California Environmental Flows Framework

California Environmental Flows Working Group,
a committee of the California Water Quality Monitoring Council

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For more information, please see:

https://mywaterquality.ca.gov/monitoring_council/environmental_flows_workgroup/index.html

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INTRODUCTION TO THE CALIFORNIA ENVIRONMENTAL FLOWS FRAMEWORK

Background

Multiple local, regional, and State agencies share responsibility for managing environmental flows, defined as the water required to protect the ecological health of California streams while balancing human uses and other water management objectives. The process of developing environmental flow recommendations is complex, often involving multi-component technical studies and lengthy public discussions that can take years to complete. Although many environmental flow assessment tools exist, managers are often constrained to using either time-intensive, site-specific studies or a limited set of rapid desktop and regional approaches that have not been tailored to California. Furthermore, environmental flow assessments have not always been consistently designed and implemented in a way that allows data to be aggregated and shared, making it difficult to accelerate learning and improve the effectiveness of environmental flows in supporting the ecological health of California's rivers and streams. Water managers need a consistent statewide approach that can help transform complex environmental data into scientifically defensible, easy-to-understand environmental flow recommendations that support a broad range of ecosystem functions[1] and preserve the multitude of benefits provided by healthy rivers and streams. Having a consistent statewide approach would also improve statewide data compatibility and promote coordinated regional flow assessments that would benefit multiple agency programs working to improve the scale and pacing at which environmental flow protections can be extended to rivers and streams across the state.

For decades, hydrologists have been working to understand the quantity, quality, and timing of flows needed to sustain the health of stream ecosystems. This work has helped advance the field toward more holistic approaches for setting flows that recognize the importance of flow variability and ecosystem functions. While it has long been known that changes in flows can have direct, predictable impacts on ecological condition, researchers increasingly have recognized the role of other factors in mediating the relationship between flow and ecology, including the physical form and structure of the stream channel, impairments to water quality, and biological interactions among species. As a result, scientists have been able to understand at a more holistic level how flows support physical, chemical, and biological functions of streams that, in turn, sustain ecosystem health. Despite these scientific advances, implementing environmental flows in a holistic manner faces significant obstacles. In most rivers, ecosystem water needs must be balanced with legal and regulatory requirements, public health and safety requirements, and social values and priorities for water, including other human uses. It is essential both to recognize these sociopolitical dimensions in the process of developing environmental flow recommendations, and also to clearly distinguish sociopolitical considerations from the underlying scientific process of assessing ecosystem water needs.

In 2017, a collaborative team of agency personnel, academic researchers, and non-governmental organization scientists from across the state formed an Environmental Flows Workgroup and began working on a common framework for determining ecosystem water needs that can be used to inform the development of environmental flow recommendations statewide. The goal of the workgroup was to develop a common, scientifically defensible approach that would enable

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[1] Ecosystem functions or processes are the dynamic actions supporting the biologic composition (individual species, communities), physical habitat (geomorphology and hydraulics), and water quality of a river (see Table 1.1).

managers from different agencies to incorporate their existing flow management tools and strategies, and that would be flexible enough to be used statewide. In 2018, the California Water Quality Monitoring Council recognized the workgroup as an official Council subgroup, which will help to ensure the framework is optimally positioned for adoption and use by the California agencies and other stakeholders. The California Environmental Flows Framework—as described in this report—should be viewed as a "living document" that will be updated periodically.

Framework overview and purpose

The California Environmental Flows Framework (hereafter the Framework) is a management approach that provides technical guidance to help managers efficiently develop scientifically defensible environmental flow recommendations that balance human and ecosystem needs for water. The Framework was developed to help managers improve the speed, consistency, standardization, and technical rigor in establishing environmental flow recommendations statewide. There are 12 steps in the Framework, which are divided into three main sections and encompass multiple tools and standardized methodologies. The key objectives of the Framework are to:

- Standardize, streamline, and improve transparency of environmental flow assessments
- Provide flexibility to accommodate diverse management goals and priorities
- Improve coordination and data sharing among management agencies and other stakeholders

The first two sections of the Framework support development of consistent, scientifically-supported ***ecological flow criteria*** – i.e., quantifiable metrics that describe ranges of flows that must be maintained within a stream and its margins to support the natural functions of healthy ecosystems. Upon this scientific foundation, users are then able to develop ***environmental flow recommendations*** that take human uses and other water management objectives into consideration. These environmental flow recommendations are expressed as a "rule set" of flow requirements that are informed by ecological flow criteria that satisfy ecosystem water needs, but also other water management objectives. Because the management contexts in which environmental flows may be established can vary substantially between sites, specific strategies for implementing recommendations are not prescribed by the Framework. Rather, general guidelines around best practices are offered to support successful implementation.

The expected user of the Framework is an individual or organization tasked with defining ecological flow criteria to inform environmental flow recommendations for a stream, watershed, or region. Thus, this Framework is intended to be used by scientists, agency personnel, non-governmental organizations, and local stakeholders working to develop environmental flow recommendations for streams in California. It may also be helpful in planning and prioritizing stream flow enhancement projects and environmental flow recovery efforts. The Framework does not establish, replace, or modify any specific agency requirements set forth under existing regulations.

Framework approach and organization

The technical approach of the Framework rests upon the scientific concept of ***functional flows*** – i.e., distinct aspects of a natural flow regime that sustain ecological, geomorphic, or biogeochemical functions, and that support the specific life history and habitat needs of native aquatic species (Yarnell et al. 2015). Most California streams have five functional flow components:

- **Fall pulse flow**: First major storm event at the end of dry season
- **Wet-season peak flows**: Coincides with the largest storms in winter
- **Wet-season baseflow**: Sustained by overland and shallow subsurface flow in the periods between winter storms
- **Spring recession flow**: Represents the transition from the wet to dry season and is characterized by a steady decline of flows over a period of weeks to months
- **Dry-season baseflow**: Sustained by groundwater inputs to rivers

Managing for these five functional flow components preserves essential patterns of flow variability within and among seasons, but it does not mandate either the restoration of full natural flows or maintenance of historical ecosystem conditions. Furthermore, a functional flows approach is not focused on the habitat needs of a particular species, but rather, is focused on identifying and preserving key ecosystem functions—such as sediment movement, water quality maintenance, and environmental cues for species migration and reproduction—that are necessary to maintain ecosystem health and that are broadly supportive of native freshwater plants and animals, including listed species.

The Framework is divided into three main sections that guide users through 12 steps (Figure 1.1). The first two sections lead to the identification of scientifically defensible ecological flow criteria in support of user-defined ecological management goals. The third section guides development of environmental flow recommendations using these flow criteria in combination with consideration of human water needs and other non-ecological management objectives:

- **SECTION A (Steps 1-4)**: Identify ecological flow criteria using natural functional flows

  Key question: *What are natural functional flows for my location of interest? What are the corresponding ecological flow criteria?*

  Section A provides ecological flow criteria for a study area (e.g., river, watershed, or region) based on predictions of the natural ranges of flow metrics (i.e., expected values in the absence of human activities) for each of five functional flow components (Table 1.1). It also provides guidance for determining if non-flow impairments – such as altered physical habitat, poor water quality, or invasive species – require further consideration because the natural range of functional flow metrics may fail to support desired functions.

- **SECTION B (Steps 5-7)**: Develop ecological flow criteria for each flow component requiring additional consideration

***Key question (as applicable)**: How do I use additional information to develop ecological flow criteria that accommodate physical and biological constraints?*

Section B provides guidance for determining ecological flow criteria for functional flow components that may be affected by non-flow impairments. This involves development of conceptual models, compiling data and information, and quantitative analyses to assess the relationship between functional flow components and ecosystem responses relevant to ecological management goals. The outcomes of the assessment are used to develop ecological flow criteria for functional flow components that were not addressed in Section A.

- **SECTION C (Steps 8-12)**: Develop environmental flow recommendations

  ***Key question**: How do I reconcile my ecological flow criteria with non-ecological management objectives to create environmental flow recommendations?*

  Section C provides guidance on balancing ecological flow criteria with competing management objectives to develop a final set of environmental flow recommendations. This involves assessing flow alteration to inform management strategies and balancing ecological and non-ecological management objectives through tradeoff analyses. Additional guidance is provided for adaptively managing environmental flows, monitoring outcomes, and implementing environmental flow recommendations.

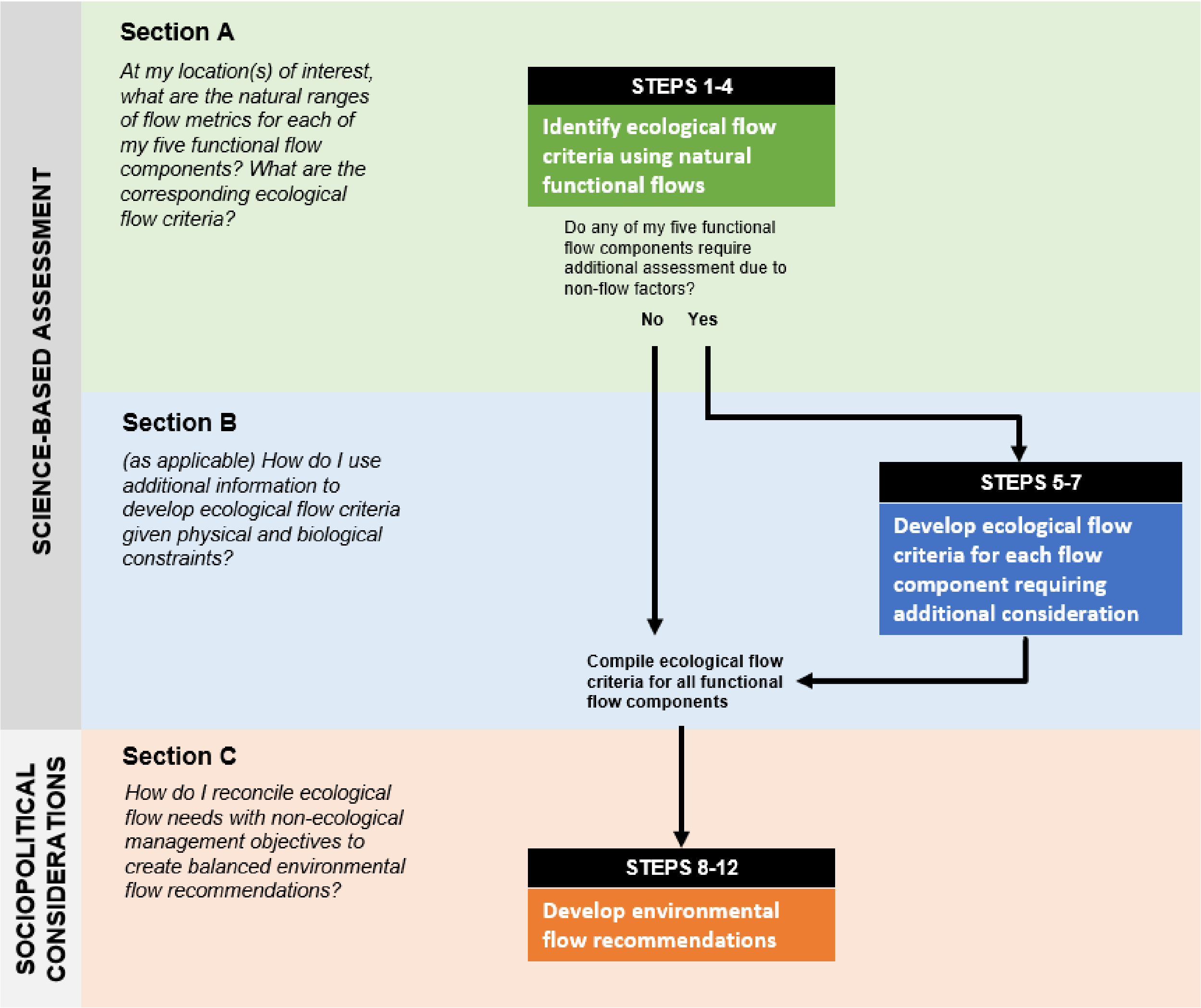

Figure 1.1. An overview of three sections and 12 steps of the California Environmental Flows Framework, with the key questions that get answered by the end of each section.

Table 1.1. List of functional flow metrics associated with each of the five natural functional flow components for California. Functional flow metrics describe the magnitude, timing, duration, frequency, and/or rate of change of flow for each of the functional flow components.

Functional Flow Component	Flow Characteristic	Functional Flow Metric
Fall pulse flow	Magnitude (cfs)	Peak magnitude of fall season pulse event (maximum daily peak flow during event)
	Timing (date)	Start date of fall pulse event
	Duration (days)	Duration of fall pulse event (# of days start-end)
Wet-season baseflow	Magnitude (cfs)	Magnitude of wet season baseflow and median flow (the 10th and 50th percentile of daily flows, respectively, during the wet season, including peak flow events)
	Timing (date)	Start date of wet season
	Duration (days)	Wet season baseflow duration (# of days from start of wet season to start of spring season)
Wet-season peak flows	Magnitude (cfs)	Peak flow magnitude (annual peak flows for 2-, 5-, and 10-year recurrence intervals)
	Duration (days)	Duration of peak flows over wet season (number of days in which a given peak-flow recurrence interval is exceeded in a year)
	Frequency	Frequency of peak flow events over wet season (number of times in which a given peak-flow recurrence interval event occurs in a year)
Spring recession flow	Magnitude (cfs)	Spring peak magnitude (daily flow on start date of spring recession-flow period)
	Timing (date)	Start date of spring recession (date)
	Duration (days)	Spring flow recession duration (# of days from start of spring to start of summer base flow period)
	Rate of change (%)	Spring flow recession rate (percent decrease per day over spring recession period)
Dry-season baseflow	Magnitude (cfs)	Magnitude of dry season baseflow and high baseflow (the 50th and 90th percentile of daily flows, respectively, during the dry season)
	Timing (date)	Dry season start timing (start date of dry season)
	Duration (days)	Dry season baseflow duration (# of days from start of dry season to start of wet season)

The hypothesis underlying Section A is that natural ranges of flow metrics for each of the five functional flow components will support multiple ecosystem functions (described in the “Primer on Functional Flows in California Rivers” section and Table 1.2 below) and satisfy the habitat needs of native freshwater and riparian species. Therefore, the natural ranges of functional flow metrics are used as the starting point for defining ecological flow criteria. However, certain forms of physical habitat alteration, water quality impairment, and biological interactions may make natural ranges for these flow metrics less effective in supporting ecosystem functions. For example, natural peak flows may not inundate floodplains if the channel is deeply incised, and thus the functions associated with floodplain inundation (e.g., fish breeding and riparian seed dispersal) may not be supported. Similarly, high stream temperatures resulting from riparian vegetation loss may limit the functionality of a summer baseflow for fish rearing if the temperatures exceed suitability thresholds. In such cases, affected functional flow components are subject to further analysis in Section B, resulting in potential revisions to ecological flow criteria that take into account the altered stream condition and thus may deviate from natural ranges of functional flow metrics. When these criteria from Section B are combined with the ecological flow criteria developed in Section A, the user obtains a full set of ecological flow criteria for all five functional flow components.

For planning applications, or where non-flow limiting factors are not a concern, the user may only need to implement the steps in Section A to obtain ecological flow criteria for their study area. The Section A ecological flow criteria can be readily translated into environmental flow recommendations in Section C and, in many cases, will help avoid resource-intensive, site-specific flow studies. In areas with non-flow limiting factors, such as altered water quality and/or physical conditions, Section B of the Framework offers a structured approach for developing a consistent, scientifically defensible set of ecological flow criteria for translation into environmental flow recommendations in Section C. Section C then provides general guidelines for how to develop environmental flow recommendations and implementation strategies.

A Primer on Functional Flows in California Rivers

River ecosystems are shaped by the dynamic interaction between flowing water and the landscape. As flows rise and fall in response to seasonal rainfall and snowmelt runoff, rivers expand and contract, temporarily inundating banks and adjacent floodplains and then receding back into their channels. High and moderate flows move sediment and wood, modifying stream channels and creating structural complexity that supports numerous plant and animal species. As flows recede into the dry season, waters warm and become more productive, stimulating plant growth and creating food for insects, fish, and birds. These predictable seasonal changes in flows also provide cues to native aquatic and riparian species for migration, breeding, rearing, and seed dispersal. Functional flows are those aspects of the flow regime that support stream processes and collectively maintain stream ecosystem health (Grantham et al. 2020).

The functionality of flows—the ability of streamflow to provide discrete ecosystem functions—is mediated by three principal factors: physical habitat, water quality, and biological interactions (Figure 1.2). Flow interacts with the stream channel morphology (i.e., channel type, size, shape, slope, and substrate) to create and maintain a nested hierarchy of physical habitats (Frissell et al. 1986) through geomorphic processes such as sediment transport, scour, deposition, and floodplain connectivity (Escobar-Arias and Pasternack 2010; Wohl et al. 2015). Together with flow, physical habitat provides the stream conditions necessary for native species to survive, grow, migrate, and reproduce. Water quality also affects the health of aquatic ecosystems and impacts the number and distribution of species in a stream (Nilsson and Renöfält 2008; Vidon et al. 2010). Flow has a dominant influence on temperature, dissolved oxygen, and concentrations of sediment and chemical constituents, including salts, nutrients, and contaminants, which directly affect the health and survival of aquatic species (Yarnell et al. 2015). Flow influences ecosystem processes that control water quality, including nutrient cycling (e.g., Ahearn et al. 2006) and primary production (e.g., Power et al. 2008). The effects of flow on ecosystem functions are likewise mediated by biological interactions. For example, wet season peak flows have been shown to influence the structure of aquatic food webs in the following dry season, affecting primary production and food availability for salmon and other predatory fish species (Power et al. 2008). Invasive species can further alter ecosystem functions, as shown for example by studies on the impacts of invasive bullfrogs in streams. Bullfrog tadpoles can outcompete native amphibian tadpoles by consuming large proportions of benthic algae and altering the dynamics of primary productivity in streams (Kupferberg 1997), while adult bullfrogs increase the prevalence of disease that can decimate susceptible native amphibians (Adams et al. 2017). Collectively, functional flows interact with physical habitat, water quality, and biological processes to sustain the ecosystem functions that ultimately control the structure and health of ecological communities (Figure 1.2).

