Structured Decision Making Workshop Case Study: Monitoring and Adaptive Management for Lower American River Channel and Floodplain Restoration

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Decision Problem

The Central Valley Project (CVP) is one of the world's largest water storage and conveyance systems, and consists of 20 dams and reservoirs, 11 power plants, and 500 miles of major canals. Originally conceived as a State project to protect the Central Valley from crippling water shortages and devastating floods, the CVP was constructed by the federal government beginning with its initial authorization in 1935. Since its authorization, the CVP has provided about 7 million acre-feet of water annually for agricultural, urban, and wildlife use, with the majority (approximately 5 million acre-feet) delivered to farms. Water deliveries contributed significantly to economic prosperity that came at a cost to native Central Valley Chinook salmon *Oncorhynchus tschawytscha* and steelhead *O. mykiss* populations. Construction and management of reservoirs created a barrier to upstream movement and changed the habitat downstream of dams (Yoshiyama et al. 2001), contributing to population declines. In response to the steady declines of Central Valley anadromous salmonids, Congress passed the Central Valley Project Improvement Act (CVPIA) in 1992. CVPIA mandated changes in management of the CVP, particularly for the protection, restoration, and enhancement of fish and wildlife. One of the sections of CVPIA, §3406(b)(13) (Channel and Floodplain Restoration Program, aka gravel program), mandated the Department of Interior to "develop and implement a continuing program for the purpose of restoring and replenishing, as needed, spawning gravel lost due to the construction and operation of CVP dams... and other actions that have reduced the availability of spawning gravel and rearing habitat " including "…the American River downstream from Nimbus Dam…" The program is also mandated to "include preventive measures, such as re-establishment of meander belts and limitations on future bank protection activities, in order to avoid further losses of instream and riparian habitat."

The gravel program has been implementing gravel augmentation projects on the lower American River (LAR) for a number of years, yet much of the in-stream habitat remains degraded due to a long-standing bedload deficit and a lack of gravel recruitment and availability (Fairman 2007; James 1997). This paucity of gravel resources on the LAR is thought to have contributed to a steady degradation of existing spawning and rearing habitat and channel incision, which limits connectivity to floodplain rearing habitat. In response to these declines in habitat quantity and quality the gravel program adopted the following vision statement:

To restore (i.e., rehabilitate and enhance) channel, floodplain and riparian ecosystem processes and critical habitats for juvenile and adult salmonids to promote the recovery of healthy and diverse Chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (O. mykiss) populations in the American River.

At present, the gravel program is creating a planning framework that will assist in management decisions and prioritizing monitoring projects on an annual and long-term basis to measure success and improve restoration activities. As part of this effort, we participated in a Structured Decision Making workshop (Hammon et al. 1999, Peterson and Evans 2003, Lyons et al. 2008) to develop a decision support tool to facilitate implementation of alternative management actions in the LAR. Our goals for this process were to:

(1) Define the fundamental and key means objectives for the gravel program's activities;
(2) Elucidate the key variables and mechanisms that must be understood in order to determine if restoration actions are achieving the fundamental objective;
(3) Develop a rapid prototype model for comparing alternative restoration actions within a model framework that can be further developed with additional data; and
(4) Incorporate the ability to assess the value of information relative to implementing restoration actions as a tool for prioritizing research and monitoring.

Background

Legal, regulatory, and political context

Fish habitat restoration activities targeting Chinook salmon and steelhead are being conducted in the LAR under the authority of the CVPIA. The intent of the gravel program in the LAR and other Central Valley watersheds is to develop and implement management actions that make all reasonable efforts to double natural production of anadromous fish in Central Valley streams (CVPIA section 3406(b)(1)), and to restore and replenish spawning gravel lost due to the construction and operation of CVP dams, bank protection projects, and other actions that have reduced the availability of spawning gravel and rearing habitat (CVPIA section 3406(b)(13)). The LAR is located in the greater City of Sacramento area and, with an associated parkway and bike path throughout its length, is an important recreational resource. Uses of the river and parkway include fishing, boating, biking, jogging, and enjoyment of nature. Key stakeholders include the Sacramento Water Forum, Sacramento Area Flood Control Agency, and Lower American River Task Force (LARTF) which represent a variety of overlapping state and federal agencies and groups with three main interests: (1) flood control, (2) maintaining aquatic and terrestrial habitats, and (3) recreation, as represented by the "River Corridor Management Plan" (LARTF 2002). A major issue related to gravel program projects includes flow level and timing, which often is dictated by flood control and Sacramento-San Joaquin Delta salinity requirements. Sacramento County Parks has jurisdiction over public safety in the

LAR, and in the past has expressed concern over project placement of instream woody material. Overall, projects implemented by the gravel program may be considered very visible and potentially controversial in light of competing resource interests and uses. Consequently, substantial interagency coordination and public outreach is required, often requiring adjustment to the project design.

Ecological context

A detailed conceptual model of fall-run Chinook salmon life-history in the LAR is provided in the "FISH Plan" (Surface Water Resources, Inc. (SWRI) 2001). Chinook salmon are anadromous, which means they are born in fresh water and migrate to the ocean as juveniles, then feed on the abundant oceanic food supply to grow to adulthood before returning to their natal streams to spawn. Any one of the life stages or transitions may present a bottleneck to the LAR fall-run Chinook salmon population. Healthy river gravels provide habitat for spawning salmon, embryo incubation and emergence, juvenile rearing, and communities of aquatic macroinvertebrates. Steelhead have a similar life history to fall-run Chinook salmon, with the following exceptions: (1) steelhead spawn in the winter; (2) many steelhead live in fresh water for a year before migrating to the ocean; and (3) some steelhead survive after spawning. Therefore, the gravel program has influence only over the following key life stages or transitions in the LAR: (1) adult spawning and egg incubation, (2) fry emergence, rearing and emigration, and (3) juvenile rearing and emigration. The intent of the program is to increase growth, survival, and recruitment into the next spawning population. However, success of habitat restoration projects may be dependent not only on physical factors such as intragravel flow and water temperature, but also on fish physiology and behavior. Program monitoring objectives consequently need to focus on identifying and quantifying project effects on particular life stages, and on distinguishing project effects from those of outside influences such as migration success through the Sacramento-San Joaquin Delta.

