# Appendix L. Example structured decision-making process to assist in the development of environmental flow prescriptions

Belize Lane and Samuel Sandoval Solis

## Introduction

There are often multiple competing water management objectives and a legal, regulatory, or social context that requires balancing among those objectives. In addition, there is often uncertainty about the consequences of implementing an environmental flow prescription on the management objectives and a desire to conduct adaptive management to learn from implementing flow actions and improve decision making over time. This type of management problem (characterized by multiple competing objectives, uncertainty, and the desire for adaptive management) is best addressed by an organized decision-making process, such as Structured Decision Making (e.g., Gregory and Keeney 2002; Runge et al. 2011). CEFF Section C outlines major considerations for balancing ecological flow regimes with human needs in the context of a functional flows approach.

In the case of structured decision making, stakeholders must describe the decision problem within the broader water system context, define a full suite of management objectives and performance metrics, develop a set of ecological and water management alternatives, predict the consequences of implementing each alternative on the objectives, evaluate trade-offs among objectives, and make a decision regarding which alternative to implement as the environmental flow prescription (Figure 1, Failing et al. 2013). **Structured Decision-Making** can facilitate this decision making process through a set of interactive modeling and display technologies (i.e. models and graphical user interface) that enable stakeholders to evaluate different environmental and human water management strategies (Loucks and VanBeek 2017).

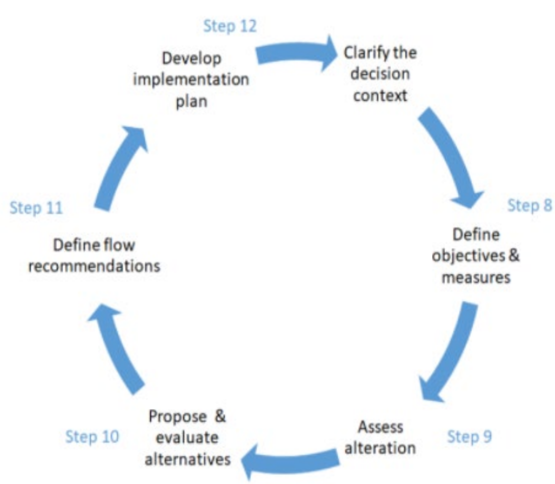


Figure 1. *The Structured Decision Making process from Failing et al. 2013.*

This appendix outlines <u>one example structured decision making process currently under development as part of a pilot study to assist in the development of environmental flow prescriptions</u> at multiple locations of interest (LOIs) in a coastal diversion-regulated watershed northern California. Specifically, this document describes the main steps undertaken and provides a brief overview of the structured decision making process. The process described here does not capture all possible stakeholder needs or management objectives. Rather, it illustrates one possible approach for defining objectives, assessing alteration, and evaluating management alternatives using a water allocation model.

This CEFF Section C process is intended to help stakeholders evaluate **ecological flow criteria**[1] developed in CEFF Sections A and B and alternative flow criteria scenarios in the context of different water management strategies and climate conditions using a water allocation model. Spatially distributed and temporally varying information related to hydrology and ecological response relationships (such as those developed in *Appendix I*) was integrated to evaluate alternative water management strategies and tradeoffs across objectives. The modular approach allows additional information to be incorporated by a user, such as updated ecological flow regimes or water management strategies. A graphical user interface provides a user-friendly platform to compare management strategies through space and time with respect to human water demand and ecological performance measures to facilitate development of environmental flow recommendations.

## Pilot Study

### *Clarify the decision context and define objectives*

Many of California's rivers and streams have highly seasonal flow regimes and immense interannual variability. Species in these systems are adapted to hydrologic variability and possess specialized life history strategies timed to take advantage of suitable habitat conditions. The seasonality of precipitation and flow also creates competition for water in the dry-season between human and ecological water needs, particularly in dry years. Several state agencies are in the process of developing **environmental flow prescriptions**[2] to sustain aquatic ecosystems while continuing to meet irrigation demands, and there is a need to evaluate trade-offs between these outcomes.

