Sacramento River
Ecological Flows Tool (SacEFT):
Design & Guidelines (v.1.00.018)

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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.

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 and Business Case

1.1 Background

CALFED's Draft Stage 1 Implementation Plan recognizes that "human activities have fundamentally, and irreversibly, altered hydrologic processes in the Bay-Delta ecosystem", including the Sacramento River. To address this problem CALFED Ecosystem Restoration Plan (ERP) Goals encourage restoring the variability of the flow regime and associated river processes "as an important component of restoring ecological function and supporting native habitats and species in the Bay-Delta ecosystem". Further, a biological assessment by the U.S. Bureau of Reclamation (USBR 2004) represents concerns over the potential effects of management actions on listed species in the Central Valley. However, restoring, or "naturalizing" the most critical components of the flow regime (e.g., timing, magnitude, ramping rate, or duration of flow) and large river processes (e.g., lateral migration of the channel, formation of oxbow habitats) must be balanced with other water-related operations, such as power generation, agricultural, municipal, and industrial water uses, as well as flood control.

Many current 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.

In response to this need, The Nature Conservancy (TNC) and its partners are investigating linkages between river flow on the Sacramento River and various ecological targets in an attempt to improve conditions for those targets. There are a number of tasks within this project including the creation of an integrated database serving as the foundation of a decision analysis tool. This tool will facilitate the study of linkages and evaluation of various management actions and their affects on ecological targets of interest. This document is an update on the development of the Sacramento River Ecological Flows Tool (SacEFT) (formerly "DA Tool") and incorporates input from stakeholders and technical specialists collected during a 2 day technical workshop (Dec. 5-6, 2005) in Davis, CA. In order to avoid misperceptions regarding the tool's capability or assumptions, this document lays out the "nuts and bolts" details of the tool's construction. The intended audience of this report is limited to the set of individuals interested in the technical details and planned system vision. It is not a background report on the TNC's project on the Sacramento River.

The Sacramento River Ecological Flows Tool (SacEFT) system is a database centered software system for linking flow management actions to changes in the physical habitats for several focal species of concern. SacEFT is designed for TNC and its partners via generous grants from the California Bay-Delta Authority (CBDA) and the Packard Foundation. The key goals for the SacEFT system are to:

- Link flow management actions to focal species outcomes on the mainstem Sacramento River.
- Improve our understanding of priority physical-biological linkages, while better clarifying critical uncertainties.
- Expand our ability to characterize ecosystem response by including a variety of species, using both quantitative and qualitative relationships.
- Capitalize on existing models and integrate many disparate information sources, using data standards and some automated import utilities to manipulate these raw input and output datasets.
- Enable exploration of *ecological* trade-offs in a manner that can rapidly "plug-in" to information sources used in a wide variety of Northern California water planning forums.
- Use SacEFT as an education and communications tool to guide the thinking of managers and decision makers in weighing the relative *ecological* merits of alternative flow actions.

Building a software system of this magnitude is an iterative process and this document is only one step. Previous steps included preparation of a workshop background document (ESSA Technologies Ltd. 2005) and holding a technical design workshop December 5-6 2005 in Davis, CA. Usually, the first iteration of a decision support tool has many data and conceptual gaps that are filled by estimates. As such, we stress that the end use of the SacEFT, especially early on, is not for accurate prediction but rather to illustrate the *relative* benefits of management alternatives, elucidate ecological tradeoffs, identify critical uncertainties, and explore potential adaptive flow management experiments.

SacEFT is built around a single database. This database will be distributed along with client software as part of a desktop application. The system will permit certain multi-user features (e.g., data reviews) but will reside only locally on individual workstations. Internet accessibility is not part of the current architecture.

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 Need for assessing ecological issues

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.

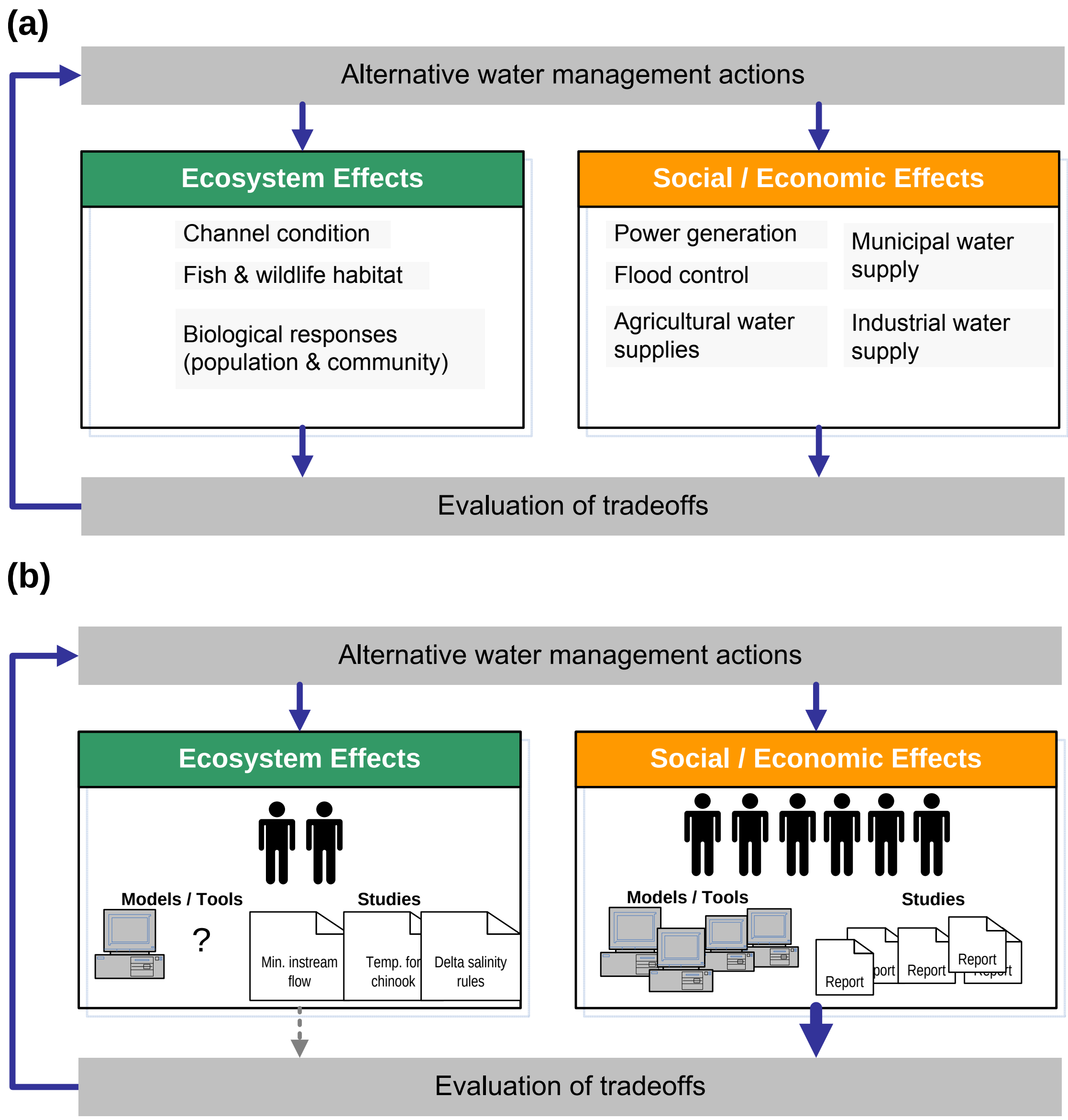

Figure 1.1. Water management on the mainstem Sacramento River affects both ecosystem and socioeconomic issues. Panel (a) lists some of the issues, while panel (b) shows the larger emphasis and number of tools/studies traditionally brought to bear on the evaluation of socioeconomic factors.

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 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. To meet this vision, the system must leverage existing physical datasets and models rather than reinventing wheels, and selectively fill 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.

SacEFT will centralize specific datasets and rules to support multi-objective and multi-disciplinary evaluation of Sacramento River water management decisions. This will be 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.

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.1.00.018 release, manual effort and steps are required to import datasets, configure metadata and new scenarios.

Table 1.1 summarizes the system's main 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.1.00.018 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.

Feature set	Description
(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)
(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 Workshop

1.3.1 Criteria and priorities

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. 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 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, no single performance measure will meet all of these criteria. Table 1.2 presents the priority performance measure that were selected after considering tradeoffs among these four criteria.

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. PMs marked in red are included in the model. Text above defines our meaning of relevance, clarity, rigor and feasibility. In this context, feasibility is more about "level of ease" for incorporation into the SacEFT software, recognizing time and budget constraints. **Those shown in red are implemented in SacEFT v.1.00.018.**

Focal species and performance measure	Relevance	Clarity	Rigor	Feasibility	Priority	Comments
CS1 - Area of suitable spawning habitat	Direct	High	High	High	High	5 aggregate reaches, 4 races, side channel included; gravel augmentation-sediment requires additional data
CS2 - Area of suitable rearing habitat	Direct	High	High	High	High	3 aggregate reaches, 4 races
CS3 - Egg-to-fry survival rate	Direct	High	Low	High	High	5 reaches, Bureau of Reclamation model
CS4 - Index of juvenile stranding	Direct	High	High	High	High	Daily flow; relationships from Gard (USFWS)
CS5 - Redd scour	Direct	Moderate	Low	High	Moderate	Max flow during incubation
CS6 - Redd dewatering	Direct	Moderate	Moderate	High	Moderate	Stage recession during incubation
CS7 - Connectivity to off-channel rearing habitats	Low	Moderate	Moderate	Low	Low	Limited data on off-channel sites; insensitive to flow; utilization quite low
CS8 - Substrate composition	High	Moderate	Moderate	Low	Moderate	Imported TUGS datasets include this information, in SacEFT
GS1 - Egg-to-larvae survival rate	Direct	Moderate	Moderate	High	High	Laboratory studies for temperature tolerance
GS2 - Area of suitable spawning habitat	Direct	Moderate	Low	Low	Low	Limited by lack of cross sections in deep high-flow channels
BASW1 – Length of channel bank with suitable nesting	Direct	Moderate	Low-Moderate	High	High	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	Moderate	Low	High	High	Used findings in Linkages report to develop an indicator of bank sloughing due to flows during nesting
BASW3 – Timing / height of flooding and nesting	Direct	High	High	Low	Low	Limited by availability of stage-discharge relations and x-section data measuring height of bank.
WPT1 – Area / connectivity of off-channel habitats	Direct	Low	High	High	High	Area of orphaned channel habitat (m^2). Detailed modeling of connectivity – dependent on stage-discharge and x-sectional data – not feasible.
WPT2 – Timing / height of flooding and nesting	Direct	Low	Moderate	Low	Low	Two key challenges: (1) given generality of sites, not feasible to use x-sections and stage-discharge relations to understand inundation of potential nesting areas, and (2) limited Sac specific information to identify important areas for WPT
WPT3 – Area of suitable nesting habitat	Direct	Low	Low	Low	Low	Requires information on many habitat variables: adjacent land-use / vegetation, oxbow recharge, water temperatures, soil types, distance to water. These data aren't available. Experts don't know location of critical habitats for WPT on Sacramento.
FC1 – Successful riparian initiation	Direct	High	High	High	High	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.

2. Prototype 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).

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. Performance measures were prioritized based on relevance, clarity, rigor and technical feasibility. Relationships between physical datasets and submodels and focal species performance measures in SacEFT are summarized in Table 2.1. The prioritized list of ecological objectives and performance measures emerging from the workshop are summarized in Table 2.2.

Table 2.1. Physical datasets that potentially impact focal species performance in SacEFT.

