

# UC Davis

## San Francisco Estuary and Watershed Science

### Title

Using Conceptual Models in Ecosystem Restoration Decision Making: An Example from the Sacramento-San Joaquin River Delta, California

### Permalink

<https://escholarship.org/uc/item/3j95x7vt>

### Journal

San Francisco Estuary and Watershed Science, 10(3)

### Authors

DiGennaro, Bruce  
Reed, Denise  
Swanson, Christina  
et al.

### Publication Date

2012

### DOI

<https://doi.org/10.15447/sfew.2012v10iss3art1>

### Copyright Information

Copyright 2012 by the author(s). This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed

# Using Conceptual Models and Decision-Support Tools to Guide Ecosystem Restoration Planning and Adaptive Management: An Example from the Sacramento–San Joaquin Delta, California

Bruce DiGennaro<sup>1</sup>, Denise Reed<sup>2</sup>, Christina Swanson<sup>3</sup>, Lauren Hastings<sup>4</sup>, Zachary Hymanson<sup>5</sup>, Michael Healey<sup>6</sup>, Stuart Siegel<sup>7</sup>, Scott Cantrell<sup>8</sup>, and Bruce Herbold<sup>9</sup>

## ABSTRACT

The Sacramento–San Joaquin Delta (the Delta) is located on the western edge of California’s Central Valley and is of critical ecological and economic importance. However, ecosystem alterations for human uses changed many of the Delta’s natural processes, and it is now considered in need of restoration. An approach was developed to evaluate and rank restoration actions in the Delta under the Ecosystem Restoration Program’s Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). The DRERIP approach provides an explicit framework for evaluating restoration actions, using linked conceptual models, an action evaluation procedure, and a decision-support tool. Conceptual models allow scientists and managers to synthesize scientific information and make qualitative predictions about ecosystem function and restoration outcomes to guide and focus restoration efforts. The action evaluation procedure is a structured assessment of restoration actions. The procedure clearly describes actions to be evaluated, assesses the magnitude (importance

and scale) and certainty of anticipated ecological outcomes, estimates degrees of worth (achieving intended outcomes) and risk (causing adverse consequences), evaluates the reversibility of the action, and identifies opportunities for learning. The values for worthiness, risk, reversibility, and learning opportunity are used in the decision-support tool to determine the fate of a proposed action. The decision-support tool is a structured decision tree that determines the disposition of an action: whether a restoration project should be discarded, revised with a different approach and re-evaluated, or implemented; and, if implemented, at what scale (targeted research, pilot project, or full implementation). The DRERIP approach provides managers with a valuable tool for restoration planning, and a foundation for integration with quantitative methods for a comprehensive ecosystem restoration plan.

## KEY WORDS

Restoration, conceptual model, adaptive management, Sacramento–San Joaquin Delta, estuary, California, planning tool, natural resource management, Delta Regional Ecosystem Restoration Implementation Plan (DRERIP).

1 The Essex Partnership. Corresponding author: [bruce@essexpartnership.com](mailto:bruce@essexpartnership.com)

2 University of New Orleans. Current affiliation: The Water Institute of the Gulf

3 The Bay Institute. Current affiliation: Natural Resources Defense Council

4 Delta Stewardship Council

5 Alpine Solutions

6 University of British Columbia

7 Wetlands and Water Resources, Inc.

8 California Department of Fish and Game

9 U.S. Environmental Protection Agency

## **INTRODUCTION**

The Sacramento and San Joaquin rivers drain approximately 40% of the state of California. An expansive delta and estuary (the Delta) forms at the rivers' confluence on the western edge of California's Central Valley. It is the largest delta on the Pacific coast. The Delta is not only critical wetland and aquatic habitat for over 700 species of birds, fish, and mammals, but is also vital for human uses. It serves as a major water supply conduit for urban and agricultural land uses, providing drinking water for 25 million people and supporting a \$27 billion agricultural industry.

Like many other large estuaries throughout the world, the Delta has been highly altered to support human uses (Figure 1). Anthropogenic alterations have extensively changed historic ecological processes, habitats, and species composition. Increased land subsidence, damming of major tributaries, water diversions, and flood control have dramatically transformed Delta geometry, channel structure, flow regimes, sediment supplies, and hydrodynamics. The Delta is also polluted with high levels of nutrients and contaminants. The Delta has been plagued with chronic introductions of non-native species, and natural community structure changes have taken place at all trophic levels. One major consequence of all these alterations has been the listing of numerous species under the state and federal endangered species acts. Current conditions are compounded by future challenges of increasing human population, climate change, and sea-level rise (Healey and others 2008; PPIC 2012; Isenberg and others 2008).

The current condition of the Delta ecosystem, particularly the status of its fisheries and other biological resources, have prompted multiple programs and plans for ecosystem restoration, including the CALFED Bay-Delta Program, the Ecosystem Restoration Program (ERP), Delta Vision (and the subsequent Delta Plan), the Bay Delta Conservation Plan, and restoration mandated by the Biological Opinions for state and federal water project operations. Although numerous small and large-scale ecosystem restoration actions have been proposed—and some implemented—in the Delta, much of the plan-

