Applying the California Environmental Flows Framework to the San Juan Hydrologic Unit – Lower Aliso Creek

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Purpose and Summary

The San Juan Hydrologic Unit in South Orange County (OC), California encompasses several major streams including San Juan Creek, Trabuco Creek, Oso Creek, Aliso Creek, among others. Flow alteration and stream erosion have been identified as the highest priority water quality conditions for the region by local watershed managers and stakeholders. Flow alteration is a pervasive issue across South OC due to the effects of historical farming and ranching and more current rapid urbanization over the past 50 to 70 years. Flashier hydrology due to urban development has led to channel erosion issues, especially in Aliso Creek, and many streams have shifted from a historically intermittent-ephemeral system to a perennial system due to augmented baseflows from irrigation overspray. In some areas, these augmented flows now support sensitive species and habitats that were not historically present. Despite the widespread hydrologic alteration, streams in South OC currently support a combination of willow and riparian scrub communities, as well as federally listed bird species, such as the least Bell's vireo (*Vireo bellii pusillus*), and fish species of special concern, such as the arroyo chub (*Gila orcuttii*).

To improve hydrologic conditions and to support habitat restoration, key implementation strategies have been identified through the South OC Watershed Management Area (WMA) Water Quality Improvement Plan including management of unnatural flows and restoration of 23,000 lineal feet (4.35 mi) of degraded stream habitat. However, reduction of in-stream flows through flow management actions, drought, and water conservation, pose a potential threat to novel habitat and sensitive species that currently depend on these "non-reference" flows. This study aims to prioritize areas for flow management and restoration and to recommend management actions. Determining environmental flow needs will shed light on how to manage water to promote streamflow enhancement and environmental restoration while balancing the needs of the communities of South Orange County. The California Environmental Flows Framework (CEFF) was applied to prioritize where to focus flow management efforts (Irving et al., 2022) and to determine ecological flow needs that consider altered channel morphology and the flow needs of species of management concern (Taniguchi-Quan et al., 2022). Taniguchi-Quan et al. (2022) summarizes the CEFF application at a priority reach in lower Aliso Creek and illustrates how CEFF was applied in a highly modified, urban watershed. This document details the results of this CEFF application. Additional information on the larger study can be found on the project website (https://www.southocwqip.org/pages/flow-ecology-study), including the study's final report and final data products.

Overview of the California Environmental Flows Framework

The California Environmental Flows Framework (hereafter "CEFF") was developed by a technical team within the California Environmental Flows Working Group, a sub-group hosted by the California Water Quality Monitoring Council that includes scientists and managers from resource agencies, academia, and non-governmental organizations. CEFF establishes a technical process for developing environmental flow targets for rivers throughout the state. CEFF is based upon ***functional flows***, a scientific concept that emphasizes the biological, chemical, and physical functions of flowing water that sustain native aquatic species and riparian ecosystems. Managing streams using functional flows represents a holistic approach for improving ecosystem health—one that delivers broad benefits for people and nature while also accommodating human demands on the system.

CEFF was established to support resource managers tasked with defining ***ecological flow criteria***—quantifiable metrics that describe ranges of flow that must be maintained within a stream and its margins throughout the year to support healthy ecosystems—for California's river and streams. CEFF aims to produce consistent, scientifically-supported ecological flow criteria that can be used to determine ***environmental flow recommendations*** that satisfy ecosystem water needs and other water management objectives. Environmental flow recommendations are expressed as a "rule set" of flow requirements that are informed by ecological flow criteria but also take human uses and other water management objectives into consideration.

The technical approach of CEFF rests upon the scientific concept of ***functional flows***—distinct aspects of a flow regime that sustain ecological, geomorphic, or biogeochemical functions, and support the specific life history and habitat needs of native aquatic species (Yarnell et al., 2015). Managing for functional flows preserves essential patterns of flow variability within and among seasons but does not mandate the restoration of full natural flows nor maintenance of historical ecosystem conditions. In addition, the functional flows approach is not focused on the habitat needs of a particular species, but rather, focuses on preserving key ecosystem functions, such as sediment movement, water quality maintenance, and environmental cues for species migration and reproduction, that maintain ecosystem health and are broadly supportive of native freshwater plants and animals.

CEFF focuses on the following five basic functional flow components that represent significant drivers of ecological processes in California, and are defined in Yarnell et al. (2020) (Figure 1):

- **Fall pulse flow**, or the first major storm event following the dry season. These flows represent the transition from dry to wet season and serve important functions, such as moving nutrients downstream, improving streamflow water quality, and signaling aquatic species to migrate or spawn.
- **Wet-season baseflow**, which support native aquatic species that migrate through and overwinter in streams.
- **Wet-season peak flows**, which transport a significant portion of sediment load, inundate floodplains, and maintain and restructure river corridors.
- **Spring recession flow**, which represents the transition from high to low flows, provide reproductive and migratory cues for native aquatic species, and redistribute sediment.
- **Dry-season baseflow**, which support native aquatic species during the dry-season period when water quality and quantity limit habitat suitability.

