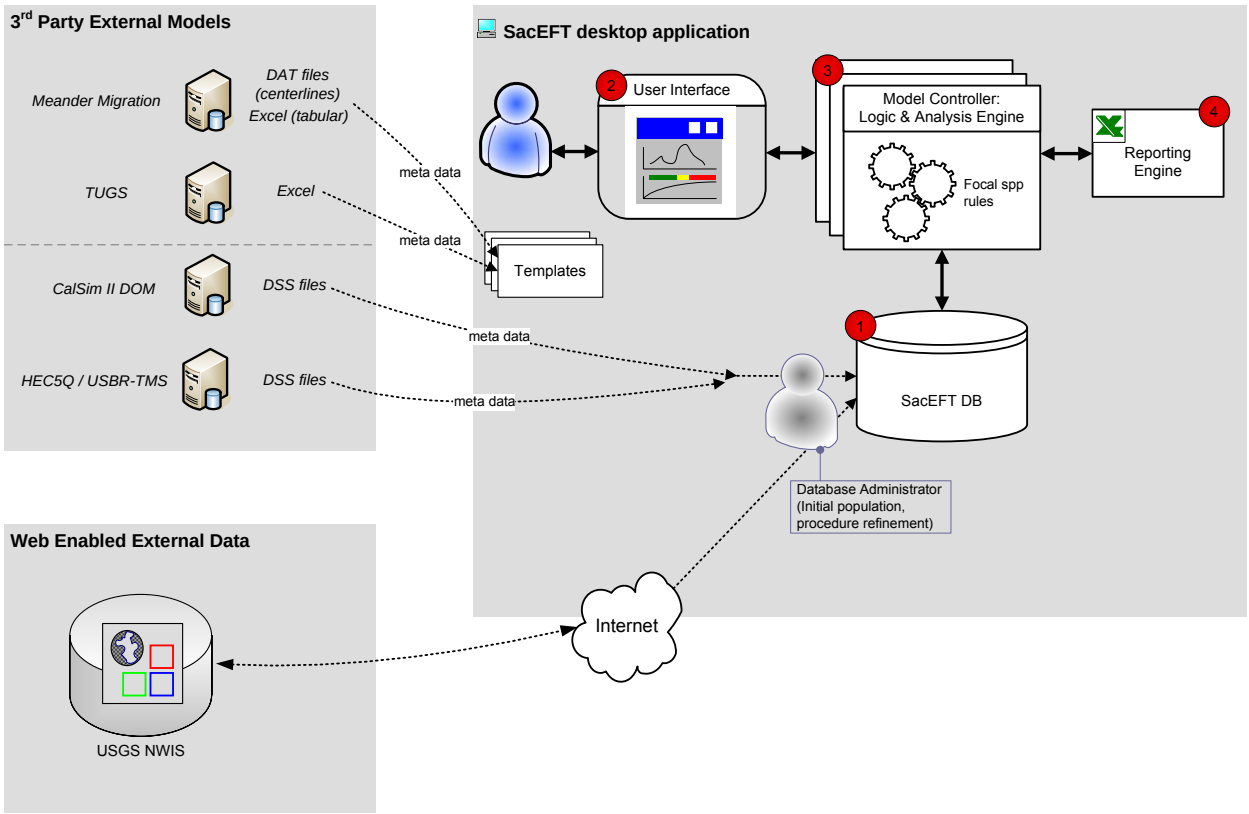

Figure 3-1. SacEFT component architecture. (Circled numbers are used for reference purposes in text below).

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 3-1, "3rd 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 USBR Upper Sacramento River Temperature Model 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 must address two issues at the time of data import**:

1. Identify output variables (daily average flows, daily average water temperatures, sediment transport variables, river bend erosion variables) within a common spatial identification system.
2. Tag imported data instances with key metadata that allow 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 involves a method to "decrypt the cipher" for a particular external model. In the initial model, this 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-SRWQM 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 will be to characterize and explore important ecological trade-offs and inform managers and decision makers about the *relative* impacts of various flow management alternatives.

In contrast, measurements and variables that lend themselves to a truly spatially explicit interpretation, such as flow at a particular stream gauge, will be less difficult in regards to deciphering and indexing locations. Segment based variables tend to be the trickiest; requiring spatial decisions about how to reference them over the landscape. Again, the standard used is the river mile concept.

Recognizing budget limitations and system priorities, automating the import process is a future goal.

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

3.3.2 Database

SacEFT will be built around a single desktop relational database (item "1" in Figure 3-1). The SacEFT Graphical User Interface (item "2" in Figure 3-1), Model Controller & Analysis Engine (item "3" in Figure 3-1) and Excel Reporting Service (item "4" in Figure 3-1) connect to and interact with this database.

The SacEFT database contains six important classes of related tables (Table 3.2).

Table 3.2. SacEFT database concepts and their general role.

Table Family	Role
(1) Spatial_	▪ 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.
(2) Data_Instances	▪ The key generic concept for tracking imported datasets and their metadata ▪ Also used to (optionally) tag information on non-imported (i.e., local) generic rules/parameter values for focal species.
(3) Data_MetaData	▪ Data.Metadata will 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.
(4) Data_Review	▪ 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.
(5) ModelRun._	▪ 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. ▪ A key table in this family is ModelRun.Compatibility, which is tightly associated with ModelRun.CompatibleInstances. These tables will be linked with Data.Instance to list imported physical model data instances that can be defensibly grouped together, based on having sufficiently similar embedded assumptions (e.g., same flows in USBR Upper Sacramento River Temperature Model and meander migration model and TUGS). "Sufficiently similar embedded assumptions" will be determined based on inspection of metadata. ▪ Unless a data instance is found in ModelRun.CompatibleInstances as part of the same compatibility family, it cannot be added to the ModelRun.Scenario table. This is how SacEFT will ensure apples and apples result sets are used amongst imported data instances.
(6) DataImport.<Model>	▪ The DataImport namespace is used to structure how data imported from external physical models are stored. Typically, the variables of interest will be arrayed by a DataInstanceID, a LocationID and a date (at the appropriate temporal resolution). ▪ These tables store the physical data itself – the streamflow, water temperatures, model results, etc.
(7) FS_ and FSOut_	▪ 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.

Conventions

The following conventions will be used in the SacEFT database:

- All tables are defined as part of a "namespace", and the descriptive definition of the table given after this namespace. This allows for a logical grouping and rapid filtering of tables within the database development environment.
- Table names use upper case letters at the beginning of proper words (only) with underscore characters between the namespace portion and the descriptive portion of the name (e.g., DataImport_Temperature)
- Most tables have a long integer primary key identifier named "ID". To limit redundancy, the definition table typically uses only the generic name, "ID". Foreign key references to these IDs in other tables use the host table name plus "ID", e.g., "DataInstanceID".
- Where tables store string name fields, the standard is varchar(50 to 255) depending on the context.
- Description or long text fields are standardized as varchar(8000) to varchar(max).
- Unique indexes are used on strings that should be unique throughout the stored data.
- Cascade delete and update are the default referential actions on relationships whose primary key is expected to have a finite lifespan or a limited requirement to archive data and results.
- Careful consideration is given to fields that are required, and those that may be null to ensure the right balance between rigor and flexibility, depending on the context.

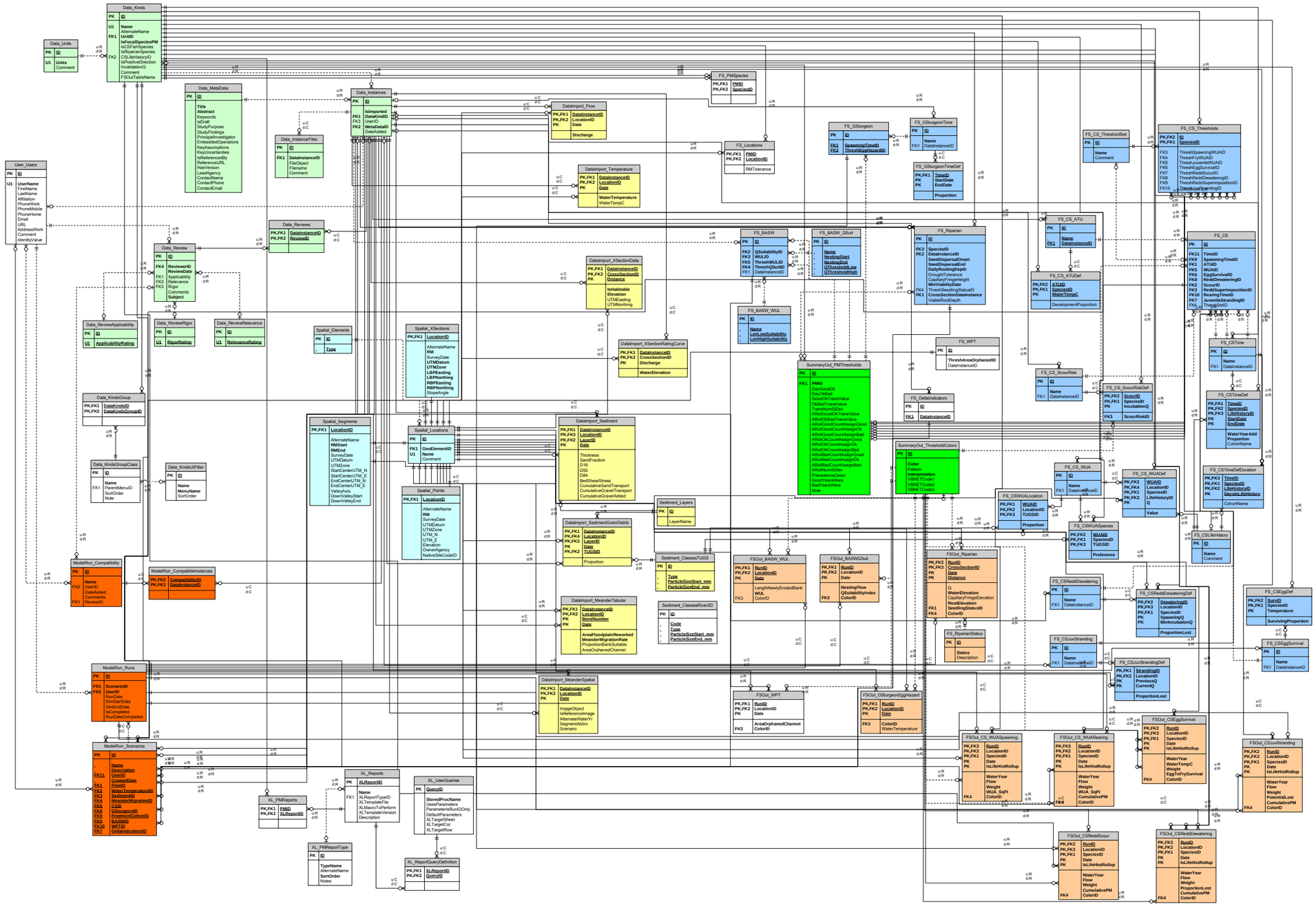

Figure 3-2. SacEFT v.1 relational database (v.2 db will include modifications): entity relationship diagram. PK = part of the primary key. FK = foreign key. U = unique index (values cannot repeat in the table). C = cascading referential action (delete and updates).

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 that understands the SacEFT database schema is required to manually 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. 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 Express 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

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. 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, users will need to choose, or create a new compatibility list for imported physical submodel datasets. This involves review of metadata and user reviews (optional) for the candidate data instances. Presently in v.2.00, this step must be performed by a SacEFT database administrator. In future, creation of compatibility lists by users and assembly of overall aggregate scenarios (consisting of both compatible physical submodel data and focal species rules) is a feature that should be automated. Should this feature become a priority, the ModelController can be extended to manage the business validation rules for this process, and necessary interactions with SacEFT database.

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 Model Controller is the thing that ensures performance measures are calculated in an orderly, sensible manner and 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 tabular and graphical reporting. 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 this reporting feature is integrated into the SacEFT User Interface is highly extensible and customizable.

3.3.5 User interface

Figure 3-3, Figure 3-4 and Figure 3-5 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.

v.2.00 emphasizes display of output rather than dialogue intensive database editing features. In our experience it is more important to demonstrate results in the first prototype 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, this 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.

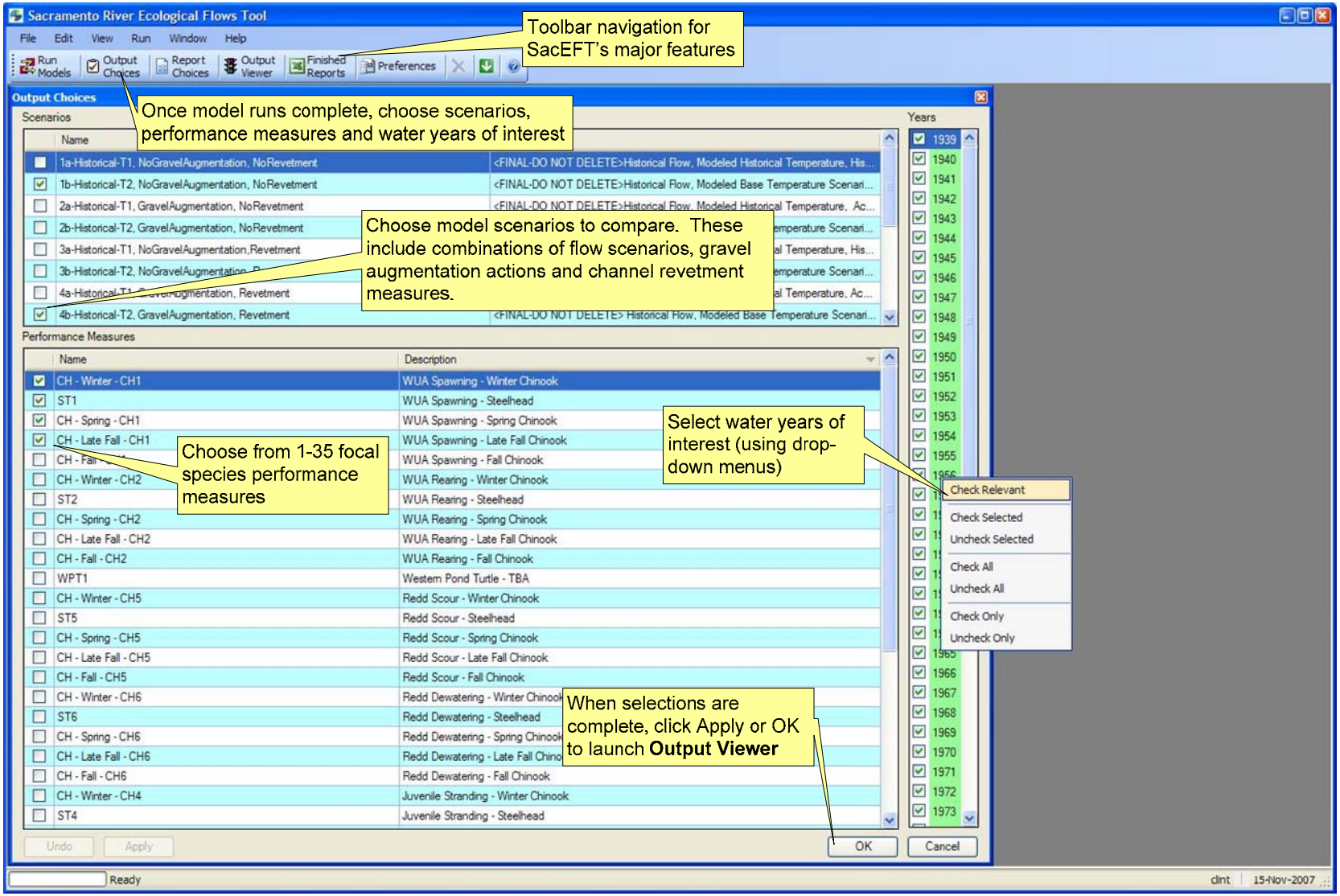

Figure 3-3: SacEFT's main screen, showing the Output Choices dialogue. SacEFT v.2.00 emphasizes display of results, assumptions and meta data over database editing features.

Figure 3-4: SacEFT's Output Viewer screen in Annual View, showing a two-scenario comparison for one performance measure (for 5 salmonid race types) using a "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 is used as a navigational aid to drill into the details.

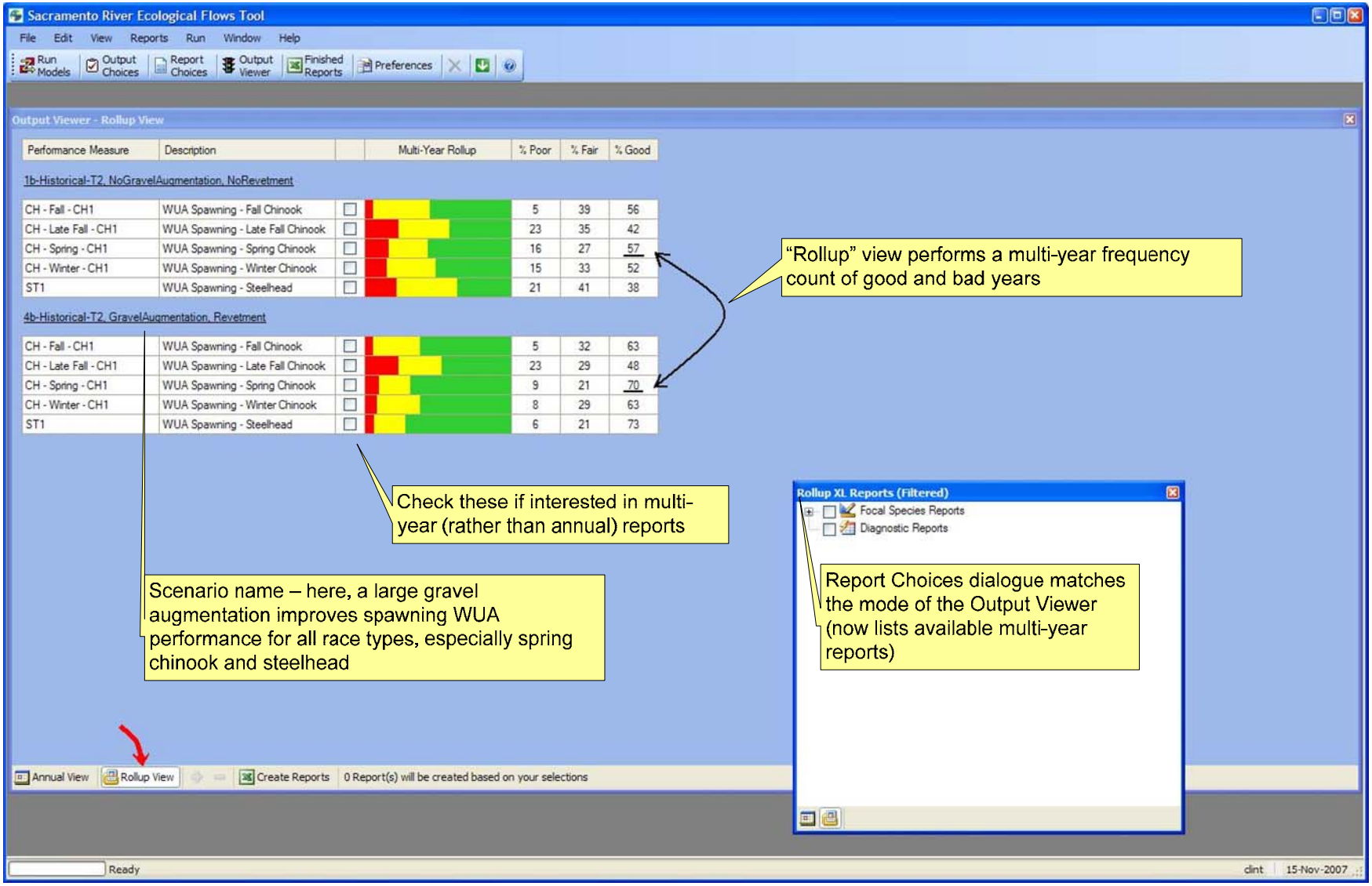

Figure 3-5: SacEFT's Output Viewer screen, showing the same information as Figure 3-4, but in multi-year Rollup View. This is the best view for quickly ascertaining the relative differences in performance among scenarios.

Output reports

MS Excel graphs and tables will serve as the primary output format. An example of SacEFT's v.2.00 spawning weighted useable area report (WUA) is given in Figure 3-6.

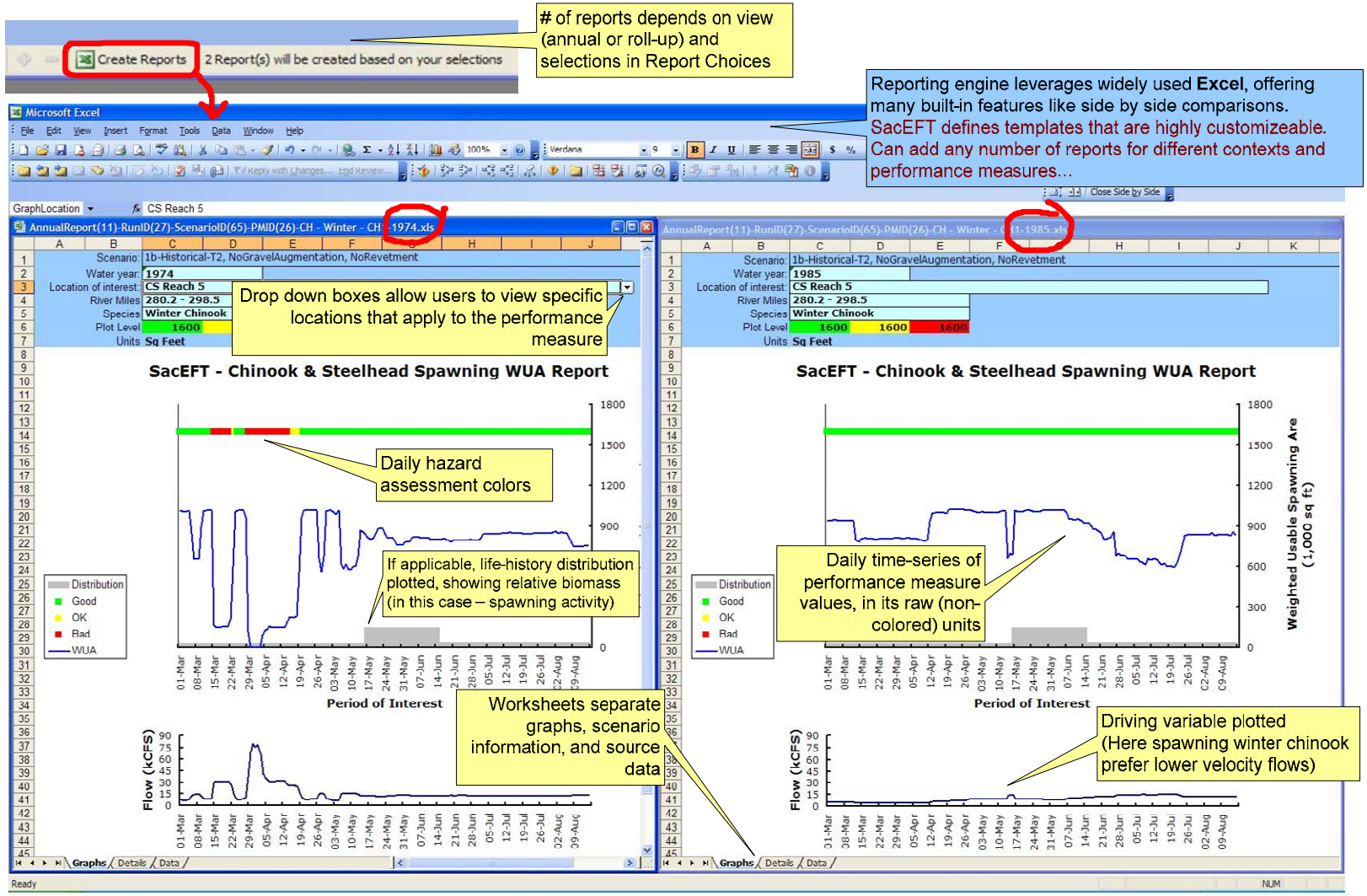

Figure 3-6: SacEFT provides detailed output on a scenario × year × performance measure basis in Excel. Here, managers and scientists can examine the detailed results in the performance measure's raw units, alongside its driving variable (e.g., flows). Refer back to Figure 3-4 for context.

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 3-7). In the future, this tool could be expanded to allow user configuration of model assumptions.