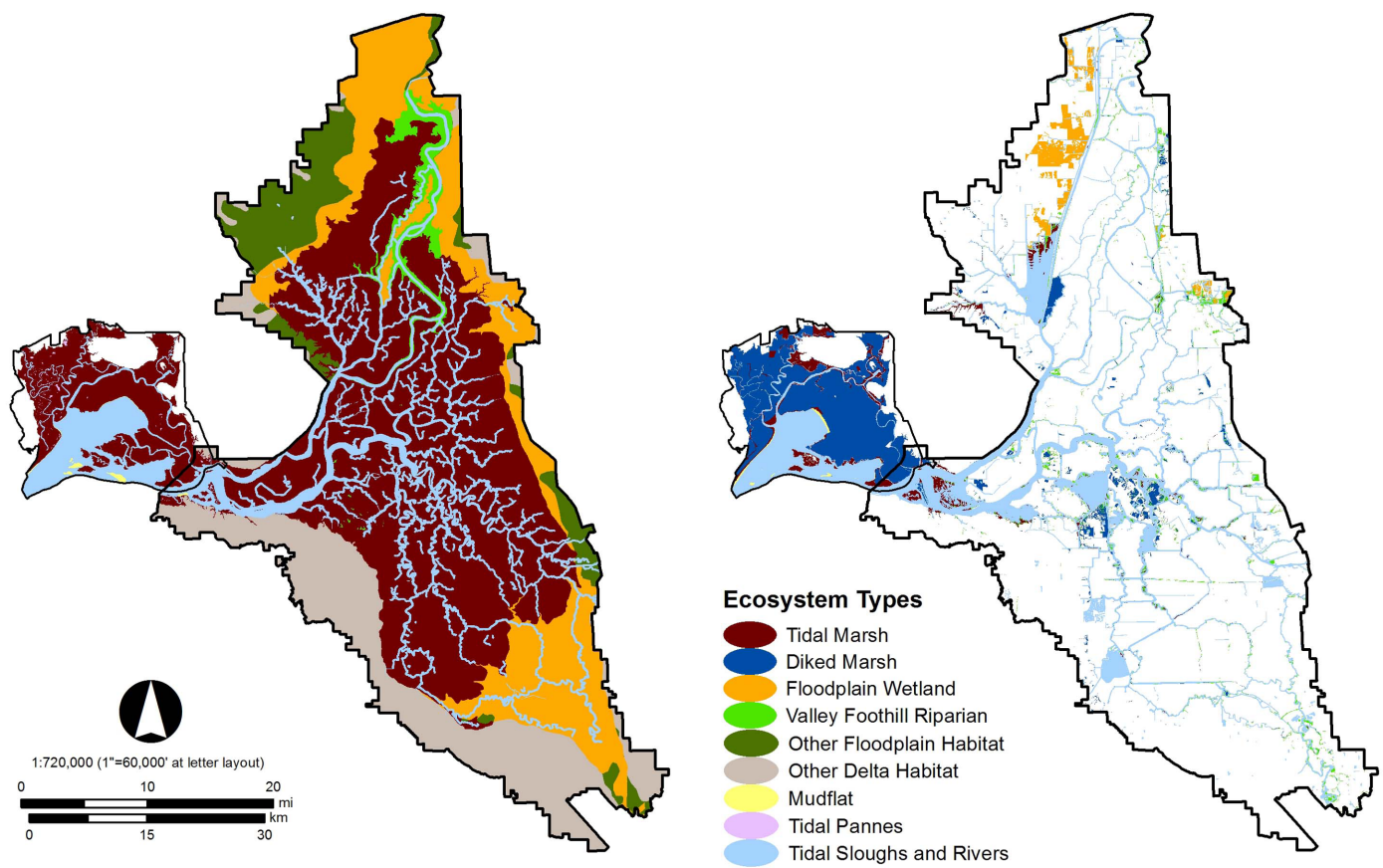
ning to date has been performed in the absence of well-articulated conceptual models and other decision-support tools.

### **Conceptual Models**

Conceptual models are “abstractions of reality created to express a general understanding of a more complex process or system” (Fischenich 2008) and have been advocated as a key element of aquatic ecosystem restoration planning (USACE-EAB 2006). They can be used in an ecological setting to summarize and synthesize scientific understanding of system function, and are useful to build understanding and consensus among scientists and managers about how natural processes and human activities interact to affect natural resources and habitats (Ogden and others 2005b). Thom (2000) considers them essential to successful adaptive management. Conceptual models provide an important organizing framework for planning in complex systems and have been considered by others to be an important way of communicating complex information (Heemskerk and others 2003). Recent examples of conceptual model applications include site-specific restoration of coastal wetlands (Chow-Fraser 1998) and alteration of flooding regimes in the Rio Grande (Molles and others 1998). Nuttle and others (2008) have noted that, in particular, conceptual models help to:

- Identify drivers of ecological processes and anthropogenic stressors, their ecological effects, and attributes useful in monitoring and forecasting ecosystem response.
- Diagram qualitative explanations of how human activities alter ecology.
- Identify points of conflicting science, develop consensus, and communicate working hypotheses.
- Identify performance measures and develop monitoring and modeling activities to support restoration and management.

For ecosystem restoration planning and adaptive management, conceptual models that explain system form and function can be used both to qualitatively



Data sources:  
 Historic Ecosystems: Suisun=SFEI 1998 EcoAtlas; Delta=The Bay Institute 1998, Atwater 1982  
 Modern Ecosystems: Suisun=SFEI 1998 EcoAtlas, DWR 2006 Blacklock; Delta=CDFG 2005 Veg Map  
 Produced by WWR, September 2012  
 maps file: historic-vs-modern-ecosystems-colorver2\_Delta-Suisun\_AL\_1163\_2012-0919dag.mxd

**Figure 1** Transformation of Delta ecosystems. Historic (TBI 1998) and modern (WRR 2008) configurations of the system.

predict the consequences of alternative restoration actions and to provide a common ‘knowledge base’ from which to develop new restoration approaches. For example, conceptual models have been used in large-scale restoration plans in the Florida Everglades and on the Louisiana coast. Both the Comprehensive Everglades Restoration Plan (CERP) and Coastal Louisiana Ecosystem Assessment and Restoration program (CLEAR) utilized conceptual models as the basis to synthesize and guide their scientific efforts. Because of successful outcomes such as these, conceptual models are now considered essential in any major restoration plan (Twilley and Owens 2008).

### The Delta Regional Ecosystem Restoration Implementation Plan

In 2000, the CALFED Bay-Delta Program outlined an ecosystem-based management approach and adaptive management framework for its Ecosystem Restoration Program (ERP) (CALFED Bay-Delta Program 2000). The ERP Strategic Plan explicitly identifies the linkages between restoration goals and objectives, management actions, information acquisition, and problem reassessment (Figure 2). The prominent role of conceptual models and the unambiguous recognition that restoration actions may include targeted research, pilot/demonstration projects, or full-scale