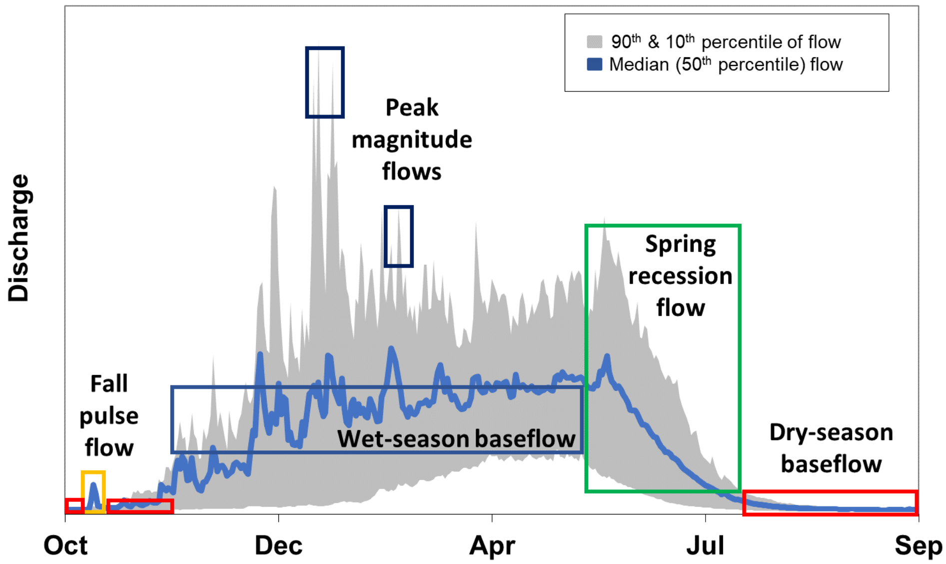

Figure 1. Functional flow components (colored boxes with labels) for California illustrated over a representative hydrograph (Figure from Yarnell et al. 2020). Blue line represents median (50th percentile) daily discharge. Gray shading represents 90th to 10th percentiles of daily discharge over the period of record.

The five functional flow components identified for California provide the basis for determining ecological flow criteria and assessing potential stream flow alteration in CEFF. Each functional flow component is quantified by several functional flow metrics that describe the magnitude, timing, frequency, duration, or rate of change of flows within the flow component. Details on the definition of each functional flow metric, including calculation methods, can be found in Yarnell et al. (2020) and CWQMC-EFW (2021). Together this suite of functional flow metrics can be used as ecological flow criteria for any stream location in the state.

The initial steps of CEFF provide guidance on setting broad ecological management goals and identifying specific location(s) of interest (LOI(s)) within the geographic region. CEFF then provides a set of ecological flow criteria that quantify the range of instream flow conditions at each LOI supportive of ecological processes under natural (i.e. non-altered) flow conditions. In instances where non-flow impairments, such as altered physical habitat or poor water quality, may limit the ability for the natural range of functional flow metrics to support desired ecological functions, CEFF provides further guidance for determining appropriate ecological flow criteria. In later steps of CEFF, the ecological flow criteria are then compared with current streamflow conditions at each LOI to assess potential flow alteration. Depending on management objectives, these ecological flow criteria can be translated into environmental flow recommendations or assessed in relation to anthropogenic water needs to determine environmental flow recommendations that balance ecological and non-ecological objectives. Further information about CEFF, including a CEFF application guidance document and FAQs, can be found at *ceff.ucdavis.edu*.

The remainder of this report is organized to follow and detail the steps outlined in CEFF (Version 1.0, April, 2021) to determine ecological flow criteria at a representative location on lower Aliso Creek. The main goal was to determine ecological flow criteria (Sections A and B), to assess flow alteration (Section C, step 9), and explore an alternative non-flow management scenario (Section C, step 10). We summarize considerations for Section C; however, additional work in collaboration with the stakeholder group should be undertaken if the goal is to develop final environmental flow recommendations. The findings of CEFF sections A and B can be used as a basis for dialogue among stakeholders to determine final environmental flows that integrate human use with ecological functions.

Section A – Identifying ecological flow criteria using natural functional flows

Step 1: Define ecological management goals

Site Context

The geographic focus of this analysis was Aliso Creek watershed within the San Juan Hydrologic Unit (Figure 2).

This analysis focused on one location of interest (LOI) on a high priority area in lower Aliso Creek (Figure 2) to illustrate the process and application of CEFF to develop ecological flow needs. However, the methods used in this study were chosen to allow for the evaluation to be applied at the regional scale, across a multitude of high priority stream reaches. The Lower Aliso study reach was selected for this study because it is subject to a potential decline in dry-weather flows from upstream outfall discharge diversions, has experienced urban-induced channel erosion, and is a soft-bottom reach of habitat importance for riparian and aquatic communities.