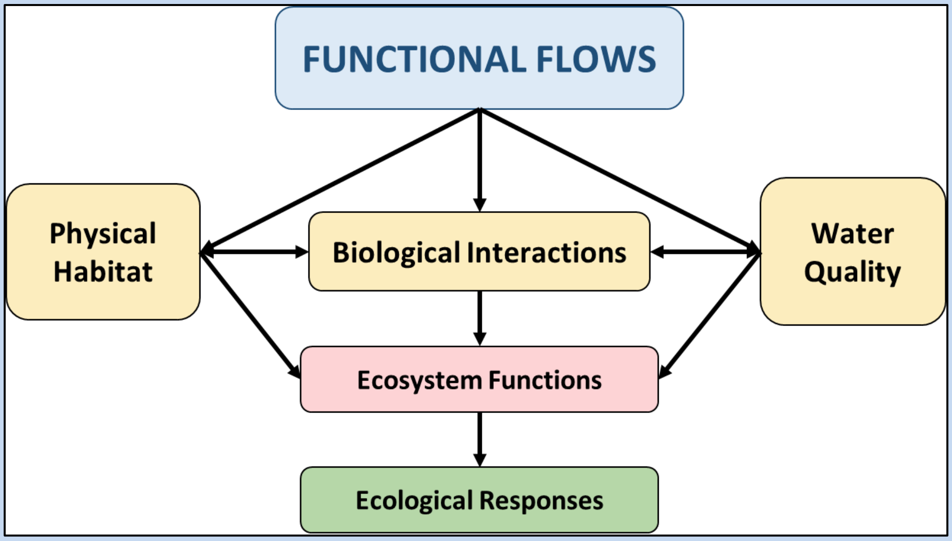

Figure 1.2. Conceptual model demonstrating relationships between functional flows (blue) and ecological responses[2] as mediated by factors such as physical habitat, water quality, and biological interactions (yellow). Together, these interacting relationships support ecosystem functions (pink) that control ecological responses (green) and sustain healthy river and stream ecosystems. Adapted from Poff et al. 1997.

Functional Flow Components

Unlike other environmental flow approaches that focus on single species management, a functional flows approach to freshwater ecosystem management focuses on those components of the flow regime that support key ecosystem functions (Yarnell et al. 2015; Grantham et al. 2020). Five key functional flow components have been identified by Yarnell et al. (2020) for California's rivers and streams (Figure 1.3). Each functional flow component supports several critical physical, biogeochemical, and biological functions

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[2] Ecological responses are the changes in ecological conditions that result from changes in streamflow through its effects on physical habitat, water quality, and/or biological interactions. Ecological responses can be assessed through the use of flow-ecology relationships, which are discussed further in Section B, Step 6.

that maintain stream ecosystem health and satisfy life history requirements of native species. These ecosystem functions are briefly summarized below (see Table 1.1 for more detailed descriptions of the ecosystem functions supported by each of the five functional flow components):

- The ***fall pulse flow*** flushes fine sediment and organic material from stream channels, increases river corridor connectivity, and rewets riparian zones. As the hyporheic zone (the stream channel bed and underlying sediments) is reactivated, exchange of nutrients occurs both vertically and laterally, increasing nutrient cycling. Water quality conditions are improved with reduced temperatures and increased dissolved oxygen, while lower salinity in estuaries and increased streamflow signal native fish species to migrate upstream or spawn.

- ***Wet-season peak flows*** maintain and restructure river corridors by scouring the river channel bed and banks and transporting substantial volumes of sediment and large wood. Inundation of the floodplain recharges groundwater increases nutrient cycling and the exchange of nutrients between the river channel and floodplain, and provides breeding and rearing habitat for native fish. These flood disturbances within the channel and floodplain reset riparian succession and limit the establishment of non-native species, increasing native plant biodiversity through time.

- The ***wet-season baseflow*** supports longitudinal connectivity through the river network for fish migration and replenishes shallow groundwater in the riparian zone. Higher wet season baseflows support increased hyporheic exchange and salmonid egg incubation within riverbed gravels.

- The ***spring recession flow*** prolongs lateral and longitudinal connectivity into the dry season, recharging groundwater, redistributing sediment within the river channel, and maintaining cooler water temperatures. The gradual reduction in flow creates a shifting mosaic of hydraulic conditions that supports high habitat diversity and resulting aquatic species diversity. The spring recession further provides reproductive and migratory cues for both aquatic and riparian species, such as cues for amphibian spawning, fish outmigration, and riparian plant seed dispersal and germination.

- The ***dry-season baseflow*** is critical for maintaining aquatic habitat for native species through the summer period, not just in perennial streams, but also in intermittent streams where contracted habitat conditions support native predators and limit non-native species less tolerant of naturally low warm flows or periods of no flow in the dry season.

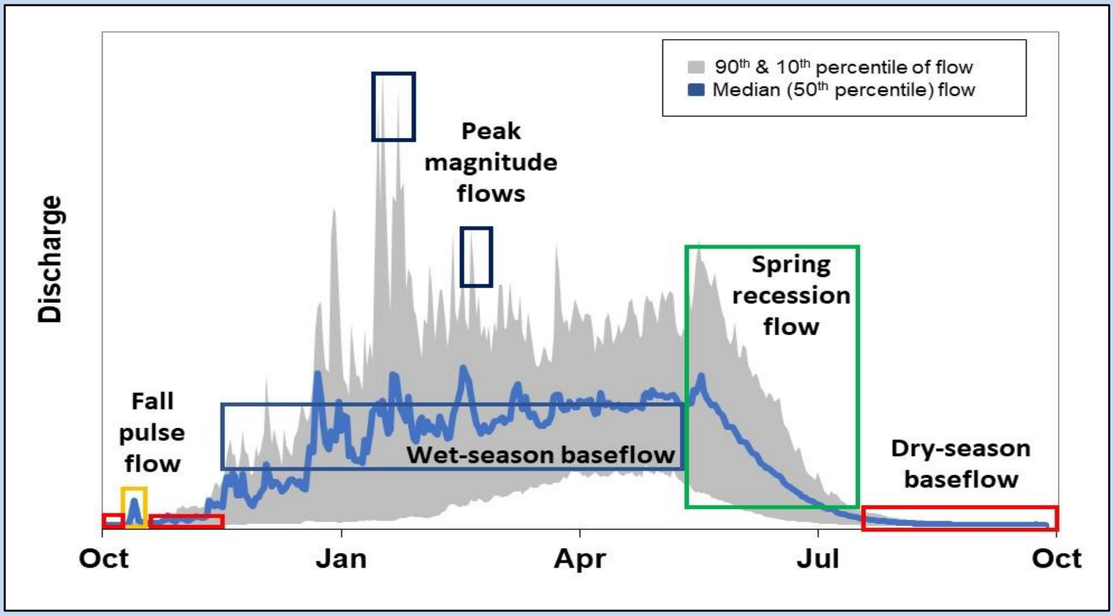


Figure 1.3. Functional flow components for California depicted on a representative hydrograph. Blue line represents median (50th percentile) daily discharge. Gray shading represents 90th to 10th percentiles of daily discharge over the period of record.

Although the five natural functional components of flows are the same for all of California's rivers, their flow characteristics – magnitude, timing, frequency, duration, and rate of change – vary regionally. For example, the spring recession flow component will have a larger magnitude and longer duration for rivers in the Sierra Nevada than for rivers in the South Coast. Characteristics of the functional flow components also vary by water year type (e.g., wet, moderate, dry conditions). Thus, the functional flow components can be quantified by a suite of ***functional flow metrics***—quantitative measures of the flow characteristics of each of the five functional flow components—that reflect the natural diversity in flow characteristics throughout the state (Table 1.2; Yarnell et al. 2020; Appendix A).

Based on a natural streamflow classification for California that categorizes the diversity of flow regimes throughout the state (Lane et al. 2018; Appendix B), functional flow metrics can be calculated for any annual hydrograph using algorithms developed by Patterson et al. (2020; Appendix C).

Table 1.2. Descriptions of the ecosystem functions that are supported by each of the five components of functional flows and the corresponding references in the scientific literature. References listed specifically link the associated flow characteristic with the ecosystem function.

Functional Flow Component	Type of Ecosystem Function	Supported Ecosystem Function	Associated Flow Characteristic	References
Fall Pulse Flow	Physical	Flush fine sediment and organic material from substrate	magnitude	Postel and Richter 2003; Kemp et al. 2011
		Increase longitudinal connectivity	magnitude, duration	Grantham 2013
		Increase riparian soil moisture	magnitude, duration	Stubbington 2012
	Biogeochemical	Flush organic material downstream and increase nutrient cycling	magnitude, duration	Ahearn et al. 2006
		Modify salinity conditions in estuaries	magnitude, duration	Postel and Richter 2003
		Reactivate exchanges/connectivity with hyporheic zone	magnitude, duration	Stubbington 2012
		Decrease water temperature and increase dissolved oxygen	magnitude, duration	Yarnell et al. 2015
	Biological	Support fish migration to spawning areas	magnitude, timing, rate of change	Sommer et al. 2011; Kiernan et al. 2012
Wet-season Baseflow	Physical	Increase longitudinal connectivity	magnitude, duration	Grantham 2013; Yarnell et al. 2020
		Increase shallow groundwater (riparian)	magnitude, duration	Vidon et al. 2010
	Biogeochemical	Support hyporheic exchange	magnitude, duration	Stubbington 2012
	Biological	Support migration, spawning, and residency of aquatic organisms	magnitude	Grantham 2013
		Support channel margin riparian habitat	magnitude	Vidon et al. 2010
Wet-season Peak Flows	Physical	Scour and deposit sediments and large wood in channel and floodplains and overbank areas.	magnitude, duration, frequency	Ward 1998; Florsheim and Mount 2002; Escobar-Arias and

		Encompasses maintenance and rejuvenation of physical habitat.		Pasternack 2010; Wheaton et al. 2010; Senter et al. 2017
		Increase lateral connectivity	magnitude, duration	Ward 1998, Cienciala and Pasternack 2017
		Recharge groundwater (floodplains)	magnitude, duration	Opperman et al. 2017
	Biogeochemical	Increase nutrient cycling on floodplains	magnitude, duration	Ahearn et al. 2006
		Increase exchange of nutrients and organic matter between floodplains and channel	magnitude, duration	Ahearn et al. 2006
	Biological	Support fish spawning and rearing in floodplains and overbank areas	magnitude, duration, timing	Jeffres et al. 2008; Opperman et al. 2017
		Support plant biodiversity via disturbance, riparian succession, and extended inundation in floodplains and overbank areas	magnitude, duration, frequency	Ward 1998; Shafroth et al. 1998; Opperman et al. 2017
		Limit vegetation encroachment and non-native aquatic species via disturbance	magnitude, frequency	Petts and Gurnell 2013; Kiernan and Moyle 2012; Poole and Berman 2001
Spring Recession Flow	Physical	Sorting of sediments via increased sediment transport and size selective deposition	magnitude, rate of change	Hassan et al. 2006; Ashworth 1996; Madej 1999
		Recharge groundwater (floodplains)	magnitude, duration	Opperman et al. 2017
		Increase lateral and longitudinal connectivity	magnitude, duration	Ward and Stanford 1995
	Biogeochemical	Decrease water temperatures and increase turbidity	duration, rate of change	Leland 2003
		Increase export of nutrients and primary producers from floodplain to channel	magnitude, duration, rate of change	Bowen et al. 2003; Ward and Stanford 1995

	Biological	Provide hydrologic cues for fish outmigration and amphibian spawning; support juvenile fish rearing	magnitude, timing, rate of change	Freeman et al. 2001; Medley and Shirey 2013; Yarnell et al. 2010
		Increase hydraulic habitat diversity and habitat availability resulting in increased algal productivity, macroinvertebrate diversity, arthropod diversity, fish diversity, and general biodiversity	magnitude, timing, rate of change, duration	Lambeets et al. 2008, Pastuchova et al. 2008; Peterson et al. 2001; Propst and Gido 2004
		Provide hydrologic conditions for riparian species recruitment (e.g. cottonwood)	magnitude, timing, rate of change, duration	Shafroth et al. 1998; Rood et al. 2005; Stella et al. 2006; Mahoney and Rood 1998
		Limit riparian vegetation encroachment into channel	magnitude, rate of change	Lind et al. 1996; Shafroth et al. 2002
Dry-season Baseflow	Physical	Maintain riparian soil moisture	magnitude, duration	Postel and Richter 2003
		Limit longitudinal connectivity in ephemeral streams; limit lateral connectivity to disconnect floodplains	magnitude, duration, timing	Lee and Suen 2012; Beller et al. 2011
		Maintain longitudinal connectivity in perennial streams	magnitude	Kiernan and Moyle 2012
	Biogeochemical	Maintain water temperature and dissolved oxygen	magnitude, duration	Yarnell et al. 2015
	Biological	Maintain habitat availability for native aquatic species (broadly)	magnitude, timing, duration	Postel and Richter 2003; Yarnell et al. 2016; Kupferberg et al. 2012
		Condense aquatic habitat to limit non-native species and support native predators	magnitude, duration	Lee and Suen 2012; Kiernan and Moyle 2012; Postel and Richter 2003
		Support primary and secondary producers	magnitude	Power et al. 2008; Yarnell et al. 2015

SECTION A – IDENTIFY ECOLOGICAL FLOW CRITERIA USING NATURAL FUNCTIONAL FLOWS

Overview

The goal of Section A is to identify ecological flow criteria—expressed as metrics describing the magnitude, timing, duration, frequency, and/or rate-of-change for five functional flow components—that must be maintained to support healthy stream ecosystems in California (Figure 2.1). These ecological flow criteria are based on functional flow metric values expected to occur in the absence of existing and historic human activities (see Table 1.1 for an overview of the functional flow metrics). The predicted, natural values of functional flow metrics can be obtained from the California Natural Flows Database for locations of interest in any stream or river in the state. Stakeholders—referred to as "the user" hereafter—then evaluate whether the range of natural values for each functional flow component may fail to support ecosystem functions due to the alteration of physical, biological, or water quality factors. The outcome of that analysis determines whether the user selects ecological flow criteria for the five flow components based on predicted natural flows and proceeds to Section C to develop environmental flow recommendations, or proceeds to Section B to develop ecological flow criteria for the subset of functional flow components for which natural flows are unlikely to support essential ecosystem functions.

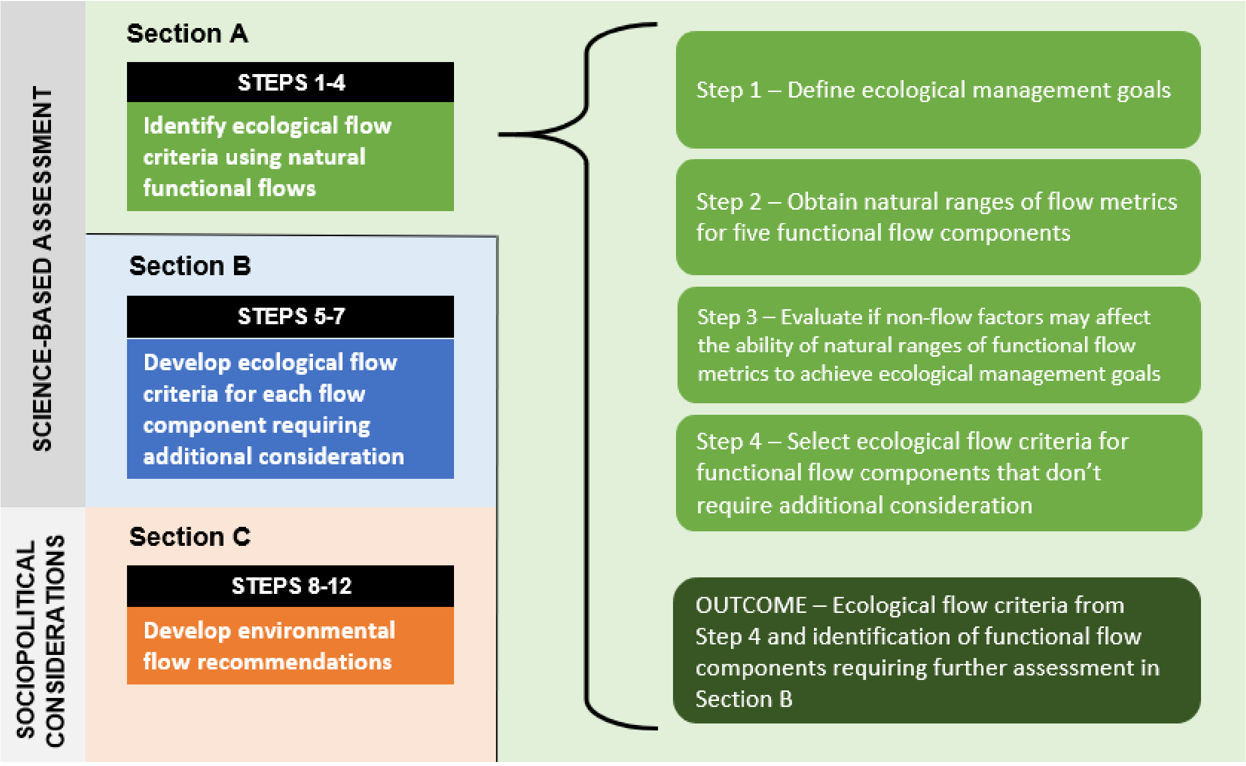
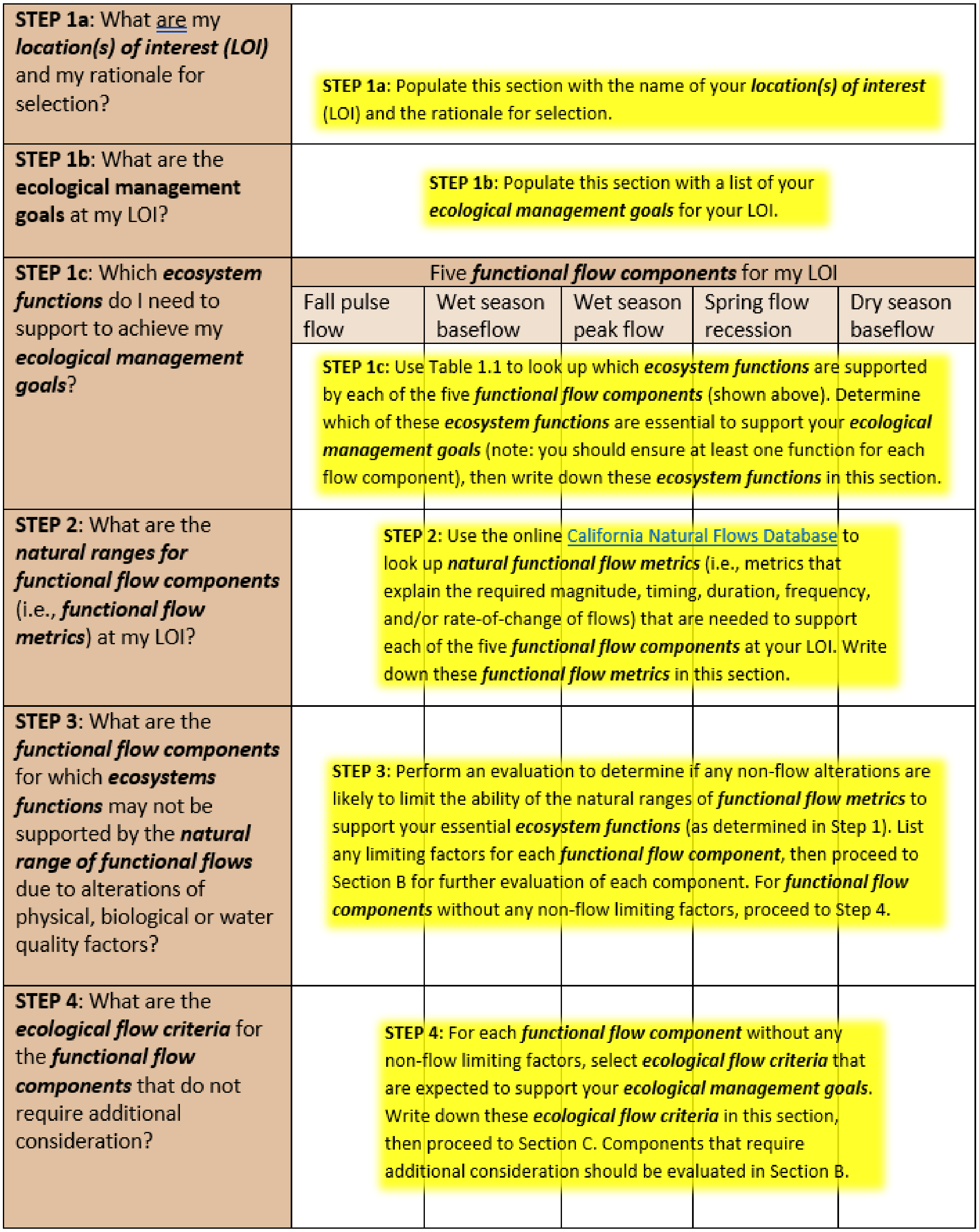


Figure 2.1. Steps in Section A of the California Environmental Flows Framework.

