Sacramento River
Decision Analysis Tool:
Workshop Backgrounder

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1. Background

1.1 Introduction

This document serves as an introduction to an effort by The Nature Conservancy and it's partners to investigate 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 the project including the creation of an integrated database serving as a decision analysis tool. This tool will facilitate evaluation of various management actions and their affects on ecological targets of interest. To date, the project team has been compiling and synthesizing existing information, developing study plans, and developing a straw-man decision analysis tool for review. This document is a summary of progress on the development of the decision analysis tool and the associated model design workshop serves as the first opportunity to gather and incorporate stakeholder review and input into the project. Stakeholder review and input on other project tasks will be sought through a separate, future workshop and it's associated document titled the "State of the System" report.

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 account for some 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, would 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. As well, incorporating other actions, such as gravel augmentation, levee setbacks, and bank protection into such decision-making forums would be important in providing a more complete understanding of how management actions can affect the Sacramento River ecosystem.

1.2 Project purpose

This project is designed to address the lack of information on the flow needs of valued ecosystem components of the Sacramento River. Major deliverables are field studies and models that fill previously identified information gaps and linked quantitative tools that can help water operations modelers and decision-makers to consider ecosystem needs in their planning. This work seeks to refine, and further develop, estimates of ecological flow needs that are critical to maintaining or restoring river processes beneficial to fish, vegetation, and wildlife species of the Sacramento River ecosystem. The use of such information in decision-making would help ensure that water flowing through the upper Sacramento River achieves more ecological benefits as it is routed to the Delta.

It is important to note that this project does not seek to return the system to its "pre-regulated" condition, nor does it attempt to identify how best to allocate Sacramento River water to meet human needs, as numerous decision-making forums already address the latter issue. Our efforts will, however, bring critical ecological information to such forums. Proactive planning can help to avoid future regulatory action by developing multi-species flow regimes, reducing scientific uncertainties, and improving our ability to effectively guide conservation efforts in the project Study Area, which extends from Colusa to Keswick Dam.

This project uses existing information synthesis, consultative and collaborative workshops, targeted field investigations, computer modeling, and a Decision Analysis (DA) Tool to quantify selected linkages among the flow regime, channel characteristics, and specific valued ecosystem components. In conducting this work we are building on previous efforts, including for example workshops[1], summary reports[2], analytical exercises[3], and other modeling efforts[4] that have been conducted in the upper Sacramento River.

The work is composed of four main Project Tasks:

Project Task 1 will synthesize existing species and habitat information in a State of the System (SOS) report (draft available September 2005) for six focal species that have been selected to represent a wide range of habitat requirements for terrestrial and aquatic species on the Sacramento River (see Section 2.1.2 for a discussion about focal species selection). As part of this report, conceptual life history models will be developed for each focal species by synthesizing existing data and highlighting key uncertainties. These conceptual models will then be used to guide subsequent field studies, develop alternative hypotheses about the human actions constraining these species, and inform development of the DA Tool.

Project Task 2 involves conducting five studies to address critical scientific uncertainties that have been previously identified. These studies will: a) quantify relationships between flows and sediment transport for a sediment transport model; b) characterize ecological attributes of oxbow cut-off habitats and quantify fluvial geomorphic processes that create and maintain these habitats for a chute cut-off model and; c) characterize channel substrate composition and permeability for a sediment transport model; d) assess and compare the effects of bank protection on in-channel habitat conditions; and e) refine a meander migration model.

Project Task 3 will develop a DA Tool to relate specific management actions to responses in the habitats that are important for the six focal species (e.g., changes in channel geometry, substrate composition, and riparian vegetation). Management actions will include candidate changes in stream flow and gravel augmentation, and where possible and appropriate other actions such as levee realignments and riprap removal. The DA tool will integrate existing quantitative and qualitative models, as well as a limited

1 North-of-the-Delta Offstream Storage Technical Advisory Group (NODOS TAG)

2 CALFED Bay-Delta Program. 2000. Flow Regime Requirements for Habitat Restoration along the Sacramento River between Colusa and Red Bluff. Integrated Storage Investigation. Sacramento, California.

3 Crone, E.E., K.D. Holl, B. Elderd, S. Greco, M. Kondolf, I. Morken, D. Wood, G. Golet, K. Moffatt, N. Nur, and S. Small. no date. Biocomplexity Incubation Activities: Linking hydrological and biological dynamics in restored riparian forests.

4 Stillwater Sciences. 2004. Standard Assessment Methodology for the Sacramento River Bank Protection Project. Prepared for the U.S. Army Corps of Engineers (and associated documents).

U.S. Fish and Wildlife Service (USFW). 2003. Flow-habitat relationships for steelhead and fall, late-fall, and winter-run Chinook salmon spawning in the Sacramento River between Keswick Dam and Battle Creek. Sacramento, CA: U.S. Fish and Wildlife Service.

number of new functional relationships, within one framework to evaluate trade-offs among the potentially conflicting requirements of the focal species given proposed management actions on the Sacramento River.

Project Task 4 will present project findings to CALFED, and groups such as the North of Delta Offstream Storage Technical Advisory Group and the Sacramento River Conservation Area Forum Technical Advisory Committee.

1.3 Workshop purpose

This workshop backgrounder describes the preliminary design of the Sacramento River DA Tool (Project Task 3). The main purpose of the upcoming workshop is to review and elicit feedback on this preliminary design from participants. The DA tool requires that the linked ecosystem components be explicitly defined, either quantitatively (e.g., mechanistic models, empirical relationships, or lookup tables) or qualitatively (e.g., conceptual or hypothesized relationships between a management action and the habitat performance measures for a focal species). Workshop participants will include individuals who have applied the existing physical / biological models, have a good understanding of the functional linkages among between management actions, habitat forming processes, physical habitats, and responses of the focal species, or are familiar with the data required to quantify these linkages.

Consulting with participants, we will review the DA tool at two scales: (1) a global level which reviews how individual model components relate to each other (e.g., whether model outputs from one component can be used as model inputs to another), and (2) a technical level which reviews the information required to link management actions to physical habitat or biological responses for one or more focal species (i.e., whether the proposed models, functional relationships, or data will appropriately provide these linkages). A review of the global design of the DA Tool will require interaction among all participants, whereas a review of the more technical details will require interaction among specialists during three breakout sessions: physical submodels; fish focal species; riparian vegetation / wildlife focal species. We will work with workshop participants to provide feedback on five key bounding issues:

Ecological objectives: What are the fundamental ecological objectives used to decide between flow-channel condition alternatives for the six focal species of interest on the Sacramento River (e.g., channel function, riparian condition, status of fish and wildlife habitat)? (see Box 1)

Performance measures: What performance measures best summarize the status of each ecosystem component under a given flow scenario? What specific inputs are required from other models or other data sources (e.g., important covariates) to generate these performance measures? How suitable is an output from one submodel at assessing the success in achieving one of the ecological objectives?

Management actions: What are the technical boundaries to manipulations of flow and channel conditions that can feasibly be integrated into the DA Tool? At this early stage we cannot anticipate the full range of management actions which the tool will be required to evaluate. However, it is critical to discuss boundaries to these alternatives so as to reliably test DA Tool components and ensure reasonable behavior of the linked submodels. Further refinement and selection of specific management scenarios will come later.

Spatial resolution / points of interest: Which river segments are represented by each submodel in the DA Tool? What are the implications of gaps in the spatial coverage of physical submodels for prediction of biologically relevant performance measures? Which river segments have the strongest and weakest overlap in coverage among submodels? What does a lack of overlap or good overlap imply about the inclusion of submodels in the DA tool? Which river segments are relevant for each focal species? What is the geographic extent over which a submodel or functional relationship can be reliably applied?

Temporal horizon and resolution: What are the critical life history periods for each focal species? Over what time periods will a submodel estimate the effect of alternative management actions? How well does the temporal resolution of one submodel link with the temporal resolution of other submodels?

Discussions of these five areas are critical to developing an ecologically relevant and scientifically defensible DA Tool. We discuss in more detail our current understanding of these issues throughout this document, but are looking for feedback to deepen and improve our knowledge at the upcoming workshop.

Box 1. Fundamental ecological objective used to guide development of the DA Tool

Fundamental objective: Restore and maintain the physical habitat conditions and flows required to recover and sustain valued ecosystem components of the Sacramento River, including fish, reptiles, birds, terrestrial and aquatic invertebrates, as well as riparian vegetation.

Clarification: Within this project, these ecosystem components are represented by six focal species with varying flow and habitat requirements: Chinook salmon (CH), steelhead trout (ST), green sturgeon (GS), bank swallow (BASW), western pond turtle (WPT), and Fremont cottonwood (FC). The DA Tool should permit an exploration of the effects of selected management actions on the key physical habitat attributes required to support each of these focal species.

2. Overview of DA Tool

2.1 What is the DA Tool?

Basically, the DA Tool is a model that quantitatively links management actions to changes in the physical habitats for various focal species on the Sacramento River. Quantitative linkages (i.e., models / functional relationships) provide the rules by which a management action will affect focal species or their habitats. Effects on the focal species and their habitats will be estimated using a series of performance measures that reflect the impact of the proposed management alternatives. It is important to point out that we are not attempting to build a tool that will make accurate predictions of ecosystem behavior or outcomes. This is generally not possible in complex, open natural systems (Oreskes et al. 1994). Rather, the tool's main purpose will be to characterize and explore potentially important ecological trade-offs and inform users about the possible relative impacts of various management alternatives. The tool is intended to act as a catalyst for deliberate or opportunistic adaptive management experiments that assess actual ecological responses that on a variety of spatial / temporal scales. This approach (model exploration of management alternatives and adaptive management experiments) will ultimately help CALFED, local resource experts, and stakeholders to converge on those options that strike a balance among a variety of potentially conflicting ecological objectives.

2.1.1 Trade-off evaluations

Complex decisions and associated trade-off evaluations are made easier when structured using formal approaches to evaluate management alternatives of interest to decision makers. Two structured approaches – formal decision analysis (Keeney 1982; Peterman and Anderson 1999; Clemen 1996) and PrOACT, a less formal method, (Hammond et al. 1999) – can be used for assessing trade-offs among different objectives, and for choosing either the management alternative that best meets these objectives (passive adaptive management) or a set of management alternatives which deserve to be formally compared (active adaptive management). On the Sacramento River, a tool to explore ecological tradeoffs is necessary to organize information and hypotheses about focal species and their habitat requirements into a rigorous framework for evaluating alternative management scenarios. Such a tool could then be used to help answer the following types of *hypothetical* questions:

> *Which alternative flow scenario (e.g., magnitude, frequency, timing, rate of change, and duration of flows) will best maintain natural river processes (meander migration processes, encourage oxbow cut-off) and maximize riparian recruitment and establishment over the next 20 years?*
>
> *What are the effects of gravel augmentation on the area of available spawning habitat for Chinook salmon?*

The project team is using PrOACT (Hammond et al 1999) as a basis from which to structure the tradeoff evaluations in the DA Tool. This approach is a simplified form of multi-objective decision analysis that provides a framework for dealing with a large number of objectives as represented by the numerous ecological attributes of interest on the Sacramento River. 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.

It is an iterative process that involves cycling over the development of alternatives, evaluating them, assessing tradeoffs, revising alternatives and then starting again, initially from a broad set of alternatives that gradually narrows to an acceptable choice or set of choices (Figure 2.1). This project will begin the iterative process of evaluating alternatives by providing a useful tool that can be used to continue that process in other forums.

ESSA has applied PrOACT successfully in the past and found it to be useful not only for selecting amongst alternatives, but also for keeping a record of alternatives as they are developed, assessed, and revised (Marmorek and Parnell 2002; Parnell et al. 2003).

Problem Definition describes the trigger that initiated this analysis. As mentioned in the introduction, decision makers on the Sacramento River are limited in their ability to evaluate the consequences of their decisions on ecological needs and then integrate these considerations into decision-making. Hence, the DA tool is being developed to help fill this gap.

Objectives are statements describing the desired condition or state of the system that decision makers want to achieve, or describe the most important considerations in a decision. Without clear objectives, it would not be possible to tell which management alternative is the best choice for the Sacramento River ecosystem. For many decisions a real challenge lies in balancing multiple and conflicting objectives. The first step in dealing with such a situation is to understand and describe the individual objectives associated with a decision problem. The focus *should* be on fundamental objectives — What would you like to achieve? The focus *should not* be on means objectives — How do you hope to achieve it? A manager can use a few simple questions to identify fundamental objectives:

What are some desirable ecosystem conditions?

What focal species, habitat units, or habitat-forming processes are of most interest?

What changes to the Sacramento River might occur that would be considered good or bad?

What elements of the Sacramento River ecosystem require restoration?

Alternatives represent the different options being considered as part of a decision. For this project, the alternatives are represented by the different combination of specific management actions (e.g., flow scenarios and gravel additions, as well as levee realignment and bank protection where possible). Management actions are activities under control of the decision makers that can be adjusted (today or in the future) in an attempt to meet specific objectives (see Section 2.2.2 for a discussion about management actions). Specific scenarios will be developed in the future with the input of local participants and CALFED staff.

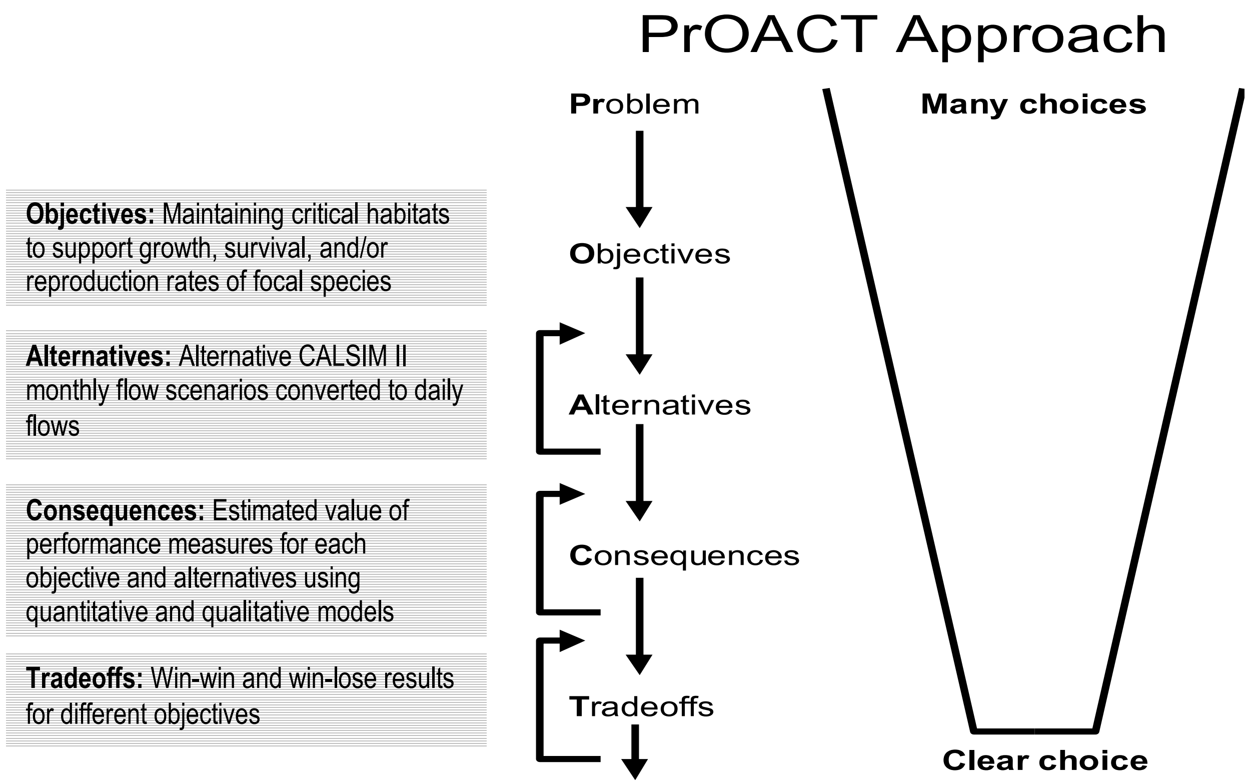

Figure 2.1. Flow of PrOACT process for narrowing the range of alternative choices.

Consequences depict the outcomes that inform comparisons among the alternatives. Consequences link to fundamental ecological objectives because they relate the performance of a decision to the level of success in achieving the stated objectives. Consequences are evaluated using quantifiable performance measures (PMs). Such measures are often found by considering things in the system that are: 1) important to local human populations (e.g., harvestable fish species), 2) have regional, national, or international profiles, or 3) if altered from their existing status, would be important in focusing management or regulatory policy (e.g., endangered species). To identify relevant performance measures, analysts can ask:

> W*hat fundamental variable(s) will inform whether decision makers have achieved their stated ecological objectives*?

Tradeoffs represent an explicit evaluation of the alternatives on the basis of how well they achieve the desired objectives. The structural framework and clear representation of tradeoffs among ecological objectives is the ultimate purpose and endpoint of the DA Tool. Typically, tradeoffs using PrOACT are presented in an "*Objectives by Alternatives*" format (e.g., Table 2.1), which is a useful way of summarizing information for decision makers. Objectives or performance measures that don't affect decisions can be removed from the table, simplifying decisions. Thoughtful weighting of the different objectives and sensitivity analyses may also be used to explore how the ranking of alternatives changes. The structure of the DA Tool and its representation of tradeoffs will necessarily evolve over the course of the project.

Table 2.1. Sample "*Objectives by Alternative*" matrix representing some preferred flow alternatives and critical objectives identified during the Cheakamus River Water Use Planning process (Marmorek and Parnell 2002). Alternative scenarios represent different dam operating regimes (i.e., flow scenarios) specified in terms of minimum flows during specific periods of the year. Performance measures are analogous to the outputs from the quantitative and qualitative models described in Section 3. IFA represents a benchmark flow scenario, termed the Interim Flow Agreement.

Fundamental Objectives	Performance Measures	Alternatives					
		Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	IFA
1. Maximize economic returns from power generation.	Average power revenue ($M/yr)	35.6	34.3	34.0	33.0	32.3	26.9
2. Protect integrity of Sqamish First Nations heritage sites and cultural value		Addressed by flood PMs and other studies					
3. Maximize physical conditions / access for recreation (kayaking, rafting, sportfishing).	Kayaking (Avg. #days/yr)	124	200	202	222	242	199
	Sportfishing (Avg. #days/yr)	58	83	142	125	193	107
4. Maximize wild fish populations	($m^2 \times 10^3$)						
RUA Resident Habitat	Rainbow Parr	35.8	42.5	42.5	42.5	42.5	40
Effective Spawning Area	Chum	9.8	9.7	9.7	9.5	7.3	6
5. Maximize area and integrity of aquatic ecosystem	Resident Riffle Benthic Biomass ($g \times 10^6$)	3.4	2.9	2.9	3.0	2.9	2.2

2.1.2 Building the DA Tool

The Sacramento River Decision Analysis Tool is being developed in six stages:

1. **Identify focal species, ecological objectives, and draft performance measures.** In the early stages of the State of the System report (Project Task 1), six focal species were selected to represent the Sacramento River ecosystem: Chinook salmon, steelhead, green sturgeon, bank swallow, western pond turtle, and Fremont cottonwood. These specific species were selected because they are important to managers, their habitat needs cover a broad range of habitat types found in the Sacramento River, and have distinct habitat requirements for which there are well-established functional relationships that can be integrated into the DA Tool. For example, these species and related life stages are dependent upon gravel spawning riffles, cutbanks, oxbows, side channels, point bars, deep pools, floodplains, and riparian forest and each of these habitat elements can be represented using available physical submodels in the DA Tool (see Section 3.0 for a description of the physical submodels that are available).
2. **Identify submodels for potential inclusion in the DA Tool.** Potential submodels relate management actions to habitats or conditions that influence the well being of focal species (as measured by changes in the performance measures) The project team has already identified

quantitative / qualitative models and functional relationships (plus some data sources needed to derive functional relationships) for potential inclusion in the DA Tool. As these models, and functional relationships are individual components of the broader DA Tool model, we describe them using the term "submodels". Submodel selection focused on those that estimate changes in habitat units supporting key life history stages of focal species (e.g., nearshore habitats that support juvenile salmonid rearing) or simulate the processes that help create and maintain those habitats (e.g., flow ranges that maintain appropriate water depths and velocities). We focused on habitat-based submodels to a greater extent than biologically-based ones because the physical submodels are required to relate management actions to changes in biological responses, as well as changes in habitats and conditions that are important to the focal species

3. **Review and refine preliminary design of the DA Tool with technical experts.** One of the most important steps will occur at a DA tool design workshop, where we will present a preliminary vision for the DA tool and review the submodels, identified during stage 1, with the technical experts who are most familiar with these components. We will then work with workshop participants through a structured process to evaluate the overall structure of the tool as well as the technical details behind each submodel. The design workshop will involve a structured set of exercises for model bounding (Holling 1978): reviewing management actions, performance measures, and spatial / temporal scales; making explicit the linkages among submodels; and specifying the inputs and functional relationships of each submodel.
4. **Construct DA Tool using clear design principles and careful prioritization.** Construction of the DA Tool will occur in stages based on the design principles and priorities (see Section 2.1.3). We will build the tool by integrating highest priority submodels first, and to the extent possible, progressively adding other components. At each stage of development, the effort and sequence involved in including additional submodels will need to be thoughtfully considered to ensure completion within time and budget constraints, reserving sufficient time for testing and analysis.
5. **Develop a set of flow and channel management scenarios to evaluate with the DA Tool.** Following construction and prototype testing, we will work with CALFED staff and local representatives to refine the set of flow and channel management scenarios (e.g., alternative flow regimes and gravel additions). We anticipate that these scenarios will be designed to test different combinations of management actions to assess their relative effects on the habitat requirements for each of the focal species.
6. **Evaluate defined management scenarios with the DA Tool.** An evaluation of the management scenarios with the DA Tool will quantify, and hence improve, our understanding of the various ecological trade-offs on the Sacramento River. Trade-offs among important habitat attributes for the focal species will be presented clearly to facilitate the use of such ecological information in external water supply planning, modeling activities, and other restoration planning efforts on the Sacramento River.

Overall, model building and development of the DA Tool will be an iterative process. Usually, the first iteration has many data and conceptual gaps that are filled by estimates. As such, we stress that the end use of the DA tool is not an entirely accurate prediction (rarely possible for any ecological model), but rather the representation of ecological tradeoffs to *rank* management alternatives being considered on the Sacramento River, identify critical uncertainties, and explore potential adaptive flow management experiments (either deliberate or opportunistic). The ecologically focused DA Tool will be used as a companion framework alongside other existing tools focused on the human need side of water deliveries in northern California (e.g., CalSim II).

2.1.3 Design principles

The DA Tool should allow exploration of trade-offs amongst key ecological components in a way that is clear to both specialists and non-specialists. The main technical product will be an integrated database, model engine, and user interface for presenting ecological trade-offs for a defined set of management scenarios. The main purpose of the DA Tool workshop is to refine our understanding of the spatial and temporal scale and resolution of individual submodels, and review the linkages among submodels so that these components can be built efficiently and linked effectively. Over time, this database, as well as the information management and reporting that it supports, will provide a foundation upon which additional submodels can be added as new relationships are developed. As well, the user interface and level of control over independent model runs within the framework of the DA tool may be refined. Our preliminary vision for the overall technical design of the DA Tool is represented by the structure shown by Figure 2.2.

The DA Tool will integrate the output of both existing models developed and applied to the Sacramento outside of this project (e.g., conversions of monthly to daily flows using a CALSIM II post-processor) and new models being developed or refined as part of this project (e.g., sediment transport and bed composition model, meander migration model).

There are six principles that we will consider when designing the DA Tool:

1. **Focus on 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 a DA Tool can be used to identify and visualize key ecological trade-offs instead of spending all resources cataloguing the entire ecosystem and racing 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 virtually all resources will have been spent in data inventory activities.
2. **Capitalize on existing submodels.** To the extent possible, we intend to integrate existing quantitative models, followed by existing qualitative models or other decision support tools (submodels listed in section 2.2.3). We may also analyze existing data to build new models (e.g., regression relationships) for other focal species, habitats, or habitat forming processes where appropriate and feasible. There are numerous quantitative and qualitative models available for the Sacramento River, so it will be necessary to prioritize integration of submodels based on:
   - a model's *relevance* to the ecological objectives (e.g., focal species) and management measures we intend to test (e.g., flow releases);
   - the *degree of support* there is for the functional relationship(s) that the submodel represents (i.e., the confidence we have in the model's validity);
   - the technical *feasibility* and *ease* of integrating a model or its output into the DA Tool; and
   - the *strength* and *reliability* of the source data used as a model's input.

   Based on these criteria, we have some idea about priorities for submodel inclusion (discussed in Section 2.2.3). However, priorities have not been finalized at this time and will require feedback from experts at the workshop and a better understanding of the available submodels and functional relationships, as well as additional data that may be useful.