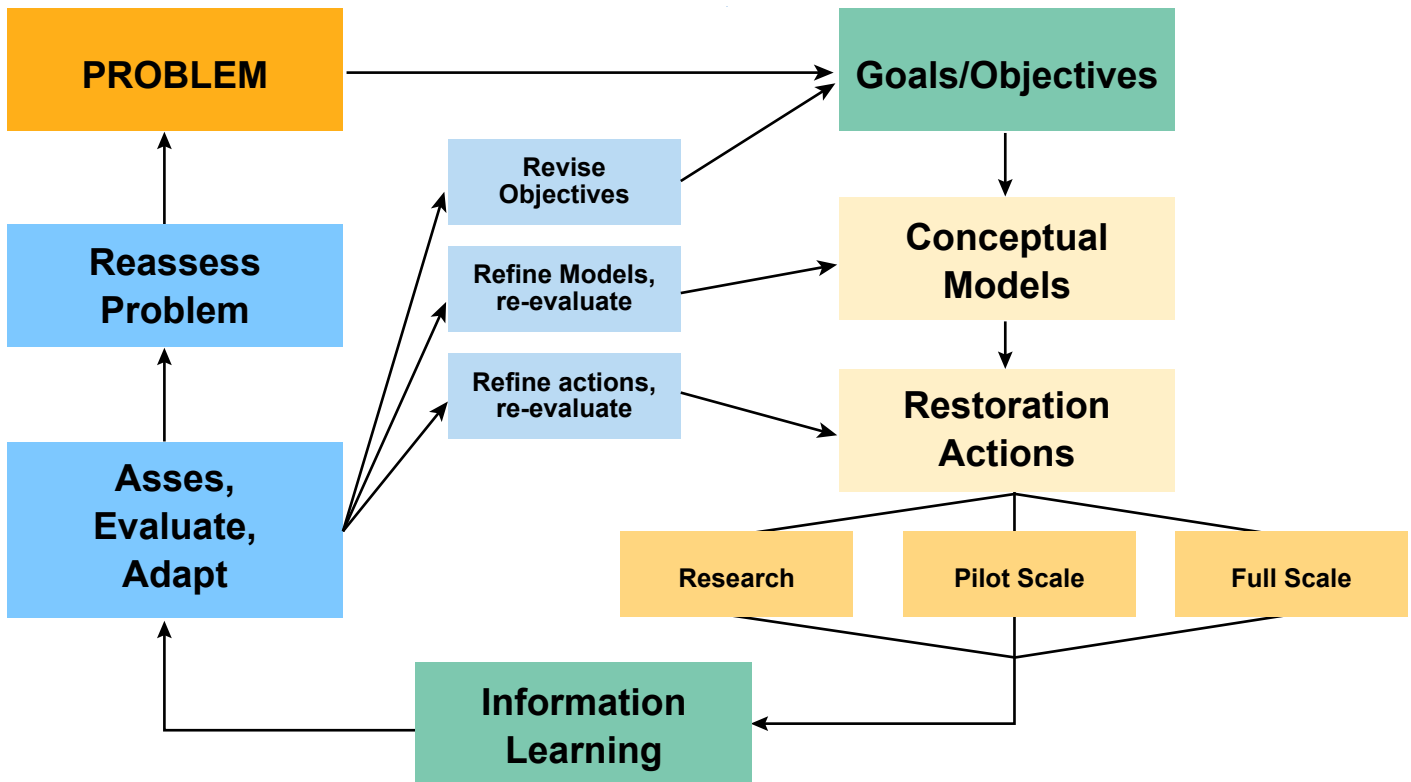


Figure 2 CALFED adaptive management approach (after CALFED Bay-Delta Program 2000)

implementation projects are notable differences from previous depictions of adaptive management systems (see NRC 2004 for examples of adaptive management application in large-scale water resources issues).

The Delta Regional Ecosystem Restoration Implementation Plan (DRERIP)—managed jointly by the California Department of Fish and Game (DFG), the U.S. Fish and Wildlife Service (USFWS), and the National Marine Fisheries Service—was established to evaluate and rank restoration actions for the Delta region from CALFED’s programmatic ERP Plan (CALFED Bay-Delta Program 2000). An Adaptive Management Planning Team (AMPT) consisting of agency technical staff and external science advisors was established to guide the DRERIP effort. The AMPT was tasked with developing a science-based procedure for evaluating which of the more than 600 proposed restoration actions contained in the ERP should be implemented as targeted research, pilot studies or as full-scale projects—or discarded because

of the lack of science-based support or unacceptably high risk. The decision-support tools and evaluation process developed by the AMPT include three elements:

- **Conceptual Models.** Linked conceptual models were developed that compile and synthesize the existing scientific understanding of Delta ecosystem function, including habitats, ecological processes, species, and stressors. All conceptual models were specifically designed to identify and characterize the scale, character, importance, and certainty of cause- and-effect relationships between ecological driver variables, and ecosystem- and species- response variables.
- **Action Evaluation Procedure.** A standardized protocol for translating information from the conceptual models into evaluations of worth, risk, reversibility, and opportunity for learning of proposed ecosystem restoration actions.



- **Decision-Support Tool.** A decision tree that uses the action evaluation results to determine whether and how to implement proposed restoration actions in the adaptive management framework.

This paper describes these three elements and provides an example of how they can be used to support science-based restoration and adaptive management decision-making in the Delta. It also provides context for specific conceptual models developed to support the DRERIP approach and described later in this issue.

## DEVELOPMENT OF CONCEPTUAL MODELS

### Purpose of the Conceptual Models

Conceptual models usually are tailored to the needs of the system at hand and the intended uses of the models (e.g., Simenstad and others 2006; Ogden and others 2005a, 2005b). As described above, the conceptual models developed for use in DRERIP are intended to provide information for the Action Evaluation and Decision Support elements. Therefore, the models need to qualitatively describe the physical, chemical, and biological linkages and attributes of the system, as well as a qualitative understanding of how restoration actions are expected to affect the ecosystem and the target species. In particular, the models were developed to illustrate the characteristics and dynamics of the system that support or limit the achievement of desired restoration outcomes.

Depending on how they are constructed, conceptual models can provide a qualitative prediction of restoration outcomes; for example, better or worse performance under different scenarios. These qualitative predictions can then be used to rank restoration actions or forecast the direction of ecosystem change. Furthermore, by summarizing current understanding of how the ecosystem works, conceptual models can provide a strong foundation for the development of benefit metrics, monitoring plans, and performance measures.

### The DRERIP Driver–Linkage–Outcome (DLO) Approach

DRERIP Ecosystem Conceptual Models developed for habitats, ecological processes, stressors, and species consisted of a diagrammatic representation of the model and a written report with background, references, and other explanatory material, such as information on geographic variations, seasonality of occurrence, or affected life history stage. Each model was structured to clearly identify and describe drivers (D), linkages (L), and outcomes (O). Drivers are physical, chemical, or biological forces (natural or artificial) that have a large influence on the system or species of interest. Drivers may be uncontrolled (i.e., not under management control or influence) or managed (i.e., under direct management control or influence). Linkages are cause- and-effect relationships between drivers and outcomes that are depicted by one-way arrows. Outcomes are environmental- or species-response variables that are predicted to be influenced by the drivers through the associated linkages. Outcomes are the elements the conceptual model attempts to explain, and may be physical, chemical, or biological.

Once drivers and outcomes have been identified, the cause-and-effect linkages between these two groups can be explored and described. The specific attributes of each linkage are defined according to:

- Character and direction of the effect—positive, negative, or threshold response
- Importance of the effect—indicated by width of line
- Understanding that underlies the effect—indicated by color/shading of line
- Predictability of the effect—indicated by line type: solid, dashed, or dotted.

**Importance** reflects the degree to which a linkage controls the outcome relative to other drivers. While the models are designed to encompass critical drivers, linkages, and outcomes, this concept recognizes that some are more important than others in determining how the system works. **Understanding** describes the known, established, and/or generally agreed upon

scientific understanding of how each driver is linked to each outcome. **Predictability** reflects the degree to which current understanding of the system can be used to predict the role of the driver in influencing the outcome. Predictability is based on understanding of the driver, and the nature of how it is linked to the outcome, and thus captures variability. For example, understanding of processes may be high, but there may be natural variability either on an inter-annual and/or a seasonal basis that is unpredictable. Or the strength of relationships and the magnitude of effects may vary so much that properly measuring and statistically characterizing inputs to the model are difficult.

To ensure that the different models used a consistent approach to characterize these linkage attributes, descriptive criteria for three levels—high, medium, and low—of each attribute were provided to model developers. For example, “high” understanding was based on the existence of peer-reviewed studies from the Delta and scientific reasoning supported by most experts on the system. Linkages characterized as having “low” understanding were based on non-peer-reviewed studies from the Delta or studies from other ecosystems. Further information on these criteria is provided below. [Figure 3](#) shows an example conceptual model diagram for part of a life history for Sacramento splittail (D. Kratville, DFG, pers. comm., 2008). As shown, hydrology is a major driver of splittail populations, and large scale spawning occurs only in years with significant inundation of flood plains. The influences of contaminants and food availability are also shown.