Like much of the state, our northern coastal California watershed is characterized by a Mediterranean climate with cool wet winters and warm dry summers. The natural flow regime is highly seasonal, with mean January flow (5,110 cfs) more than 90 times greater than mean September flow (56 cfs). This seasonality intensifies competition for water in the dry-season between human water demands for irrigation and aquatic species needs, underpinning the need for a process to evaluate tradeoffs. Dry-season low flows have been further reduced by streamflow diversions (CDFW 2014), both permitted and unpermitted, driving stream temperature, sediment, and habitat impairments (NCRWQCB 2013, 2014). Although the watershed has been identified as a salmon stronghold, populations are severely depressed (CDFW 2015a). Several native salmonid populations in the SFER are now federally listed as threatened, including SONCC coho salmon, North Coast steelhead, and Coastal Chinook salmon. To address these challenges, the SFER was selected as one of five priority stream systems for developing environmental flow prescriptions as part of the California Water Action Plan effort.

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[1] ***Ecological Flow Regime***: consolidation of outcome-specific ecological flow criteria into an overall flow regime that balances the needs of all ecological outcomes.

[2] ***Environmental flow prescriptions*** (Environmental Flow Recommendations): ecological flow prescriptions adjusted to consider and balance other competing human uses to produce a flow regime that balances human and ecological needs.

## *Process overview*

In this pilot study, inputs to the structured decision-making process include the ecological flow criteria and flow-ecology relationships developed in **CEFF Section B**. A water allocation model for the study watershed was developed to evaluate these flow criteria in the context of human water needs and priorities over the long-term daily streamflow record.

The main user steps were to (1) generate flow regime scenarios, (2) build a water allocation model that describes the water availability and allocation system throughout the geographic region, (3) define water management scenarios, and (4) evaluate system performance with respect to human water demands and aquatic species needs under current and alternative water management strategies to the facilitate stakeholder decision-making process for setting **environmental flow prescriptions** (Figure 2). These steps are described in more detail below.