Focal Species Performance Measures	Physical datasets and submodels				
	Flow	Stage-Discharge	Temperature	Sediment Transport	Meander Migration
Fremont cottonwood (FC)	●	●			
Bank swallow (BASW)	●				●
Western pond turtle (WPT)	●				
Green sturgeon (GS)	●		●		
Chinook, steelhead (CS)	●		●	●[1]	

[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.

Table 2.2. Ecological objectives and performance measures.

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 index (Red/Yellow/Green hazard zones)
Chinook salmon, Steelhead trout (CS))	Maximize quality of habitats for adult spawning	CS1 – Area of suitable spawning habitat (ft^2)
	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)

2.2 Spatial extent and temporal horizon

The spatial extent of SacEFT includes the mainstem Sacramento River at RM 301 (Keswick) downstream to RM 143 (Colusa) (Figure 2.1). Specific locations identified in SacEFT are chosen based on three factors:

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

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

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

2.3 Spatial and temporal resolution

Three spatial elements 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.

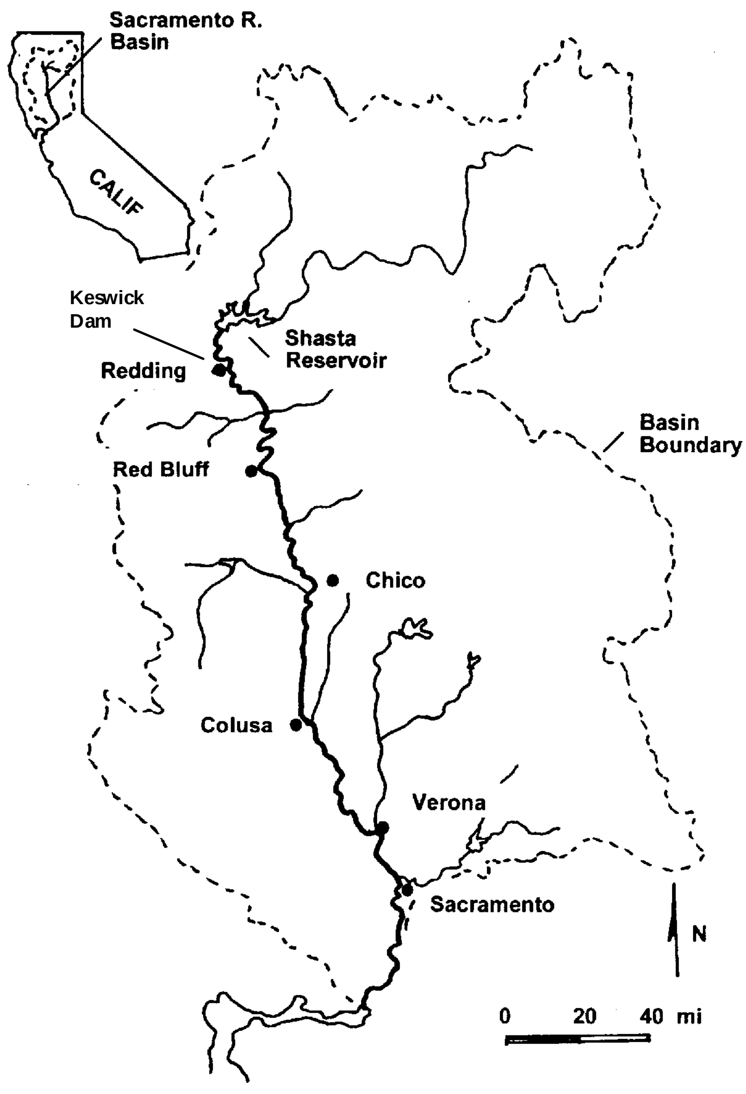

Figure 2.1. Map of the Sacramento River watershed and study area over which the SacEFT will be applied – from Keswick Dam (RM 301) to Colusa (RM 143) (source of map: CALFED Bay-Delta Program 2000).

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 advance 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.

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 2.6 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 2.3 summarizes both the spatial and temporal resolution of performance measures in SacEFT.

Table 2.3. 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 2.2. 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 2.5.

		Physical Driving Variables						Linked Models		Biological Models					
		Historical [1]		NODOS [2,4]		Shasta +18.5 [3,4]		TUGS [8,]	Meander Migration	Freemont 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	5				•	•	▮	▮		▮				218
207	GCID Pump			•	•	•	•		▮		▮				207
201									▮		▮				201
199	Hamilton City	6		•	•	•	•		▮		▮	•		•	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	7		•	•	•	•								143

Table 2.4. 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 2.2. 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 2.5.

		Physical Driving Variables						Linked Models				Biological Models																			
												Chinook & Steelhead Spawning & Egg Stage PMs [9]										Chinook Steelhead Juvenile Rearing Stage PMs									
		Historical [1]		NODOS [2,4]		Shasta +18.5 [3,4]		TUGS [8]		Meander Migration		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	5				•	•		▮	▮					▮								▮		▮		▮		▮		
207	GCID Pump			•	•	•	•			▮																					
201										▮	▮																				
199	Hamilton City	6		•	•	•	•				▮																				
197											▮																				
192											▮																				
190	Stony Creek			•	•						▮																				
185										▮	▮																				
183										▮																					
182										▮																					
172										▮																					
170										▮																					
168	Butte City	•		•	•	•	•																								
143	Colusa	7		•	•	•	•																								

Table 2.5. Annotations for Table 2.3 and Table 2.4.

[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 time span of the Shasta +18.5ft scenario discharge (Q) and temperature (T) data is **1-Oct-1921 to 30-Sep-1994**.

[4] 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.

[5] Two missing data segments at Vina (1-Oct-1938 to 12-Apr-1945; 1-Oct-1978 to 30-Sep-2004) interpolated by linear regression of incomplete "SACRAMENTO R A VINA BRIDGE NR VINA CA" v. complete "SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA": (1.2459 x BendBridge – 1364.5) (Yantao Cui, Stillwater Sciences, pers. comm.).

[6] Three missing data segments at Hamilton City (1-Oct-1938 to 20-Apr-1945; 15-Jan-1956 to 18-Jun-1956; 3-Oct-1980 to 30-Sep-2004) interpolated by linear regression of incomplete "SACRAMENTO R NR HAMILTON CITY CA" v. complete "SACRAMENTO R AB BEND BRIDGE NR RED BLUFF CA": (1.2047 x Bend Bridge - 1987.4) (Yantao Cui, Stillwater Sciences, pers. comm.).

[7] Numerous winter gaps at Colusa (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% used to develop a fairly smooth predictive relationship, applied to missing Colusa dates.

[8] 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 4.2.3.

[9] Chinook and Steelhead *spawning* WUA relationships shown in pale blue are mapped from the closest downstream segment, as described in Section 4.2.4. 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 4.2.4

Table 2.6. 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 2.2. 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 central period between 25th and 75th percentile when half of the population is 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 standard 120 day period following emergence. The values shown here are typical and may shift by as much as five days earlier or later, depending on year and reach.

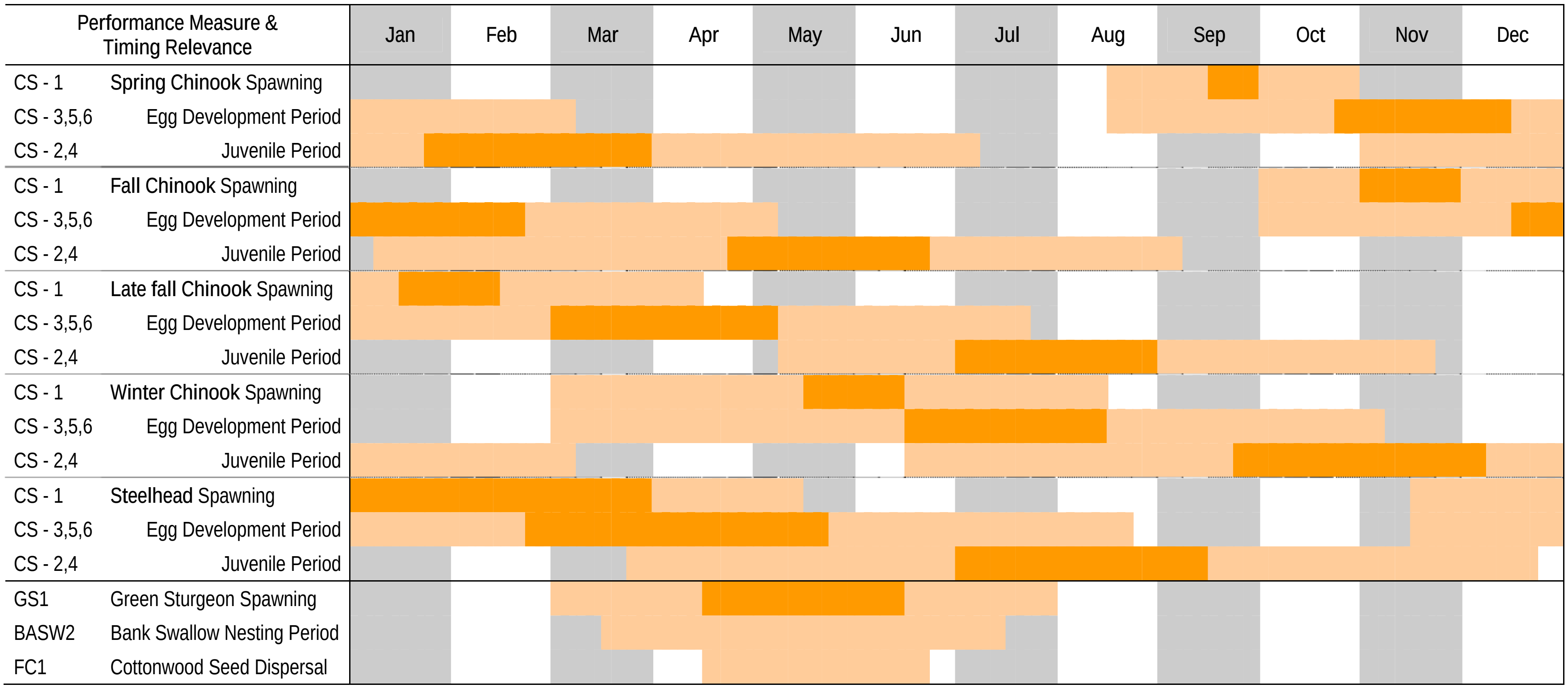

Table 2.7. Summary of the spatial and temporal resolution of performance measures. Abbreviations of performance measure are described in Table 2.2. Physical submodels are abbreviated as: FLOW – Historical flow records and CALSIM-SRWQM, STAGE – stage-discharge relations, TEMP – historical water temperatures 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).

Spatial resolution		Temporal 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$^{\delta}$			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					

$^{\delta}$ Not implemented in SacEFT v.1.00.018.

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

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, and the USBR Upper Sacramento River Temperature Model. 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.