Pre- and post-project monitoring at both treatment and control sites generally suggests that past habitat restoration efforts have been effective. Key findings indicate that in many cases (1) adult Chinook salmon and steelhead began using enhanced gravel for spawning within 30 days of project completion; (2) both the number and proportion of Chinook salmon and steelhead redds increased in gravel enhancement locations; and (3) juvenile salmonids also utilized enhanced areas (Cramer Fish Sciences 2009; 2010). However, monitoring project effects on adult spawning is much easier than for embryos, fry, or juveniles. Furthermore, fundamental information needed to assess project success, such as whether spawning or rearing is the limiting life stage, is lacking. A more holistic and realistic assessment of the gravel program effectiveness is needed.

Decision Structure and Analysis

Through the process of Structured Decision Making (SDM), we constructed an Influence Diagram (ID) to graphically represent a conceptual model of management actions that can be implemented by the gravel program and how those actions influence anadromous fish. IDs illustrate the most important variables and linkages influenced by decisions made by the gravel program, and capture information on relationships, dependencies, and uncertainty. IDs can represent decision effects at three levels of specification: 1) relation, describing the general relationships between variables in a conceptual model; 2) function, specifying the nature of the relationship between variables; and 3) number, assigning quantitative values to the functions based on data or expert opinion (Howard and Matheson 2005). In the case of the gravel program, we developed a probabilistic ID that modeled the relation among components using conditional probability (Howard and Matheson 2005, Stewart-Koster et al. 2010). Each component in the ID is graphically represented by nodes and the causal relations between model components are represented by arcs with the arrows indicating the directionality or causality of the relations. Each node consists of a set of mutually exclusive states, or discrete classes. The classes are mutually exclusive in that there is no overlap in values that define each class and are collectively exhaustive in that they represent the range of possible values.

We used the software package Netica (Norsys 2005) to create a graphical predictive model representing the key variables related to spawning and rearing of fall-run Chinook in the LAR that can be influenced by decisions made within the gravel program (i.e., excluding flow and temperature management) and their conditional dependencies (Figure 1). At this stage in the process (rapid prototyping) we have defined the important variables and their relationships, based on the fundamental objective, key means objective, and alternative actions available to the program and key ecological processes that could be influenced by these alternative actions, and relied on expert opinion (Kuhnert et al. 2010) to parameterize the model. Next steps (described in greater detail in the discussion and recommendations) are to more fully define and quantify the functions by parameterizing the model using empirical models and data.

Predictive model overview

Because Pacific salmon often require many distinct habitats throughout their life cycles, impacts from various environmental parameters may have disproportionate and distinct influences on a given salmon population within and across years (Anderson et al. 2009; Honea et al. 2009). Therefore, understanding how an anadromous salmonid population responds to environmental effects, such as water development, climatic variation or habitat restoration, will depend on direct analysis of life history parameters and relative survival during each stage of its life. Thus, the quantitative analysis of environmental variation and management/restoration action effects on freshwater productivity must be based on models which consider, besides the environmental parameters of interest, estimating relative survival from one life stage to the next. These estimates of relative life stage survival must be accurate enough not only to detect annual variation during a given life stage but between life stages to determine key parameters driving overall population variation from year to year without biologically significant differences being swamped by sampling (measurement) error.

The fundamental objective of the gravel program was to determine the most efficient use of management resources to maximize the number and condition of fall-run Chinook salmon smolts leaving the LAR. To achieve this objective, our key means objectives were to maximize the quality and amount of spawning and rearing habitat for Chinook salmon in the LAR. Our fundamental objective was reflected in our model utility function, represented by the terminal node of our ID, which provides a common measurement of the relative costs and benefits of alternative actions and reductions of uncertainty (e.g., investing in monitoring activities). The optimal management decision (which could be a restoration action, research and monitoring, or a combination of the two) is the decision that provides the most desirable ecological outcome relative to its costs, thus considering both ecological response and economic constraints (Stewart-Koster et al. 2010). Ultimately, the gravel program plans to add a second fundamental objective to also maximize the number and condition of steelhead smolts leaving the American River. However, at this point in the process we decided to simplify the ID to only consider fall-run Chinook salmon.

Reflecting our objectives, we developed a model that estimates the response of Chinook salmon outmigrants to habitat management activities on the LAR. The model predicts the marginal gain in the number of outmigrating smolts within each management site (utility function; change in smolts per unit cost) at multiple time steps. This allows us to predict the relative benefit of the management action at the 0, 5, and 10 year time steps. The management actions taken have been identified as three restoration actions, currently being implemented in the Central Valley, for increasing the quantity and quality of spawning and rearing habitats at various levels of effort.

To determine the marginal gain in the number of outmigrating smolts resulting from alternative management actions, we examined the relationships between four model components: (1) future habitat availability; (2) fry emergence; (3) potential juveniles; and (4) Chinook outmigrants. The future habitat availability component was defined by relationships between alternative restoration actions, discharge during spawning or rearing, and time since the previous action (defined in more detail below). Fry emergence was dependent on future spawning habitat, spawning potential, and escapement. Potential juveniles were defined by fry emergence, juvenile habitat zone potential, future in-channel rearing habitat, and future seasonally inundated habitat. Chinook outmigrants was related to potential juveniles and system dynamics, a measure of the uncertainty in whether spawning or rearing habitat was limiting the population from year to year. Ultimately, these biological components and management action components provided an estimate of the number of outmigrants per unit cost in response to each alternative management action on the LAR. Model components and individual parameters are described in more detail below. The team recognized the importance of eventually comparing the effectiveness of channel and floodplain restoration projects against other restoration actions with the objective of benefiting salmonid populations, such as flow and temperature management; however, for this exercise we chose to focus on the management activities that could be implemented within the authority of the gravel program.