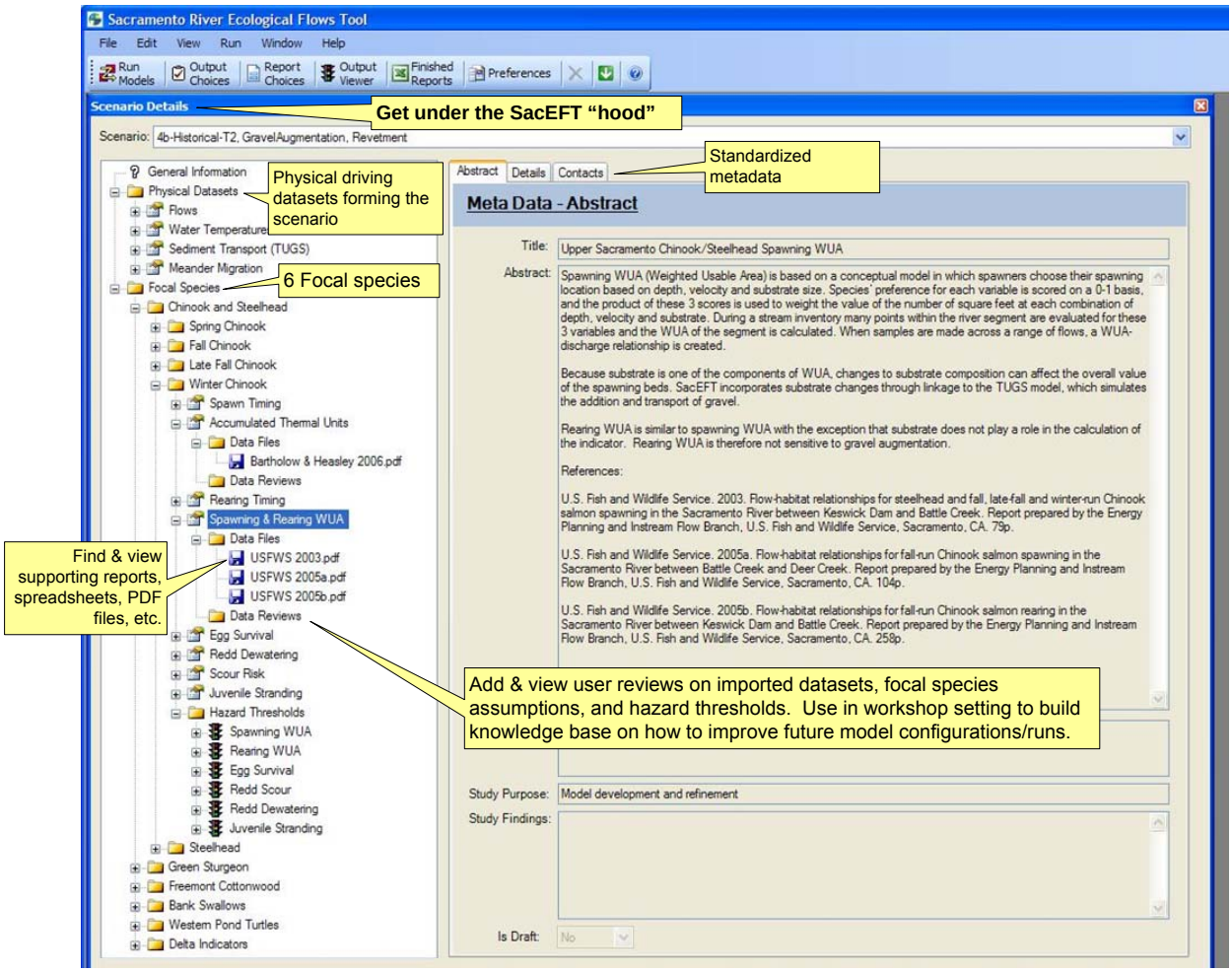

Figure 3-7: SacEFT's Scenario Details and Reviews dialogue for learning more about imported datasets and focal species assumptions.

3.4 Future directions

SacEFT v.2.00 will represent a significant first step at improving the tools available to expand ecological considerations in water management decisions on the Sacramento River. Based on our experience, these types of software projects are never perfected without iteration. Hence, serious efforts at moving this tool into routine use in operational planning requires an investment in model testing, refinement and training.

The major future direction involves extending the SacEFT software to incorporate Delta targets and management actions – Sac-DeltaEFT.

4. SacEFT Submodels: Functional Details

4.1 Physical driving submodels

The physical data sets used in this section originate from several high-profile planning models. The intent is to leverage the extensive existing efforts made in these systems to supply key inputs necessary to calculate focal species performance measures. In addition to these models, select mainstem Sacramento River gauging records have been used for river discharge and water temperatures. Using data from models and stream gauges permits mixed 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 will be imported into the SacEFT database. The temporal resolution that will be used for discharge will be daily averages.

Table 4.1. Mainstem Sacramento River USGS stream gauges included in SacEFT. Source: The United States Geological Survey (USGS), surface water data web site (waterdata.usgs.gov/usa/nwis) and related web service (river.sdsc.edu/NWISTS/nwis.asmx).

Native Site Code	Name	UTM Zone	UTM Datum	UTM_N	UTM_E	RM	Elev (meters)	Owner Agency
11370500	SACRAMENTO R A KESWICK CA	10T	NAD27	4,494,415.947	547,098.993	301	146.2	USGS
11377100	SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA	10T	NAD27	4,459,898.695	569,229.379	260		USGS
11383730	SACRAMENTO R A VINA BRIDGE NR VINA CA	10S	NAD27	4,417,891.359	577,616.258	218	60.05	USGS
11383800	SACRAMENTO R NR HAMILTON CITY CA	10S	NAD27	4,400,469.206	586,147.110	199		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
11390500	SACRAMENTO R BL WILKINS SLOUGH NR GRIMES CA	10S	NAD27	4,318,336.625	601,855.350	117		USGS
11391000	SACRAMENTO R A KNIGHTS LANDING CA	10S	NAD27	4,295,498.199	611,558.963	90		USGS
	SACRAMENTO R A VERONA CA	10S	NAD27			78		USGS
	SACRAMENTO R A SACRAMENTO CA	10S	NAD27			59		USGS

These records can be accessed very efficiently over the internet using the National Water Information System (NWIS) web service, via a simple method call along the following lines:

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

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

Future versions of SacEFT may leverage this web service to periodically access near real-time records and automatically update gauging station records.

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 – 12-Apr-1945; 1-Oct-1978 – 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 – 20-Apr-1945; 15-Jan-1956 – 18-Jun-1956; 3-Oct-1980 – 30-Sep-2004) 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 imputed using a nonlinear relationship with SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA discharge, even though >100mi upstream. Best relationship obtained with Colusa discharge day 't' graphed against Bend Bridge at 't-1' (1 day lag). Loess smoothing with a span of 2.5% was used to develop a fairly smooth predictive relationship, applied to the missing Colusa dates.

With these gaps filled, the available data span a common period from 1-Oct-1938 to 30-Sep-1994: Water Years 1939-1994, a minimum of 24,107 historical records for each location.

Future/prospective flows: Sacramento River Water Quality Model (SRWQM) / CalSim II daily operations model (DOM)

SacEFT prospective daily flow datasets are based on 2005 baseline assumptions as simulated using the CALSIM – SRWQM – HEC5Q modeling complex. The Common Assumptions team has agreed that the daily disaggregation results from SRWQM below Red Bluff Diversion Dam are flawed. Hence, it is important to emphasize that in SacEFT v.2.00, these datasets were used for testing and demonstration purposes. DWR is working on a modified disaggregation algorithm intended to resolve the stability concerns below Red Bluff. The timeline for this updated product is not clear.

CalSim is a generalized water resource planning tool developed jointly by the Department of Water Resources (DWR) 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. Unsurprisingly, given the spatial complexity and number of feedbacks in the system calibration and verification processes for CalSim are complex.

CalSim II simulates CVP and SWP operations at a monthly time-step. While a monthly time-step is suitable for most CVP and SWP water supply planning studies, it is too coarse to assess the ecological performance measures listed in Table 1.2 summarizes the priority performance indicators that were identified by workshop participants, and distinguishes indicators selected for inclusion in SacEFT v.2

after considering the (historic) selection criteria. This table also differentiates existing indicators that are unchanged in SacEFT v.2 from those that are to receive a significant overhaul.

Table 1.2. For these variables, finer temporal changes must be considered. Recently, an extension has been developed for CalSim called the Daily Operations Model or DOM. The purpose of the DOM is to estimate the impact of variable daily hydrology on project operations. The CalSim II DOM thus operates on a **daily time-step**, simulating CVP and SWP operations in the same manner as CalSim II. Each month, the DOM passes end-of-month storages back to CalSim II, before monthly outputs are returned back to the DOM disaggregation and optimization routines. The DOM is relatively new, with a base model available. Changes are ongoing, emphasizing work on upstream disaggregation routines (Daniel Easton, personal communication 2005).

Form of CALSIM – SRWQM output to be accessed and imported: DSS file

CALSIM – SRWQM – HEC5Q output is stored in U.S. Army Corps of Engineers' Hydrologic Engineering Center (HEC) Data Storage System (DSS) format. HEC-DSS is a binary database system designed to efficiently store and retrieve sequential time-series data. HEC-DSS has been the proprietary standard incorporated into most of HEC's major software programs.

By convention, DSS files are separated into six major parts, labeled "A" through "F", as follows:

Part	Description
A	Project, river, or basin name
B	Location
C	Data parameter
D	Starting date of block, in a 9 character military format
E	Time interval
F	Additional user-defined descriptive information

The DSS system also provides a mechanism for other programs to retrieve and store data. *HEC-DSSVue* is an application that provides a user interface for navigating, filtering, graphing and exporting DSS data. Optional plug-ins written using Java and compiled into a Java ".jar" file are optionally available to extend the basic features of HEC-DSSVue. (These files are placed into the HEC-DSSVue\Plugins directory and automatically loaded and accessible from the HEC-DSSVue program). Since HEC-DSSVue is written in the same language by programmers who understand it's API (Application Program Interface) and the DSS format, they can provide extended capabilities and manipulate these database files directly.

Figure 4-1 illustrates the manual tabular export feature of HEC-DSSVue. This requires users to choose the appropriate "parts", view the data in tabular format, then export the information to a comma separated file. This set of steps must be repeated for every location of interest.

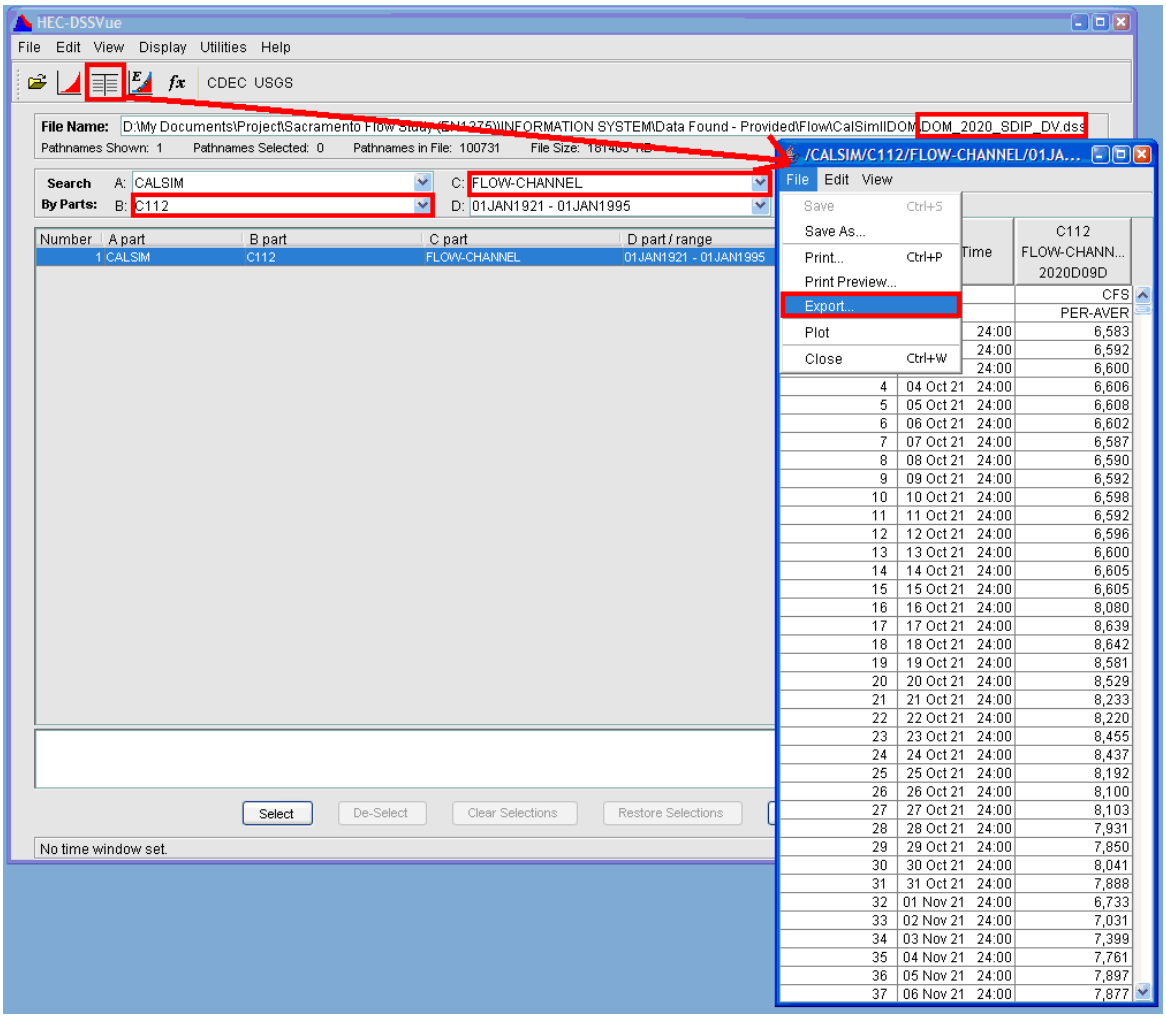

Figure 4-1. Manual export feature of HEC-DSSVue to comma separated files.

Figure 4-1 illustrates the direct export of data to MS Excel using a HEC-DSSVue java plug-in. As with standard tabular exports, this requires users to choose the appropriate “parts” and repeat the export for every location of interest.

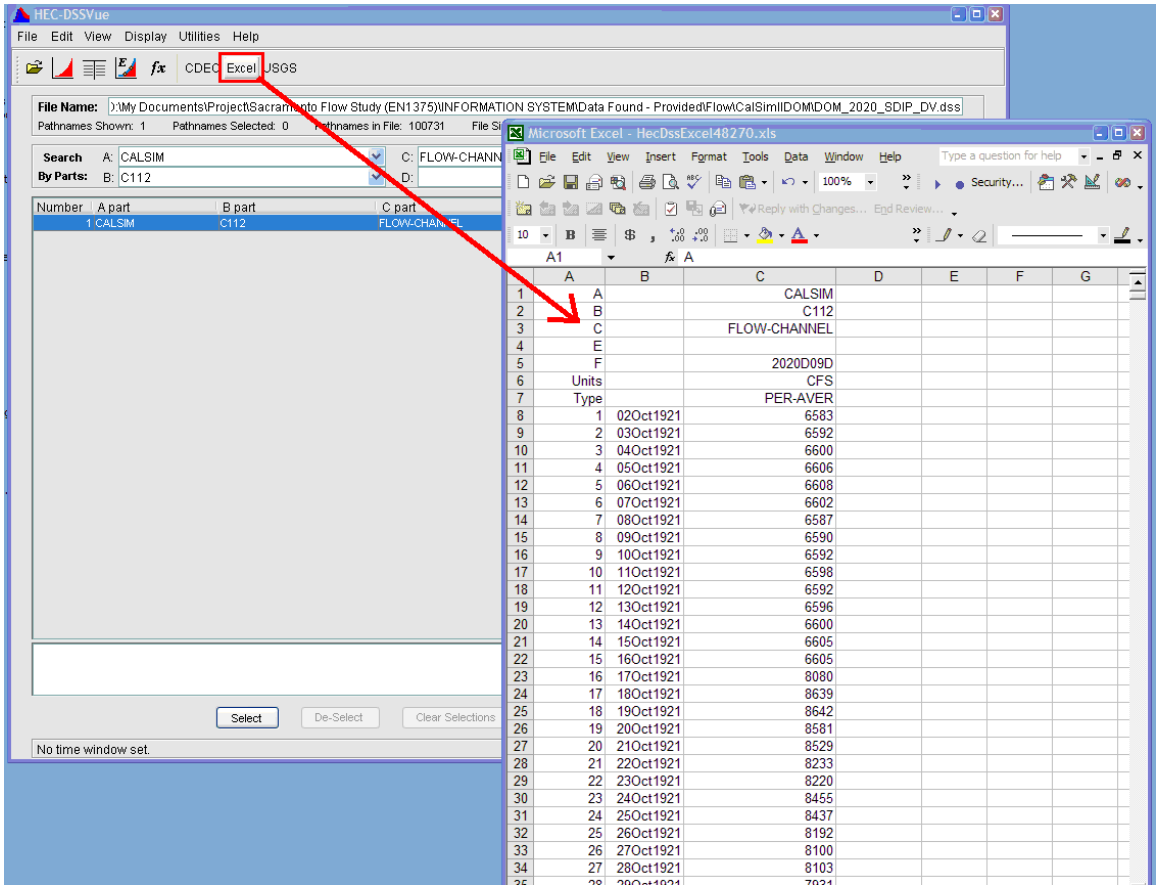

Figure 4-2. Excel plug-in for directly exporting DSS data to an Excel spreadsheet.

Ultimately, these tools are required as DSS files are a proprietary binary file type with no published format. In other words, one must use HEC software to “decrypt” the proprietary file structure (Figure 4-3).

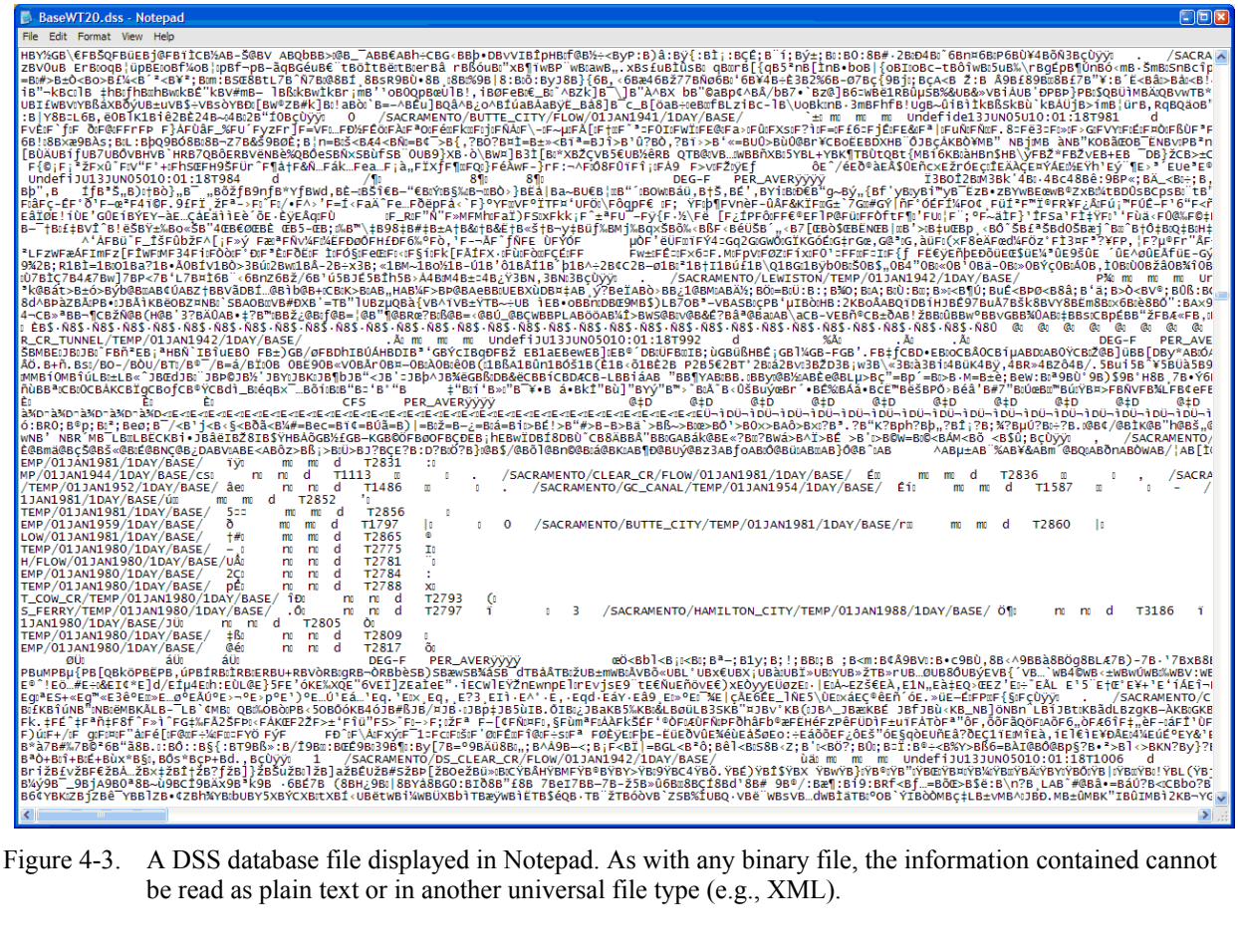

Figure 4-3. A DSS database file displayed in Notepad. As with any binary file, the information contained cannot be read as plain text or in another universal file type (e.g., XML).

If the functionality exists, one future possibility is to locate and use a HEC Dynamic Link Library (DLL) that contains a set of functions that can be executed by a Windows application to access the flow records for our 5 nodes/arcs of interest. This would eliminate the need for time consuming manual export of DSS data using HEC-DSSVue so the data could be imported into the SacEFT database in a relational form that can be more readily manipulated. However, this depends on the existence and interoperability of such a tool with SacEFT's technology platform. In a future version, the simplest solution would be to allow users to point to a DSS file on their computer using a standard File Open dialogue, then use the as-yet-defined HEC component *directly from within SacEFT code* to access and import all flow records for nodes/arcs of interest. Presently, a SacEFT database administrator is required to import the required data.

> Reviewers of the an earlier draft of this design recommended speaking with Bill Charley. Ken Kirby mentioned that several DLL's have been developed in the past to work with various platforms, including Visual Basic (pre- .NET). Dan Easton also stated a VB (classic) DSS wrapper was available for free from David Ford Engineers in Sacramento (http://www.ford-consulting.com/index.htm).

CALSIM – SRWQM – USRDOM output incorporated into SacEFT

Over the course of model development DWR provided several sets of daily disaggregated discharge data for a variety of scenarios. Two of these, "NODOS 2030" (North of Delta Offsite Storage) and "Shasta +18.5" were selected. Although both sets of scenarios are preliminary and the daily flow disaggregations below Red Bluff Diversion Dam are flawed, they offered the best opportunity to explore contrasting flow regimes for model testing of the sensitivity of the ecological performance measures to the flow patterns.

The two scenarios span a common time period from 1-Oct-1921 to 30-Sep-1994 (Water Years 1922-1994), with 26,663 records for each location. These locations are shown in Table 2.4a, with many of the locations coinciding with USGS gauge locations.

Metadata needed to develop scenario compatibility lists

By design, SacEFT requires no pre-requisite knowledge or experience in the operation of CalSim or SRWQM. CalSim is a complex model requiring specialized expertise to configure and implement. A set of seven standardized text files or tables describe system connectivity, the components of the hydrosystem and the assigned weights. WRESL text files describe the system being modeled and the priorities for allocating water. WRESL statements that express operational constraints are written in a text editor and grouped into files and directories using a tree-structure for organization of related constraints. Initial conditions and state variables such as system inflows are stored in separate binary files. Other data such as reservoir area-elevation-capacity data are stored in space delimited text files called look-up tables. The model user interface and companion tools exist to manipulate these various input files.

Rather than become CALSIM – SRWQM – HEC5Q 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 – SRWQM DSS database in a form non-CalSim experts can understand. To achieve this, we apply the metadata standard shown in Figure 4-4 to all physical submodel datasets that are imported into SacEFT.

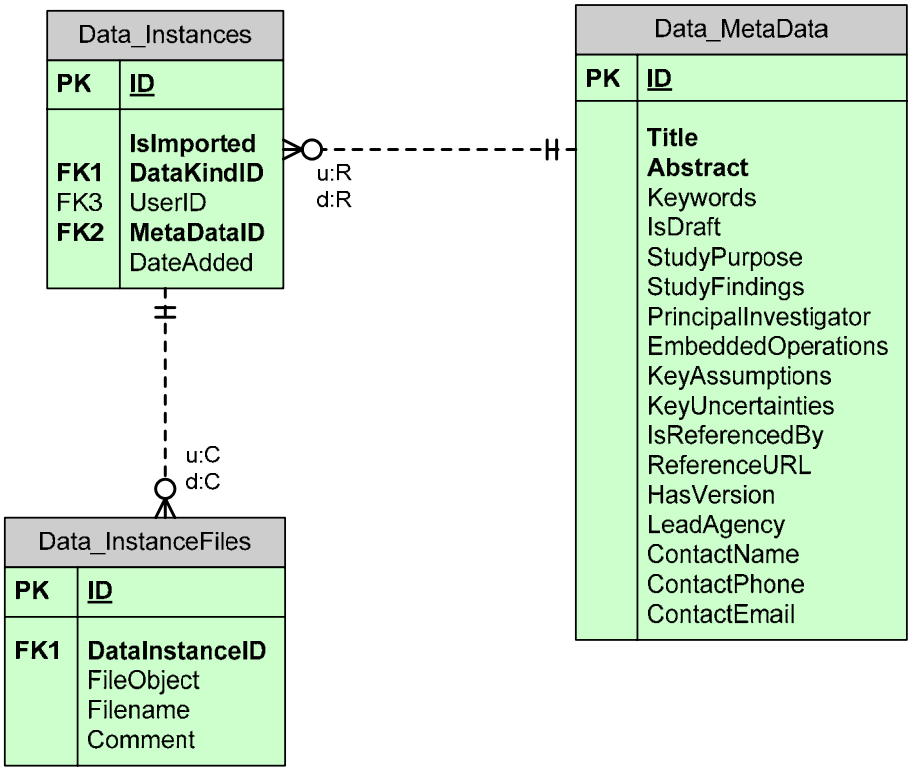

Figure 4-4. Underlying database design showing how each imported DSS file from CalSim (and any other data from an external physical model) is associated with a DataInstance and a set of MetaData. A considerable number of the fields in Data_MetaData are optional.