The consistent framework and structure used to develop the conceptual models allowed individual models to be linked together, with the outcome from one model also functioning as a driver in another model. For example, the Delta hydrodynamic model’s outcome for salinity variation is also a driver in the Vegetated Habitat model. Most DRERIP conceptual models were linked in sequence with others, with the species conceptual models usually providing the ultimate outcome and objective for many of the proposed restoration actions.

## **EVALUATING RESTORATION ACTIONS**

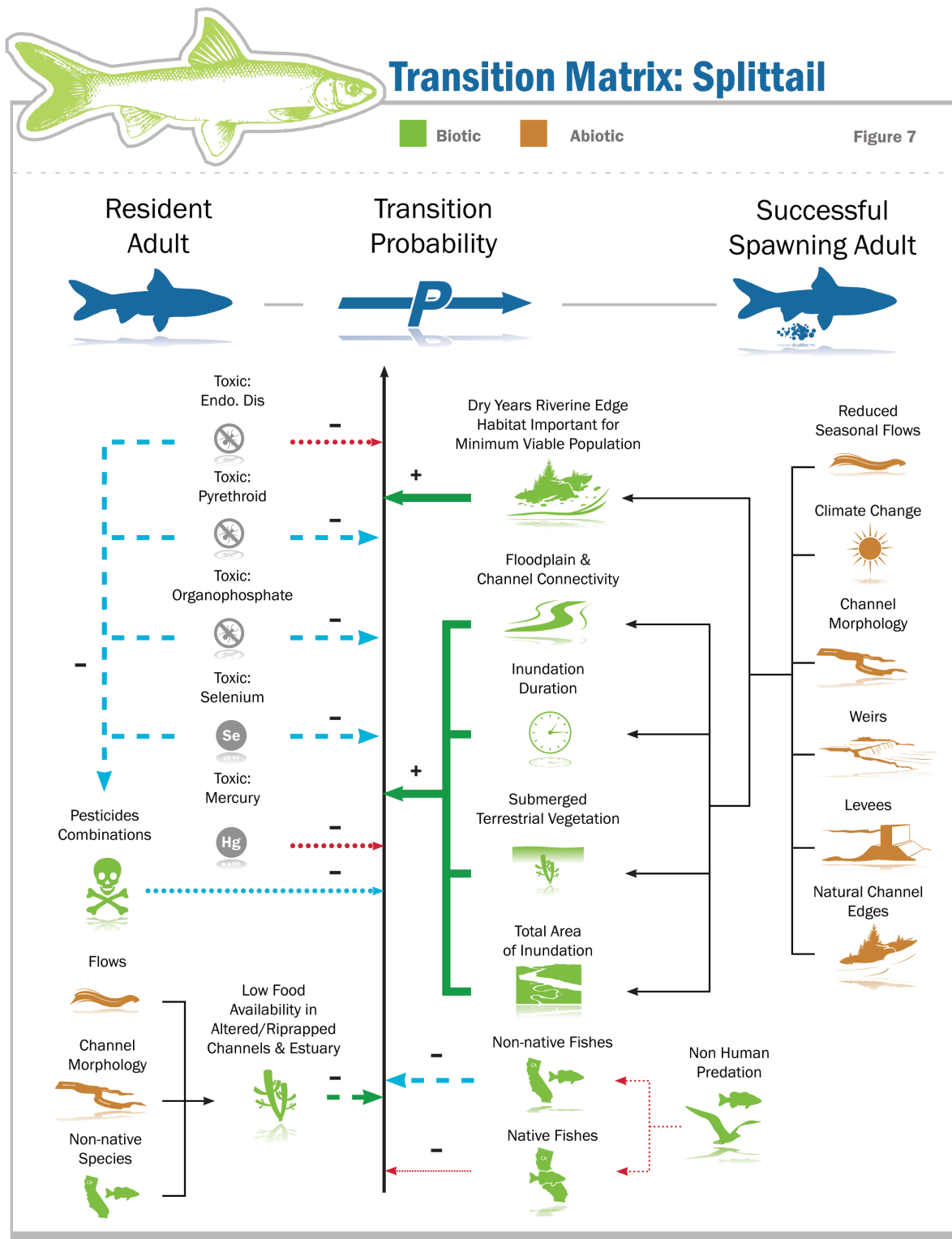
The second major component of the DRERIP scientific foundation is an Action Evaluation Process designed to evaluate proposed restoration actions using the scientific information provided in the conceptual models. The Action Evaluation Process is a structured and transparent step-by-step procedure, which uses standardized evaluation criteria designed to be compatible with the conceptual model format. The end product of each evaluation was a clearly-articulated description of the restoration action, and numeric “scores” for the worth, risk, reversibility, and information value for adaptive management of the proposed action. The Action Evaluation Process is described in more detail below using an example application. Other example applications of the process are available at the Bay Delta Conservation Plan DRERIP worksheet website (<http://baydeltaconservationplan.com/BDCPPlanningProcess/BackgroundDocuments/FullDRERIPWorksheets.aspx>).

The proposed restoration action evaluated in this example is:

“Increase the frequency and duration of Yolo Bypass flooding to at least once every other year for at least 45 days during the late winter or early spring by modifying the Fremont Weir to allow lower-stage flows of the Sacramento River to pass through the Yolo Bypass. The increase in flooding is expected to improve splittail spawning and rearing habitat.”

### **Step 1: Clearly Describe Action to be Evaluated**

The first step in the process is to describe the action in sufficient detail to identify unambiguously the what, how, and why being proposed. For a restoration action to be evaluated using this process it needs to contain clear statements of three distinct elements: what is being changed (action), how it is being changed (approach), and why it is being changed (anticipated outcome). At this stage, the anticipated outcomes are the focus of attention. However, if the three elements of the action cannot be readily defined, the evaluation team must work with those



**Figure 3** Sacramento splittail life history stressor sub-model. An example DRERIP species model. The arrows depict the importance of the processes the level of understanding of the processes and the predictability of the processes. A plus sign (+) indicates a positive effect on the transition probability, while a minus sign (-) indicates a negative one.



proposing the action to provide a sufficient level of specificity and clarity; general descriptions make the action difficult to evaluate. In this example the Yolo Bypass restoration action can be separated into the following elements:

- **Action:** Increase the frequency and duration of Yolo Bypass flooding to at least once every other year for at least 45 days during the late winter or early spring
- **Approach:** Modify the Fremont Weir to allow lower-stage flows of the Sacramento River to pass through the Yolo Bypass
- **Outcome:** Improve splittail spawning and rearing habitat

**Step 2: Compare Action to Baseline Conditions**

It is important to discern whether or not the action is actually doing something different relative to current conditions, because otherwise it is not really an “action.” With the example action, the spill frequency of Fremont Weir would be 48% of years (38 of 79 years), assuming 4,000 cubic feet per second (cfs) and a 45-day duration, with a spill intermission of no more than 7 days, compared to 6% of years (5 out of 79 years) at the existing weir height. Since the Fremont Weir is at a fixed elevation, the variability is a function of inter-annual variability in the hydrograph, which includes upstream water-management actions. Implicit here is that flooding from the Sacramento River serves as the primary inundation mechanism for the Yolo Bypass. If the evaluation team considers other flood sources to be important for the Yolo Bypass, then it should modify the baseline conditions accordingly. and evaluate the action based on the incremental change in flooding frequency and duration attributable to the action.