Future habitat availability component

The availability of future habitat was modeled as functions of current habitat availability, flows during the appropriate season, and the management action (Figure 2). Future habitat was defined in terms of suitability for spawning or rearing and location in the channel or floodplain:

(1) Future spawning habitat (Figure 3) – in-channel, gravel substrate (generally a mixture of gravel in the 1/8" - 5" range with a median particle size around 1 - 1 ½"), with HSI values greater than 0.5, corresponding to depth predominantly in the range of 1' - 6' and velocity in the range of 0.3 – 1.25 and 2 - 3 feet/sec (depending on species), and located in river reaches likely to have suitable temperatures for successful incubation;
(2) Future in channel juvenile habitat (Figure 4) – in-channel, but located along channel margins or in side channels with access to cover, with HSI values greater than 0.5, corresponding to depths of less than 3.4' - 5.4' (depending on species and life stage) and with a diversity of velocities with slow water areas (<0.8 – 1.95 feet/sec) adjacent to faster water (1 - 6 feet/sec) ; and
(3) Future seasonally inundated habitat – floodplain inundated on average once per year or less frequently, with cover and a diversity of velocities with slow water areas near faster water areas.

Current and future habitat availability was expressed in terms of acres of habitat within the defined combinations of suitable depth, current velocity, and substrate or cover for the particular life history stage. The ranges for habitat availability were based on expert judgment and the discretization of the node states was at uniform intervals over the range. The nodes were parameterized using expert opinion that informed functions in the "Habitat avail function elicitation" Excel worksheet accompanying this document.

Future habitat availability is dependent on alternative restoration actions, discharge during spawning or rearing, and time since previous action. These parameters are described below and illustrated in Figure 2.

<u>Alternative management actions</u>

During the workshop process, we identified seven potential actions that could be implemented to improve the quality and quantity of spawning/incubation and juvenile rearing habitat to ultimately maximize outmigrants. These included:

(1) doing nothing;
(2) small gravel injection, < 10,000 tons, resulting in a estimated 0.5 (+/- 0.7) acres of habitat at a cost of 0.35 (+/- 0.1);
(3) large gravel injection, > 10,000 tons, resulting in an estimated 3.5 (+/- 1) acres of habitat at a cost of 5.0 (+/- 0.1);
(4) small gravel placement, mean 0.5 (+/- 0.1) acres of habitat at a cost of 0.5 (+/- 0.2);
(5) large gravel placement, mean 3 (+/- 0.6) acres created habitat at a cost of 1.0 (+/- 0.2);
(6) small floodplain habitat enhancement by excavation, mean 2 (+/- 0.5) acres of perched floodplain at a cost of 0.5 (+/- 0.2); and

(7) large floodplain habitat enhancement by excavation, mean 4 (+/- 1) acres of perched floodplain at a cost of 2.8 (+/- 0.5).

These alternative actions and their associated costs were provided as input into our ID (Figure 1) to define the cost basis and ultimate ecological outcomes for comparison among alternatives.

Discharge during spawning or rearing

This node represented the uncertainty associated with streamflow conditions during the spawning (November - December) or rearing (February - June) periods. The nodes consisted of three states:

Low: streamflows that are lower than design flows
Design: the streamflows for which the projects are designed
High: streamflows greater than the design flows

Annual probabilities for each state were determined by expert opinion.

Time since previous action

This is a constant node that represents the amount of time since the management action intended to increase habitat availability. The node was included to incorporate the effect of high flows on the persistence of habitat enhancement projects. The node consisted of 3 discrete states: zero, 5 and 10 years from present.

Fry emergence component

Fry emergence was modeled similarly under no action (do nothing) management scenario and the alternative management actions. For both components, fry emergence was modeled as a function of escapement, spawning zone potential, and (current or future) spawning habitat availability (Figure 3) as:

fry = minimum(0.08*spawning habitat availability*spawning potential OR
escapement/2)* 2000

where *fry* is the number of emerging fry, 0.08 is a constant representing the number of redds per acre of habitat (based on expert judgment), and 2000 a constant representing is the number of fry produced per redd (based on expert judgment), the criteria used to quantify spawning habitat availability is described above, and the remaining components are described below. The value of fry is controlled by the habitat availability when habitat is limiting; otherwise it is controlled by the number of returning females (assuming a 50-50 sex ratio). The constant values and assumed sex ratio could be treated as uncertain parameters by adding additional nodes representing each component.

Fry emergence is dependent on spawning potential and escapement. These parameters are described below and illustrated in Figure 5.

Spawning potential

This node represents the probability that the condition of a site (i.e., thermal regime, historic spawning) are appropriate for spawning. The value of the node ranges from 0 - 1 with 1 indicating perfectly suitable and zero indicating completely unsuitable area for spawning. The node is composed of 4 uniformly discretized values: 0 - 0.25, 0.25 - 0.50, 0.50 - 0.75, and 0.75 - 1.0. The model was parameterized using expert opinion on the nature of the relation between distance from dam (a constant node) and spawning potential.

<u>Escapement</u>
Escapement is estimated as the number of adult Chinook salmon returning to a stream site. The range of values for escapement was based on expert opinion and the values were uniformly discretized.

Potential juveniles component

The number of potential outmigrating juveniles was modeled similarly under no action (do nothing) management scenario and the alternative management actions. For both components, potential juveniles was modeled as a function of number of emerging fry, juvenile habitat zone potential, and (current or future) availability of in channel and seasonally inundated habitat (Figure 4) as:

> *juveniles* = minimum ((in channel habitat + seasonally inundated habitat)*juvenile potential *500 OR fry emergence)

where *juveniles* is the number of outmigrating juveniles, 500 is a constant representing the number of juveniles per acre of suitable juvenile habitat (based on expert judgment), the quantity of in channel habitat and seasonally inundated juvenile habitat availability, and juvenile habitat zone potential. The value of juveniles is controlled by the habitat availability when habitat is limiting; otherwise it is a controlled by the number of emerging fry. The constant value for the number of juveniles per acre could be treated as an uncertain parameter by adding additional nodes representing each component.

Potential juveniles are dependent on juvenile habitat zone potential. This parameter is described below and illustrated in Figure 6.