Note: **This metadata standard (Figure 4-4) 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, a riparian submodel scenario may use a different tap-root growth rate from that of another. While this will not require nearly as great a level of detail in metadata documentation as a CalSim DataInstance, the rationale for one growth rate over another is the kind of information that can be tracked using the metadata standard.

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

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, sWaterTempCode[1], "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 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.

USBR Upper Sacramento River Temperature Model

A preliminary review (Watercourse Engineering 2003) has been completed for the US Bureau of Reclamation Upper Sacramento River Temperature Model developed by RMA for Reclamation. The overall framework is viewed as promising by Reclamation for both planning and operational studies. Critical features of the model include ease of data management (model input and output) and output processing (visualization or tabulation). These two often burdensome tasks are, for the most part, automated within the model (Watercourse Engineering 2003).

HEC-5Q is the central element to the Upper Sacramento River Temperature Model software (RMA 2003). The USBR Temperature Model was developed and calibrated for the Upper Sacramento River system (RMA 2003) including Trinity Dam, Trinity River to Lewiston, Lewiston Dam, Clear Creek Tunnel, Whiskeytown Dam, Spring Creek Tunnel, Shasta Dam, Keswick Dam, Sacramento River from Keswick to Knights Landing, Clear Creek below Whiskeytown, Red Bluff diversion Dam, Black Butte Dam, and downstream Stony Creek. This model was then modified and extended to include the North of Delta Offstream Storage (NODOS) options for the purpose of evaluating the impacts of the creation of Sites Reservoir and accompanying diversions on temperature and water quality. The NODOS configured HEC-5Q model extends from Keswick Dam to Knights Landing and includes the Sacramento River, Red Bluff diversion Dam, Black Butte Dam and downstream Stony Creek, Tehama Colusa Canal, Glenn Colusa Canal, Colusa Basin Drain, proposed Maxwell pipeline, enlarged Funks Reservoir, and proposed Sites Reservoir. The USBR Temperature Model also leverages a pre-processor program (CalSim25Q) to

[1] The parameter code for water temperature in NWIS is: "00010"

convert CALSIM II monthly average flows into daily values based on historical hydrologic patterns and operation constraints.

The USBR temperature model data were provided as part of the NODOS and Shasta management scenarios for SacEFT Version 1 testing and scenario analysis. The estimated water temperatures are given at daily resolution for the period 31-Oct-1921 to 30-Sep-1994 for the NODOS scenario and 1-Oct-1921 to 30-Sep-1994 for the Shasta scenario. Both management scenarios are known to provide flawed daily estimates of temperature and discharge **below Red Bluff Diversion Dam**. Hence, the NODOS and Shasta scenario datasets are used for model testing and demonstration purposes only.

Upper Sacramento River calibration results for the USBR Temperature Model appear favorable (Figure 4-5).

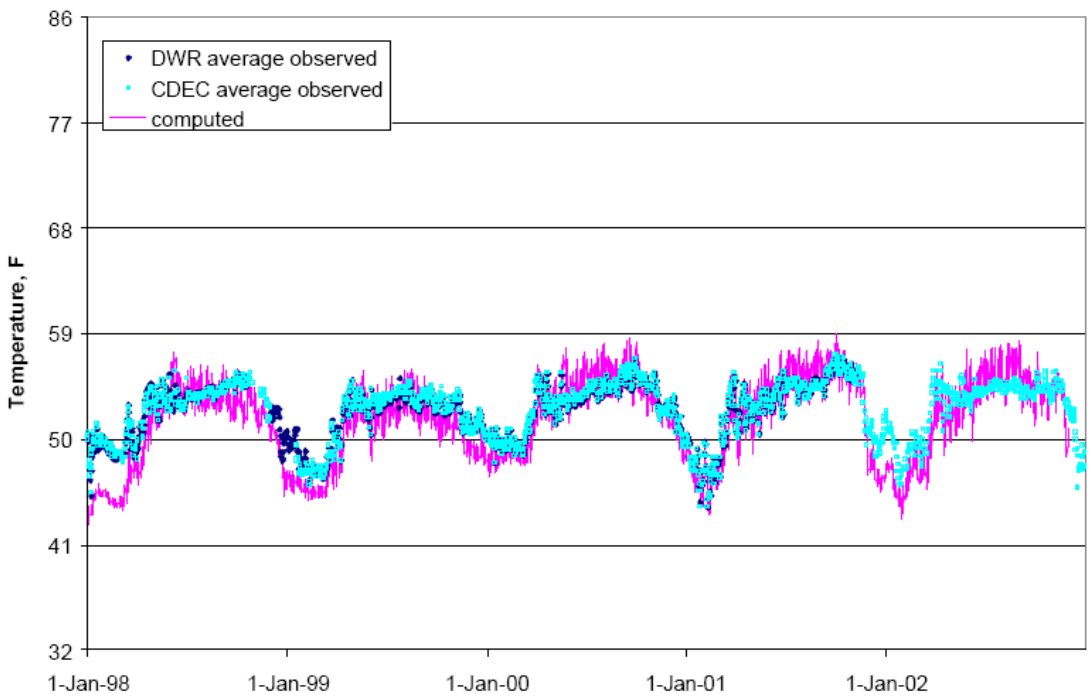

Figure 4-5. Computed and observed temperature time series in Sacramento River at Balls Ferry. Source: RMA 2003.

Spatial resolution and interpretation of node links

SacEFT treats USBR Temperature Model 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 in the table are based on the Sacramento River Atlas, "Sacramento River, Sloughs, and Tributaries, California, 1991 Aerial Atlas, Collinsville to Shasta Dam, US Army Corps of Engineers, Sacramento District, July 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

Form of USBR Temperature Model output to be accessed and imported: DSS file

As with CalSim II DOM, USBR Temperature Model output is stored in HEC-DSS format (Figure 4-6).

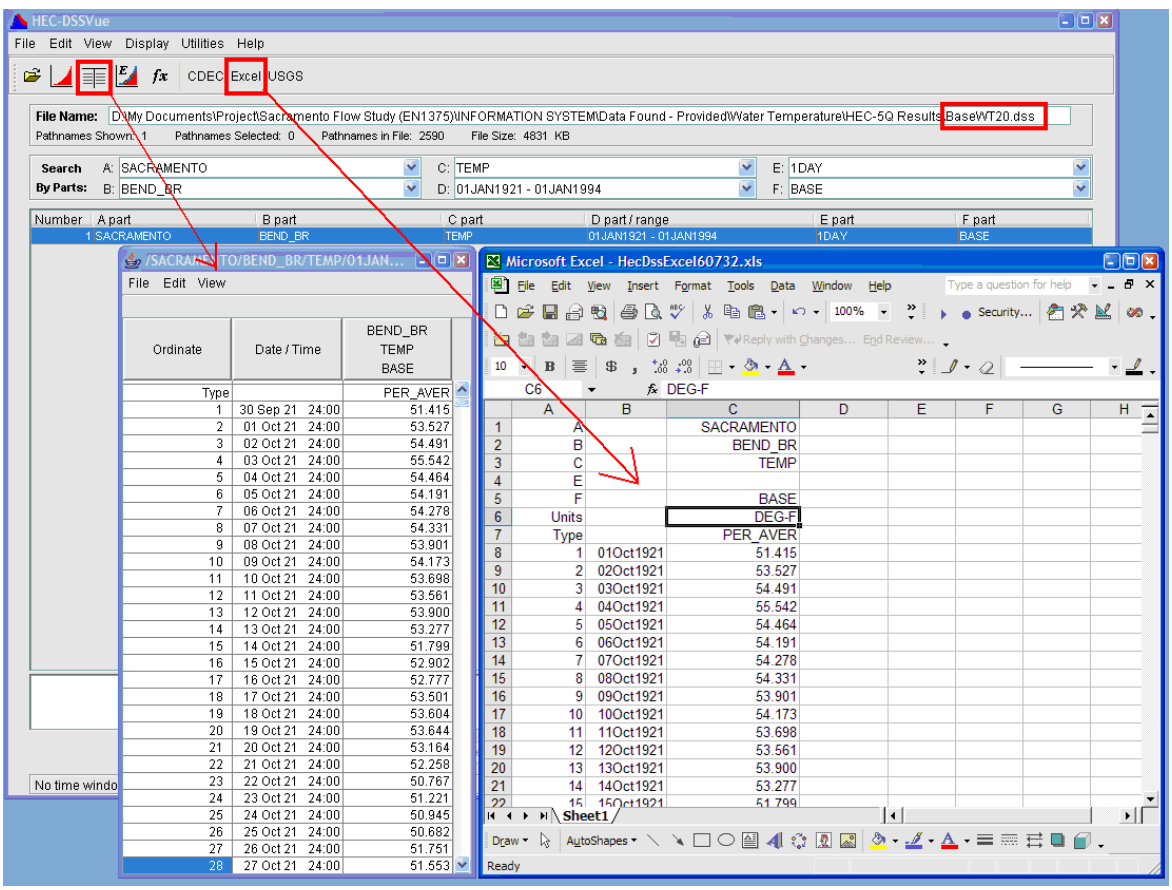

Figure 4-6. Manual and Excel plug-in export features of HEC-DSSVue for obtaining USBR Temperature Model water temperature data.

The planned design for accessing USBR Temperature Model DSS data will thus be analogous to the approach described for CALSIM – SRWQM DSS results (see Section 4.1.1).

Metadata needed to develop scenario compatibility lists

As with CALSIM – SRWQM results, SacEFT users will be tasked with aligning model assumptions between a given USBR Temperature Model run and other related physical models (CalSim II DOM, 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 non-USBR experts can understand.** As described earlier (Section 4.1.1 Metadata needed to develop scenario compatibility lists), we apply a metadata standard (see Figure 4-4).

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 range of flows of interest are not present 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 (CDWR Comprehensive Study, USGS, USFWS, Ayers and Associates consultants, TNC). Unfortunately, many of these studies only considered 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 researches have developed detailed elevation models that provide stage-elevation and wetted area relations, but the output 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 examined during the 2003 Beehive Bend study (Roberts et al. 2002, Roberts 2003) met the two criteria above:

- RM172
- RM183
- RM192

These sites are assumed to be representative of the Colusa to Red Bluff section of the Sacramento River. SacEFT's riparian initiation submodel will be applied to these 3 sites.

Form of cross-section data to be imported

These three "vetted" cross-sections and matching stage-discharge relations will be bulk loaded into SacEFT's database in the relational form shown in Figure 4-7.

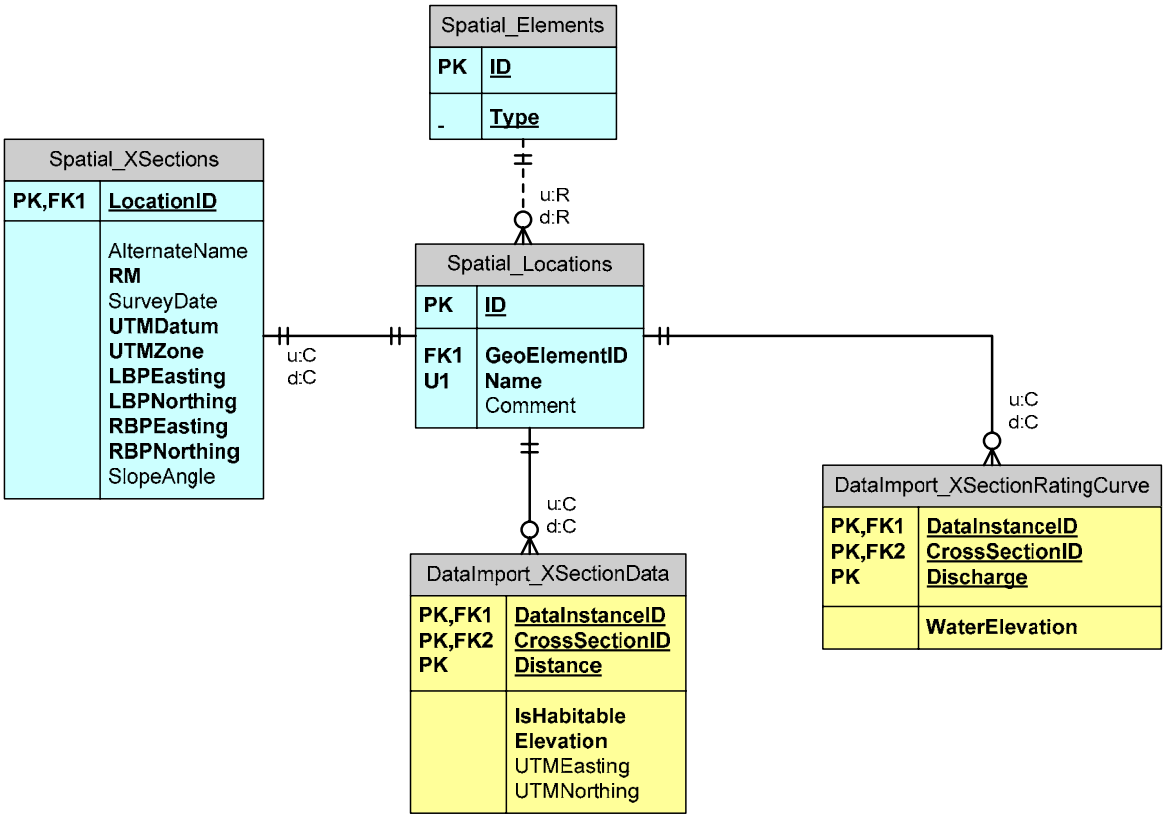

Figure 4-7. Relational database design used by SacEFT for cross section and stage-discharge information.

Metadata needed

As with any other dataset in SacEFT, these manually imported data sets will be tagged with a DataInstance ID. This will allow 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, of both the surface and subsurface. 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 is developed by employing:

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) the 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 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 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.)

Spatial horizon and resolution

The 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. The model will be calibrated for the Sacramento River using existing bulk sampling data collected by CDWR in 1980, 1984, and 1994. Stillwater Sciences will add 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 were collected, and where 2005 bulk sampling will occur. Generally, sediment transport and routing models including TUGS involve a high initial effort to calibrate.

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

The model will also use existing cross-sections developed by the ACOE and CDWR as part of the Comprehensive Study.

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 track these two classes of sediment by their proportions in surface and subsurface layers. The current output format for the model is shown in Figure 4-8.

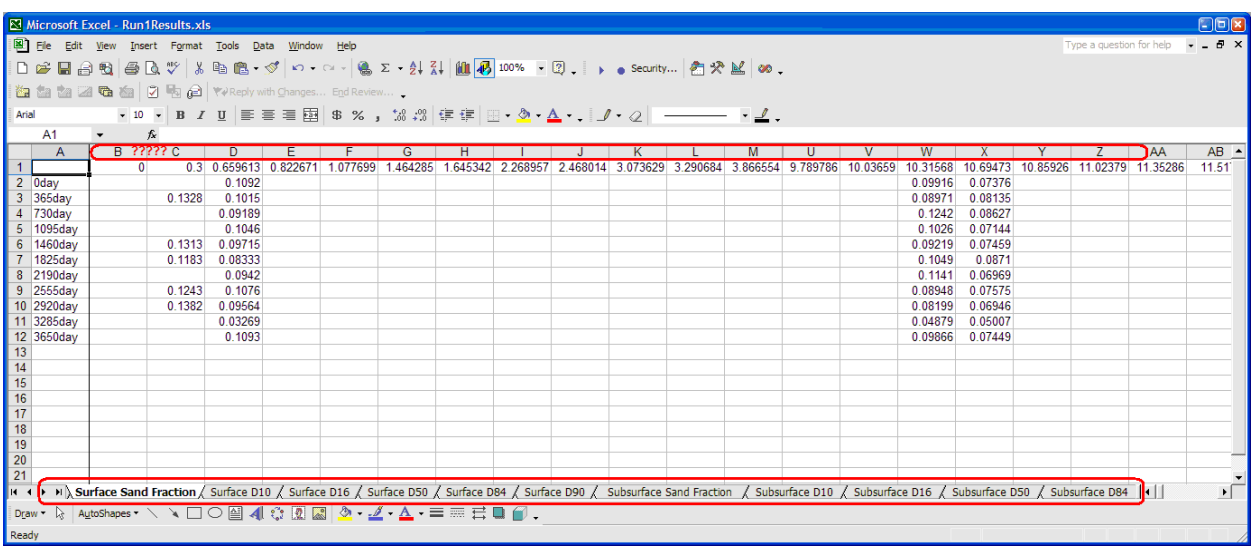

Figure 4-8. Current "untamed output" from TUGS model. Numerous worksheets contain results for specific performance measures. As shown, it is not always clear what distance (location) or time period is associated with a particular value. An Excel template was developed to better organize and streamline this information for orderly import into the SacEFT database.

With the benefit of a new Excel template, TUGS output are bulk loaded into SacEFT's database in the relational form shown in Figure 4-9.

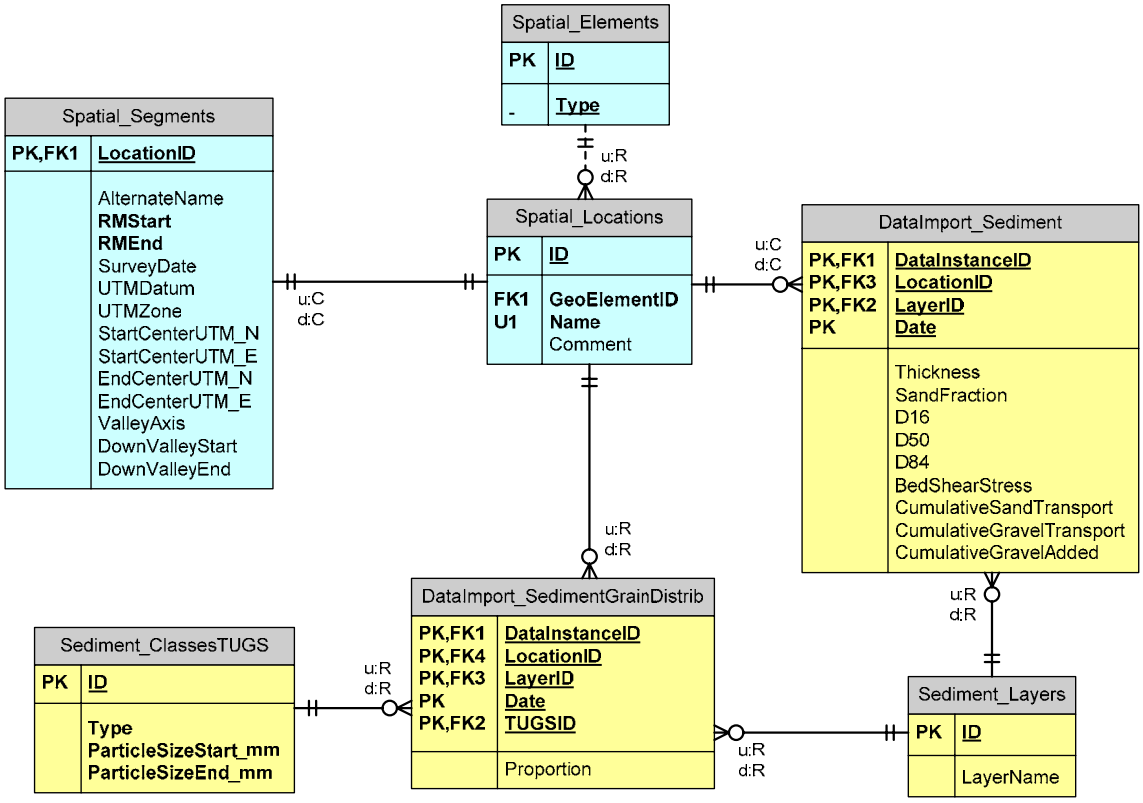

Figure 4-9. Relational database design used by SacEFT for storing TUGS model output.

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 are implemented over 5 reaches as shown in Table 4.4. The results of the TUGS scenarios are integrated with Spawning WUA 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^3) (when present)
301.956	299.800	
299.800	297.000	179,423$^{\delta}$ (234,677 yd^3)
297.000	295.600	
295.600	292.400	188,662$^{\delta}$ (246,760 yd^3)
292.400	289.375	

$^{\delta}$ 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. 2006) 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 will be 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. in review).

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

The meander migration model applied and configured for SacEFT focuses on three river segments located between RM 170-185, RM 185-201, and RM 201-218. The model has also been previously applied in various locations between Red Bluff (RM 243) and Colusa (RM143).

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 will still be 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 will treat locations as fixed throughout model simulations for purposes of generating focal species performance measures, variables that are inherently spatial, like centerline change, 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.

Form of meander migration output to be accessed and imported: .DAT and Excel

The meander migration model produces output in two formats: (1) year-specific centerlines are provided in .DAT text files (Figure 4-10); and (2) summary performance measures are manually calculated during GIS analyses and summarized in Excel (Figure 4-11).

curvature1950.dat - Notepad

File Edit Format View Help

```
Sac River
LASR Data
0
1950 channel

file written 07-Mar-2006 14:44:26
Meander version: Meander 7.3

1976 channel                    Dimensioned        Dimensioned       Dimensioned        Dimensioned
(smooth_chan2.dat)        Bend  Downstream       curvature,        velocity           Eta
      X            Y      Numb  distance,s       sigma_d           perturbation,ud    (bed topo)

   580249.15   4407064.461  1            0              0                0     -1.254e-007
  580291.851   4407025.536  1   57.78012521     9.3186e-005        0.0016817         0.01355
 580334.2854   4406986.434  1    115.483361    -3.2166e-005        0.0033239        0.027424
 580376.8556   4406947.352  1   173.2724785      -0.0001161        0.0061482        0.052079
 580419.6721   4406908.571  1    231.041412      -0.0001132         0.011533         0.10351
 580462.6206   4406870.177  1   288.6489267    -6.3832e-005          0.01965         0.19041
 580505.8358   4406831.831  1   346.4245094    -6.2058e-005         0.028841         0.30454
 580549.4315   4406793.426  1   404.5236353     -0.00019251         0.036523         0.42515
 580593.0006   4406755.897  1    462.027415      -0.0010972         0.040912          0.5347
 580638.5218   4406721.425  1   519.1281688     9.6086e-005         0.042172         0.63116
 580683.7632   4406686.773  1   576.1153609       -0.000486         0.041331         0.72383
  580730.148   4406653.246  1   633.3482125     -0.00078072         0.038249         0.81449
  580778.465   4406621.525  1   691.1475145     -0.00080036         0.030215         0.87997
 580828.3754   4406591.974  1   749.1505195      -0.0007153         0.012915         0.87397
 580879.5483   4406564.478  1   807.2426294     -0.00059179        -0.016728            0.75
 580931.6848   4406538.734  1    865.388563     -0.00046675        -0.057806         0.49057
 580984.0564   4406514.613  2   923.0481404     -0.00029321         -0.10442         0.12126
 581036.3125   4406491.602  2   980.1462762    -2.2798e-005         -0.14829        -0.30215
  581089.133   4406468.425  2    1037.82801      0.00032631         -0.18287        -0.72368
   581142.47   4406443.803  2   1096.573899      0.00073548         -0.20539         -1.1138
 581193.8399   4406417.362  2   1154.349158       0.0010665         -0.21781         -1.4762
 581240.4284   4406389.747  2   1208.507228       0.0012224          -0.2236         -1.8242
 581282.4255   4406361.058  2    1259.36786       0.0014778         -0.22176         -2.1455
 581322.3412   4406329.126  2   1310.484095       0.0018614         -0.20552         -2.3875
 581361.4868   4406290.911  2   1365.190345        0.002033         -0.16535         -2.4709
 581398.4235   4406245.421  2     1423.7879       0.0019618        -0.096084         -2.3259
 581430.6482   4406194.616  2    1483.95132       0.0017212       -0.0024216         -1.9256
 581457.0766   4406141.579  2   1543.208274       0.0013502          0.10321         -1.3013
 581478.5737   4406088.284  2   1600.674892      0.00087399          0.20525         -0.5433
 581497.0133   4406035.087  2   1656.977173      0.00034724          0.28795         0.21682
 581514.3732   4405981.655  3   1713.158788     -0.00015455          0.33788         0.84299
 581532.3441    4405927.94  3   1769.800073     -0.00056099          0.34802          1.2393
 581552.1833   4405874.385  3   1826.912201     -0.00081501          0.32122          1.3808
 581574.6132   4405821.546  3   1884.314048     -0.00089203          0.26913          1.3139
 581599.8041   4405769.763  3   1941.900068     -0.00082948          0.20718          1.1297
 581627.4867    4405719.16  3   1999.579864     -0.00072361          0.14929         0.92671
 581657.2087   4405669.834  3   2057.168625     -0.00067141          0.10428         0.77832
 581688.6814    4405621.89  3   2114.519866     -0.00070651         0.074711         0.71781
 581721.9889    4405575.37  3   2171.733952      -0.0007789         0.058171         0.74246
 581757.4079   4405530.294  3   2229.060754      -0.0010166         0.049882         0.82825
 581795.7618   4405486.967  3   2286.924924     -0.00052136         0.044901         0.94479
  581835.563   4405444.654  3   2345.015583     -0.00099438         0.039627           1.066
 581877.8585   4405404.606  3   2403.262515      -0.0011917         0.032474          1.1775
 581922.9157   4405367.527  3   2461.614993      -0.0012049          0.02426          1.2825
 581970.3891    4405333.76  3   2519.872589      -0.0011898         0.017939          1.4039
 582019.8799   4405303.483  3   2577.890225      -0.0012758         0.017187           1.578
 582071.3607   4405277.006  3   2635.780709      -0.0015123         0.024143          1.8372
 582125.1457   4405255.072  3   2693.866197      -0.0018514         0.037501          2.1895
 582181.2075   4405238.997  3   2752.187265      -0.0021944         0.052094          2.6067
```

Figure 4-10. Example of meander migration centerline file produced by MATLAB software.