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

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

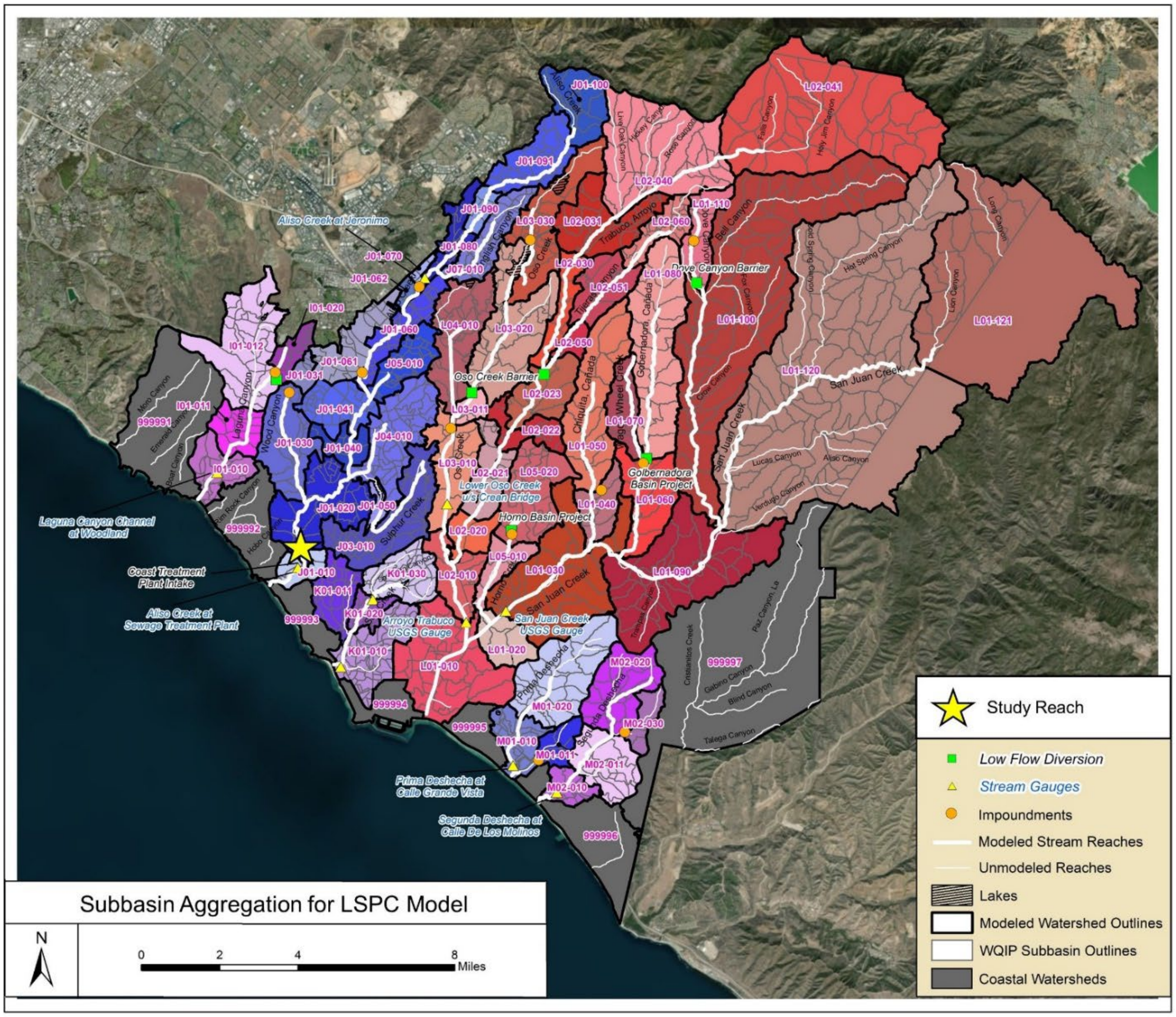

Figure 2. Geographic study region, San Juan Hydrologic Unit, and location of interest for this study (star) in Aliso Creek watershed (dark purple shading).

Ecological Management Goals

Establishing ***ecological management goals***, or the ecological or biological response that occurs due to a management action aimed at improving or maintaining overall stream health or conditions, allows for the critical evaluation of whether functional flow criteria at the LOI adequately address management needs.

A critical component to implementing CEFF is ongoing stakeholder engagement that seeks to integrate stakeholder values and local knowledge into the scientific process. We have collaborated closely with the County of Orange Public Works, Geosyntec Consultants, and all member agencies on our technical and stakeholder advisory group, which included federal and state resource and regulatory agencies, local water districts, non-governmental and private organizations, local watershed groups, and academic researchers (Table 1).

Table 1. Participating agencies and organizations involved in the technical and stakeholder advisory groups. Note: this list may not include all participating agencies or organizations.