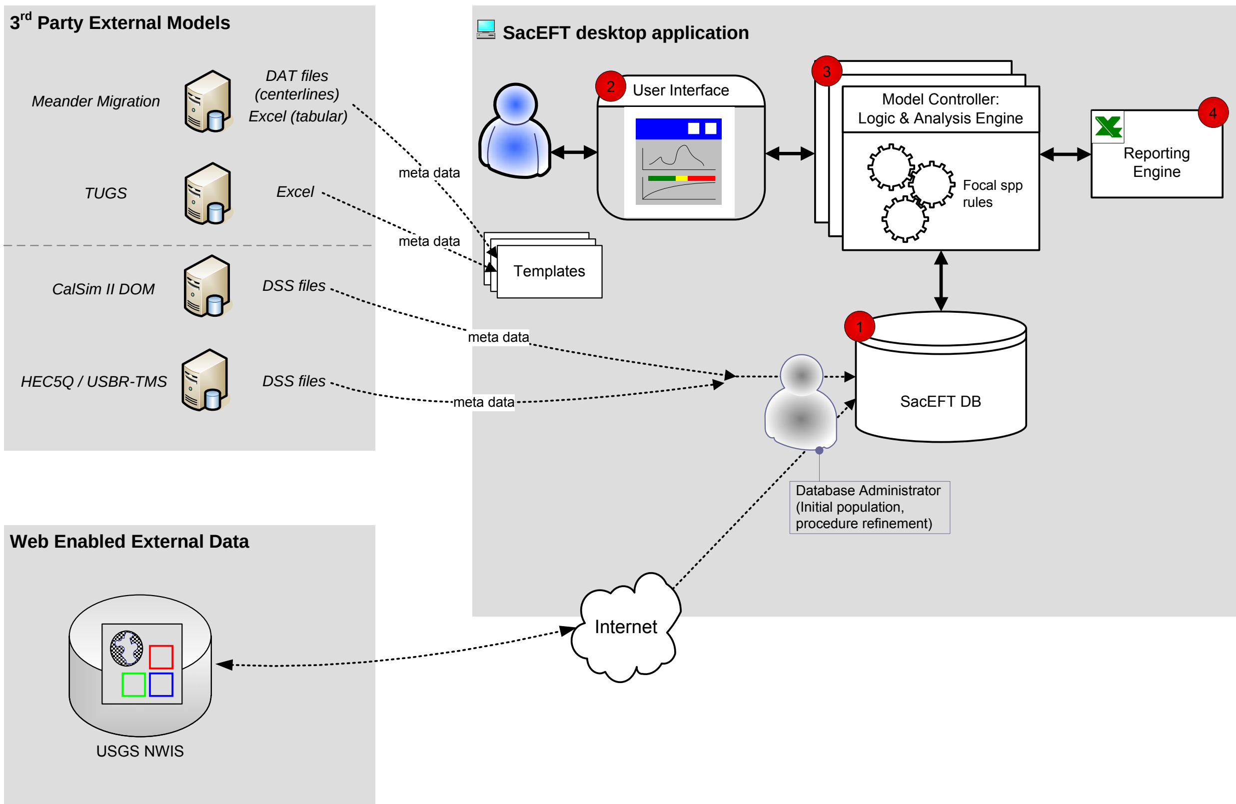

Figure 3.1. SacEFT component architecture. (Circled numbers are used for reference purposes in text below).

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.

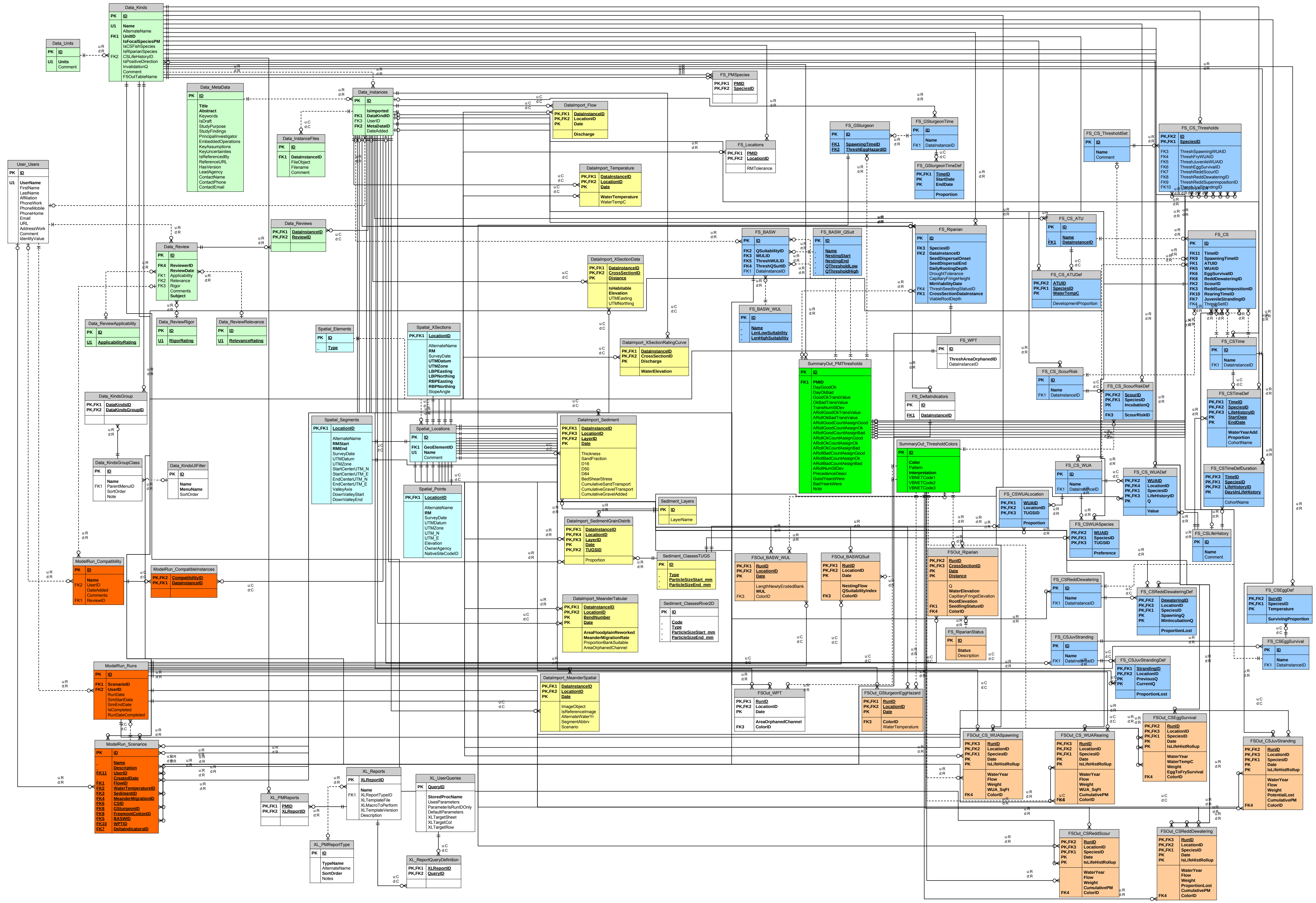

Figure 3.2. SacEFT relational database: entity relationship diagram. PK = part of the primary key. FK = foreign key. U = unique index (values cannot repeat in the table). C = cascading referential action (delete and updates).

Import/Export Manager

As discussed above, a critical feature of SacEFT is the need to leverage existing systems and data sources. Doing so in a manner that affords a low time footprint on users and minimizes the need for advanced system support requires automation of import of datasets from these external models, into the SacEFT database. However, while an important feature, it was not a priority for version v.1.00.018 of the software. In future, as budget resources permit, we recommend adding an Import/Export Manager (IEM) for reconciling spatial location information, adding new locations as necessary, or otherwise informing users of the information SacEFT needs to define a new location that it does not currently have a cipher for (e.g., through a "Wizard" type feature). Such import/export feature would also need to perform basic QA/QC on the data, ensuring there were not gaps, that the units were known, etc. The IEM would also need to ensure that data instances are associated with the appropriate metadata. Since the IEM obviously cannot employ artificial intelligence, templates would likely be required at the level of the external model user (both for source data and metadata). For well-organized data sources, once a location cipher is established, the IEM could automate access and import from the native data format (e.g., DSS files).

The IEM from time to time may also be needed to export datasets for input to other external models. This could be a feature worth exploring once immediate priorities have been addressed.

Presently in v.1.00.018, 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.1.00.018, 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.1.00.018. This user interface was developed using Windows Forms with Visual Studio 2005 and the Visual Basic 2005 programming language.

v.1.00.018 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.

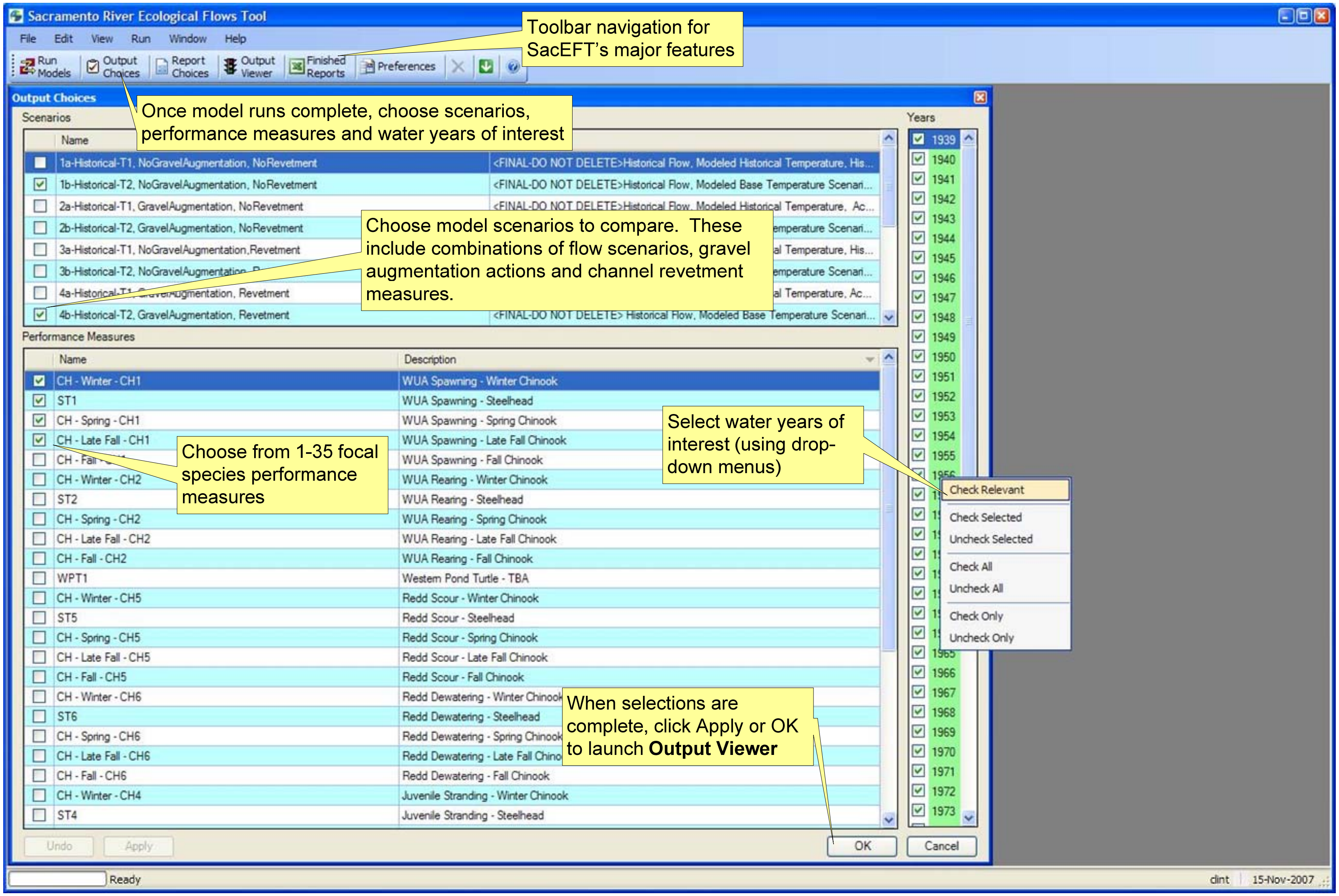

Figure 3.3: SacEFT's main screen, showing the Output Choices dialogue. SacEFT v.1.00.018 emphasizes display of results, assumptions and meta data over database editing features.