<u>Juvenile habitat zone potential</u>
This node represents the probability that the condition of a site (i.e., downstream from spawning) are appropriate for juvenile rearing. The value of the node ranges from 0 - 1 with 1 indicating perfectly suitable and zero indicating completely unsuitable area for spawning. The node is composed of 4 uniformly discretized values: 0 - 0.25, 0.25 - 0.50, 0.50 - 0.75 and 0.75 - 1.0. The model was parameterized using expert opinion on the nature of the relation between distance from upstream spawning (a constant node) and juvenile habitat potential.

Chinook outmigrants component

The number of outmigrating Chinook was modeled similarly under no action (do nothing) management scenario and the alternative management actions. For both components, outmigrating Chinook was modeled as a function of number of emerging fry, number of juveniles, and system dynamics (Figure 7). The system dynamics component represented uncertainty in whether spawning or rearing habitat was limiting the population from year to year. When system dynamics was assumed to be limited by the availability of spawning habitat, the number of outmigrants was equal to the number of fry. When system dynamics was assumed to be limited by the availability of rearing habitat, the number of outmigrants was equal to the number of juveniles.

System dynamics

This node represented the uncertainty in whether spawning or rearing habitat was limiting the population. It was composed of 2 states:

Spawning habitat: spawning habitat is limiting
Rearing habitat: juvenile rearing habitat is limiting

The probability of each state was assumed equal (i.e., 50-50).

Utility value

The utility value of each decision was estimated by calculating the marginal gain as:

(Chinook outmigrants action - Chinook outmigrants no action) / cost

where Chinook outmigrants action is the estimated number of outmigrants under an alternative management action, Chinook outmigrants no action is the estimated number of outmigrants with no management action, and cost is the cost of management action (Figure 8).

The optimal decision

The optimal decision is defined as the decision that maximized the utility, which in this model is the marginal gain. For the current prototype model structure, the optimal and next best two decisions at time = 0 is injection small with a marginal gain of 291, gravel placement small with a gain of 263, and excavation small with 188. The value of the gravel decisions diminishes with time and at time = 10 the marginal gains of injection small, gravel placement small, and excavation small are 252, 250, and 188, respectively.

Uncertainty

The current prototype model was rapidly developed over a four-day workshop, but provides a structured decision making foundation for further evaluation of a suite of gravel enhancement restoration actions in the LAR. Each of the influence diagram's (Figure 1) components incorporated expert opinion in multiple nodes for each component. The workgroup recognized more information is likely available about many of these nodes to further quantify the relationships between components and independent parameters.

One example where further quantification is likely would be the nodes that informed functions in the "Habitat avail function elicitation" Excel worksheet accompanying this document. These functions are essential to the quantification of future habitat availability resulting from injections, gravel placement, and excavation. Significant design effort is spent on this step, and empirical observation and hydraulic simulation can provide accurate quantifications not included in the parameterization of available habitat. Another example where the workgroup felt more accurate quantification could be included in the influence diagram was related to the model used for fry emergence. Further discussion on the equation's constants as well as the relationships and discretization of values in the spawning habitat availability and spawning potential components would benefit the evaluation of alternative restoration measures' effect on fry emergence. These examples may be good starting points for reevaluation of expert opinion, but all components should be further reviewed.

One way uncertainty about population dynamics was explicitly modeled was in the system dynamics node. The workgroup felt that it was possible that under some situations, spawning habitat or rearing habitat could be limiting the population. The probability of either of these situations occurring was decided with expert opinion and assumed equal, but more quantification and a relationship between escapement or distance from dam could help define these probabilities. In all of the cases described in this section, where uncertainty is modeled in a node through expert opinion or assumptions about discretization of values, the influence diagram can help us prioritize modeling to reduce uncertainty by using the model to identify which nodes have the greatest influence on changing the utility value.

Discussion

Value of decision structuring

The decision structuring process is an important step in developing transparent project design, identification of potential near- and long-term benefits, and refining monitoring and research needs focused on LAR gravel enhancement. Our recent experience developing influence diagrams demonstrates the on-going struggle for fisheries managers to incorporate ecological assumptions and processes, such as the utility of value- marginal gain, into restoration planning. Influence diagram development and node parameterization highlight the importance of narrowing the number of conceptual processes thought to influence gravel enhancement, while acknowledging that many of the factors driving fry emergence and rearing success are outside the scope of the LAR gravel enhancement program.

The introduction of our group to the SDM decision making process allowed us to identify key objectives, a useful decision making process, and ultimately, the appropriate restoration actions associated with LAR gravel augmentation program that best achieve those objectives. The development of clear objectives and a restoration evaluation model highlights relevant information needed for measuring the success of the LAR program. A potential dilemma is that the higher priority information needed to better parameterize our model may be costly to obtain (Roni et al. 2002). The utility value concept will be beneficial to use in prioritizing LAR gravel enhancement management actions, other CVPIA restoration actions, and agency mission responsibilities.

Prototyping process and further development required

Rapid prototyping of decision structuring for the LAR gravel enhancement program provides a foundation for our workgroup to evaluate the marginal gain in juvenile Chinook salmon production from alternative restoration actions. Throughout the influence diagram we used expert opinion and assumptions about probability discretization to rapidly prototype an evaluation of alternate restoration activities associated with LAR gravel enhancement. Focusing on each of these nodes would be critical to formalizing model use for planning gravel enhancement on the LAR.

Recommendations

While the workgroup did not spend significant time developing recommendations from their rapid prototyping exercise, our notes captured several interesting future actions.

1. This model should be further developed beyond the prototyping process. This will require the CVPIA program to decide if it would expend funding of facilitators or a cadre of the workgroup would attempt to move the model forward. Such a model could be integrated into other CVPIA program's models focused on a similar utility as marginal gain, to evaluate alternative restoration actions such as flow augmentation, improvement on control structures (i.e., Head of Old River Barrier, Delta Cross Channel), and screening pumping plants.
2. Focus monitoring efforts on areas that help define values that are important to the relationships in the influence diagram. The influence diagram reflects the workgroup's best understanding of the benefits of gravel enhancement on Chinook production. Thus, understanding more about specific uncertainties such as the role of egg production or redd placement on juvenile production could be very informative to reducing uncertainty in the model.
3. Continue to periodically revisit the fundamental objectives of the gravel enhancement program within the CVPIA program and of the other fisheries provisions of the CVPIA program as a whole. The legislation remains the same but societal values and our understanding of natural systems is changing. We will need to continue to be responsive to these changes in the management decisions we affect.