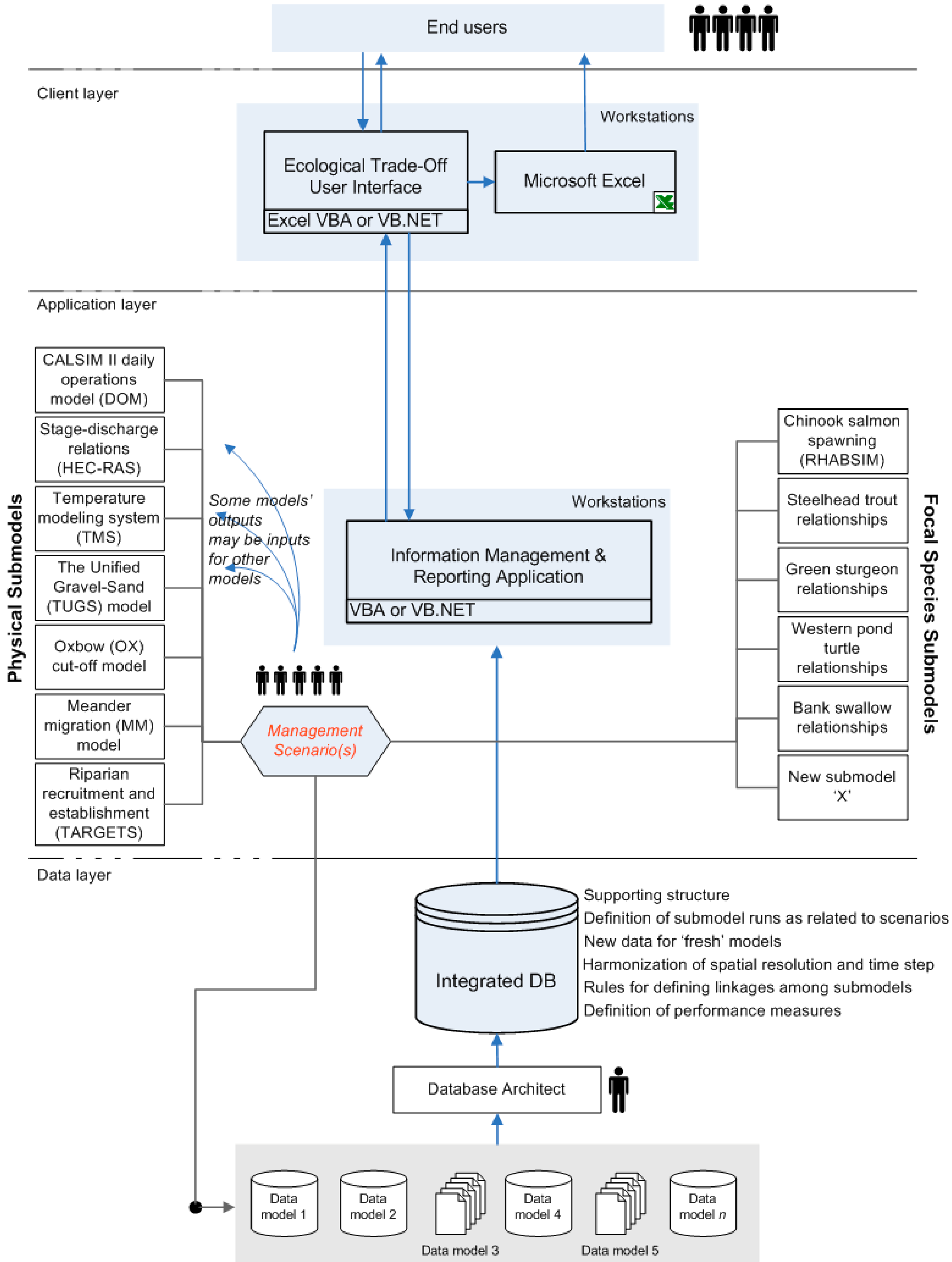

Figure 2.2. Preliminary technical design for DA Tool showing relationships between data, application, and client layers in the DA Tool.

3. **Develop a database for common model engine and flexibility to add additional submodels.** Linking together existing models with new ones to evaluate trade-offs for different scenarios requires a substantial level of planning. Given the potentially 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 a common way of defining locations and time-steps, linking output for submodels that are in common with a given point-of-interest and running scenarios to give key output in a useable format. To achieve this and significantly reduce likelihood of errors, we will design, construct and populate a relational database. This database will support an information management engine that will automate the Sacramento trade-off analysis to the greatest degree possible. Interpretation of model output will be essential.
4. **Develop an early prototype with a phased project life-cycle.** It is crucial that a first prototype of the system be up and running as quickly as possible, so that users can provide feedback and influence its focus and direction before development has proceeded to the point where making changes is more difficult. Developing and testing early prototypes can reduce the time and resources required to get a final version of the tool up and running.
5. **Use a flexible model architecture and object-oriented design.** The DA tool will incorporate software development strategies that maximize adaptability and ease of revision. The system architecture should follow a tiered design (see Figure 2.2) that separates the database (first tier) from submodel logic (middle tier) and any user interface (third tier) components (e.g., user reports). It should also use object-oriented design (OOD) within each of these components. The fundamental physical objects and processes represented by each submodel would be defined by classes that can be inherited and extended, then instantiated to take on specific parameter values and behaviors (i.e., different scenarios) and rapidly passed *en-masse* into the fundamental algorithms needed to produce the desired outputs. This type of programming strategy will greatly assist in efficiently automating flow and channel management scenarios and the “plugging-in” of future submodels.
6. **Produce output reports that are readable using widely held applications.** To simplify communication and dissemination of results and reduce costs, the reporting tool used to manage queries against the relational database should produce reports that are readable in common software applications such as Microsoft Excel. This typically reduces development costs associated with the alternative of tedious manual generation of output or programming / customizing third party reporting products.

2.2 What are the boundaries of the DA Tool?

2.2.1 Ecological objectives and performance measures

We compiled a list of potential relevant ecological objectives being discussed in a variety of management forums (Table 2.2) and identified the related performance measures by following three steps. First, we selected six focal species (Chinook salmon, steelhead trout, green sturgeon, bank swallow, western pond turtle, and Fremont cottonwood) while reviewing information for a separate document being prepared within this project, the State of the System (SOS) report. Second, building on our understanding of the key life history needs and habitat requirements developed during the development of SOS report, we identified those data and models that could be used to estimate the response of the focal species and their habitats to changes in management. Finally, we prepared statements (Table 2.2) describing ecological objectives that relate to the six focal species and the physical processes that create and maintain their habitats. These statements focus on critical habitat requirements for each focal species and can be represented by quantifiable performance measures.

Table 2.2. Description of the *potential* ecological objectives as related to the focal species, *potential* performance measures that may be used to measure progress towards the objectives, and *potential* management actions that may be used to evaluate effects on ecological performance. Not necessarily all of these actions, objectives, and performance measures will be integrated into the DA Tool. Inclusion will depend on how well we understand the linkage between a management action and biological or habitat performance.

Focal species	Management actions	Ecological objectives	Performance measures
Chinook salmon (CH)	▪ Flow management ▪ Gravel additions	(1) Maximize quality of habitats for adult spawning (2) Maximize quality of habitats for egg incubation (3) Maximize availability and quality of habitats for juvenile rearing (all runs)	▪ Substrate composition ▪ Area of suitable spawning habitat ▪ Redd scour / depth ▪ Area of suitable rearing habitat ▪ Connectivity to off-channel rearing habitats ▪ Index of juvenile stranding ▪ Egg-to-fry survival rate
Steelhead trout (ST)	▪ Flow management ▪ Gravel additions	(1) Maximize quality of habitats for adult spawning (2) Maximize quality of habitats for egg incubation (3) Maximize availability and quality of habitats for juvenile rearing	▪ Substrate composition ▪ Area of suitable spawning habitat ▪ Redd scour / depth ▪ Area of suitable rearing habitat ▪ Connectivity to seasonally connected rearing habitats ▪ Index of juvenile stranding ▪ Egg-to-fry survival rate
Green sturgeon (GS)	▪ Flow management ▪ Gravel additions	(1) Maximize quality of habitats for adult spawning (2) Maximize quality of habitats for egg incubation	▪ Area of suitable spawning habitat ▪ Egg-to-larvae survival rate
Western pond turtle (WPT)	▪ Flow management ▪ Levee setback	(1) Maximize availability and quality of nesting habitats (2) Maximize availability and quality of habitats for foraging, basking, and predator avoidance (3) Maximize nesting success	▪ Area / connectivity of off-channel habitats ▪ Timing / height of flooding and nesting ▪ Area of suitable nesting habitat
Bank swallow (BASW)	▪ Flow management ▪ Bank protection ▪ Levee setback	(1) Maximize availability and quality of nesting habitats (2) Maximize nesting success	▪ Length of vertical bank with suitable soil texture for nesting ▪ Ramping rates ▪ Timing / height of flooding and nesting ▪ Area of suitable nesting habitat
Fremont cottonwood (FC)	▪ Flow management	(1) Manage stage and rate of stage decline during focal species seed dispersal periods at critical index habitats to improve seedling survival	▪ Zones of successful riparian recruitment (on representative cross-sections) for specific tree species in summer/fall.

2.2.2 Management actions

Based on the anticipated effect on the focal species and our ability to estimate habitat and biological responses, we identified two tiers and four types of management actions that may be integrated. *Tier I* actions include flow management and gravel augmentation, while *Tier II* actions include changes in levee setback and bank protection. Table 2.2 aligns each of these actions with the focal species. Not necessarily all of these management actions will be considered for each focal species. The specific actions that are considered will depend on the level of information available to quantify the link between a management action and habitat or biological response, as well as the level of effort required to integrate such relationships into the DA Tool.

For Tier I actions, we are focusing on flow management to the greatest extent possible because the primary intention of the DA Tool is to provide ecological information about alternative flow scenarios for water planning forums. As well, we are including gravel augmentation because such actions can be integrated more confidently into the DA Tool than Tier II actions.

Tier II actions are somewhat more terrestrially based. It is logical to include these action because of the high degree to which they are inter-related to river flow. However, these actions are not the focus of this project. Therefore, we may consider these actions at only a few locations within the Study Area where relationships with habitat and biological responses have been well defined, and they have a high degree of management relevance.

2.2.3 Submodel definitions and looking outward

The DA Tool will use a series of well-quantified physical models to describe the physical foundation to the Sacramento River ecosystem. Outputs from these models can then be used to describe changes in the critical habitats for the focal species. In most instances, the functional relationships between physical habitat variables and habitat requirements for the focal species are not well quantified. Thus quantification of these relationships is a key step in developing the DA Tool and an important discussion topic at the workshop.

Table **2.3** summarizes the list of submodels (or functional relationships) available for potential inclusion in the DA Tool. In developing this list of components, we evaluated each submodel based on their ability to evaluate the management actions being considered, the spatial and temporal overlap with other DA Tool components, and the estimated level of effort required for integration. Other models were reviewed, but did not meet these requirements and have not been included here. Three sources of information helped develop this list of submodels:

a) review of available submodels during the SOS report in Project Task 1 (e.g., CALSIM II daily operations model, USBR temperature modeling system, RHABSIM);
b) project specific submodels being developed or refined as part of Project Task 2 (e.g., sediment transport and substrate composition, meander migration, and chute cut-off models); and
c) new empirical and/or qualitative relationships derived from information or data identified during the preparation of the SOS report, provided at the design workshop, or collected during the field studies.

These submodels model the relevant performance measures at one of three levels of rigor (e.g., Figure 2.3):

1. conceptual models or hypotheses, with weak empirical support, that link the life history requirements of focal species with habitat availability and ecological processes, through qualitative ‘rules’;
2. models of limiting factors that identify critical life history stages and habitats for focal species, with a moderate level of empirical support; and
3. quantitative models with a high level of empirical support that relate habitat quality and availability to the survival, growth, reproduction, or abundance of focal species.

Table 2.3. Complete list of the submodels being *considered* for inclusion in the DA Tool. For each submodel we have identified the focal species to which it may be related, briefly described the relationship being quantified, listed some important covariates, and suggested priorities for inclusion. Priorities are based on a consideration of the criteria presented in Section 2.1.3.

Focal Species		CH										
Submodel	**Priority**	**Spring**	**Fall**	**Late-fall**	**Winter**	**ST**	**BASW**	**WPT**	**GS**	**FC**	**Description of relationship(s)**	**Covariates not modeled and assumed to be constant, but potentially changing and affecting outcomes**
Q_monthly (CALSIM II)	H	X	X	X	X	X	X	X	X	X	Water operations model looking at allocation of monthly flows across space	
Q_monthly-Q_daily (DOM)	H	X	X	X	X	X	X	X	X	X	Conversion of CALSIM II monthly flows to daily flows (daily operations model – DOM)	
Q-channel migration (MM)	H						X	X		X?	Meander migration (MM) model that relates discharge and bank strength to changes in channel migration	Local geology and soils, bank protection, land use
Q-chute cut-off (OX)	H		X?					X?			Oxbow cut-off (OX) model that relates discharge to creation of chute cut-offs	Local geology, soils, bank protection, vegetation
Q-sediment-substrate (TUGS)	H	X	X	X	X	X			X?		Sediment transport and substrate composition model (The Unified Gravel-Sand model – TUGS)	Channel cross-sections, watershed sediment supply, local hydraulics
Q-water temperature (USBR TMS)	H		X	X	X	X			X?		USBR temperature modeling system relating flow to water temperature throughout the upper Sacramento	Implicitly assumes historical range of air temperature
Q-stage (HEC-RAS)	H	X?	X?	X?	X?	X?	X?	X?	X?		Stage-discharge relations from a variety of studies on upper and lower Sac. TNC is compiling this information.	Channel cross-sections
Q-riparian (TARGETS)	H									X	Relationship between flow and riparian recruitment and establishment	Local soils, groundwater extraction
Q-bed composition	M		X?	X?	X?	X?					Effect of discharge on grain size distribution (using TUGS) and the resulting effect on survival-to-emergence (not as strong of a link?)	Watershed sediment supply??
Q-spawning habitat (RHABSIM)	H		X (+River2D)	X	X	X					Physical salmonid habitat simulation model (RHABSIM only models spawning, River2D also modeled spawning for fall run)	Gravel additions and peak flow events altering channel
Gravel-spawning area	L		X?	X?	X?	X?					Effect of gravel additions on amount of spawning habitat (and egg mortality due to redd superimposition – link available??)	
Q-redd scour	H		X?	X?	X?	X?					Relationship between discharge and scour (plus effects of gravel augmentation)	
Q-temp-survival	M		X	X	X	X					USBR salmon mortality model (can't use as is, may be able to extrapolate relationships)	Air temperatures
Q-rearing habitat (River2D)	H	X	X	X	X	X					Physical salmonid habitat simulation model (River2D mainly considers rearing)	Gravel additions and peak flow events altering channel, cross-sections, and substrate
Q-stranding	L	X?	X?	X?	X?	X?					USFWS juvenile salmonid stranding surveys	

Submodel (Focal Species)	Priority	CH Spring	CH Fall	CH Late-fall	CH Winter	ST	BASW	WPT	GS	FC	Description of relationship(s)	Covariates not modeled and assumed to be constant, but potentially changing and affecting outcomes
Q-habitat connectivity (side channel, floodplain, oxbows)	L	X?	X	X?	X?						Three relationships: a) Discharge and side channel habitats (used by fall-run fry only) b) Discharge (high flow events) and inundation of floodplains and bypasses c) Discharge and connection to oxbow habitats	Characteristics of non-modeled areas (depth, velocity, temperature residence time of floodplain/oxbow, off-channel areas)
Q-bank-nesting	H						X				Relationship between high flows and bank erosion to create vertical banks	Soil type (location and texture), colony size and age, bank length, bank height, bank slope, adjacent habitat (e.g., grasslands)
Q-timing-stage-nesting	M						X				Coincidence in timing of high flows and nesting activities of colony	Soil type, bank height, bank slope (and effect of low flows on slumping)
Bank-nesting	L						X				Potential nesting habitat available with changes in bank protection	Soil type (location and texture), colony size and age, bank length, bank height, bank slope, adjacent habitat (e.g., grasslands)
Q-off-channel-basking and foraging	H							X			Relationship between off-channel habitat creation and potential rearing areas	Aquatic vegetation, predators, water quality
Q-timing-stage-nesting	L							X			Coincidence in timing of high flows and peak breeding at specified nesting locations (can be some distance from water)	Soil moisture, soil type, slope, adjacent habitat (e.g., grassland or other herbaceous veg), existing nests, distance from water
Q-floodplain-nesting	L							X			Relationship between age of floodplain and continuity of nesting habitat	Soil moisture, soil type, slope, adjacent habitat (e.g., grassland or other herbaceous veg), existing nests, distance from water
Q-levees-nesting	L							X			Effect of levee changes on inundation of existing nesting sites	Soil moisture, soil type, slope, adjacent habitat (e.g., grassland or other herbaceous veg), existing nests, distance from water
Q-temp-egg survival	H								X		Relationship between water temperatures (using TMS) and hypothesized green sturgeon incubation	
Q-gravel-spawning	L								X		Relationship between discharge, substrate, depth, velocity and suitability of habitat for spawning	

A critical bounding and integration issue for the DA Tool is to consider the kinds of information a submodel needs to receive as inputs (i.e., outputs from other submodels, covariates that may change and affect outcomes but are not modeled to keep the scope reasonable, and/or attributes of a management scenario) and the potential outputs that are available (either as outputs to other submodels or to use as performance measures) (Figure 2.4). This process requires "looking outward" from the perspective of each submodel. Figure 2.5 represents our conceptual overview of the DA Tool and the relationship among potential submodel components. Details about the individual submodel components are provided in Section 3.

2.2.4 Spatial and temporal horizon of interest

An essential issue for bounding the DA Tool and its components is to define the spatial boundaries of the system and the temporal horizon over which managers wish to consider the effects of their decisions. Submodel boundaries are discussed in Section 3. We recognize there are three ways to describe the areas that can define the spatial extent or geographic scope of this project:

Area of interest — *What is the overall study area that people care about?* Our project study area extends along the upper Sacramento River from Colusa (RM 143) to Keswick Dam (RM 302) (Figure 2.6).

Area of field studies — *What are the locations of the field sample sites that are relevant to the DA Tool?* These locations are unique to the field studies being conducted in Project Task 2. Three field studies will provide information and/or quantitative relationships for the DA Tool: a) gravel studies, b) bank protection studies, and c) oxbow biological surveys.

Points of interest that are quantitatively / qualitatively modeled — Each quantitative model will be calibrated using data from various sites and will provide estimates of habitat performance measures at these unique locations. Hence:

> *What representative sites can be used in the quantitative models?*

The location of model predictions may not coincide with field study sites, and models may have been developed for areas other than the project study area.

Decisions on the temporal horizon of the DA Tool would involve the following types of questions:

> *How long into the future do we need to run a submodel to understand the consequences of a particular management action?*
>
> *What is the appropriate duration of flow years to be used in management scenarios to capture natural environmental variation?*

The answers to all such questions are unique to each submodel and performance measure. Typically, some variables change quickly (e.g., changes in flow and stage-discharge relations) while others take longer periods of time to achieve a dynamic equilibrium with changes in flow years (e.g., creation of oxbow habitats, riparian vegetation). As well, there will be some periods within a year that are of interest for a focal species due to the anticipated timing of activity for a particular life stage (Figure 2.7).

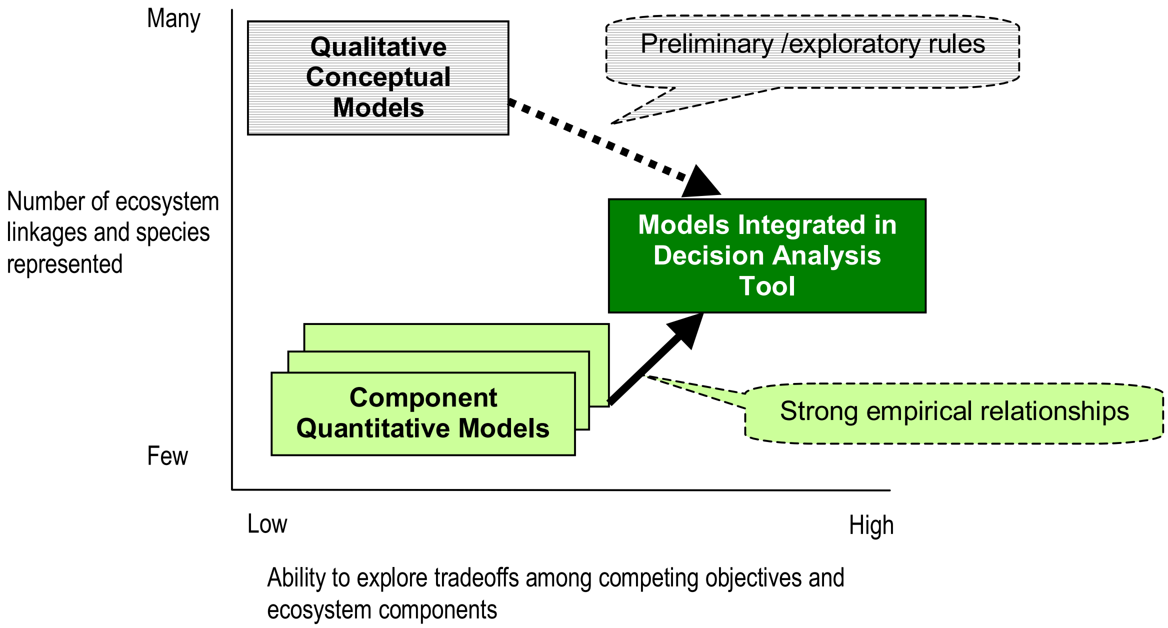

Figure 2.3. Representation of quantitative and qualitative submodels and their ability to be integrated into a tool to evaluate ecological tradeoffs. Well defined quantitative models usually focus on a single ecosystem processes or species, whereas more qualitative or conceptual models are better able to describe a number of ecosystem components and species requirements. Each of these types of models can operate independently — offering few insights to decision making —or they can be integrated to in a single framework, such as the DA tool proposed here, to provide much greater insights for decision makers.

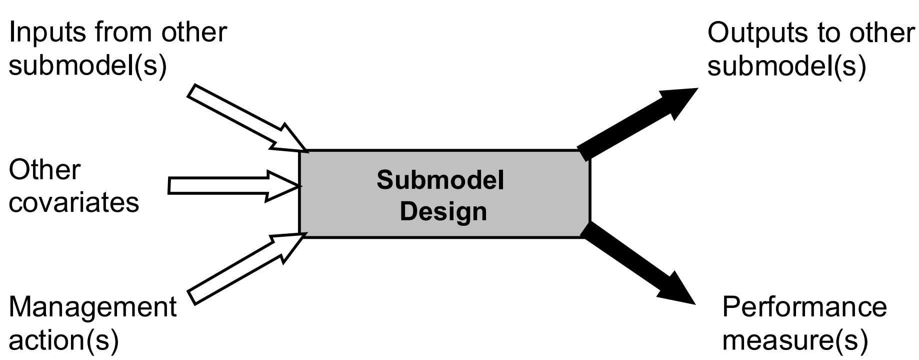

Figure 2.4 Representation of the relevant inputs to a submodel (e.g., output from other submodels, covariates assumed to be constant, description of the relevant attributes of the management actions being evaluated) and outputs available for other uses (e.g., other submodels, performance measures for trade-off evaluation).

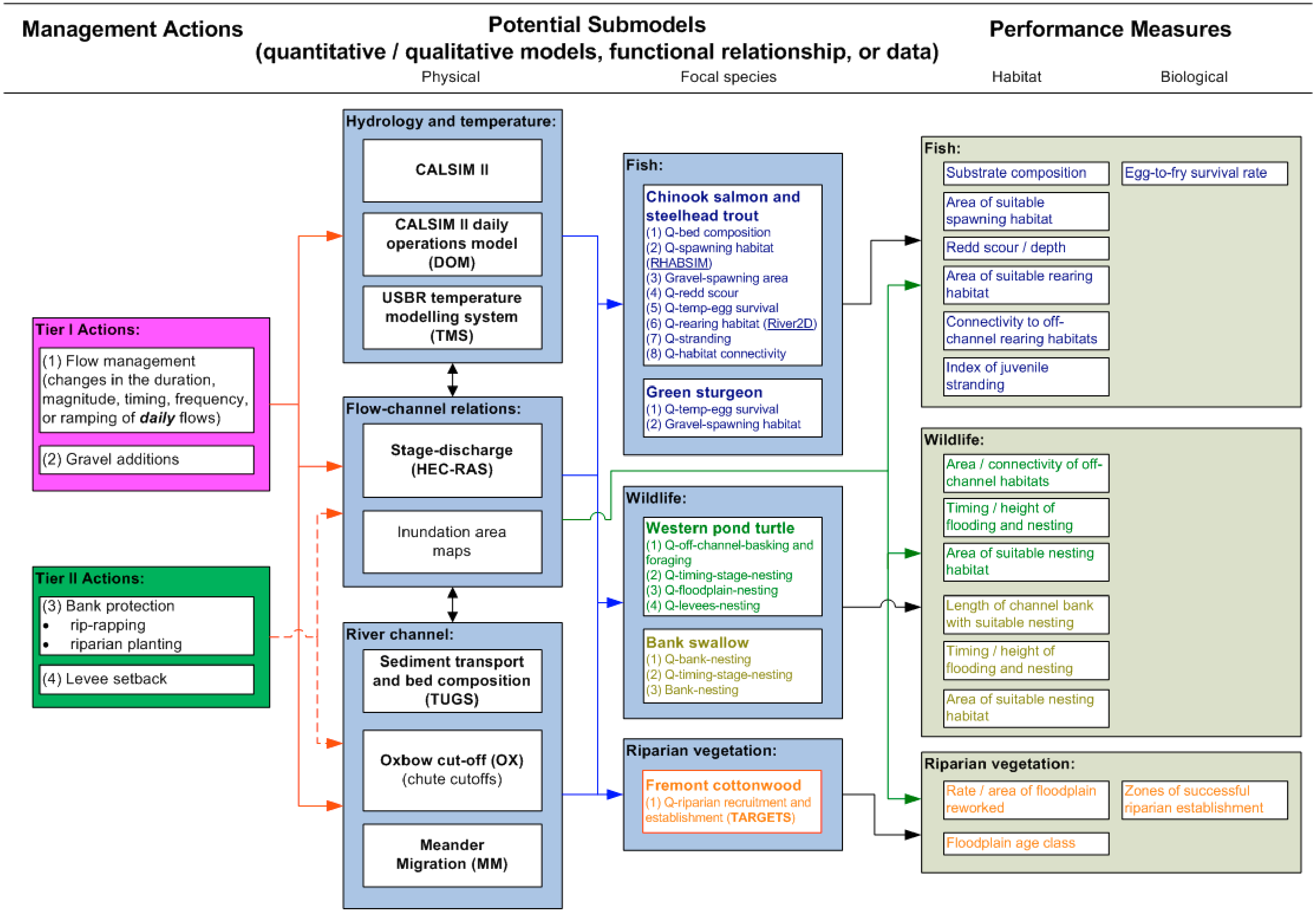

Figure 2.5. Conceptual model representing the linkages among management actions, submodels, and performance measures being *considered* for inclusion in the Sacramento River Decision Analysis Tool.