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.

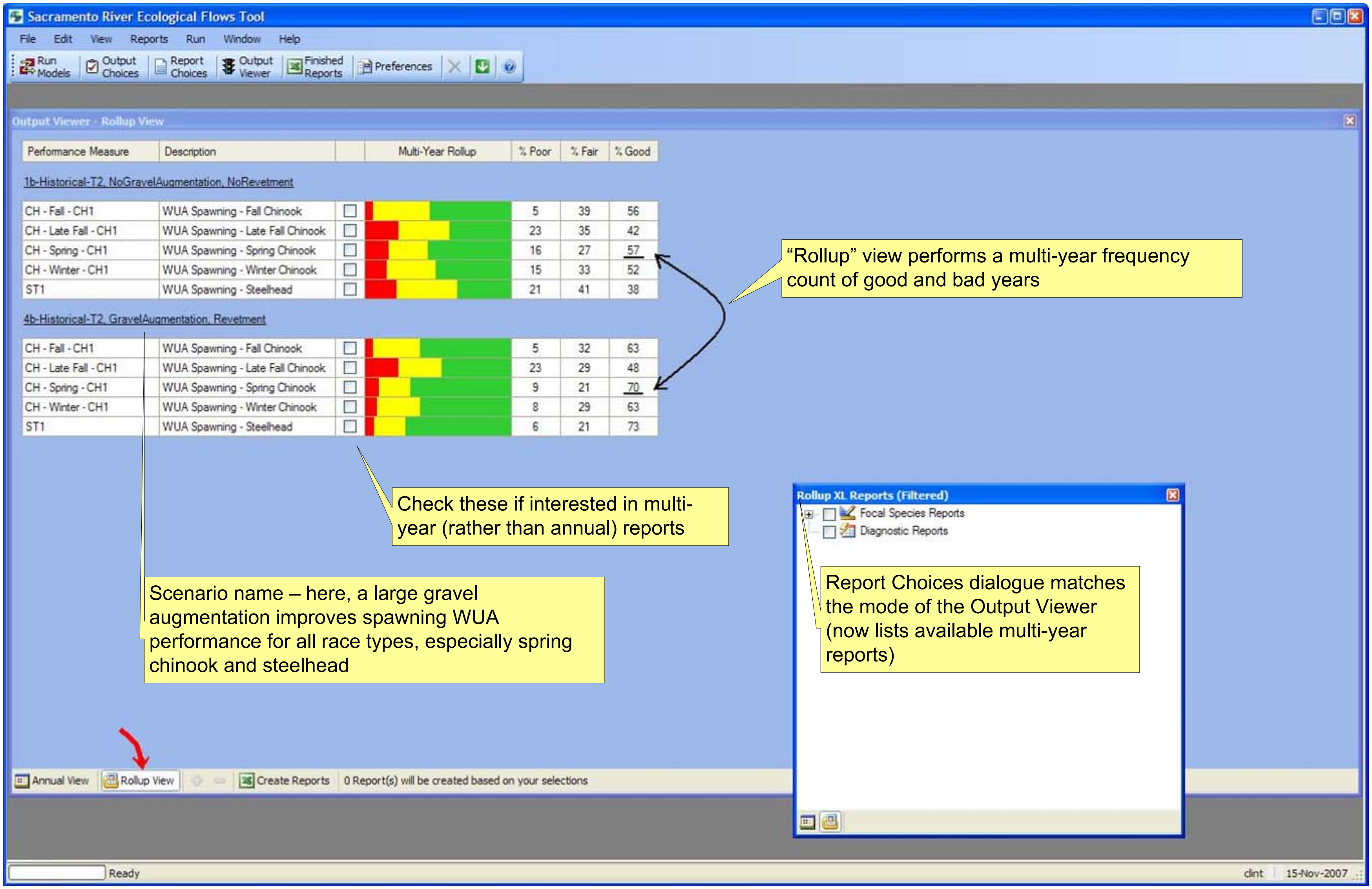

Figure 3.5: SacEFT's Output Viewer screen, showing the same information as Figure 3.4, but in multi-year Rollup View. This is the best view for quickly ascertaining the relative differences in performance among scenarios.

Output reports

MS Excel graphs and tables will serve as the primary output format. An example of SacEFT's v.1.00.018 spawning weighted useable area report (WUA) is given in Figure 3.6.

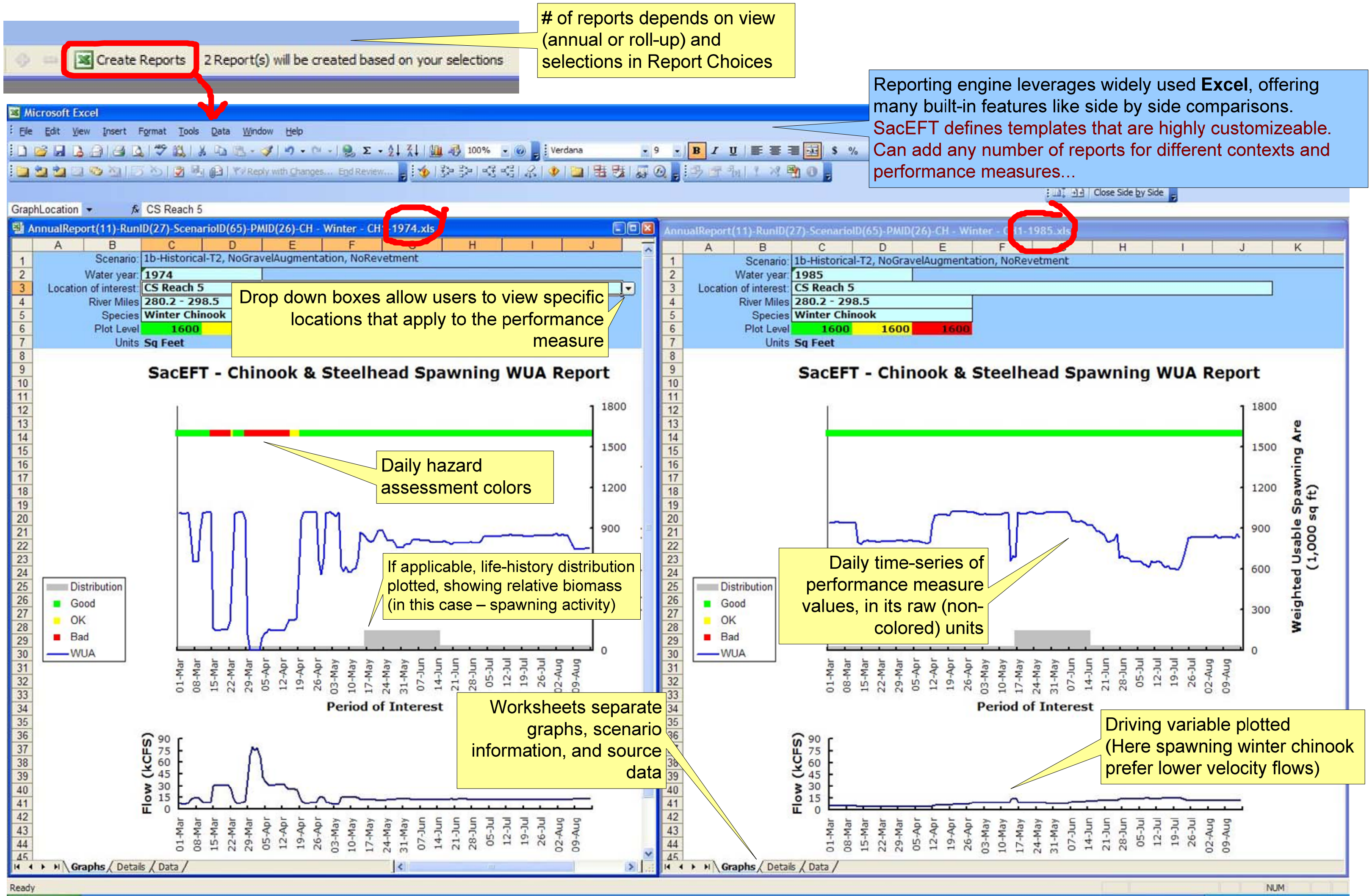

Figure 3.6: SacEFT provides detailed output on a scenario × year × performance measure basis in Excel. Here, managers and scientists can examine the detailed results in the performance measure's raw units, alongside its driving variable (e.g., flows). Refer back to Figure 3.4 for context.

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.

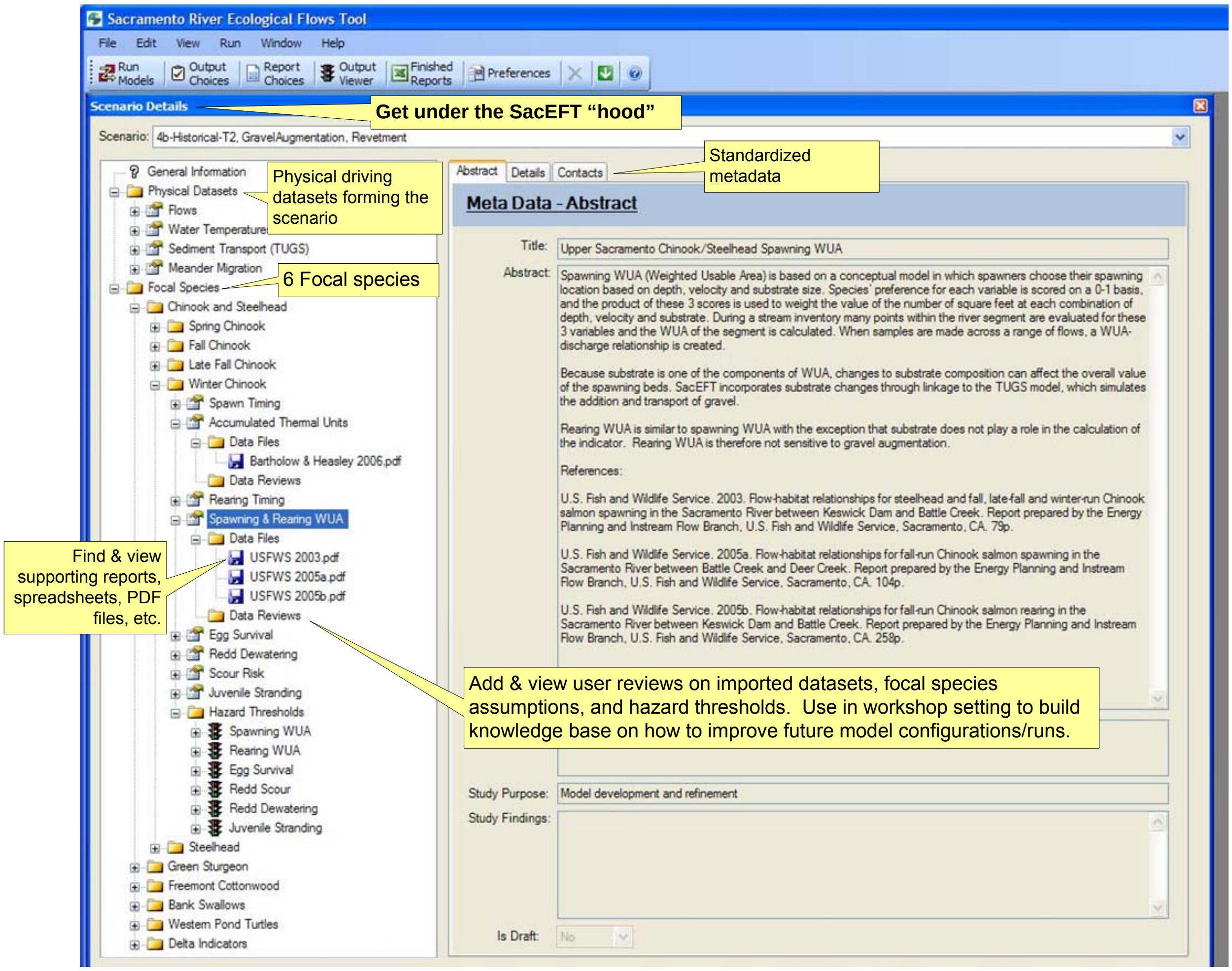

Figure 3.7: SacEFT's Scenario Details and Reviews dialogue for learning more about imported datasets and focal species assumptions.