Participating Agency/Organization
Alta Environmental
B/E Aerospace
Bespoke Mitigation Partners
California Department of Fish and Wildlife
California Indian Legal Services
California Trout
California Water Quality Monitoring Council
CalTrout
City of Carlsbad
City of Dana Point
City of Laguna Beach
City of Laguna Niguel
City of San Juan Capistrano
City of Temecula
City San Juan Capistrano
Clean Water Now
County of Orange / OC Environmental Resources
County of Orange / OC Parks
County of San Diego
Custom Chemical Formulators, Inc.
CWE
Dudek Environmental
FluvialTech Inc.
HDR
Huitt-Zollars
ICF
Inland Empire Utilities Agency
King County Water and Land Resources Division
LA County Sanitation District
Laguna Bluebelt Coalition
Laguna Canyon Foundation
Laguna Ocean Foundation
Larry Walker Associates
Michael Baker International
Monterey Peninsula Water Management Agency
Moulton Niguel Water District
Municipal Water District of Orange County

NOAA Fisheries
Orange County Transportation Authority
Orange County Coastkeeper
Rancho Mission Viejo
Riverside County Flood Control and Water Conservation District
San Diego Regional Water Quality Control Board
San Juan Basin Authority
South Coast Water District
South Orange County Wastewater Authority
State Water Board
California Department of Water Resources
The Nature Conservancy
Trout Unlimited
U.S. Fish and Wildlife Service
UC Berkeley
UC Davis
UltraSystems Environmental. Inc.
University of California Cooperative Extension
USACE-SPL, Regulatory Division
Ventura County Public Works Agency
Wood Environmental & Infrastructure Solutions, Inc.

A total of 9 stakeholder meetings were held over the course of two years, where the group agreed upon management goals and project scope and provided valuable input on the overall technical approach. The overarching ecological management goals for this study, identified through the stakeholder process, are stated below. Specific performance measures for these goals are delineated in step 8.

Ecological Management Goals for Lower Aliso Creek (LOI 1):

- Improve stream flow conditions to benefit overall stream ecosystem health
- Ultimately maintain or provide suitable habitat conditions for indicator species of management concern, willow and arroyo chub, which are representative of riparian and aquatic habitats.

Arroyo chub (*Gila orcutti*) and Goodding's black willow (*Salix goodingii*) are indicator species of management concern that are representative of aquatic and riparian habitats. Arroyo chub are native to the streams of southern California, however have been extirpated in recent years due to habitat degradation, urbanization and fragmentation (Benjamin, May, O'Brien, & Finger, 2016; Moyle, Yoshiyama, Williams, & Wikramanayake, 1995). The willow are key components of riparian vegetation and provide important habitat for the endangered Least Bell's Vireo (*Vireo bellii pusillus)*. In highly urban areas of the study region, channelized reaches lack riparian habitat. Therefore, areas with augmented baseflows that support novel riparian habitat, may be of critical importance.

Using Table 1.2 from CEFF (CWQMC-EFW 2021), a set of ecosystem functions needed to achieve the above ecological management goals was selected for each of the five functional flow components (Table 2).

Table 2. A summary of functional flow components and associated ecosystem functions that must be supported to achieve ecological management goals in Lower Aliso Creek.

Functional Flow Component	**Ecosystem Function(s)**
Fall pulse flow	Increase riparian soil moisture, flush organic material downstream and increase nutrient cycling, reactivate exchanges/connectivity with hyporheic zone
Wet season baseflow	Increase shallow groundwater (riparian), support migration, spawning, and residency of aquatic organisms, support channel margin riparian habitat
Wet season peak flows	Scour and deposit sediments and large wood in channel and floodplains and overbank areas (encompasses maintenance and rejuvenation of physical habitat), increase nutrient cycling on floodplains, increase exchange of nutrients between floodplains and channel, support fish spawning and rearing in floodplains and overbank areas, support plant biodiversity via disturbance, riparian succession, and extended inundation in floodplains and overbank areas, limit vegetation encroachment and non-native aquatic species via disturbance
Spring flow recession	Recharge groundwater (floodplains), decrease water temperatures and increase turbidity, increase hydraulic habitat diversity and habitat availability resulting in increased algal productivity, macroinvertebrate diversity, arthropod diversity, fish diversity, and general biodiversity, provide hydrologic conditions for riparian species recruitment (e.g. cottonwood), limit riparian vegetation encroachment into channel
Dry season baseflow	Maintain riparian soil moisture, maintain water temperature and dissolved oxygen, maintain habitat availability for native aquatic species (broadly), condense aquatic habitat to limit non-native species and support native predators, support algal growth and primary producers

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.

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 (rivers.codefornature.org).

A continuous simulation Loading Simulation Program in C++ (LSPC) hydrologic model was developed and calibrated to characterize current functional flow conditions across the South OC WMA (Figure 2). This model was then applied to estimate reference conditions. We did not use the predicted natural range of functional flow metrics produced by Grantham et al. (2022) in this study because the LSPC model provided finer spatial and temporal resolution than the statewide model and allowed for prediction of future scenarios.

A detailed description of model parameterization and calibration can be found in Taniguchi-Quan et al. (2022). A reference condition model scenario was developed to quantify the natural range of functional flow metrics (CEFF Section A) and to evaluate alteration of the current flow regime to inform management decisions (consideration for CEFF Section C). The reference condition scenario used the current climatic, soil, and slope conditions in the watershed. However, urban and agricultural land, imported water, water extraction, water impoundments, and other flow regulation systems were removed. This condition is not intended to represent a specific point in time but instead to serve as broad characterization of the natural flow variability in absence of anthropogenic disturbances.