Section A has four steps (Figure 2.1). In Step 1, the user defines the study area and locations of interest (LOIs) for establishing flow criteria, specifies ecological management goals, and identifies the specific ecosystem functions that must be supported by ecological flow criteria to satisfy those goals. In Step 2, the user characterizes natural functional flows at their LOIs by obtaining predictions of the natural ranges of flow metrics from the California Natural Flows Database or locally calibrated hydrologic model. In Step 3, the user evaluates whether there are any physical, biological, or water quality factors that may limit the ability of natural functional flows to support ecosystem functions. If non-flow factors may limit the effectiveness of the natural range of flow metrics to support ecosystem functions for any flow component, further analysis is required in Section B to define ecological flow criteria for these focal flow components. In Step 4, the user selects ecological flow criteria based on the predicted natural flow ranges for the functional flow components that do not require additional consideration. A sample worksheet is provided in Figure 2.2 to illustrate what types of information are gathered in Section A and how the information is linked in each step.



<table>
<tr><td>STEP 1a: What are my <i>location(s) of interest (LOI)</i> and my rationale for selection?</td><td colspan="5">STEP 1a: Populate this section with the name of your <i>location(s) of interest</i> (LOI) and the rationale for selection.</td></tr>
<tr><td>STEP 1b: What are the ecological management goals at my LOI?</td><td colspan="5">STEP 1b: Populate this section with a list of your <i>ecological management goals</i> for your LOI.</td></tr>
<tr><td rowspan="3">STEP 1c: Which <i>ecosystem functions</i> do I need to support to achieve my <i>ecological management goals</i>?</td><td colspan="5">Five <i>functional flow components</i> for my LOI</td></tr>
<tr><td>Fall pulse flow</td><td>Wet season baseflow</td><td>Wet season peak flow</td><td>Spring flow recession</td><td>Dry season baseflow</td></tr>
<tr><td colspan="5">STEP 1c: Use Table 1.1 to look up which <i>ecosystem functions</i> are supported by each of the five <i>functional flow components</i> (shown above). Determine which of these <i>ecosystem functions</i> are essential to support your <i>ecological management goals</i> (note: you should ensure at least one function for each flow component), then write down these <i>ecosystem functions</i> in this section.</td></tr>
<tr><td>STEP 2: What are the <i>natural ranges for functional flow components</i> (i.e., <i>functional flow metrics</i>) at my LOI?</td><td colspan="5">STEP 2: Use the online California Natural Flows Database to look up <i>natural functional flow metrics</i> (i.e., metrics that explain the required magnitude, timing, duration, frequency, and/or rate-of-change of flows) that are needed to support each of the five <i>functional flow components</i> at your LOI. Write down these <i>functional flow metrics</i> in this section.</td></tr>
<tr><td>STEP 3: What are the <i>functional flow components</i> for which <i>ecosystems functions</i> may not be supported by the <i>natural range of functional flows</i> due to alterations of physical, biological or water quality factors?</td><td colspan="5">STEP 3: Perform an evaluation to determine if any non-flow alterations are likely to limit the ability of the natural ranges of <i>functional flow metrics</i> to support your essential <i>ecosystem functions</i> (as determined in Step 1). List any limiting factors for each <i>functional flow component</i>, then proceed to Section B for further evaluation of each component. For <i>functional flow components</i> without any non-flow limiting factors, proceed to Step 4.</td></tr>
<tr><td>STEP 4: What are the <i>ecological flow criteria</i> for the <i>functional flow components</i> that do not require additional consideration?</td><td colspan="5">STEP 4: For each <i>functional flow component</i> without any non-flow limiting factors, select <i>ecological flow criteria</i> that are expected to support your <i>ecological management goals</i>. Write down these <i>ecological flow criteria</i> in this section, then proceed to Section C. Components that require additional consideration should be evaluated in Section B.</td></tr>
</table>

Figure 2.2. Sample worksheet providing a conceptual overview of the key pieces of information that are gathered during each step of Section A. An example of a completed worksheet is provided at the end of Section A (Figure A.4).

Step 1: Define ecological management goals

Objective: *To identify ecological management goals for the study area and the corresponding ecosystem functions that must be supported by ecological flow criteria to satisfy those goals*

First, the user identifies their study area, which should be defined by watershed boundaries and could include multiple watersheds, a single watershed, or a subwatershed.[3] Ecological management goals, which can be broad or qualitative in nature, for the study area should then be specified. An assumption under the Framework is that the protection of general stream ecosystem health will always be an overarching ecological management goal and that maintenance of ecosystem functions associated with each of the functional flows components will be required. However, ecological management goals can also express more specific objectives that ecological flow criteria are intended to achieve. For example, goals may include supporting the habitat and life history requirements of native fish species or maintaining freshwater macroinvertebrate communities in good condition. When developing goals, the user should also address legal requirements for listed species, water quality, or other biological objectives expressed in applicable policies and regulations.

Next, the user identifies LOIs on which subsequent analyses will be performed. The Framework requires that LOIs be specified at the stream-reach scale, defined by the USGS National Hydrography Dataset Plus, medium resolution, version 2 (NHD). The NHD is a representation of California's stream network that includes over 100,000 unique stream reaches. Stream reaches vary in size but are, on average, 2 km long. The LOIs selected by the user might include locations with:

- a monitoring station, such as a streamflow gage
- the outlet of a river basin
- an infrastructure feature, such as point of diversion, discharge, or dam outlet
- a zone of ecological sensitivity, such as spawning reaches or critical habitat for listed species

The selected LOIs might also include a set of reaches that are a representative sample of stream classes within the study area (Lane et al. 2017; see also Appendix B). At the end of Step 1, the user creates a study area map, depicting watershed boundaries, the stream network, and all LOIs.

Finally, the user identifies the specific ecosystem functions that must be supported by ecological flow criteria to achieve ecological management goals. Table 1.2 documents a wide variety of physical, biogeochemical, and biological functions associated with each functional flow component, such as maintenance of fish spawning and rearing habitat, hydrologic connectivity, sediment mobilization, and suitable dissolved oxygen and temperature levels. Under the Framework, all functional flow components must be maintained to achieve ecological management objectives. Therefore, the user should identify at least one ecosystem function in

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[3] We use the terms watershed and sub-watershed throughout this document to refer to discrete portions of the landscape that drain to a common water body or river. These terms are used interchangeably with basin and sub-basin, and do not refer to a specific size or scale.

Table 1.2 for each of the five functional flow components that are relevant to their ecological management goals. This will help to ensure that the assessment considers the many functions that flows support throughout the year to maintain ecosystem health.

Outcome of Step 1

- A well-defined study area accompanied by a written description and map with watershed boundaries, the stream network, and LOIs (stream reaches)
- A list of LOIs with a short description of why they were selected
- A list of ecological management goals
- A list of ecosystem functions (associated with each functional flow component) that must be supported by ecological flows to achieve ecological management goals

Example: Coastal Watershed in Northern California

In this hypothetical example, the study area encompasses a watershed in northern California (Figure A.1). The watershed is 150 km^2 in area and encompasses a stream network that is 200 km in total length. Two locations of interest have been identified in the study area, including one located at a long-term flow gage (Figure A.1; Table A.1). Another LOI was selected at the outlet of a tributary stream that is known to support high-quality salmon spawning and rearing habitat.

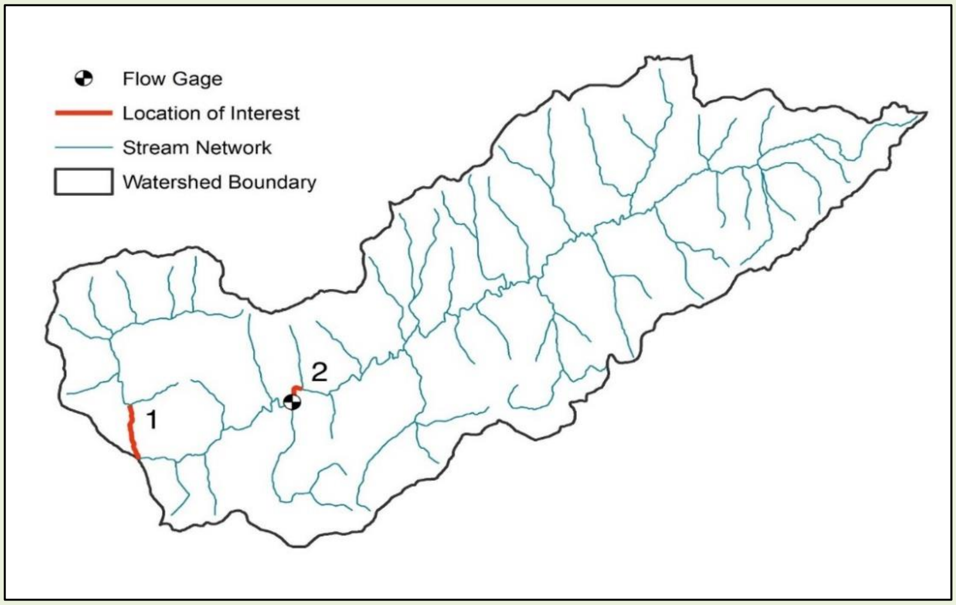

Figure A.1. Map of hypothetical study area in a north coast California watershed, highlighting two locations of interest (red stream segments) and a flow gage.

Table A.1. Locations of interest for study area.

Location of Interest	Reason for Selecting
1	Stream reach on tributary to mainstem river known to support high-quality salmon spawning and rearing habitat
2	Stream reach with long-term flow gage at which flow alteration can be assessed and environmental flow implementation monitored

The overall ecological management goal for the study area is to preserve stream health to sustain salmon populations. Specific goals are to maintain juvenile salmon rearing habitat and to protect passage flows for adult migration and smolt outmigration (Table A.2).

Table A.2. Ecological management goals.

Goals
Maintain stream ecosystem health
Maintain suitable habitat conditions for juvenile salmon rearing
Preserve passage flows during adult salmon migration and smolt outmigration

Using Table 1.2, a set of ecosystem functions needed to achieve ecological management goals was selected from each of the five functional flow components (Table A.3).

Table A.3. Ecosystem functions that must be supported by ecological flows to satisfy ecological management goals in the study area.

Functional Flow Component	Ecosystem Function(s)
Fall pulse flow	Flush fine sediment and organic material from substrate, increase longitudinal hydrologic connectivity, increase nutrient cycling, decrease water temperature and increase dissolved oxygen, trigger fish migration
Wet-season baseflow	Maintain longitudinal hydrologic connectivity, support hyporheic exchange, support riparian habitat along channel margins, support fish migration and spawning
Wet-season peak flows	Scour and deposit sediment and large wood in channel and overbank zones, increase lateral hydrologic connectivity, support riparian vegetation diversity and health through disturbance and overbank inundation, limit non-native species and in-channel vegetation encroachment through disturbance and displacement
Spring recession flow	Provide hydrologic cues for fish spawning and out-migration, support juvenile fish rearing, maintain hydraulic habitat diversity that supports diversity of aquatic plants and animals
Dry-season baseflow	Limit warming of water, concentration of contaminants, and low dissolved oxygen, support algal growth and primary productivity, maintain habitat availability and connectivity for aquatic species

Step 2: Obtain natural ranges for functional flow metrics

Objective: *To download natural functional flow metrics and characterize natural functional flow components at locations of interest*

Natural functional flow metrics can be viewed and downloaded at the California Natural Flows Database for any stream segment in the state. Metrics are quantified as a range of values expected to occur at LOIs under natural conditions over a long-term period of record (10 or more years). The range of predicted metric values is defined by quantiles (the 10th, 25th, 50th, 75th, and 90th percentiles below which predicted values fall). In addition to reporting the expected range of values for each metric across all years, predictions are also provided for wet, moderate and dry water year types.[4]

How the California Natural Flows Database was developed

Statewide models have been developed to predict natural functional flows (Table 1.1) for all stream reaches in California. The models rely on streamflow data from reference gages in California located on streams with minimal disturbance to natural hydrology and land cover (Falcone et al. 2010). Functional flow metrics were calculated at each reference gage from daily flow values, using algorithms described by Patterson et al. (2020; Appendix C) based on the natural streamflow classification for California (Lane et al. 2018; Appendix B). Separate statistical models were then developed for each functional flow metric, using machine learning methods to relate functional flow metric values to watershed characteristics, following the approach described by Zimmerman et al. (2018). Additional details of the modeling approach, input data, and performance evaluation are provided in Appendix D.

Once downloaded, the natural functional flow metrics should be summarized by flow component. In the example below, natural flow metrics at a location of interest indicate that the fall pulse flow is an event in which flows reach between 30 and 180 cfs for a period 2 to 7 days between October 7 and October 28 (Table A.4). At this location, the natural dry season baseflow period starts around June 20 (June 5-July 7), lasts for 151 (121 - 183) days and has a magnitude of 10 (7-15) cfs. It may be helpful to plot predicted component ranges in relation to hydrographs from a reference gage at or near LOIs (Figure A.2).[5]

If the user has a hydrologic model for their watershed, it may be preferable to calculate natural functional flow metrics from the locally calibrated model. Functional flow metrics can be calculated from time series of simulated daily flow timeseries of natural stream flow using the functional flow calculator (Appendix K). Predicted values of the functional flow metrics should be compiled in a format similar to that provided by the California Natural Flows Database before proceeding to Step 3.

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[4] Water year types have been defined for all years between 1950-2015 at all stream segments by partitioning the range of predicted natural mean annual flow into terciles, reflecting dry (lower 33% of values), moderate (34%-65% of values), and wet (upper 33% of values) conditions.

[5] Tools for exploring and visualizing flow data from California reference gages are available at https://eflows.ucdavis.edu

Outcome of Step 2

- A table of natural functional flow metric values associated with each functional flow component for each LOI, downloaded from the California Natural Flows Database or calculated from a locally calibrated hydrologic model.

Example: Coastal Watershed in Northern California

In Step 2, natural functional flow metric predictions are obtained for LOIs within the study area. These data should be downloaded at rivers.codefornature.org and compiled in a table for each LOI (Table A.4). These data can also be visualized graphically (Figure A.2).

Table A.4. Example of predicted flow metric values for five functional flow components (at location of interest 2), obtained from the California Natural Flows Database. Note: 16 of 24 natural functional flow metrics are included here for simplicity.