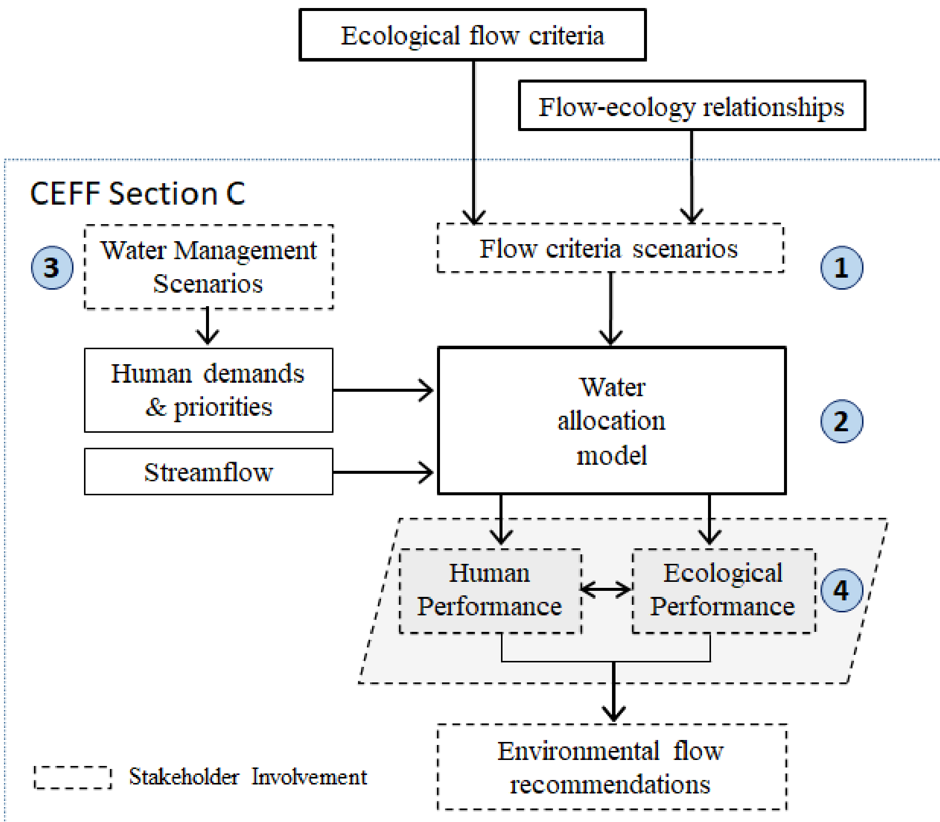


Figure 2. Overview of an example DSS to assist in the development of environmental flow prescriptions for LOIs throughout the SFER watershed. Development of the ecological flow regimes used as inputs here is detailed in *Appendix I*. Activities with stakeholder involvement are outlined in dashed lines. Labeled steps 1 - 4 correspond with the steps described in the text below.

## *Develop alternatives*

**Step 0 - Generate flow criteria (CEFF Section B)**

In CEFF Section B, conceptual models were developed to describe focal flow component controls on desired ecological outcomes, including mediating factors. The specific approach described in *Appendix G* was used to develop flow- hydraulic habitat relationships at each LOI. These relationships were linked to established habitat preference curves of aquatic species of interest to generate quantitative **flow-ecology relationships** (CEFF Step 6) and subsequently **ecological flow criteria** (CEFF Step 7) for LOIs.

**Step 1- Generate flow criteria scenarios**

By definition, environmental flow recommendations incorporate multiple competing objectives for water and represent some balancing of competing uses. Ecological flow criteria can be thought of as one alternative flow regime that optimizes for ecological outcomes while ignoring other management needs. On the other hand, the complete lack of ecological flow criteria can be thought of as another alternative that optimizes for human needs while ignoring ecological outcomes. Any other flow criteria scenario will likely have consequences for ecosystems and human water uses. In coordination with agency staff and local stakeholders, a set of scenarios can be developed along this spectrum of competing objectives or using different existing implementation methods (e.g. Tessman, Percent of Flow, etc.) to facilitate tradeoff analysis.

**Flow criteria scenarios** for each LOI should include the ecologically optimal **ecological flow criteria** developed in CEFF Section A and B as well as other instream flow calculation methods relevant for available for the LOI. It is important to note that these scenarios are intended to facilitate evaluation of tradeoffs during the decision-making process and may or may not be considered acceptable flow recommendations by the stakeholder community. Flow criteria scenarios may be specified to:

- represent different levels of variability or alteration in key functional flow metrics,
- assess the ability to provide specific physical habitat conditions, or to
- represent different probabilities of species occurrence / risk levels.

In the pilot watershed study, flow criteria scenarios were generated by adjusting key flow criteria (e.g. dry-season baseflow magnitude) selected through stakeholder coordination to highlight water management tradeoffs associated with providing a range of juvenile steelhead rearing habitat conditions (low to high probability of rearing occurrence) over the dry-season in specific reaches (LOI) and water year types (WYT). Habitat suitability relationships for juvenile steelhead rearing were already established for the watershed (Figure 3a). The reference ranges for the dry season baseflow functional flow metric were calculated at each LOI using the Functional Flows Calculator (CEFF Section A) based on modeled unimpaired daily streamflow data provided through an independent physically-based hydrologic model. The hydraulic conditions associated with this range of flows was evaluated as described in *Appendix G* to generate LOI-specific hydraulic response relationships between dry-season baseflow magnitude and hydraulic conditions relevant to the ecological outcome (i.e. median reach velocity) (Figure 3b). Different flow criteria scenarios (i.e. alternative dry-season diversion thresholds for each WYT) result in changes to the flow metric of interest (i.e. dry season baseflow magnitude) (Figure 3c, see Step 2 below) associated with different velocities that can be assigned to habitat suitability categories (Figure 3d). This information can be used to select a range of flow criteria scenarios associated with different rearing suitability categories.