**Step 3: Assess the Magnitude and Certainty of Anticipated Ecological Outcomes**

The conceptual models are then used to assess whether the action will have the desired (stated) outcome. Although improving splittail spawning and rearing

habitat is postulated as the prime reason for pursuing this action, changes of this magnitude are also expected to have other consequences. The next step in the process is to identify additional outcomes, both positive and negative, that are likely to occur. The conceptual models support this process by allowing DLO chains to be followed within and among applicable model(s) to identify relevant outcomes, and to estimate the magnitude and certainty of these outcomes. Outcomes also may be identified using the expertise of the evaluation team (i.e., best professional judgment). In theory, the list of potential outcomes is very large. In practice, the agency or program supporting the evaluation is most interested in identifying whether the action supports specific management outcomes and/or avoids risks. However, the process is designed to be flexible, and the evaluation team determines which outcomes will be included. If specific interest groups consider an outcome important it can be included in the evaluation, and a complete record will be produced that documents how and why the outcome might influence the proposed action. For the Yolo Bypass example, three positive (P) and two negative (N) outcomes are considered:

- P1. Improved splittail spawning and rearing habitat (intended outcome)
- P2. Improved juvenile Chinook salmon rearing habitat
- P3. Increased detritus and phytoplankton inputs to downstream food web
- N1. Increased mercury methylation
- N1. Increased native fish species stranding

The conceptual models are essential to the next step in the scientific evaluation process where the cause-and-effect relationships that link the action to the outcomes are considered in more detail. The conceptual models and other relevant material (e.g., papers and reports produced since conceptual model development, or information on aspects of the ecosystem not covered by the models) are used by the evaluation team to assign scores to each outcome, which reflect the expected **magnitude** of each outcome and the level of **certainty** regarding that magnitude. Attributes of the linkages as designated by the line

characteristics in the conceptual model are used to determine magnitude (importance attribute) and certainty (understanding and predictability attributes). Determining magnitude of effect also requires consideration of another factor: scale of actions. Scale is evaluated according to definitions in Table 1, magnitude and certainty according to definitions in Tables 2 and 3, respectively.

The definitions presented in Tables 1 through 3 indicate how challenging it is for an individual action to achieve a magnitude score of 4 (population level effect) in a complex ecosystem with many stressors. Similarly, because many outcomes are influenced by highly variable (and thus unpredictable) ecosystem dynamics, only rarely will an individual action

**Table 1** Criteria for establishing scale of actions

<b>Spatial Scale</b> addresses temporal and spatial considerations, quantity and/or degree of change contained within the Action.	
<b>Big</b>	Large spatial extent, significant duration and/or annually, and/or major reversal compared to existing conditions. Landscape scale. Requires a large-scale action.
<b>Medium</b>	Moderate spatial extent, moderate duration and/or annually or close to annually, and/or moderate change compared to existing conditions. Regional scale. Requires at least a medium-scale action.
<b>Small</b>	Small acreage, short duration or only on occasional years, and/or small change compared to existing conditions. Local scale.

achieve high- or even medium-certainty scores. A measure with a “low” magnitude score can still be implemented—and the cumulative effects of many such actions may result in a greater effect at the population level.

For some species, particularly salmonids and sturgeon that spend a relatively short portion of their life cycle in the Delta, an action must target (and resolve) a clearly known and major impediment if that action is to have population-level effects. The benefits of measures in the Delta can easily be overwhelmed by conditions upstream and/or downstream (i.e., ocean), which may be driving the population in more substantial ways.

Example results of the magnitude and certainty evaluations for some of the positive and negative outcomes identified for the Yolo Bypass action are shown in Table 4. The action evaluation process also includes documentation of the rationale for the identified outcomes, based on the conceptual models and additional information sources.

Summary evaluations for outcomes P1 and P2 are shown in Table 4. Outcome P3—increased detritus and phytoplankton inputs to downstream foodweb—was difficult to evaluate. Although the floodplain model addresses phytoplankton production and export resulting from inundation (and assigns high importance, understanding, and predictability), it is not clear that this additional production has a landscape-scale effect, and therefore this outcome may not war-

**Table 2** Criteria for scoring the magnitude (importance and scale) of ecological outcomes

<b>Magnitude</b> reflects the importance and scale of the action to the outcome. It describes the size or level of the outcome, either positive or negative, in terms of population or habitat effects on a given species. Magnitude is not the same as the scale of the action; however, higher magnitude scores require consideration of scale. Magnitude must consider the complete DLO chain leading to the outcome being evaluated and must consider the importance of the linkages throughout that chain.		
<b>4</b>	<b>High</b>	Expected sustained major population level effect, e.g., the outcome addresses a key limiting factor, or contributes substantially to a species population’s natural productivity, abundance, spatial distribution and/or diversity (both genetic and life history diversity) or has a landscape scale habitat effect, including habitat quality, spatial configuration and/or dynamics. Requires a large-scale action.
<b>3</b>	<b>Medium</b>	Expected sustained minor population effect or effect on large area (regional) or multiple patches of habitat. Requires at least a medium-scale action.
<b>2</b>	<b>Low</b>	Expected sustained effect limited to small fraction of the population, addresses productivity and diversity in a minor way, or limited spatial (local) or temporal habitat effects.
<b>1</b>	<b>Minimal</b>	Conceptual model indicates little effect.

**Table 3** Criteria for scoring certainty (understanding and predictability) of ecological outcomes

<b>Certainty</b> – the likelihood that a given Restoration Action will achieve a certain Outcome. Certainty considers both the predictability and understanding of linkages in the pathway from the action to the outcome. Generally, high importance-low predictability linkages drive the scoring; it is important to ensure that certainty is not unduly weighted by a comparatively low-importance, albeit low-predictability linkage.		
<b>4</b>	<b>High</b>	Understanding is high (based on peer-reviewed studies from within the system and scientific reasoning supported by most experts within the system) and outcome is largely unconstrained by variability (i.e., predictable) in ecosystem dynamics, other external factors, or is expected to confer benefits under conditions or times when the model indicates greatest importance.
<b>3</b>	<b>Medium</b>	Understanding is high but nature of outcome is dependent on other highly variable ecosystem processes or uncertain external factors or understanding is medium (based on peer-reviewed studies from outside the system and corroborated by non peer-reviewed studies within the system) and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
<b>2</b>	<b>Low</b>	Understanding is medium and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors or understanding is low (based on non peer-reviewed research within system or elsewhere) and nature of outcome is largely unconstrained by variability in ecosystem dynamics or other external factors
<b>1</b>	<b>Minimal</b>	Understanding is lacking (scientific basis unknown or not widely accepted), or understanding is low and nature of outcome is greatly dependent on highly variable ecosystem processes or other external factors