Flow Component	**Flow Metric**	**Predicted Range at LOI 1** median (10th - 90th percentile)	**Predicted Range at LOI 2** median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	9 (3 - 40) cfs	62 (30-180) cfs
	Fall pulse timing	Oct 19 (Oct 7 - Oct 29)	Oct 20 (Oct 7 - Oct 28)
	Fall pulse duration	3 (2 - 7) days	3 (2 - 7) days
Wet-season baseflow	Wet-season baseflow	34 (21 - 54) cfs	324 (260 - 410) cfs
	Wet-season timing	Nov 15 (Nov 1 - Dec 13)	Nov 13 (Nov 3 - Nov 30)
	Wet-season duration	162 (115 - 192) days	168 (145 - 184) days
Wet-season peak flows	5-year peak flow magnitude	870 (500 - 1000) cfs	3790 (3000 - 4800) cfs
	5-year peak flow duration	3 (1 - 6) days	3 (1 - 6) days
	5-year peak flow frequency	1 (1-3) events	1 (1-3) events
Spring recession flow	Spring recession magnitude	90 (34 - 267) cfs	520 (300 - 980) cfs
	Spring timing	Apr 25 (Mar 25 - May 20)	Apr 28 (Apr 6 - May 14)
	Spring duration	46 (29 - 98) days	50 (36 - 66) days

	Spring rate of change	6 (3 - 10) % decline per day	6 (3 - 10) % decline per day
Dry-season baseflow	Dry-season baseflow	1 (0.5 - 2.5) cfs	10 (7 - 15) cfs
	Dry-season timing	June 17 (May 13 - Jul 20)	June 20 (June 5 - July 7)
	Dry-season duration	160 (115 - 218) days	151 (121 - 183) days

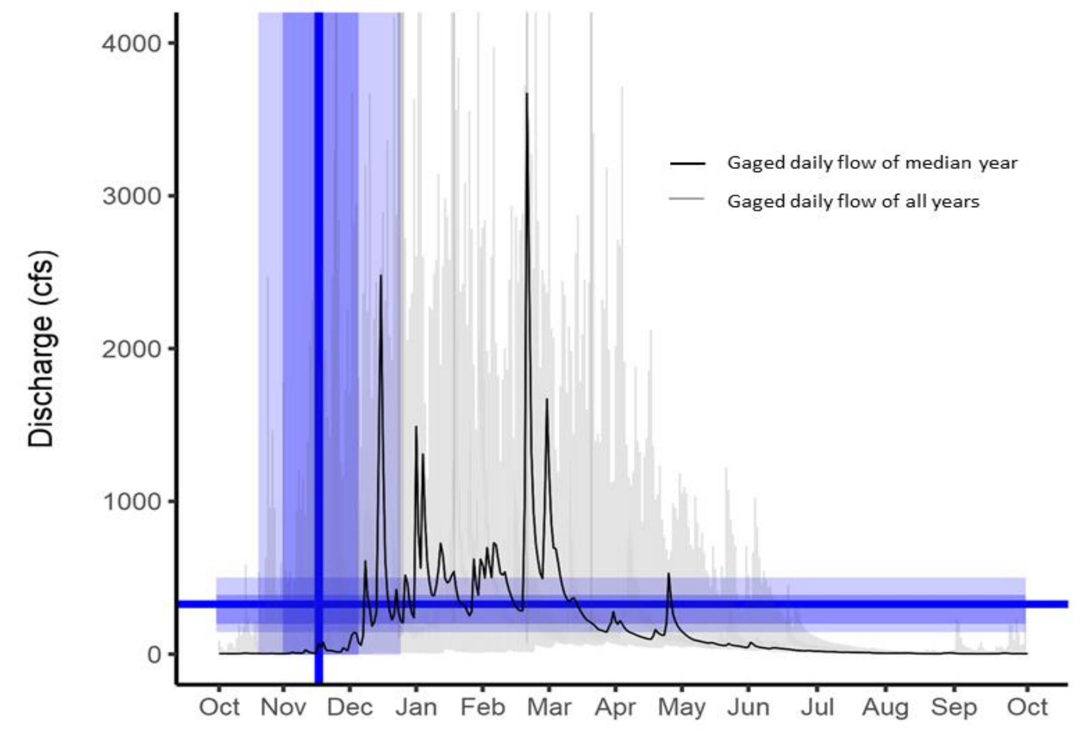

Figure A.2. A hydrograph representing the range of daily flows observed at a flow gage in the study area and the start timing and magnitude of wet-season baseflow. The dark line represents the median gaged daily flow, the grey lines are the gaged daily flows for all years. The vertical blue bands show the range of variation (10th, 25th, 50th, 75th and 90th percentile) in wet-season start timing and the horizontal blue band shows the range of variation (10th, 25th, 50th, 75th and 90th percentile) in wet-season baseflow magnitude.

Step 3: Evaluate whether the natural ranges of function flow metrics will support functions needed to achieve ecological management goals

Objective: *To perform an evaluation of factors that may limit the ability of the natural range of functional flow metrics to support essential ecosystem functions*

Maintaining functional flows within their natural range is hypothesized to support ecosystem functions and sustain healthy ecosystem conditions for native freshwater species under natural watershed conditions. However, historical and ongoing land- and water-management activities have the potential to degrade the physical, chemical, and biological conditions of rivers and streams, such that the natural ranges of functional flow metrics may be less effective in supporting essential ecosystem functions. For example, channel widening may make it less likely that natural baseflows can support in-channel pools that provide refugia for juvenile fish.

In this step, the user evaluates historical and ongoing land- and water-management activities that may limit the effectiveness of the natural range of functional flow metrics in supporting ecosystem functions (Table 2.1). The evaluation should focus on the potential influence of physical habitat, water quality, and biological interactions on the relationship between natural functional flows and ecosystem functions, identified in Step 1, that are essential to achieving ecological management goals. The direct effects of flow alteration on ecosystem functions from land and water management activities are not considered in this step, but are addressed in Section C.

Table 2.1. Examples of land- and water-management impacts that may limit the effectiveness of the natural range of functional flow metrics in supporting ecosystem functions.

Mediating factor	Example Land- and Water-Management Impacts
Physical habitat	Altered sediment supply, channel incision, channelization, levees, bank stabilization, bed armoring, impoundments, barriers
Water quality	Altered temperature patterns, low dissolved oxygen, high conductivity, high concentrations of contaminants, excess fine sediment, excess nutrients
Biological interactions	Non-native species predation or competition, parasitism, limited food supply, vegetation encroachment, altered wood supply

This step does not require a rigorous quantitative analysis, but rather encourages the user to appraise if alteration of non-flow conditions may undermine ecological management goals. For example, consider a stream reach below a large dam that has modified both the physical conditions of the river channel and downstream water temperatures. By blocking sediment movement and altering the downstream flow regime, the dam has changed the shape of the river from a shallow, meandering, wide channel, with flows often connected to the floodplain, to a deep, incised, narrow channel, now disconnected from the floodplain. In this case, the ecosystem functions that depend upon floodplain inundation – controlled by wet season peak flows – are compromised by channel incision. Thus, the channel may need higher magnitude peak flows than estimated under natural conditions to access the floodplain. Similarly, the temperature regime of the river may have been modified as a result of water releases from the reservoir. For example, dam releases during the dry season may be higher or lower than natural temperatures, depending on the depth of where water is drawn from the reservoir. In this case, the magnitude of the natural dry-season baseflow may be inadequate for sustaining temperatures within the tolerance range of species of concern (e.g., juvenile salmon). Flow releases above or below the natural range may be required to sustain desired temperatures.

There may also be circumstances in which additional flow metrics may be needed to ensure that ecological management goals are satisfied. For example, hydropeaking operations at a dam may result in sub-daily alteration of river flow that can impact ecological function but not be captured by the functional flow metrics. In this case, the user should work through Section B to evaluate the appropriate functional flow component(s) and construct one or more conceptual models and flow-ecology relationships that address additional flow metrics (e.g., coefficient of variation of daily flow, Richards-Baker flashiness index).

The evaluation of natural functional flows in relation to ecosystem functions should be performed as a high-level exercise, in which potential limiting factors are considered for each target function. In the dammed river example described above, the user would evaluate the specific ecosystem functions for each component and may determine that the natural range of flows are expected to support functions associated with the fall pulse flow, wet-season baseflow, and spring flow recession. However, downstream channel incision may limit the effectiveness of natural wet season peak flows in supporting floodplain functions and temperature alteration may limit the effectiveness of natural dry season baseflows in supporting fish rearing habitat. Therefore, further investigation should be performed (in Steps 5-7 of Section B) to develop ecological flow criteria for wet-season peak flows and dry season baseflow. Since current conditions at the sites are not expected to impair the functions of the fall pulse flow, wet-season baseflow, and the spring flow recession, the natural range of functional flow metrics for those components can be selected as ecological flow criteria (in Step 4).

In many cases, it will not be possible to directly assess the current condition of mediating factors and their potential to alter the relationship between flows and ecosystem functions. However, an evaluation of land use within the watershed can provide indirect evidence of impairment from non-flow factors. For example, urbanization is frequently associated with stream channelization, riparian vegetation removal, and water quality impairment, while agriculture often increases fine sediment inputs to streams, limits floodplain connectivity, and impairs water quality from runoff containing fertilizers, pesticides, herbicides, and manure. Lands subject to intensive grazing are prone to soil compaction, mass wasting, erosion, increased nutrient loads, and declines in riparian and instream habitat quality and diversity. Because of these known associations between land use and river ecosystem impacts, assessing land use patterns can help identify potential limiting factors to ecosystem functions and those focal components that warrant additional consideration in Section B.

Outcome of Step 3

- Identification of functional flow components where there is evidence that their natural range of flow metrics will not be supportive of ecological management goals, and a list of associated limiting factors and potentially affected ecosystem function(s); these focal components will be subject to further investigation in Section B to develop their corresponding ecological flow criteria.

Example: Coastal Watershed in Northern California

This step involves a high-level evaluation of factors that can alter the relationships between natural functional flows and ecosystem functions. For the North Coast stream example, no limiting factors are identified for the ecosystem functions associated with the five functional flow components for LOI 1. However, one potential limiting factor is identified for the dry season baseflow component in LOI 2 (Table A.5). Specifically, altered stream morphology from intensive logging activity in the upper watershed is identified as a potential limiting factor to juvenile salmonid habitat for rearing in the dry season. Logging activity has increased sedimentation, reduced riparian cover, and decreased woody debris recruitment which has resulted in decreased channel complexity, wider stream channels, and reduced riparian vegetation cover downstream. Natural dry season baseflows may not be adequate to protect water temperature and provide depths suitable for rearing under these altered conditions. As a result, further investigation is needed (in Section B) to assess the dry season baseflows that will support ecosystem functions at LOI 2 to achieve ecological management objectives.

Table A.5. The potential limiting factors that may alter the relationship between the natural range of functional flow metrics and their intended functions for each functional flow component at locations of interest.

Functional Flow Component	Potential Limiting Factor	Affected Ecosystem Function(s)
Fall pulse flow	None identified	None
Wet-season baseflow	None identified	None
Wet-season peak flows	None identified	None
Spring recession flow	None identified	None
Dry-season baseflow	Altered channel morphology and riparian vegetation condition from historic logging activity (at LOI 2)	Potential warming of water and limited habitat availability for juvenile salmonid rearing

Step 4: Select ecological flow criteria

Objective: *To select ecological flow criteria for all functional flow components (unless it is determined in Step 3 that further assessment is required for one or more components) to support ecological management goals using natural functional flow metrics*

Ecological flow criteria are selected for all functional flow components for which the natural range of metrics is expected to support ecosystem functions. These ecological flow criteria are defined by a median and bounded range of metric values for each flow component. The median represents the long-term value around which a metric is expected to center. The 10th to 90th percentiles represent the lower and upper bounds, respectively, in which the metric is expected to vary. For example, ecological flow criteria for the dry-season baseflow would be specified by median, 10th, and 90th percentile values of flow magnitude, timing, and duration. The annual values of these metrics are expected to vary under natural conditions, but over many years, are expected to be distributed around the predicted median value. The 10th and 90th percentiles of the ecological flow criteria represent an interval between which annual values of a metric are expected in fall in most years. This interval is accounts for both inter-annual variation in the metric as well as model prediction uncertainty.

Ecological flow criteria can be defined for all water years, or by water year type. The median, 10th, and 90th percentile values of flow metrics have been calculated for dry, moderate, and wet water year types. Once selected, ecological flow criteria should be organized by flow component and compiled in a table for each LOI in the study area (Table A.6). Note that ecological flow criteria will not be selected for those functional flow components identified in Step 3 that require additional consideration; criteria for those components will be developed in Steps 5-7 in Section B.

If the user desires greater certainty that ecological flow criteria will support ecological management goals when they are established as environmental flow recommendations (Section C), actions to monitor their effectiveness should be included in the Implementation Plan (Step 12).

Outcome of Step 4

- Ecological flow criteria values for functional flow components where the natural range of functional flow metrics are expected to support ecological management goals

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Example: Coastal Watershed in Northern California

Following the assessment in Step 3, ecological flow criteria based on the natural functional flow metrics are selected for all five functional flow components for LOI 1 and for all components except dry-season baseflow for LOI 2 (Table A.6, Figure A.3). At LOI 2, altered geomorphic and water quality conditions may limit the ecosystem functions associated with natural dry season baseflows (Table A.5). Therefore, the dry-season baseflow component for LOI 2 requires further investigation in Section B before ecological flow criteria can be specified.

Table A.6. Ecological flow criteria for functional flow components at locations of interest.

Flow Component	Flow Metric	**Ecological Flow Criteria at LOI 1** median (10th - 90th percentile)	**Ecological Flow Criteria at LOI 2** median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	9 (3 - 40) cfs	62 (30-180) cfs
	Fall pulse timing	Oct 19 (Oct 7 - Oct 29)	Oct 20 (Oct 7 - Oct 28)
	Fall pulse duration	3 (2 - 7) days	3 (2 - 7) days
Wet-season baseflow	Wet-season baseflow	34 (21 - 54) cfs	324 (260 - 410) cfs
	Wet-season timing	Nov 15 (Nov 1 - Dec 13)	Nov 13 (Nov 3 - Nov 30)
	Wet-season duration	162 (115 - 192) days	168 (145 - 184) days
Wet-season peak flows	5-year peak flow magnitude	870 (500 - 1000) cfs	3790 (3000 - 4800) cfs
	5-year peak flow duration	3 (1 - 6) days	3 (1 - 6) days
	5-year flood frequency	1 (1-3) event	1 (1-3) event

Spring recession flow	Spring recession magnitude	90 (34 - 267) cfs	520 (300 - 980) cfs
	Spring timing	Apr 25 (Mar 25 - May 20)	Apr 28 (Apr 6 - May 14)
	Spring duration	46 (29 - 98) days	50 (36 - 66) days
	Spring rate of change	6 (3 - 10) % decline per day	6 (3 - 10) % decline per day
Dry-season baseflow	Dry-season baseflow	1 (0.5 - 2.5) cfs	To be determined in Section B
	Dry-season timing	June 17 (May 13 - Jul 20)	To be determined in Section B
	Dry-season duration	160 (115 - 218) days	To be determined in Section B

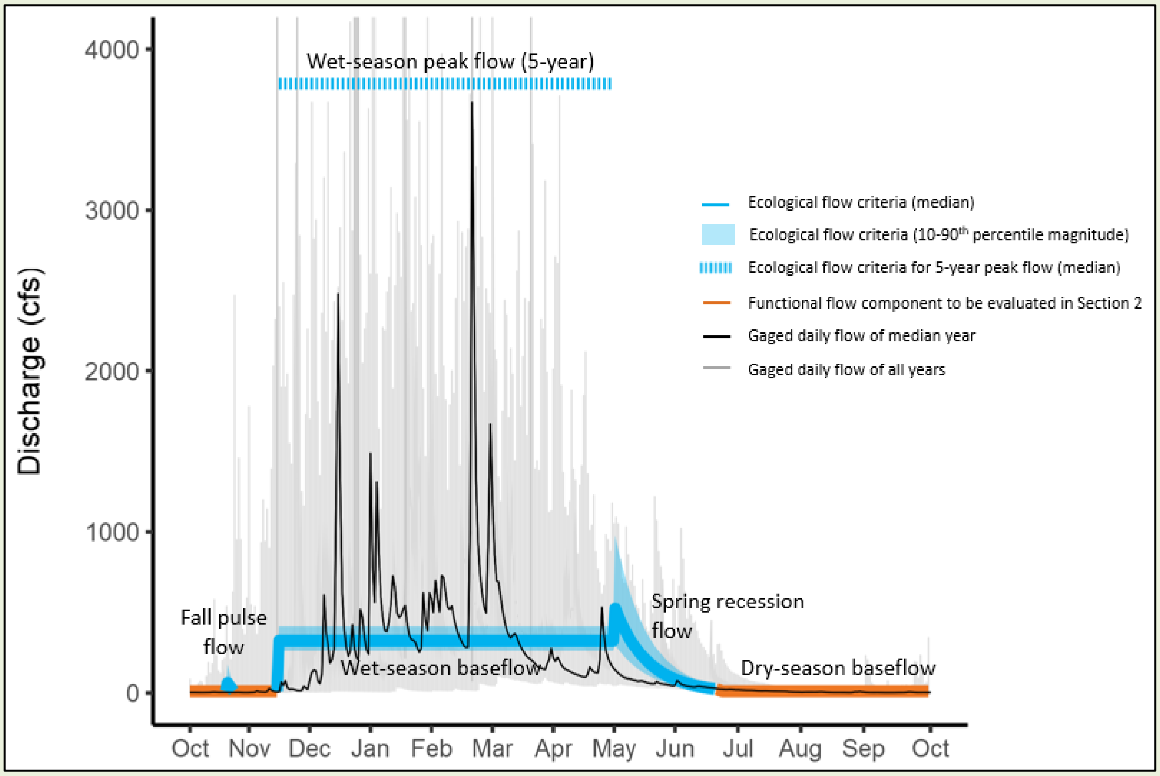

Figure A.3. Ecological flow criteria for functional flow components at LOI 2, displayed in blue, plotted against a median gaged water year (black line) and displaying mean daily flow over the

entire gaged period of record (shaded gray). Dry season baseflow is shown in orange. Ecological flow criteria for this functional flow component will be developed in Section B.

Outcome of Section A for North Coast Example

At the end of Section A, ecological flow criteria are selected for LOI 1 based on the range of natural functional flows (Table A.6). The natural range of functional flows are also used to establish ecological flow criteria at LOI 2, with the exception of criteria for dry-season baseflow. The dry-season baseflow requires further evaluation in Section B because of the potential for physical habitat and water quality degradation to alter the relationship between flow and ecosystem functions in the dry season.

For an overview of all of the information obtained in Section A for this North Coast watershed, see Figure A.4.

Outcome of Section A

After completing Steps 1 to 4 in Section A, the user will have defined ecological management goals for their study region and identified the ecosystem functions needed to achieve them. The outcome of Section A will be a set of ecological flow criteria derived from natural functional flow metrics that characterize the natural variability in flow that supports essential ecosystem functions. The user will also have evaluated whether there are non-flow mediating factors that could limit the effectiveness of the natural range of functional flow metrics in supporting ecosystem functions. If limiting factors are identified for one or more flow components, the user should proceed to Section B to develop ecological flow criteria for those focal component(s).