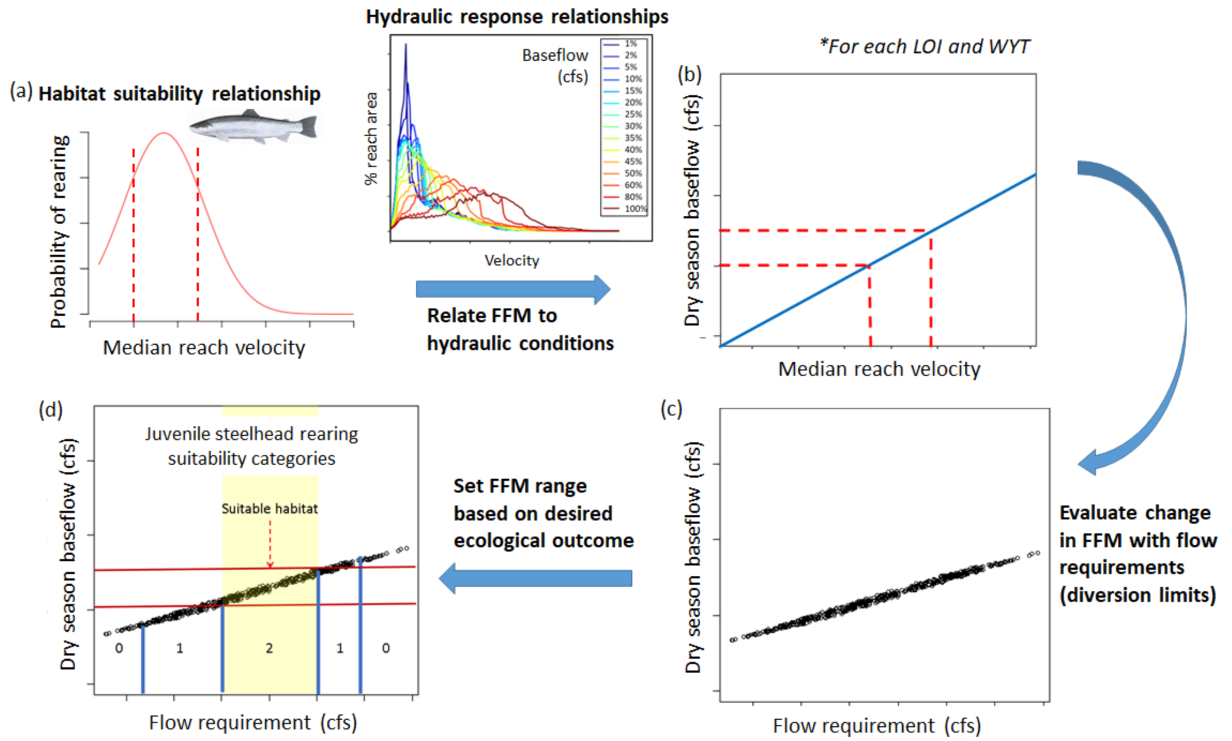


Figure 3. (a) LOI-specific hydraulic response relationships were combined with rearing habitat preferences for juvenile steelhead to (b) relate the dry-season baseflow magnitude flow metric to hydraulic habitat conditions. These relationships were then combined with (c) predicted changes in the flow metric with WYT-specific water management scenarios such as dry-season instream flow requirements to (d) assess the habitat suitability category associated with each management scenario. This information can be used to .

Based on conversations with watershed stakeholders and water managers, these ecological response relationships were translated into a set of six flow regime scenarios at each LOI for each WYT (Table 1). These scenarios consisted of the predicted natural functional flow metric values obtained in CEFF section A except for the dry season baseflow magnitude metric, which was replaced as described above to represent a range of juvenile steelhead rearing suitability and associated likelihood of occurrence. This flow metric was a focus of the pilot study because species of concern for the watershed are very sensitive to changes in dry-season baseflow magnitude and the reference range is not always met due to dry-season irrigation diversions. Habitat suitability categories associated with different flow criteriacould also be translated into risk to juvenile salmonids associated with allowable water diversions, or other performance measures of interest to the stakeholder community. Ultimately, ranges of acceptable values should be determined for each relevant flow metric based on the natural functional flow metric ranges, and critical life history needs established through flow-ecology relationships.  Combining the acceptable ranges of all functional flow metrics should ensure that all functional flow components are achieved, thereby producing an ecologically protective flow regime.