Modelled reference and current hourly flow timeseries from water year 1993–2019 were post-processed to mean daily flow, and functional flow metrics were quantified using the Functional Flows Calculator API client package in R (version 0.9.7.2, https://github.com/ceff-tech/ffc_api_client), which uses hydrologic feature detection algorithms developed by Patterson et al. (2020) and the Python functional flows calculator (https://github.com/NoellePatterson/ffc-readme). The functional flows calculator has difficulty detecting the timing of seasonal flow transitions (i.e., transition from dry-season to wet-season or wet-season to spring recession) if the annual hydrograph lacks seasonality. In such cases, the timing, duration, and magnitude metrics cannot be estimated for the water year. If timing values were not quantified with the calculator, we used the median timing value calculated across the period of record, to calculate the seasonal magnitude metrics for dry-season and wet-season baseflow and spring rate of change. The natural ranges of the flow metrics were defined as the 10th to 90th percentiles of the reference metric values calculated across the modelled time-period.

Table 3 below contains the natural ranges of functional flow metrics for Lower Aliso Creek.

Table 3. Natural functional flow metrics for Lower Aliso Creek (LOI 1). Values reflect medians and 10^{th}-90^{th} percentiles of each functional flow metric for all water year types combined. Magnitude metrics are expressed in cubic feet per second (cfs), duration metrics are expressed as the number of days, and frequency metrics are expressed as the number of events per wet season. Definitions for each metric and types of baseflows are provided in CWQMC-EFW (2021).

Flow Component	Flow Metric	**Natural Functional Flow Metrics at LOI 1** median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	2.4 (1.7 - 5) cfs
	Fall pulse timing	Nov 29 (Oct 24 - Dec 3)
	Fall pulse duration	11 (3 - 16) days
Wet-season baseflow	Wet-season baseflow magnitude	3 (2 – 5) cfs
	Wet-season timing	Dec 15 (Oct 10 – Jan 25)
	Wet-season duration	67 (30 - 133) days
	Wet-season median magnitude	6 (4 – 11) cfs
Peak flows	2-year peak flow magnitude	31 cfs
	2-year peak flow duration	4 (1 – 25) days
	2-year peak flow frequency	2 (1 – 8)
	5-year peak flow magnitude	423 cfs
	5-year peak flow duration	3 (1 - 6) days
	5-year peak flow frequency	3 (1 - 4) event(s)
	10-year peak flow magnitude	1753 cfs
	10-year peak flow duration	1 (1 – 2) days
	10-year peak flow frequency	1 (1 – 2) events(s)
Spring recession flows	Spring recession start magnitude	15 (3 - 528) cfs
	Spring timing	Mar 3 (Feb 22 - Mar 18)
	Spring duration	109 (76 - 125) days
	Spring rate of change	1.4 (0.9 – 1.9) % decline per day
Dry-season baseflow	Dry-season baseflow magnitude	2 (0.5 – 4) cfs
	Dry-season timing	June 20 (May 9 - Jul 10)
	Dry-season duration	198 (116 - 220) days
	Dry-season high magnitude	5 (3 – 6) cfs

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

Maintaining functional flows within their natural range is hypothesized to support ecosystem functions and sustain healthy ecosystem conditions for native freshwater species (see CEFF guidance document). 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 ecosystem functions.

Here, we evaluate factors that may limit the effectiveness of the natural range of functional flow metrics in supporting ecosystem functions within lower Aliso Creek. We focus on the potential influence of ***non-flow*** aspects, including physical habitat, water quality, and biotic interactions (flow-related impacts will be addressed in steps 8-12), on the relationship between natural functional flows and ecosystem functions, identified in Step 1, that are essential to achieving 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

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.

In lower Aliso Creek, portions of the reach have been identified to have clear bank instabilities and major hydromodification impacts due to increases in peak flows from upstream urbanization (County of Orange, 2021). Channel incision and widening via fluvial erosion and mass failure are the primary channel responses to altered flood hydrology in lower Aliso Creek (Collison & Garrity, 2009). In some areas where incision and subsequent widening have decreased the longitudinal slope, the channel was vertically stable and slightly aggregational, as evidenced by the age of riparian trees observed on the inset floodplain (Collison & Garrity, 2009; Tetra Tech, 2014). Excessive channel widening in lower Aliso Creek, however, has resulted in infrastructure failure of sewer lines and the adjacent road (Tetra Tech, 2012; Figure 3). Although there is limited space for future development in the contributing watershed and minimal potential for future changes to peak flows, additional bank failure and channel widening are likely to occur in locations where banks are nearly vertical, composed of unconsolidated alluvium, and contain tension cracks (Tetra Tech, 2010, 2014).