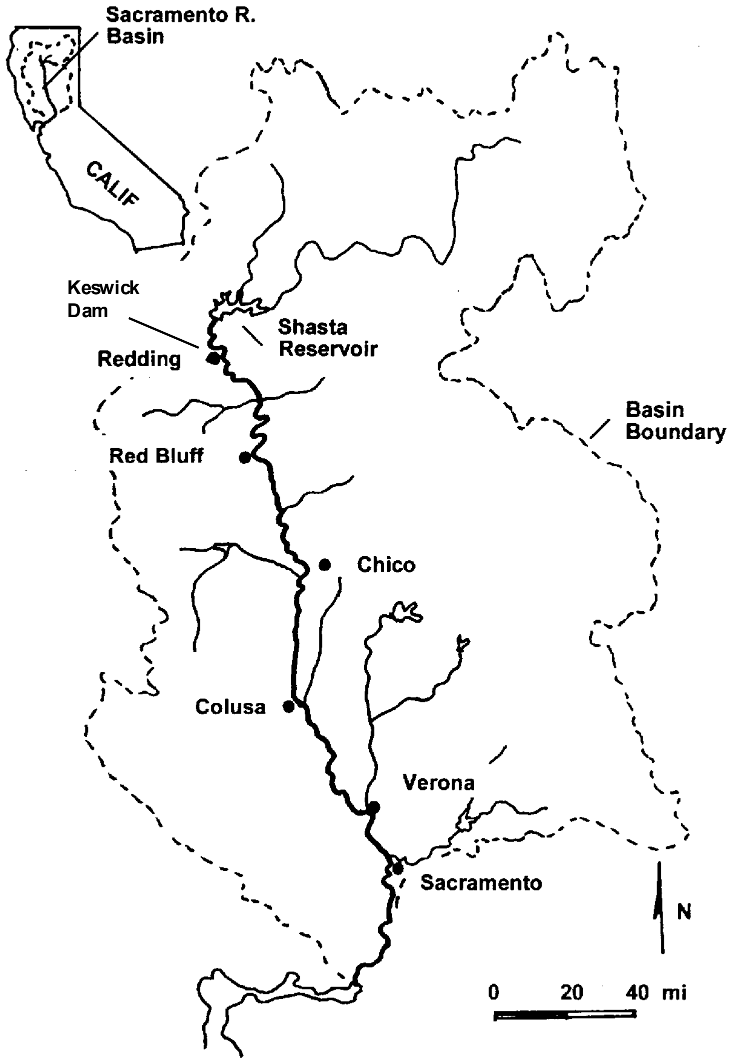

Figure 2.6. Map of the Sacramento River watershed and the study area over which the decision analysis tool will be applied. The project study area extends from Keswick Dam (RM 302) to Colusa (RM 143) (Source of map: CALFED Bay-Delta Program 2000).

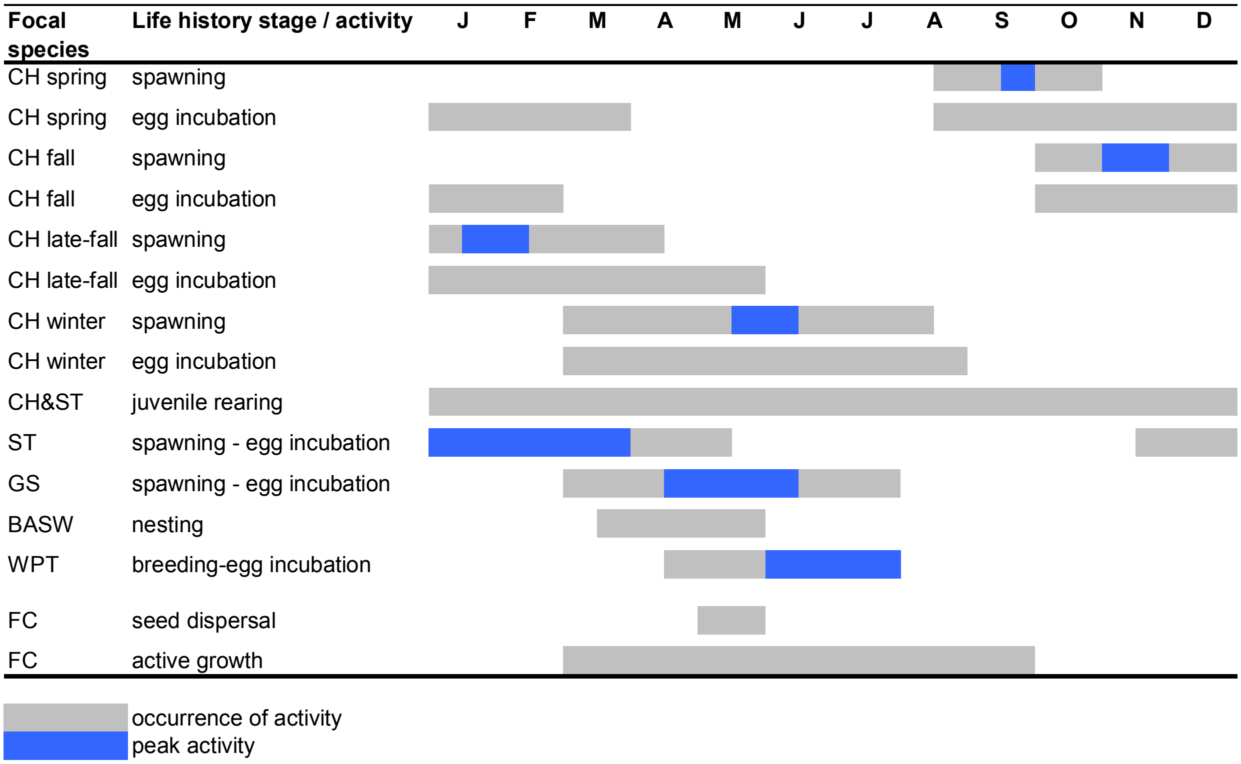

Figure 2.7. Diagram representing the life history timing for some of the important life stages of the focal species. Note the data on life history timing for spring-run Chinook are derived from tributary populations because there are no data available for mainstem spawning. The spring-run incubation period stretches longer than fall-run, even though they start spawning earlier, most likely because these data include populations from both the Mill/Deer Creek and Big Chico/Butte Creek systems – streams that are colder than the Sacramento.

2.2.5 Spatial and temporal resolution of submodels

We also need to define the spatial and temporal resolution of the DA Tool components. One way of thinking about spatial resolution is to ask technical experts which spatial locations are quantifiable using a particular submodel. These locations may be different across submodels, requiring either aggregation or interpolation of submodel outputs. As a first step in clarifying the spatial structure of the DA Tool, we took the list of individual submodels and asked:

> *For what portions of the area of interest does this model output relevant performance measures (Figure 2.8 – y axis)?*

At the workshop we will compare Figure 2.8 with a discussion of where managers would like to know about a particular performance measure.

Model time-step is another important issue bounding the DA Tool, and requires asking:

> *Should we model various processes on an annual, monthly, weekly, or even a daily time step, given both the rates of change of system components, and the current state of knowledge?*

Again, the answers to these questions usually depend on the variables in question. On the x-axis of Figure 2.8 we summarize the temporal resolution of individual submodels in the DA Tool. Figure 2.8 summarizes both the spatial bounds and temporal resolution of the primary submodels being considered for the DA Tool.

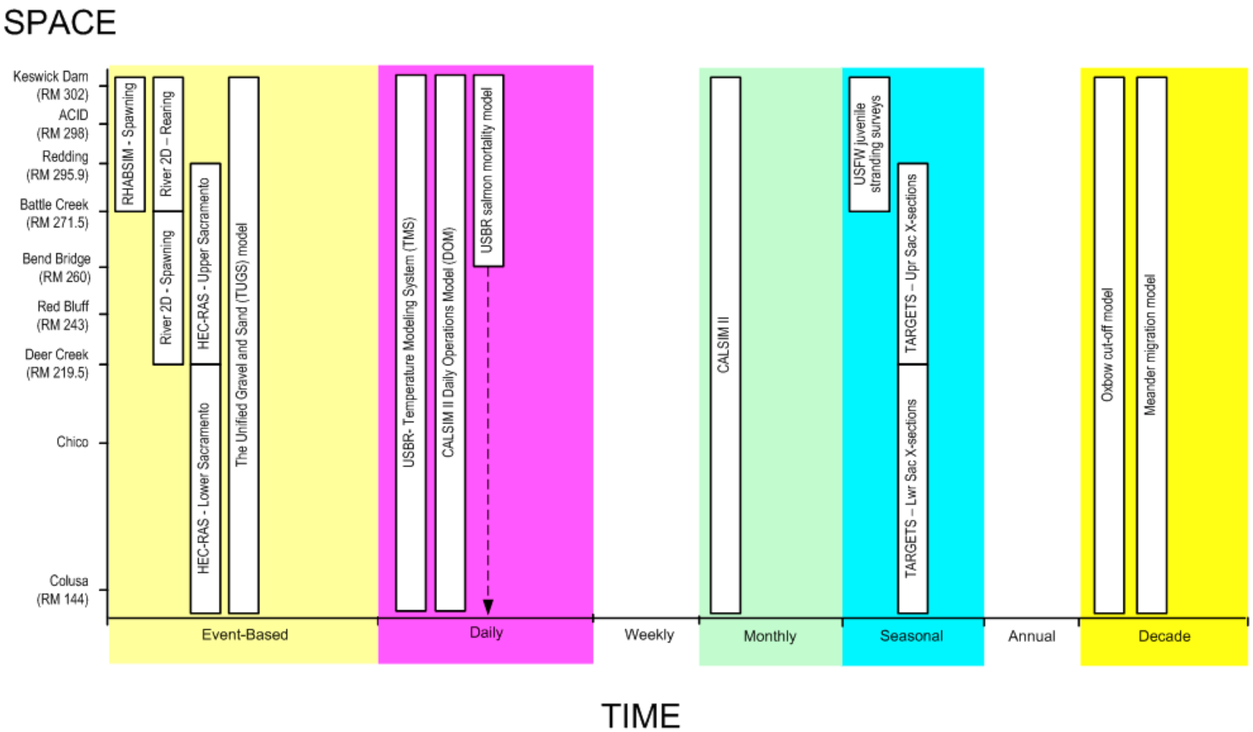

Figure 2.8. Mapping of the spatial bounds and temporal resolution of existing submodels. The spatial resolution of these submodel is discussed in Section 3. Only predefined models have been included here. Other focal species' functional relationships need to be added at the workshop.

3. Components of DA Tool

This section serves as a blue print for constructing the tool by describing the study team's understanding of the models, functional relationships and datasets that, after preliminary feasibility review remain as candidates for inclusion in the DA Tool. We start by summarizing the physical submodels (Section 3.1) that have been reviewed and short listed as likely candidates for inclusion in the software to support the information needs of the six focal species on the upper Sacramento River. We then discuss the additional information available to represent the linkages among management action, habitat forming processes, physical habitats, survival mechanisms, and critical life stages for the focal species (Section 3.2). Quantification of these linkages for the focal species relies heavily on the physical submodels presented below.

Note Section 3 synthesizes information compiled in a series of model summary and focal species memos provided by Stillwater Sciences, as well as a review of available models by ESSA Technologies.

3.1 Physical submodels

3.1.1 Hydrology (Historical flow records + CalSim II Daily Operations Model)

Model description

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.

Users of CalSim software represent various operational constraints and weights via a proprietary programming language (called WRESL). A linear programming solver then routes water though the hydrosystem network given the pre-specified objective function (including user priorities or weights). A challenge with CalSim's rule-based approach is that it can be time consuming to optimize the objective function and it must be refined through repeated simulation. Because of this, some reviewers of CalSim have noted that it can be difficult to reproduce the models results exactly (Ferreira et al. 2005). In the end, CalSim is a model for a complex system that requires considerable expertise to implement and interpret (Ferreira et al. 2005).

A common criticism of CalSim is its monthly time-step, which cannot capture finer hydrologic variability adequately. This is the primary limitation that must be addressed in order for CalSim to be used within the DA tool. 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; the major difference being the use of a disaggregation approach to address the existing monthly hydrology. In addition, the DOM is capable of applying hydrosystem regulation rules more directly, due to the use of a daily time-step. 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. Calibrations are ongoing, emphasizing work on upstream disaggregation routines (Daniel Easton, personal communication, 2005).

Another utility tool exists for converting CalSim II monthly hydrology to daily flows called "CalSim25Q". This utility has been used in conjunction with the HEC-5Q model (a model used to simulate the water temperature responses in the Upper Sacramento River and associated reservoirs). While very little documentation is available, our understanding of the CalSim25Q procedure is that a typical annual volume distribution and minimum release pattern are developed from historical data and used to disaggregate CalSim II monthly flows. However, it does not track Delta conditions (exports, water quality, outflow requirements, etc.) the way the DOM does and, therefore, does not account for North of Delta (NOD) reservoir operations governed by Delta needs. Since, NOD reservoirs are often being operated for NOD in-stream flow requirements, temperature control and flood control often have little to do with Delta requirements. Moreover, it often happens that releases for upstream needs are sufficient to meet those in the Delta (Daniel Easton, personal communication 2005). However, when there is a Delta water quality problem or an X2 Delta outflow trigger, responding NOD reservoir releases can be significant and the CalSim25Q tool does not capture these dynamics.

Developers of CalSim25Q maintain reservoir flood pools and model results can be post-processed to ensure that that reservoir releases meet NOD in-stream flow requirements (Daniel Easton, personal communication 2005). Further discussion with experts on CalSim25Q like Don Smith or Russ Yaworsky are needed for more accurate description of CalSim25Q and to make comparisons of strengths and weaknesses between it and the DOM.

The DA tool will also permit bulk importing historical daily stream gage records. Hence, the hydrology component of the model will operate in two modes: 1) retrospective using historical data; and 2) prospective using some form of disaggregated CalSim output. This will also speed initial prototype development and testing, avoiding being hamstrung by technical issues that exist coding a utility routine for bulk import or in-memory manipulation of CalSim DSS files.

Spatial horizon and resolution

The spatial horizon for the DA tool is the mainstem Sacramento River from Keswick Reservoir (RM 302) to Colusa (RM 143). The spatial resolution of the hydrology component of the model is at two levels: (a) *point based* for real stream gages/recorders; and (b) *segment based* (i.e., river mile start and end) when provided by CalSim (Figure 3.1).

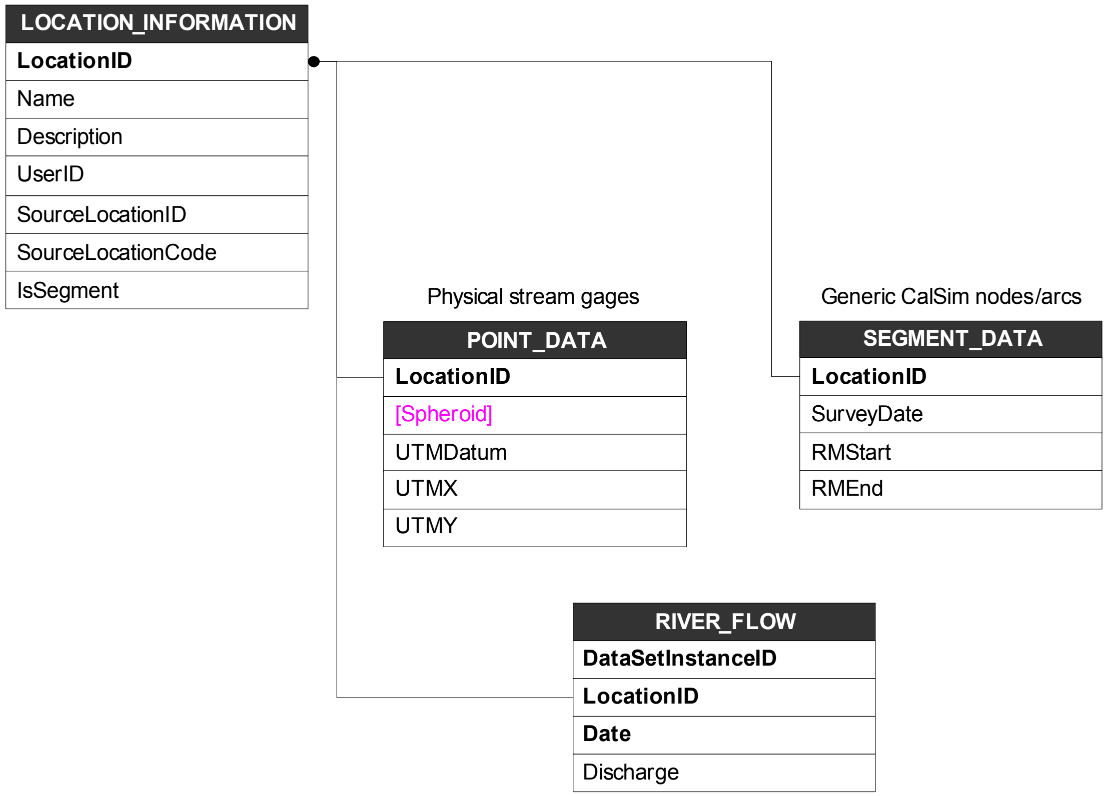

Figure 3.1. Proposed relational database design used by the DA tool for location information. (For simplicity, some fields are not defined).

CalSim II models all areas that contribute flow to the Delta, including the Sacramento River Valley, the San Joaquin, and the upper Trinity River. The network includes over 300 nodes and over 900 arcs, representing 24 surface reservoirs in the hydrosystem (Draper et al. 2004). The schematic for the DOM was designed to minimize the number of nodes and arcs while maintaining a mass balance upstream of key points of operation (reservoirs, in-stream flow requirements, etc.). Hence, the CalSim II DOM models a simplified CalSim II system, by aggregating nodes and arcs. This reduces the number of system constraints and the linear solver solution time. So while there are approximately 28 CalSim II nodes/arcs of interest in the Sacramento ecological flow study (C5, C103-C105, C108-110, C112-118, C122-129, C134,C160, C162-C163, and C165-166) only a fraction of these are available in the DOM (Daniel Easton, personal communication 2005). Further reviews of the CalSim II DOM schematic will determine the appropriate nodes/arcs for the DA tool.

It is important to note that the DOM and CalSim will not be used for point-scale predictions of flows on the Sacramento River. Instead, they will be used to determine a representative flow along an aggregated river reach and used for comparison rather than predictive purposes. Hence, identification of these reaches may involve specifying river mile start and end points instead of a precise point location as is possible with a stream gauge.

Temporal horizon and resolution

CalSim II can simulate operation of the CVP-SWP system from October 1922 to the near present (~1994), using a monthly time-step. CalSim II's DOM "appendage" disaggregates monthly results into a daily time-step. **Daily time-step results are required when considering ecological implications of alternative time and place hydrographs.** Hence, we plan to leverage the DOM (or CalSim25Q) extension to CalSim II.

Inputs

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.

By design, the Sacramento DA tool will require no pre-requisite knowledge or experience in the operation of CalSim. DA tool users will instead be tasked with aligning model assumptions between a given CalSim run and other "downstream" physical models, such as those used to provide water temperature information.

Outputs

CalSim II's time-series outputs are stored using the Hydrologic Engineering Center's Data Storage System (HEC-DSS) (USACE 1995, as cited in Draper et al. 2004) (Figure 3.2). This data can be viewed as charts or tables.

Considering CalSim's level of complexity and sophistication, ESSA's proposed architecture for *prospective* analyses involves automating the import of CalSim DOM results into a relational database (e.g., Figure 3.1). Alternatively, an on-demand, in memory routine may be developed to work directly with the DSS time-series files. (This decision depends on speed/performance and storage considerations that remain to be explored). Regardless, our software architecture does not contemplate an interactive interface for working directly with CalSim, HEC, DOM or any other software. Rather, our approach can be thought of as an "Eco-Plug-in" to CalSim (and other models) that is capable of revealing the ecological implications of a particular operational regime.

When using a particular CalSim DOM result set, the Sacramento DA tool will provide basic validation to ensure that other dependent models such as water temperature outputs align (as best as possible) with the operations and embedded assumptions associated with a particular CalSim result. Otherwise, the ecological consequences will be badly in error due to use of "apples and oranges" inputs from non-aligned physical models. **These inter-dependencies are an important subject of discussion during review of the proposed design**.

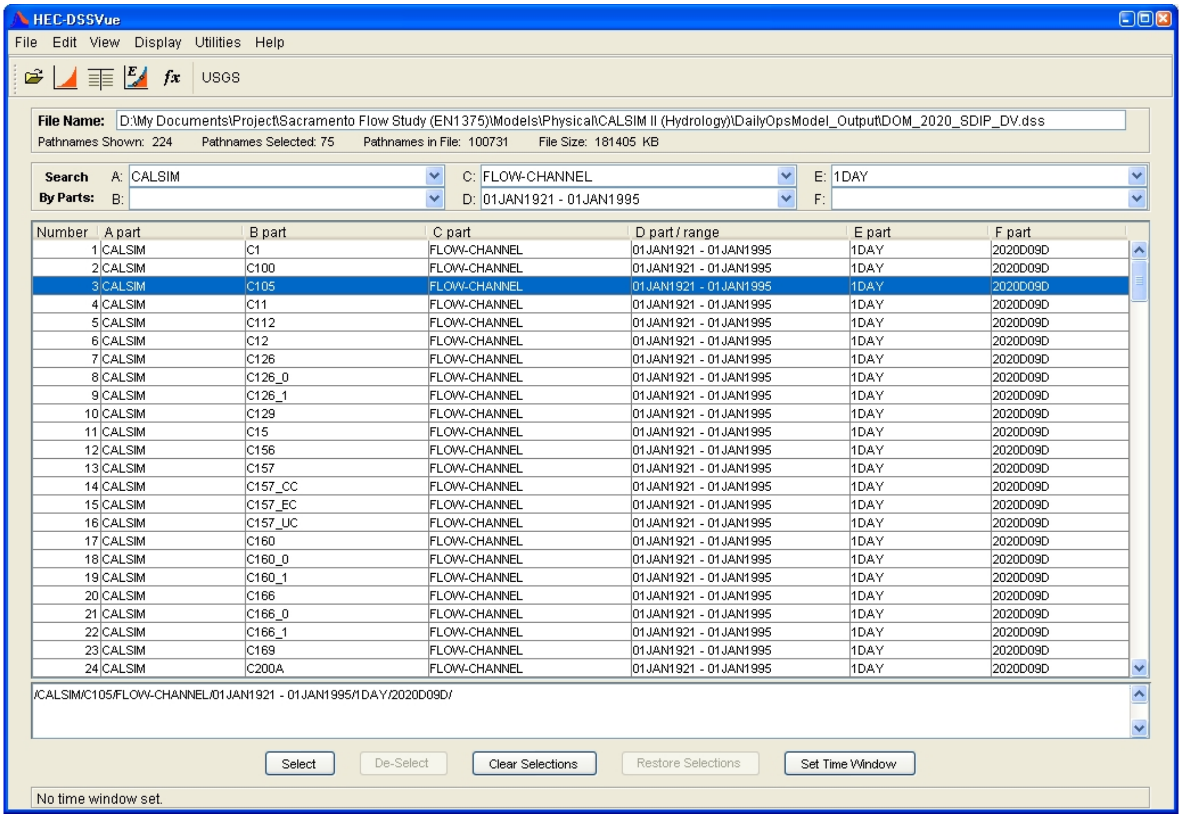

Figure 3.2. HEC-DSS Vue software for viewing and exporting binary DSS file results from CalSim.

3.1.2 Water temperature (USBR-TMS / HEC-5Q)

Model description

To this point, the role of water temperature modeling has not been widely reviewed by the study team. However, we suspect this information will be important for informing on spawning success and early life-history survival for certain fish and wildlife species. Most likely, temperature model results will be most relevant to Chinook spawning and egg incubation. Water temperature relationships are one of the few ecological relationships presently accounted for in current water operations management, largely due to its recognized importance on salmon survival-to-emergence.