STEP 1: What are my ***location(s) of interest (LOI)*** and my rationale for selection?	Hypothetical north coast watershed LOI 2: Stream reach with long-term flow gage at which flow alteration can be assessed and environmental flow implementation monitored. This LOI has been affected by historical logging activity which may reduce its suitability for salmon rearing and migration				
STEP 1: What are the **ecological management goals** at my LOI?	1. Maintain stream health needed to support salmon populations 2. Maintain suitable habitat conditions for juvenile salmon rearing 3. Preserve passage flows during adult salmon migration and smolt outmigration				
STEP 1: Which ***ecosystem functions*** do I need to support to achieve my ***ecological management goals***?	Five ***functional flow components*** for my LOI				
	Fall pulse flow	Wet-season baseflow	Wet-season peak flows	Spring recession flow	Dry-season baseflow
	Flush fine sediment and organic material from substrate, increase longitudinal hydrologic connectivity, increase nutrient cycling, decrease water temperature and increase dissolved oxygen, trigger fish migration	Maintain longitudinal hydrologic connectivity, support hyporheic exchange, support riparian habitat along channel margins, support fish migration and spawning	Scour and deposit sediment and large wood in channel and overbank zones, increase lateral hydrologic connectivity, support riparian vegetation diversity and health through disturbance and overbank inundation, limit non-native species and in-channel vegetation encroachment through disturbance and displacement	Provide hydrologic cues for fish spawning and out-migration, support juvenile fish rearing, maintain hydraulic habitat diversity that supports diversity of aquatic plants and animals	Limit warming of water, concentration of contaminants, and low dissolved oxygen, support algal growth and primary productivity, maintain habitat availability and connectivity for aquatic species
STEP 2: What are the ***natural ranges for functional flow components*** (i.e., ***functional flow metrics***) at my LOI?	Fall pulse magnitude 62 (30-180) cfs Fall pulse timing Oct 20 (Oct 7 - Oct 28) Fall pulse duration 3 (2 - 7) days	Wet-season baseflow 324 (260 - 410) cfs Wet-season timing Nov 13 (Nov 3 - Nov 30) Wet-season duration 168 (145 - 184) days	5-year peak flow magnitude 3790 (3000 - 4800) cfs 5-year peak flow duration 3 (1 - 6) days 5-year peak flow frequency 1 (1-3) events	Spring recession magnitude 520 (300 - 980) cfs Spring timing Apr 28 (Apr 6 - May 14) Spring duration 50 (36 - 66) days	Dry-season baseflow 10 (7 - 15) cfs Dry-season timing June 20 (June 5 - July 7) Dry-season duration 151 (121 - 183) days

				Spring rate of change 6 (3 - 10) % decline per day	
STEP 3: What are the ***functional flow components*** for which ***ecosystems functions*** may not be supported by the ***natural range of functional flows*** due to alterations of physical, biological or water quality factors?	None identified	None identified	None identified	None identified	*Potential Limiting Factor* Altered channel morphology and riparian vegetation condition from historic logging activity *Affected Ecosystem Function* Potential warming of water and limited habitat availability for juvenile salmonid rearing
STEP 4: What are the ***ecological flow criteria*** for the ***functional flow components*** that do not require additional consideration?	Fall pulse magnitude 62 (30-180) cfs Fall pulse timing Oct 20 (Oct 7 - Oct 28) Fall pulse duration 3 (2 - 7) days	Wet-season baseflow 324 (260 - 410) cfs Wet-season timing Nov 13 (Nov 3 - Nov 30) Wet-season duration 168 (145 - 184) days	5-year peak flow magnitude 3790 (3000 - 4800) cfs 5-year peak flow duration 3 (1 - 6) days 5-year peak flow frequency 1 (1-3) events	Spring recession magnitude 520 (300 - 980) cfs Spring timing Apr 28 (Apr 6 - May 14) Spring duration 50 (36 - 66) days Spring rate of change 6 (3 - 10) % decline per day	*(to be determined in Section B)*

Figure A.4. The sample worksheet shown in Figure 2.2, filled in with the information for the Example watershed.

SECTION B – DEVELOP ECOLOGICAL FLOW CRITERIA FOR FOCAL FLOW COMPONENTS REQUIRING ADDITIONAL CONSIDERATION

Overview

Section B is necessary if the ecological management goals (identified in Step 1) would not be expected to be met by the natural ranges of flow metrics for one or more flow components. If the user determines in Section A that the natural ranges of flow metrics can be used to develop ecological flow criteria for all five functional flow components, the user skips Section B and proceeds to Section C. However, where alteration of non-flow factors (e.g., physical habitat, water quality, or biologic conditions) limit the ability of the natural ranges for flow metrics to support desired ecological functions and achieve ecological management goals (Step 3), further analysis for these functional flow component(s) is completed in Section B.

In Section B, the user performs a detailed analysis of the linkages between flow, physical habitat, water quality, and biological interactions to develop ecological flow criteria for the functional flow components requiring additional consideration. At the end of Section B, these criteria are combined with those developed in Section A to define a full set of ecological flow criteria associated with all functional flow components (Figure 3.1).

Section B begins with developing a conceptual model that links the functional flow components requiring additional consideration—referred to as focal functional flow components—to ecological management goals (Step 5). This involves specifying the direct and indirect pathways in which changes in flow metrics can affect ecological responses. Next, the various pathways within the conceptual model are quantified using either existing flow-ecology relationships or analytical methods that rely on existing data or data generated from site-specific studies (Step 6). The outcome of Step 6 is one or more flow-ecology relationships that quantify how changes in functional flow components and associated flow metrics affect ecological responses of interest, accounting for mediating factors such as water quality, physical habitat, and biological interactions. In Step 7, the user evaluates the flow-ecology relationships to identify a targeted range of flow metrics and define ecological flow criteria for the focal functional flow components. These ecological flow criteria are then combined with those defined in Section A to establish a full set of ecological flow criteria for all five functional flow components required to achieve ecological management goals.

Section B requires general knowledge of the ecology and hydrology of the study area and familiarity with the technical methods used to quantify flow-ecology relationships. General guidance on constructing and quantifying conceptual models is included in Steps 5 and 6; however, these steps do not provide specific guidance on which mediating factors and ecosystem functions should be included in conceptual models, which tools should be used to quantify relationships, or how simple or complex of a model is appropriate for a given location. Decisions on how to structure the conceptual models and apply tools and quantitative methods will have a significant influence on the quality and nature of the results, and as such, should be developed through an open, collaborative process informed by experts and multiple stakeholders.

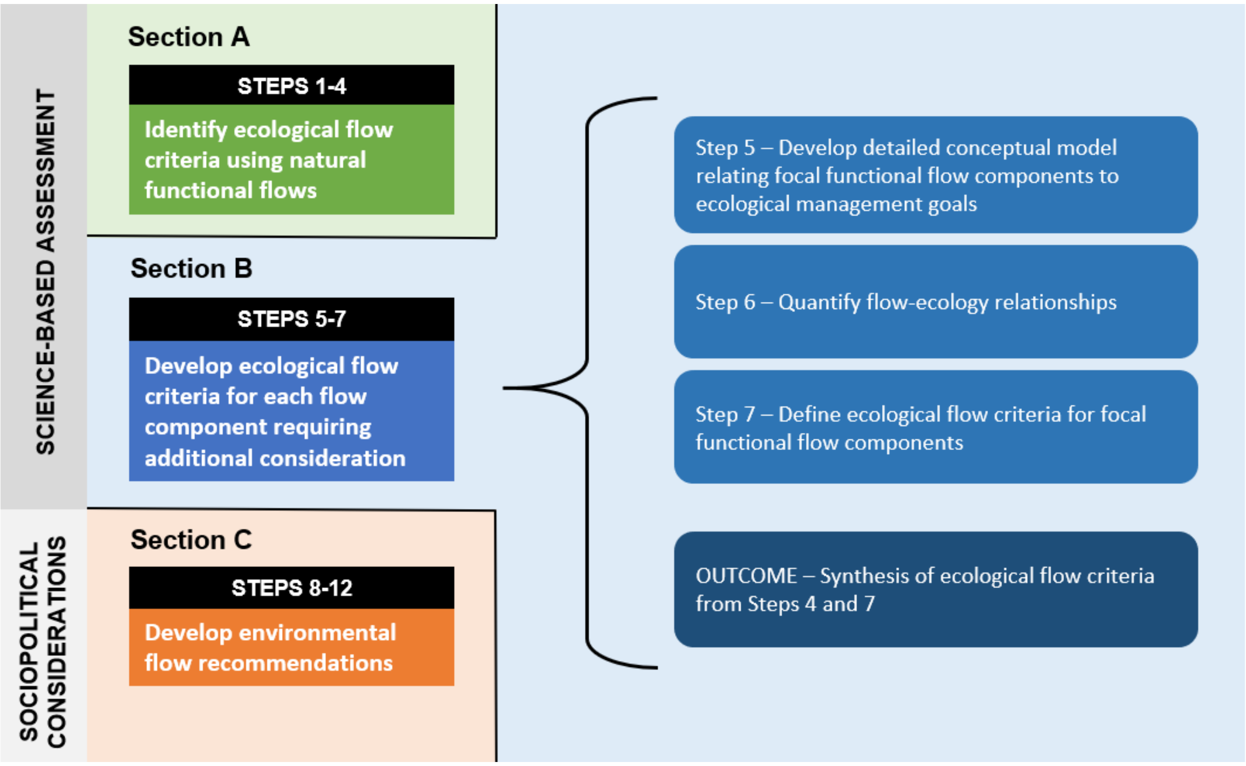

Figure 3.1. Overview of Section B steps.

Step 5: Develop detailed conceptual model relating focal flow components to ecological management goals

Objective: *To develop a conceptual model to visualize the relationship between functional flow components and the physical, chemical, and biological factors that influence ecological management goals*

In this step, the user creates a conceptual model that represents all important linkages between a focal flow component and ecological management goal(s). The conceptual model provides a visual illustration of the user’s understanding of the system and guides the user in compiling or collecting data required to quantify and verify flow-ecology relationships in Step 6. Figure 3.2 represents a generic conceptual model that can be used as a starting point when developing models for specific ecological management goals in a study area. The final conceptual model should be informed by experts and multiple stakeholders through an open and transparent process. This stakeholder group may recommend a final conceptual model that should be approved by a decision maker (the person or group responsible for approving final ecological flow criteria) before moving on to Step 6.

What is a flow-ecology relationship?

A conceptual model that explicitly links a flow component with ecological management goals helps the user to better understand and visualize how physical habitat, water quality, and/or biological interactions could affect the relationships between flow and ecological response. These relationships are referred to as ***flow-ecology relationships.*** Flow-ecology relationships are any quantitative relationship that predicts an ecological response due to a change in flow. Such relationships can be direct or indirect. A direct relationship quantitatively relates a change in functional flow component to an ecological response. An indirect relationship accounts for mediating factors, such as biological interactions, water quality, or physical habitat, that influence the effects of flow on ecological responses.

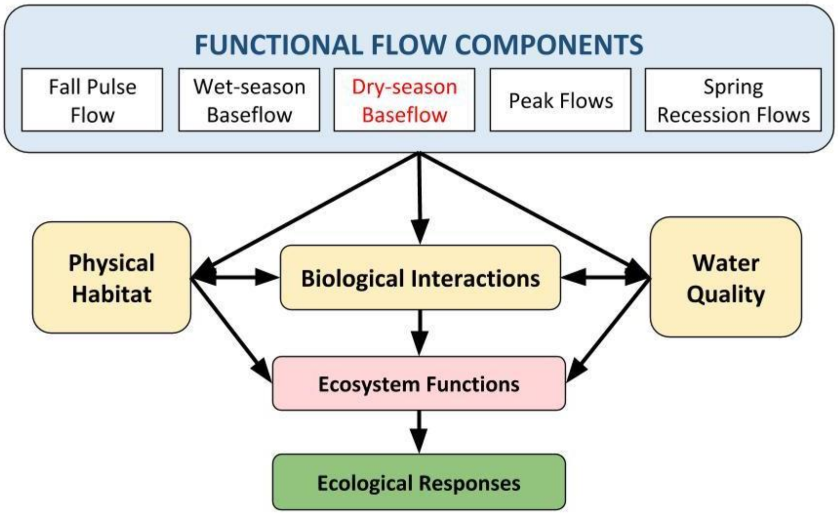

Figure 3.2. Generic conceptual model demonstrating relationships between a functional flow component, ecosystem functions, and ecological response as mediated by factors such as physical habitat, water quality, and biological interactions. This figure can be used as a starting point when developing conceptual models for focal functional flow components in Step 6. Adapted from Poff et al. 1997.

The conceptual model should specify the relationships between flow metrics and ecological management goals, which are expressed as ***ecological performance measures***. Flow metrics are quantitative measures of a specific characteristic of a flow component, e.g., the magnitude of the dry season baseflow component (measured in cubic feet per second [cfs]) or start timing of the spring recession flow (measured as the water year date of occurrence). Ecological performance measures are quantitative measures of ecological conditions that are expected to respond (directly or indirectly) to changes in flow and that can be directly measured using standard monitoring techniques. The choice of both flow metrics and ecological performance measures should be guided by the ecological management goal, knowledge of the study area, and available data. For example, if an ecological management goal for a study area is the maintenance of a healthy macroinvertebrate community, biological indicators such as the California Stream Condition Index (CSCI) can be used as an ecological performance measure. The CSCI is a statewide biological scoring index that is applied to samples of macroinvertebrates, which are regularly collected in streams as part of a statewide monitoring program. The CSCI translates information about benthic macroinvertebrates living in a stream into an overall measure of stream health (Rehn et al. 2015), enabling ecological performance measures to be specified as a range of desired CSCI values. Performance measures for listed species might be measured by population targets or recruitment rates. Ecological performance measures could also be specified for intermediate links in the conceptual model, such as geomorphic processes or water quality parameters including dissolved oxygen, temperature, and contaminants. However, performance measures for intermediate links should be paired with measures for ecological responses.

The conceptual model should also include mediating factors that are likely to influence the relationship between flow metrics and ecological performance measures (identified in Section A, Step 3). These may include, but are not limited to, physical habitat factors, water quality conditions, and biological interactions (see box). This conceptual model is intended to illustrate flow ecology relationships, not the possibility of implementing non-flow actions (e.g., habitat restoration). Trade-offs between implementing flow and non-flow actions can be explored in Section C, if appropriate.

Mediating factors in flow-ecology relationships

Flow metrics and ecological performance measures often have one or more mediating factors that influence the flow-ecology relationship. These mediating factors can be categorized by physical habitat conditions, water quality, or biological interactions (Figure A.5).

The physical form and structure of rivers and floodplains interacts with flow to influence ecological responses. In particular, channel morphology (i.e., channel type, size, shape, slope, and substrate) determines how flow is expressed as hydraulic conditions (water depth and velocity). Many species have distinct preferences for depths and velocities (Bovee 1986) as well as tolerance thresholds (e.g., related to the swimming ability of tadpoles (Kupferberg et al. 2012) or juvenile salmon (Katzman et al. 2010)). Hydraulic habitat preferences may differ at different life stages (e.g., Gard 2006; Yarnell et al. 2016). However, hydraulic tolerances and preferences often hold across different stream types, flow regimes, and geomorphic conditions, and thus can be useful for evaluating habitat suitability within and across diverse geographic areas (Nestler et al. 2019).

Water quality affects the health of aquatic ecosystems by controlling the condition, survival, and distribution of freshwater species. Many water quality parameters that species are sensitive to are influenced by flows. These include water temperature, salinity (often measured by specific conductance), nutrients, dissolved oxygen (DO), and dissolved organic carbon (DOC) (Nilsson and Renöfält 2008). Therefore, it may be necessary to include these or other water quality parameters in conceptual models that link changes in flow to ecological responses.

Biological interactions also have the potential to influence ecological responses to changes in flow. For example, the presence of non-native species could affect the response of native species to streamflow through competition, predation, or habitat alteration (Doubledee et al. 2003; Adams et al. 2017). Biological interactions can also directly influence ecosystem functions, such as primary production, which can have a significant influence on the growth, survival and health of target species (e.g., Kupferberg 1997).

Additional information on suggested data sources, tools, and methods for determining flow-ecology relationships are provided in Step 6 and Appendix E.

Outcome of Step 5

- A detailed conceptual model for each LOI (or study area, if it includes multiple LOIs that can be addressed by the same conceptual model) that illustrates the flow-ecology relationships that influence ecological responses and management goals expressed as ecological performance measures. A separate conceptual model is required for each functional flow component that is addressed in Section B.

Example: Coastal Watershed in Northern California

Continuing the example from Section A, altered stream morphology from intensive logging activity in the upper watershed was identified as a potential limiting factor to juvenile salmonid habitat for rearing during the dry season at LOI 2. The effects of physical habitat alteration on rearing salmon were expressed through two mediating factors. First, stream channel widening and degradation of riparian vegetation has increased solar radiation to the channel, potentially increasing water temperatures beyond the tolerance limits of juvenile salmon. Second, logging activity has widened the stream channel such that natural dry season baseflows may not be adequate to provide depths suitable for rearing juvenile salmon.

The user determined that the two mediating factors would only influence one characteristic of dry-season baseflow: flow magnitude. Mediating factors were not expected to alter the relationship between dry-season duration or timing and ecological management goals; therefore, the natural ranges of duration and timing were specified for these two flow characteristics (with values obtained from Section A). The user examined the life history stages and timing for salmon and determined that only the juvenile life history stage would be affected by dry season baseflow magnitude. The user chose juvenile salmon growth and survival rates as two ecological performance measures relevant to the ecological management goal of supporting healthy salmon populations.

The conceptual model for the system captures the effects of the two mediating factors by linking (1) dry-season baseflow magnitude to water temperature and salmon physiology, and (2) dry-season baseflow magnitude to water depths and velocities and juvenile salmon hydraulic habitat preferences (Figure A.5). Both pathways ultimately affect growth and survival of juvenile salmon.