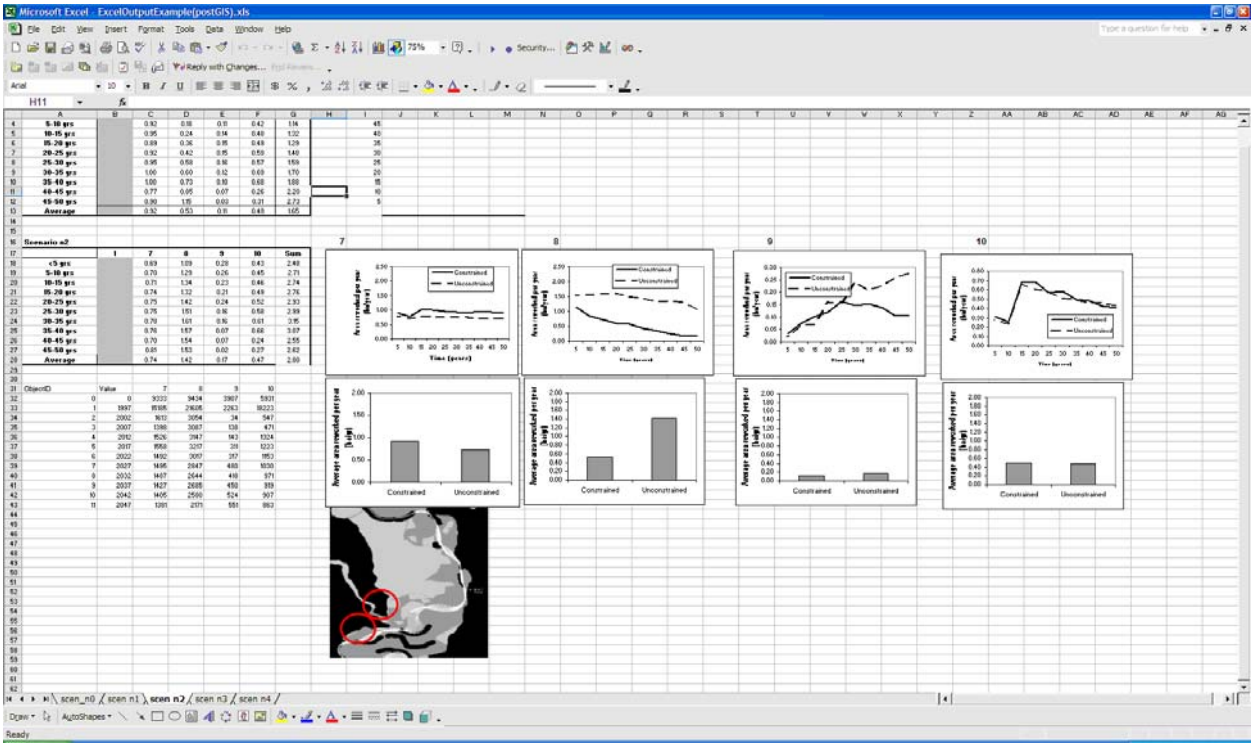

Figure 4-11. Example of meander migration summary results in Excel following GIS centerline analyses.

To enable import of meander migration results to SacEFT, a new Excel template will be provided to "tame" meander migration output so it is compatible with the relational form shown in Figure 4-12.

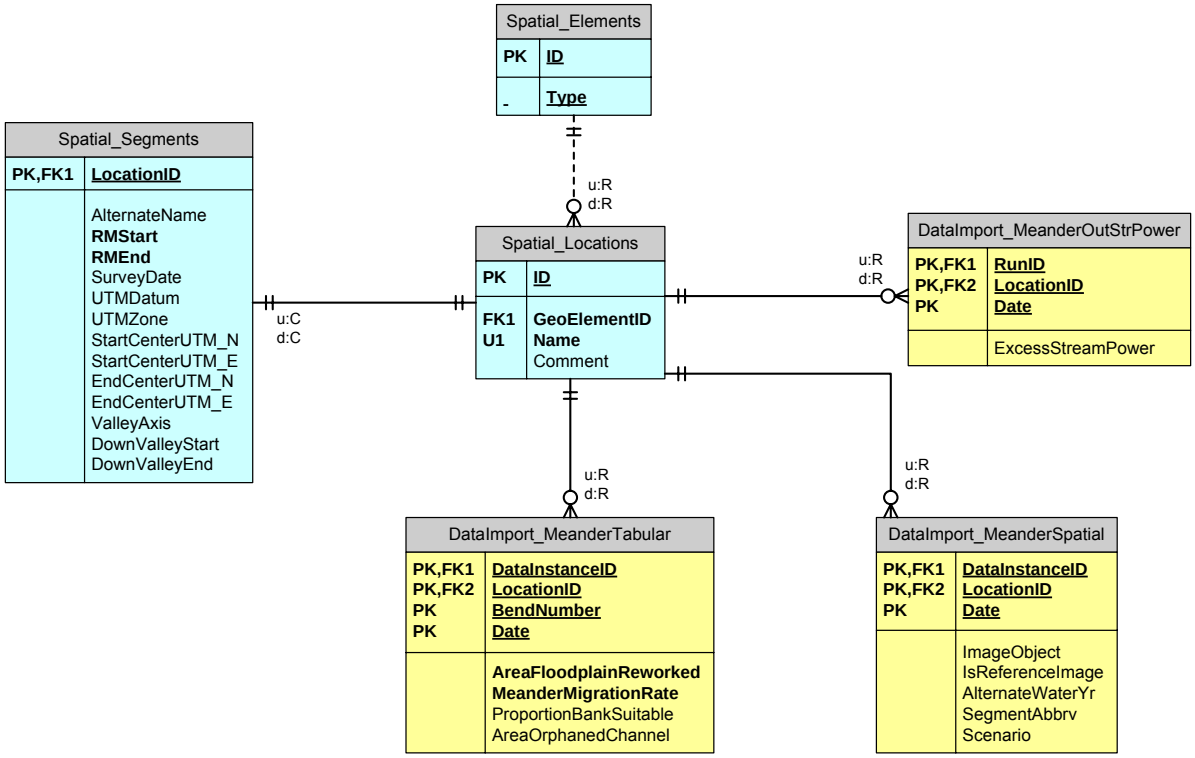

Figure 4-12. Relational database design used by SacEFT for storing meander migration model output.

Note, in Figure 4-12 ("DataImport_MeanderTabular"), *ProportionBankSuitable* refers to soil types associated with bank swallow nesting habitat. At this time, this information cannot be provided by meander migration researchers. Meander Migration outputs are simplified to *MeanderMigrationRate* and *AreaFloodplainReworked*, from which the length of eroded bank is calculated without reference to soil suitability. This affects calculations of bank swallow performance measures (see Section 4.2.4). We will assume a fixed default proportion soil suitability in SacEFT v.2.00 until data on soil suitability is made available to meander migration researchers in a GIS format they can work with, and incorporated into their analyses of eroded bank per bend.

While infrequent, the Meander Migration model also predicts channel cutoff events and corresponding orphaned channel areas under certain year/flow combinations. These are incorporated into the western pond turtle performance measure (see Section 4.2.5).

Finally, information in "DataImport_MeanderSpatial" is used for visualizing channel centerline migration over time. Date stamped image objects are loaded into SacEFT's database, and run along a set time interval to see change moving from time t to time t_n.

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 races spawning in WY *y*.

4.2.2 Matching physical variables to focal species locations of interest

Each PM model is designed to accommodate the temporal framework of its input data: daily for flow and temperature and annual for TUGS and MM data. SacEFT accepts inputs that may be point-based (e.g. discharge and temperature) or segment-based (e.g., TUGS data). It links these to 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 is 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 is considered a perfect match. Failing a match within the tolerance zone the nearest upstream data is usually selected. In a 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 the 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) was mapped to the downstream segments used by the Chinook and steelhead submodels each year for each of the 6 combinations of 3 flow scenario and 2 gravel scenario. In the case of fall Chinook, the most distant segment extends 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 is to obtain 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 races

Chinook and steelhead spawning and rearing WUA performance measures (CS1, CS2) are parameterized for two downstream 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 3 upstream 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 races. Habitat preferences for spring Chinook are not available and we assumed they followed those of fall Chinook (Mark Gard, pers. comm.).

4.2.5 Linking Chinook and steelhead WUA relationships to TUGS substrate classes

The Chinook and steelhead spawning 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^2; otherwise it has some smaller value. Gard's results are based on the River-2D hydrodynamic model (Steffler and Blackburn 2002, USFWS 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:

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

The a_{11} vector was found to be fairly insensitive to discharge, and we therefore took the average a-vector across the full range of flows (3.25 to 31 kCFS), 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_{11} vector calculated by River-2D was transformed to the 8 size categories 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^*_s 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 (including Version 2 enhancements to existing indicators)

4.3.1 Chinook salmon & steelhead trout

The salmonid conceptual model is shown in Figure 4-13. Readers are referred to ESSA Technologies (2005) for details on the development of this model and the decisions that led to its current structure.

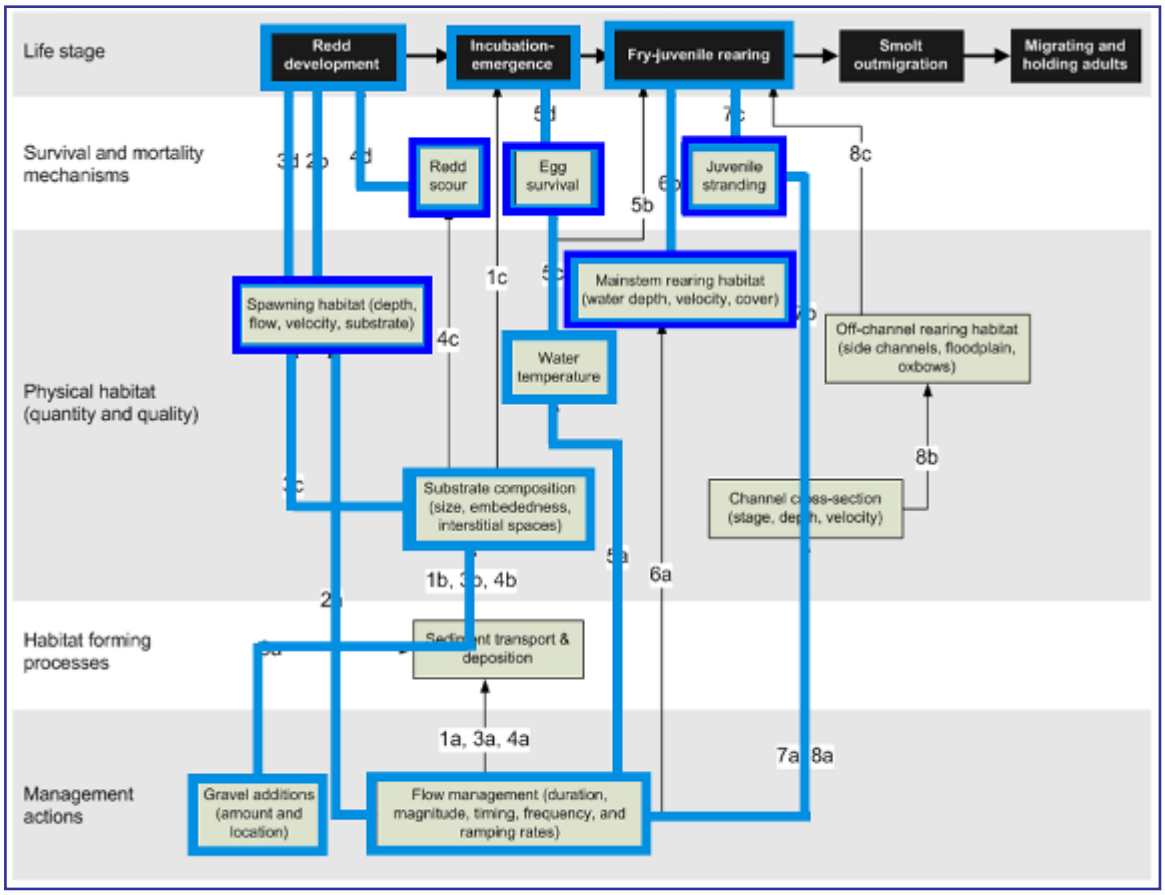

Figure 4-13. The salmonid conceptual model. Heavy lines show the processes and linkages that are currently implemented. See ESSA Technologies (2005) for additional context and detail on processes and linkages shown here.

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. PMs marked in **blue** have been significantly modified from Version 1; those marked in **red** are new candidate PMs.

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
Redd superimposition		CS99	Index
Juvenile weight gain		CS98	grams

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 has been provided from relationships published for the SALMOD model (Bartholow and Heasley 2006).

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. Because parameterized relationships were not always available for every location and PM, relationship mapping was carried out by assuming that relationships parameterized for a race or location could be applied to another race or location (Mark Gard, pers. comm.).[1] For example, based on USFWS (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 *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 Red/Yellow/Green 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 currently graphed) the terciles of the annual average for the PM are used to create Indicator Ratings. At the daily scale – the Indicator Rating (and color bars) that are present on most Excel reports – the terciles of the *daily* historic result are used, and daily evaluations of the PM are again assigned daily Red/Yellow/Green Indicator Rating based on the benchmark historical run.

[1] One reviewer notes 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 be accommodated in Version 2.

Although each model operates internally on the basis of a daily cohort, the distributional and cumulative results shown on the Excel often portray the 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.

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

		Spawning PMs					Rearing PMs				
Upstream	**Downstream**	***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		▮				▮	▮	▮	▮	

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 avoid designs where one PM depended on another and which therefore resembled population-based models. In general we have adhered to this principle; but where the linkage between closely related PMs seemed robust, in one case we have 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 will 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. In addition, 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 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, as many as 3 calibration measures are computed for some CS1, CS3, CS4 and CS6 (Spawning and Rearing WUA, Juvenile Stranding and Redd Dewatering, respectively):

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 third (**terciles**) of the sorted values are termed daily Hazard Threshold boundaries and are shown as a horizontal Red/Yellow/Green (R/Y/G) line 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.

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, 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 for each particular year. These data are sorted and then graphed to examine the 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 rollups 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 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.

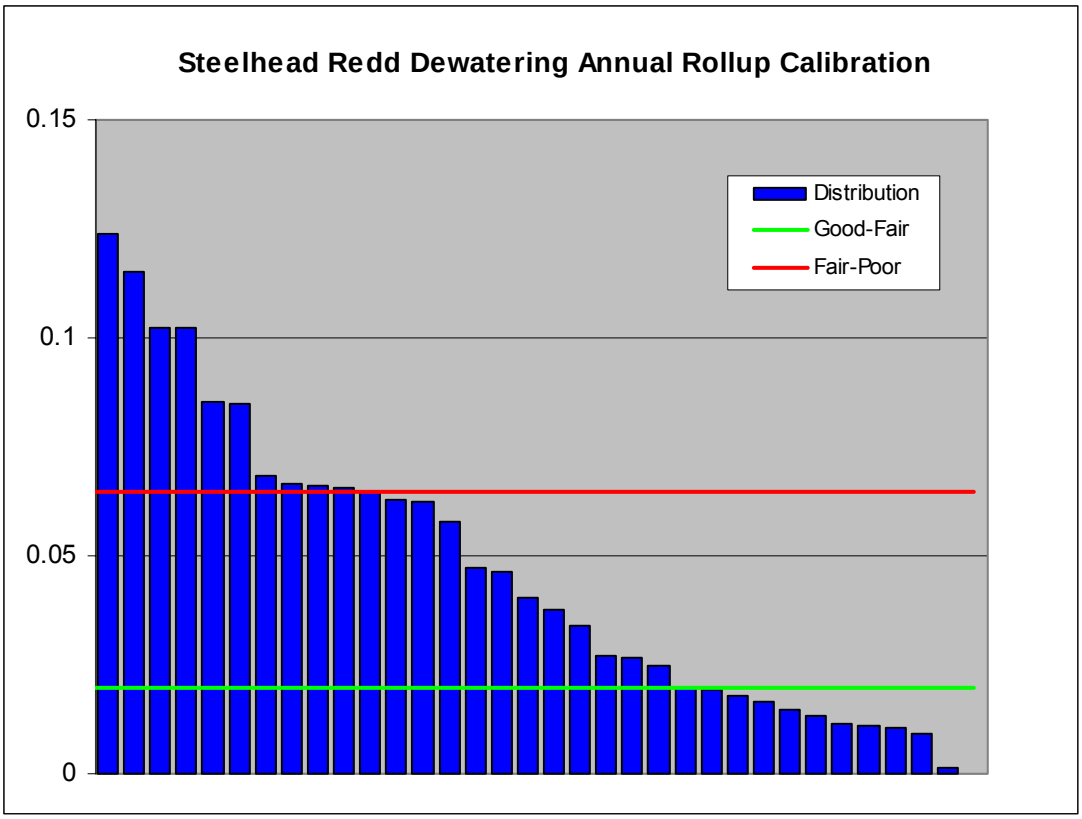

Figure 4-14. An example showing the distribution of the Redd Dewatering (CS6) index for Steelhead trout based on the average annual value for all reaches, sorted by year from largest to smallest value. Similar graphs are created for all 3 temporal resolutions (daily, annual, and annual rollup) for 5 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) PMs follows a slightly different path 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 is 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 race and river segment. The historical or simulated gages provide daily average flow *(Q)* over the spawning period *D* for each location *(l)* and race *(r)* combination[1].

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 *annual* PM is computed for each location and race by computing the average contribution for the segment, with each day's contribution to the average weighted by the proportion of the population spawning (w_d) on that day.

$$CS1_{l,r} = \frac{1}{D}\sum_{d=1}^{D} f(l,r,Q_d^*)\, w_d$$

The *rollup* PM is computed by averaging across all locations (*L*).

Version 1 (Then)

In Version 1, a 1/L average is used rather than a sum, so that thresholds are more meaningful should the number of locations vary across years and/or races, based upon the availability of the underlying flow and water temperature data.

$$\boxed{CS1_r = \frac{1}{L}\sum_{l=1}^{L}\left(\frac{1}{D}\sum_{d=1}^{D} f(l,r,Q_d^*)\, w_d\right) = \frac{1}{L}\sum_{l=1}^{L} CS1_{l,r}}$$

Version 2 (Now)

Incorporating suggestions and information provided at the SacEFT refinements workshop (ESSA 2008), The CS1 annual rollup has been modified to account for long term observed differences in the use of each reach by spawners of each race. This replaces the average (1/L) approach used in Version 1 with location-weights (w_l) which modify the contribution of each spawning reach to the annual PM. Possible values for location weights are provided in Table 4.7.

$$\boxed{CS1_r = \sum_{l=1}^{L}\left(\frac{1}{D}\sum_{d=1}^{D} f(l,r,Q_d^*)\, w_d\right) w_l = \sum_{l=1}^{L} (CS1_{l,r})\, w_l}$$

[1] For convenience only we use the term 'race' in these descriptions, recognizing that there are four Chinook run-types and that Steelhead trout and Chinook salmon are a unique species.

Table 4.7. A possible distribution of location-weights (w_l) for salmonid spawning and egg PMs is shown here. These weights are based on observed distribution of fall, late-fall and winter run Chinook spawning (1989–1994) (USFWS 2003, Table 1) and have been adjusted to create segment weights that sum to 100%. Plausible distributions or default assumptions must be found for steelhead and spring-run Chinook.

Segment		Run type				
Upper boundary	Lower boundary	Fall	Late fall	Winter	Spring	Steelhead
Keswick	ACID	9	24	2	?	?
ACID	Cow Creek	38	52	80	?	?
Cow Creek	Battle Creek	13	8	3	?	?
Battle Creek	Red Bluff	16	7	9	?	?
Red Bluff	Deer Creek	25	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.

Version 2 Revision

A thorough re-reading of USFWS (2006) has made it clear that reach-weights from USFWS (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 (USFWS 2006) represent post-flooding conditions that have changed substantially in the more downstream reaches, with downgraded habitat availability below Battle Creek. A comparison of Table 4.7 with SacEFT Version 2 CS1 Spawning WUA for three run-types is shown below in Table 4.8, and 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 4.8. A comparison of 1989-1994 field observations of redd distribution (%) compared to 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	-

Whatever WUA prediction model is incorporated, SacEFT assumes that WUA predictions are stationary over time, an assumption that loses strength as simulation time periods move away from the time period in which the field assessments generated the underlying WUA curves.

Indicator Reliability

The indicator credibility rankings for CS1 are shown in Table 4.11.

Table 4.9. 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

Version 1 (Then)

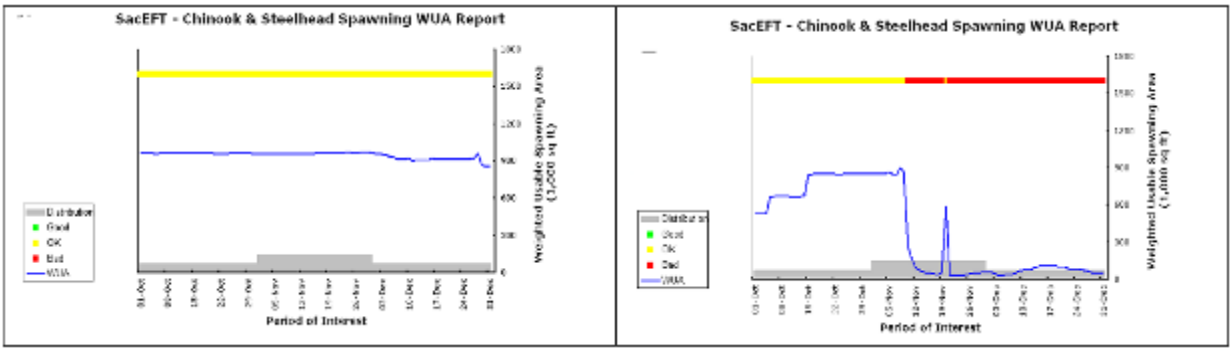

Figure 4-15. The CS1/ST1 – Spawning WUA daily Performance Measure as implemented in SacEFT v.1.00.018.

Version 2 (Now)

A discharge graph will be added below the Spawning WUA figure (Figure 4-15). This change will be made by adding flow data to the program code and stored procedure, and flow graphing code to the XLT template.

Model Calibration

The calibration process described above produces the Indicator Rating boundaries shown in Table 4.10.

Table 4.10. CS1 - Spawning WUA indicator rating breakpoints. Units are population-proportion-weighted square feet.

	Resolution					
	Daily		Annual		Rollup	
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor
Winter-run Chinook	430060	195486	3513	1130	2880	2475
Spring-run Chinook	607975	217913	8734	2785	5825	4775
Fall-run Chinook	1006472	29967	10619	3406	8470	5500
Late-fall-run Chinook	520424	280581	4522	2772	4250	2760
Steelhead	18692	13447	101	76	135	106

CS2 – Weighted usable area for rearing

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

Version 1 (Then)

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 relationship. This creates a linkage to the spawning performance measures CS1, with a delay between the days on which a cohort of eggs is spawned and the days over 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 race-dependent residence period (r) after emergence, with the variable r set to 120 days for all races. 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:

$$w_d = \sum c_e \quad where\ (e \le d),\ and\ ((e + r - 1) \le d)$$

Version 2 (Now) – Option A

Incorporating suggestions and information provided at the SacEFT refinements workshop (ESSA 2008), The CS2 Performance Measure has been modified so that the variable r is set to 90 days for all Chinook run-types and 365 days for steelhead.