A preliminary review has been completed for the USBR Temperature Modeling System (USBR-TMS or TMS) under development by RMA (Water Course Engineering 2003). The overall framework promises to be a powerful framework for USBR staff for both planning and operational studies. Critical features of TMS 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 TMS (Water Course Engineering 2003).

Specifically, HEC-5Q is the central element to the “Temperature Modeling System (USBR-TMS) software (RMA 2003). The HEC-5Q 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 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. HEC-5Q also leverages a pre-processor program (CalSim25Q) to convert CALSIM II monthly average flows into daily values based on historical hydrologic patterns and operation constraints.

Upper Sacramento River calibration results for USBR-TMS/HEC-5Q appear favorable (Figure 3.3).

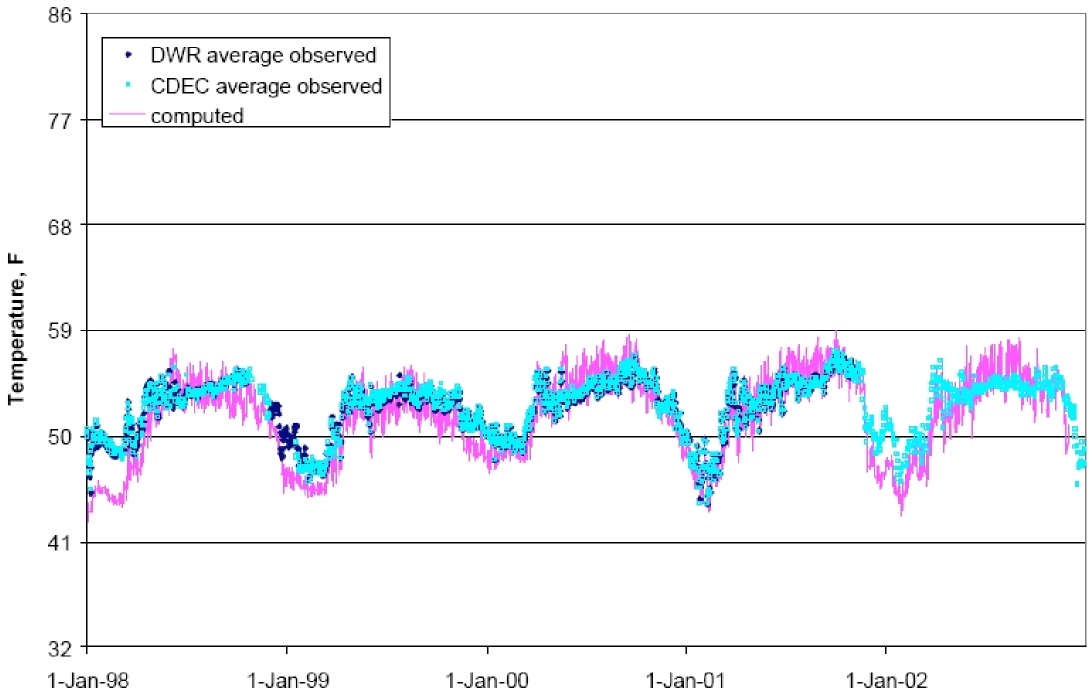

Figure 3.3. Computed and observed temperature time series in Sacramento River at Balls Ferry. Source: RMA 2003.

Spatial horizon and resolution

The Upper Sacramento River model extends from Shasta Dam (RM 312) to Knights Landing (RM 89). Rivers and reservoirs comprising the upper Sacramento River system are represented as a network of reservoirs and streams and discretized into sections within which flow and water quality are simulated. Control points (CP) represent reservoirs and selected stream locations. Flows, elevations, volumes, etc. are computed at each control point.

In HEC-5Q, a reach of a river, is represented as a linear network of segments or volume elements (Figure 3.4). The length, width, cross-sectional area and a flow versus depth relationship characterize each element. Cross-sections are defined at all control points and at intermediate locations when data are available. Major units include:

- Below Keswick
- Confluence Clear Creek

- Balls Ferry
- Jellys Ferry
- Bend Bridge
- Red Bluff Diversion Dam
- Tehama
- Woodson Bridge
- Hamilton City
- Butte City
- Colusa
- Colusa Basin Drain

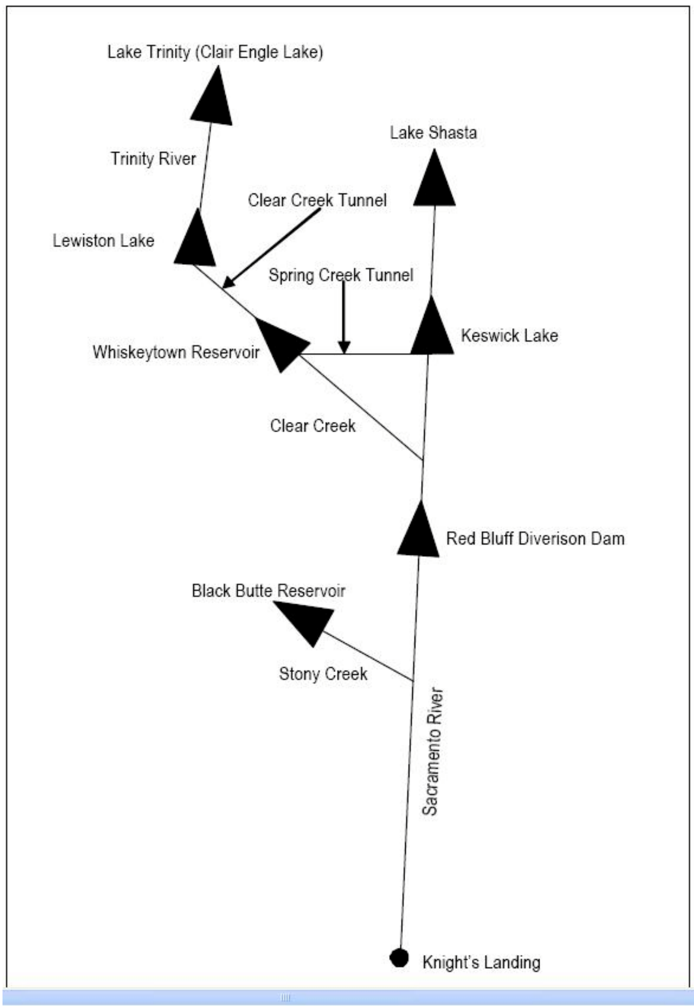

Figure 3.4. Schematic of the HEC-5Q Upper Sacramento River model. Source: RMA (2003).

Temporal horizon and resolution

Temporal horizon in this context is likely to be seasonal (e.g. incubation periods), as defined by focal species life-history requirements. Temporal resolution would not appear to be of concern, given USBR-TMS's 6-hour time steps that provide an approximation of diurnal variations in temperature. For the DA tool, we may need to perform post-processing of results and aggregate to daily average water temperatures. While the 6-hour bins are interesting in that they can reveal potential short-term effects on egg-alevin survival that could be masked by the use of daily mean temperatures, use of 6-hour bins may unnecessarily increase computing time and complexity.

Inputs

Users of the DA tool will require no pre-requisite knowledge to operate the USBR-TMS/HEC-5Q model. When using a particular USBR-TMS result set, the Sacramento DA tool will provide basic validation to ensure that other related models such as CalSim align (as best as possible) with the operations and embedded assumptions associated with a particular USBR-TMS result. Otherwise, the ecological consequences will be badly in error due to use of "apples and oranges" inputs from non-aligned physical models. These inter-dependencies are an important subject of discussion during review of the proposed design.

Outputs

The performance measures of interest are being developed in accordance with focal species life-history requirements. Examples include (but are not limited to):

- number of days water temperature > 56°F;
- incubation window / period vulnerability (ATUs) & instantaneous survival rates as a *f*(temperature); and
- lethal thresholds.

As with CalSim, HEC-5Q stores results in DSS files, and thus, HecDssVue (Figure 3.2) can be used to access most data. There also apparently exists a post-processor for HEC-5Q output that is able to export data to spreadsheets for plotting things such as reservoir temperature profiles, seasonal time-series and accumulative temperature exceedance plots.

3.1.3 Stage-discharge (HEC-RAS 3.1.x)

Model description

A variety of 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. Increasingly, technology such as LiDAR is also being used to provide 3-D topography that can in theory be cut at any particular point to derive a cross-section (subject to having adequate accuracy and precision). Next, investigators then record water surface elevations at these cross-section locations over a range of flows and use interpolation to yield a stage-discharge relationship. However, this process 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).

HEC-RAS is a software application designed to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels under both steady and unsteady flow assumptions. Other versions, such as HEC-GeoRAS can perform two-dimensional hydraulic calculations to derive flood inundation areas. HEC-RAS simulations can also produce additional useful parameters beyond water surface elevation at each cross-section, including: in-channel and overbank velocities, stream power, wetted channel width, in-channel and overbank shear stress, hydraulic depth, and Froude number (all of these parameters are cross-sectionally averaged for the specified discharge). Such information can be useful for other modeling requirements, such as developing sediment transport relationships.

A variety of groups have used HEC software on the Sacramento River, including CDWR in the Comprehensive Study between Redding (RM 295.9) and Deer Creek (RM 214.0). The purpose of this implementation of HEC was to establish existing hydraulic conditions and develop floodplain inundation areas. This HEC implementation was also used to develop base (existing) condition water surface profiles and floodplain inundation maps along the upper Sacramento River. The implementation encompassed 180 surveyed cross-sections between RM 295.9 and RM 214.0. There is approximately one cross-section per ½ mile with a higher density of cross-sections upstream and downstream of bridges. Also, some of these cross-sections extend into overbank areas, generally meeting with high ground or natural terrace formations. Unfortunately, the model has been used to simulate only a few, relatively large discharges (50-, 100-, and 200-year events) and largely ignores lower-magnitude discharges. There is little documentation, though an informal draft write-up of the model exists from CDWR Northern District.

A HEC-RAS implementation has also been developed by USACE (2002) for the lower Sacramento River Comprehensive Study between Deer Creek (RM 215) and the Sacramento Delta (RM 0.84). Here, HEC-RAS was developed as an interim step in producing the more comprehensive UNET model used for the final hydraulic analysis for the Comprehensive Study. However, the channel geometry used in the HEC-RAS model is the same as for the UNET model; the primary difference between the two models is the detail of flow routing used in the UNET model exceeds that used in HEC-RAS. The implementation encompasses 926 cross-sections between RM 215 and RM 0.84. There is approximately one cross-section per 1/4 mile with a higher density of cross-sections upstream and downstream of bridges. Here too, the model has been used to simulate only a few discharges (20,000 cfs, 40,000 cfs, 80,000 cfs, 120,000 cfs, 150,000 cfs, 200,000 cfs, 250,000 cfs, and 350,000 cfs from RM 215 to 134).

Overbank geometry data has also been developed from U.S. Geological Survey (USGS) Digital Elevation Models (DEM's). Contours have been generated at 5-foot intervals for RM 295 to 220. The Sacramento River and Deer Creek Mapping Project contour data was used for all ground geometry data in that area of the study (RM 219 to 214). Contours intervals were 2-foot in-channel and 5-foot in the overbank areas. Cross-sectional width varies significantly, ranging from 688 ft to 19,303 ft with a mean cross-section width of 7,341 ft. The typical bankfull channel width of the cross-sections ranges from 1,000 to 1,500 ft with the remaining cross-section length traversing the floodplain.

We understand Ayers and Associates consultants have also worked with HEC on the Sacramento River, including some of the aforementioned implementations.

We also note the USFWS surveyed potential stranding sites in the upper Sacramento River between Keswick Dam (RM 302) and Battle Creek (RM 271.5). As part of the survey, USFWS determined the flow at which the stranding sites become isolated from the main channel. USFWS determine the stranding flows using a hydraulic model, direct field surveys during low flows, and stage-discharge relationships. USFWS surveyed a total of 108 stranding sites, for which they will have some form of stage-discharge relationship. However, the stage-discharge data they have are basically spot measurements, which may be difficult to extrapolate.

Lastly, in support of RHABSIM and River2D modeling, the transects that USFWS collected to support the RHABSIM and River2D modeling included water surface elevations. Thus, stage-discharge relationships should be available for aquatic habitats at selected sites between Keswick Dam and Battle Creek, and for the six study sites between Battle Creek and Deer Creek. The upper end of discharges for which water surface elevations were surveyed for transects was ~30,000 cfs. Depending on the location, the surveyed and modeled stage for the upper range of discharges may provide some information relevant to riparian recruitment surfaces and side channel/back channel inundation.

Spatial horizon and resolution

The spatial horizon for stage-discharge information is the Sacramento River between Keswick Dam (RM 302) and Colusa (RM 143). **The spatial resolution, which for our purposes is a set of specific cross-sectional locations & their stage-discharge relations, is a matter of discussion that will be driven by two considerations**:

1. Where focal species submodels need to know this information; and
2. Where geometric data and HEC implementations already exist or can readily be run to satisfy "1".

The text above lays out the HEC implementations we are aware of.

Temporal horizon and resolution

Issues of routing aside, the response of water surface elevation to flow at a given point is largely an instantaneous response with respect to modeling, occurring in a matter of minutes or hours. In the DA tool stage-discharge information would essentially be treated as lookup information, called up on a frequency determined by focal species submodel demands (e.g., Figure 3.5).

Inputs

As with CalSim / CalSim DOM, users of the DA tool will require no pre-requisite knowledge or experience in the operation of HEC models. Instead, all HEC and other "vetted" cross-sections and stage-discharge relations are to be bulk loaded into the tool's relational database (Figure 3.5).

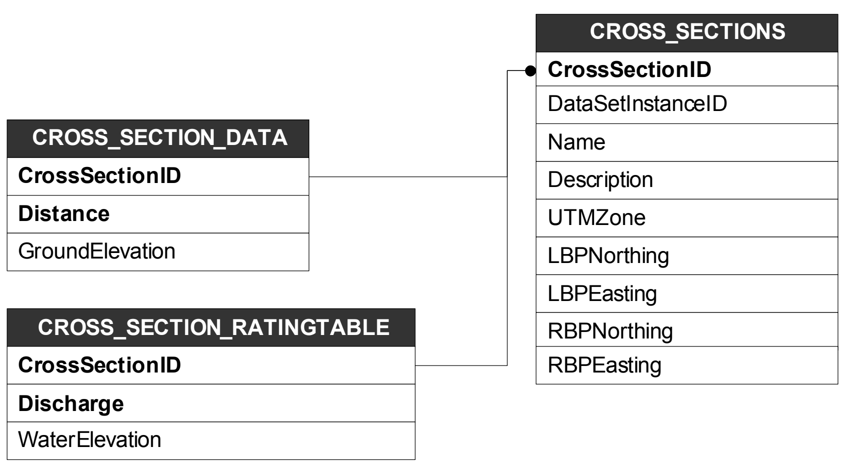

Figure 3.5. Relational database design used by the DA tool for cross section information. (For simplicity, some fields are not defined).

Outputs

Stage-discharge information in conjunction with hydrographs will be passed to focal species submodels to determine certain ecological responses. Again, this is merely a lookup exercise on the database tables shown in Figure 3.5.

3.1.4 Sediment transport and bed composition (TUGS)

Model description

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 (in review), 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 (a) 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 posits no relationship among surface, subsurface, and bedload grain size, which limits the application of the equation to field conditions. However, the research of (d) 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 et al. (1998) showed that subsurface sand fraction is strongly correlated with the standard deviation of the grain size distribution of the coarse sediment. Consequently, it is possible to hypothesize a relation among the subsurface, surface, and bedload grain size distributions (e), and to combine this relation 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 (e) 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 (e) 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.

TUGS model was developed using a dataset developed in the Sandy River in Oregon.

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 3.1 displays the river miles where the CDWR bulk samples were collected, and where 2005 bulk sampling will occur.

Table 3.1. Bulk sampling sites in the Sacramento River where surface and subsurface grain size distribution data is available

Upper Sacramento River		**Middle Sacramento River**	
Approx. RM	**Site Name**	**Approx 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.

TUGS 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.)

Temporal horizon and resolution

TUGS model applies daily average discharge record as input for hydrologic conditions, and is suitable for long-term simulation. Results from the model should be interpreted at an annual basis.

Inputs

The model can be applied to any reach for which channel cross-sections and surface and subsurface grain size data are available. Generally, sediment transport and routing models including TUGS involve a moderate to high initial effort to calibrate.

Outputs

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 (e.g., Figure 3.6 - Figure 3.10).

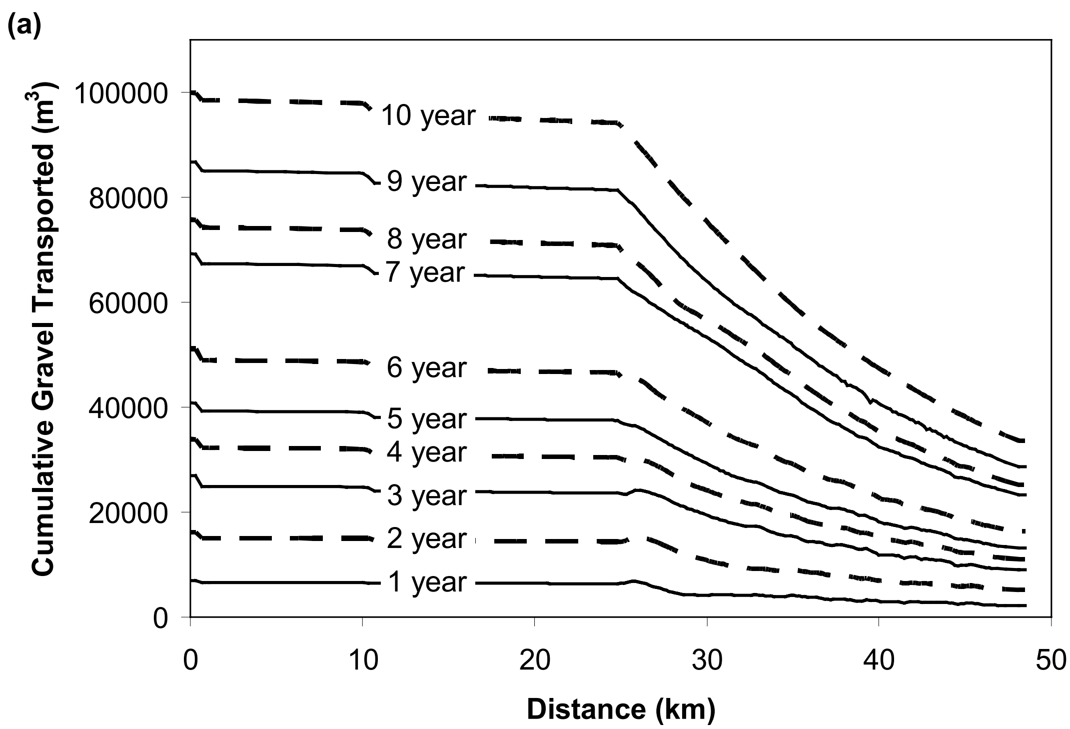

Figure 3.6. Example output from TUGS model: cumulative gravel transport isopleths by river kilometer.

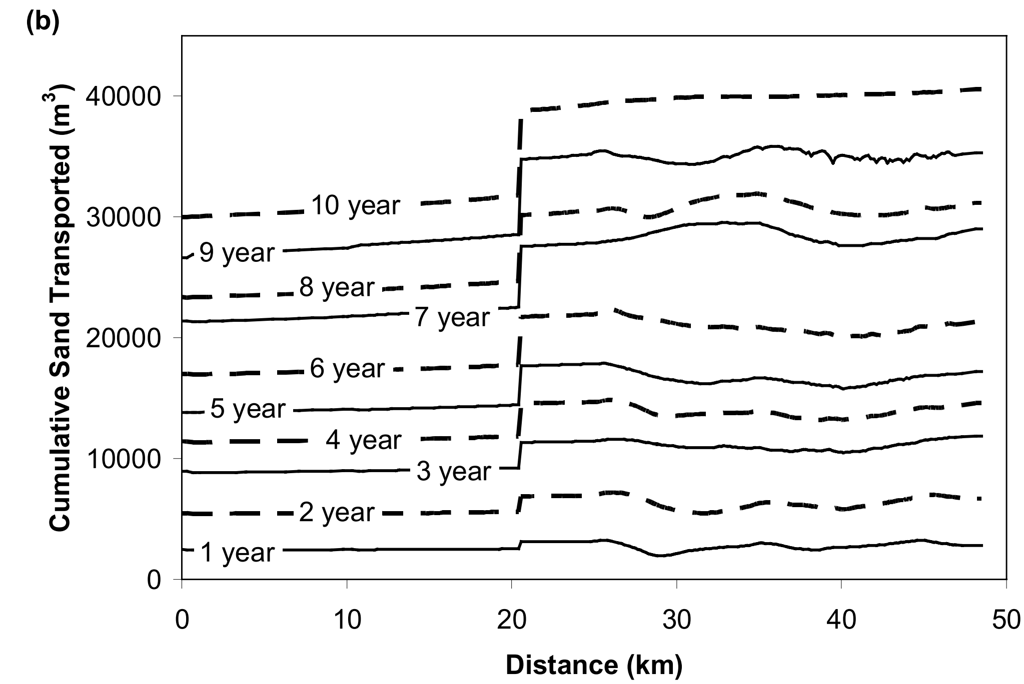

Figure 3.7. Example output from TUGS model: cumulative sand transport isopleths by river kilometer.

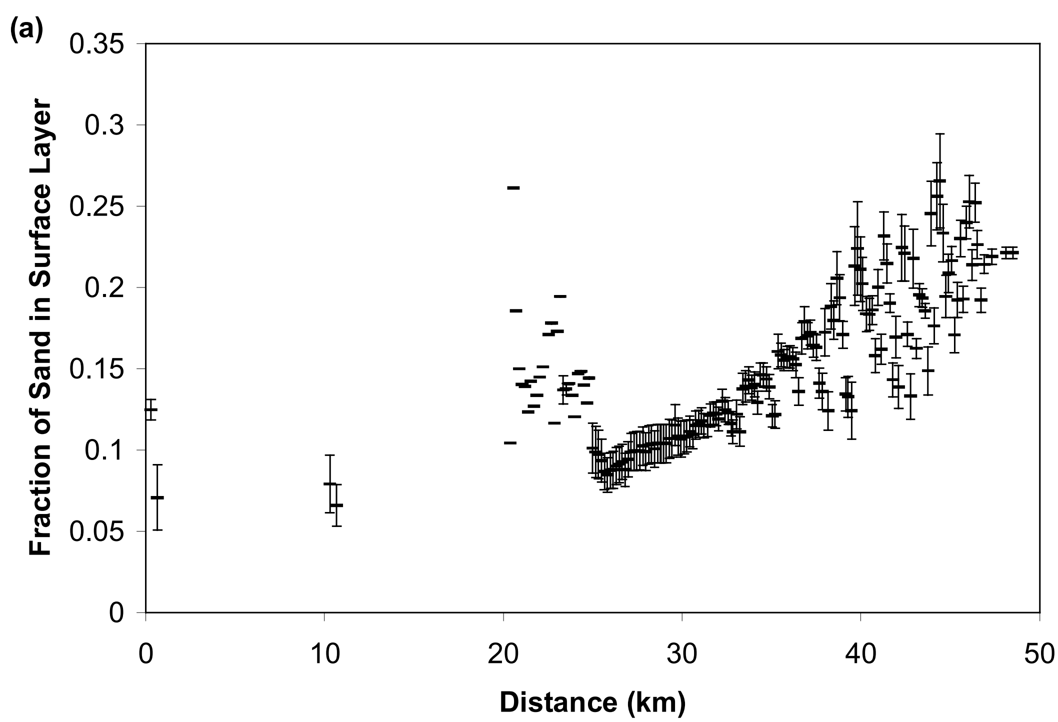

Figure 3.8. Example output from TUGS model: fraction of sand in surface layer by river kilometer.

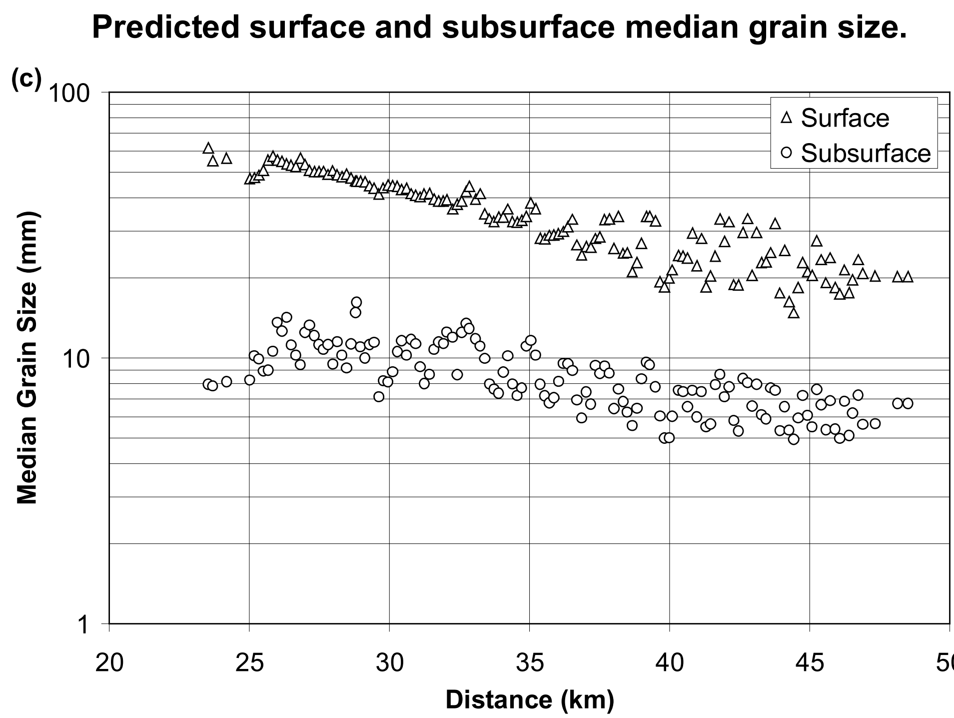

Figure 3.9. Example output from TUGS model: median grain size by river kilometer in the surface and subsurface.