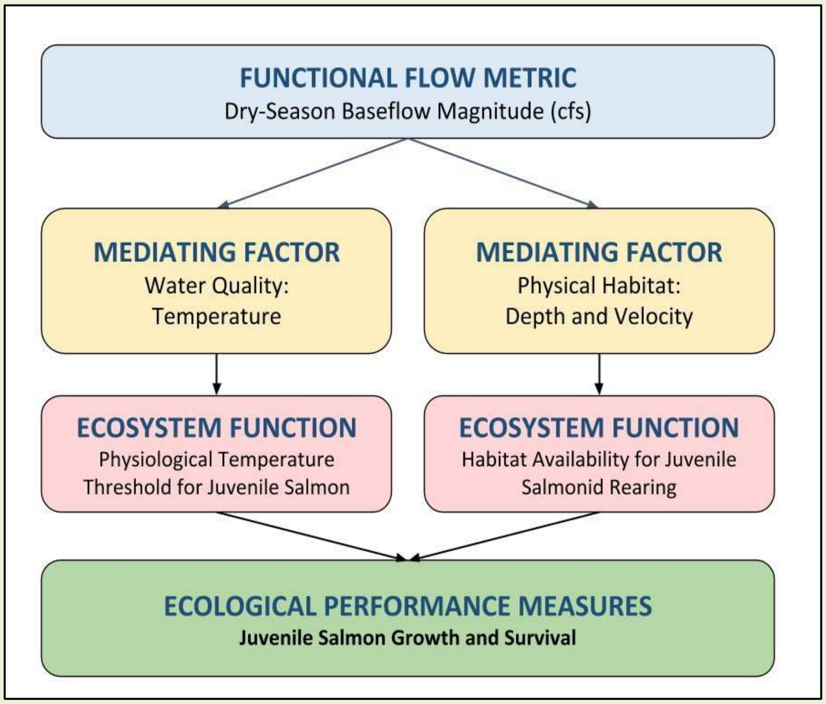

Figure A.5. Conceptual model linking the focal flow component in a coastal watershed in Northern California (dry-season baseflow) with mediating factors, ecosystem functions (as defined in Table A.3), and ecological performance measures that relate to the ecological management goal of healthy salmon populations.

Step 6: Quantify flow-ecology relationships

Objective: *To quantify flow-ecology relationships in the conceptual model using provided guidance on data sources and methods for defining these relationships*

Using the conceptual model as a guide, the user collects any existing flow criteria and data from previous studies (i.e., site-specific studies conducted for the LOI or comparable watersheds) that might provide insights into flow-ecology relationships for the study area. The user first evaluates any existing flow criteria or documented ecological relationships and determines whether they are applicable for the study area. If not available, the user then compiles existing data for components of the conceptual model. Suggested datasets and repositories are provided in Appendix E. If relationships in the conceptual model cannot be quantified using existing data, the user may choose to quantify the relationship by designing a study to collect new data. If resources are not available to collect new data, the user may choose to quantify relationships based on expert knowledge that is elicited following standard methodologies (see below).

Incorporating flow-ecology relationships from existing flow criteria

Flow criteria may exist for the user's study area or LOI. For example, for streams that have been identified as high priority for the State (e.g., through the California Water Action Plan or Public Resources Code 10000), the California Department of Fish and Wildlife (CDFW) has conducted studies to develop flow criteria (CDFW 2020). Current and completed instream flow studies and recommended ecological flow criteria can be found on CDFW's Instream Flow Studies page.

When reviewing existing flow criteria, the user ensures that they will be adequate to achieve desired ecological management goals or address additional management concerns. Specifically, the user considers whether the criteria:

- consider one or more of the focal functional flow components
- are conceptually linked to ecosystem functions in streams and ecological management goals
- have been developed in a comparable physical setting or watershed context to the study area and/or LOI

For example, an instream flow study might focus on winter spawning flow needs, which correspond to the wet-season baseflow functional flow component. Findings of the flow study could be used to establish ecological flow criteria for wet-season baseflow magnitude, but other sources of information and/or data analysis may be required to develop ecological flow criteria for other baseflow characteristics (timing, duration) or other focal flow components addressed in Section B.

Developing flow-ecology relationships from new and/or existing data

Whether relying on new or existing data, there are a wide variety of approaches that can be used to quantify flow-ecology relationships; these methods have been extensively described, reviewed and categorized (e.g., Arthington 2012; Williams et al. 2019). Although many methods do not specifically address functional flows, some approaches may help to develop ecological flow criteria from some functional flow components and/or characteristics. There are three key guiding principles for selecting methods for developing flow-ecology relationships:

- The methods should be appropriate for, and relevant to, assessing the relationship between ecological management goals defined in Step 1 and functional flow components.
- The methods should be chosen based on the conceptual model of the relationships between each flow component and ecological performance measures. In the case that there are many mediating factors important to a flow-ecology relationship, two or more complementary methods may be needed.

- The final method (or set of methods) should quantify each link in the conceptual model. An example of flow-ecology relationships with geomorphology and hydraulics as mediating factors is shown in Appendix G.

Developing flow-ecology relationships by expert opinion

If existing flow criteria or data are not available, and resources are not sufficient to collect new data, the user may quantify flow-ecology relationships using expert elicitation. Expert elicitation is often used in conservation decision-making (Martin et al. 2012) and can be rigorous if information is elicited using established methods (Burgman 2016). The most frequently used method is the Delphi process (Runge et al. 2011; Mukherjee et al. 2015), which is a structured approach to identifying experts, eliciting quantitative values independently, allowing for discussion and revision of initial values, and applying statistical methods to calculate means and confidence intervals across experts.

Tools for quantifying indirect flow-ecology relationships

While there are countless methods available for quantifying and evaluating flow-ecology relationships that include mediating factors, certain categories of tools will be frequently used.

Physical form and structure: When stream hydraulics (variation in depth and velocity) have a significant effect on ecological responses, models are used to simulate changes in hydraulics over a range of flows. Such models require topographic data of the channels, as well as measurements of water level (or stage) across a range of flows for model training and validation.[6] Hydraulic model outputs are then paired with assessments of hydraulic habitat preferences for one or more species (or life history stage) to predict how habitat suitability changes in response to flow[7]. Hydraulic models can also be coupled with sediment transport models to simulate physical processes that create and redistribute habitat for target species. Often, such physical habitat assessments identify an optimal flow value that maximizes suitable habitat for a given life stage for the species of interest, such as salmon spawning habitat. However, to link physical habitat to ecological performance measures, additional work may be needed. For example, if performance metrics are juvenile salmon growth and survival, additional analytical steps may be needed to assess how stream hydraulics affect food resources (e.g., using bioenergetics models).

Water-quality parameters: Water quality parameters that influence ecological responses include temperature, turbidity/clarity, DO, contaminants, and others. When water quality is a mediating factor, modeling the response of the water quality metric to a range of flows is necessary. For example, low flows are often associated with high temperatures that may be detrimental to ecological management goals. In this case, a temperature model is necessary to determine how water temperature is expected to respond to a change in flow conditions. The results of a water quality model can then be compared to physiological temperature thresholds, such as those published by USEPA (2003), to quantify ecological responses.

Biological species interactions: Biological conditions that may mediate flow-ecology relationships include food supply (instream or in off-channel habitat), predator-prey interactions, and abundance of non-native species that may compete with natives for habitat

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[6] Appendix F provides a geomorphic classification for several regions of the State of California. This information can be used to develop hydraulic response relationships, as described in Appendix G.

[7] Appendix H provides functional flow requirements for umbrella fish species that represent native fish communities across regions in California. Appendix I describes functional flow metrics that are best correlated with stream health condition as quantified by the California Stream Conditions Index. This information can be used in developing flow-ecology relationships.

and food. For example, the relative abundance of non-native fish to native species often changes in response to flow (Feyrer and Healey 2003; Kiernan et al. 2012), and these relationships should be incorporated in the conceptual model using statistical methods to predict ecological responses.

Outcome of Step 6

- Quantitative flow-ecology relationships that relate focal functional flow components to ecological responses

Example: Coastal Watershed in Northern California

In Step 6, it was determined that there were no flow criteria from previous studies that can be used to relate dry season baseflow to juvenile growth and survival; however, resources were available to conduct site-specific hydraulic and temperature modeling (Figure A.6). For the first conceptual model pathway, a temperature model was used to evaluate changes in weekly maximum and weekly mean temperatures over the same flow range as evaluated by the hydraulic model. Optimal temperature ranges for juvenile salmon growth and survival depends on food supply. Optimal range is 13°-20°C for unlimited food and 10°-16°C with limited food (USEPA 2003). Data were lacking on food supply, so a target of 13°-16°C was chosen to overlap the two food supply states. Results from the temperature model showed that a dry-season baseflow magnitude of at least 22 cfs would be required to achieve optimal temperature conditions.

For the second conceptual model pathway, a hydraulic model was used to evaluate changes in water depth and velocity over a wide range of dry season baseflow scenarios, and then habitat suitability criteria were applied to the modeling results to estimate salmon rearing habitat availability over the flow range. Using a model that was developed to link rearing habitat availability to juvenile growth and survival, it was determined that dry-season baseflow magnitude in the range of 17-23 cfs would provide habitat conditions that would achieve ecological management goals.

The two modeling efforts resulted in different flow criteria to achieve desired levels of juvenile growth and survival. However, the results suggest that a dry-season baseflow magnitude of 22-23 cfs during the period that juvenile salmon are rearing would satisfy both temperature and physical habitat requirements.

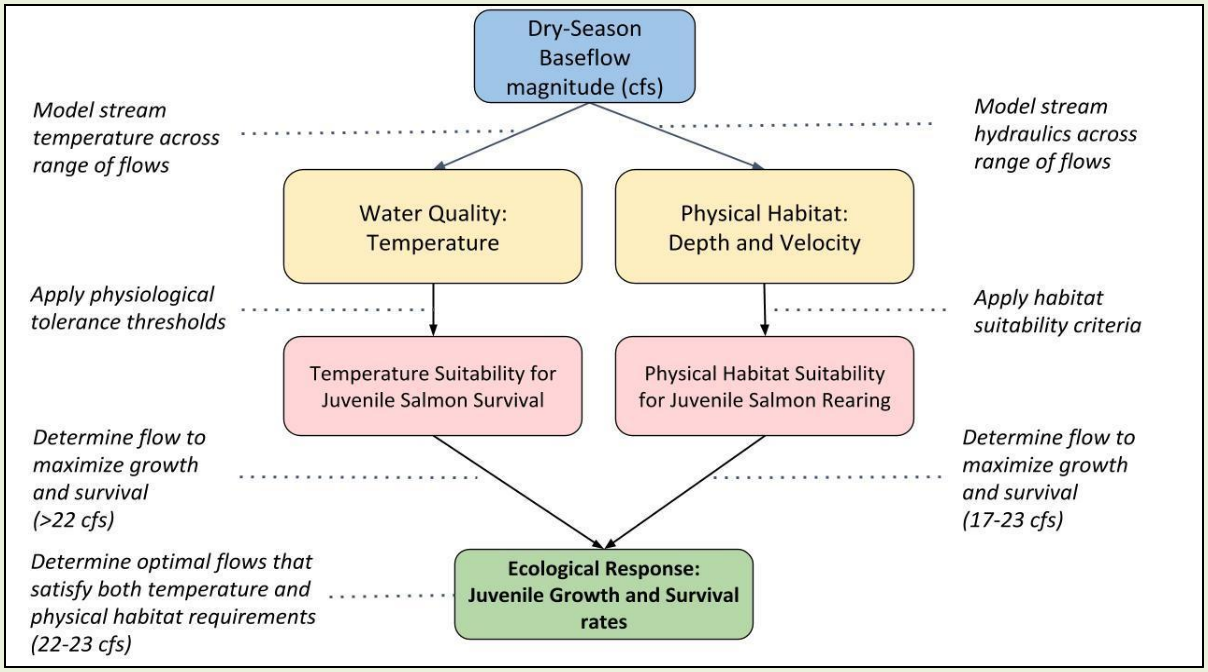

Figure A.6. The conceptual model for a coastal watershed in Northern California (from Step 5) with specific tools that can be applied to each link in the model to quantify flow-ecology relationships. Results for flows that optimize juvenile salmon growth and survival are shown for the final links in the model.

Step 7: Define ecological flow criteria for focal flow components

Objective: *To select ecological flow criteria for each focal functional flow component that support the ecological management goals defined in Step 1*

Based on the information gathered in Steps 5 and 6, the user defines ecological flow criteria for each focal functional flow component. The user then combines these ecological flow criteria with those defined in Section A to develop a comprehensive set of criteria for all five functional flow components. In some cases, the process of constructing and evaluating conceptual models may result in the identification of one or more additional sets of flow metrics and/or ranges (e.g., coefficient of variation of daily flow) that are important for a particular species' life history needs. For example, previous studies have shown that dry season baseflow stability (e.g. coefficient of variation of daily flow) has a significant effect on the condition of the benthic invertebrate communities (Steel et al. 2017). It therefore may be helpful in Section B to develop an additional flow criterion for this particular flow metric range.

Outcome of Step 7

- Ecological flow criteria for all flow components defined from Sections A and B.

Example: Coastal Watershed in Northern California

Using the results of Step 6, the range of 22-23 cfs was defined as an ecological flow criterion for dry-season baseflow magnitude.[8] Natural functional flow metric values for dry-season timing and duration were accepted as flow criteria in Step 5. The full table (Table A.7) of ecological flow criteria for all five functional flow components and a corresponding ecological flow regime (Figure A.7) is shown below.

Table A.7. Example of ecological flow criteria for all functional flow components (at locations of interest 1 and 2). All flow criteria were selected from the natural range of flow metrics identified in Section A, except for the dry-season baseflow magnitude that was determined in the Section B site-specific analyses.

Flow Component	Flow Metric	Ecological Flow Criteria at LOI 1 median (10th - 90th percentile)	Ecological Flow Criteria at LOI 2 median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	9 (3 - 40) cfs	62 (30-180) cfs
	Fall pulse timing	Oct 19 (Oct 7 - Oct 29)	Oct 20 (Oct 7 - Oct 28)
	Fall pulse duration	3 (2 - 7) days	3 (2 - 7) days
Wet-season baseflow	Wet-season baseflow	34 (21 - 54) cfs	324 (260 - 410) cfs
	Wet-season timing	Nov 15 (Nov 1 - Dec 13)	Nov 13 (Nov 3 - Nov 30)
	Wet-season duration	162 (115 - 192) days	168 (145 - 184) days
Wet-season peak flows	5-year peak flow magnitude	870 (500 - 1000) cfs	3790 (3000 - 4800) cfs
	5-year peak flow duration	3 (1 - 6) days	3 (1 - 6) days
	5-year peak flow frequency	1 (1-3) event(s)	1 (1-3) event(s)
Spring recession flow	Spring recession magnitude	90 (34 - 267) cfs	520 (300 - 980) cfs
	Spring timing	Apr 25 (Mar 25 - May 20)	Apr 28 (Apr 6 - May 14)
	Spring duration	46 (29 - 98) days	50 (36 - 66) days
	Spring rate of change	6 (3 - 10) % decline per day	6 (3 - 10) % decline per day
	Dry-season baseflow	1 (0.5 - 2.5) cfs	**22-23 cfs**

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[8] Note that the values differ from the predicted natural functional flow range of 7-15 cfs and a median of 10 cfs

Dry-season baseflow	Dry-season timing	June 17 (May 13 - Jul 20)	June 20 (June 5 - July 7)
	Dry-season duration	160 (115 - 218) days	151 (121 - 183) days

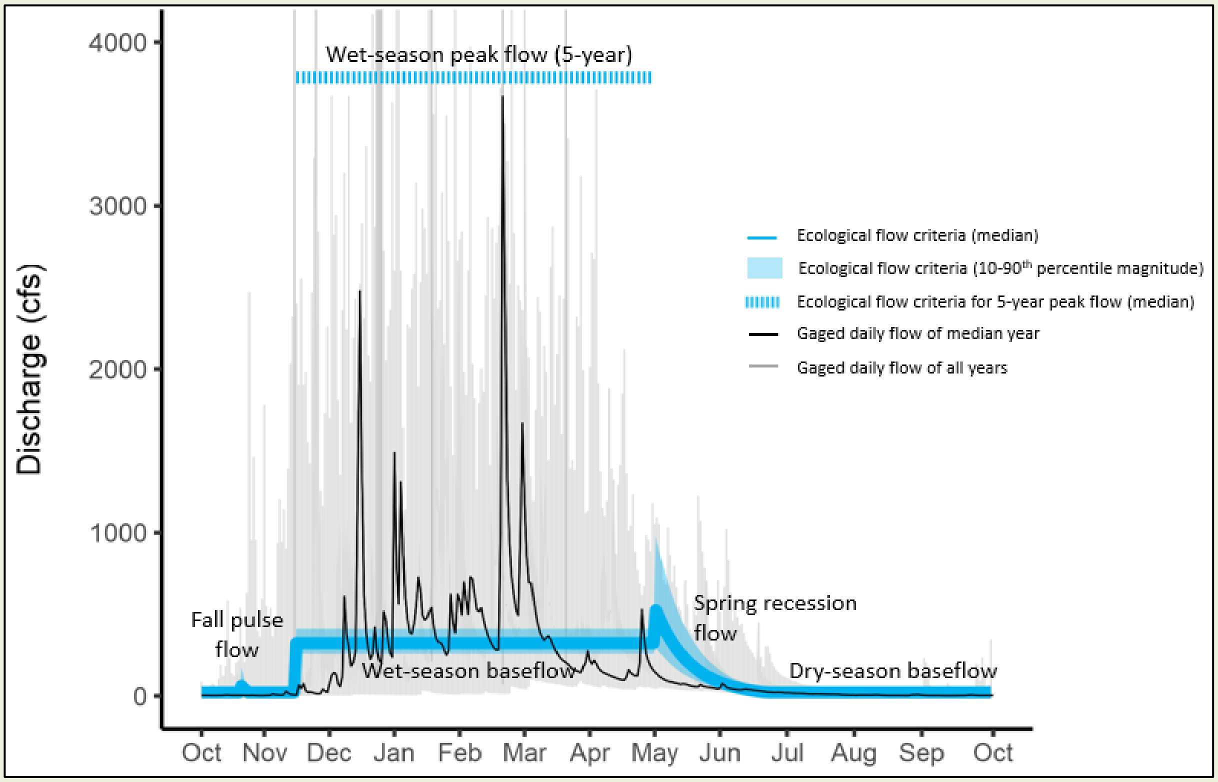

Figure A.7. Ecological flow regime developed from the ecological flow criteria presented in Table A.7. Note that only dry-season baseflow magnitude was determined in Section B, while all other criteria were selected from the natural range of functional flow metrics identified in Section A.

Outcome of Section B

The outcome of Section B is a full set of ecological flow criteria that include the natural ranges of flow metrics for some functional flow components (Section A) and ecological flow criteria developed in this section for the focal functional flow components evaluated in Steps 5-7. Flow criteria will be defined for all LOIs within a study area, with their specific values compiled in tables and visualized as ecological flow regimes.