Version 2 (Now) – Option B

An alternative to a fixed period of juvenile residence would be to use a temperature-driven juvenile weight gain relationship (Figure 4-16, Brett et al. 1969) to compute growth. Assuming a typical food ration of 4.5% and final mature weight, this function would compute the r days to maturity. This option requires further study, but temperature sensitivity is appealing because it would provide sensitivity to climate change scenarios that would otherwise be absent. ***It is not yet possible to provide the exact equation form for this dome-shaped option.***

Version 2 (Now) – Option C

As an alternative to using the temperature-weight gain function to incrementally arrive at a mature juvenile weight (Option B above), the same function could be used to calculate final weight after the 90 or 365-day development period. The advantage of computing weight gain over fixed time (Option C), compared to time to achieve a mature weight (Option B), is that the Option B approach is indeterminate, making the algorithm more problematic if weight gain fails to produce a mature weight within the annual framework of the model. This option would create a new **Juvenile Weight Gain (CS98)** Performance Measure. Option B and Option C are obviously different ways to measure the same relationship, so probably only one of them need be considered. ***It is not yet possible to provide the exact equation form for this dome-shaped option.***

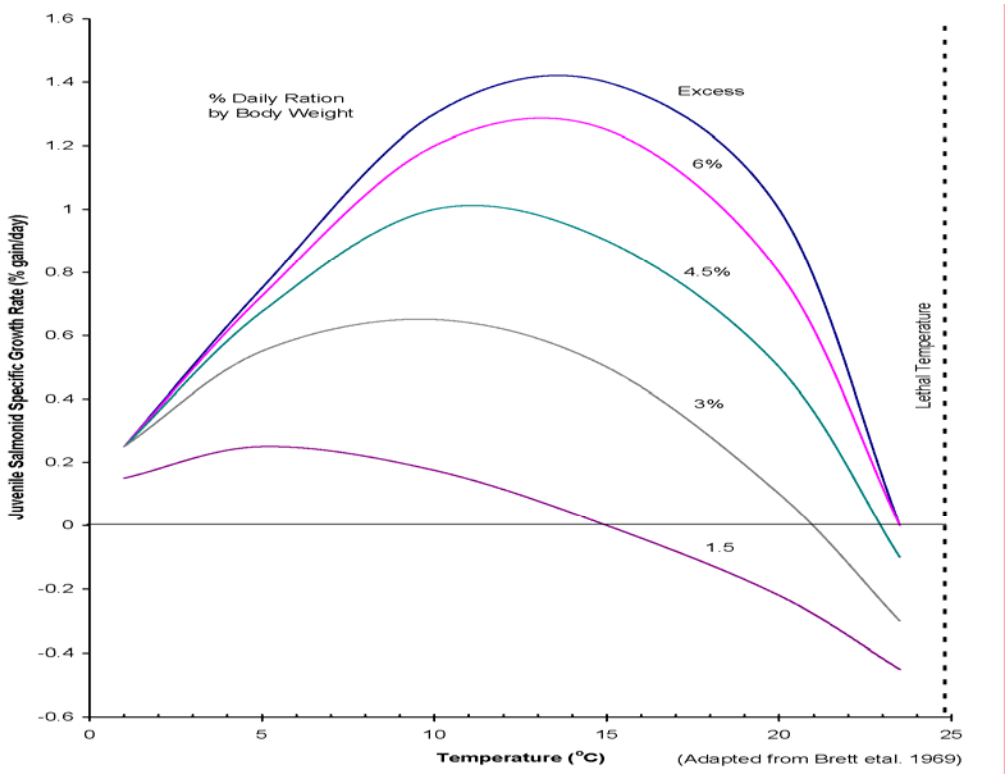

Figure 4-16. Juvenile Chinook growth as a function of temperature and % daily ration (from Brett et al. (1969)).

Whichever method is adopted in Version 2, the emergence function makes it possible to have multiple spawning day cohorts emerge on the same day, particularly during periods of warmer 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), 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 instead they are assumed to remain in the reach they were spawned.

Version 2 Revision

This PM will be incorporated into DeltaEFT Version 1, where it will drive the maturation of juveniles in Yolo Bypass.

The *daily* PM is computed by interpolating the WUA-flow relationship (which for rearing does *not* vary with substrate composition) *f(l,r,Q)* 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, even though internally, each day-cohort is tracked separately.

The *annual* PM is computed for each location and race by computing the average contribution for the individual segment (*l*), with each day's contribution to the average weighted by the proportion of rearing (*w*) on that day.

$$CS2_{l,r} = \frac{1}{D}\sum_{d=1}^{D} f(l,r,Q_d)\,w_d$$

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 races, based upon the availability of the underlying flow and water temperature data.

$$CS2_r = \frac{1}{L}\sum_{l=1}^{L}\left(\frac{1}{D}\sum_{d=1}^{D} f(l,r,Q_d)\,w_d\right) = \frac{1}{L}\sum_{l=1}^{L} CS2_{l,r}$$

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

Table 4.11. 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

Version 1 (Then)

The daily PM ranking, a horizontal R/Y/G bar shown on many Excel reports, is not useful for this report and actually confuses the interpretation of behavior.

Version 2 (Now)

The Version 2 Excel report implements (Figure 4-17) a vertical bar showing the annual rollup for the PM, which is more consistent with the cumulative PM plotted on the figure.

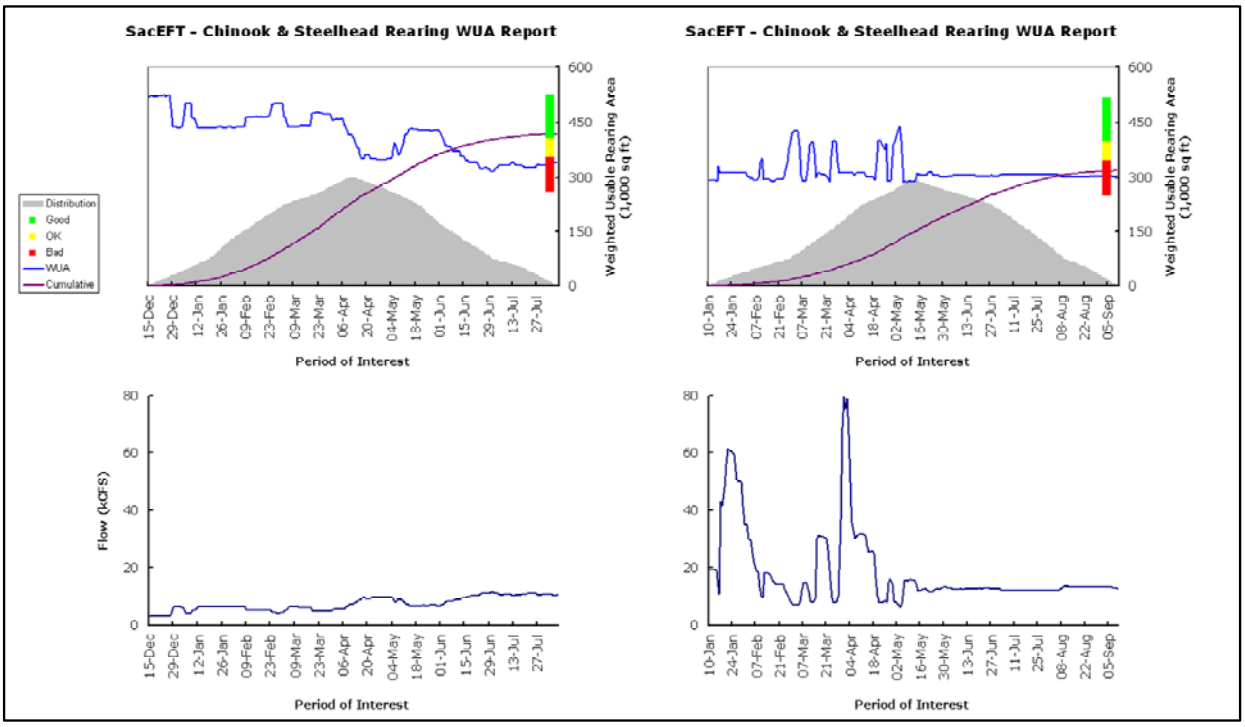

Figure 4-17. An example of the Version 2 Excel report for CS2 - Chinook juvenile rearing WUA using fall-run 1977 (Very Dry Year, left panel) and 1974 (Wet Year, right panel).

Model Calibration

The calibration process described above produces the Indicator Rating boundaries shown in Table 4.12.

Table 4.12. CS2 – Rearing WUA indicator rating breakpoints. Units are population-proportion-weighted square feet for Daily resolution; cumulative for the Annual and Rollup scales.

	Resolution					
	Daily		Annual		Rollup	
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor
Winter-run Chinook	32532	9662	5446214	4938088	7497759	7350129
Spring-run Chinook	98352	29539	13522267	8561616	18885831	13958748
Fall-run Chinook	48166	17573	11324769	4880811	14717925	10624775
Late-fall-run Chinook	43604	13801	7084424	4520139	10107957	9109028
Steelhead	123583	30142	34346884	9525018	47816594	41352562

CS3 – Egg-to-fry thermal mortality

Egg survival is calculated using daily cohorts of eggs over their temperature-driven development period (δ) following their spawning period *(D)*, for each combination of location *(l)* and race *(r)*. Temperature contributes to two opposing processes in SacEFT. First, warmer water makes development faster through a temperature-maturation relationship (Figure 6, Bartholow and Heasley 2006), reducing the period of exposure to thermal mortality. However, survival *s(T)* declines at warmer temperature, which has the opposite effect (Table 11, Bartholow and Heasley 2006). Note: lengthening of the egg development and juvenile growth window also lengthens 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.

Version 2 Comment

Following the review workshop we searched for improved egg thermal mortality relationships. In particular, we wanted to find better coefficients for steelhead. Following the review of Richter and Kolmes (2005) and Myrick and Cech (2010), we decided to ***continue*** to apply the Chinook coefficients to steelhead. These coefficients were taken from Bartholow and Heasley (2006) for Version 1. Myrick and Cech (see Figure TT.5 and TT.6 in that paper) conclude that thermal mortality of steelhead eggs 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.

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 *annual* PM is then calculated by taking the average daily survival of each spawning day-cohort:

$$CS3_{l,r} = \frac{1}{D}\sum_{d=1}^{D} w_d \prod_{\delta} s(T)$$

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

$$CS3_r = \frac{1}{L}\sum_{l=1}^{L}\left(\frac{CS1_{\overline{x,l}}}{CS1_{\overline{x}}}\right)\left(\frac{1}{D}\sum_{d=1}^{D} w_d \prod_{\delta} s(T)\right) = \frac{1}{L}\sum_{l=1}^{L}\left(\frac{CS1_{\overline{x,l}}}{CS1_{\overline{x}}}\right) CS3_{l,r}$$

During the design of this model we anticipated using the USBR egg mortality model, but later adopted the mortality ATU models used by SALMOD, since the SALMOD formulation reports and corrects some mathematical errors that may be present in the USBR model.

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.

Version 1 (Then)

All run-types make use of a single temperature maturation function based on the values used by SALMOD.

Version 2 (Now)

Following the review workshop we searched for improved salmonid egg development (ATU) relationships. In particular, we wanted to find unique coefficients for steelhead, since the Version 1 steelhead relationship was identical to Chinook. Following a review of Myrick and Cech (2010) we decided to apply separate Chinook and rainbow trout (*Salmo gairdneri = O. mykiss*) models developed by Crisp (1981). Crisp's model is the basis for Chinook egg maturation used in SALMOD (Bartholow and Heasley 2006). Besides 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, and those in Version 2 are taken from Crisp's fitted models, where D is the total days of egg development time at temperature T (Celsius) :

$$\log_{10} D = -1.8126 \times \log_{10}(T+6) + 3.9166 \qquad \textbf{Chinook}$$

$$\log_{10} D = -2.0961 \times \log_{10}(T+6) + 4.0313 \qquad \textbf{Steelhead}$$

Proportion maturation per day is then the reciprocal of D.

Indicator Reliability

Table 4.13. CS3 – Egg thermal mortality indicator credibility assignments following the workshop.

	Category				
	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

Excel Reports

Version 1 (Then)

The Version 1.00.018 Excel Report currently displays the spawning calendar distribution, which does not fully capture the details of the weighting scheme

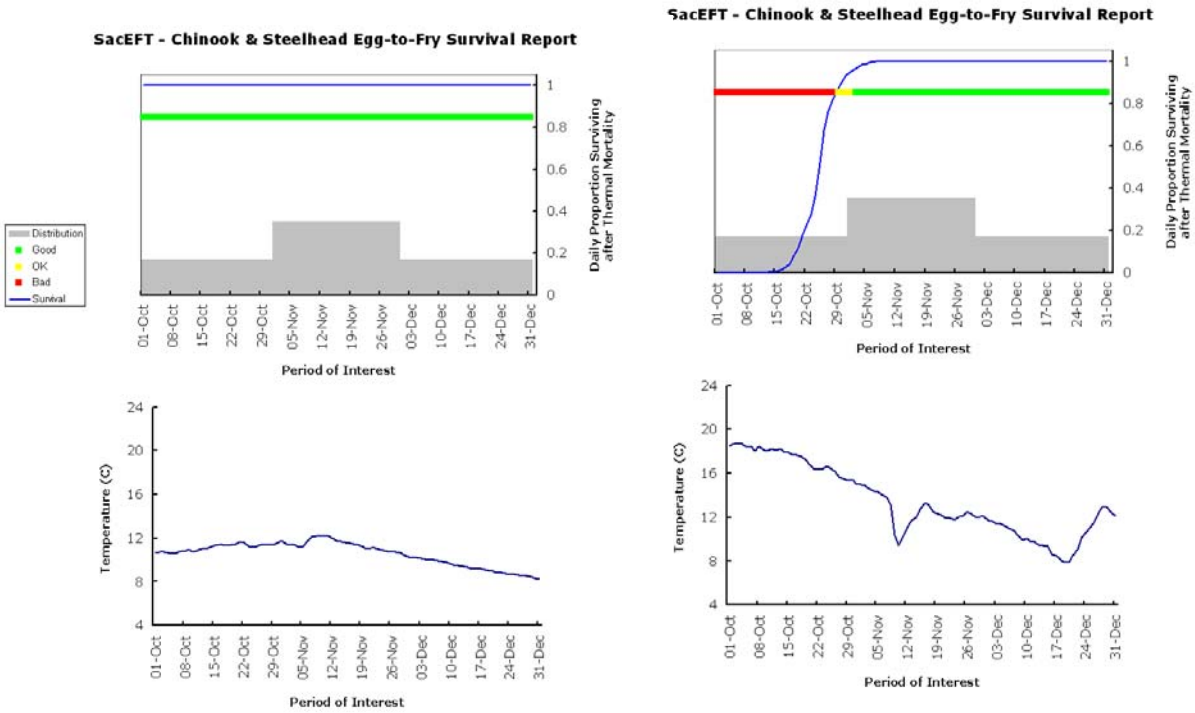

Figure 4-18. An example of the Version 1 Excel report for CS3 – Egg-to-Fry Thermal Mortality ll-run 1977 (Very Dry Year, left panel) and 1974 (Wet Year, right panel). This report will be modified so that it is consistent with the weighted annual rollups for CS5 and CS6.

Version 2 (Now)

The Version 2 Excel Report follows the style of the redd scour (CS5) and redd dewatering reports (CS6) shown in Figure 4-17, using a vertical bar to show the annual rollup for the PM. This display is more consistent with the cumulative PM plotted on the figure.

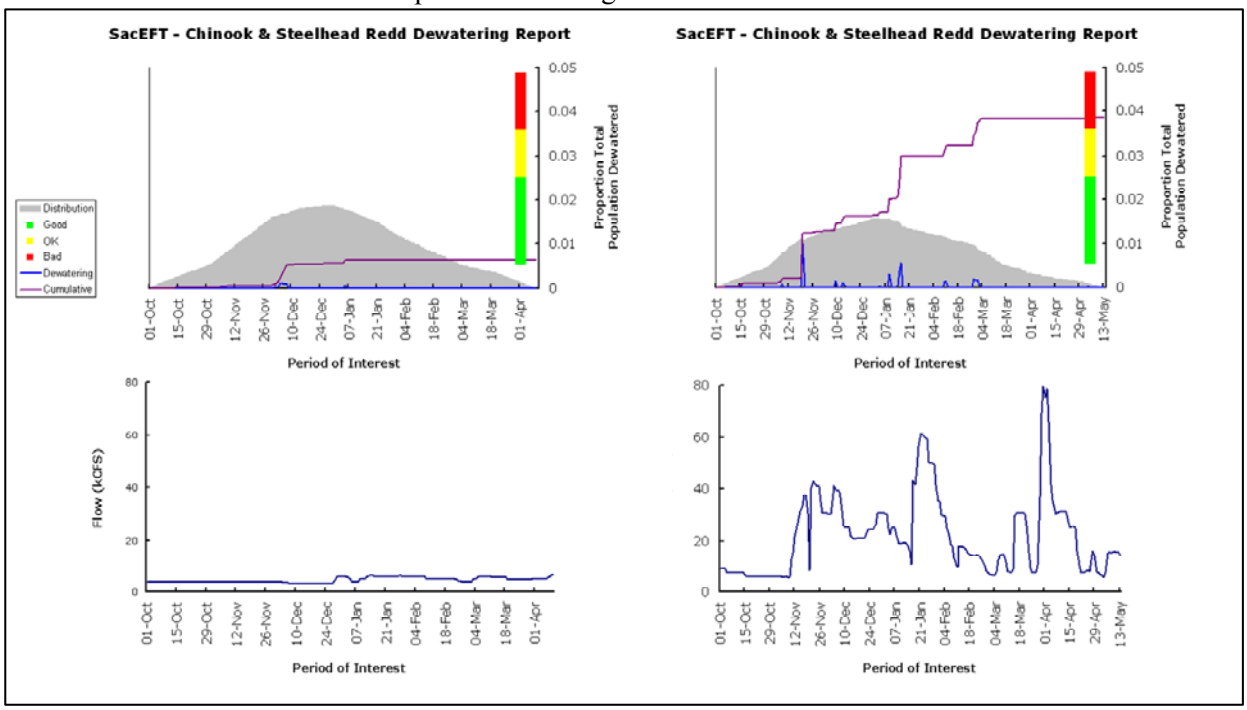

Figure 4-19. The Version 2 Excel Report for Egg Thermal Mortality (CS3) will resemble the style of the Report shown above, for redd dewatering (CS6) of fall Chinook Excel in 1977 (Very Dry Year, left panel) and 1974 (Wet Year, right panel).

Model Calibration

The calibration process for CS3 is based on mortality thresholds of 5% and 10%, as shown in Table 4.14

Table 4.14. CS3 –Egg-to-fry Thermal Mortality indicator rating breakpoints. Units are % Mortality for all temporal scales. Annual and Rollup scales incorporate population-proportion weights.

	Resolution					
	Daily		Annual		Rollup	
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor
Winter-run Chinook	5	10	5	10	5	10
Spring-run Chinook	5	10	5	10	5	10
Fall-run Chinook	5	10	5	10	5	10
Late-fall-run Chinook	5	10	5	10	5	10
Steelhead	5	10	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 race *(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, it 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:

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

For example, no losses will occur on the first day a juvenile cohort emerges. If a drop occurs on the second day the loss is not accounted for until the end of the second day, causing the cohort weight to decline on the third day (*e=1, d=3*). As the day-cohort weight changes juveniles present in the segment with potential exposure to stranding, thus changing the weight. Based upon this 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:

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

Version 1 (Then)

The *daily* performance measure 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 segment level used by SacEFT. Gard's results do not include time explicitly. Rather, his model estimates proportion of rearing WUA lost (if any) at each location (*l*) between the day of emergence and the end of the residency period. Although races 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-l}, 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).

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 identical to 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 appropriate, even though the underlying model measures changes to the proportional change in rearing WUA.

The *annual* PM is contains the cumulative sum of all the daily losses of each cohort tracked from the start of the distribution period until the end:

$$CS4_{l,r} = \sum_{i=1}^{D} (c_{i,D+1} - c_{i,D})$$

The rollup PM for juvenile stranding is calculated by taking the average across locations (L). An average rather than a sum is used to have thresholds be applied more consistently should the number of locations across years and/or races vary based upon the availability of the underlying flow and water temperature data.

$$CS4_{r} = \frac{1}{L} \sum_{l=1}^{L} \sum_{i=1}^{D} (c_{i,D+1} - c_{i,D}) = \frac{1}{L} \sum_{l=1}^{L} CS4_{l,r}$$

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.

Version 2 (Now)

The workshop 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 will explore whether other pre-existing datasets exist that are compatible for extending our existing formulation of this indicator. For example, side channel studies described in the Stillwater Sciences (2007) (Figure 4-20), may be adapted to the tabular model structure adopted for Gard's data. Mark Gard (pers. comm.) has suggested that the "normalized disconnected inundated area" from this figure corresponds most closely to the methodology used to estimate stranding at upstream locations. Even if this is possible, there is a 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 4-20. if possible, higher hazards are associated only with low flows.

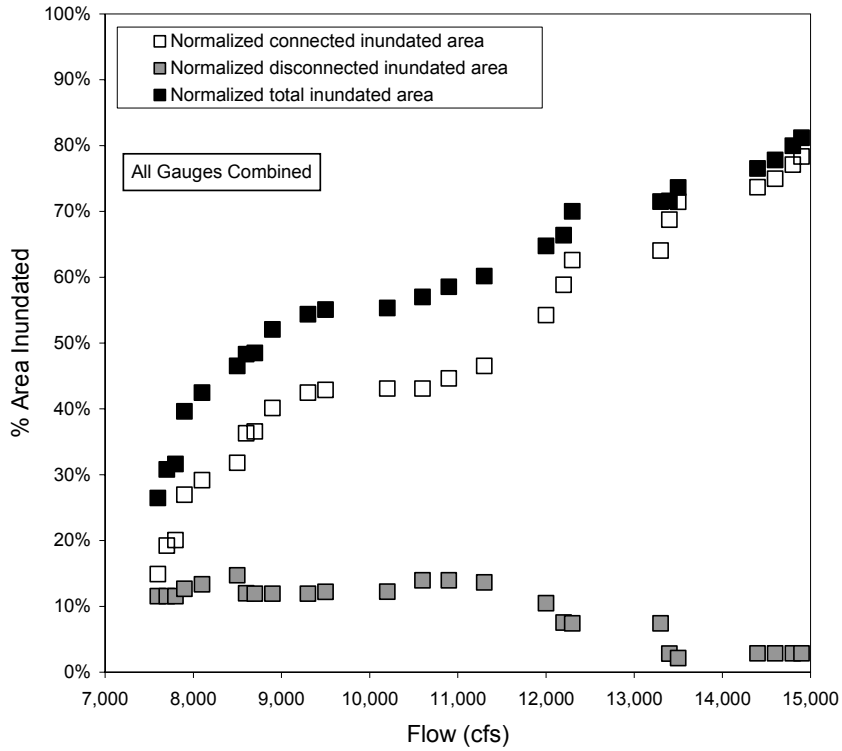

Figure 4-20. Normalized connected (white symbols), disconnected (gray symbols), and total inundated area (black symbols) averaged over all study sites for varying flows on the Sacramento River. Each site is normalized by the maximum potential inundated area, such that they each have equal weight in determining 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).

Version 2 Comment

We have so far been able to find a mathematically consistent way to incorporate the information in Figure 4-20 in the PM.

Indicator Reliability

Table 4.15. 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

Version 1 (Then)

The daily PM ranking, a horizontal R/Y/G bar shown on many Excel reports is not useful for this report and actually confuses the interpretation of behavior.

Version 2 (Now)

The example below shows the style for the Version 2 Excel Report for CS4. A vertical R/Y/G bar will show the annual rollup breakpoints for juvenile stranding index.

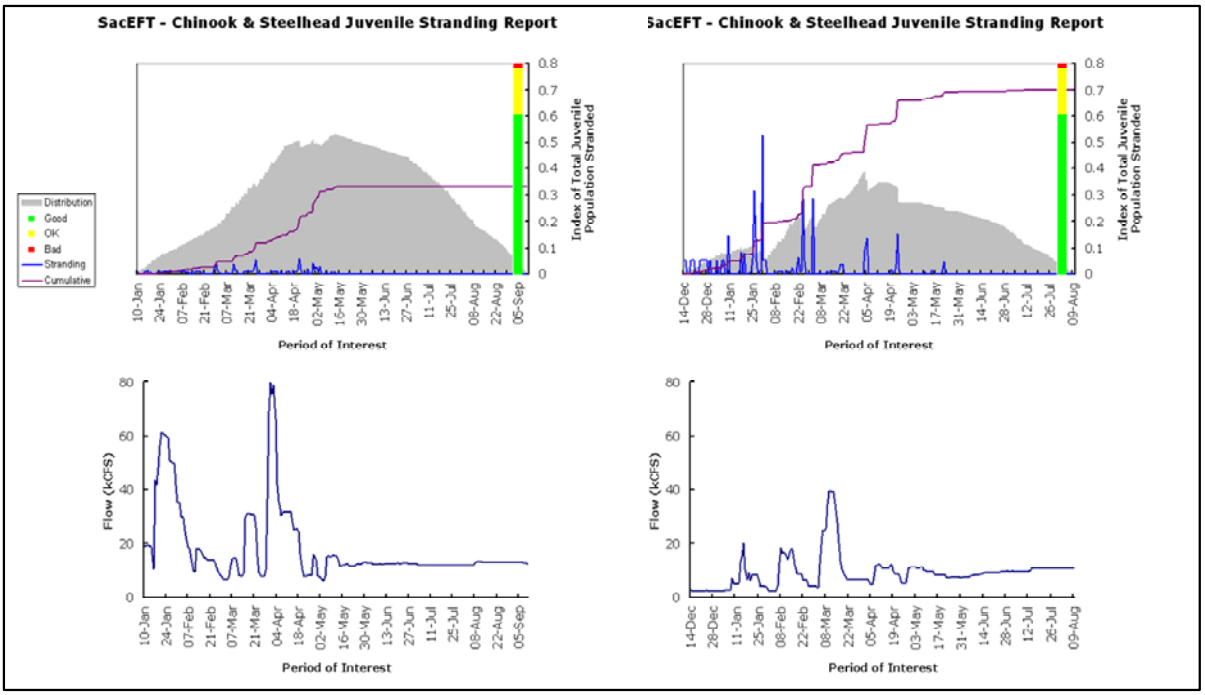

Figure 4-21. Excel Reports of CS4 – Juvenile stranding, showing fall-run Chinook for 1974 (Wet Year, left panel) and 1978 (Above Normal Year, right panel). The example shows the manual addition of annual PM rollup using the vertical colored bar at the right of the upper panels.