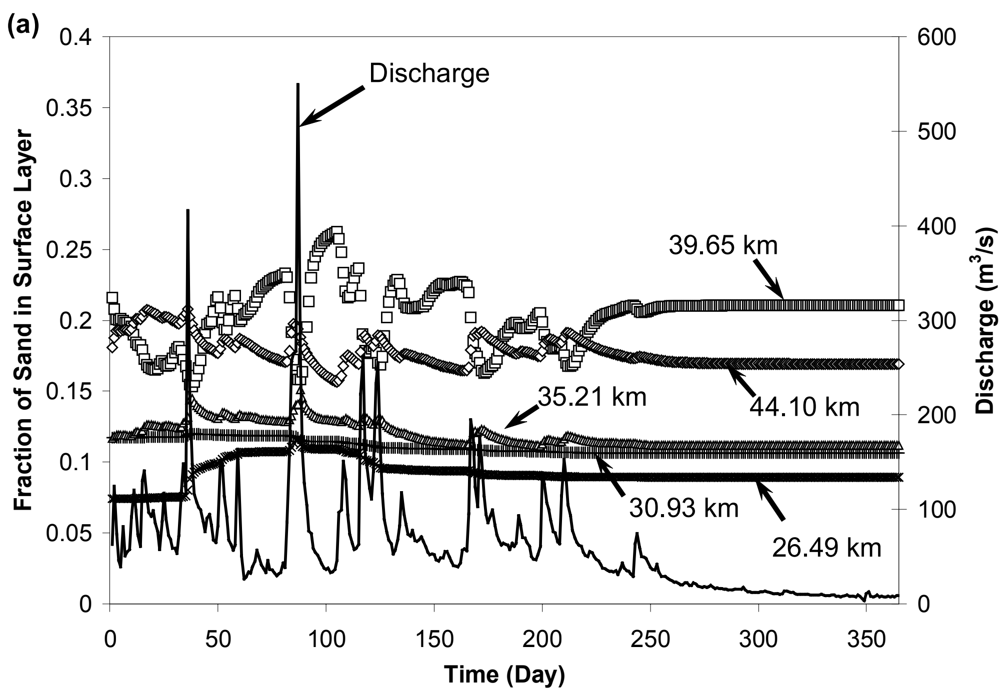

Figure 3.10. Example output from TUGS model: fraction of sand in the surface layer over time (in days), in response to variable hydrograph.

3.1.5 Oxbow chute cut-off

Model description

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 3.11.

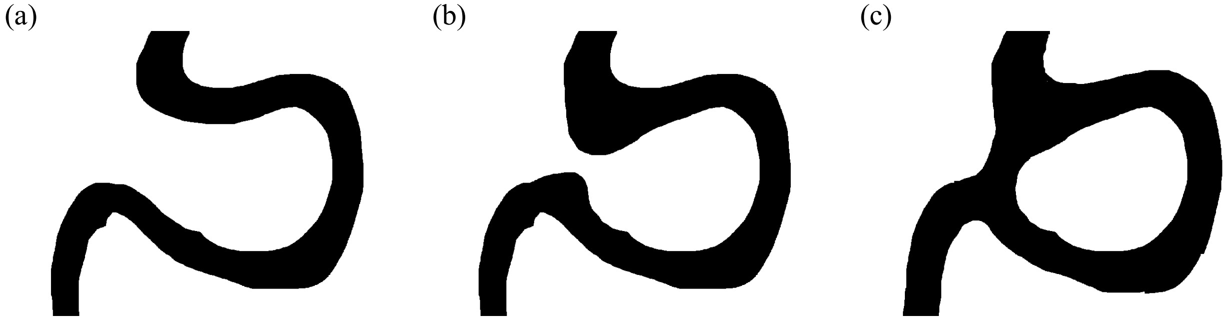

Figure 3.11. Evolution of a chute cutoff.

During low flow events, flows pass through the existing channel (Figure 3.11a). 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 3.11b). 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 3.11c). 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. For this reason, Stillwater Sciences is developing a mechanistically-based numerical model to simulate the initiation and development of chute cutoffs in low-gradient alluvial rivers. The model will be used to examine the potential flow events that are needed to initiate and complete a chute cutoff at an example site by running different hydrographs through the model. The model assumes that the formation of a chute cutoff is the result of a higher gradient through the cutoff route, as compared to the gradient of the existing channel route, and that flow inertia plays an insignificant role in the formation of the chute cutoff.

The chute cutoff model is a one-dimensional model applied to individual meander bends. For a defined cutoff route, the model uses trapezoidal cross-sections, treating the initiation of the cutoff channel as a triangular shape, which can be used as a special case of a trapezoidal channel.

Stillwater Sciences has developed a prototype chute cutoff model that is currently being debugged using topographical information for the cutoff at RM 212 to RM 215, where cutoff occurred in 1974.

Spatial horizon and resolution

The chute cutoff model will be developed and tested initially based on the site conditions of a chute cutoff at RM 212 to RM 215 that occurred in 1974. As part of the current project, the chute cutoff model will be applied at an example to predict the flow events required to initiate chute cutoff at that site. The model can be applied to other potential chute cutoff sites as well, though the model must be re-calibrated. The chute cutoff model will be most relevant for the reach of the Sacramento River below Red Bluff (RM 243), where cutoffs are most likely to occur.

Temporal horizon and resolution

The chute cutoff model is event-based; that is, it examines the effects of individual high flow events on the initiation and completion of a chute cutoff channel for a pre-defined channel alignment.

Inputs

The chute cutoff model can be applied to any meander bend for which the required input data are available, which include: (1) topographic data; (2) discharge record; and (3) information about the riparian vegetation in the defined cutoff route. Knowledge of riparian vegetation is required to facilitate the definition of a critical shear stress for riparian layer erosion, which is an input parameter for the model.

Outputs

We assume that output from the model will be a flag indicating whether a flow event does or does not produce a chute cutoff at a particular site of interest, effectively re-setting the age of local floodplain habitats.

3.1.6 Meander migration

Please note the model description provided here is in rough form and requires review by Eric Larsen. Said reviews had not occurred by press time.

Model description

As outlined by Larsen et al. (2004), river meandering and associated river bend cutoff are geomorphic processes necessary for the establishment and maintenance of riparian, oxbow lake, and river bank ecosystems. Traditional flood control and river bank erosion control measures (e.g., the installation of rock along the river bank, called rip rap) prevent river channel movement and can have detrimental effects on riparian habitat integrity (Keller 1980, as cited in Larsen et al. 2004). Setback levees have been suggested as alternatives to traditional flood control techniques (e.g., rip rap and near-bank levees) to help maintain the ecological integrity of riparian systems while still providing the necessary flood control.

A numeric model of river meander migration (Johannesson and Parker 1989, Larsen 1995), based on relationships for the sediment transport and fluid flow, calculates how an alluvial river channel moves over time scales of years to decades. The model assumes that the local bank erosion rate is proportional to a local velocity factor such that: $M = Eo*ub$ where M is the bank erosion rate (in meters per year), Eo is a dimensionless bank erodibility coefficient and ub (meters per second) is a velocity factor equal to the difference between the velocity near the bank and the reach-average velocity. The terms ub and Eo are described in Larsen and Greco (2002). Higher Eo values result in greater erosion potential. Although the model analytically calculates the velocity field in some detail, it represents bank erodibility by an empirically estimated coefficient (Larsen and Greco 2002). The model incorporates a spatial surface of erosion potential throughout the landscape (i.e., a map showing the erodibility of the various areas). This erosion potential map delineates areas of higher and lower erosion potential due to differences in land cover, soil, and geology. The method combines a geographic information system (GIS) with the numeric migration model. In a GIS format, grid-based erodibility is derived from remotely sensed data. This surface is imported into the migration model in which erodibility is expressed in units of particle size. Higher particle size values result in less erosion potential. A single erodibility surface is developed from GIS data by spatially combining (ESRI 2003) a layer of land use and geology. These erodibility datasets provide composite maps detailing how certain geology types and land uses tend to erode at different rates. Certain actions, such as the effect of rip rap are simulated by modifying these erosion potential grids. Erodibility surfaces are then used as the basis for all analyses. Finally, these datasets are converted into a raster (or grid) and exported as ASCII text, which is easily imported into the migration model, which is coded in MATLAB.

Various model parameter values (hydraulic, smoothing, and cutoff parameters) are calibrated using a process involving comparisons between digitized aerial photographs of channels taken in different years (e.g., 1980 and 1997). The model simulates channel movement using the solutions of the equations representing the physical processes of migration. Assumptions about flow rates are central to these analyses (e.g., an assumption of constant flow rate would produce a channel that moves approximately the same distance each year). Key results include channel location, area reworked and floodplain age data for each year, output as an ASCII text file, which are then imported into a GIS shapefile format using a custom ArcView 3.3 Avenue script.

Spatial horizon and resolution

The appropriate communications with the meander migration model experts did not occur by press time. However, project team members are aware of a number of river reaches (i.e. RM 201- 185) where the model, in its existing form, has been carefully calibrated.

Temporal horizon and resolution

For a given flow scenario, forecasts out to 100-years can be produced. As with the oxbow chute cutoff model, the meander migration model is largely event-based; that is, significant channel migration is not expected until specific flow thresholds are exceeded.

Inputs

As with other detailed physical models, users of the DA tool will require no pre-requisite knowledge or experience in the operation of the meander migration model. Instead, currently undefined scenarios and results from the meander migration model will be imported into the DA tool's database in raw form or otherwise aggregated as rules or lookup information.

Outputs

As the appropriate communications with the meander migration model experts did not occur by press time, we are unclear as to specific type and format of model outputs that are of most interest to stakeholders and the project team. However the following performance measures have been discussed:

- area of floodplain re-worked; and
- age of floodplain patches. (??)

3.2 Focal species submodels

For each focal species we summarize here our current understanding of two issues: (a) critical life history requirements, and (b) submodels and information sources needed to quantify the link between management actions and habitat or biological performance. We start by discussing the key habitat requirements and life history timing for each of the focal species. We then present the following:

- *management actions* that could affect critical habitats;
- *ecological objectives* for the key habitat requirements;
- *performance measures* that can be used to evaluate how well a particular management scenario achieves the desired objectives;[5] and
- *conceptual diagrams* representing the series of links along the cause-effect pathway from management actions to habitat forming processes to physical habitats to survival mechanisms and finally to some effect on a life history stage.

The conceptual diagrams represent the key components (boxes) and models or data (arrows) that *may* be available to quantify each link (see Figure 3.12). They do not represent the entire cause-effect pathway about what is known or hypothesized to be important for a particular focal species unless those relationships can be quantified. Numbers represent individual cause-effect pathways that quantify links between management actions and habitat or biological performance measures. Letter assignments represent the individual steps along the pathway which require distinct models, functional relationships, or data to quantify the link. For instance, most pathways rely on at least one of the physical models described in Section 3.1 (e.g., steps 1a and 1b in Figure 3.12 can be quantified using the sediment transport and substrate composition model). A simple means of summarizing the effects of management action for decision makers could be to color the top boxes (life stages) in green (good), yellow (fair), or red (poor) depending on the level of various performance measures. Further probing of results from the DA Tool could be used to reveal which habitat attributes caused a yellow or red warning flag.

Next, we briefly summarize the models, functional relationships, and/or data that *may* be available to quantify each link along the various pathways presented in the conceptual diagrams. Pathways are tentatively prioritized based on a consideration of the criteria presented in Section 2.1.3; these priorities have not been finalized and are open for discussion at the workshop. At a conceptual level these summaries propose data sets or analyses that may be required to generate relevant performance measures.

3.2.1 Chinook salmon (CH)

Key life history requirements (critical habitats and life history timing):

Chinook salmon is the most studied species on the Sacramento River, which supports four races – winter-run, spring-run, fall-run, and late-fall run. Two of these runs (winter and spring) are on both state and federally listed species. The main habitat features being integrated in the DA Tool relate to adult spawning and juvenile rearing habitats.

Adult Chinook salmon require clean gravels (< 30% fines) with a median size ranging from 32 mm to XX mm (REF), though the preferred particle size distribution depends on the size of fish. Fall-run salmon dig egg pockets to a depth of ~18 cm (TID 1998). Discharge can affect the spatial availability of spawning habitat because Chinook salmon require water depths greater than 1 ft and prefer water

[5] The performance measures presented here are not final; rather they represent the general types of measures that may be available for inclusion in the DA Tool.

velocities between 1.0 to 3.0 ft/sec (Swift 1979). However, spawning populations in large mainstem rivers appear to use habitats with a much wider range of velocities, between 0.3 and 6.9 ft/sec (Groves and Chandler 1999; Geist et al. 2000). Fall-run, winter-run, and late-fall-run Chinook are known to spawn in the upper Sacramento River. Since the completion of improvements to the ACID fish ladder in 1997, CDFG aerial escapement surveys have shown an upstream shift in spawning distribution above ACID dam.

Fall- and winter-run fry generally disperse upon emergence to near-shore, shallow water habitats, which can make them vulnerable to stranding from flow fluctuations or entrainment in water diversions. Limm and Marchetti's work (2003) in the Sacramento highlight the importance of shallow side-channel habitats for rearing fall-run fry, which also likely provide important rearing habitat for winter- and spring-run fry. Limm and Marchetti's work also suggests that mainstem fry rearing habitats seem to be boundary areas between fast and slow water, where fry can minimize their energy requirements for maintaining position in slower velocity water and adjacent fast water delivers invertebrate drift for food. Floodplain and bypass flooding can dramatically increase the amount of prime rearing habitat by providing low-velocity, shallow water habitats with warmer water temperatures and higher food availability.

Spring-run and late-fall-run salmon likely exhibit a yearling life history strategy, in which emergent fry establish and defend territories in headwater areas where they can survive summer water temperatures. Consequently, rearing habitat for juveniles of any mainstem spawning population of spring- and late-fall-run will likely be located close to Keswick Dam, where suitable water temperatures are maintained year-round, especially during the summer rearing period.

Adult winter-run migrate upstream between December and early June, with the peak (as recorded at Red Bluff Diversion Dam (RBDD)) in March-April (Snider et al. 1998; 1999; 2000; 2001). After a short holding period, adults spawn between mid-April and mid-August, with the peak in late May and early June (Snider et al. 1998; 1999; 2000; 2001). Fry emergence occurs between mid-June through mid-October (NMFS 1997). Emigration may be bi-modal, with fry dispersal occurring between July and October, with a peak in September (as measured at RBDD) (Vogel and Marine 1991), and then a second wave of juveniles migrating past Knights Landing in January-March (Snider and Titus 1998; 2000a, 2000b). The temporal distribution of winter-run fry/juvenile emigration is hypothesized to be related to flow pulses.

Adult spring-run enter their natal streams between mid-February and July, with a peak in May (CDFG 1998). Adults generally hold through the summer months and begin spawning in late August through October, with a peak in late September (CDFG 1998). It is not clear, however, if there is a spawning population of spring-run Chinook in the mainstem Sacramento River. However, in other systems fry emergence varies widely by stream because of differences in water temperature patterns. The pattern of fry/yearling emigration also varies among tributaries to the Sacramento. For instance, in Butte and Big Chico creeks a large fraction leave as fry in the December and January (Ward et al. 2004a; 2004b; Hill and Webber 1999; CDFG 1998), while others remain to rear and emigrate as yearlings between October and February the following year (Brown 1995; Hill and Webber 1999). It is unclear if one emigration strategy (fry vs. yearling) is more successful in contributing to the population of spring-run Chinook on the tributaries.

Adult fall run migrate upstream between August and December, with a peak in October. Spawning generally occurs between October and December, with a peak in November (Vogel and Marine 1991). The duration of egg incubation depends on time of spawning and water temperatures, but generally occurs between October and March, with peak emergence in late January through February. Fry begin dispersing from January through June, but the timing of peak dispersal and outmigration is hypothesized to be a function of flow magnitude and turbidity. Winter pulse flows can stimulate larger fractions of newly emergent fry to disperse downstream during January and February; in drier winters, fall-run dispersal and emigration may peak as late as mid-May.

Adult late-fall-run migrate upstream between mid-October and mid-April, with a peak in December and January. Spawning occurs between January and mid-April, but the peak of spawning isn't clear. Vogel and Marine (1991) report the peak of spawning as being February. The late-fall-run carcass counts conducted by Snider et al. (1998; 1999; 2000) suggest that late-fall-run spawning may peak in January; however, they note that their carcass recoveries in February and March can be affected by winter storm events, thereby confounding the re-constructed peak of spawning as determined by carcass counts. Eggs incubate between January and June, with peak emergence in April. Late-fall-run emigration appears to be bi-modal, with fry emigrating between April and June, while a fraction of juveniles remain in the upper river to rear throughout the summer and then migrate as smolts between July and November (CDFG 1990).

Submodel bounding and integrating:

Given the importance of spawning and rearing habitats to Chinook salmon in the upper Sacramento, we have identified the following relevant management actions, ecological objectives, and performance measures. Note that most of the information below also applies to steelhead trout:

Management actions

- Flow management
- Gravel additions

Ecological objectives

(1) Maximize quality of habitats for adult spawning (all Chinook runs except spring, plus steelhead)

(2) Maximize quality of habitats for egg incubation (all Chinook runs except spring, plus steelhead)

(3) Maximize availability and quality of habitats for juvenile rearing (all Chinook runs, plus steelhead)

Performance measures

- Substrate composition
- Area of suitable spawning habitat
- Redd scour / depth
- Area of suitable rearing habitat
- Connectivity to off-channel rearing habitats
- Index of juvenile stranding
- Egg-to-fry survival rate

The sequence of steps that may be available to link these management actions and performance measures is presented in Figure 3.12. The following describes our understanding of the pathways to quantify these linkages using available models and/or data (summarized in Table 3.2) and priorities for integration in the DA Tool (summarized in Table 2.3):

Pathway 1: Discharge-bed composition [Moderate priority]. The sediment transport and substrate composition model (TUGS) predicts changes in the surface and subsurface particle size distribution as a function of bed mobilization and scour. Consequently, we should be able to assess the effects of discharge on grain size distribution and relate those changes to preferences for spawning and egg survival-to-emergence.

Pathway 2: Discharge-spawning habitat [High priority]. The USFWS has applied RHABSIM and River2D modeling to heavily used spawning sites in the upper Sacramento River. Consequently, flow-spawning habitat relationships have been developed for fall-run, winter-run, and late-fall-run salmon as well as steelhead between Keswick Dam (RM 302) and Deer Creek (RM 220). These functional relationships have some limitations (e.g., hydraulic data were collected in 1997-1999 prior to some major storm events in Feb-March 2004). Because of the uncertainty about the existence of a mainstem spawning population of spring-run Chinook salmon in the Sacramento River, no flow-habitat relationships are available for this run.

Pathway 3: Gravel-spawning habitat [Low priority]. Gravel augmentation may be an important restoration strategy for the upper river if bed coarsening progresses over time. Additions of gravel could increase spawning habitat and reduce the potential for egg mortality associated with redd superimposition. However, gravel addition would alter the flow-habitat relationships predicted by RHABSIM / River2D modeling. It may be possible to use TUGS to estimate changes in substrate due to gravel additions and then re-apply the physical habitat models to a hypothetical channel in which a broader extent of the channel bed is assumed to contain suitable gravels to support spawning, to examine its effects on flow-spawning relationships.

Pathway 4: Discharge-redd scour [High priority]. Bed scour greater than 18 inches (the average depth at which egg pockets are buried) during the incubation phase can increase egg and alevin mortality by exposing them to predation. Relationships between discharge and scour of redds would likely be an important consideration in combination with any gravel augmentation because a finer bed composition would mobilize and scour at lower magnitude thresholds than the currently coarsened bed. Field studies planned for water year 2006 may provide relationships between discharge and scour depth for reaches of the Sacramento River, depending on the occurrence of high flow events.

Pathway 5: Discharge-water temperature-egg survival [Moderate priority]. The USBR Temperature Modeling System (TMS) is able to predict water temperatures at locations across the study area at 6-hour intervals. Hence, it may be possible to relate changes in discharge and water temperature to effects on egg-alevin survival by using known thermal tolerances to develop indices of survival, or modifying existing models that relate water temperature to egg survival (e.g., USBR salmon mortality model). The model's empirical flow-temperature regressions implicitly assume that the future range of variability in air temperatures will mimic the paste. These regressions also do not consider potential changes in the complex water operations that determine water temperatures in the upper Sacramento River.

Pathway 6: Discharge-mainstem rearing habitat [High priority]. The River2D model has been applied to selected sites in the mainstem Sacramento between Keswick Dam (RM 302) and Battle Creek (RM 271.5) to assess relationships between flow and mainstem rearing habitat for all runs of juvenile Chinook salmon and steelhead trout. River 2D has to date not included such off-channel habitats as backwater areas and sloughs, though results from this project's field studies might permit such expansion (i.e., Pathway 8)

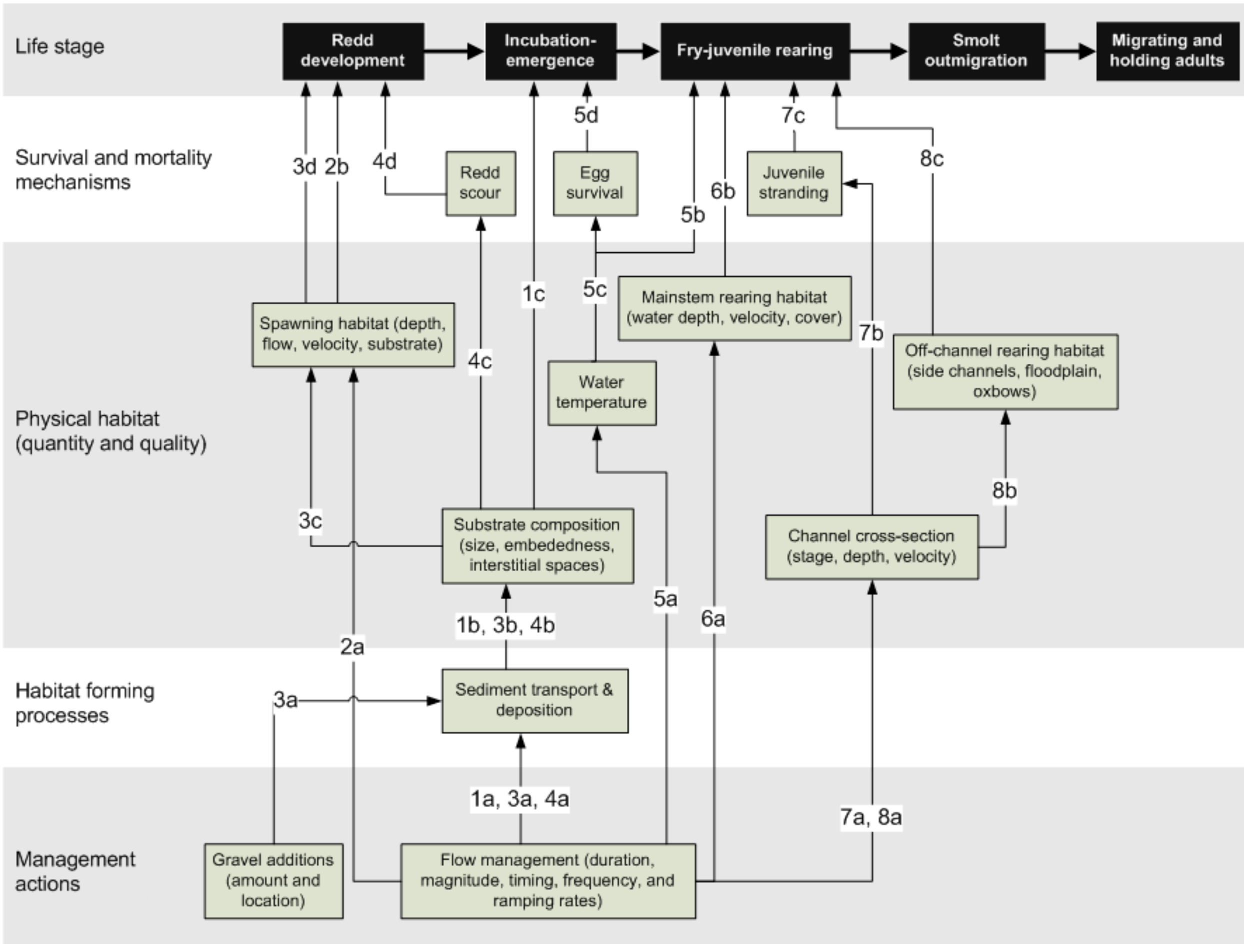

Figure 3.12. Conceptual diagram representing the links between management actions and important life stages for *Chinook salmon and steelhead trout*, as mediated by changes in habitat forming processes, physical habitats, and survival or mortality mechanisms. Pathways represent those with the greatest potential to be quantified using available (or new) models, functional relationships, and/or data. Numbers represent pathways linking management actions to performance measures of interest. Letters represent individual and quantifiable linkages along the pathway.