SECTION C – DEVELOPING ENVIRONMENTAL FLOW RECOMMENDATIONS

Overview

Section C outlines a process for developing environmental flow recommendations that balance ecological management goals with other non-ecological water management objectives, such as those prioritized for human use. This section represents a transition from a scientific process in which ecological flow criteria are developed (Sections A and B) to a process that incorporates social values, and other management needs, including human uses of water, public health and safety needs, and legal and regulatory requirements (Figure 4.1). In Section C, the user should be continuing to engage stakeholders (including traditionally underrepresented groups) to guide the development of a final set of environmental flow recommendations, along with an implementation plan for their study area, in collaboration with agency partners.

Section C follows a structured decision-making process. Structured Decision Making (Figure 4.2) and, in general, the field of Multi-Criteria Decision Analysis (e.g., Gregory and Keeney 2002; Runge et al. 2011) offer a systematic framework to guide development of environmental flow recommendations that are characterized by trade-offs and uncertainty. Section C begins with defining specific and quantifiable management objectives and the legal, regulatory and social context in which environmental flow recommendations are to be developed (Step 8). This section also evaluates existing flow conditions relative to ecological flow criteria to understand the changes in management that may be required (Step 9). Next, a set of management alternatives hypothesized to satisfy all management objectives are developed, and the consequences of each alternative—including trade-offs among objectives—are assessed (Step 10). Then, a preferred management alternative is selected, and environmental flow recommendations defined (Step 11). Finally, an implementation plan is developed (Step 12). The plan should include feedback mechanisms to guide future refinement of environmental flow recommendations, following an adaptive management approach (Figure 4.2).

Because users must take into account numerous sociopolitical considerations that are often site-specific and non-scientific, Section C provides less prescriptive guidance than Sections A and B. Instead, Section C is intended to offer a conceptual framework, including suggested tools, to help the user appropriately balance ecological and non-ecological management objectives to develop a set of environmental flow recommendations. These recommendations should consider all relevant regulatory requirements and stakeholder priorities. Implementation guidelines will be developed in the future in response to specific issues and based on lessons learned from early applications of the Framework.

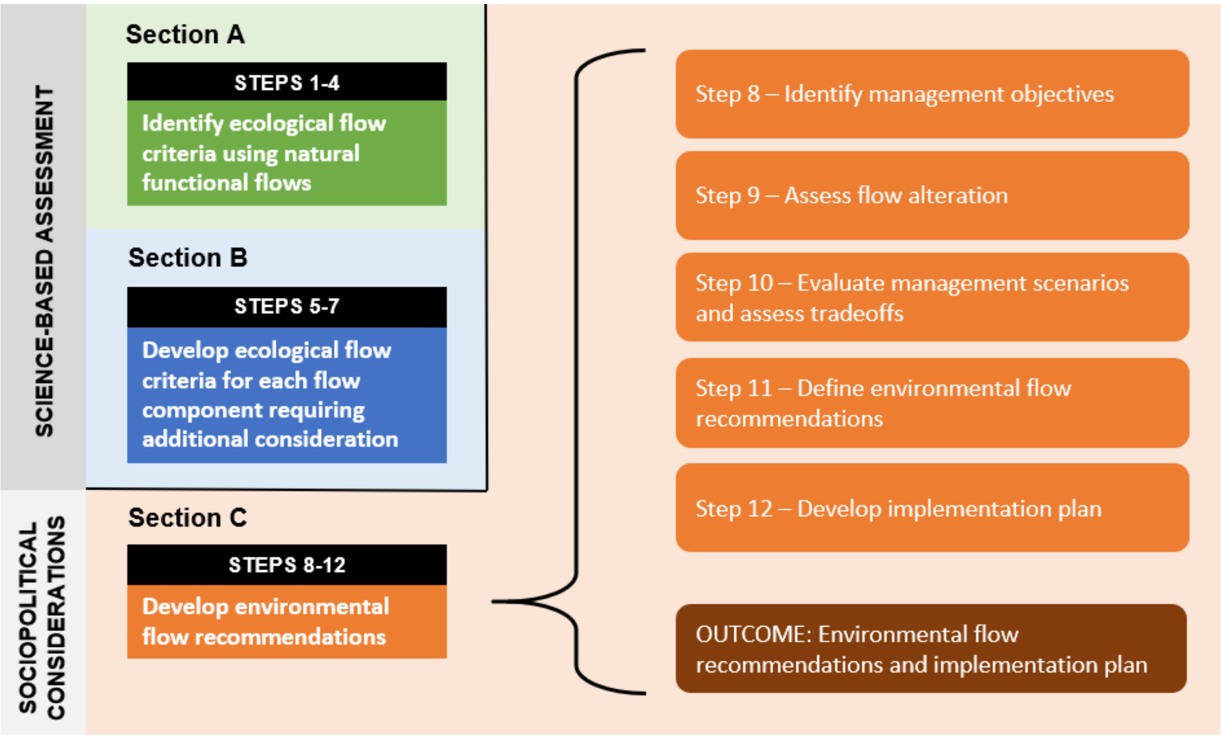

Figure 4.1. Overview of Section C steps.

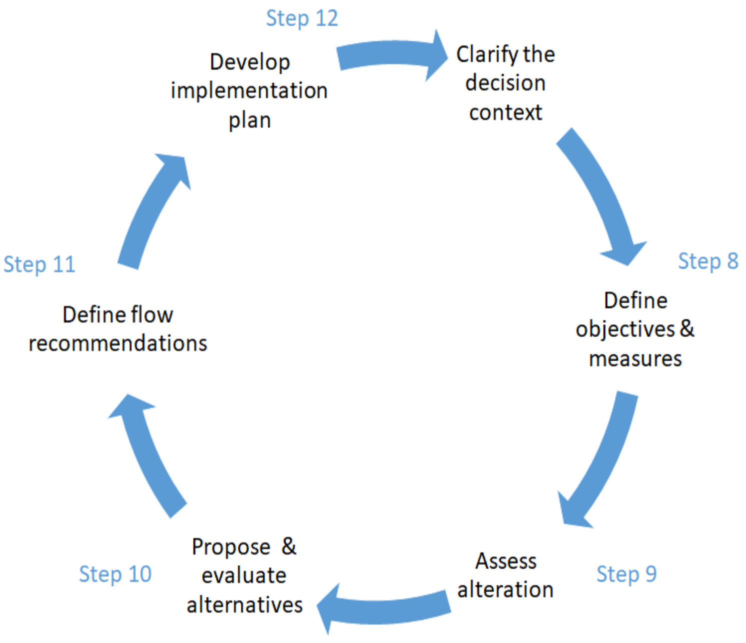

Figure 4.2. A Structured Decision-Making process for developing and implementing environmental flow recommendations, adapted from Failing et al. (2013). Associated Framework Steps 8-12 are indicated in blue.

Step 8: Identify management objectives

Objective: *To identify the full set of management objectives that should be considered in determining environmental flow recommendations, including both ecological management goals (from Step 1) and non-ecological management goals, in addition to any regulatory requirements*

Clarify the decision context

Consideration of relevant federal, statewide, and local laws and policies related to beneficial uses, streamflow and ecological conditions is important in helping the user understand how existing policy and legal conditions may be used to support the implementation of environmental flow recommendations. In California, existing laws, policies and processes focused on water quality, water supply, and habitat often also relate to environmental flows. Some, but not all, regulations that should be considered include:

- State and federal Endangered Species Acts, which prohibit unauthorized "take" of threatened and endangered species through factors including habitat and hydrologic alteration
- Federal Clean Water Act and State Porter Cologne Act, which establish the beneficial use for fish and wildlife preservation and enhancement, and the procedure to apply for a water right for instream use
- The Federal Energy Regulatory Commission (FERC) relicensing process, which provides the opportunity to negotiate dam operations to facilitate ecological flows for species of interest
- California Fish and Game Code 5937, which requires that dam operators release sufficient water to keep fish below dams in good condition
- Sustainable Groundwater Management Act (SGMA) - which require consideration of "undesirable results" associated depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water caused by groundwater conditions occurring throughout the basin, such as effects on the ability to support priority species.
- Recycled Water Policy - encourages the safe use of recycled water from wastewater sources in a way that meets state and federal water quality laws, protects public health and the environment, such as making sure to substitute the use of surface water/groundwater sources with recycled water, and reassuring that the reduction in the wastewater treatment discharge does not affect the water quantity or quality that support freshwater ecosystems.
- State water rights law (including Water Code Section 106), which may affect environmental flows recommendations due to competing or senior water rights

- Other local ordinances that may constrain environmental flow implementation (e.g., stormwater management, wastewater discharge requirements)

Identify management objectives and measures

The ecological flow criteria developed in Sections A and B support the ecological management goals for a study area. Development of environmental flow recommendations, however, also requires consideration of non-ecological management goals, which may broadly include meeting municipal and agricultural water demands, generating hydropower, flood management, eliminating or reducing nuisance dry weather flows, discharging wastewater outflow, and providing water for recreational purposes. When identifying specific and quantifiable non-ecological management objectives, the user also identifies the responsible agencies or stakeholders associated with these objectives within their geographic area, and the requirements that the agencies must fulfill. These agencies or stakeholders should be involved in the objective-setting process, with the user expressing management objectives as a desired outcome that includes associated performance measures (i.e., the same strategy used in Step 6 for ecological management goals). Specific agency mandates and regulations should be considered when developing management objectives; however, consistency and compliance with these regulations will be determined by each relevant agency.

Outcome of Step 8

- A full set of management objectives, that incorporate both ecological and non-ecological water management goals, and associated performance measures
- Relevant regulatory requirements necessary to evaluate management objectives
- List of key stakeholders and a process for ongoing stakeholder engagement

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Example: Coastal Watershed in Northern California

Continuing the example from Sections A and B, it was determined that LOI 1 had no non-ecological water management goals, and that the ecological flow criteria at this location are accepted as environmental flow recommendations. However, there are competing management objectives for LOI 2 – specifically, satisfying the water needs of domestic and agricultural water users in the watershed (Table A.8).

Table A.8. Non-ecological Water Management Goals for LOI 2.

Non-ecological Management Goal	Performance Measure
Meet domestic and agricultural surface water use needs in the area of interest	Proportion of monthly water demand satisfied for domestic and agricultural water users

It was also determined that the following regulations should be considered when developing environmental flow recommendations for LOI 2:

- **Lake and Streambed Alteration Agreement (LSA)**: Agreements would be necessary for the construction of diversion structure.
- **Federal and California Endangered Species Act (ESA) authorization**: Review and authorization under federal and State ESA would be required if diversions may affect species or habitats protected under the Acts.
- **Section 404 and 401 Clean Water Act permits**: Federal Clean Water Act permits would be required for construction and maintenance of diversion structures.

As part of Step 8, the following stakeholders were also identified for inclusion in the process of developing environmental flow recommendations:

- Local landowners
- Local irrigation district
- Local environmental NGOs
- California Department of Fish and Wildlife
- Local Resource Conservation District

Step 9. Assess flow alteration

Objective: *To evaluate whether flow conditions at the location(s) of interest (LOI) are likely unaltered, likely altered, or indeterminate by comparing present-day ranges of functional flow metrics for functional flow components to the ecological flow criteria defined in Step 7*

Compare present-day conditions to ecological flow criteria

First, the user compares current hydrologic conditions at the LOI to ecological flow criteria to assess whether current conditions are likely altered, likely unaltered, or indeterminate. If current conditions are altered relative to flow conditions in the absence of all human activity, the user proceeds to Steps 10-12, including evaluating opportunities to modify existing management practices to reduce alteration (Step 10), developing environmental flow recommendations that consider the need to balance ecological and non-ecological management objectives (Step 11), and identifying mitigation measures to reduce the effects of altered flow (Steps 11 and 12). For detailed methods on this analysis, see Appendix J.

The assessment consists of the following steps (which are intended for non-peak flow metrics only):

1. Obtain the list of ecological flow criteria for each functional flow metric range at the LOI (outputs of Sections A and B, defined in Step 7)
2. Obtain current, daily flow data at each LOI from gage stations or hydrologic models
3. Quantify values for functional flow metrics based on current conditions using the functional flow calculator at https://eflows.ucdavis.edu/hydrology (Appendix K)
4. Assess hydrologic alteration to identify which metrics do not currently meet the ecological flow criteria and quantify the direction and degree of alteration. This can be done for all years combined or by water year type if there is sufficient data.

Then, the user evaluates whether local observed flow conditions are likely unaltered, likely altered, or indeterminate by comparing present-day functional flow metric ranges to the ecological flow criteria defined in Step 7. A flow alteration assessment approach has been developed for applications in which a user compares observed ranges of flow with predicted, natural ranges of functional flow metrics obtained from the California Natural Flows Database (Appendix J). In such cases, flow alteration status is determined according to the following rules (Figure 4.3):

- Current conditions are *likely unaltered* if the median observed value falls within the 10th to 90th percentile range of the ecological flow criteria and greater than 50% of the observations fall inside of the 10th to 90th percentile range.
- Current conditions are *likely altered* if the median observed value falls outside the 10th to 90th percentile range of the ecological flow criteria.
- Alteration is *indeterminate* if the median observed value falls within the 10th to 90th percentile range of the ecological flow criteria but less than 50% of observed values fall within the 10th to 90th percentile range.

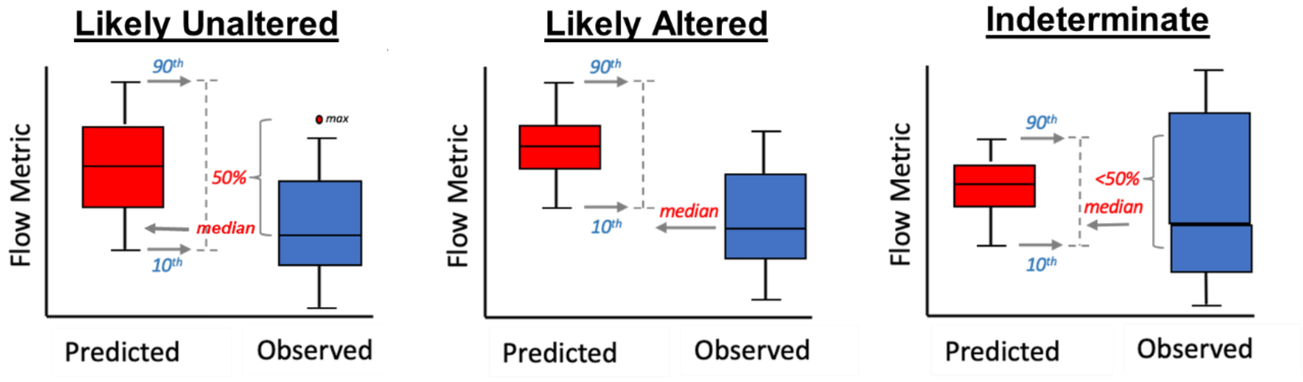

Figure 4.3. Alteration assessment determination for a functional flow metric. Predicted natural ranges for functional flow metrics (in red) represent the ecological flow criteria at a LOI against which observed values (in blue) are compared. The box and whiskers plots represent the range

(10th, 25th, 50th, 75th, and 90th percentiles) of predicted and observed values for the functional flow metric.

How to visualize hydrologic alteration (optional)

In order to better understand the nature of flow alteration at an LOI, the user may decide to qualitatively compare observed flow patterns with those at regional reference gages. Reference hydrology can be explored at two scales:

Reference gage data: Locally, users can identify and examine the flow data from reference gages occurring within their geographic region. Reference gages are defined as having minimal hydrologic disturbance based on the criteria described in Falcone et al. (2010) and reported in the USGS GAGES II database. Lane et al. (2018) identified 223 streamflow gages as reference quality in California. Reference streamflow gage locations, stream classes, and records can be viewed and downloaded at eflows.ucdavis.edu/hydrology.

Regional stream patterns: The user can also explore stream patterns at a regional scale for a specific stream class using dimensionless reference hydrographs (DRHs), which are unimpaired daily streamflow time series that have been non-dimensionalized by dividing daily flows by average annual flow. These DRHs represent the seasonal and inter-annual variation of natural hydrologic conditions in the absence of alteration from land use, diversions, or impoundments. DRHs have been constructed for each of the nine hydrologic stream classes and for each reference gage to explore the inherent variability of hydrologic conditions that occur in the geographic region. DRHs for reference data are available to view interactively on eflows.ucdavis.edu/hydrology. Users can compare DRHs to dimensionless observed hydrographs calculated for their LOI(s) using tools on the eflows website to provide insight into current local flow patterns versus reference flow conditions (Figure 4.4). For example, the impacts of winter diversions can alter the wet-season baseflow magnitude and frequency and magnitude of peak flows (Figure 4.4b) relative to reference conditions (Figure 4.4a).

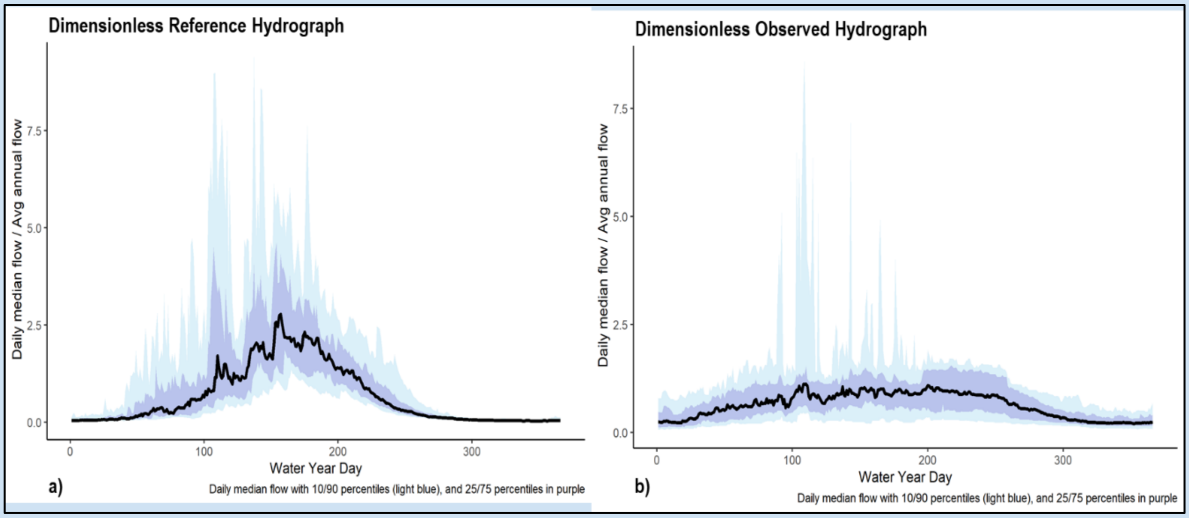

Figure 4.4. An example of a) dimensionless reference hydrograph (DRH) for a low-volume snowmelt and rain stream and b) a dimensionless observed hydrograph for a gage in the Sierra

Nevada where flows are altered due to a diversion dam. Both figures were calculated and output from eflows.ucdavis.edu/hydrology.