Model Calibration

The calibration process described above produces the Indicator Rating boundaries shown in Table 4.16.

Table 4.16. CS4 – Juvenile Stranding indicator rating breakpoints. Units are population-proportion-weighted stranding index for Daily resolution; cumulative for the Annual and Rollup scales.

	Resolution					
	Daily		Annual		Rollup	
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor
Winter-run Chinook	3.9915E-05	3.0166E-04	0.02061	0.05096	0.0515913	0.1111661
Spring-run Chinook	1.1791E-04	9.1650E-04	0.02833	0.12915	0.10	0.20
Fall-run Chinook	9.7418E-05	5.4636E-04	0.03043	0.07537	0.10	0.20
Late-fall-run Chinook	5.1089E-05	1.9633E-04	0.00859	0.03790	0.0551377	0.0710698
Steelhead	1.4168E-04	1.6280E-03	0.11553	0.23248	0.3261355	0.4140899

CS5 – Redd scour

Version 1 (Then)

Redd scour risk is modeled using the daily proportion of eggs present by race (r) and location (l) coupled to categorical hazard classes at times when flow exceeds threshold values. These threshold values (currently 20,000 and 32,000 CFS) are triggers for assigning different Indicator Ratings, once they are combined with cohort-weighting information. Flows above 20,000 CFS can trigger a Yellow Hazard, with flows above 32,000 CFS required to trigger a Red Indicator Rating level. The model couples these hazard categories to each race's spawning distribution and uses a temperature-driven emergence function to create an aggregated egg distribution for each day of the egg development period, as described below. In a final step, the daily weight is scaled by the relative daily proportion of spawning WUA at the given location. 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 river segment.

Version 2 (Now) – Option A

Incorporating suggestions and information provided at the SacEFT refinements workshop (ESSA 2008), the breakpoints for the CS5 performance measures are modified so that the G/Y threshold is set to 60,000 CFS. The Y/R threshold will be set at a larger value to be determined through discussion with Scott McBain and Christine May.

Version 2 (Now) – Option B

As an alternative to Option A, an analysis of 10-year peak flow will be used to define the Y/R breakpoint, and the peak 5-year flow to define the G/Y breakpoint.

The *daily* PM is calculated as follows. If the daily flow is below the lower threshold then the PM has a value of zero. If flow is above the lower threshold, then the PM is the product of the flow and the value of incubation distribution for that day and location. Internally, the model uses terciles of the historical distribution of this product to determine the R/Y/G Indicator Rating. Thus, if flow is above the upper threshold but the proportion of eggs exposed to the high flow are very low, the daily Rating will be only moderate (Yellow).

The *annual* PM for each location is simply the sum of the daily PMs at the location. Since the daily PM is already averaged over river segments, no segment-weighting is required. The annual PM is configured so that half the year-location outcomes rank with a Green Indicator Rating. The next quarter of the observations is ranked as Yellow and the final upper quarter of the distribution receives a Red Indicator Rating. A year-location with a Red Indicator Rating must also have at least one observation above the upper flow threshold value; otherwise it reverts to a Yellow Indicator Rating.

The *rollup* PM is calculated as the average of annual PM values, with the same heuristic rules applied.

Indicator Reliability

The PM scores shown in Table 4.17 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 open to revision.

Table 4.17. 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

Model Calibration

The calibration process for CS5 is based on Annual critical values of 55,000 CFS and 75,000 CFS, representing 1-in-5 year and 1-in-10 year peak flows for the main stem. Daily thresholds are based on a distribution of daily scores calculated by multiplying the population-proportion-weight by daily flow. The Rollup threshold is the average of the cumulative sum of daily weights. The thresholds are shown in Table 4.18.

Table 4.18. CS5 – Redd Scour indicator rating breakpoints. Units are % Mortality for all temporal scales. Annual and Rollup scales incorporate population-proportion weights.

	Resolution					
	Daily		Annual		Rollup	
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor
Winter-run Chinook	3027	7442	55000	75000	5000	10000
Spring-run Chinook	3027	7442	55000	75000	5000	10000
Fall-run Chinook	3027	7442	55000	75000	5000	10000
Late-fall-run Chinook	3027	7442	55000	75000	5000	10000
Steelhead	3027	7442	55000	75000	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 race *(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 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:

$$c_{s,d} = \begin{cases} c_s \quad when\ (s \le d < (s+1)) \\ c_s\left(1 - f(l,r,Q_s,Q_{d-1})\right) \quad when\ (s < (d-1))\ and\ up\ to\ emergence\ (d < e) \\ 0.0 \quad otherwise,\ e.g.\ when\ (d < s)\ or\ (d \ge e) \end{cases}$$

For example, no losses will occur on the day an egg cohort is spawned. If a drop occurs on the second day the loss is not accounted for until the end of the second day, causing the cohort weight to decline on the third day ($e=1,d=3$). As the day-cohort weight changes eggs present in the segment are potentially exposed to dewatering, thus changing the weight. 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 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-l}, 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:

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

Cumulative losses are the sum of previous 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 cumulative *annual* PM is the sum of all losses in all segments for the entire egg-development period (*D)*:

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

The *rollup* PM is based on taking the sum 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:

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

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

Indicator Reliability

The PM reliability rating for redd dewatering is shown in Table 4.19. 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.

Version 2 (Now)

If directly-measured relationships can be found for spring-run Chinook, they will be implemented. This would raise the overall rating for this run-type to H.

Table 4.19. 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

Version 1 (Then)

The daily PM ranking, a horizontal R/Y/G bar shown on many Excel reports is not useful for this report and actually confuses the interpretation of behavior.

Version 2 (Now)

The example below shows the style for the Version 2 Excel Report for CS6. A vertical R/Y/G bar will show the annual rollup breakpoints for redd dewatering.

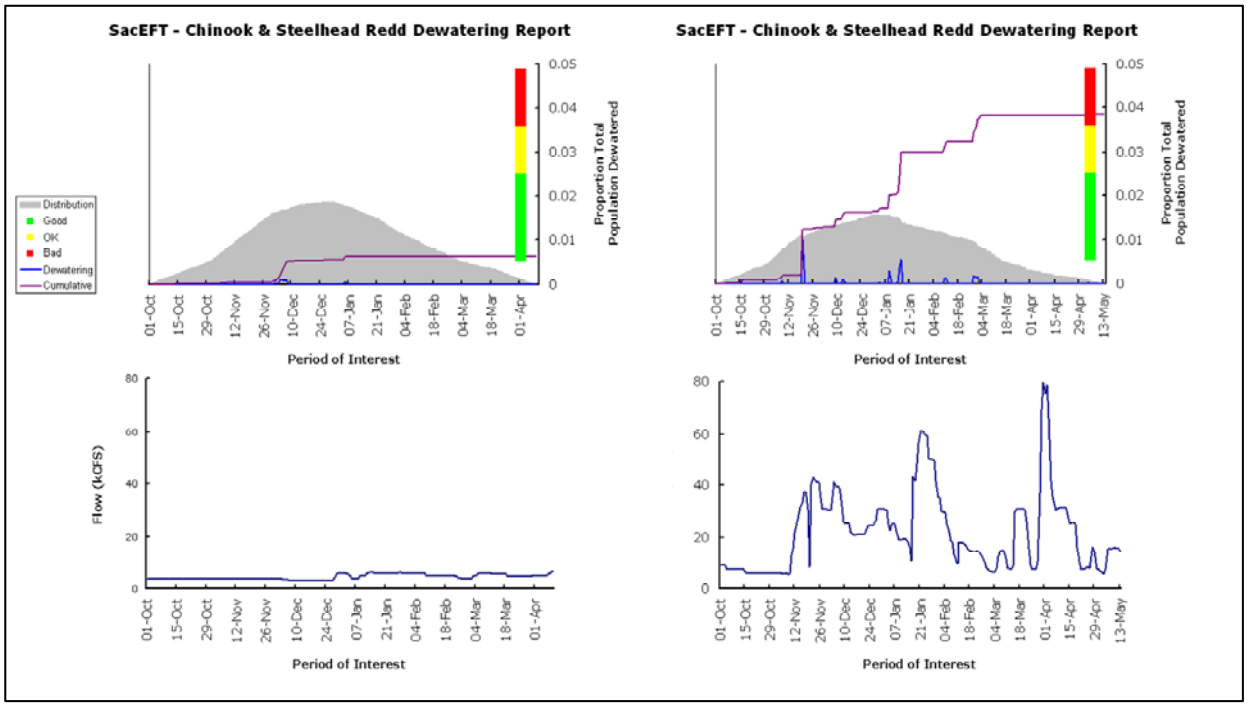

Figure 4-22. Detailed fall Chinook redd dewatering Excel reports for 1977 (Very Dry Year) and 1974 (Wet Year) are shown in the left and right panels.

Model Calibration

The calibration process described above produces the Indicator Rating boundaries shown in Table 4.20.

Table 4.20. CS6 – Redd dewatering indicator rating breakpoints. Units are population-proportion-weighted redd dewatering index for Daily resolution; cumulative for the Annual and Rollup scales.

	Resolution					
	Daily		Annual		Rollup	
	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor	Good-Fair	Fair-Poor
Winter-run Chinook	1.59662E-05	1.90994E-04	0.00822	0.03079	0.05	0.09
Spring-run Chinook	1.33643E-05	1.84567E-04	0.01657	0.04379	0.12	0.22
Fall-run Chinook	3.97552E-06	4.04227E-05	0.00493	0.01426	0.015	0.03
Late-fall-run Chinook	6.18416E-05	7.33250E-04	0.05069	0.07862	0.07	0.13
Steelhead	1.18102E-05	1.42790E-04	0.01689	0.04585	0.1	0.17

CS98 – Juvenile Weight Gain

This candidate PM is an alternative implementation of CS2 (Rearing WUA) Version 2 Option B, described therein as Version 2 Option C. As a new PM, this would hold residency period fixed, assume a typical feeding ration and compute weight gain as a function of temperature over the residency period. The advantage of computing weight gain over fixed time, compared to time to achieve a mature weight, is that the second approach is indeterminate, making the algorithm more problematic if weight gain fails to produce a mature weight within the annual framework of the model.

Indicator Reliability

The PM reliability rating for juvenile weight gain is shown in Table 4.22. The uncertainty in overall Priority is currently low, pending a review of the available literature.

Table 4.21. CS98 – Juvenile weight gain credibility assignments.

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

Excel Reports

The CS98 report would be modeled on the CS5 graph, with cumulative juvenile population and cumulative weight gain as the main graph, and temperature as a supplemental figure. We would probably provide the annual rollup PM for CS98, since most reviewers have found daily PMs to be confusing.

Decision

The processes involved in estimating juvenile maturation will be included in DeltaEFT Version 1 and will help to predict juvenile condition in Yolo Bypass. The functionality will not be added to SacEFT Version 2.

CS99 – Redd superimposition

Redd superimposition was discussed as a possible additional PM. Existing information about average redd area, coupled with assumptions or information about the statistical properties of superimposition, might be used to create a new Performance Measure that quantifies the risk of a spawning day-cohort being lost or reduced through superimposition. If redd superimposition is added, it would probably also result in a cascade of changes to other existing PMs. For example, Redd Dewatering (CS6) is already linked to Spawning WUA (CS1), and a good case could be made for adding the additional effect of redd superimposition on Redd Dewatering, Redd Scour (CS5) and other PMs.

While the PM has obvious merit, this approach introduces a significant departure from SacEFT design principle of basing PMs on habitat and generally avoiding the complexity of *population dynamics*. If this PM is to be developed, a key missing piece of information is the population number. Whether it is expressed as a reach sub-population or as the reach-proportion of the entire run-type population, this calculation would require the number of female spawners each year. Developing the PM will require the inclusion of the historical number of female spawners, their distribution among the reaches, and for each scenario, the future number of female spawners each Water Year. These data needs may be known for historical simulations, but become quite arbitrary when alternative development scenarios or climate change scenarios are applied.

Indicator rating

Table 4.22. CH99/ST99 – Redd superimposition indicator credibility assignments.

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

Decision

The level of uncertainty in past and future spawning conditions (see CS1 – Spawning WUA discussion)

makes redd superimposition a fairly unreliable PM. It will not be included in Version 2.

Green sturgeon

The salmonid conceptual model is shown in Figure 4-23. Readers are referred to ESSA Technologies (2005) for details on the development of this model and the decisions that led to its current structure.

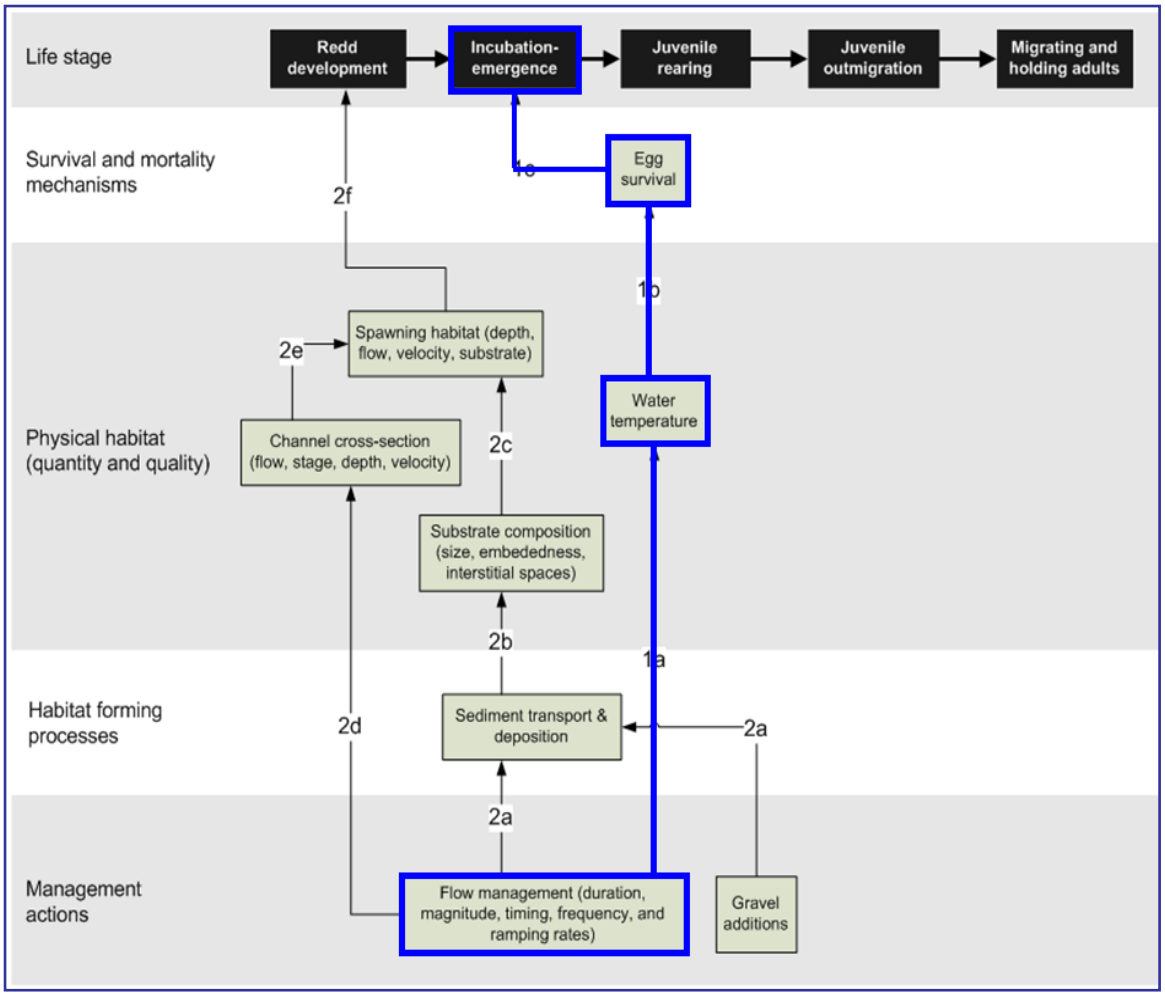

Figure 4-23. The green sturgeon conceptual model. Heavy lines show the processes and linkages that are currently implemented. See ESSA Technologies (2005) for additional context and detail on processes and linkages shown here.

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: 17^0C and 20^0C, 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 spawning day separately. The simplicity of the model stems from the lack of information about temperature-based mortality, referring instead to the categorical evaluation created by Cech et al. (2000, cited in (NMFS 2003)) 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.

Version 1 (Then)

The *daily* performance measure for each spawning day at each location is computed by tracking the day-cohort over the 14 day egg development period. The worst (highest) temperature experienced by the day-cohort is used to assign a of R/Y/G Indicator rating to the daily performance measure. Thus, only a single day above 20^0C is required to assign a day's spawners in a Red Indicator Rating.

Version 2 (Now)

The participants recommended that the Version 1 habitat scoring rule, which is based on the most common (modal) outcome, should be changed to one that approximates a temperature-mortality relationship with full survival below 17 °C and complete mortality above 20 °C. The relationship will be linear between these two temperatures. Daily cohort survival above 95% should be 'Good' for the year-cohort; 90-95% survival should be 'Yellow' and less than 90% should be 'Poor.'

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 combing 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.

We note that Sacramento River water temperatures in the yellow (fair) and red (poor) ranges are very uncommon during green sturgeon spawning and incubation.

Version 2 (Now)

At the model refinements workshop (ESSA 2008), the participants suggested adding an additional potential spawning site at Vina (RM218).

Indicator Reliability

The PM reliability rating for thermal egg mortality is shown in Table 4.23. The low ratings reflect the uncertain linkage between laboratory studies of egg maturation with field observations of larval development.

Table 4.23. 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

Version 1 (Then)

The daily PM ranking, a horizontal R/Y/G bar shown on many Excel reports is not useful for this report and actually confuses the interpretation of behavior.

Version 2 (Now)

The example below shows the style for the Version 2 Excel Report for CS6. A vertical R/Y/G bar will show the annual rollup breakpoints for redd dewatering.

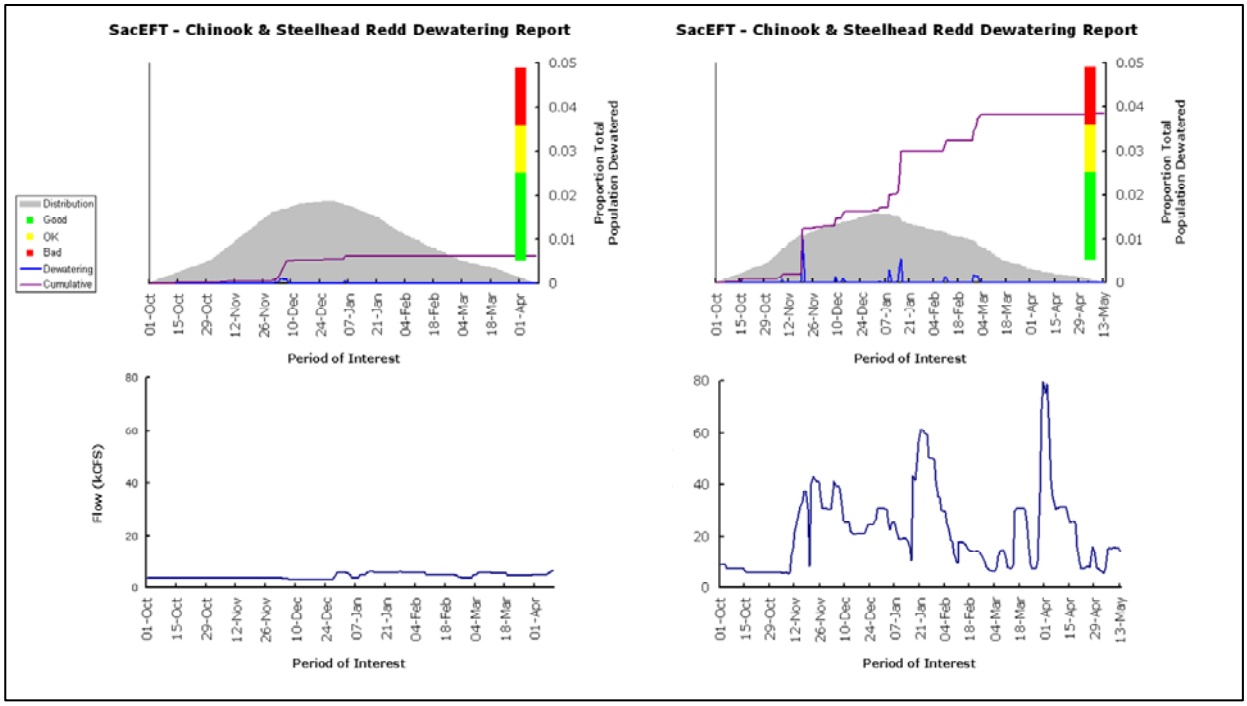

Figure 4-24. Detailed fall Chinook redd dewatering Excel reports for 1977 (Very Dry Year) and 1974 (Wet Year) are shown in the left and right panels.

4.3.2 Bank swallow

The bank swallow conceptual model is shown in Figure 4-25 . Readers are referred to ESSA Technologies (2005) for details on the development of this model and the decisions that led to its current structure.

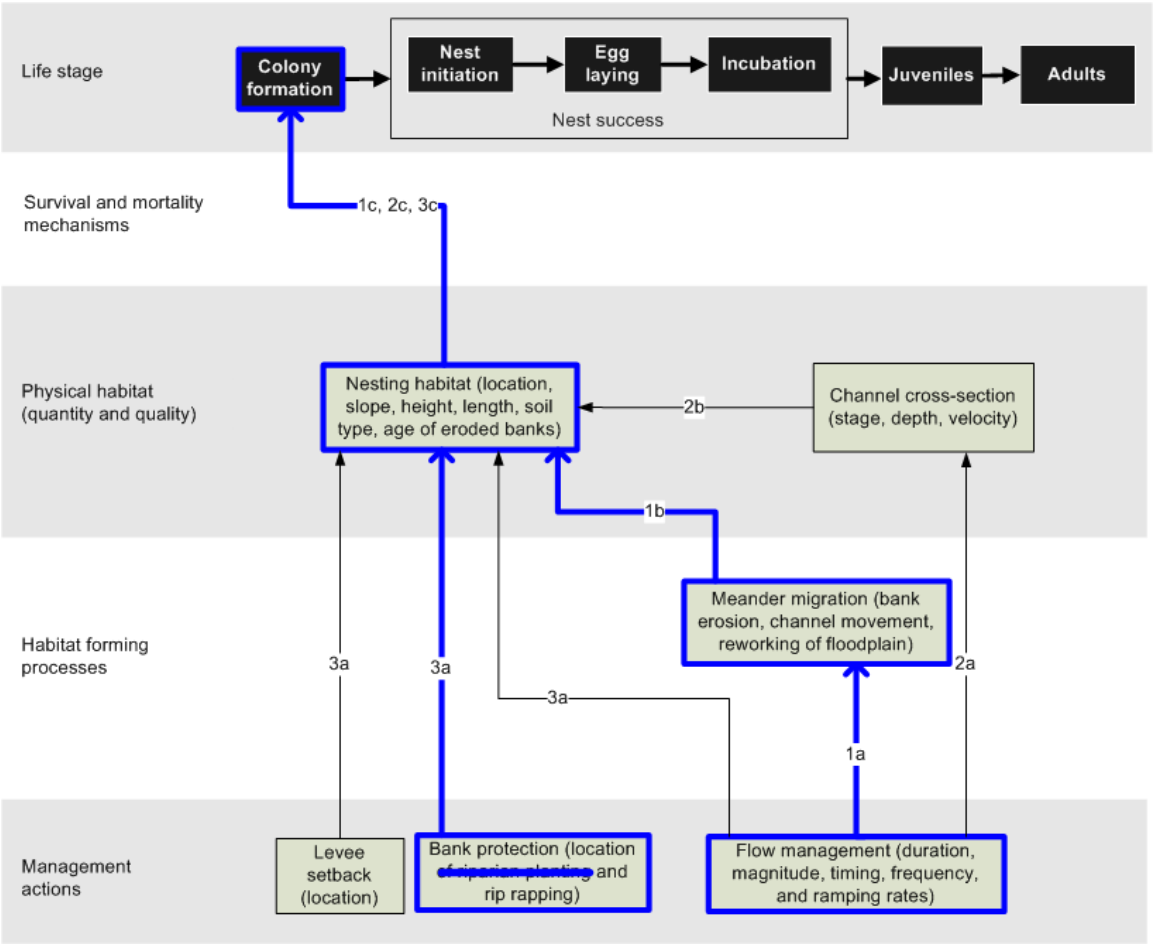

Figure 4-25 The bank swallow conceptual model. Blue heavy lines show the processes and linkages that are currently implemented.

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 1998, 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 SWS (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 Version 2, 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 – Length of Newly Eroded Bank

River banks used for nesting need to be regularly eroded by the river in order to create new nesting habitat. Consequently, areas that have not been reworked (i.e., eroded) to a depth of greater than or equal to 1m every few years become unsuitable and are abandoned because of the high densities of ectoparasites in existing burrows and a lack of suitable soil to build new burrows in the area (Stillwater Sciences 2007).

The meander migration model provides annual estimates of meander migration rate (W) and area of floodplain reworked (A) for each modeled bend (b)[1] in each of three river segments (l): ($L_{l,b}$) shown in Table 2.4.