Table 3.2. Summary of the pathways linking management actions to performance measures, the individual links that may be quantified, and the models, functional relationship, and/or data that may be used to quantify the links represented in Figure 3.12.

Pathway and Link	Link		Proposed model, functional relationship, and / or data source
	From	**To**	
1a	Flow	Sediment transport and deposition	DOM / historical flow data -> TUGS
1b	Sediment transport	Substrate composition	TUGS
1c	Substrate composition	PM for egg incubation / redd development	Habitat suitability information?? Permeability data??
2a	Flow	Area of suitable spawning habitat	DOM / historical flow data -> RHABSIM or River2D
2b	Area of suitable spawning habitat	PM for redd development	RHABSIM or River2D
3a	Gravel and flow	Sediment transport and deposition	DOM / historical flow data -> TUGS??
3b	Sediment transport and deposition	Substrate composition	TUGS??
3c	Substrate composition	Area of suitable spawning habitat	Modifications to RHABSIM or River 2D??
3d	Area of suitable spawning habitat	PM for redd development	
4a	Flow	Sediment transport and deposition	DOM / historical flow data -> TUGS
4b	Sediment transport and deposition	Substrate composition	TUGS
4c	Substrate composition	Index of redd scour	Relationship between scour depth and egg survival Field studies information
4d	Index of redd scour	PM for redd development / egg incubation	
5a	Flow	Water temperature	DOM / historical flow data -> USBR TMS
5b	Water temperature	PM for juvenile rearing in mainstem	Literature review of optimal temperatures for **steelhead**
5c	Water temperature	Egg survival	Literature review / modifications to USBR salmon mortality model??
5d	Egg survival	PM for egg incubation	Link scour and temperature effects for **Chinook salmon**?
6a	Flow	Area of suitable rearing habitat in mainstem	DOM / historical flow data -> River2D
6b	Area of suitable rearing habitat	Surrogate PM for juvenile rearing survival	River2D
7a	Flow	Channel cross section	DOM / historical flow data -> cross sections assumed constant
7b	Channel cross section	Index of juvenile stranding	USFWS juvenile salmonid stranding surveys
7c	Index of juvenile stranding	PM for juvenile rearing	
8a	Flow	Channel cross-section	DOM / historical flow data -> cross sections assumed constant
8b	Channel cross-section	Off-channel rearing habitat availability	Stage discharge relations from field studies, other sources??
8c	Off-channel rearing habitat availability	PM for juvenile rearing Index of juvenile stranding	Oxbow habitat field studies from this project

Pathway 7: Discharge-juvenile stranding [Low priority]. USFWS has developed stage-discharge relationships for a number of sites in the upper Sacramento River where juvenile salmon are at risk of stranding from flow fluctuations. They measured the elevation of the control point at which a site becomes hydrologically isolated. Calculation of an index of stranding will require an analysis of the timing, magnitude, and rate of change in discharge to identify the potential for cumulative stranding in the upper river.

Pathway 8: Discharge-off-channel habitat connectivity [Low priority]. Timing and connectivity of three types of off-channel habitats (side channels, floodplains, oxbows) may affect juvenile rearing. First, recent research on fall-run rearing indicate that *shallow water side channel habitats* are being used heavily. This project's field studies plan to establish the discharge magnitude required to connect many of the side channel rearing habitats. Consequently, we may be able to assess relationships between the magnitude and timing of discharges and the availability of these rearing habitats. Second, *floodplains and bypasses* can provide areas for juvenile rearing. Hence, an analysis of stage-discharge relationships that incorporates high flow events to inundate floodplains could be used to indicate the areal extent of rearing habitat available. One complication is our inability to assess other habitat characteristics (e.g., water depth, velocity, residence time, water temperature), which can affect habitat quality. Third, *oxbow habitats* may act as juvenile salmon sinks because the duration of connectivity is too short to allow ingress and egress, and these habitats harbor non-native predators. The oxbow field studies include efforts to define the magnitude of discharge needed to connect the mainstem with several oxbow habitats. Hence, we may be able to use these data to assess stranding potential in oxbows.

3.2.2 Steelhead (ST)

Key life history requirements (critical habitats and life history timing):

Historically steelhead in the Central Valley used habitats in mid- to high-elevation streams, as well as mainstem rivers (to a greater extent than Chinook salmon). Substantial habitat losses and barriers (i.e., dams) have restricted access to headwater areas more recently suggesting that mainstem rearing and spawning habitats are more critical to sustaining steelhead populations. For example, it has been estimated that only 58% (286 of 493) of the historical pre-dam river miles are still available for steelhead on the Sacramento River (USBR 2004). Recent abundances have been documented substantially below historical levels, and comprised mostly of hatchery fish. Central Valley steelhead are designated as "threatened" under the federal Endangered Species Act. As steelhead spawning and rearing habitat requirements overlap somewhat with those of Chinook, we are focusing on the same habitat elements: adult spawning and juvenile rearing.

Sacramento River steelhead are winter-type (as opposed to summer steelhead), so they are sexually mature when they arrive on spawning grounds. Bovee (1978) reports steelhead prefer water depths of 14 inches for spawning, with a range between 6 and 24 inches, and water velocities of 2 ft/sec, with a range of 1 to 3.6 ft/sec. Steelhead are iteroparous, though the percentage of adults that survive spawning in the Central Valley ESU is thought to be low (USBR 2004). There is no Sacramento-specific information about water temperature requirements for successful spawning and incubation, but values derived from other steelhead stocks in more northerly locations suggest optimal spawning temperatures are between 39^{o}F and 52^{o}F, with egg mortality occurring at water temperatures above 56^{o}F (Bovee 1978; Reiser and Bjornn 1979; Bell 1986; all as cited in McEwan and Jackson 1996). Fry emergence is also influenced by water temperature, but hatching generally requires four weeks, with another four to six weeks before emergence. Emergent fry disperse to near-shore areas with coarse substrates and shallow water (< 14 in.), with water temperatures ranging between 45^o and 60^{o}F. Bovee (1978) suggests that fry prefer water depths of 10 inches, with a range between 10 and 20 inches.

Steelhead migrate up the Sacramento River July through March, with a peak in late September (Bailey 1954; Hallock et al. 1961, both as cited in McEwan and Jackson 1996). Thermal tolerances and preferences for upstream migration are unknown for Central Valley stocks, but optimal temperatures for more northerly stocks range between 46^{o}F and 52^{o}F (Bovee 1978; Reiser and Bjornn 1979; Bell 1986; all as cited in McEwan and Jackson 1996). Spawning in the upper Sacramento River generally occurs between November and late April, with a peak between early January and late March (USBR 2004). Juvenile steelhead typically rear in freshwater from 1-3 years before emigrating (McEwan and Jackson 1996). Juvenile emigration from the upper Sacramento River occurs between November and late June, with a peak between early January and late March (USBR 2004). Steelhead require water temperatures less than 57^{o}F for smoltification (Bovee 1978; Reiser and Bjornn 1979; Bell 1986; all as cited in McEwan and Jackson 1996).

Submodel bounding and integrating:

For a description of submodel structures relevant to steelhead, see Section 3.2.1 for Chinook salmon. It seems appropriate to consider the same submodels (i.e., RHABSIM, River2D) because there is overlap in habitat requirements of these two species. Key differences relate to the timing of life history events, and their spawning habitat suitability curves. Other important distinctions in the Pathways presented in Figure 3.12 include:

Pathway 2: Discharge-spawning habitat [High priority]. The USFWS has developed flow-habitat relationships (applying RHABSIM) for steelhead spawning in the upper Sacramento River. However, because of the paucity of steelhead data in the Sacramento River system, USFWS had to use habitat suitability criteria developed in the American River watershed for the upper Sacramento River habitat modeling. Hence, there may be limitations in drawing conclusions about the amount of available spawning areas in the upper Sacramento.

Pathway 5: Discharge-water temperature-juvenile rearing [Moderate priority]. Little is known about the thermal tolerances and preferences of Central Valley steelhead. Reported ranges of optimal water temperatures for different life history stages are generally below water temperature conditions in the upper Sacramento River. Nevertheless, water temperature will likely be one of the few factors related to our management actions (e.g., flow) and which can be estimated using the USBR Temperature Modeling System. Because steelhead spawning peaks in January through March, water temperatures during incubation likely won't be a major factor. Rather, water temperatures during the steelhead rearing period will be most relevant for analysis. Because steelhead juveniles rear in the river for 1-3 years, their distribution downstream of Keswick will be constrained by suitable water temperatures, and there is no "season" for the water temperature requirements, because juveniles will be rearing in the river year-round.

Pathway 8: Discharge-off-channel habitat connectivity [Low priority]. Off-channel habitats (side channels, floodplains, oxbows) are not believed to be important for rearing of juvenile steelhead, because they occur primarily in the middle Sacramento River where water temperatures are too high to support a yearling life history strategy.

3.2.3 Green sturgeon (GS)

Key life history requirements (critical habitats and life history timing):

The Sacramento River is home to one of three known spawning populations of Green Sturgeon (others on the Klamath, and Rogue Rivers). A petition to list green sturgeon was received by the National Marine Fisheries Service in 2001 (EPIC et al. 2001), but a status review in 2002 determined that a listing under the Endangered Species Act was not warranted at the time, although there may be concerns in the future

(Adams et al. 2002). Little is known about specific green sturgeon habitat requirements and life history on the Sacramento River, but they are currently believed to spawn upstream of Hamilton City (~RM 200) and perhaps as far upstream as Keswick Dam (CDFG 2002, as cited in NMFS 2003). Adults have also been observed downstream of RBDD when the gates are closed in mid-May. Juveniles have been collected annually in trapping operations at RBDD and at the Glenn-Colusa Irrigation District pumping facility in Hamilton City (NMFS 2003). Captures at these locations occur primarily from May to August, and peak in June and July (NMFS 2003). Given our current understanding of egg incubation and spawning habitat requirements we believe these habitat elements can be integrated in the DA Tool.

Specific habitat preferences for spawning remain largely unknown, though broadcast spawning is known to occur in deep (>3 m) and fast mainstem reaches (Moyle et al. 1992; Moyle 2002). Large cobble is believed to be the preferred substrate, with eggs settling into cracks between substrate particles, though substrate from clean sand to bedrock may also be used (Moyle 2002). In the Rogue River, suspected spawning sites (inferred from telemetry studies) include those areas with beds composed of cobbles and boulders, water depths greater than 10-15 feet, and are immediately downstream of turbulent water where a slope break in the channel causes water to roil (Erickson, personal communication). Spawning success in most sturgeons has been related to flow and temperature (Dettlaff et al. 1993, as cited in LCFRB 2004), but optimum values for green sturgeon spawning and incubation are unknown. Temperatures over 20°C (68°F) were found to be lethal to green sturgeon embryos in the laboratory (Cech et al. 2000, as cited in NMFS 2003). Van Eenennaam et al. (2005) conducted laboratory studies that suggest water temperatures above 17°-18°C may be stressful.

Females reach sexual maturity after about 17 years (NMFS 2003). Spawning was previously believed to occur every 3 to 5 years (Tracy 1990, as cited in NMFS 2003), but may occur as frequently as every 2 years (Lindley and Moser, personal communication 2004, as cited in NMFS 2005). Adults are anadromous, typically returning to fresh water beginning in late February. Spawning occurs from March to July, with peak spawning from mid-April to mid-June (Emmett et al. 1991, as cited in Moyle 2002). Following spawning, adults migrate downstream to hold in the low-velocity, deep pools through the summer and fall months. Adults migrate to the ocean on winter freshets and when water temperatures drop below 10°C (Erickson et al. 2002; Erickson personal communication).

Green sturgeon larvae do not have a post-hatching pelagic stage like other sturgeon species (LCFRB 2004), but exhibit hiding behavior after hatching (Deng et al. 2002). Larvae feed 10 days after hatching and grow quickly, reaching a length of 300 mm their first year (NMFS 2005). Larvae and juveniles appear nocturnal (Cech et al. 2000), which may protect them from downstream displacement (LCFRB 2004). Juveniles remain in fresh and estuarine habitats for one to four years until they reach a length of 300–750 mm (NMFS 2005). Emmett et al. (1991, as cited in Moyle 2002) suggests that juveniles seem to outmigrate in the summer and fall before the end of their second year. After entering the ocean, individuals disperse widely.

Submodel bounding and integrating:

We have identified the following management actions, ecological objectives, and performance measures as being relevant to green sturgeon:

Management actions	Ecological objectives	Performance measures
▪ Flow management	(1) Maximize quality of habitats for adult spawning	▪ Area of suitable spawning habitat
▪ Gravel additions	(2) Maximize quality of habitats for egg incubation	▪ Egg-to-fry survival rate

The sequence of calculations that may be available to link these management actions and performance measures is presented in Figure 3.13. The following describes our understanding of the steps to quantify these linkages using available models and/or data (summarized in Table 3.3) and priorities for integration in the DA Tool (summarized in Table 2.3):

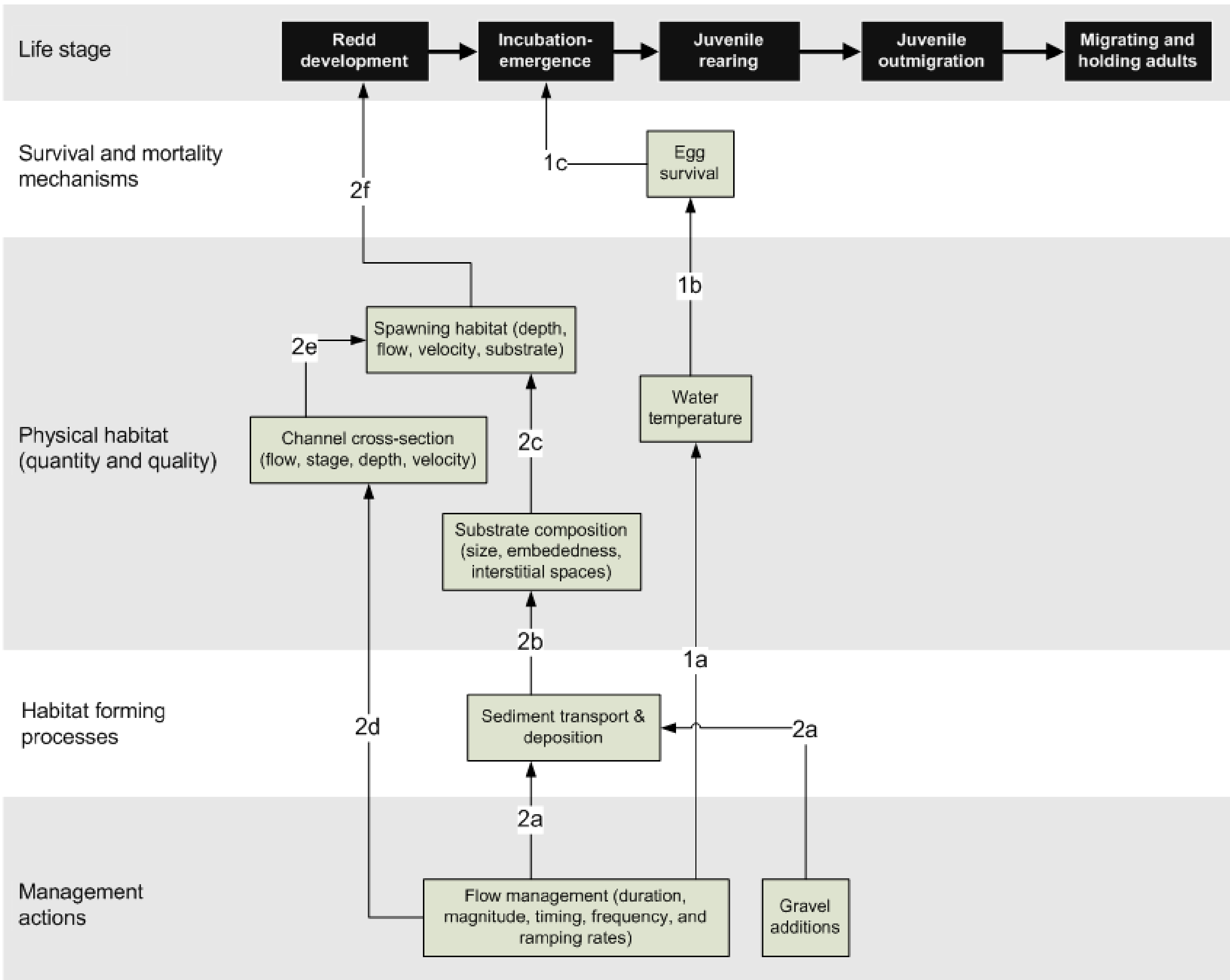

Figure 3.13 Conceptual diagram representing the links between management actions and important life stages for *green sturgeon*, as mediated by changes in habitat forming processes, physical habitats, and survival or mortality mechanisms. Pathways represent those with the greatest potential to be quantified using available (or new) models, functional relationships, and/or data. Numbers represent pathways linking management actions to performance measures of interest. Letters represent individual and quantifiable linkages along the pathway.

Table 3.3. Summary of the pathways linking management actions to performance measures, the individual links that may be quantified, and the models, functional relationship, and/or data that may be used to quantify the links presented in Figure 3.13.

Pathway and Link	Link		Proposed model, functional relationship, or data source
	From	**To**	
1a	Flow	Water temperature	DOM / historical flow data -> USBR TMS
1b	Water temperature	Egg survival	Literature review or expert elicitation of habitat preferences (thermal preferences or thresholds)
1c	Egg survival	PM for egg incubation	
2a	Flow and gravel	Sediment transport and deposition	DOM / historical flow data -> TUGS??
2b	Sediment transport and deposition	Substrate composition	TUGS??
2c	Substrate composition	Area of suitable spawning habitat	Data related to important covariates (flow, depth, velocity, substrate) Field observations, literature review or expert elicitation of habitat preferences??
2d	Flow	Channel cross-section	DOM / historical flow data -> cross-sections assumed constant
2e	Channel cross-section	Area of suitable spawning habitat	Field observations, literature review or expert elicitation of habitat preferences??
2f	Area of suitable spawning habitat	PM for redd development	

Pathway 1: Discharge-water temperature [High priority]. Laboratory studies indicate embryo mortality of green sturgeon at temperatures > 20°C, and potential stress at temperatures > 17°-18°C. Optimum temperatures for growth and survival of green sturgeon eggs and larvae are believed to range from 15° to 19°C (Mayfield and Cech 2004, as cited in NMFS 2005). Consequently, the USBR TMS may be applied to estimate water temperatures at relevant river sections along the upper Sacramento River. Optimum and lethal temperature ranges could then be use to track habitat suitability during egg incubation and larval development stages (March through July). A challenge will be specifying green sturgeon spawning locations because this spatial information is currently poor, though telemetry studies are expected to address this gap in the future. As well, this relationship may not be an informative measure because current water operations are designed to protect winter-run eggs by maintaining temperatures below 13°C. These existing targets may provide suitable protection for sturgeon eggs and larvae down to Hamilton City.

Pathway 2: Flow-spawning habitat [Low priority]. Researchers believe that green sturgeon spawn in fast, turbulent, and deep (> 3 m) water with coarse substrates. If the data collected to develop the RHABSIM or River2D models can be used to develop new relationships between flow, depth, velocity, and bed material, then it may be possible to apply hypothesized habitat preferences to these relationships to provide qualitative relationships between flow, gravel, and spawning habitat suitability. Such an analysis would be limited in its conclusions, however, because habitat suitability information would be developed from general principles about habitat preference rather than direct observation. Also, Chinook spawning habitat modeling may not even capture the types of habitat green sturgeon use for spawning. If the information isn't available immediately, tagging and telemetry studies in the Sacramento and Rogue River may provide some useful information about habitat preferences in the near future.

3.2.4 Bank swallow (BASW)

Key life history requirements (critical habitats and life history timing):

The highest concentrations of nesting Bank Swallows in California occur along the Sacramento River from Red Bluff to Colusa (J. Silveira, personal communication, 2004). Active bank erosion, as driven in part by river discharge, is necessary for maintaining the vertical bank faces that are suitable as nesting sites for swallow colonies (Garrison 1998).

Birds nest in colonies in tall, vertical banks with friable soils along streams, lakes, and in coastal areas. Nest site selection appears to be primarily based on soil type, bank height, and slope (Garrison 1989). Among other factors, active erosion is necessary for creating suitable nesting sites for colonies. High flows create vertical banks and deposit alluvial soils required for burrowing. Without high flows, banks and bluffs gradually become more gently sloped and unsuitable for nesting (Garrison 1998). In California, nesting banks average 3.3 m in height, ranging from 1.3 to 7.3 m (Humphrey and Garrison 1987, as cited in Garrison 1998). Bank lengths at nesting colonies in California average 455 m, ranging from 13 to 1,900 m (Humphrey and Garrison 1987, as cited in Garrison 1998). Longer banks can support larger colonies, which tend to persist longer than smaller colonies (Josefik 1962; Freer 1977; B. Garrison, unpublished data, all as cited in Garrison 1998). Vegetation structure or type on top of the banks does not appear to affect bank selection (Garrison 1998), though bank protection projects can limit distribution of colonies (J. Silveira, personal communication, 2004). Bank swallows show fairly strong affinity to breeding and natal nest sites, but interchange between colonies also occurs (Moffatt et al. 2005). As well, colonies along the Sacramento River are usually active for less than 7 years and the species can be thought of in terms of a metapopulation that persists through a balance of extinction and recolonization of colonies (Moffatt et al. 2005). Not every suitable bank is colonized by swallows; approximately 40–60% of banks suitable for nesting on the Sacramento River are used in any given year (Garrison 1998). During the nesting season, birds usually forage within 200 m of the colony, although distance may vary depending on foraging habitat availability (Turner 1980, as cited in Garrison 1998). Foraging habitat includes aerial space over lakes, ponds, streams, meadows, fields, pastures, wetlands, and occasionally forested habitat (Stoner 1936, Gross 1942, Turner and Rose 1989; all as cited in Garrison 1998).

Bank Swallows arrive on breeding grounds in California beginning in late March and early April, with most arriving in late April and early May (Garrison 1998). Eggs generally require two weeks to hatch, and nestlings in the Sacramento River basin require, on average, 18-21 days before fledgling (Garrison, unpublished data, as cited in Garrison 1998). Moffatt et al. (2005) studied the effects of maximum river discharge, surrounding land cover, estimated colony size, temperature, and precipitation on bank swallow nest site extinctions and colonizations on the Sacramento River. Their study suggests that higher discharge had a net positive effect on colony dynamics, but also increased both colonization and extinction rates. Of the factors studied, river discharge before the breeding season was the only factor that appeared to influence colonization. Hence, high flows occurring before the beginning of the breeding season (late March) would benefit bank swallows by creating suitable habitat.

Submodel bounding and integrating:

Below we list the management actions, ecological objectives, and performance measures that are relevant to bank swallow:

Management actions	Ecological objectives	Performance measures
▪ Flow management	(1) Maximize availability and quality of nesting habitats	▪ Length of channel bank with suitable nesting
▪ Bank protection	(2) Maximize nesting success	▪ Ramping rates
▪ Levee setback		▪ Timing / height of flooding and nesting
		▪ Area of suitable nesting habitat

Based on these submodel boundaries and our review of the literature we have identified three functional relationships that may quantifiable, and are described below (priorities for integration area also included and summarized in
Table **2.3**). Figure 3.14 illustrates the cause-effect pathway for each of these relationships, while Table 3.4 summarizes the models, functional relationships, and/or data that may be available to quantify each step in the cause-effect pathway.

Pathway 1: Discharge-bank erosion-nesting habitat [High priority]. It may be possible to estimate length and location of newly eroded banks created per time period (using outputs from the meander migration model) and combine these data with soil type (spatial location of soils with suitable texture for burrow construction) using a GIS to predict the area of suitable nesting habitat under alternative flow scenarios. However, it is uncertain whether available soil maps have the degree of precision that would be useful for such an analysis. Also, this analysis could not account for two potentially confounding variables: bank slope and bank height. Using the meander migration model, it may be possible, however, to make some assumptions about the age of an eroded bank in suitable soils (e.g., time since last erosion event at a particular location) and bank slopes, reasoning that bank slopes flatten through time in the absence of successive erosion events. This reasoning assumes that bank full events are limited and as a result creation of new cutbanks is limited, which seems unlikely. It's also not clear if existing topographic data (i.e., digital elevation models) or other field studies (e.g., Koll Buer's bank erosion study, CDWR bank protection mapping) will inform identification of bank heights that are suitable for colony formation.