If different hydrologic models are used to assess current and predicted, natural flows, the user may develop alternative rule sets to classify alteration status. However, in all cases, a functional flow component should be considered *altered* if any of its functional flow metrics are likely altered.

Identify likely causes of alteration

Once patterns of alteration are assessed, the user identifies potential causes of alteration that can be addressed by management interventions. Sources of alteration may be near the LOI or further upstream, and can include factors such as physical alteration of the stream channel, controlled discharges, diversions, impoundments, groundwater withdrawals, or land use practices. Users may consult the State Water Board's eWRIMS water rights database and consult with local agency staff regarding sources of diversions. For each potential source of alteration, the user should identify the potential mechanisms responsible for altered flow. Understanding the relationship between the source of alteration, the effect on functional flow components, and related effects on ecosystem functions will support evaluation of measures to reduce impacts and assess tradeoffs between ecological and non-ecological management objectives. To the extent possible, this analysis should also attempt to account for anticipated changes in future flows associated with climate change based on the best available local projections and models.

Outcome of Step 9

- Determination of which functional flow metrics and functional flow components are altered
- Comparison of current and reference annual hydrology using dimensionless hydrographs (optional)
- Identification of likely causes of hydrologic alteration

Example: Coastal Watershed in Northern California

An alteration assessment was conducted on all functional flow components at LOI 2. It was determined that only dry-season baseflow was altered. Current summer baseflow magnitudes were found to be substantially lower (5-7 cfs) than the ecological flow criteria (22-23 cfs) (Table A.9). It was further determined that the difference between current conditions and the criteria was the result of stream widening and sparse vegetation (caused by historic logging activity), such that higher flows are needed to maintain desired temperatures. The impacts of upstream diversions were also impacting streamflow in the dry season by depleting dry season baseflows.

Table A.9. Results of alteration assessment for LOI 2. All components were found to be likely unaltered except the dry-season baseflow. Note: The natural range of functional flows for dry-season baseflow magnitude at LOI 2 was estimated to be 7-15 cfs.

Flow Component	Flow Metric	Ecological Flow Criteria	Current Conditions	Alteration Status	Likely Source of Alteration
Dry-season baseflow	Dry-season baseflow	22-23 cfs (determined in Step 7)	5 - 7 cfs	likely altered	stream widening creates need for higher baseflow; upstream diversions reduce flow magnitude
	Dry-season timing	June 20 (June 5 - July 7)	June 10 - July 15	indeterminate	uncertain source of alteration
	Dry-season duration	151 (121 - 183) days	125 - 185 days	likely unaltered	not applicable

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Step 10. Evaluate management scenarios and assess tradeoffs

Objective: *To explore non-flow and flow-based strategies to satisfy ecological flow criteria, quantify the ecological consequences of failing to satisfy ecological flow criteria, and propose mitigation measures to offset impacts, if any*

Environmental flow recommendations incorporate multiple competing objectives for water and may require balancing of competing uses. There is rarely a single, optimal set of flow recommendations that will satisfy all needs, or equally distribute impacts. Ecological flow criteria represent one possible environmental flow recommendation that achieves ecological management objectives but that potentially disregards other management needs. Environmental flow recommendations that deviate from ecological flow criteria may satisfy other management needs, but risk failure in achieving ecological management objectives. There are countless possible environmental flow recommendations that entail different tradeoffs among management objectives; however, there is likely to be a discrete set of scenarios that are potentially acceptable to stakeholders and require detailed evaluation.

Propose and simulate alternative management scenarios

Identify non-flow management actions

The user, in coordination with agency staff and local stakeholders, identifies a set of non-flow actions that have the potential to satisfy all management objectives for the study area, including both ecological and non-ecological management goals. These actions may include direct channel modifications, changes in land use, or riparian revegetation, among others, that will make it possible to achieve ecological flow criteria while satisfying other management needs.

Identify flow-based management actions

If non-flow actions cannot satisfy ecological flow criteria, flow-based management alternatives should also be considered. In this case, the user identifies flow-management strategies that minimize deviance from the ecological flow criteria. These strategies include changes to existing water management practices (e.g., reservoir re-operations, adjusted wastewater releases, diversion scheduling, etc.) that attempt to satisfy ecological flow criteria while minimizing or avoiding adverse effects to other non-ecological management objectives.

If proposed changes to management practices allow users to meet ecological flow criteria while satisfying other non-ecological management objectives, then the environmental flow recommendations will be the same as ecological flow criteria. However, if proposed actions do not allow users to satisfy ecological flow criteria without significantly compromising other non-ecological management objectives, alternative environmental flow recommendations that deviate from ecological flow criteria should be identified.

Evaluate consequences and assess management tradeoffs

Any environmental flow recommendation may have consequences for both ecological and non-ecological management goals. For example, adoption of ecological flow criteria from Section B could require consideration of alternative flow diversion practices to meet agricultural water needs. Many quantitative tools, including mechanistic models, statistical relationships, water allocation models, cost-benefit analyses, life-cycle models, infrastructure planning, or social (system dynamics) models among others, may be used to predict the outcomes and consequences of implementing alternative management scenarios for each management objective. As part of the Framework, we do not recommend or advocate for any specific approach; the choice of approach is case-specific and should be made as part of the stakeholder process. Similarly, it is beyond the scope of this document to provide a comprehensive review of available tradeoff approaches.

Quantify tradeoffs

Once alternative environmental flow scenarios have been assessed, the user assesses tradeoffs among management objectives for each alternative. Multi-Criteria Decision Analysis (MCDA) provides a useful approach for quantifying tradeoffs and can include simple checklists, tradeoff curves, optimization models, and other quantitative predictions. Tradeoff assessment should consider options for maximizing certain benefits during specific times of the year or under specific climatic conditions (i.e., wet years vs. dry years). Appendix L describes one example of a decision support system and collaborative MCDA modeling approach to assist managers and stakeholders in assessing tradeoffs and developing environmental flow recommendations that achieve an acceptable balance among competing management objectives.

Outcome of Step 10

- Tradeoff analysis between ecological and non-ecological management objectives under alternative management scenarios
- Identification of preferred management alternative

Example: Coastal Watershed in Northern California

The alteration assessment indicates that ecological flow criteria can be satisfied under current conditions for all components except dry-season baseflow. These criteria are therefore proposed as environmental flow recommendations with no modifications. However, to develop environmental flow recommendations for dry-season baseflow, both flow and non-flow management actions are considered. The reduction of summer water diversions is identified as a key strategy for increasing dry season baseflow. Impacts to water users can be minimized by incentivizing off-stream water storage projects for domestic and agricultural water users that are filled in the wet season. The potential impacts of wet season water diversions are also evaluated to ensure that ecological flow criteria for wet-season baseflow and peak flows can still be satisfied. The various alternatives are evaluated using a tradeoff consequence table based on the approach of Gregory et al. (2012). Results of the tradeoff analysis indicate that small off-stream storage is expected to restore the dry-season baseflow magnitude to 7-12 cfs and provide reasonable habitat and recreational use benefits, while allowing dry season diversions only for essential domestic water use (Table A.10).

Table A.10. Consequence table showing results of the tradeoff analysis for LOI 2. Small off-channel storage results in a reasonable balance between ecological and non-ecological objectives.

Alternative	Dry-season baseflow magnitude (cfs)	Reduction in water availability	Habitat benefit	Recreation value (rank)
current conditions	5-7	*	L	1
small off-channel storage	7-12	**	M	4
large off-channel storage	15-20	***	M	3
no diversion/no storage	22-23	****	H	2

Nevertheless, even with the reduction in seasonal diversions, dry-season baseflow magnitudes are not expected to satisfy the ecological flow criterion (Table A.9). Non-flow management actions are also required to enhance the function of summer baseflow in maintaining desired water temperatures. Priority actions include the restoration of the stream channel to support deeper, more shaded pools through the addition of large woody debris and planting of riparian vegetation along the river channel. These actions would improve shading, reduce temperatures, and aid in narrowing the channel, thereby increasing the functionality of lower magnitude baseflow.

Step 11. Define environmental flow recommendations

Objective: *To select a preferred management alternative set of environmental flow recommendations in collaboration with stakeholders and agency partners based on the results from the previous 10 steps, and then to develop the final set of environmental flow recommendations*

In Step 11, the user defines final environmental flow recommendations that account for both human and ecological objectives. For some functional flow metrics, the environmental flow recommendations and the ecological flow criteria will be the same, but they may differ in cases where management trade-offs cannot be avoided. As mentioned previously, balancing among management objectives is a process driven by social values and interpretation of regulatory requirements, and it will need to account for ecological, economic, social, and public safety considerations, among others. Multiple stakeholders, including relevant State agencies, should be involved in selecting final environmental flow recommendations.

Final environmental flow recommendations should also include measures that enhance the effectiveness of flow in support of ecosystem functions and habitat for target species, especially when recommendations deviate from ecological flow criteria. Mitigation measures might include riparian revegetation to reduce temperature through shading, channel grading to reconnect floodplains and off-channel habitats, or invasive species control. Mitigation measures should be included in the implementation plan developed in Step 12.

Outcome of Step 11

- Final set of environmental flow recommendations
- List of measures to enhance the effectiveness of environmental flows or mitigate adverse effects (if final recommendations deviate from ecological flow criteria)

Example: Coastal Watershed in Northern California

In Step 7, it was determined that dry-season baseflow should be 22-23 cfs to meet temperature, water depth, and velocity needs of salmonids under current conditions. However, it is not possible to increase dry season baseflows over the natural reference range via diversion restrictions. A range of 7-12 cfs is established as the environmental flow recommendation for dry-season baseflow magnitude. In addition, the stream restoration measures identified in Step 10 are recommended to improve habitat conditions for salmonids by narrowing the channel, deepening pools, and recovering riparian vegetation to enhance the functionality of the lower baseflow magnitude.

Table A.11 summarizes the environmental flow recommendations for LOI 2. Ecological flow criteria are used to establish flow recommendations for LOI 1 because there are no non-ecological management goals for this LOI. For most components and metrics at LOI 2, the environmental flow recommendations and the ecological flow criteria (defined in Step 7) are the same, but they differ for dry-season baseflow magnitude based on the results from Steps 8-10.

Table A.11. Environmental Flow Recommendations for LOI 2. Note that environmental flow recommendations are the same as ecological flow criteria for all but dry-season baseflow magnitude.

Functional Flow Component	Flow Characteristic	Ecological Flow Criteria	Environmental Flow Recommendation
Fall pulse flow	Fall pulse magnitude	62 (30-180) cfs	62 (30-180) cfs
	Fall pulse timing	Oct 20 (Oct 7 - Oct 28)	Oct 20 (Oct 7 - Oct 28)
	Fall pulse duration	3 (2 - 7) days	3 (2 - 7) days
Wet-season baseflow	Wet-season baseflow	324 (260 - 410) cfs	324 (260 - 410) cfs
	Wet-season timing	Nov 13 (Nov 3 - Nov 30)	Nov 13 (Nov 3 - Nov 30)
	Wet-season duration	168 (145 - 184) days	168 (145 - 184) days
Wet-season peak flows	5-year peak flow magnitude	3790 (3000 - 4800) cfs	3790 (3000 - 4800) cfs
	5-year peak flow duration	3 (1 - 6) days	3 (1 - 6) days
	5-year peak flow frequency	1 (1-3) event(s)	1 (1-3) event(s)
Spring recession flow	Spring recession magnitude	520 (300 - 980) cfs	520 (300 - 980) cfs
	Spring timing	Apr 28 (Apr 6 - May 14)	Apr 28 (Apr 6 - May 14)
	Spring duration	50 (36 - 66) days	50 (36 - 66) days
	Spring rate of change	6 (3 - 10) % decline per day	6 (3 - 10) % decline per day
Dry-season baseflow	Dry-season baseflow	22-23 cfs	**7 - 12 cfs**
	Dry-season timing	June 20 (June 5 - July 7)	June 10 - July 15
	Dry-season duration	151 (121 - 183) days	125 - 185 days

Step 12. Develop an implementation plan

Objective: *To develop an implementation plan that includes an adaptive management plan and monitoring strategy that will guide implementation of environmental flow recommendations, including the associated mitigation measures*

Implementation and adaptive management

Once environmental flow recommendations are developed, an implementation plan and an adaptive management plan are developed by the local agencies responsible for managing flows. The implementation plan should identify:

a) What management actions or strategies should be implemented in order to achieve environmental flow recommendations

b) Where and when management actions should be implemented

c) Who is responsible for implementing different management actions (Implementation responsibility may be shared among different entities based on jurisdiction, location in the watershed, or mission. When implementation is shared, a coordination mechanism should be developed to facilitate ongoing cooperation during the implementation phase and to reduce redundancy.)

d) What resources are necessary over what timeframes to support implementation (This will require a consideration of the timeframe of implementation. For example, are management measures temporary, permanent, seasonal, etc.?)

e) What the ongoing operations and maintenance requirements of various management measures should be, and who is responsible for conducting the maintenance (In many cases, it may be necessary to develop a dedicated maintenance plan that provides details on maintenance responsibilities and how they will be supported. Long-term funding mechanisms for ongoing maintenance and monitoring must also be considered.)

f) How the outcomes of management actions will be assessed and provide feedback that guides future management actions (i.e., adaptive management)

The implementation plan should be closely related to the maintenance and monitoring strategy (see below) in that it should include performance measures that assess how well management measures are working and what adaptive management measures may be appropriate if performance is less than desired. Example implementation plans and resources can be found on the USEPA’s Wetlands website and on the California Water Quality Monitoring Council’s State Wetland and Riparian Monitoring Program website.

The California Environmental Flows Framework and its approach to establishing environmental flow recommendations is relatively new and, like all environmental flow approaches, is associated with uncertainty regarding actual ecological impacts. As such, monitoring and adaptive management are critical to evaluating the efficacy of the overall approach and performance in specific locations. These efforts will provide critical data that can be used to further refine flow-ecology relationships and conceptual models in each study area. Adaptive management is defined as learning by doing and modifying future actions (adapting) based on information that is learned (Walters and Holling 1990). However, adaptive management is not the same as trial and error. It is a systematic approach to learning and improving decision making over time, and it is appropriate when there are alternative hypotheses about best management actions to achieve desired outcomes. Adaptive management should have a systematic learning component and an explicit plan for future actions that will be taken under each different monitoring outcome (Williams and Brown 2012; Runge 2011).

Monitoring

Monitoring is a crucial component of adaptive management, because monitored ecological responses are used to determine future implemented actions. Monitoring results should be closely coupled to the implementation plan so that measured indicators can be used to determine if performance measures are being met or if adaptive management measures need to be implemented. Performance measures should generally meet the following criteria:

- Clear and unambiguous
- Defensible and science-based
- Readily quantifiable with known levels of confidence
- Descriptive and inclusive of the set of management objectives
- Can be used as pre-defined triggers in the adaptive management plan

Like all monitoring programs, monitoring of environmental flow implementation should be question-driven and modular. USEPA provides general guidance on the elements of a good monitoring program that can be consulted in preparing a monitoring plan. Typical questions that should be addressed through a monitoring program include:

1. **Question #1 (Performance assessment)**: How effective are specific management measures/strategies?
2. **Question #2 (Effectiveness assessment)**: How effective is the overall flow management program at achieving regional or watershed management objectives?
3. **Question #3 (Trends assessment)**: Are conditions getting better or worse over time?
4. **Question #4 (Causal assessment)**: What are the predominant factors that affect performance of management measures and overall program effectiveness?

Monitoring design should be catered to each question. For example, Question #1 (performance assessment) may be addressed through targeted monitoring of key locations where management measures have been applied, along with relevant comparator or reference sites. Question #2 (effectiveness assessment) may be addressed through a combined probabilistic and targeted design. Question #3 (trends assessment) may be best addressed by monitoring sentinel sites or repeat visit sites. The state of California Framework for Developing Hydromodification Monitoring Programs (Stein and Bledsoe 2013) provides a useful example for developing flow-ecology monitoring.

A multi-indicator approach should generally be used that includes continuous hydrologic monitoring along with seasonal monitoring of geomorphology, water quality, and biology. In all cases, the ecological outcomes being managed for and associated performance measures (identified in Step 8) should be included to both directly assess whether the desired ecological responses have been achieved and to help provide data to improve flow-ecology relationships and reduce uncertainties for future application. The monitoring program should include detailed quality control procedures, including standard operating procedures and data quality objectives for every parameter being measured. Data templates should also be included to facilitate efficient data management and dissemination of information to agency staff, stakeholders, and the public. It is important to keep in mind that if the monitoring program only measures ecological management objectives, then the adaptive management plan can only inform aspects of the environmental flow recommendation designed to provide desired ecological responses. It cannot inform decisions regarding how well a flow recommendation balances competing management objectives or achieves ecological or non-ecological management goals. For adaptive management to inform all aspects of an environmental flow regime, the monitoring plan should be inclusive of metrics that describe outcomes for all management objectives.

Implementing a flow management program will require ongoing monitoring, management, and adaptation. Changing land use and water use practices, climate change, and effects of mitigation and management measures will result in a dynamic situation that requires periodic assessment and potentially adjusting environmental flow recommendations. This process will be most successful if coordinated through established workgroups that include experts on ecological, social, and policy issues within the study area.

Outcome of Step 12

- Implementation plan that includes mitigation measures and adaptive management
- Monitoring strategy that informs adaptive management
- Schedule for assessing performance and determining if adaptive management is necessary

Outcome of Section C

In completing all 12 steps of the Framework, the user develops environmental flow recommendations necessary to support the broad suite of ecological functions and human water needs associated with their locations of interest. These will include articulation of the physical, biogeochemical, and biological factors that should also be addressed through enhancement and mitigation measures to ensure that all ecosystem functions are met. At the end of Section C, the development of an implementation plan and monitoring strategy that incorporate adaptive management principles increases the likelihood that environmental flow recommendations will achieve desired management objectives.

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