3.4 Future directions

SacEFT v.1.00.018 represents 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 iterating on the first prototype. Hence, serious efforts at moving this tool into routine use in operational planning requires an investment in model testing, refinement and training.

In addition to the physical and focal species components described in Section 4 we recognize there are a variety of other considerations which could be integrated into SacEFT. Given our emphasis to first build a functional model, we will not integrate these considerations at this time. However, these considerations could form the basis of future refinements. During design, we were aware of the following five future areas of improvement.

- First, there is a trade-off between investing resources to fully automate linking with external systems and delivering a proof of concept solution that shows integration of all key components (coding physical data → focal species PMs; reconciling spatial transfers; user interface for presenting results; setting up actual scenarios and running the model; documenting/ communicating these results). Part of the issue is learning how to best work with proprietary data formats like DSS files and "negotiating" suitable output data templates with owners of external models. In the first iteration, it will be necessary to do some of this work manually. Long-range, these steps need to be as automated as possible.
- Second, SacEFT will integrate a limited set of management actions—our emphasis is on flow alterations and gravel additions. Future phases may investigate the effect of other management actions such as the effects of levee setbacks, diversion screens, delta pumping rates, etc.
- Third, the project team selected the six focal species discussed here, in part, because the project study (upper portion of Sacramento River) represents critical habitats for these species. However, we realize that water management decisions in the upper Sacramento River affect important species and critical habitats at other locations (e.g., the Delta and Delta smelt). Other important focal species and geographic locations could be integrated into SacEFT in the future.
- Fourth, Section 4 we discuss 6 physical submodels and 11 focal species performance measures. As we improve our understanding, functional relationships will become better defined, and the modeled outcomes will more accurately represent focal species' responses. All workshop participants realize that there are limitations in the application of these relationships. Over time, these limitations will be reduced through both improved scientific understanding (e.g. research that yields better understanding of bank swallow and western pond turtle habitat requirements) and new data collection (e.g. updating channel conditions after large hydrologic events for Chinook and steelhead models, obtaining more stage-discharge relationships to extend application of cottonwood recruitment models). The most critical uncertainties are those which could potentially make a significant difference to flow and other river management decisions (Alexander et al. 2006). Sensitivity analyses of SacEFT can help to elucidate which uncertainties are most sensitive to flow management decisions.
- Fifth, it may be of interest down the road to web-enable SacEFT, centralizing the database to a server computer accessible over the internet, and scaling SacEFT to be a truly multi-user application.

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.1.00.018, 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. 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.

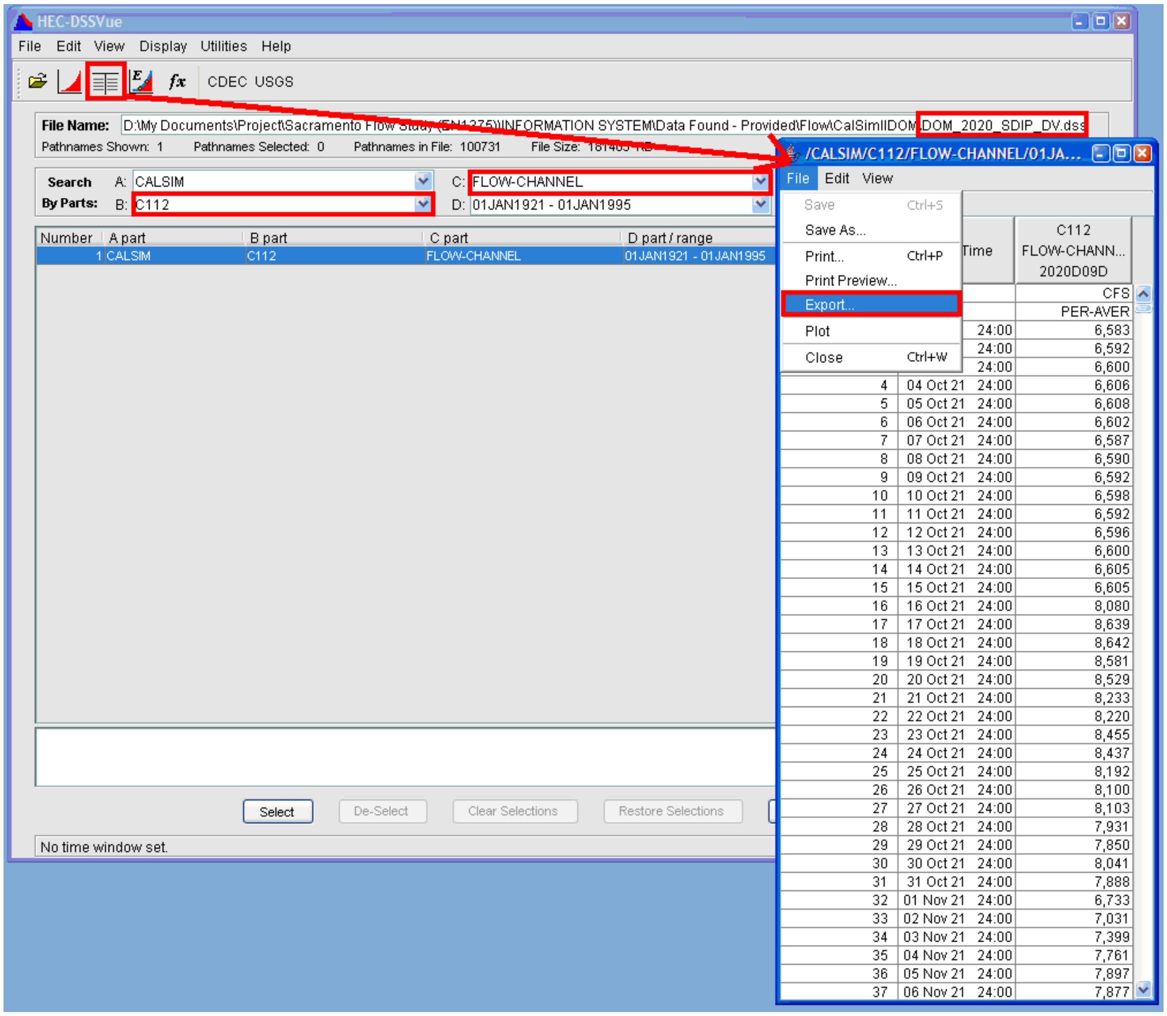

Figure 4.1. Manual export feature of HEC-DSSVue to comma separated files.

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.

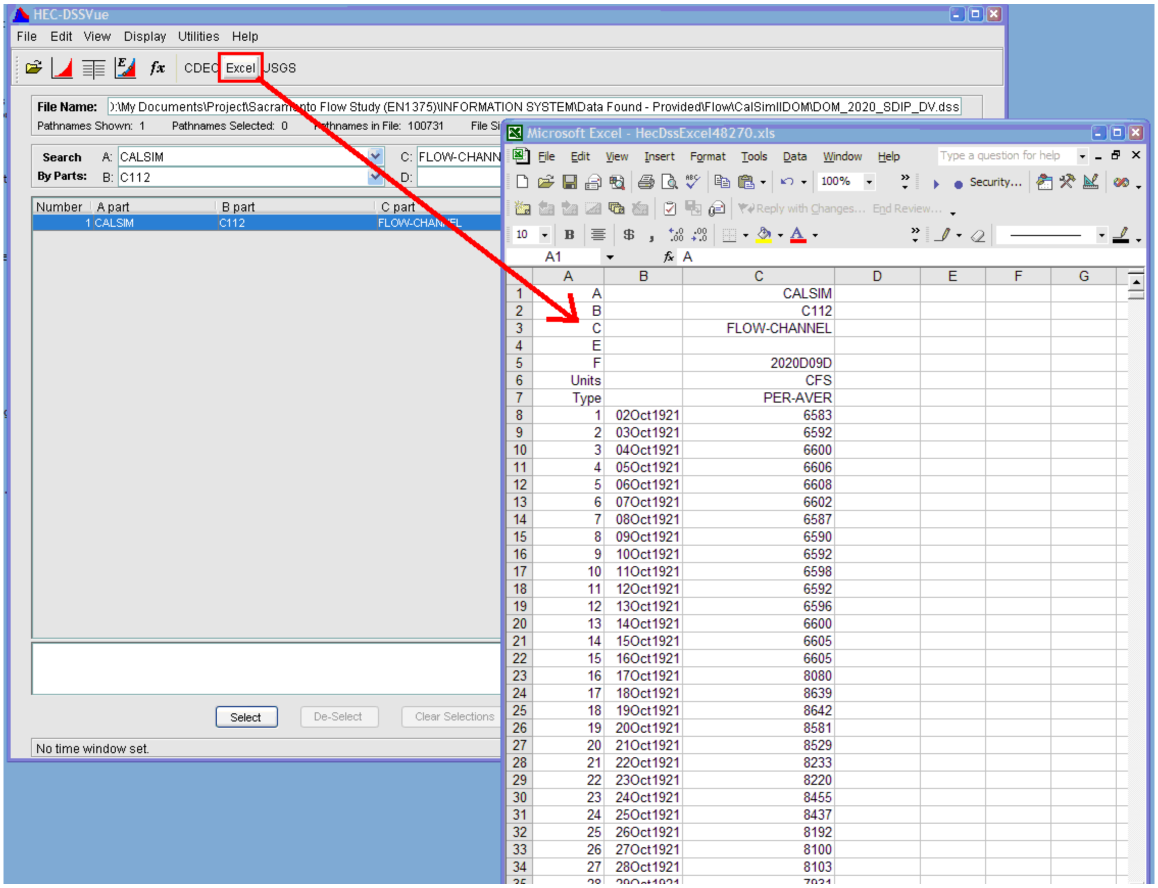

Figure 4.2. Excel plug-in for directly exporting DSS data to an Excel spreadsheet.

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).