Pathway 2: Discharge-timing-nesting habitat [Moderate priority]. High flows from mid-March to the end of July may be detrimental if they undercut banks with active colonies (Humphrey and Garrison 1987, as cited in Moffatt et al. 2005) or drown nestlings (Moffatt et al. 2005). Consequently, we may be able to assess the timing and magnitude of high flow events to assess colony failure or inundation using stage-discharge relationships in both the areas mapped as existing colonies and areas believed to be suitable in the future if new bank erosion were to occur. This analysis would require a range of bank heights to be modeled: the full range of bank heights (1.3 to 7.3m), an average bank height (3.3 m), or a minimum bank height (1 m) suitable for colony formation (all as reported by Garrison 1998). Though it seems likely that burrow are clustered near the top of exposed banks away from the water level. Then, the meander migration model could be linked with soils information, and bank height information in a GIS to evaluate the timing and location of discharge events that will affect bank swallow colonies during their nesting period (March-July). A complicating factor is whether this analysis could account for the effects of lower magnitude discharges on erosion of bank toes, thereby causing slumping. Hence, an evaluation of the relationship between drawdown rate and slump failures may provide insights because there is some evidence that ramping rates may be important.

Pathway 3: Bank protection-nesting habitat [Low priority]. One of the biggest factors affecting habitat availability is direct loss of nesting habitat due to bank protection and flood control projects (Garrison et al. 1987, as cited in Garrison 1998). Very few suitable banks remain in some reaches of the Sacramento River due to extensive bank protection and channelization. Therefore, removing riprap from sufficiently high banks with soils suitable for nest burrows may directly increase availability of nesting habitat and lead to more a more stable metapopulation along the Sacramento River (Moffatt et al. 2005). Based on this rationale we may be able overlay bank protection mapping (conducted by CDWR) with soils information to examine the amount of potential nesting habitat that becomes available with the removal of bank protection at specific locations.

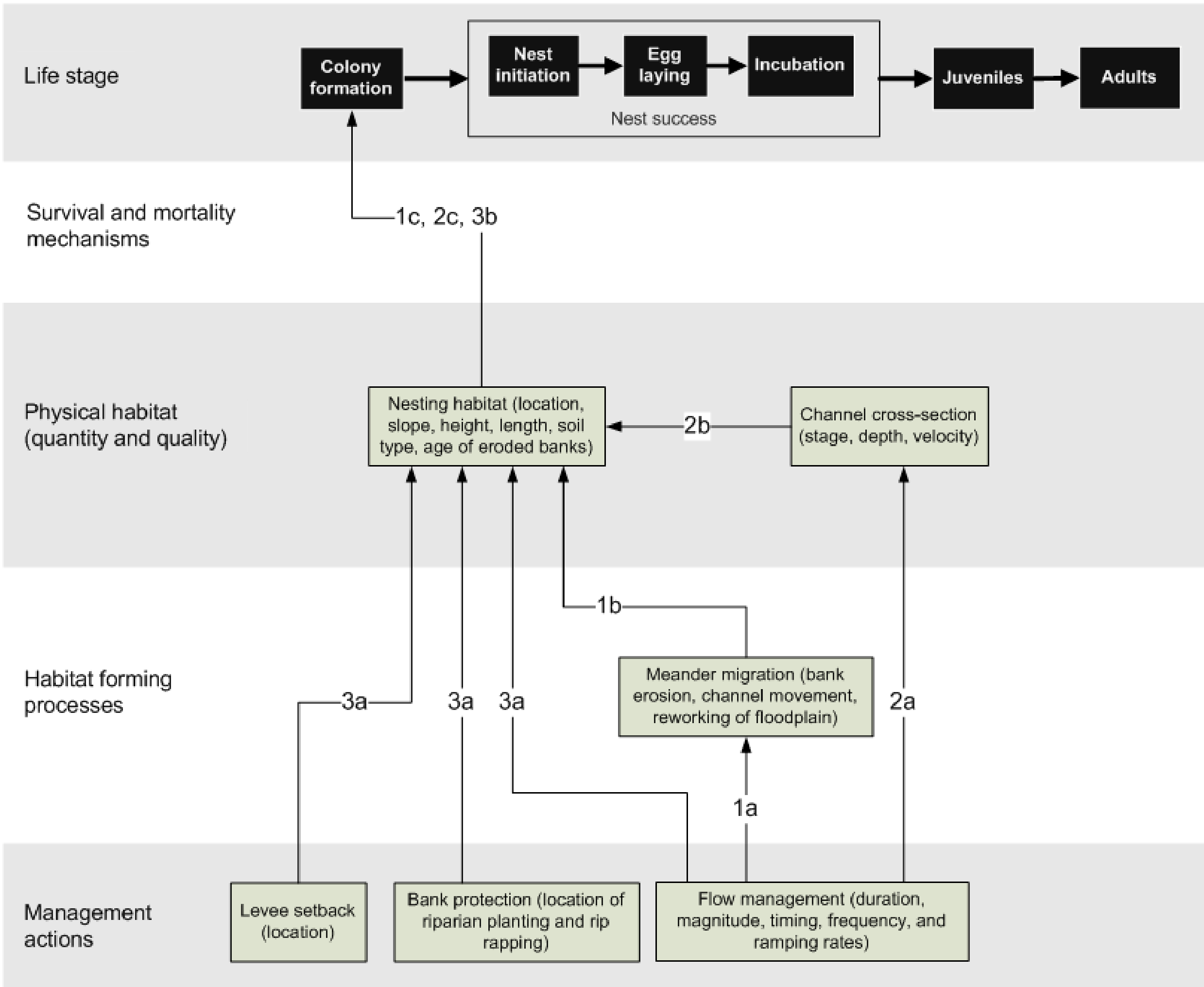

Figure 3.14. Conceptual diagram representing the links between management actions and important life stages for *bank swallow*, as mediated by changes in habitat forming processes, physical habitats, and survival or mortality mechanisms. Pathways represent those with the greatest potential to be quantified using available (or new) models, functional relationships, and/or data. Numbers represent pathways linking management actions to performance measures of interest. Letters represent individual and quantifiable linkages along the pathway.

Table 3.4. Summary of the pathways linking management actions to performance measures, the individual links that may be quantified, and the models, functional relationship, and/or data that may be used to quantify the links presented in Figure 3.14.

Pathway and Link	Link		Proposed model, functional relationship, or data source
	From	To	
1a	Flow	Meander migration	DOM / historical flow data -> Meander migration model
1b	Meander migration	Quality of nesting habitat	Data related to important covariates (soils, bank height, bank slope) Literature review or expert elicitation of habitat preferences??
1c	Quality of nesting habitat	PM for colony formation	
2a	Flow	Channel cross-section	DOM / historical flow data -> cross-sections assumed constant
2b	Channel cross-section	Quality of nesting habitat	Data related to important covariates (soils, bank slope) Literature review or expert elicitation of habitat preferences??
2c	Quality of nesting habitat	PM for colony formation	
3a	Flow, levee setbacks and bank protection	Channel cross-section	DOM / historical flow data -> cross-sections assumed constant or input as an action (e.g., levee setback),
3b	Channel cross-section	Area of accessible nesting habitats	Data related to important covariates (levees, bank protection, soils, bank height, bank slope) Literature review or expert elicitation of habitat preferences??
3c	Area of accessible nesting habitat	PM for colony formation	

3.2.5 Western pond turtle (WPT)

Key life history requirements (critical habitats and life history timing):

Currently there is little information about western pond turtle distribution in the upper Sacramento River system to guide selection of specific habitats to analyze in the DA Tool. However, building on information from other systems, we believe nesting areas and off-channel habitats provide critical areas on which western pond turtle depend.

Females select nesting sites in dry clay, loam, or silt soils on shallow slopes (< 15%) in grassland or other herbaceous vegetation at distances ranging from 1.5 to 402 m. away from water bodies, with an average distance of 45 m. from water (Holland and Bury in press, as cited in Spinks et al. 2003; Nussbaum et al. 1983, Holland 1994; Reese 1996). Western pond turtle also exhibit philopatry (home loving), so continuity of nesting habitat from year to year may be important. They also have low fecundity, with eggs requiring 80 days to incubate. During this time they are vulnerable to increased soil moisture as a source of early life mortality.

Both Germano and Holland (personal communication, 2005) hypothesize that off-channel habitats provide the primary aquatic habitat for western pond turtle in large river systems like the Sacramento River, suggesting that processes like oxbow formation are important for creating and maintaining habitats. Hatchlings spend much of their time in shallow water with dense vegetation of submergents or short emergents (Holland, personal communication, as cited in Jennings and Hayes 1994), while juveniles and adults require basking habitat to thermoregulate and aid digestion. Basking habitat in the mainstem river likely isn't limiting, however, because the Sacramento River provides plenty of exposure to the sun, and warm water temperatures suggesting that basking not be as important as it is on river systems with colder water temperatures (e.g., Trinity River).

Hatchling and juvenile life stages are thought to have low survival, while adults have high survival (Jennings et al. 1992). Hence, there are hypotheses that bullfrogs, bass, and birds (e.g., herons, egrets) may provide a significant mortality mechanism on hatchlings in low-velocity off-channel habitats. There has been little study to test such hypotheses and little information available relating the abundance and distribution of potential predators to off-channel connectivity. Water quality in oxbow habitats may also affect turtle health and survival, either directly by affecting survival or indirectly by influencing the abundance and distribution of zooplankton – a key food source for hatchlings. However, Chico State researchers have found western pond turtle in wastewater treatment ponds, and there hasn't been much discussion of water quality effects in the literature.

Generally, breeding can occur throughout the year, but peaks in June and July (Holland 1994, Reese 1996). It is unknown if this specific timing also applies to populations in the Sacramento River. Eggs are sensitive to soil moisture, hence dramatic increases in flow/stage within the critical 4 month nesting period (e.g., during egg incubation and hatchling time in the nest) could be a source of mortality. Consequently, there is likely a competitive advantage of breeding in June and July, after the rainy season has ended due to a reduced threat to incubating eggs. On the other hand, non-peak breeders (between April and May) may have attuned to regular changes in stage-discharge at other times of the year by selecting higher grounds for nesting and may also be less prone to egg mortality during these periods.

Submodel bounding and integrating:

Below we list the management actions, ecological objectives and performance measures that are relevant to western pond turtle:

Management actions	Ecological objectives	Performance measures
▪ Flow management ▪ Levee setback	(1) Maximize availability and quality of nesting habitats (2) Maximize availability and quality of habitats for foraging, basking, and predator avoidance (3) Maximize nesting success	▪ Area / connectivity of off-channel habitats ▪ Timing / height of flooding and nesting ▪ Area of suitable nesting habitat

The sequence of calculations that may be available to link these management actions and performance measures is presented in Figure 3.15. The following describes our understanding of the steps to quantify these linkages using available models and/or data (summarized in Table 3.5) and priorities for integration in the DA Tool (summarized in Table 2.3):

Pathway 1: Discharge-off-channel habitat [High priority]. Both Germano (personal communication, 2005) and Holland (personal communication, 2005) hypothesize that off-channel habitats provide the primary aquatic habitat for western pond turtle in large river systems like the Sacramento River. Therefore, we propose relating flow characteristics (primarily magnitude, but also duration and frequency) and off-channel habitat extent and distribution using the oxbow cut-off model. A potential performance measure would track the area of off-channel habitats over time. As information describing the spatial distribution and abundance of western pond turtles in the Sacramento River is limited today, we could eventually refine these measures to focus on the areal extent of off-channel habitats in particular reaches, or even specific off-channel habitats, that are heavily used by western pond turtle.

Pathway 2: Discharge-timing-stage-nesting habitat [Low priority]. Although current water operations generally prevent dramatic increases in stage-discharge during the peak breeding season for turtles (June-July), we may want the DA Tool to be able to evaluate the implications of quick increases in flow on this species. For example, we may want to be able to consider the effects of increases in discharge to prepare seedbeds for cottonwood recruitment between April and June, and possible ecological tradeoffs between cottonwood and turtles (though we recognize that is unlikely that turtles will be nesting at the same elevation as cottonwood recruitment). This analysis requires an estimation of those times and locations at which a particular discharge would flood turtle nests. One complication is that we will need to define the lateral distance from the channel for which stage-discharge can be estimated, because nesting sites are reported at a wide range of distances from water bodies (1.5 to 402 m). This information may be difficult to acquire because stage-discharge relationships are site-specific and available for a limited range of high flow events.

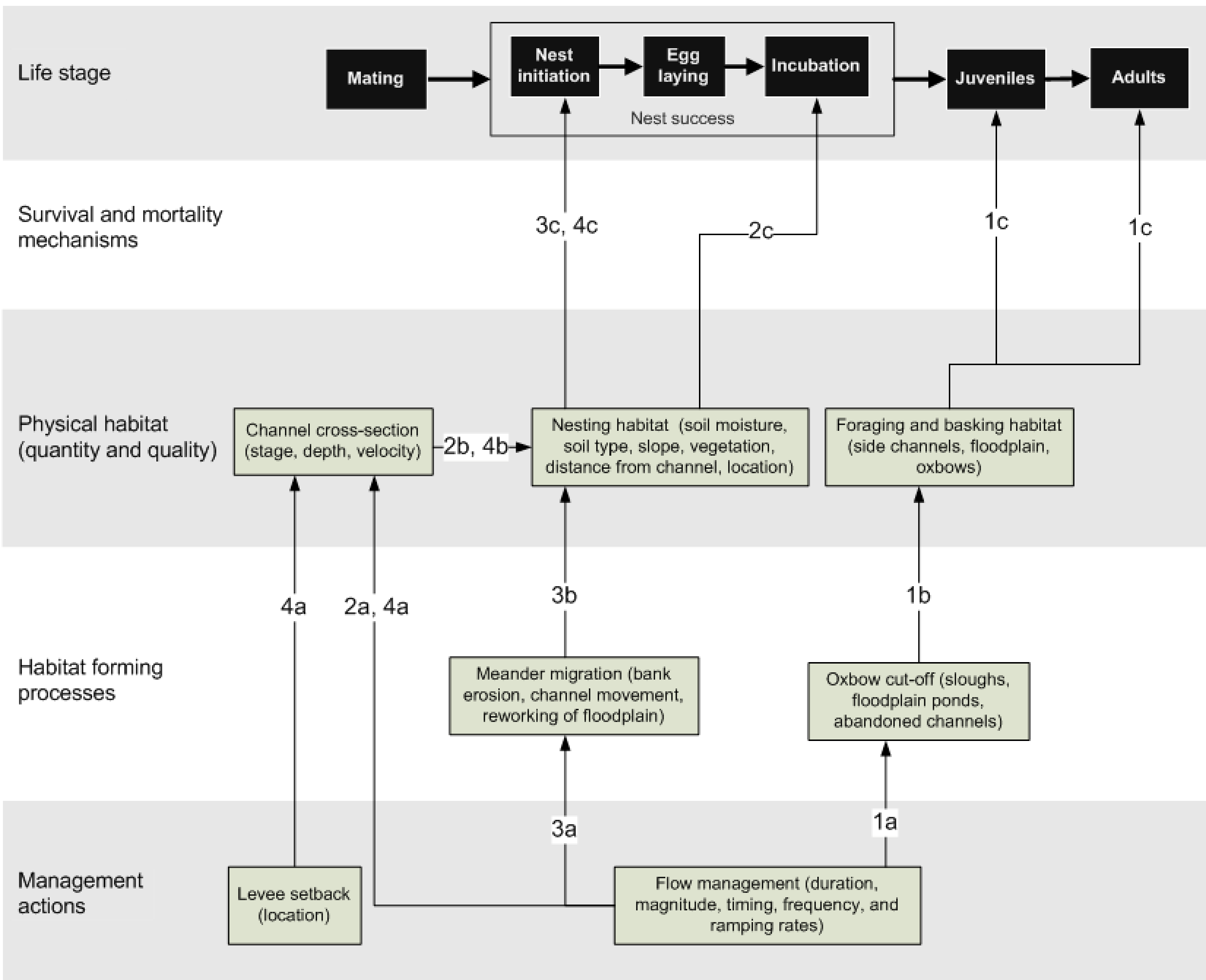

Figure 3.15. Conceptual diagram representing the links between management actions and important life stages for *western pond turtle*, as mediated by changes in habitat forming processes, physical habitats, and survival or mortality mechanisms. Pathways represent those with the greatest potential to be quantified using available (or new) models, functional relationships, and/or data. Numbers represent pathways linking management actions to performance measures of interest. Letters represent individual and quantifiable linkages along the pathway.

Pathway 3: Discharge-floodplain-nesting habitat [Low priority]. Continuity of nesting habitat may also be important to turtles because of their tendency towards philopatry. Consequently, we may be able to use the meander migration model and estimates of the "area of floodplain re-worked" to track continuity of existing and potential nesting habitat. A complication though, is that the area of floodplain re-worked would be an ambivalent metric. Re-worked areas could either reduce the suitability of existing nesting sites or by scouring the floodplain channel migration may create new areas of grassland and herbaceous cover, which are believed to be preferable for nesting. We also do not have any information regarding the spatial distribution of turtles, and may not have the information to describe turtle preferences for other habitat features along the Sacramento.

Pathway 4: Discharge-levees-nesting habitat [Low priority]. In the DA Tool, it may be possible to consider the effect of setting back levees on inundation of existing and potential nesting habitats, thereby causing nest failure. However, it may also be possible that relocating setback levees will open up new areas for nesting. Nonetheless, we may be able to track the area of existing and potential nesting habitat affected by changes in levee setback and refine the biological preferences for variations in this metric as we learn more about western pond turtle along the Sacramento.

Table 3.5. Summary of the pathways linking management actions to performance measures, the individual links that may be quantified, and the models, functional relationship, and/or data that may be used to quantify the links presented in Figure 3.15.

Pathway and Link	**Link**		**Proposed model, functional relationship, or data source**
	From	**To**	
1a	Flow	Oxbow cut-off	DOM / historical flow data -> oxbow cut-off model
1b	Oxbow cut-off	Foraging and basking areas	Area of suitable habitat Field studies, literature review or expert elicitation of habitat preferences
1c	Foraging and basking habitat	PMs for juvenile and adult habitat	
2a	Flow	Channel cross-section	DOM / historical flow data -> cross-sections assumed constant or input as an action (e.g., levee setback)??
2b	Channel cross-section	Quality of nesting habitat	Data related to important covariates (spatial distribution of existing habitats, bank slope, bank height, distance from water, adjacent vegetation) Literature review or expert elicitation of habitat preferences??
2c	Quality of nesting habitat	PM for egg incubation	Timing of inundation of potential nesting habitats
3a	Flow	Meander migration	DOM / historical flow data -> meander migration model
3b	Meander migration	Quality of nesting habitat	Literature review or expert elicitation of habitat preferences??
3c	Quality of nesting habitat	PM for nest initiation	
4a	Levee and flow	Channel cross-section	DOM / historical flow data -> cross sections with hypothetical changes to levee setback and timing of inundation of potential nesting habitats
4b	Channel cross-section	Quality of nesting habitat	Literature review or expert elicitation of habitat preferences??
4c	Quality of nesting habitat	PM for nest initiation	

3.2.6 Fremont cottonwood (FC)

Key life history requirements (critical habitats and life history timing):

Sacramento hydrosystem operations have reduced the viability of certain tree species like Fremont cottonwood to establish in some riparian habitats. The DA tool aims to explore Fremont cottonwood early life history responses at certain sites to alternative flow regimes. This focal species submodel includes just one fundamental process: riparian initiation—the process of plant seedling germination and initiation as a function of flow magnitude, duration and timing and bed material (Figure 3.16). It does not include riparian scour—the process of flow-induced seedling mortality based on magnitude and plant location (though this could be added at a future date). The submodel also ignores multi-species interactions such as succession. (Stand development beyond the first 1-2 years involves successional pathway modeling of some form, such as the widely used VDDT model). The combination of initiation and scour processes determines the long-term spatial locations for riparian establishment. The former process focuses solely on whether new seedlings will likely survive the first year of life at a given site. Hence, in the DA tool this submodel can be used to develop portions of the flow release hydrograph to improve riparian establishment.

Submodel bounding and integrating:

Management actions	Ecological objectives	Performance measures
▪ Flow management	(1) Manage stage and rate of stage decline during focal species seed dispersal periods at critical index habitats to improve seedling survival	▪ Zones of successful riparian recruitment (on representative cross-sections) for specific tree species in summer/fall.

The riparian initiation (germination) relationships used on the Sacramento River will be based on the box recruitment model proposed by Mahoney and Rood (1998). This conceptual model has been implemented in a generic format in the TARGETS model (Alexander 2004). TARGETS provides x and y coordinates along a cross section indicating on any given date the presence and state of a riparian seedling. Seeds are either absent, alive or dead. The computational process for each cross-section involves tracking the daily rate of stage decline (or increase) for an input hydrograph, soil moisture (i.e., factoring in the capillary water fringe), root growth rates, and seed dispersal timing to evaluate whether a plant would successfully initiate. This process can be repeated for different hydrographs and different channel geometries to improve flow releases. For any given cross section and date, TARGETS provides graphs of bands of successful riparian initiation (Figure 3.17).

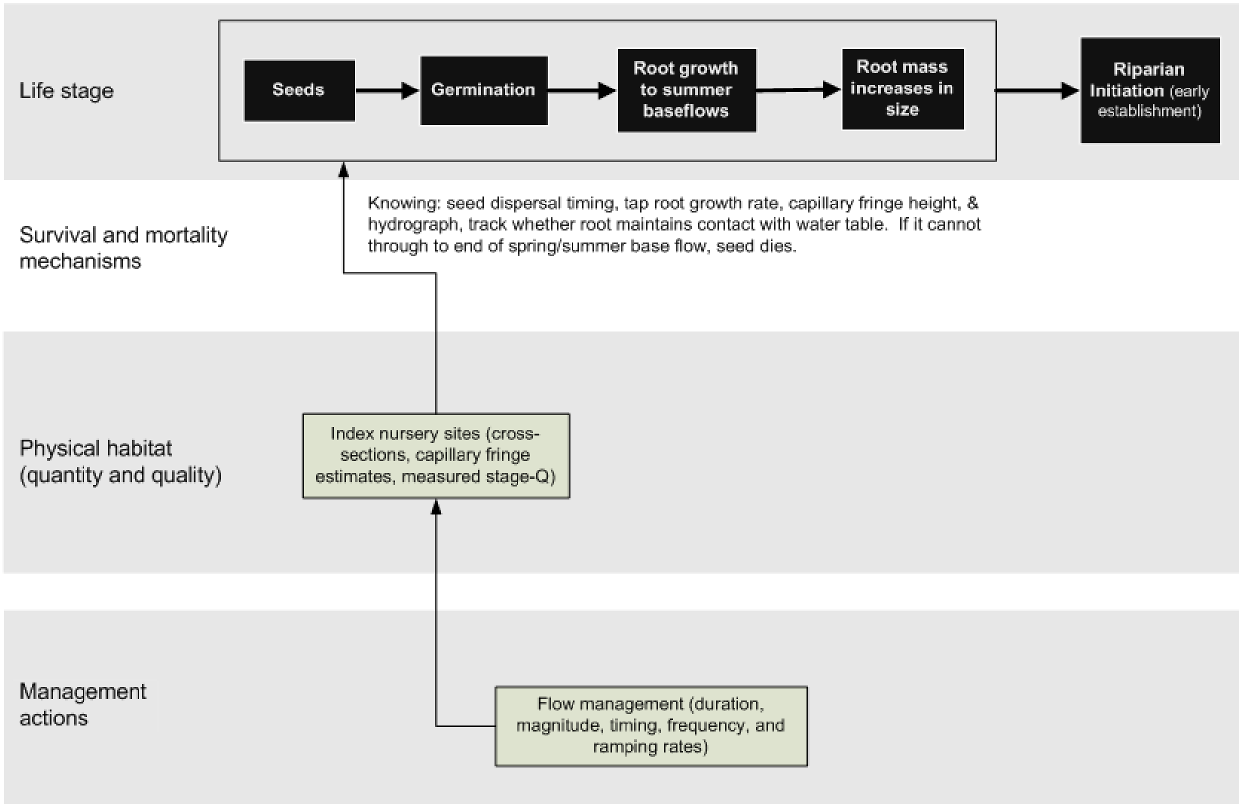

Figure 3.16. Conceptual diagram representing the links between management actions and important life stages for *Fremont cottonwood* as represented using available models, functional relationships, and/or data.

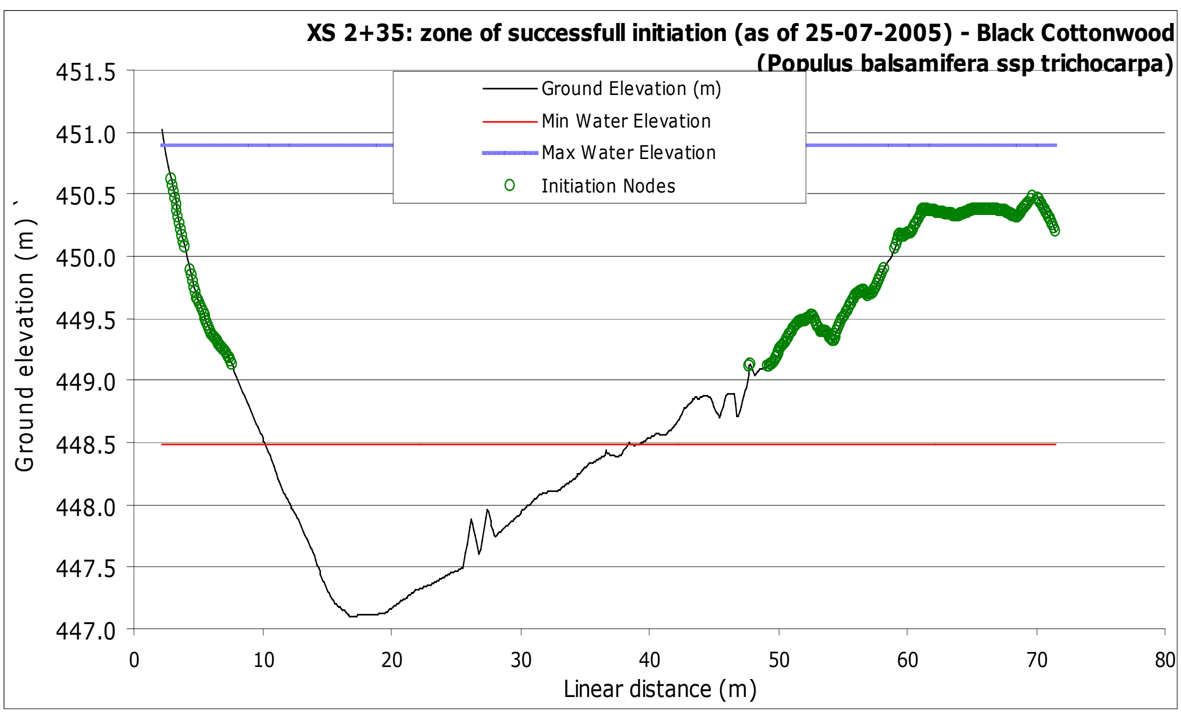

Figure 3.17. Example of an output obtained from TARGETS model.