The length of newly eroded bank (L_b) in each bend can be approximated by the *simple* geometrical approximation:

$$L_b = \frac{A}{W}$$

Version 1 (Then)

The area of floodplain reworked (A) in Version 1 of SacEFT does not account for depth of bank erosion (i.e., A = yellow shaded + grey shaded area in Figure 4-26), consequently, the 'length of newly eroded bank' (L_b) does not account for the depth of bank erosion.

Version 2 (Now)

Incorporating suggestions and information provided at the SacEFT refinements workshop (ESSA 2008), we account for the depth of bank erosion by defining floodplain reworked (A) as the area of river bank that has been eroded to a depth of and/or greater than 1m (yellow region in Figure 4-26). The grey region in Figure 4-26 has not been eroded to depth of 1m, therefore it is not included in floodplain reworked (A).

[1] There are up to 14 modelled bends in each river segment.

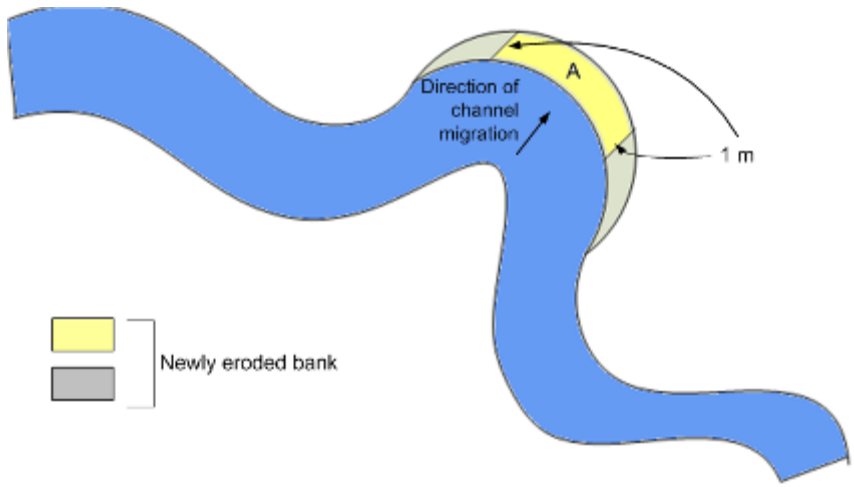

Figure 4-26 Bird's eye view of floodplain reworked (*A*) as output from the meander migration model is the total area of floodplain that has been eroded up to a depth of 1meter.

The length of each modeled bend (***b***) is then assigned a weighting (***w_b***) dependent on its length.

Version 1 (Then)

The weighting scheme in Version 1 is:

$$w_b = \begin{cases} 0 & when\ (L < 13m) \\ \dfrac{L-13}{7} & when\ (13m \le L < 20m) \\ 1 & when\ (L \ge 20m) \end{cases}$$

The small scale range (13 to 20m) is not well suited to the scale at which the Meander Migration model is parameterized (e.g., almost all river bends are longer than 500m; therefore, the weight (w_b) will almost always be 1.0). This disconnect in scale contributes to a lack of sensitivity in BASW1.

Version 2 (Now)

Studies of bank swallows specific to the Sacramento River show that bank length < 13m remain unused (i.e., habitat suitability = 0) and that habitat suitability increases linearly with bank length up to 40m, after which habitat suitability remains constant (i.e., habitat suitability = 1) (Garrison et al. 1987 in Stillwater Sciences 2007). In version 2, we update the weighting scheme for bends to reflect empirical evidence specific to the Sacramento River.

$$w_b = \begin{cases} 0 & when\ (L < 13m) \\ \dfrac{L-13}{7} & when\ (13m \le L < 40m) \\ 1 & when\ (L \ge 40m) \end{cases}$$

Even with a modified weighting scheme and an upper limit of 40m, Version 2 may exhibit a similar lack of sensitivity to that observed in Version 1, i.e., the scale range of 13 to 40m is still small relative to the scale at which the Meander Migration model is parameterized.

After bend weights have been determined, the total length of eroded bank for the river is calculated by summing the length of eroded bank for each bend multiplied by its respective weight for all river segments (***l***),

$$BASW1_l = \sum_{b=1}^{B} L_b w_b ,$$

The *annual* PM for BASW1 sums the length of eroded bank across all river bends and river segments.

$$BASW1 = \sum_{l=1}^{L} \sum_{b=1}^{B} L_b w_b \ .$$

BASW1 is undefined for specific locations.

Version 2 (Now) +

The desired frequency of 1m horizontal erosive events for habitat renewal is about once every 3 years (i.e., it does not need to occur annually). If the length of newly eroded bank (*BASW1)* is small after the depth of annual erosion is taken into consideration, it will be important to reflect in the model that burrows can be reused for up to 3 years without significant renewal taking place. In addition, the model will have to be capable of accounting for cumulative erosive events over multiple years. Based on discussions from the SacEFT refinements workshop (ESSA 2008), *the functional relationship for habitat suitability in response to depth of horizontal erosion is a linear decay function where newly eroded banks (i.e., horizontal erosion ≥ 1m) receives a habitat suitability index of 1. Habitat suitability declines linearly each year until year 3*, after which habitat suitability is zero for those bank areas that have not experienced

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). Further refinement to the terciles may be necessary as they show a very narrow range in variation, which contributes to the insensitivity of BASW1 in Version 1 (maybe Version 2).

To address the lack of sensitivity, the length scale has been increased from an upper limit of 20m to 40m. In Version 1, the discrepancy in spatial scale, coupled with the low year-over-year variability in length of newly eroded bank returned by the Meander Migration model, created a performance measure with extremely low contrast. By taking into account depth of horizontal bank erosion, coupled with the slightly larger range for bank length, we think that BASW1 will exhibit more sensitivity in Version 2.

Finally, recognizing that soil type is a critical factor in determining whether newly eroded banks are suitable for Bank swallow, SacEFT v.2.00 and Version 2 contain a database placeholder for the proportion of newly eroded banks that is suitable. If this data can be provided at the necessary (fine) resolution, it may be incorporated into the habitat suitability index.

Indicator Reliability

Table 4.24. BASW1 – Length of newly eroded bank - 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
BASW 1 - Length of Newly Eroded Bank	H	H	H	M	H

BASW1 receives a score of Medium for Feasibility because the performance measure only captures about half of the important characteristics with respect to nest habitat suitability. Data on soil types are not available, therefore BASW1 is likely to overestimate the extent of suitable nesting habitat because it

includes soils that are not the correct consistency for burrowing. This limitation of BASW1 decreases its power.

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 et al. 1997; Moffatt 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 20kCFS to 50kCFS will typically erode some banks, causing partial collapse. Flows above 50kCFS are more than likely to cause widespread erosion leading to widespread colony failure at many sites if breeding swallows are present (Stillwater Sciences 2007).

Version 1 (Then)

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 **March 15 to July 15** (Table 2.7) nesting period. Hazard is modeled using two flow breakpoints: 20 kCFS and 50 kCFS, to provided estimates of risk during flow excursions into zones of moderate and high flow, respectively.

Version 2 (Now)

Calculations for peak flow during the nesting period remain the same as described above in Version 1. The one minor modification to Version 2 reflects information gathered at the SacEFT refinements workshop (ESSA 2008). The period of interest for BASW2, i.e., the nesting period, is changed to **April 15 to July 31**.

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:

$$BASW2 = \begin{cases} 1 & when\ (Q < 20kCFS) \\ 1 - \left(\dfrac{Q-20}{30}\right) & when\ (20kCFS \le Q < 50kCFSm) \\ 0 & when\ (Q \ge 50kCFS) \end{cases}$$

The R/Y/G Indicator Ratings are based on a heuristic developed from the distribution of the BASW2 indicator based on a historical flow scenario across all river locations. Based on the flow thresholds, ***Q*** < 20kCFS are considered low risk and receives a score of 1, whereas ***Q*** ≥ 50kCFS are considered high risk and receive 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.

Daily suitability indices of BASW2 are then assigned based on a heuristic developed from the historical distribution of the BASW2 indicator across all river locations,

$$BASW2 \quad suitability \quad index = \begin{cases} green & when\ (BASW2 \ge 0.1) \\ yellow & when\ (BASW2 > 0.01) \\ red & when\ (BASW2 \le 0.01) \end{cases}$$

The annual PM for a given location is equal to the suitability index of BASW2 for the day with the highest flows, consequently, The *annual* PM for each location is undefined.

The rollup PM for BASW2 is based on a heuristic that aggregates the annual PM across all three locations. For example, the rollup PM is assigned a good rating if 2 or more locations have a good indicator rating for the year. Lower ratings are assigned as ratings across locations become worse.

Version 2 (Now)

River locations used as index sites for BASW2 are not representative of all bank swallow nesting sites. During the SacEFT refinements workshop, we were informed that the top ¼ of the bank is where approximately half of the nest burrows are located. Hence, the flow that is observed to reach this point should be the natural flow threshold for high risk (red). Opportunistic observations at Hamilton City gauge suggest that all nests in the area that are ≤ 3m above a stage of 130.19 feet (flow of 7250cfs)[1] would be inundated at 50,000cfs which has a stage of approximately 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 50,000cfs. 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, he current threshold specifications of the indicator will remain the same in Version 2.

Indicator Reliability

Table 4.25. 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
BASW 2 – Peak flow during nesting period	H	M	M	M	H

With respect to understanding and rigour, BASW2 receives a score of Medium because 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.

Excel reports

Version 1 (Then)

The daily PM ranking, a horizontal R/Y/G bar shown on many Excel reports, is not useful for this report and actually confuses the interpretation of behavior.

Version 2 (Now)

The Version 2 Excel report implements (Figure 4-27) a vertical bar showing the annual rollup for the PM, which is more consistent with the cumulative PM plotted on the figure.

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

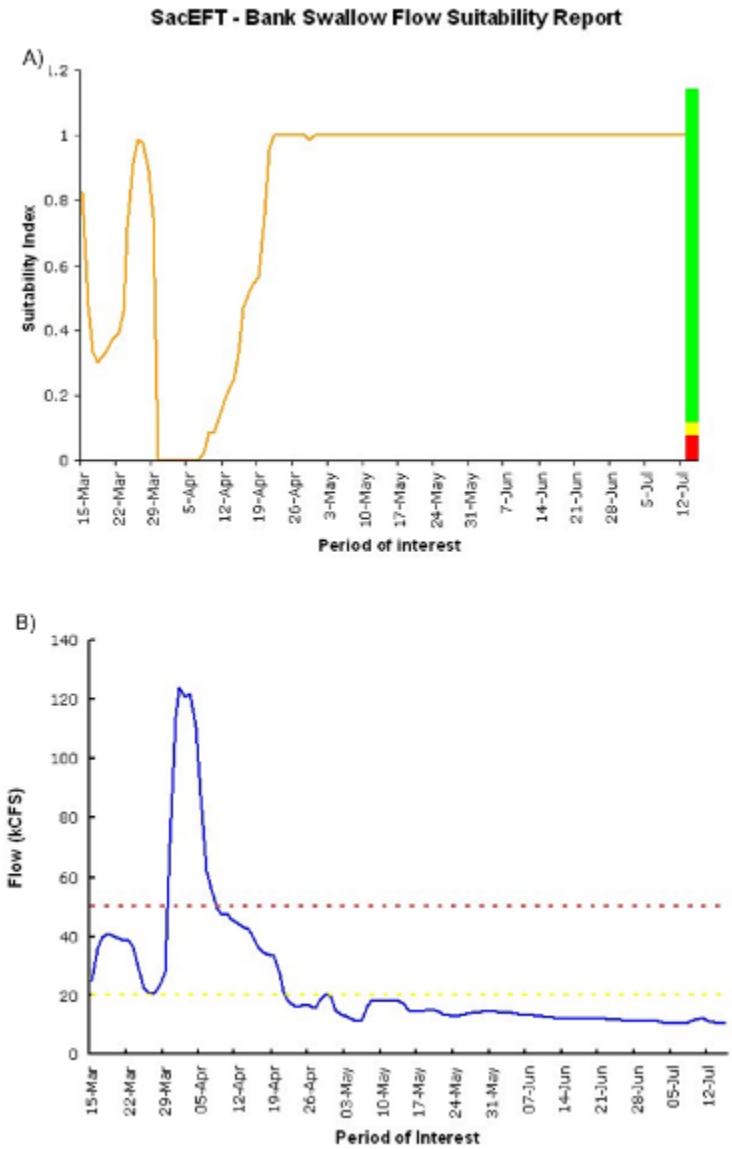

Figure 4-27 A) Daily roll up for BSW2 during the nesting period (Mar 15 to Jul 15). A suitability index score ≥ 0.1 is ranked as **good**. A suitability score < 0.1, but > 0.01 is ranked as **OK**. A suitability score ≤ 0.01 is ranked as **bad**. B) Maximum daily flow during the nesting period. Flows ≥ 50kCFS (red dashed line) are automatically assigned a suitability index of 0 (**bad**). Flows < 20kCFS are automatically assigned a suitability index of 1 (**good**).

4.3.3 Fremont cottonwood

The Fremont cottonwood conceptual model is shown in Figure 4-28 . Readers are referred to ESSA (2007) or details on the development of this model and the decisions that led to its current structure.

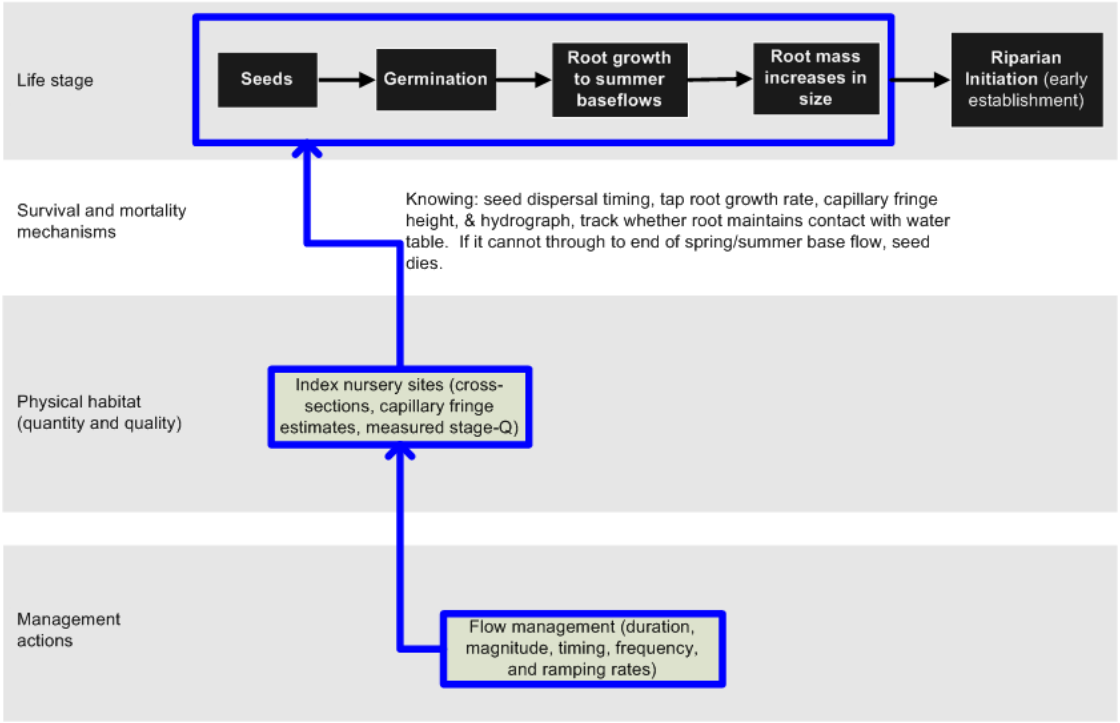

Figure 4-28 The Fremont cottonwood conceptual model. Blue heavy lines show the processes and linkages that are currently implemented.

Version 1 of SacEFT includes one performance measure (PM) that describes changes in the physical habitat available for Fremont cottonwood initiation success. In version 2, we add 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 three locations on 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 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 three locations (see Table 2.4) on the Sacramento River.

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 CALSIM II
	Stage-discharge relations	Roberts et al. 2002; Roberts 2003

Focal species performance measure	Required input	Data source
	Channel cross-sections	Roberts et al. 2002; Roberts 2003
	Capillary fringe height = 30cm	Roberts et al. 2002; Roberts 2003
	Seed dispersal timing (start and end)	FC experts
	Seedling tap root growth rate = 29 mm/d	Roberts et al. 2002; Roberts 2003
	Preference relationship for PM	FC experts
	Other assumptions: Standard recruitment box model Sampled cross section nodes, if non-uniform, are representative of the overall cross-sectional characteristics. ▪ Drought tolerance of 2 days (roots can be out of contact with water table for 2 days without being declared dead) ▪ Cottonwood seedlings whose roots reach a depth of 45cm 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, pers. comm..). Note: all these assumptions are fully configurable in the SacEFT database.	

Version 1 (Then)

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 2.5). Seeds that land on non-inundated ground 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., 30cm), 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 29 mm/day). Cottonwood seedlings whose roots reach a depth of 45cm 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 4-29). 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.

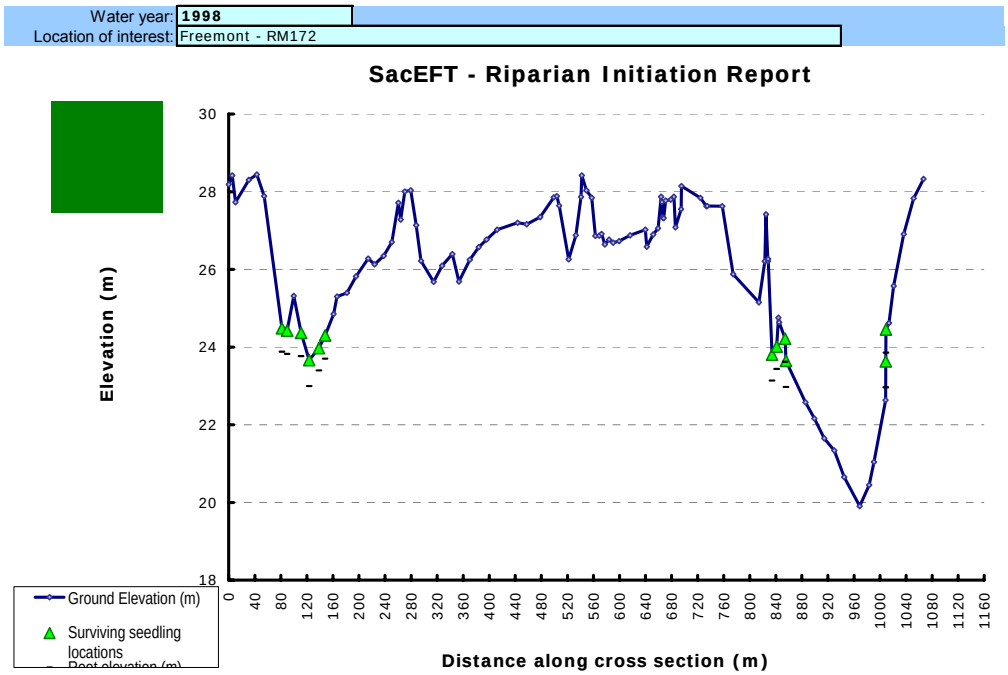

Figure 4-29: SacEFT Fremont Cottonwood seedling initiation success: 1998 (good year).

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 8500cfs elevation + 3ft), where surviving seedlings were found. At present, with the existing three cross-sections, the value 7 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 record. Likewise, *ARollGoodCountAssignBad* represents the equivalent information, defining the lower bound on successfully initiating nodes before the color red/bad is assigned (node count ≤ 3).

These breakpoints are initial values for model demonstration purposes, and involve subjective judgment made by non-focal species experts. At present, years revealed by SacEFT as having the potential for strong riparian initiation success are: 1941, 1942, 1952, 1958, 1967, 1969, 1971, 1983, 1998 and 2003 (historical data in SacEFT does not extend beyond 2005).

Version 2 (Now)

The basic structure of FC1 will remain unchanged in version 2. Refinements to the performance measure will focus on increasing the accuracy of representativeness of **cross section profiles, stage-discharge relationships, and default parameter values**. The degree to which these refinements are possible depends on the input from participants at the SacEFT refinements workshop. We will contact Adam Henderson, DWR for updated cottonwood data for existing point bar sites (DWR stopped monitoring in 2006). TNC stopped in 2001. For existing sites in SacEFT, obtain updated stage-Q relationships from Tara Morgan (part of DWR work, sites taken over from TNC). During the October 2008 workshop we were told that a memorandum was nearly ready (Adam H; data by Tara Morgan). John Stella's work – off-channel study, has more stage-Q and cross-section data in it, explore. Any modeling that allows cross sections to be cut at high-resolution (i.e., better than 1/2 foot resolution) can be considered, if paired stage-Q relations are available. Tools/cross-section surveys are needed to act on the workshop recommendation to include more representative index locations; that is, to include sites that do not simply represent classic point bars (like RM 172, 183, 192).

Should we receive no additional information on parameter values, model representativeness of good recruitment years, cross-section profiles, and stage discharge relationships, FC1 will remain unchanged in Version 2. As previously mentioned, all the assumptions for default parameter values are configurable in the SacEFT database and do not require any structural changes to the performance measure.

Indicator Reliability

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	M - L	H

FC1 scores High with respect to Rigor because the model is based on field observation data derived for the Sacramento River (though admittedly only at 3 index locations). 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. Feasibility is scored as Medium - Low because although information is available for the 3 index locations, the representativeness of these index locations is debatable. That being said information for additional index sites is not readily available, therefore it is not possible increase the number of index sites.

NEW - Riparian scour (FC2)

Version 1 (Then)

This performance measure was not included in SacEFT version 1.

Version 2 (Now)

Based on recommendations from the SacEFT refinements workshop, a second performance measure will be 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 two years, 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 or t+2 with a scouring flow (Figure 4-30).

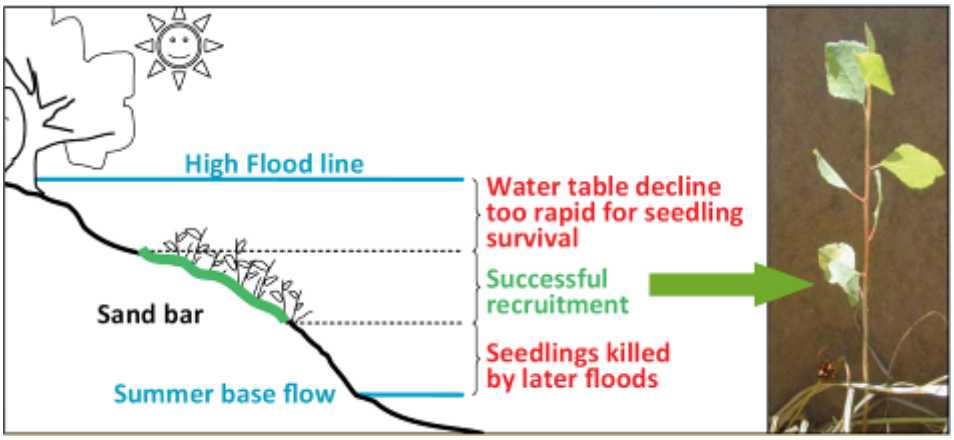

Figure 4-30. Generalized pattern of successful seedling initiation observed for cottonwoods along alluvial rivers. Seedlings that germinate too high on the bank cannot grow roots fast enough to keep up with the receding water table and soil moisture level during the hot summer months, while seedlings 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.

Initial scour thresholds for assignment of R/Y/G proposed by riparian subgroup participants were identified as follows. A flow of ≥ 90,000cfs would *ensure* 100% scour mortality of riparian seedlings ≤ 2 years (i.e., = red classification), wiping out recruitment success of the previous year. That is, flows of ≥ 90,000cfs are expected to generate gravel mobilization down to 2ft or more (based on scour chain observations). Further discussions are required to identify appropriate thresholds for "moderate" seedling scour in the target initiation zone is required (i.e., the flow between 0 and 90,000 cfs that produces a yellow classification).

Indicator Reliability

Table 4.28. 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	H	M	H	M - L	H

FC2 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. FC2 receives a score of Medium to Low for Feasibility for the same reason given for FC1.

4.3.4 Western pond turtle (move to proxy indicators)

The Western pond turtle conceptual model is shown in Figure 4-31.