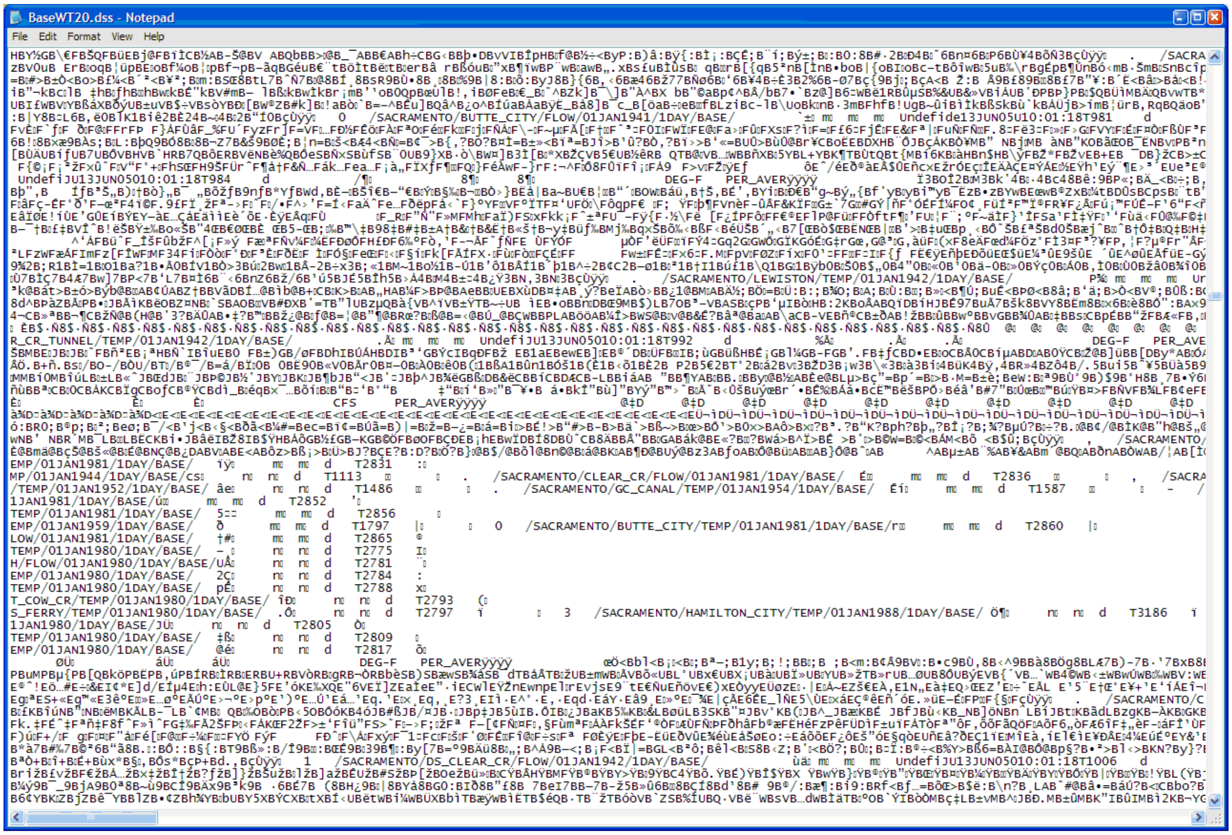

Figure 4.3. A DSS database file displayed in Notepad. As with any binary file, the information contained cannot be read as plain text or in another universal file type (e.g., XML).

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 import 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 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 2.3a, 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.

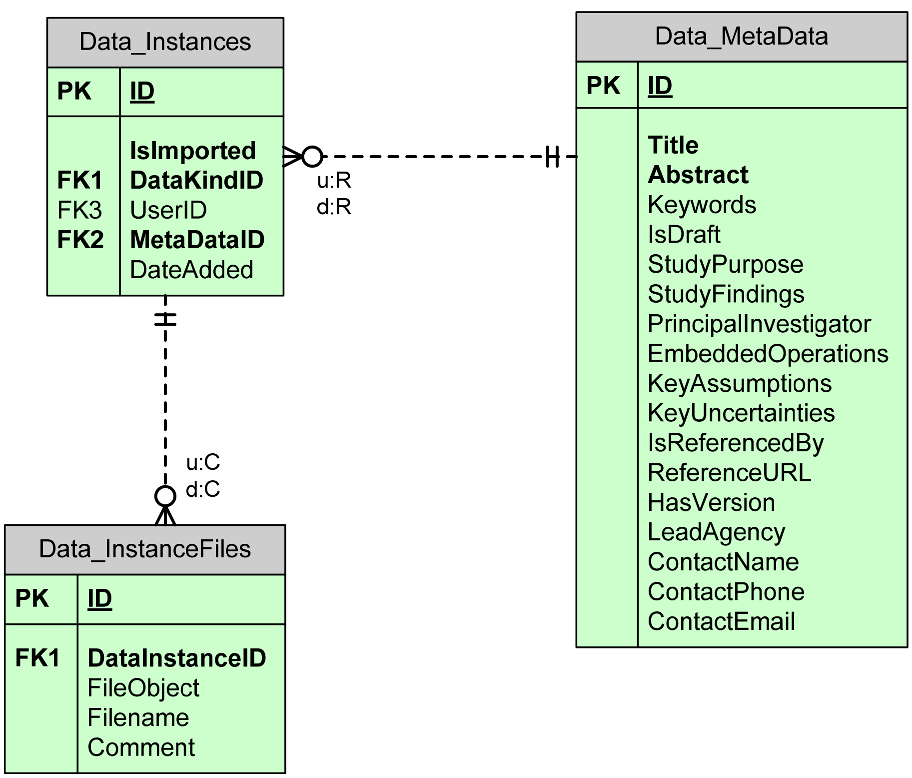

Figure 4.4. Underlying database design showing how each imported DSS file from CalSim (and any other data from an external physical model) is associated with a DataInstance and a set of MetaData. A considerable number of the fields in Data_MetaData are optional.

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 2.3 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 to SacEFT as part of the NODOS and Shasta management scenarios. 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).

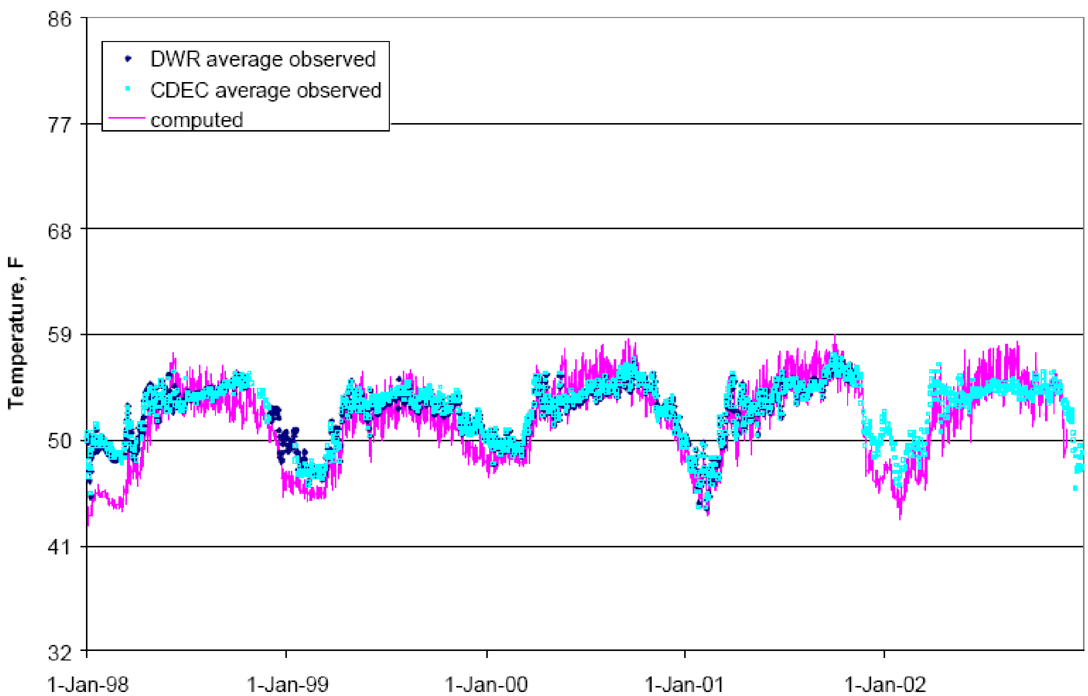

Figure 4.5. Computed and observed temperature time series in Sacramento River at Balls Ferry. Source: RMA 2003.

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).

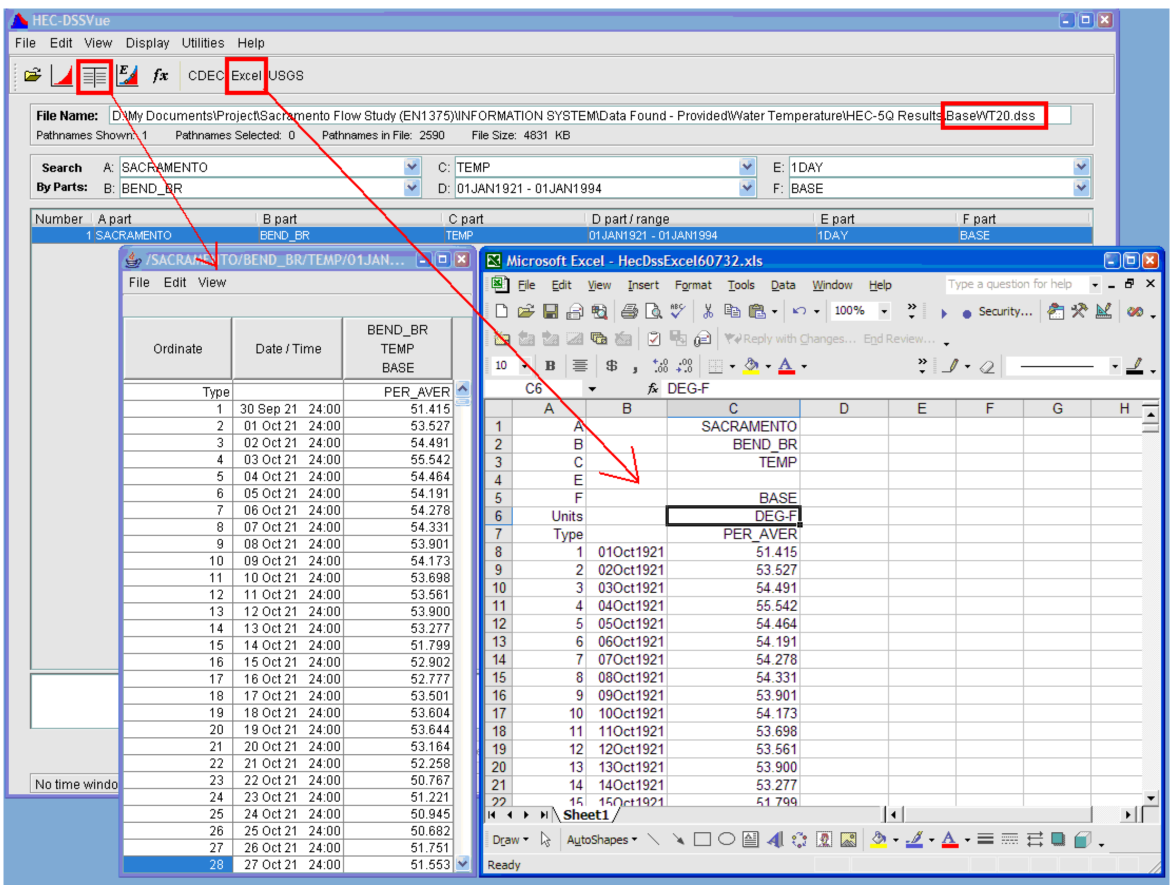

Figure 4.6. Manual and Excel plug-in export features of HEC-DSSVue for obtaining USBR Temperature Model water temperature data.

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.