**Table 4** Summary findings for P1, P2, N1, and N2 outcomes for the example action

<b>Criteria</b>	<b>Ranking</b>	<b>Rationale for ranking</b>
<b>Outcome P1: Improved splittail spawning and rearing habitat</b>		
<b>Magnitude</b>	<b>4</b>	Splittail model (Kratville 2009) indicates high importance DLO paths from floodplain inundation to production of eggs and juveniles.
<b>Certainty</b>	<b>4</b>	Splittail model indicates high understanding and predictability.
<b>Outcome P2: Improved rearing habitat for juvenile Chinook salmon</b>		
<b>Magnitude</b>	<b>4</b>	Salmon model (Williams 2009): Juvenile Emigration and Rearing sub-model does not explicitly cover floodplain; model text indicates that fall-run and perhaps late-fall and spring runs rear on the Yolo Bypass when inundated (pages 19 to 20 <sup>9</sup> ). Salmon rearing on the Yolo Bypass experience elevated growth rates (Sommer and others 2005, cited in Williams 2009). Peer-reviewed literature strongly supports bypass as valuable rearing habitat (Sommer and others 2001, 2005). Model 3D of the Floodplain Conceptual Model (Opperman 2008) also discusses benefits.
<b>Certainty</b>	<b>4</b>	See Sommer and others 2001, 2005
<b>Outcome N1: Increase in methylation of mercury</b>		
<b>Magnitude</b>	<b>3</b>	Table 1 and Section 3.1.3.4 of the Hg model (Alpers and others 2008): Floodplains have been shown to support high rates of methylation. Episodic flooding may be associated with increased methylmercury production due to the drying of soils (and enhanced oxidation rates) between floods.
<b>Certainty</b>	<b>2</b>	Intermittent flooding results in high potential for methylation; floodplains with highest concentration of MeHg are those that experience intermittent flooding. Some question as to whether a single, long inundation (e.g., 45 days) might limit the amount of methylation. The mercury model (Alpers and others 2008) does not assign importance, understanding, and predictability to methylation in specific habitat types. It is not clear which floodplains the methylation rates in Table 1 of the model are based on (Is the Yolo Bypass included?).
<b>Outcome N2: Increased native fish species stranding</b>		
<b>Magnitude</b>	<b>2</b>	Stressor tables in conceptual models for salmon (Williams 2009) and sturgeon (Israel and others 2009) do not show this to be an important factor at the population level.
<b>Certainty</b>	<b>3</b>	Several studies from Cosumnes and Yolo indicate that increasing temperatures in floodplain waters trigger movement of native species off the floodplain (T. Sommer, DWR, pers. comm., 2008).

a Note that the use of page numbers in this table is to illustrate the type of tracking information that needs to be recorded during the process. The page numbers may not be correct in current versions of the models available at [http://www.dfg.ca.gov/ERP/conceptual\\_models.asp](http://www.dfg.ca.gov/ERP/conceptual_models.asp) as a result of reformatting.

rant a high score for magnitude. To fully evaluate this action, additional information on the quantity and availability of this increase in phytoplankton is necessary. However the sedimentation model indicates that the Yolo Bypass represents a major source of suspended sediment for the Delta, which potentially could be used as a surrogate for phytoplankton transport. A degree of uncertainty still exists, however, because even though phytoplankton represents one of the most important food sources for the pelagic food web, the inputs from the Yolo Bypass may not be available to the downstream food web because of local consumption (Durand 2008). In instances like this, the process calls for the expert evaluation team to decide a score for magnitude and certainty, and fully document their assumptions.

#### Step 4: Estimate Degrees of Worth and Risk

The next step is to combine individual magnitude and certainty scores into evaluations of “worth” and “risk.” **Worth** estimates the degree to which the action achieves the intended outcomes. **Risk** estimates the potential the action has to cause adverse consequences.

For positive outcomes, scores for magnitude and certainty are converted into an overall evaluation of the cumulative “value” or “worth” of a restoration action using the matrix shown in [Table 5](#). Actions are considered more ‘worthy’ if there is a high certainty of large-magnitude positive outcome(s). Similarly, negative outcome scores are combined to assess the level of “risk” associated with an action using the matrix shown in [Table 6](#). Actions are considered more “risky” if the magnitude of negative outcomes is large and certainty is low. Notably, a score of 4 for magnitude and 4 for certainty for negative outcomes is not considered high risk, because it is assumed that high levels of certainty allow risk to be understood and managed during implementation.

When there is more than one positive outcome, the evaluation team considers the collective scores of all the outcomes to determine overall worth. In the Yolo Bypass example, where the magnitude is 3 to 4 and the certainty is 3 to 4, the worth assessment is high, according to [Table 5](#), no matter which score is taken.

**Table 5** Conversion matrix for combining magnitude and certainty scores for positive outcomes

WORTH		Certainty			
		1	2	3	4
Magnitude	1	Low	Low	Med	Med
	2	Low	Med	Med	High
	3	Med	Med	High	High
	4	Med	High	High	High

**Table 6** Conversion matrix for combining magnitude and certainty scores for negative outcomes

RISK		Certainty			
		1	2	3	4
Magnitude	1	Med	Med	Low	Low
	2	High	Med	Med	Low
	3	High	High	Med	Med
	4	High	High	High	Med

For the assessment of risk, the most “risky” outcome is chosen if there is more than one negative outcome. For the Yolo Bypass example, this means that outcome N1 with a magnitude of 3 and a certainty of 2 determines the overall assessment that risk is high.

#### Step 5: Evaluate Reversibility of the Action

The action evaluation process also calls for an assessment of the reversibility of the action, recognizing the value of readily-reversible actions within an adaptive management context. If the outcome of the action is not as beneficial as expected, or the negative outcomes of the action are severe, then readily-reversible actions maximize the opportunity to adaptively manage to reverse or terminate the action and/or implement alternative higher-risk/lower-worth actions while avoiding long-term damage. Reversibility is defined as the ease and predictability with which a restoration action or a group of restoration actions can be terminated and/or reversed. For example, if the action changes physical habitat structure, can the original form be readily re-established? As another example, actions that modify flow levels in a highly-managed system like the Delta are fairly easy to reverse (although some outcomes of such



an action may have also affected physical changes such as sediment mobilization or deposition that may persist after the action is terminated). In contrast, actions that introduce or promote establishment of a new species can be difficult or impossible to reverse. In the Yolo Bypass example, the action of periodic flooding is considered reversible, since the action relies on straightforward operational modifications of an existing weir.