Altered channel morphology, including channel widening and instability, may be a factor that could limit functionality of the natural range of flow metrics for the spring recession flow, wet-season baseflow, and dry-season baseflow component (Table 4). For example, the widened channel could potentially limit baseflows from providing necessary depths to support migration, spawning, and residency of aquatic organisms. The widened channel could also limit the natural range of the spring recession flow from inundating the floodplain, which is necessary for riparian seed dispersal and providing adequate soil moisture prior to the dry-season. However, the functionality of the natural range of the fall pulse flows and peak flows may not be limited as these higher flows within the widened channel can provide a range of depths and velocities that promote scour, deposition, inundation, and floodplain connectivity. These issues are explored in more detail in Section B.

Figure 3. Bank erosion along lower Aliso Creek showing undermined pipeline due to channel widening (photo courtesy of South OC Wastewater Authority (Tetra Tech, 2012)).

Table 4. Potential ***non-flow*** 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 the location of interest. Flow-related factors are discussed in step 8.

Functional Flow Component	**Potential Non-flow Limiting Factor**	**Affected Ecosystem Function(s)**
Fall pulse flow	None identified	Reference flow ranges should provide suitable functionality
Wet-season baseflow	Altered channel morphology	Potential limited habitat availability (i.e., depth) to support migration, spawning, and residency of aquatic organisms; Potential limited access to shallow groundwater (riparian)
Wet-season peak flow	None identified	Reference flow ranges should provide suitable functionality
Spring flow recession	Altered channel morphology	Potential limited floodplain inundation and hydrologic conditions for riparian species recruitment and seed dispersal

Dry-season baseflow	Altered channel morphology	Potential limited habitat availability (i.e., depth) for native aquatic species; Potential limited riparian soil moisture

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.

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.

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 as the median (50th percentile) metric value and bounded by the 10th to 90th percentile range of metric values for each flow component. The median represents the long-term value around which annual values should center. The 10th to 90th percentile values represent the lower and upper bounds, respectively, in which annual values of the metric are expected to vary. Ecological flow criteria can be defined for all water years, or by water year type (e.g. wet, moderate, dry).

Following the assessment in Step 3, channel widening and instability may be a factor that could limit functionality of the natural range of flow metrics for the spring recession flow, wet-season baseflow, and dry-season baseflow component. Therefore, the natural functional flow metrics are selected as ecological flow criteria for the fall pulse flow and peak flows for LOI 1 as shown in Table 5. Ecological flow criteria for the other three functional flow components will be further evaluated in steps 5-6 to determine the degree to which alterations to physical habitat may affect the relationship between the natural range of functional flow metrics and their intended functions and whether alternate flow criteria may be needed.

Table 5. Ecological Flow Criteria for Lower Aliso Creek (LOI 1) for those functional flow components where additional evaluation of non-flow factors is not needed. Values reflect medians and 10th – 90th percentiles in parentheses of functional flow criteria for all water year types combined.

Flow Component	Flow Metric	**Ecological Flow Criteria at LOI 1** median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	2.4 (1.7 - 5) cfs
	Fall pulse timing	Nov 29 (Oct 24 - Dec 3)
	Fall pulse duration	11 (3 - 16) days
Wet-season baseflow	Wet-season baseflow magnitude	*To be determined*
	Wet-season timing	Dec 15 (Oct 10 – Jan 25)
	Wet-season duration	67 (30 - 133) days
	Wet-season median magnitude	6 (4 – 11) cfs
Peak flows	2-year peak flow magnitude	31 cfs
	2-year peak flow duration	4 (1 – 25) days
	2-year peak flow frequency	2 (1 – 8)
	5-year peak flow magnitude	423 cfs

	5-year peak flow duration	3 (1 - 6) days
	5-year peak flow frequency	3 (1 - 4) event(s)
	10-year peak flow magnitude	981 cfs
	10-year peak flow duration	1 (1 – 1) days
	10-year peak flow frequency	1 (1 – 1) events(s)
Spring recession flows	Spring recession start magnitude	*To be determined*
	Spring timing	Mar 3 (Feb 22 - Mar 18)
	Spring duration	109 (76 - 125) days
	Spring rate of change	1.4 (0.9 – 1.9) % decline per day
Dry-season baseflow	Dry-season baseflow magnitude	*To be determined*
	Dry-season timing	June 20 (May 9 - Jul 10)
	Dry-season duration	198 (116 - 220) days
	Dry-season high magnitude	5 (3 – 6) cfs

Section B – Develop ecological flow criteria for focal flow components requiring additional consideration

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

A conceptual model that explicitly links a flow component with ecological management goals will help understanding and visualization of how physical habitat, water quality, or biological interactions may affect the relationships between flow and ecological response. The conceptual model also guides collection of the data required to quantify these ecological response relationships (if needed) as described in Step 6. The structure of the conceptual model 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 stakeholders.

Conceptual models to determine ecological flow needs for the focal flow components considered altered channel morphology, as the key limiting factor identified in Step 3, and the life history needs of focal species, willow (Figure 4) and arroyo chub (Figure 5) as the ecological responses related to management goals identified in Step 1.