Table 1. Dry-season baseflow magnitude flow criteria scenarios for a single LOI in different water year types (WYT). These scenarios can be combined with other flow criteria based on the references ranges or analogous scenarios to generate a series of WYT specific annual flow regime scenarios for evaluation within a water allocation model.

| | Dry-season baseflow flow criteria scenarios (cfs) | | | | | |
|---|---|---|---|---|---|---|
| ***Water Year Type*** | **p99** | **p90** | **p75** | **p50** | **p25** | **p10** |
| *Dry* | 1.06 | 0.81 | 0.63 | 0.43 | 0.18 | 0.10 |
| *Moderate* | 2.39 | 1.77 | 1.42 | 1.15 | 0.86 | 0.52 |
| *Wet* | 4.17 | 2.75 | 2.22 | 1.95 | 1.60 | 1.24 |

**<u>Step 2- Construct a water allocation model</u>**

A watershed water allocation model was developed by the Stockholm Environmental Institute (SEI) using the Water Evaluation And Planning (WEAP) software platform. The WEAP model is a daily time-step water balance simulation model (Figure 4). Long-term daily streamflow inputs to each of 392 sub-watersheds are based on results from a physically-based hydrologic model for the watershed developed by consultants. The model includes water diversion points, permitted and unpermitted human water demands, off-stream storage reservoirs, and estimated return flows.

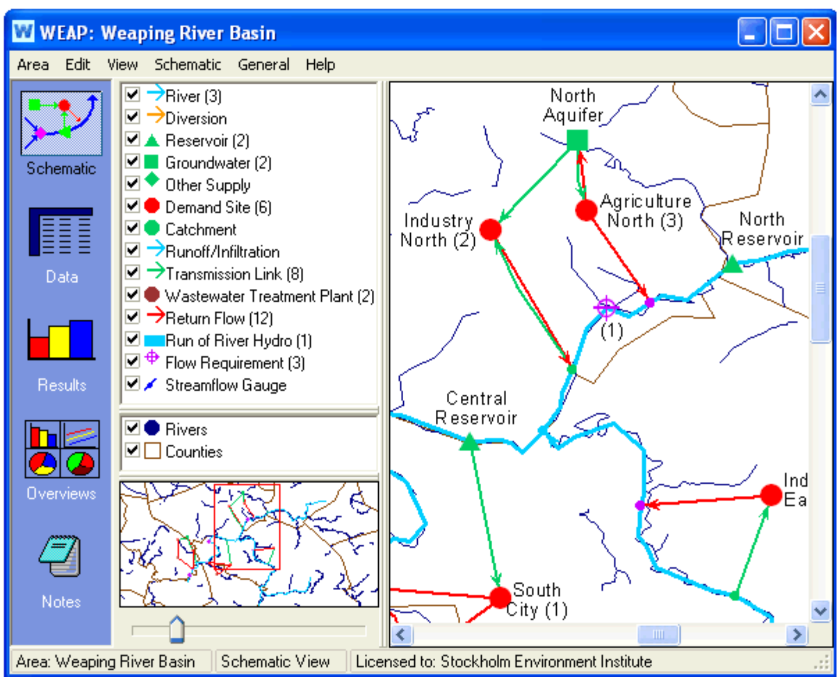

Figure 4. Example WEAP water allocation model interface.

**<u>Step 3- Define water management scenarios</u>**

A full set of management objectives is required to balance among competing uses for water, including an articulation of non-ecological objectives such as meeting municipal and agricultural water demands, generating hydropower, flood management, recreation, etc. In this application, the primary water management objective was to meet agricultural water demands. A stakeholder working group was convened to define water management scenarios of interest related to this objective. The scenarios were intended to evaluate uncertainty or sensitivity associated with water demands (diversion rate, timing, allocation priority, etc) and storage (capacity, timing, etc). Specifically, key water allocation model variables considered in scenario development included permitted water demands and storage volumes, estimated unpermitted cannabis demands and storage volumes, and water rights priorities. The water allocation model (Step 2) was run for numerous combinations of flow regime scenarios (Step 1) and water management scenarios.