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Figures and Tables

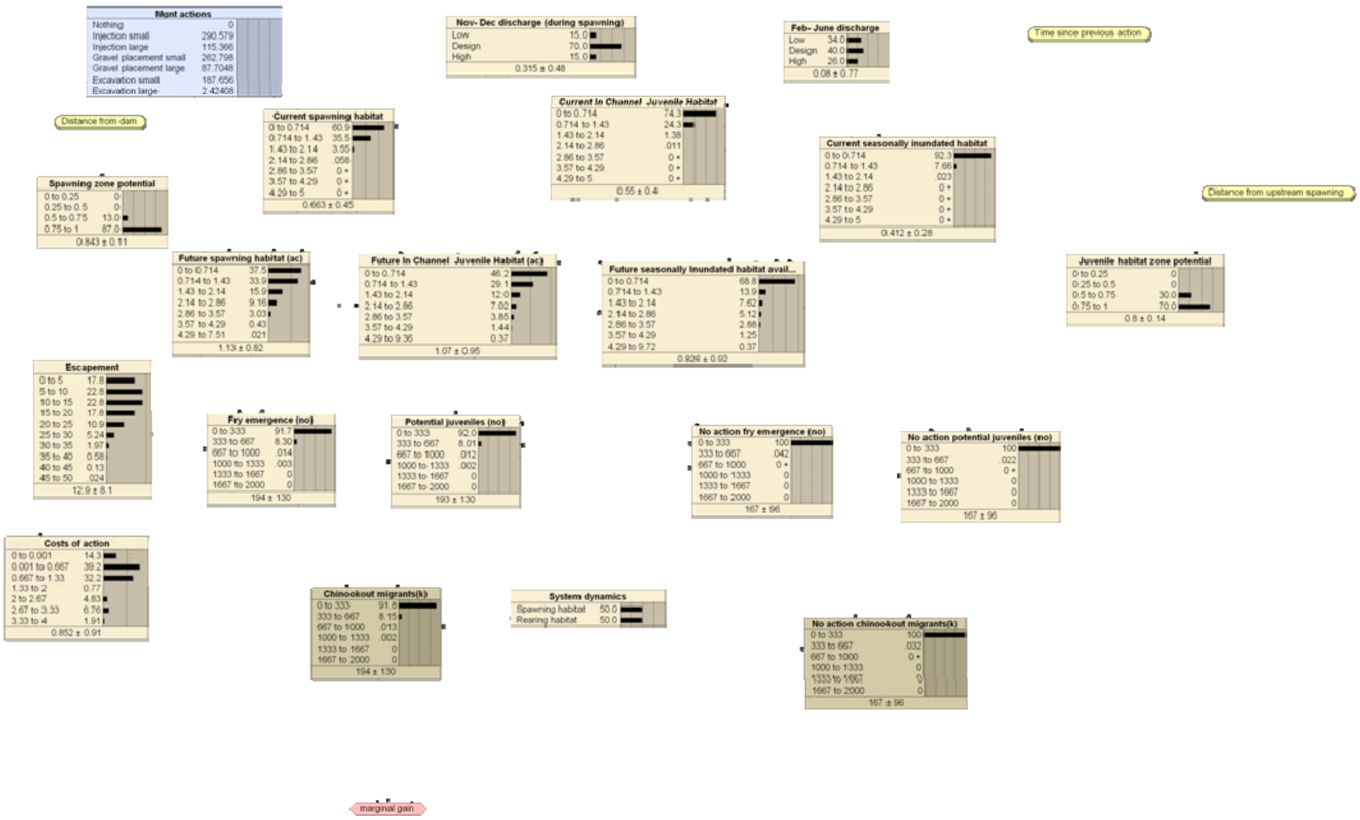

Figure 1. Influence diagram of prototype model for predicting Chinook salmon outmigrants in response to habitat management decisions made by the Channel and Floodplain Restoration Program.

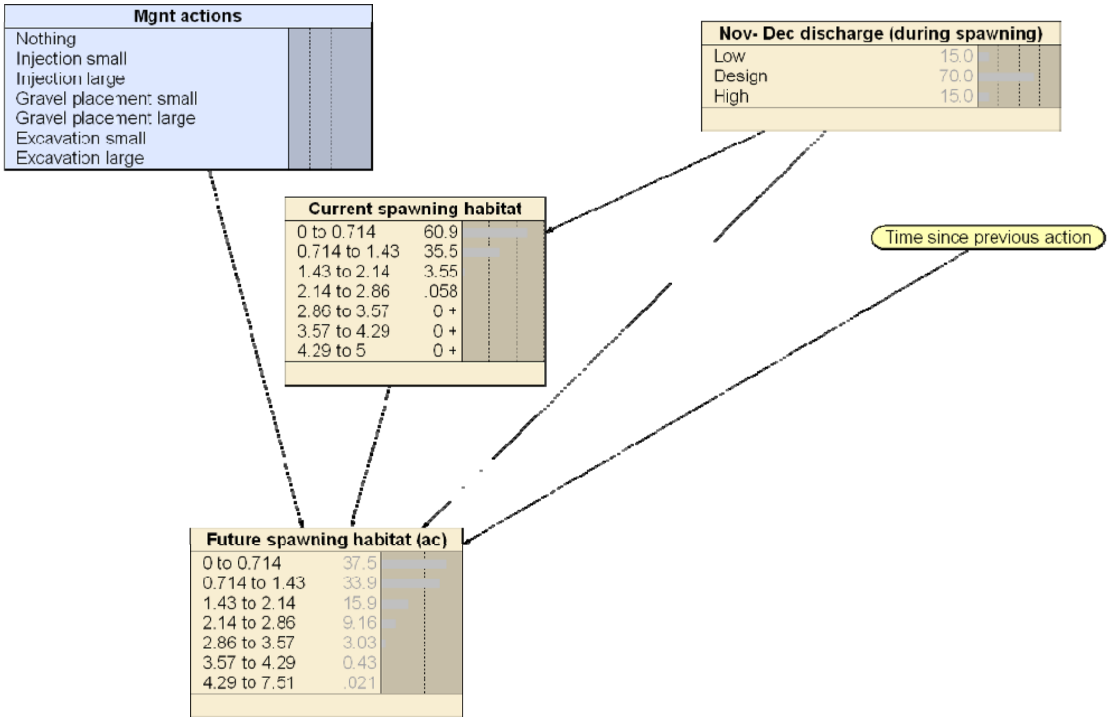

Figure 2. Future habitat availability component (spawning habitat shown here) of prototype model for predicting Chinook salmon outmigrants in response to habitat management activities on the American River.