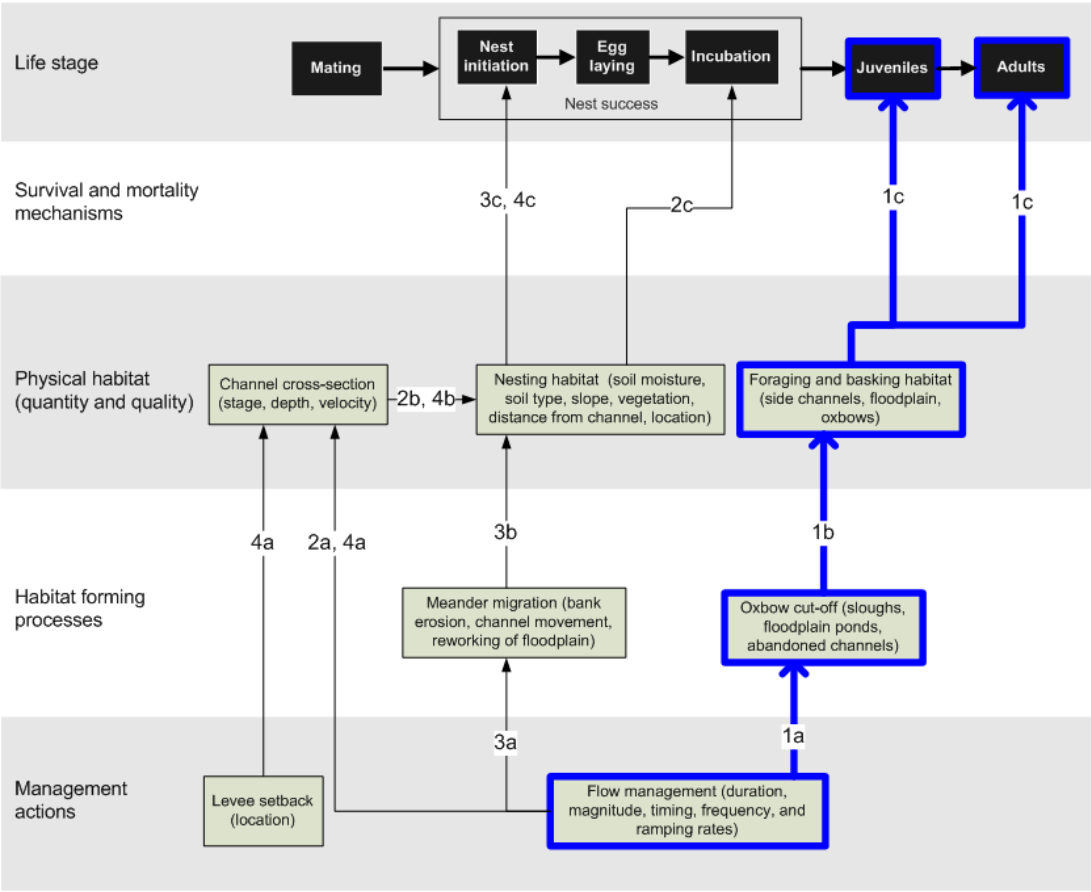

Figure 4-31 The Western Pond Turtle conceptual model. Blue heavy lines show the processes and linkages that we attempted to implement.

In the case of creation of newly orphaned channels (WPT1), the meander migration model predicted only two events. These occurred in WY 1939 and 1941 only,[1] reshaping Bend 5 of the most-downstream segment (see Table 2.4) and adding 2070 m^2 and 425 m^2 of new orphaned channel habitat in the process. These events occurred under all three flow regimes (historical, NODOS and Shasta) when revetment (rip rap removal) was simulated, and also under the NODOS flow regime when no revetment (no rip rap removal) was simulated.

The fact that the major cutoff event occurred during the first simulation year and across all three flow regimes strongly suggests that the bend morphology became unstable once rip-rap was removed. However, once this event took place, the newly aligned bend was subsequently insensitive to variations over the following half century of variation or across variations caused by the water management regime.

Taken together these results show that simulated rip rap removal can cause channel realignment in cases where the bed morphology has reached a point of instability, but that such events are infrequent under the current channel morphology even when rip-rap is removed. This is not a reflection of lack of sensitivity of

[1] The smaller 1941 cutoff event can be seen with the SacEFT Meander Visualization tool by selecting View > Meander Visualization; then selecting any revetment scenario at segment "MM Segment 1 – Butte City"

the WPT1 indicator itself per se, but reflects the overall lack of contrast in meander migration results. **The lack of contrast in meander migration results did not allow us to calibrate and implement WPT in SacEFT version 1. Similarly, WPT1 will not be included in SacEFT version 2.**

Instead, feedback from the SacEFT v.1 refinements workshop recommended that we focus on surrogates or proxy habitat indicators that would enhance off-channel suitability for WPT relative to non-native and invasive species with which they compete. For example, keeping water temperatures low and increasing the amount of large woody debris in the main channel would favor WPT over non-native turtle species (See sections 4.4.2, 4.4.3, and 4.4.4. for more detail).

4.4 SacEFT Version 2: New - High Priority Candidate Indicators

Short timelines following re-start of the EFT grant (combined with a compressed schedule) have prevented us from completing consultations with domain experts and finalizing the four new candidate habitat indicators below for SacEFT. These steps will be completed concurrent with model development and documented in the final version of the design.

4.4.1 Riparian floodplain age diversity

The riparian subgroup participants recommended use of riparian **floodplain age diversity, FAD1** (heterogeneity) as a useful proxy variable for a variety of focal species habitat benefits. This would be achieved by leveraging the work of Fremier (2007), in combination with floodplain age calculations derived from the Meander Migration model (Figure 4-32).

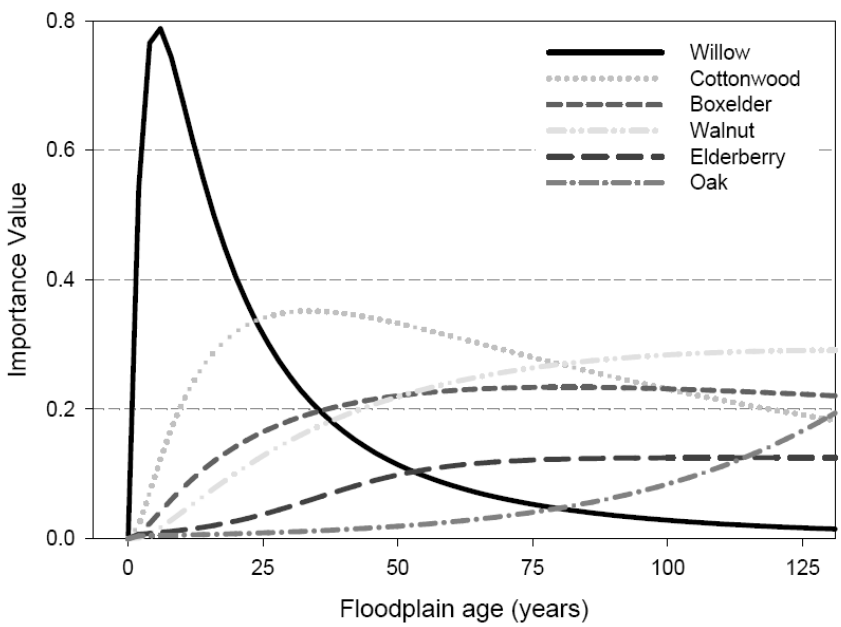

Figure 4-32. Importance values by floodplain age class for six woody riparian species, i.e., the relative contribution of each species over the floodplain age gradient. These values sum to 1.0 over all floodplain age classes. *Source*: Fremier (2007), Figure 3.6.

On the Sacramento River, Fremier (2007) suggested that in the presence of channel constraints such as rip rap most adversely affects early to mid-seral stages, namely cottonwood, due to reduced channel migration rates (planning horizons ≤ 130 years).

Implementing this indicator (**FAD1**) in SacEFT Version 2 would be relatively straightforward, ***assuming the Meander Migration model is capable of accurately modeling the distribution of floodplain age throughout the study area (summing up from floodplain ages at the bend resolution).*** It is assumed that this indicator would only be relevant for simulations of at least 50 years, but this is not immediately clear. One of the biggest formulation challenges would be ensuring that the annual channel migration "slices" derived from the Meander Migration model were not artificially small and arbitrarily categorized or treated as distinct floodplain habitats. Artificial mathematical assignments of floodplain age due to such spatial artifacts from the Meander Migration model might lead to a highly skewed exponential-type frequency distribution (either left- or right-skewed). Perhaps aggregating MM "slices" in 5 or 10yr bins would produce ecologically meaningful floodplain sizes.

A number of details need to be addressed by riparian subgroup members to determine the feasibility of implementing FAD1 in SacEFT Version 2:

1. ***Issue:*** Provide a description of how/whether the Meander Migration model would/could determine the distribution of floodplain ages in the study area, and whether these modeled floodplain surfaces are indeed the appropriate spatial habitat units of concern.
   Action: Eric Larsen to generate a 1-2 page recommendation and statement of feasibility; plus other riparian subgroup participants comment on their understanding of the suitability of the Meander Migration model for this purpose. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824)
   ***Outcome*:** still to determine/in progress
2. ***Issue*:** What frequency distribution of floodplain ages would be poor, fair and good? Is a uniform distribution the most ideal? Exponential to the left? Rising exponential to the right? Normal?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) are to provide us with their expert opinion. Without an answer to this question, the practical utility of the FAD1 indicator is doubtful. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824). Presumably we would want a distribution similar to what was there historically. Riparian subgroup participants are asked to provide any references on this for the Sacramento or other relatively similar alluvial rivers.
   ***Outcome*:** still to determine/in progress
3. ***Issue*:** What would be the minimum model simulation duration needed for this indicator to be relevant? SacEFT runs do not extend beyond 50–60 years.
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) are to provide us with their expert opinion. Without an answer to this question, the practical utility of the FAD1 indicator is doubtful. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824)
   ***Outcome*:** still to determine/in progress
4. ***Issue*:** Using an *a priori* thought experiment, can we really expect meaningful *contrast* in this performance indicator across SacEFT flow scenarios?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) are to provide us with their expert opinion. If the answer to this question is "no", then this performance measure would not add any discriminatory power to make trade-off decisions in SacEFT, and the FAD1 indicator should not be pursued. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824)
   ***Outcome*:** still to determine/in progress

Indicator Reliability

Table 4.29. FAD1 – Floodplain age diversity indicator credibility assignment following the workshop.

	Category				
	I	U	R	F	P
Floodplain age diversity		M	M	M/H	M

Technical feasibility, risks & priority

The technical feasibility, associated risk, and level of priority for this new indicator are summarized in Table 4.30.

Table 4.30. Summary of performance measure issues, estimated amount of effort required to implement the modification in the SacEFT software, modification feasibility, level of risk, and modification priority.

PM	Issue	Effort	Feasibility	Priority	Risk / Potential barriers
FAD1	#1 – MM model can/cannot generate meaningful histograms of floodplain age	Moderate	Moderate-High	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether MM modeled floodplain surfaces would be the appropriate habitat units of concern.
FAD1	#2 – Interpretation and communication of results, what floodplain age distribution is 'desired' from a management standpoint?		As above		No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether riparian ecologists can state what type of floodplain age distribution is preferred (poor, fair and good). If they cannot, there is no practical utility to the FAD1 indicator.
FAD1	#3 – Min. model simulation needed for indicator to be relevant		As above		No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether SacEFT runs (~ 50 – 60 years) are sufficiently long to incorporate this indicator. If 50-60 year runs are too short, there is no practical utility to the FAD1 indicator.
FAD1	#4 – Expected contrast given Shasta/NODOS type flow scenarios		As above		No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether MM floodplain frequency distributions for alternative 50-60 year runs would contain any meaningful contrast. If the answer is no, then there is likely no practical utility to the FAD1 indicator.

4.4.2 Off-channel / floodplain inundation patterns

Off-channel and floodplain inundation (OFI1) was a surrogate indicator recommended by the riparian subgroup to capture the geomorphic processes necessary for habitat creation for a number of aquatic and riparian focal species. Three types of flows were discussed in relation to this indicator:

- *side-channel connection flows* (12,000 CFS);
- *overbank flows* (>90,000 CFS); and
- *scour and maintenance flows* (>>100,000 CFS).

Allowing for connection flows would maintain floodplain connectivity and provide cooler water to off-channel habitat which would benefit Western Pond Turtle and juvenile fish. Overbank flows would allow the important geomorphic process of floodplain deposition (creates nesting habitat for both Western Pond Turtle and bank swallow in the future) and oxbow formation. In addition, overbank flow would release

large doses of nutrients for fish. Last, scour and maintenance flows would provide flushing benefits to the channel by reducing certain types of invasive species (see Section 4.4.4 for more details). In addition, scour and maintenance flows would flush fine sediments out of the channel and provide gravel transport.

Implementing this indicator (**OFI1**) in SacEFT Version 2 would be relatively straightforward; however a number of details need to be addressed by riparian subgroup members to ensure its usefulness (***all in progress***):

1. ***Issue:*** Provide confirmation of the flow **magnitude** for each of the flow types: 1) connection flows (12,000 CFS); overbank flows (>90,000 CFS); and scour and maintenance flows (>>100,000 CFS). In particular, what does ">>100,000 CFS" mean, what is the appropriate flow threshold? 100,000 CFS? 150,000 CFS?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. Without an answer to this question, the practical utility of the OFI1 indicator is doubtful. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996)
2. ***Issue*:** What frequency is desirable for each flow type to characterize whether a multi-decadal flow regime would be poor, fair and good? We assume the "more" maintenance and scour flows over the course of a 50+ yr simulation, the better. How often is it important to have connection flows? Further clarity is needed from the riparian subgroup.
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. Without an answer to this question, it will not be possible to rate the significance of the overall multi-decadal counts for this indicator. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996)
3. ***Issue*:** What is the desired timing for each flow type so that focal species receive the most benefit/least harm? What are the trade offs?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996)
4. ***Issue*:** From an *a priori* thought exercise, can we expect meaningful contrast in this performance indicator across flow scenarios (i.e., under some flow scenarios will it not be possible to achieve the desired flows (with respect to magnitude and frequency)?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. If the answer to this question is "no", then this performance measure would not add any discriminatory power to make trade-off decisions in SacEFT, and the OFI1 indicator should not be pursued. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996).

Indicator Reliability

Table 4.31. OFI– Off-channel floodplain inundation patterns credibility assignment.

	Category				
	I	U	R	F	P
Off-channel floodplain inundation pattern		L/M	M	L/M?	L/M

Technical feasibility, risks & priorities

The technical feasibility, associated risk, and level of priority for the indicator OFI1 are summarized in Table 4.36.

Table 4.32 Summary of new performance issues, amount of effort required to implement the modification in the SacEFT software, modification feasibility, level of risk, and modification priority. Indicator issues and required modifications (i.e., actions).

PM	Issue	Effort	Feasibility	Priority	Risk / potential barriers
OFI1	#1 - Flow magnitude confirmation	Low	High	High	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether flow information is available for each flow type
OFI1	#2 - Interpretation and communication of results, what frequency is desirable for each flow type to characterize whether a multi-decadal flow regime is good, fair or poor?	Low	Moderate	High	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether riparian ecologists can state what type of flow events (duration, magnitude, and frequency) are preferred (poor, fair and good). If they cannot, there is likely no practical utility to the OFI1 indicator.
OFI1	#3 - What is the desired timing for each flow type to maximize benefits to focal species	Low	High	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether focal species ecologist can provide optimal flow timing information.
OFI1	#4 - Expected contrast given Shasta/NODOS type flow scenarios	Low	High	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether flow events (hydrographs) under different scenarios would have sufficient contrast. If the answer is no, then there is no practical utility to the OFIP1 indicator.

4.4.3 Large woody debris recruitment to mainstem Sacramento River

Another suggested habitat indicator from the riparian subgroup was **large woody debris recruitment** (**LWD1**) to the main channel of the Sacramento River. This suggestion came up during the discussion of Western Pond Turtle (WPT) improvements, where Don Ashton recommended that the main channel not be ruled out as suitable habitat for WPT. The suggestion was to attempt to make the main channel more hospitable to WPT, and indeed, LWD is well known to provide habitat complexity and cover beneficial to salmonids.

Implementing this indicator (**LWD1**) in SacEFT Version 2 assumes that Meander Migration model could be configured to calculate **the "area re-worked that is in 'old' forest".** Eric Larsen suggested he may even be able to give an actual "count" of tree stems dropping into the mainstem Sacramento River, or, provide the number of hectares of forests eroded into main channel. Details to resolve include defining what is "old" (e.g., AFRP says 40-70yrs is mature (10cm diameter or greater is considered minimum for LWD), whether orchards would also be included (e.g., walnut trees). The most important assumption however is whether it would be reasonable to use a "static forest" assumption during SacEFT simulations, e.g., start form one static vegetation cover map at the start of the model simulation and assume "static forest" thereafter in MM modelling? Hence, there are several details that need to be addressed by riparian subgroup members to determine the feasibility of implementing **LWD1** in SacEFT Version 2:

1. ***Issue:*** Provide a description of how/whether the Meander Migration model would/could determine the area re-worked that is in 'old' forest in the study area, and whether the performance measure should be the number of trunks recruited or the number of hectares of forests eroded into the main channel.
   Action: Eric Larsen to generate a 1-2 page recommendation and statement of feasibility[1]; plus other riparian subgroup participants comment on their understanding of the suitability of the Meander Migration model for this purpose. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824);

[1] E.g., Include details such as whether it is reasonable to use 2007 veg. mapping and assume a "static forest" from the start of the MM/SacEFT simulations or not.

2. ***Issue*:** What # of trunks or area of old forests eroded into the main channel over 50-60 years would be poor, fair and good?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. Without an answer to this question, the practical utility of the LWD1 indicator is doubtful. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824);
3. ***Issue*:** Using an *a priori* thought experiment, can we expect meaningful *contrast* in this performance indicator across SacEFT flow scenarios?
   ***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. If the answer to this question is "no", then this performance measure would not add any discriminatory power to make trade-off decisions in SacEFT, and the LWD1 indicator should not be pursued. Send responses to Clint Alexander at ESSA (calexander@essa.com; 250.860.3824).

Indicator Reliability

Were it implemented in the manner suggested above, LWD1 would be assigned the reliability shown in Table 4.34. This is a semi-quantitative proxy performance indicator reliant on the Meander Migration model.

Table 4.33. Credibility assignment for LWD1– Large woody debris recruitment.

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

Technical feasibility, risks & priority

The technical feasibility, associated risk, and level of priority for this new indicator are summarized in Table 4.34.

Table 4.34. Summary of performance measure issues, estimated amount of effort required to implement the modification in the SacEFT software, modification feasibility, level of risk, and modification priority.

PM	Issue	Effort	Feasibility	Priority	Risk / Potential barriers
LWD1	#1 – MM model can/cannot generate area re-worked that is in 'old' forest	Moderate-High	High	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether MM modeled areas re-worked in old forests captured the habitat units of concern.
LWD1	#2 – Interpretation and communication of results, what amount of old forest habitat recruited is 'desired' from a management standpoint?	As above			No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether riparian ecologists can state what amount of LWD recruitment (hectares or # trunks) is preferred (poor, fair and good). If they cannot, there may be no practical utility to the LWD1 indicator.
LWD1	#3 – Expected contrast given Shasta/NODOS type flow scenarios	As above			No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether MM derived hectares (or # trunks) recruited to the mainstem would contain any meaningful contrast. If the answer is no, then there may be no practical utility to the LWD1 indicator.

4.4.4 Invasive species deterrence: water primrose and large mouth bass

Riparian subgroup participants recommended using invasive species deterrence flows **(ISDF1)** as a surrogate indicator for improving target focal species habitats (e.g., **like Western Pond Turtles**) and placing at a competitive disadvantage ("deterring"), invasive species. Hence, the flow targets used to deter invasive species would in some cases also favor focal species. Two invasive species highlighted by the riparian subgroup as being most undesirable are **large mouth bass** (*Micropterus salmoides*) and **water-primrose** (*Ludwigia hexapetala*) (Figure 4-33).

Figure 4-33 Photograph (October 9th 2008) of a slough infested by *Ludwigia hexapetala*, commonly known as water-primrose. Slough is located near Phelan Island Wildlife refuge – RM 190-192.

On the Sacramento River, *Ludwigia* is problematic because it forms dense mats in waterways, reaching above and below the water surface. This dense growth impedes water movement, blocks the growth of native plants, and reduces available habitat for water birds and fish. The riparian subgroup suggested that large flushing flows would improve upstream habitat and would impede the spread of *Ludwigia* further upstream. Flood flows greater than 100,000 cfs (to 140,000 cfs) were believed to be sufficient to push large mats of *Ludwigia* downstream and out of side channels and sloughs.

Large mouth bass is also problematic on the Sacramento River because it out competes native fish and preys on juvenile focal fish species, as well as juvenile Western Pond Turtles. The riparian subgroup suggested that flows large enough to get into large mouth bass habitat off-channel habitat would deliver cold water that could inhibit spawning if delivery timing and duration are correct.

Implementing components of this indicator (**ISDF1**) in SacEFT Version 2 would be relatively straightforward, *assuming* that all the information necessary for determining the required flow magnitude and duration to achieve the above stated invasive deterrent actions can be clearly stated. Details that need to be addressed by riparian subgroup members (***all in progress***) to determine the feasibility of implementing ISDF1 in SacEFT Version 2 are:

1. ***Issue:*** Largemouth bass have an optimum growth rate at temperature of 25-27 ºC (Trebitz 1991). The temperature range that largemouth bass are reported to spawn at is 12 - 25 ºC, however higher temperatures are preferable (Rogers et al. 2006). Nesting success is reduced if temperatures drop below 15.5 ºC during incubation because this temperature generally cause males to leave the nest leaving it unprotected against predators (Davis and Lock 1997). Spawning can take place over a period of several weeks or longer, depending on water temperatures. Largemouth bass have been reported to spawn in all months except for September and October (Simon and Wallus 2008). In California, spawning typically occurs in spring (mid-March to late

May) when water temperatures become favorable for spawning (Simon and Wallus 2008). **Low temperatures during largemouth bass spawning period will inhibit successful spawning (≤10ºC).** Providing sufficient flows to maintain these low temperatures at the appropriate time of year may shift the competitive advantage to native target species. The length of time that these flows should be maintained is likely to be dependent on the length of the spawning season, i.e., the time period during which water temperatures are favorable in the absence of deterrent flows.
***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. A complication with the temperature issue for bass spawning is that temperatures in off-channel habitats may be quite a bit warmer than in the main channel due to differences in residence time of the water. And the temps may also be highly variable from one off-channel to the next due to differences in connection with the river. In SacEFT Version 2 we will not have this resolution of water temperature data. We may be able to apply a fixed temperature increase based on off-channel habitat study data. Without an answer to these questions it will not be possible to set thresholds and parameterize the indicator. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996);

2. ***Issue:*** Provide confirmation of the flow **magnitude** and **duration** required to push *Ludwigia* mats downstream (i.e., how many days at >> 100,000 CFS).
***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. Without an answer to this question, the practical utility of the ISDF1 indicator is doubtful. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996);

3. ***Issue*:** What multi-decadal frequency of deterrence flows would be poor, fair and good?
***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. How quickly does *Ludwigia* recolonize? Could this be revealed by looking at aerial photos after floods? *Ludwigia* has been mapped from air photos by the Geographical Info Center at CSUC (Greg Golet, pers. Comm.). Without an answer to this question, it will not be possible to assess the multi-year significance of different counts of ISDF1 flows. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996);

4. ***Issue*:** From an *a priori* thought exercise, can we expect meaningful contrast in this performance indicator across flow scenarios?
***Action*:** Riparian subgroup participants (and any other reviewers asked to consider this question) provide us with their expert opinion. If the answer to this question is "no", then this performance measure would not add any discriminatory power to make trade-off decisions in SacEFT, and the FAD1 indicator should not be pursued. Send responses to Katherine Wieckowski at ESSA (kwieckowski@essa.com, 604 733 2996).

Indicator Reliability

Were it implemented in the manner suggested above, IDFS1 would be assigned the reliability shown in Table 4.35. This indicator is largely based on opportunistic observations with respect to the *Ludwigia* and on laboratory and field observations from other locales with respect to large mouth bass. Expert judgment is involved.

Table 4.35. Credibility assignment for IDFS1 – Invasive species deterrence flows.

	Category				
	I	U	R	F	P
IDFS1 – Invasive species deterrence flows		M	M	M	M

Technical feasibility, risks & priorities

The technical feasibility, associated risk, and level of priority for the indicator ISDF1 are summarized in Table 4.36.

Table 4.36 Summary of new performance issues, amount of effort required to implement the modification in the SacEFT software, modification feasibility, level of risk, and modification priority. Indicator issues and required modifications (i.e., actions).

PM	Issue	Effort	Feasibility	Priority	Risk / Potential barriers
ISDF1	#1 - Temperature and length of exposure to inhibit LMB spawning	Moderate	Moderate	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether the information on required temperature for spawning can be can be used to determine the flow required to inhibit spawning (i.e., provide sufficient flow to keep water temperature low)..
ISDF1	#2 - Flow magnitude confirmation	Low	High	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether flow information is available. Input information (on temperature and duration of exposure) is needed to determine required flow magnitude for largemouth bass. Field observations of Ludwigia response to large flow events are necessary to answer the question
ISDF1	#2 - Interpretation and communication of results, what frequency of deterrence flows is desirable to characterize whether a multi-decadal flow regime is good, fair or poor?	Moderate	Moderate	High	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether riparian ecologists can state what frequency of flow events are preferred (poor, fair and good). If they cannot, there is likely no practical utility to the ISDF1 indicator.
ISDF1	#4 - Expected contrast given Shasta/NODOS type flow scenarios	Low	High	Moderate	No technical implementation risks from a SacEFT software standpoint. Potential barrier is whether flow events (hydrographs) under different scenarios would have sufficient contrast If the answer is no, then there is no practical utility to the ISDF1 indicator.

5. References and Further Reading

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

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

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

Invited water managers for Day 1: October 7

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	

Invited biologists for Days 1 and 2: October 7 and 8

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

Appendix B – Sensitivity Analysis

Sensitivity analysis ideas are documented in the SacEFT v.2 workshop technical memo (ESSA 2008) and in text in this document (e.g., "**Version 2 (Now) – Options**"). Sensitivity analyses must be completed in parallel with subtask 1.5 (i.e., while constructing or after having working software). Results of these analyses will be documented in the final version of this document completed with subtask 3.1 June 2010 quarterly report.