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

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.

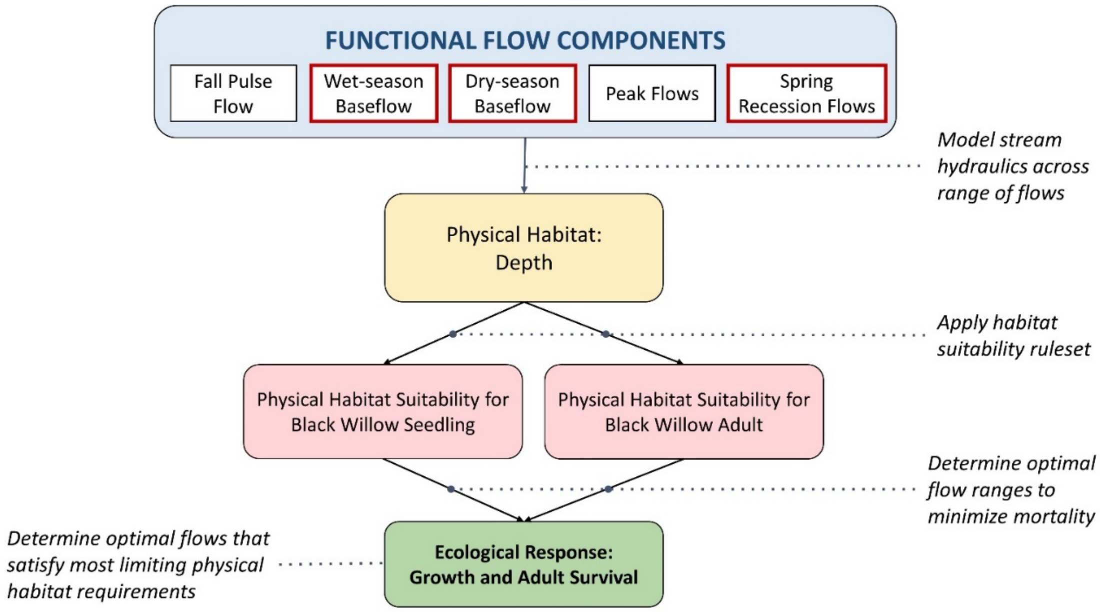

Figure 4. Example conceptual model linking spring recession flows and wet and dry season baseflows with physical habitat (channel enlargement was a limiting factor identified in step 3), key ecosystem functions, and ecological management goals related to willow identified in step 1.

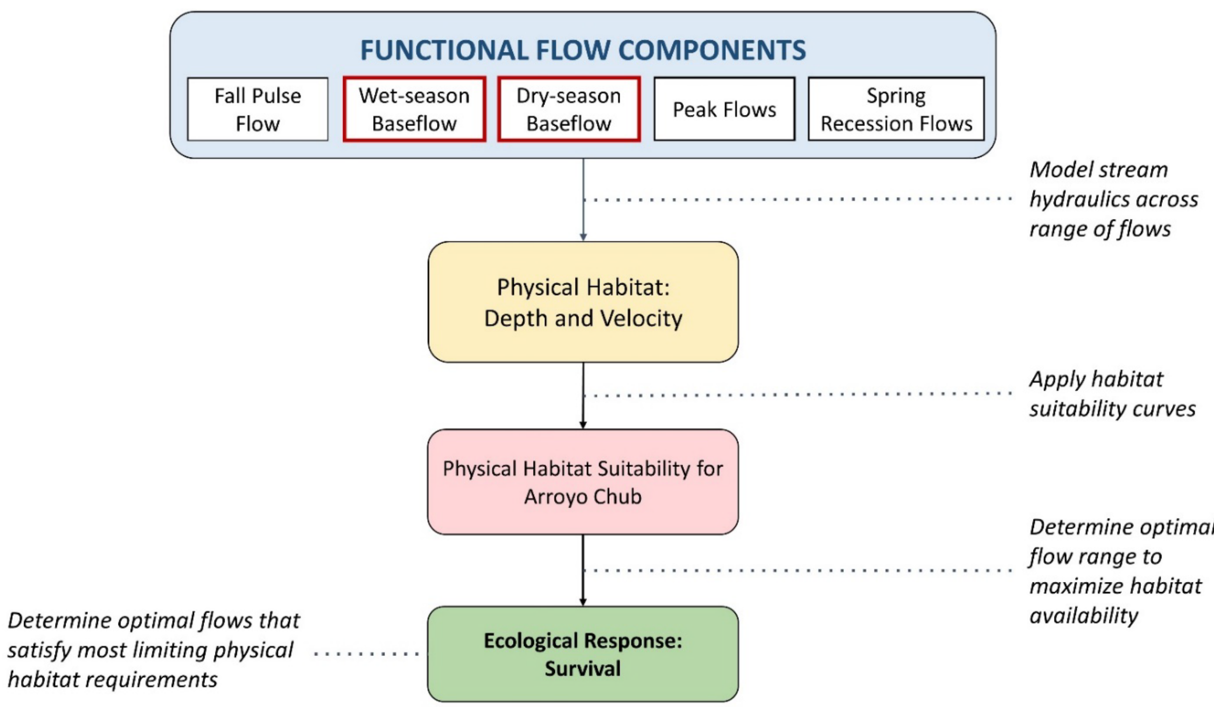

Figure 5. Example conceptual model linking wet and dry season baseflows with physical habitat in the main channel (channel widening was a limiting factor identified in step 3), key ecosystem functions, and ecological management goals relating to arroyo chub identified in step 1.