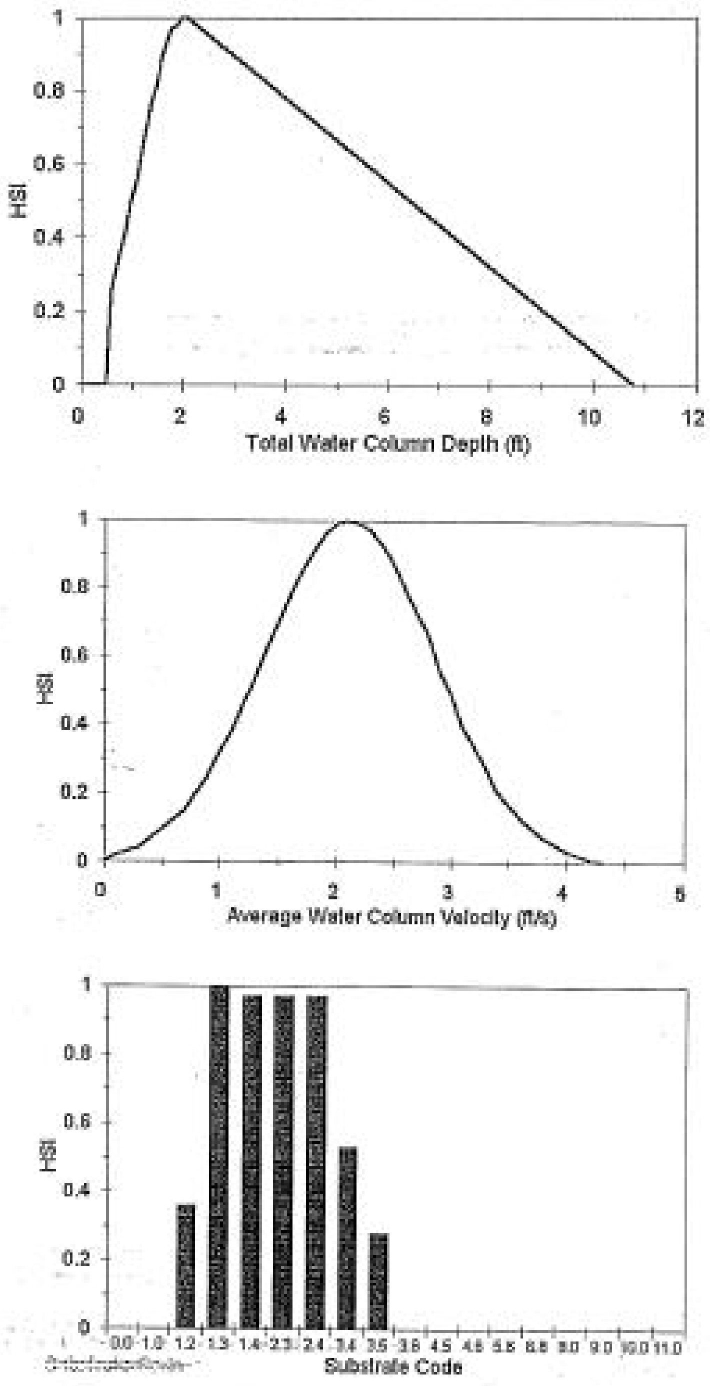

Figure 3. American River fall-run Chinook salmon spawning habitat suitability criteria (USFWS 1997).