### **Step 6: Identify Opportunity for Learning**

The opportunity to learn from implementing the proposed restoration action is another important factor to consider, and the final step in the action evaluation process. Effective adaptive management requires monitoring of both implementation of the action and its outcomes, and evaluation of these monitoring results for both desired objectives and anticipated risks. For the DRERIP action evaluation process, the opportunity to learn is defined as the likelihood that appropriate monitoring of restoration action implementation or a group of restoration actions and their outcomes will increase understanding of the species, ecological process, habitat condition, region, or system that is in question or of concern. In the context of adaptive management, learning is, in fact, a principle objective of targeted research and pilot-level implementation of restoration projects. Such information can then be used to improve conceptual models, design alternative or refined restoration actions, enhance monitoring and evaluation programs, and improve the implementation of future similar projects that may be undertaken in other parts of the system. In the Yolo Bypass example, the opportunity for learning is high, because study techniques are already well-established to assess the outcomes expected as a result of the action.

### **USING THE DECISION-SUPPORT TOOL**

The results of the action evaluation process for worth, risk, reversibility, and opportunities for learning are the inputs for the DRERIP decision tree (Figure 4).

The decision tree provides an objective and structured process to determine whether the action should be

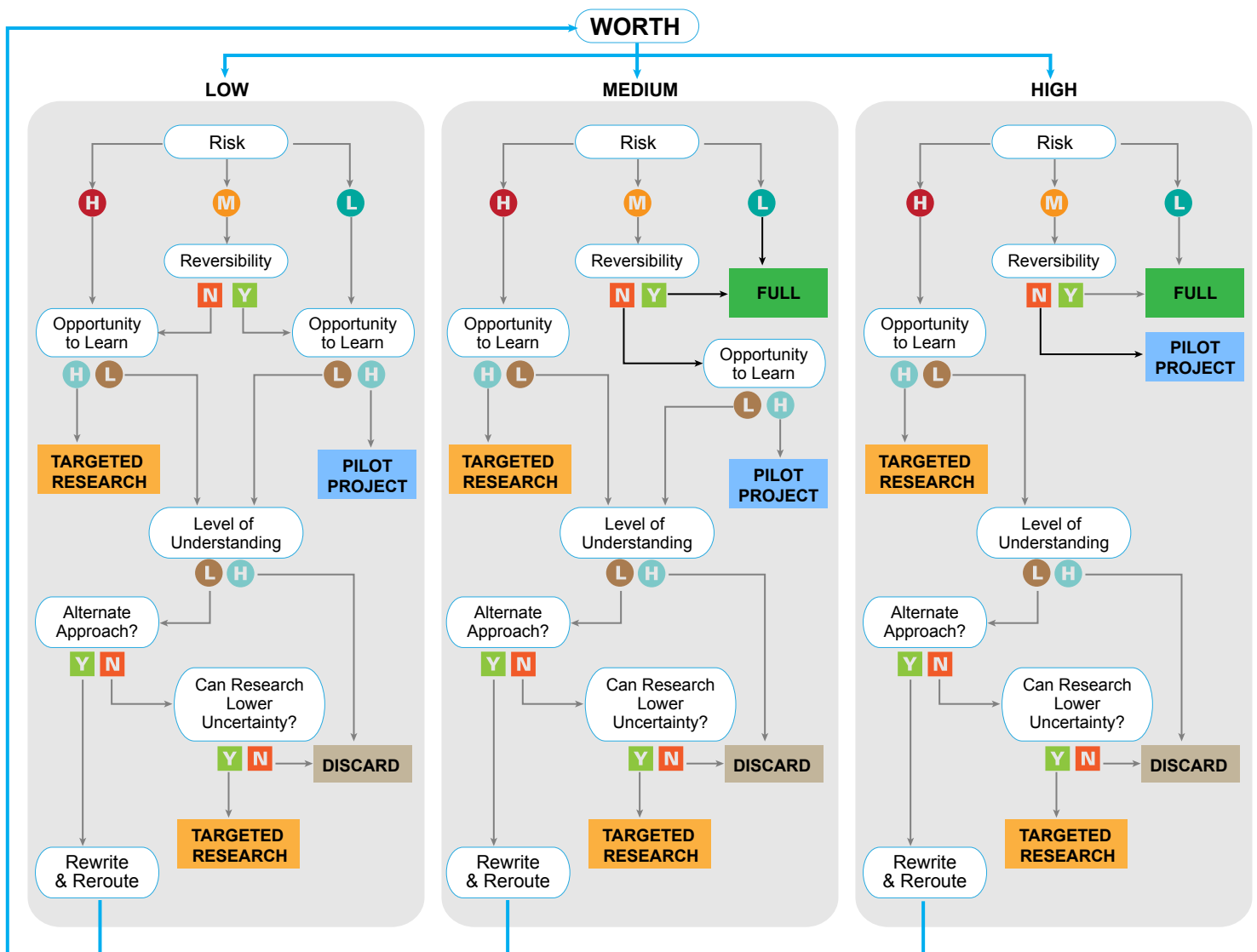
implemented, and at what scale (i.e., targeted research, pilot-scale or full-scale implementation); whether it should be discarded; or whether it should be revised to use an alternative restoration approach, and then re-routed through the decision tree for re-evaluation. The first decision point considers the worth of the action, reflecting that the more worthwhile actions should be given greater opportunity to be routed to implementation. The riskiness of the action is the second factor considered, reflecting the importance of the precautionary principle in decisions about implementing restoration actions with multiple likely outcomes in complex ecosystems. Following worth and risk, the decision tree next considers reversibility and opportunity for learning to allow an action to reach an implementation result. The general goal of the decision tree is to allow ample opportunity for at least targeted research implementation of an action, and to discard actions only when it is clearly understood that the action carries high risk and little opportunity for learning. Actions that fare poorly but for which an alternative approach to achieving the intended outcome can be identified are given a second chance, via rewriting and re-evaluating the action.

In the Yolo Bypass example, high worth, high risk, and opportunity to learn lead to targeted research in the decision tree. The high risk finding stems from methyl mercury; if risk were considered lower (e.g., medium), then the reversibility of the action would lead to full implementation. Managing the methyl mercury risk could occur through further research that improves our understanding of methyl mercury biogeochemistry, or through other actions that could mitigate the methyl mercury risk in one way or another. The sensitivity of the Yolo Bypass example to risk illustrates the importance of considering the potential negative effects or risks associated with restoration outcomes in the adaptive management process.

### **CONCLUSION**

Conceptual models can provide valuable insight for complex ecosystem restoration planning, especially when used in a structured evaluation process that considers both desired and potentially undesirable outcomes. However, conceptual models alone





**Figure 4** DRERIP decision tree for decision support

are insufficient, and several groups have called for the development of more quantitative approaches to understanding and predicting change within the Delta (e.g., Healey and others 2007; NRC 2010). Quantitative models, including both statistical and process models, are more valuable for understanding specific interactions between the at-risk species and their environment. They are also better for identifying the specific outcomes of restoration actions (particularly in relative terms or in cost-benefit analyses),

identifying the cumulative effects of multiple actions, and, ultimately, for informing and guiding adaptive management.

Development of a comprehensive restoration and management plan for the Delta will require the complementary use of conceptual models, statistical models, and multiple types of process models within an integrated analytical framework. The California Delta Ecosystem conceptual models and the DRERIP action evaluation process represent a step toward integra-

tion and a system-wide view of the consequences of restoration actions. In a system as complex as the Delta, we believe the DRERIP approach is an important advance.