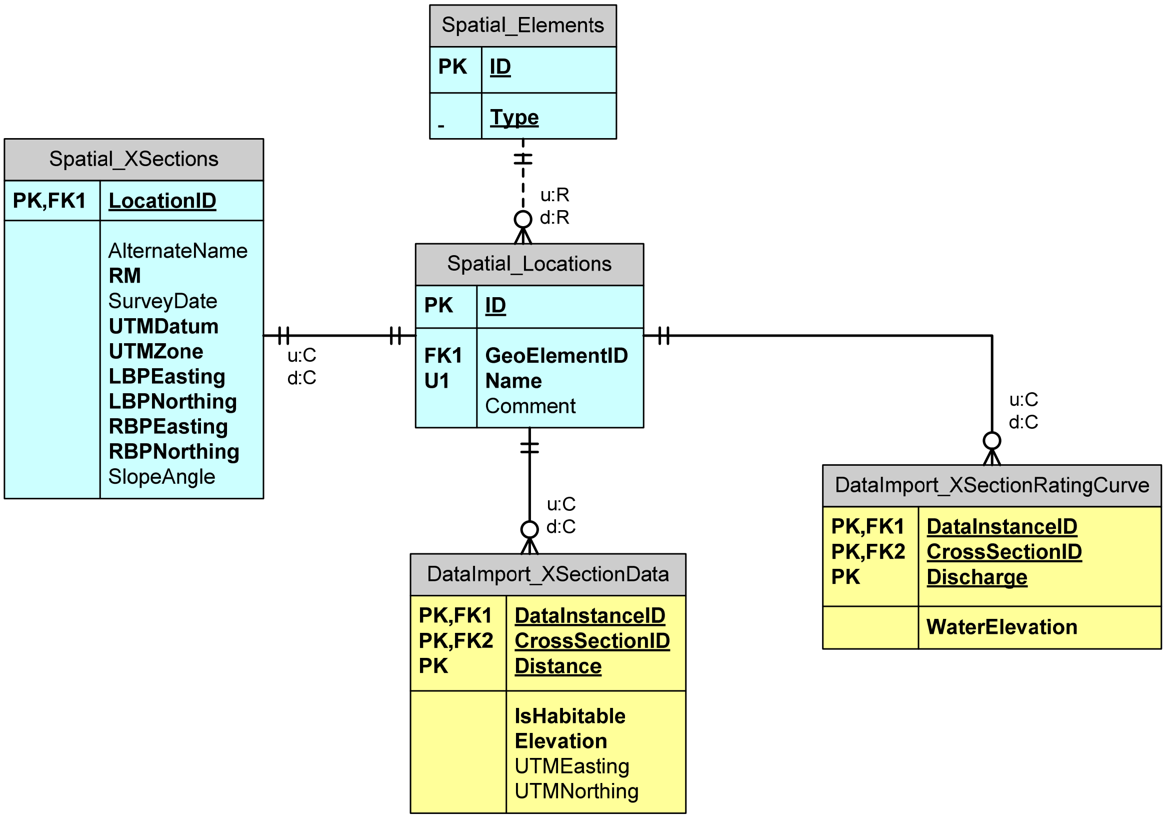

Figure 4.7. Relational database design used by SacEFT for cross section and stage-discharge information.

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.

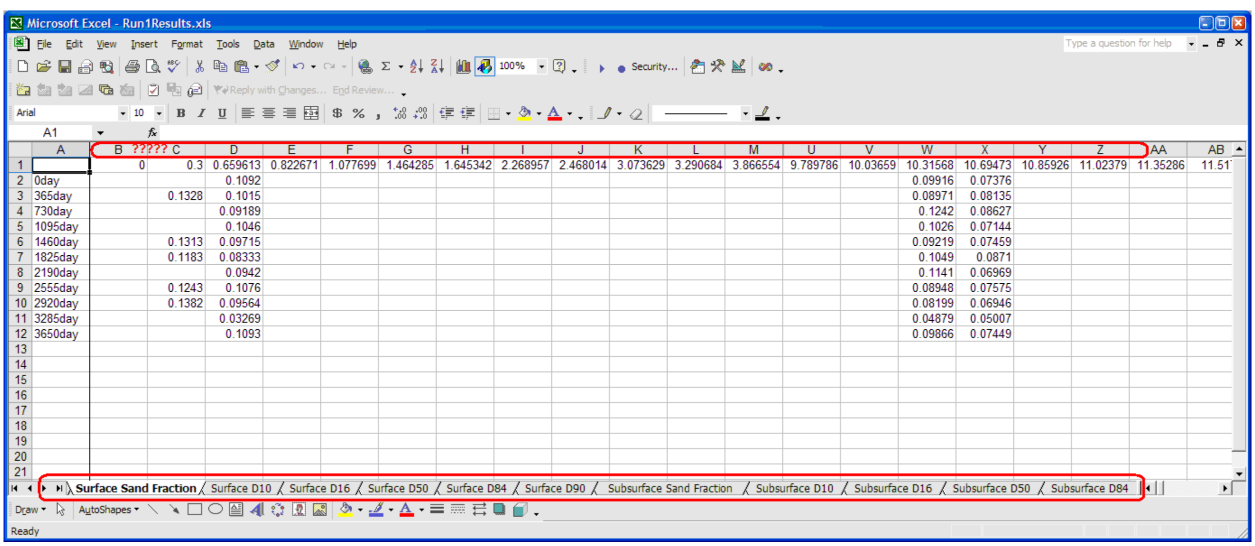

Figure 4.8. Current "untamed output" from TUGS model. Numerous worksheets contain results for specific performance measures. As shown, it is not always clear what distance (location) or time period is associated with a particular value. An Excel template was developed to better organize and streamline 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.

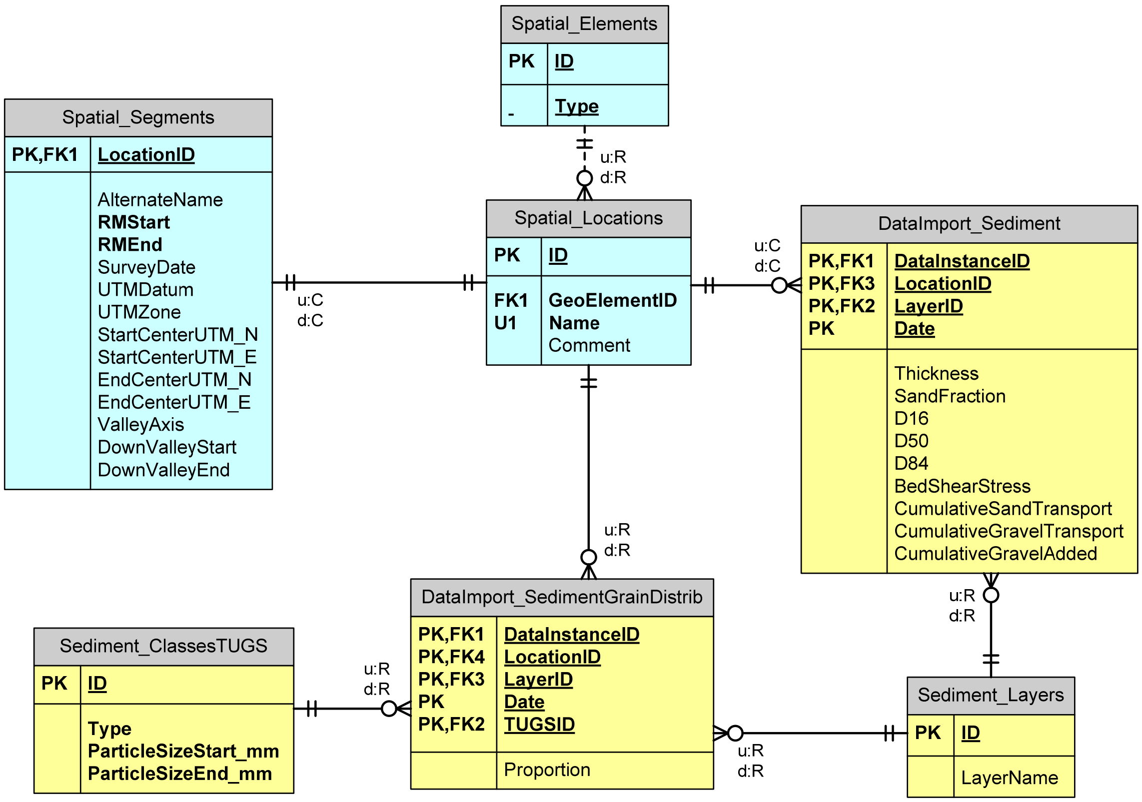

Figure 4.9. Relational database design used by SacEFT for storing TUGS model output.

After consultations between Stillwater Sciences and TNC, two scenarios were incorporated into SacEFT for v.1.00.018: 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-RM 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.

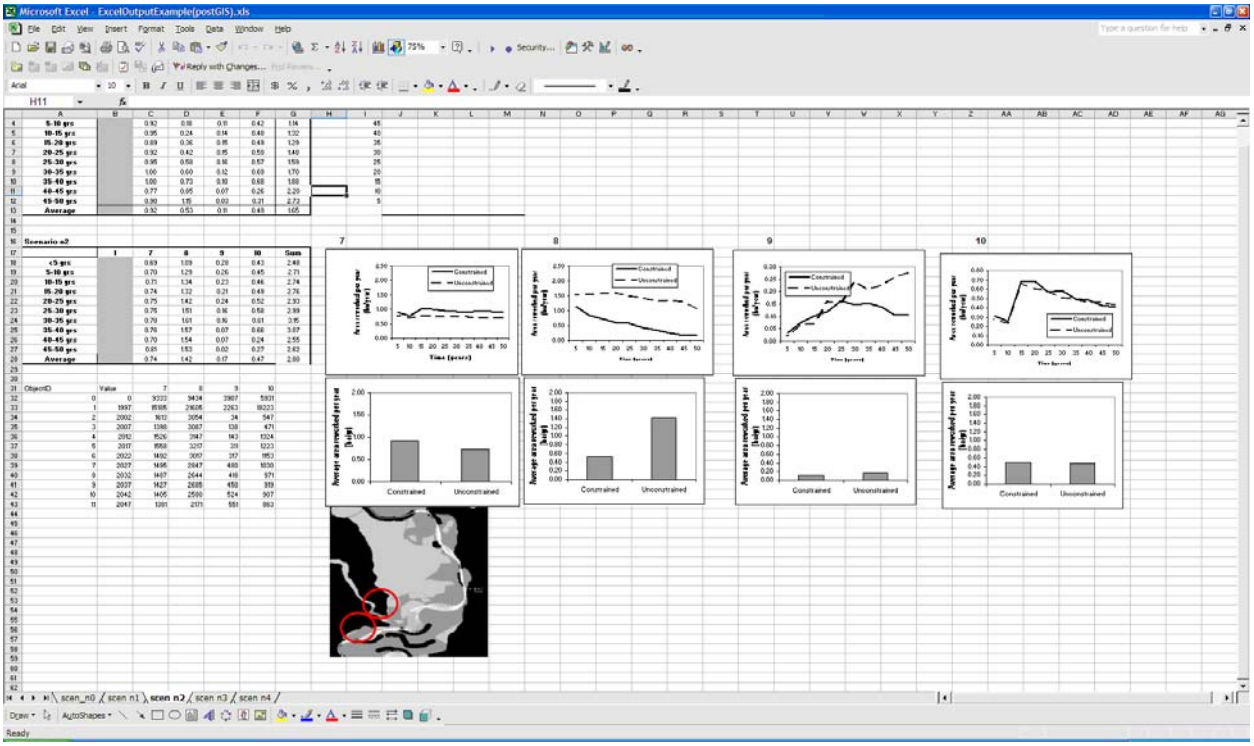

Figure 4.11. Example of meander migration summary results in Excel following GIS centerline analyses.

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.