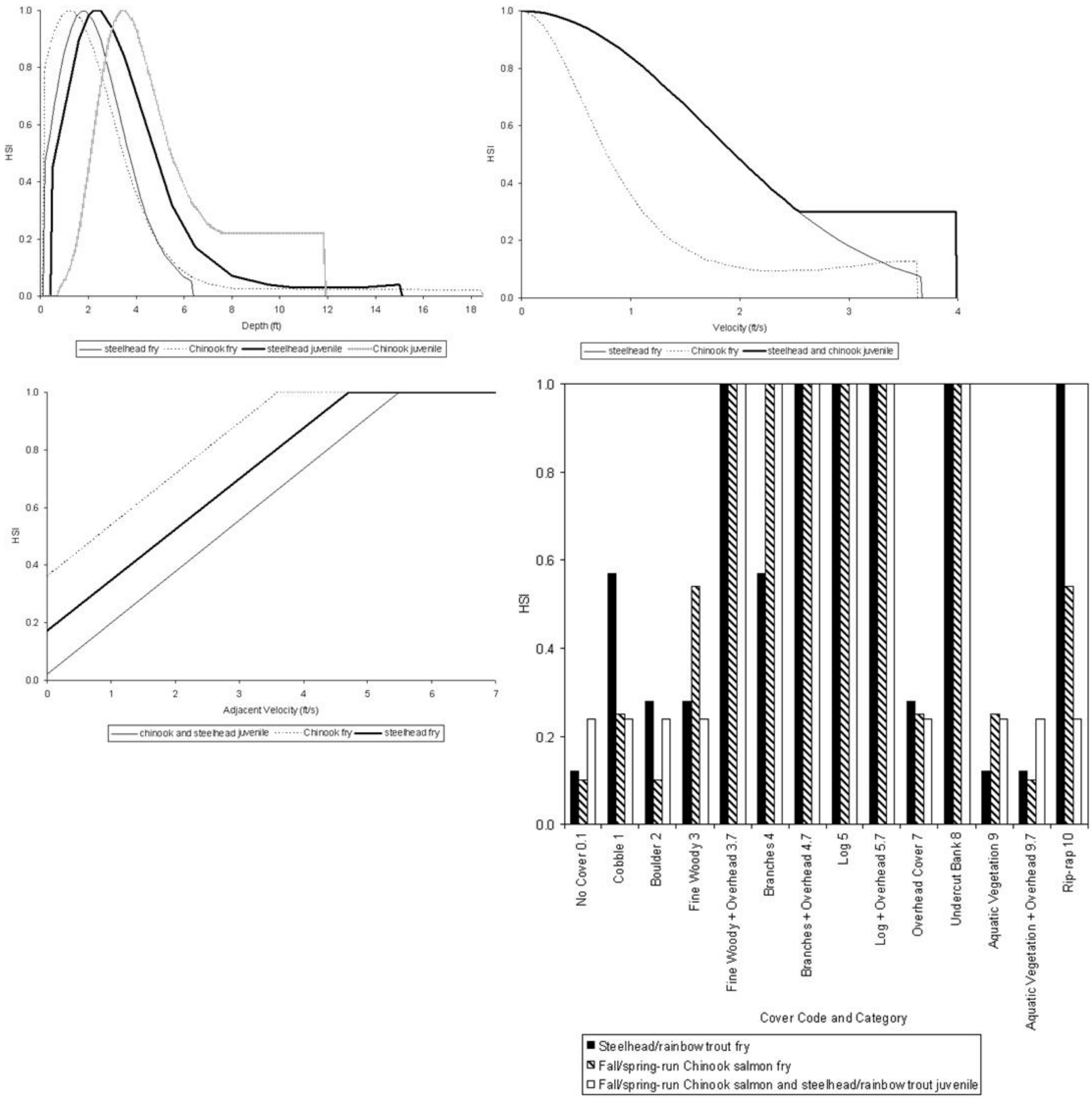

Figure 4. Yuba River fall-run Chinook salmon and steelhead rearing habitat suitability criteria (U. S. Fish and Wildlife Service 2010).

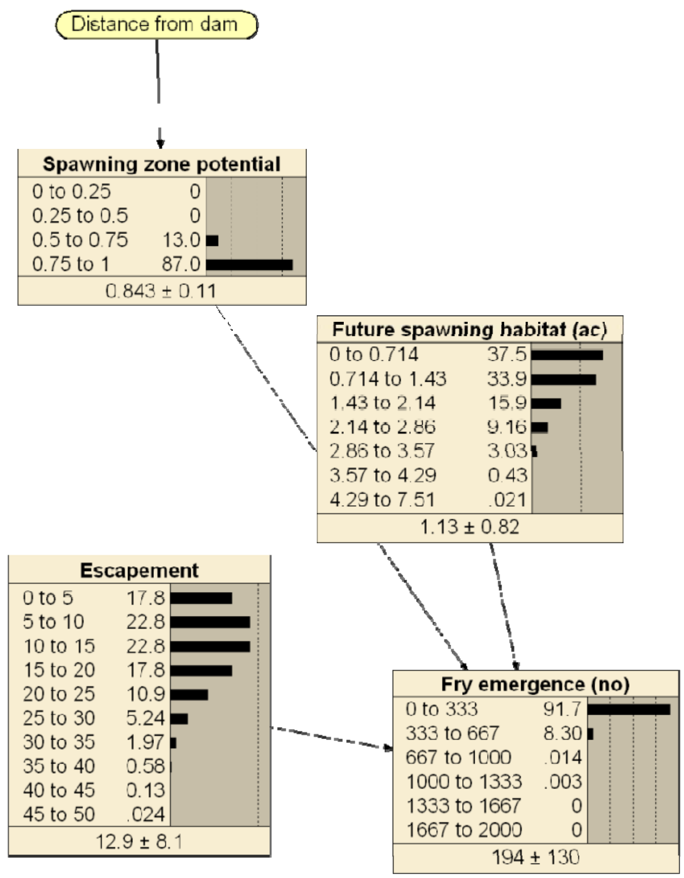

Figure 5. Fry emergence component of prototype model for predicting Chinook salmon outmigrants in response to habitat management activities on the American River.