4. Workshop Structure

The workshop is being structured as a forum to elicit feedback and technical input for the DA Tool. This section is meant to clarify the structure of the workshop, form of participation, and steps to elicit technical feedback. The design workshop will occur in October 11-12, 2005. Appendix A provides a sample invitation letter sent to all invitees, while Appendix B provides a workshop agenda, and Appendix C the list of all invitees.

4.1 Workshop objectives

We have four objectives going into the workshop:

1. review a draft design of Sacramento River DA Tool with technical experts;
2. consult with technical experts on submodel components and their integration across submodels;
3. develop a common understanding of the key relationships between flow, channel condition and habitat requirements for Sacramento River focal species; and
4. decide on next steps for refining key relationships.

4.2 Day 1: Reviewing DA Tool components

During the first day of the workshop, the entire group will review the project background, approach to tradeoff evaluation (i.e., PrOACT) and intended uses of the Tool. However, the majority of the day will be spent reviewing the bounding and integrating issues of the individual submodel components (i.e., physical and focal species submodels). Review of this information will prepare participants for more detailed subgroup discussions on Day 2. For the physical submodels (i.e., the physical foundation of the DA Tool) this includes a review of:

- required inputs for each model;
- general model structure and intended applications;
- spatial / temporal resolution of outputs;
- simplifying assumptions and limitations;
- dependence on other models; and
- previous applications in the Sacramento River.

For the focal species presentations we will focus on summarizing our current ideas by discussing:

- conceptual diagrams for each focal species;
- available functional relationships / models available to link management actions to biologically relevant performance measures;
- required inputs from the physical models;
- spatial / temporal resolution of outputs (i.e., performance measures);
- simplifying assumptions and limitations; and
- further work required to link changes in physical habitats to biological relevance.

4.3 Day 2: Refining the DA Tool

On day 2 we will directly engage technical experts that have experience and expertise in key aspects of the Sacramento River ecosystem by working with them in one of three facilitated subgroups: (1) a physical subgroup (hydrology, water temperature, stage-discharge, sediment transport and substrate composition, chute cut-off, and meander migration), (2) a fish subgroup (Chinook salmon, steelhead trout, and green sturgeon), and (3) a riparian and wildlife subgroup (western pond turtle, bank swallow, and Fremont cottonwood).

4.3.1 Physical subgroup

The physical subgroup will include technical experts who are familiar with the six submodels (listed above) that are available to describe changes in the physical foundation of the DA Tool. This subgroup will be tasked with:

- clarifying where and when we need to know submodel inputs and outputs;
- determining the order of operations or sequence of required model runs; and
- identifying a range of flow years (and other management actions) that would provide good testing of physical (and focal species) submodels,

We will lead discussions around these topics by working through three main tasks:

Task 1: Using a "*Looking Outward Matrix*," participants will describe how the physical components of the system fit together to form an interacting system. A looking outward matrix is formed by arraying submodel components as presented in Figure 4.1. Each element in the matrix represents a potential transfer of information between submodels, as well as an explicit recognition about which management actions and driving variables are relevant to a model. Experts of an individual submodel will focus on understanding what is required from all the other submodels to predict how the individual's submodel will behave (e.g., units of measure, spatial and temporal resolution). This exercise will also provide a framework to discuss model assumptions and review the coordination necessary to ensure coherent integration and consistency in assumptions among the physical submodels. A key requirement to run the DA Tool and physical submodels components will be to determine the range of management scenarios that can be evaluated. Hence, during this task we will also discuss ranges of management scenarios (e.g., flow and channel configuration scenarios) that are feasible for submodel testing. The looking outward process is extremely beneficial because it helps define the responsibility of each submodel at: (1) providing identified performance measures for their submodel, and (2) providing the outputs required by all the other submodels (see Figure 2.4).

Task 2: Next, as a complement to the looking outward matrix, we will use our space-time diagram (Figure 2.8) as a starting point from which to map the spatial extent of physical changes along the Sacramento River and review the temporal scale and resolution of each submodel component. A large map of the Study Area will also be used to define the specific locations of interest to the physical submodels.

Task 3: This subgroup will also develop a flow chart depicting the order of operations or sequence of model runs required to develop coherent coordination among submodels. For instance, hydrological data from CALSIM II will be a key requirement (and first step) prior to running all the other physical submodels.

Task 4: Once the two focal species subgroups have better articulated their ideal requirements for physical submodel output (Task 1 in Section 4.3.2), we will discuss with them what types of indicators can in reality be feasibly generated from the current physical submodels.

To: / From:	**CALSIM II**	**Water temperature**	**Stage-discharge**
CALSIM II			
Water temperature			
Stage-discharge			
Actions			
Driving Variables			

Figure 4.1. Basic structure of a Looking Outward Matrix and the potential links among physical submodels.

4.3.2 Focal species subgroups

We will discuss and refine approaches to linking the physical drivers to biological relevance in two focal species subgroups: (1) Chinook salmon, steelhead trout, green sturgeon, and (2) bank swallow, western pond turtle, Fremont cottonwood. Discussions will focus on:

- clarifying what specific outputs are required from physical submodels;
- refining hypothetical functional relationships between physical habitat performance measures and biological relevance (i.e., habitat suitability);
- discussing possible analyses to refine these functions (who could contribute and when);
- assigning priorities for integrating these functional relationships in the DA Tool;
- determining which range of flow years (plus other management actions) would provide good testing of these functional relationships; and
- discussing appropriate ways to aggregate performance measures across space and time for the DA Tool.

To focus these discussions, subgroups will work through four tasks:

Task 1: First, focal species experts will review the individual linkages and pathways described by the conceptual diagrams (Figure 3.12 through Figure 3.15) and related tables (Table 3.2 through Table 3.5). This review will: (a) specify exactly what inputs are required from physical models (units, spatial / temporal resolution); (b) verify whether linkages are feasible to quantify given available physical submodels; and (c) explore whether new functional relationships can be developed with available data. This discussion will also determine which range of management actions (i.e., flow and channel configuration) would provide good testing of the functional relationships for the focal species. We will also need to do some initial prioritization (i.e., establish which submodels are "must have" vs. "nice to have" in the DA Tool). After this task, some discussion will occur with the physical subgroup to confirm what is feasible (Task 4 Section 4.3.1)

Task 2: Next, we will review the spatial (critical habitats) and temporal (life history timing) components of interest to the focal species. Although there are many habitat elements and life history stages of potential interest to managers on the Sacramento River, the ecological objectives presented earlier (Table 2.2) define the boundaries to this review. Using a map of the Sacramento River ecosystem we will identify areas supporting the relevant life stages of focal species (e.g., aquatic habitats for western pond turtle). Important locations may be defined by historic, current, and/or potential habitats that could become suitable in the future under alternative management scenarios. These sites may be distinguished by differences in the lateral, longitudinal, and vertical configurations of habitats across the Sacramento River. Indicators of habitat condition, as provided by the physical submodels, must also be available to describe these areas. To refine our understanding of critical life history timing, we will use a life history timing diagram (e.g., Figure 2.7) to review the timing of life history events which could be influenced by management actions in the DA Tool. A key aspect to this discussion will also focus on identifying important covariates that may also contribute to habitat quality at specific times of the year.

Task 3: The majority of time for the focal species subgroups will focus on refining *hypothetical* functional relationships, discussing ideas for analyses to refine these relationships, and assigning priorities for their integration. Due to the emphasis on habitat-based performance measures, a key issue spanning most focal species and submodel relationships relates to how we should assign biological meaning to habitat-based performance measures in the DA Tool – i.e., relating the physical foundation of the DA Tool to habitat requirements for the focal species. In cases where the relationship between a habitat variable and biological preference are well understood for a focal species, we can simply use the available literature to inform these relationships (e.g., thermal preferences). However, in other cases, the literature related to a focal species may be incomplete (e.g., for green sturgeon and egg incubation temperatures) or the habitat variable may be measured in a way that has not been related to habitat preference (e.g., rate of floodplain reworked). For these cases, we cannot simply assume that a higher value of a performance measure is necessarily better for a focal species (i.e., there is a linear relationship between a habitat variable and biological preference); habitat preferences may be non-linear (see Figure 4.2). Thus, this task will focus on describing the shape and estimating key parameter values (e.g., slope and intercept) for these functional relationships.

Task 4: The main output of the DA Tool will be to calculate performance measures that relate various ecological objectives (Table 2.2) to the management scenarios that will be evaluated in the DA Tool. Performance measures will be estimated at a variety of spatial locations (e.g., oxbow lakes, sloughs, pools, or point bars across the Study Area) and over various temporal scales (e.g., instantaneous, daily, monthly, annual, or decadal periods). Thus, a key task at the workshop will be to consider ways to aggregate or summarize these performance measures across space and time. For example, performance measures could then be summarized using the average, median, or 10^{th} and 90^{th} percentile values over a number of water year alternatives (e.g., Figure 4.3). Such summaries could then provide insight into the year-to-year ability of a management scenario in meeting the desired ecological objectives. Explicit representation of the variability in performance measures may also be useful in exploring underlying uncertainties in the DA Tool: variability in data (e.g., historical flow data), model structure (e.g., competing models), or poorly understood relationships (e.g., shape of functional relationships). Undoubtedly there will be several important unknowns that will affect the DA Tool and could influence future water planning decisions. In some cases, the effect of such uncertainties on performance measures could be evaluated through sensitivity analyses.

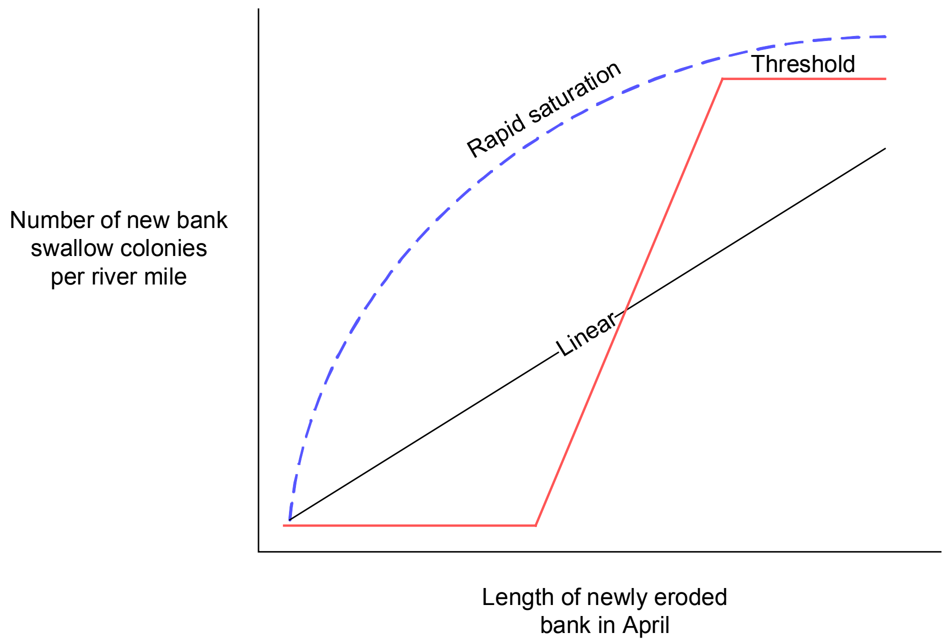

Figure 4.2. Three *hypothetical* forms describing the functional relationship between a habitat variable (provided by the meander migration) and a biologically relevant measure for bank swallows. The shape and parameter values of potential relationships will form the basis of the focal species subgroup discussion among technical experts.

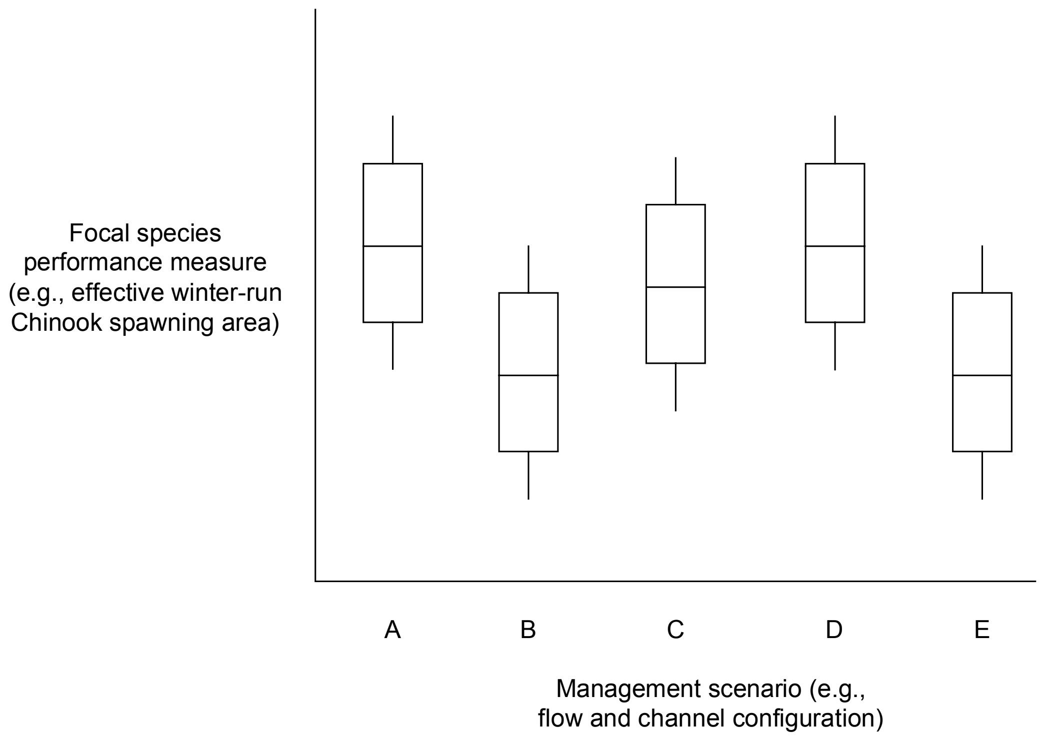

Figure 4.3. Sample of the way in which variability in performance measures (across space and time) could be presented in the DA Tool. These box plots represent the 10^{th}, 25^{th}, 50^{th}, 75^{th}, and 90^{th} percentiles of values for the estimated effective area of spawning for winter-run Chinook salmon.

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Appendix A – Workshop Invitation

The Nature Conservancy
SAVING THE LAST GREAT PLACES ON EARTH

September 5, 2005

Re: Workshop Invitation: "Designing a Decision Analysis Tool to Evaluate the Effects of Alternative Management Actions on the Sacramento River Ecosystem." October 11-12, Sacramento, California.

Dear Workshop Invitee:

We are contacting you because we value your technical expertise and would welcome your attendance at a 2-day workshop (October 11 and 12 in Sacramento) to review our preliminary design of a Decision Analysis (DA) Tool for the Sacramento River.

There are numerous water planning efforts occurring in California that are attempting to balance various demands on water supply. Many of these efforts are hindered by the difficulty in evaluating changes in stream flow resulting from various management decisions and their resulting affects on the ecosystem and specifically on the ecosystem of the mainstem Sacramento River. 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. Describing additional attributes of the flow regime, and the manner in which they maintain the ecological function of the Sacramento River, would help formulate more effective water management and while maintaining functioning river systems as best as possible.. 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. Hence, motivating purposes for our work are to both address this lack of information and to provide some quantitative tools to assist water operations modelers and decision-makers in considering Sacramento ecosystem needs in their planning. To address this need we are reviewing and summarizing existing information in a State of the System report, conducting field studies to fill critical information gaps, refining and developing new physical models, and developing a decision support tool to evaluate ecological tradeoffs on the Sacramento River.

Your attendance at the workshop will assist water planning efforts on the Sacramento River by contributing to the development of this decision support tool. Our goal is to create an ecological model capable of "plugging-in" to existing water planning models (i.e. CALSIM II). The DA Tool will relate specific management actions, such as changes in stream flow or gravel additions, to responses in the habitats required to maintain six focal species (Chinook salmon, steelhead trout, green sturgeon, bank swallow, western pond turtle, and Fremont cottonwood). The DA tool will integrate existing quantitative and qualitative models, as well as a limited number of new functional relationships, within one framework to rapidly evaluate trade-offs among the different habitat requirements of the focal species. Since the knowledge base is quite limited for some focal species, the DA Tool will also function to explore implications of alternative hypotheses concerning species' habitat dependencies.

At the workshop we plan to consult with technical experts, such as yourself, on the physical models available to predict changes in physical habitats as well as existing or new functional relationships linking physical habitat conditions to the biological performance of the focal species. Plenary and subgroup discussions will focus on key issues of bounding and integrating these models and functional relationships. The specific objectives of the workshop will be to:

1. review a draft design of Sacramento River DA Tool with technical experts,
2. consult with technical experts on submodel components and their integration across submodels,
3. develop a common understanding of the key relationships between flow, channel condition and habitat requirements for Sacramento River focal species, and
4. decide on next steps for refining key relationships.

If you plan to attend, please contact Ryan Luster at The Nature Conservancy by **September 23, 2005** to confirm your participation. Attached you will find a workshop agenda and a list of people invited to the workshop. On September 12th we will email you a "backgrounder document" describing our preliminary design of the DA Tool and the feedback / participation that we are requesting at the workshop, we will also give you information at that time as to the location of the meeting that will be held in Sacramento on October 11th and 12th.

We look forward to your response.

Regards,

Ryan Luster

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Appendix B – Workshop Agenda

Designing a Decision Analysis (DA) Tool to Evaluate the Effects of Alternative Management Actions on the Sacramento River Ecosystem

Workshop objectives

1. review a draft design of Sacramento River DA Tool with technical experts,
2. consult with technical experts on submodel components and their integration across submodels,
3. develop a common understanding of the key relationships between flow, channel condition and habitat requirements for Sacramento River focal species, and
4. decide on next steps for refining key relationships.

Day 1 – Tuesday, October 11

Introductions and background

9:00	Welcome, introductions, and overview of TNC Sacramento River Flow project and study area (Ryan Luster, The Nature Conservancy)
9:40	Objectives and intended uses of the DA Tool (David Marmorek, ESSA Technologies) *[PrOACT approach to evaluation of alternatives; exploration of alternative hypotheses]*
10:15	Overall structure of DA Tool and components (Clint Alexander and David Marmorek, ESSA Technologies) *[Model interdependence, spatial and temporal scales, integration challenges, order of operations, management scenarios]*
10:55	Challenges in linking physical and focal species submodels (Marc Nelitz, ESSA Technologies)
11:10 – 11:30	**BREAK**

Physical submodel
[Model bounding and integrating: required inputs, general model structure, spatial / temporal resolution of outputs, simplifying assumptions and limitations, dependence on other models, previous applications in the Sacramento River]

11:30	Hydrology: CALSIM II and the Daily Operations Model (Clint Alexander, ESSA Technologies / plus relevant expert)
12:10	Water temperature: USBR Temperature Modeling System (Clint Alexander, ESSA Technologies / plus relevant expert)
12:30-1:30	**LUNCH**
1:30	Stage-discharge: Previous applications of HEC-RAS in study area (relevant expert)
1:50	Sediment transport and substrate composition: The Unified Gravel and Sand Model (Yantao Cui, Stillwater Sciences)
2:10	Oxbow cut-off model (Yantao Cui, Stillwater Sciences)
2:30	Meander migration model (Eric Larsen, UC Davis)

Focal species' submodels (or raw materials for potential submodels)
[Linking physical drivers to biological relevance: conceptual diagrams, available functional relationships / models, required inputs, spatial / temporal resolution of outputs, simplifying assumptions and limitations, further work]

2:50	Chinook salmon (Frank Ligon, Stillwater Sciences / plus relevant expert)
3:10	Steelhead trout (Frank Ligon, Stillwater Sciences / plus relevant expert)
3:30-3:50	**BREAK**
3:50	Green sturgeon (Mike Fainter, Stillwater Sciences / plus relevant expert)
4:10	Bank swallow (Bruce Orr, Stillwater Sciences / plus relevant expert)
4:30	Western pond turtle (Bruce Orr, Stillwater Sciences / plus relevant expert)
4:50	Fremont cottonwood (Mike Roberts, The Nature Conservancy / Bruce Orr, Stillwater Sciences)
5:10	**ADJOURN**

Day 2 – Wednesday, October 12

9:00 – 3:00 *Subgroup discussions* (facilitated by David Marmorek, Clint Alexander, and Marc Nelitz, ESSA Technologies)

12:30 – 1:30 **LUNCH** and meetings between physical and focal species subgroup participants to clarify information transfers

<u>Physical subgroup:</u> Hydrology, water temperature, stage-discharge, sediment transport and substrate composition, chute cut-off, and meander migration

- clarify where and when we need to know submodel inputs / outputs
- determine order of operations / runs of individual models

- determine which range of flow years (plus ranges for other management actions) would provide good testing of submodels

Focal species subgroups: (1) Chinook salmon, steelhead trout, green sturgeon, and (2) bank swallow, western pond turtle, Fremont cottonwood

- clarify where and when we need to know outputs from physical submodels
- refine *hypothetical* functional relationships between physical habitat performance measures and biologically relevant measures of habitat suitability
- discuss possible analyses to refine these functional relationships (who to complete and by what date)
- assign priorities for integrating these functional relationships
- determine which range of flow years (plus ranges for other management actions) would provide good testing of focal species relationships
- discuss appropriate ways to aggregate performance measures across space and time for DA Tool

3:00-3:20 **BREAK**

3:20 *Plenary session* (facilitated by David Marmorek, ESSA Technologies)

- report back on subgroup progress
- brief discussion about next steps

5:00 **ADJOURN**

Appendix C – Invited Workshop Participants

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

Name	Subgroup	Area of Expertise	Organization	Phone / Fax	Email
Russ Yaworsky	Physical	USBR-TMS	USBR	916-978-5099	ryaworsky@mp.usbr.gov
Tom Smith	Physical	HEC-RAS middle Sac	Ayres Associates	916-563-7700	smitht@AyresAssociates.com
Harry Rectenwald	Fish	Chinook salmon	CDFG	530-225-2368	hrectenw@dfg.ca.gov
Jim Smith	Fish	Chinook salmon	USFW, Red Bluff	530-527-3043	Jim_Smith@fws.gov
Dennis McEwan	Fish	Steelhead	CDFG	916-327-8850	dmcewan@dfg.ca.gov
Rob Titus	Fish	Steelhead	CDFG	916-227-6399	rtitus@dfg.ca.gov
Peter Klimley	Fish	Green sturgeon	UC Davis	530-752-5830	apklimley@ucdavis.edu
Kurt Brown	Fish	Green sturgeon	USFWS – Coleman Hatchery		brown_kurtis@fws.gov
Wim Kimmerer	Fish	Chinook salmon modeling	San Francisco State Univ.	415-338-3515	kimmerer@sfsu.edu
Mark Gard	Fish - Not available	PHABSIM, River 2D, juvenile stranding surveys	USFWS	916-414-6600	Mark_Gard@fws.gov
Dave Germano	Riparian / Wildlife	Western pond turtle	CSU, Bakersfield	661-664-2471	David_Germano@firstclass1.csubak.edu
Bruce Bury	Riparian / Wildlife	Western pond turtle	USGS	541-750-1010	Bruce_Bury@usgs.gov
Tag Engstrom	Riparian / Wildlife	Western pond turtle	California State University, Chico	530-898-6748	tengstrom@csuchico.edu
Ron Schlorff	Riparian / Wildlife	Bank swallow	CDFG	916-654-4262	RSchlorf@dfg.ca.gov
Barrett Garrison	Riparian / Wildlife	Bank swallow	CDFG, Rancho Cordova	916-358-2945	bagarris@hq.dfg.ca.gov
Joe Silveira	Riparian / Wildlife	Bank swallow	USFWS	530-934-2801	joe_silveira@fws.gov
Naduv Nur	Riparian / Wildlife	Riparian and songbirds	PRBO	415-868-1221 ext 315	nnur@prbo.org
John Bair	Riparian / Wildlife	TARGETS	McBain & Trush	707-826-7794	john@mcbaintrush.com
Steve Greco	Riparian / Wildlife	riparian-bird community	UC Davis	530-754-5983	segreco@ucdavis.edu