## *Estimate consequences and evaluate tradeoffs*

### **Step 4- Evaluate human and ecological performance measures to assess tradeoffs**

Daily ecological performance measures were selected for the watershedto describe hydraulic habitat conditions relevant to juvenile steelhead rearing. Biological conditions were not used as direct performance measures to avoid likely influences of independent external controls and lag times on these measures. However, biological information is a critical component of adaptive management of environmental flow prescriptions and will be monitored along with flow. Human water supply performance was quantified using common metrics such as water supply reliability in volume and frequency, resilience and vulnerability.

A graphical user interface (GUI) is currently under development in collaboration with watershed stakeholders to provide a dynamic, user-friendly interface for water managers and stakeholders. Using the Tableau™ software program, the GUI  will allow users to compare and visualize tradeoffs through space and time under different *flow regime* and *water management* scenarios. A user can filter water allocation model results related to ecological and human performance measures by: LOI, period of interest (e.g. water month type, calendar month, date range), water right type (e.g. domestic, irrigation, etc.), and desired ecological outcome. Visualizations include stream network heat maps illustrating spatial patterns of ecological (stream lines) and human (sub-catchment polygons) performance, boxplots of performance measure distributions, and tradeoff curves of human - ecological performance across management scenarios. Figure 5 shows an example display from the GUI with drop-down options for stratifying ecological performance results by calendar month, water management scenario, flow regime scenario, LOI, and water year type.

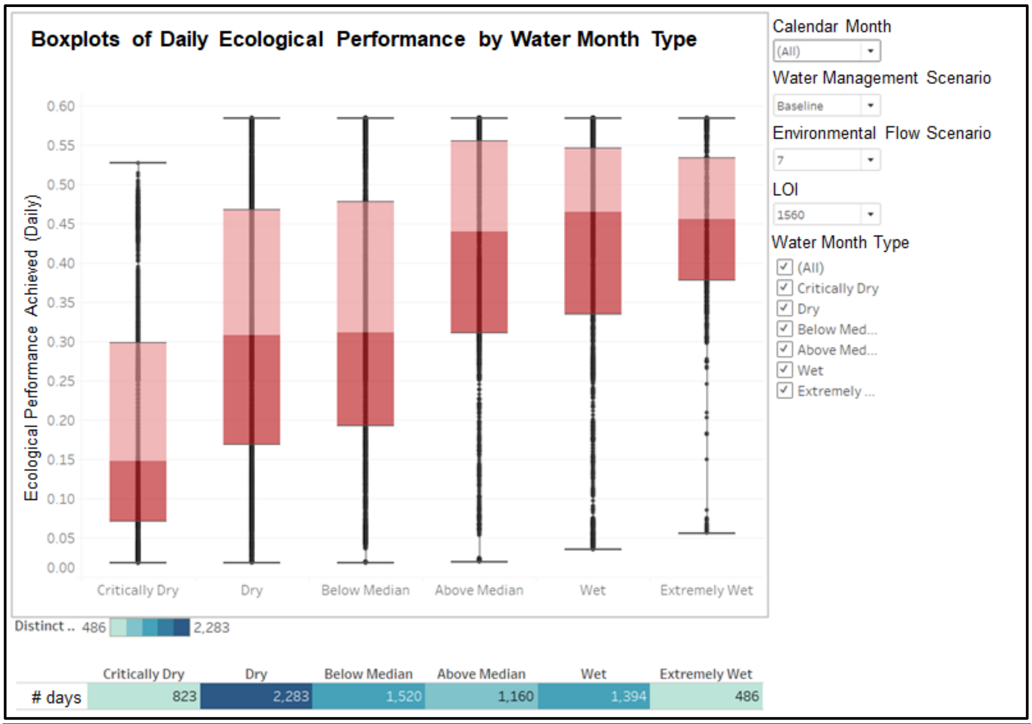


Figure 5 – Example results graphic from the GUI showing boxplots of daily ecological performance at a single LOI across water month types under a selected environmental flow regime and water management scenarios.

## References


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