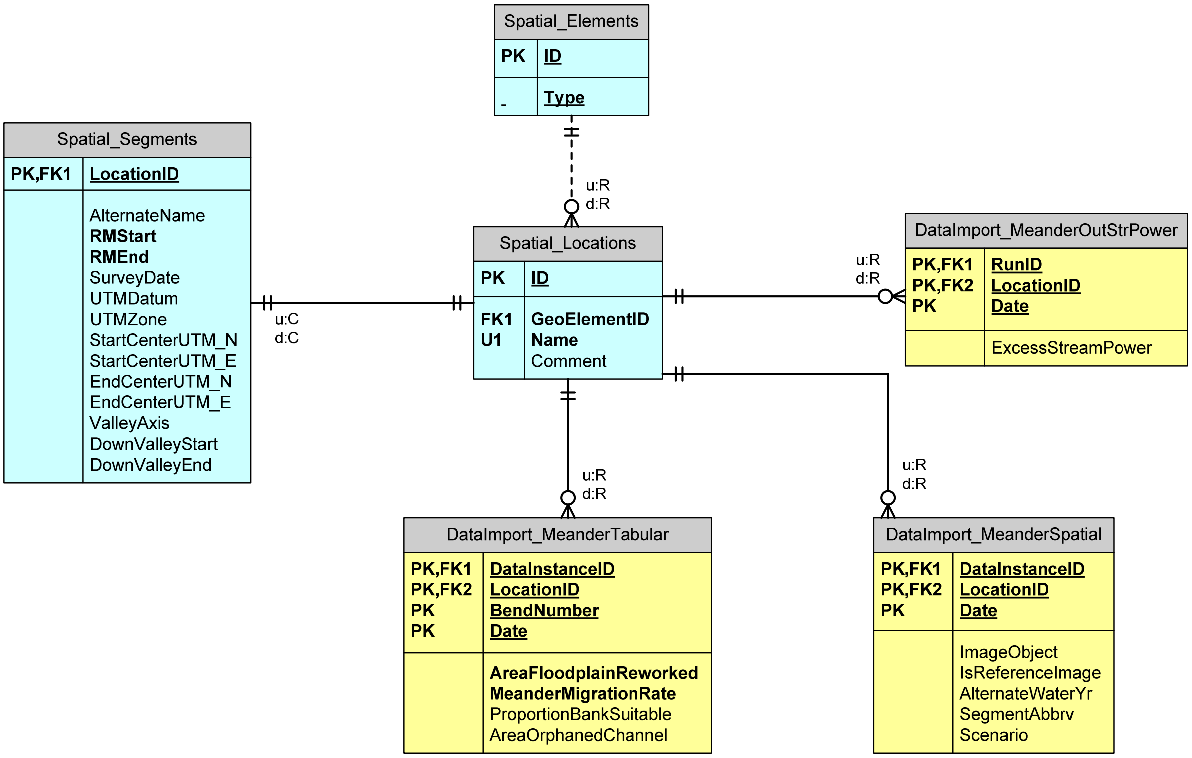

Figure 4.12. Relational database design used by SacEFT for storing meander migration model output.

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.1.00.018 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.

4.1.6 Oxbow chute cut-off

Oxbow lakes are a type of off-channel habitat, and they form when meander bends are cut off as flow occupies a new, straighter main channel alignment. Oxbow lakes can form from neck or chute cutoffs. Neck cutoffs occur when the radius of curvature of a meander bend becomes so extreme that bank erosion eventually scours the narrow "neck" of floodplain that separates the upstream and downstream end of a meander loop. Therefore, neck cutoffs are primarily a function of bank erosion.

In comparison, chute cutoffs form during high flow events when overbank flows scour a pilot channel on the floodplain and eventually capture the discharge, as illustrated in Figure 4.13.

(a) (b) (c)

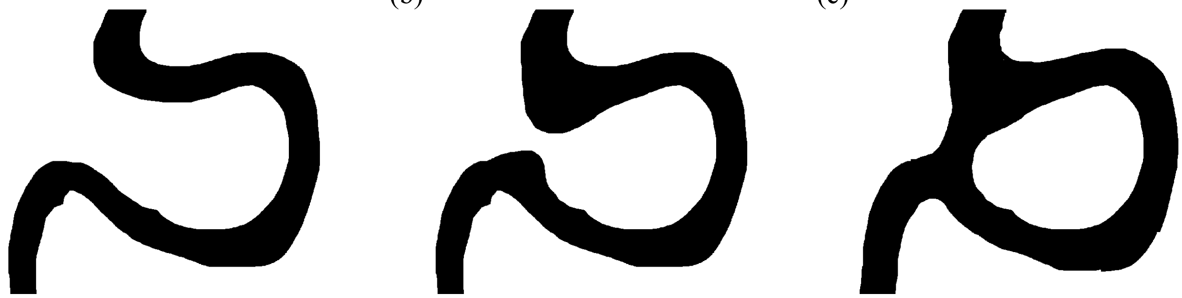

Figure 4.13. Evolution of a chute cutoff.

During low flow events, flows pass through the existing channel (Figure 4.13a). With an increase in discharge, water will inundate the lower area near the bend where previous high flow events may have carved the topography lower (Figure 4.13b). Once the discharge increase is high enough, flow will pass through both the existing channel and the area where the cutoff is to occur (Figure 4.13c). Although the water in the cutoff area is shallow, its gradient is significantly higher than the existing main channel, which will result in scouring and promoting cutoff.

Thus, the physical processes that initiate a chute cutoff are different than those that create neck cutoffs. It is possible to identify the potential for neck cutoffs by applying a meander migration model like the one developed by UC Davis, because the model simulates the effects of bank erosion. There is currently no model to simulate how flows initiate chute cutoffs. Recent efforts to develop a chute cutoff model by members of the Sacramento River Flows project team were unsuccessful, and this process has not been incorporated into SacEFT v.1.00.018.

4.2 Integration of physical data, linked models and SacEFT submodels

4.2.1 Time basis 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 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 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.

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 2.4). 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 2.4 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

4.3.1 Chinook salmon & steelhead trout

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

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

Steelhead trout and four races of Chinook salmon 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 six 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 2.4. 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 results are used, and daily evaluations of the PM are again assigned daily Red/Yellow/Green Indicator Rating based on the benchmark historical run.

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

[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.). Rearing segments in **Error! Reference source not found.** have been extended downstream to try to accommodate this observation.

Table 4.5. 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. (Taken from Table 2.4).

		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 2.6). 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.

Weighted usable area for spawning (CS1)

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].

[1] For convenience only we use the term ‘race’ in these descriptions, recognizing that there are four races of Chinook salmon and that Steelhead trout are a unique species.

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

The *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) 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). 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.

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

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.

Weighted usable area for rearing (CS2)

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.

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 fixed residence period of 120 days after emergence. The proportion of juveniles (w_d) present on any given day (d) is therefore given by:

$$w_d = \sum c_e \quad where\ (e \le d),\ and\ ((e + 120 - 1) \le d)$$

The emergence function makes it possible to have multiple spawning days emerging on the same day, particularly during a period of warmer water. After emergence, each juvenile day-cohort is followed for a fixed residency period of 120 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 120 days the day-cohort is no longer tracked. Note: SacEFT does not track movement of cohorts between reaches, and instead they are assumed to remain in the reach they were spawned.

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.

Egg-to-fry thermal mortality (CS3)

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)* spawning each day over the egg development period. Unlike the Rearing WUA performance measure, which shows relative abundance of rearing salmonids, the Excel report for egg survival portrays the spawning-day distribution only and not the relative abundance of in-gravel eggs.

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

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

The *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.

$$CS2_r = \frac{1}{L}\sum_{l=1}^{L}\left(\frac{CS1_{\overline{x,l}}}{CS1_{\bar{x}}}\right)\left(\frac{1}{D}\sum_{d=1}^{D} w_d \prod_{\delta} s(T)\right) = \frac{1}{L}\sum_{l=1}^{L}\left(\frac{CS1_{\overline{x,l}}}{CS1_{\bar{x}}}\right)CS3_{l,r}$$

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.

Juvenile stranding (CS4)

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:

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

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-1}, and the flow on day Q_d. If there is a drop, then some proportion of juveniles are potentially stranded: $f(l,Q_{d-1},Q_d)$, and bilinear interpolation is used to calculate proportional losses between the tabular values found in Gard's tables (U.S. Fish and Wildlife Service 2006b).

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.

Redd scour (CS5)

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 and 32 kCFS) are triggers for assigning different Indicator Ratings, once they are combined with cohort-weighting information. Flows above 20 kCFS can trigger a Yellow Hazard, with flows above 32 kCFS 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.

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.

Redd dewatering (CS6)

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.

4.3.2 Green sturgeon

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.1.00.018.

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 then 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.

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.

4.3.3 Bank swallow

Performance measures

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 banks 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. The models are based on Garrison's (1989) habitat suitability index (HSI) model and refinements proposed by Stillwater Sciences 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.1.00.018 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.

Length of Newly Eroded Bank (BASW1)

The meander migration model provides annual estimates of meander migration rate (W) and area of floodplain reworked (A) for each of up to 14 modeled bends (b) in each of three river segments (l): ($L_{l,b}$) shown in Table 2.3. From these two indicators, the length of newly eroded bank in each bank can be approximated by the *simple* geometrical approximation:

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

The *annual* performance measure is then the sum of each bend's newly eroded bank with the contribution of each bend weighted:

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

A performance measure reflecting the weighted useable bank length (*BASW1*) for each reach is then of all the bends in the segment:

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

The *annual* PM for each location is undefined for BASW1.

The *rollup* PM is based on the terciles of total length taken from a historical run with no bank revetment. These terciles show a very narrow range of variation and may need further assessment and revision once the range of SacEFT scenarios has been reviewed by domain experts. In particular, the choice of a fairly small length-scale (13m - 20m) for the model is not well suited to the scale at which the Meander Migration model is parameterized: almost all bends are longer than 500m, and therefore the weight (w_d) is almost always 1.0[1]. Coupled with the low year-over-year variability in length of newly eroded bank returned by the Meander Migration model, this creates a performance measure with extremely low contrast. The 'length of newly eroded bank' generated by $L_b = \dfrac{A}{W}$ also does not account well for the depth of bank erosion. Lengths predicted by this formula can also in some cases be artificial, having a trivial depth of erosion along the length.

Finally, recognizing that soil type is a critical factor in determining whether newly eroded banks are suitable for Bank swallow, SacEFT v.1.00.018 contains a database placeholder for the proportion of newly eroded banks that is suitable, even though this information was not made available to our modeling team.

Peak flow during nesting period (BASW2)

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 four river segments (see Table 2.3) during the March 15–July 15 (Table 2.6) 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.

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:

[1] These suitability thresholds, identified during the model design workshop, were based on research by Garrison et al. (1978) and Garrison (1989). In a study of 32 colonies on the Sacramento River (Garrison et al. 1987), bank lengths were found to range from 43 to 6,233 ft (13 to 1,900 m). Garrison's (1989) HIS model indicated that banks greater than 20m in length are considered to be optimal (with SI=1) and banks with zero length have SI=0. Data specific to the Sacramento River suggest that the minimum and optimal bank length thresholds in the HSI could be revised to 13m and 40 m respectively (Stillwater Sciences 2007).

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

The R/Y/G Indicator Ratings are then based on a heuristic developed from the distribution of the BASW2 indicator based on a historical flow scenario across all river locations. Daily Indicator Ratings therefore closely follow the BASW2 indicator, with values near zero assigned a Red Indicator Rating and values near one a Green Rating. Because of the fast ramping of flooding flows during the nesting period, days assigned a Yellow Indicator rating are infrequent.

The *annual* PM for each location is undefined for BASW2.

The *rollup* PM is based on a heuristic that aggregates the annual PM across all four locations. For example, the rollup is assigned a Good rollup Indicator Rating if 3 or more locations have a Good Indicator Rating, and lower ratings as poorer ratings become more predominant across the locations.

4.3.4 Fremont cottonwood

Performance measures

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 4.6, 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 2.3) on the Sacramento River.

Table 4.6. 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
	Channel cross-sections	Roberts et al. 2002; Roberts 2003
	Capillary fringe depth	Roberts et al. 2002; Roberts 2003
	Seed dispersal timing (start and end)	FC experts
	Seedling tap root growth rate	Roberts et al. 2002; Roberts 2003
	Preference relationship for PM	FC experts

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 2.4). 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 an 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.

4.3.5 Western pond turtle

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 2.3) 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 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 v.1.00.018.

[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"

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