## **ACKNOWLEDGEMENTS**

This paper represents the collective work of many people over a number of years. The ideas first emerged with the CALFED Ecosystem Restoration Program (ERP) Science Board over 10 years ago, and ERP program staff should be recognized for their early support of developing a science-based decision-support process. Kateri Harrison, John Petrillo, and Ross del Rio assisted with final editing of the manuscript. Daniel Kratville of the California Department of Fish and Game developed Figure 3. Denise Reed appreciates support from the U.S. Geological Survey (Contract #08WRS0151) to prepare the manuscript.

## **REFERENCES**

Alpers C, Eagles-Smith C, Foe C, Klasing S, Marvin-DiPasquale M, Slotton D, Winham-Myers L. 2008. Mercury conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan. Available from: [http://www.dfg.ca.gov/ERP/conceptual\\_models.asp](http://www.dfg.ca.gov/ERP/conceptual_models.asp). [Accessed 28 Sept 2012].

CALFED Bay-Delta Program. 2000. Ecosystem Restoration Program: strategic plan for ecosystem restoration. Final programmatic EIS/EIR technical appendix. July 2000. 230 p.

Chow-Fraser P. 1998. A conceptual ecological model to aid restoration of Cootes Paradise Marsh, a degraded coastal wetland of Lake Ontario, Canada. *Wetlands Ecology and Management* 6:43-57.

Durand J. 2008. Delta foodweb conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan. 134 p.

Fischenich C. 2008. The application of conceptual models to ecosystem restoration. EMRRP-EBA-01. Vicksburg (MS): U.S. Army Engineer Research and Development Center. 23 p.

Healey MC, Angermeier PL, Cummins KW, Dunne T, Kimmerer WJ, Kondolf GM, Moyle PB, Murphy DD, Patten DT, Reed DJ, Spies RB, Twiss RH. 2007. Conceptual models and adaptive management in ecological restoration: the CALFED Bay-Delta Environmental Restoration Program. 40 p.

Healey MC, Dettinger MD, Norgaard RB, editors. 2008. The state of Bay-Delta science, 2008. Sacramento (CA): CALFED Science Program. 174 p.

Heemskerk M, Wilson K, Pavao-Zuckerman M. 2003. Conceptual models as tools for communication across disciplines. *Conservation Ecology* 7(3):8. Available from: <http://www.consecol.org/vol7/iss3/art8>. [Accessed 28 Sept 2012].

Isenberg P, Florian M, Frank RM, McKernan T, McPeak SW, Reilly WK, Seed R. 2008. Delta vision: our vision for the California Delta. Sacramento (CA): State of California Resources Agency. 70 p.

Kratville D. 2009. Sacramento splittail conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan. Available from: [http://www.dfg.ca.gov/ERP/conceptual\\_models.asp](http://www.dfg.ca.gov/ERP/conceptual_models.asp). [Accessed 28 Sept 2012].

Molles MC, Crawford CS, Ellis LM, Valett HM, Dahm CN. 1998. *BioScience* 48:749-756.

[NRC] National Research Council. 2004. Committee to assess the U.S. Army Corps of Engineers methods of analysis and peer review for water resources project planning. Panel on Adaptive Management for Resource Stewardship. Washington D.C.: National Academy Press. 123 p.

[NRC] National Research Council. 2010. A scientific assessment of alternatives for reducing water management effects on threatened and endangered fishes in California's Bay Delta. Water Science and Technology Board & Ocean Studies Board, National Academy of Sciences. Washington D.C.: National Academy Press. 69 p.

Nuttle WK, Sklar FH, Owens AB, Inoue M, Justic D, Kim W, Melancon E, Pahl J, Reed D, Rose K, Schexnayder M, Steyer G, Visser J, Twilley R. 2008. Chapter 7. Conceptual ecological model for river diversions into Barataria Basin, Louisiana. In: Twilley RR, editor. 2008. Coastal Louisiana Ecosystem Assessment & Restoration (CLEAR) Program: a tool to support coastal restoration. Volume IV. Final report. Baton Rouge (LA): Department of Natural Resources, Coastal Restoration Division. 140 p.

Ogden JC, Davis SM, Barnes TK, Jacobs KJ, Gentile JH. 2005a. Total system conceptual ecological model. *Wetlands* 25:955–979.

Ogden JC, Davis SM, Jacobs KJ, Barnes T, Fling HE. 2005b. The use of conceptual ecological models to guide ecosystem restoration in South Florida. *Wetlands* 25(4):279–809.

Opperman J. 2008. Floodplains conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan. Available from: [http://www.dfg.ca.gov/ERP/conceptual\\_models.asp](http://www.dfg.ca.gov/ERP/conceptual_models.asp). [Accessed 28 Sept 2012].

[PPIC] Public Policy Institute of California. 2012. California 2025: planning for a better future. 2012 update. San Francisco (CA): Public Policy Institute of California. 52 p.

Simenstad C, Logsdon M, Fresh K, Shipman H, Dethier M, Newton J. 2006. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems. Puget Sound Nearshore Partnership Report No. 2006–03. Seattle (WA): Washington Sea Grant Program, University of Washington. Available from: <http://pugetsoundnearshore.org>. [Accessed 28 Sept 2012].

[TBI] The Bay Institute. 1998. From the Sierra to the sea: the ecological history of the San Francisco Bay–Delta Watershed. Novato (CA): The Bay Institute of San Francisco. Available from: <http://www.bay.org/display.aspx?pageid=164>. [Accessed 28 Sept 2012].

Thom R. 2000. Adaptive management of coastal ecosystem restoration projects. *Ecological Engineering* 15:365–372.

Twilley RR, Owens A. 2008. Executive summary. Conceptual ecological models. In: Twilley RR, editor. 2008. Coastal Louisiana Ecosystem Assessment & Restoration (CLEAR) Program: a tool to support coastal restoration. Volume IV. Final report. Baton Rouge (LA): Department of Natural Resources, Coastal Restoration Division. 25 p.

[USACE–EAB] U.S. Army Corps of Engineers, Environmental Advisory Board. 2006. Environmental benefits and performance measures: defining national ecosystem restoration and how to measure its achievement. Report to the Chief of Engineers. December 2006. Available from: [http://www.usace.army.mil/Portals/2/docs/Environmental/ebpm\\_mar07.pdf](http://www.usace.army.mil/Portals/2/docs/Environmental/ebpm_mar07.pdf). [Accessed 28 Sept 2012].

Williams JG. 2009. Steelhead and Chinook salmon conceptual model. Sacramento (CA): Delta Regional Ecosystem Restoration Implementation Plan. Available from: [http://www.dfg.ca.gov/ERP/conceptual\\_models.asp](http://www.dfg.ca.gov/ERP/conceptual_models.asp). [Accessed 28 Sept 2012].

[WRR] Wetlands and Water Resources. 2008. Distribution and extent of Delta and Suisun natural habitats, based on data from California Department of Fish and Game. Unpublished map report.