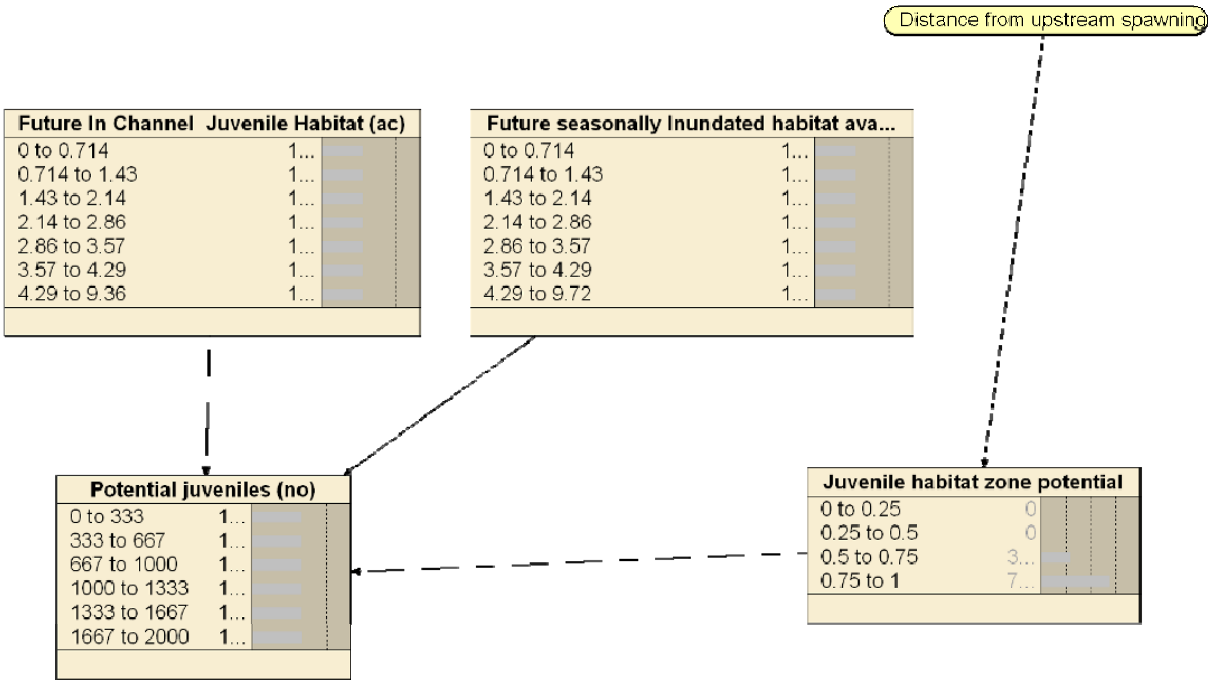

Figure 6. Potential juveniles component of prototype model for predicting Chinook salmon outmigrants in response to habitat management activities on the American River.

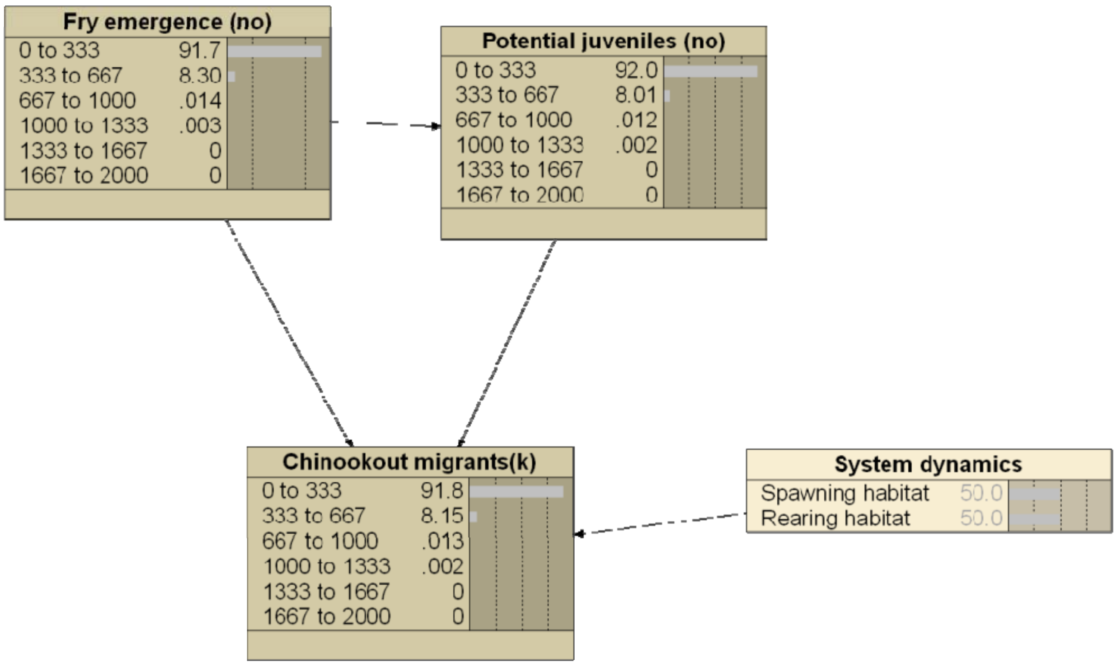

Figure 7. Chinook outmigrant component of prototype model for predicting Chinook salmon outmigrants in response to habitat management activities on the American River.

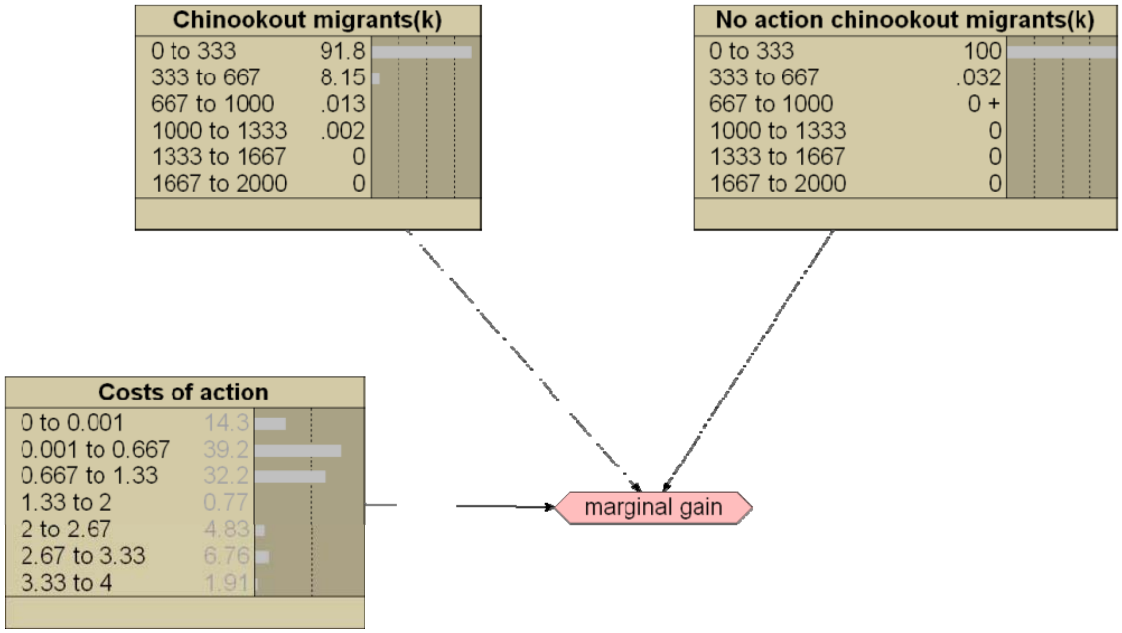

Figure 8. Marginal gain (utility) component of prototype model for predicting Chinook salmon outmigrants in response to habitat management activities on the American River.