Step 6: Quantify flow-ecology relationships

We conducted a literature review of existing studies and compiled data to quantify the linkages in the conceptual model and develop habitat suitability relationships in consultation with the stakeholder and technical advisory group. The following subsections describe the methods and results of quantifying the flow-ecology relationships for arroyo chub and willow.

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

Outcome of Step 6:

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

Arroyo chub (*Gila orcuttii*)

The data collated for arroyo chub consisted of fish abundance and associated measurements of depth and velocity (Wulff, Brown, & May, 2017a, 2017b). The fish abundance and hydraulic data on depth and velocity were collected from 17 50m reaches in 2015 (Wulf 2017a) and 20 50m reaches in 2016 (Wulff 2017b). At each reach, fish abundance data were collected through a combination of seine netting, snorkeling, and electrofishing techniques. Fish abundance, depth, and velocity (at 0.6 of the depth) data were collected where fish abundance data were collected. Reach habitat data were measured at transects positioned perpendicular to flow at every 10m throughout the reach. Depth and velocity measurements were taken at each of 10 equidistant points along each transect. Depth was measured with a graduated wading rod. Velocity was measured with an electronic flow meter in the upstream direction. The hydraulic data where fish were located were defined as fish presences and reach habitat data where fish were not found were defined as fish absences. Limited data were available that described different life stages of chub, therefore individuals of all lengths were included in the model.

Following the procedure for developing fish species models in Stein et al. (2021), each hydraulic variable was modelled separately with either fish abundance or presence/absence. In brief, habitat suitability models were built for chub and velocity by first calculating a frequency histogram of fish abundance and velocity. A probability density curve was calculated from the histogram following a normal distribution probability function. To remove the accumulative probability values usually attained from this calculation, the habitat data were centered around the mean and scaled to one standard deviation. To maintain intuitiveness of the curve, the scaled habitat data were transformed back to their raw values. This results in a maximum potential probability value of 0.4 (vs. 1.0) because the total area under the curve represents the full range of probabilities. The habitat suitability model for the hydraulic variable depth was developed by applying Generalized Linear Models (GLMs) with binomial error distribution (1,0) with logit link function. The abundance data were transformed into presence/absence data. Habitat suitability models for arroyo chub survival developed for the hydraulic variable velocity and depth (deviance = 265.84, $p < 0.001$) are shown in Figure 6.

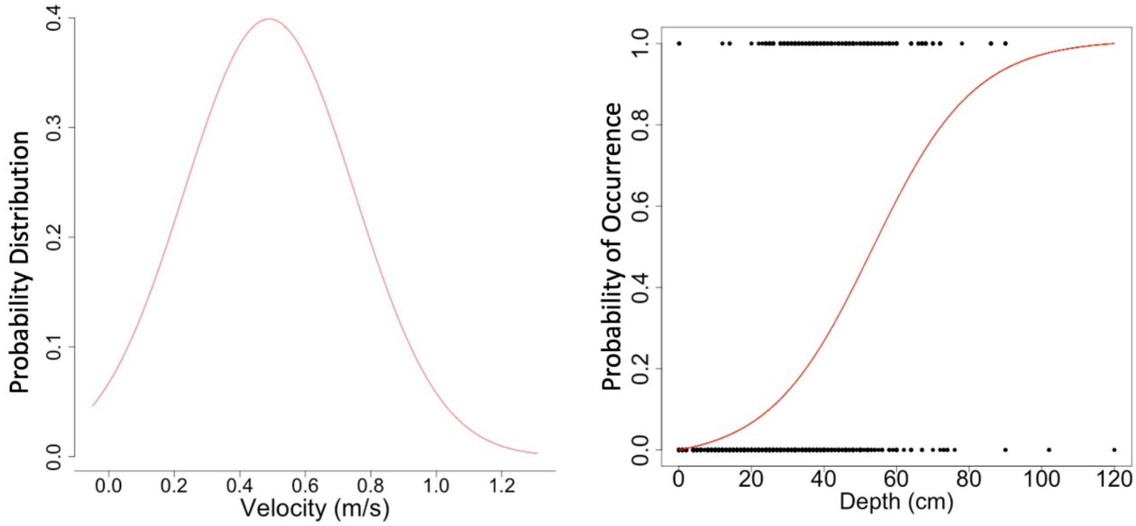

Figure 6. Suitability relationships for arroyo chub survival based on velocity (left) and depth (right). Data used to generate curves were from (Wulff et al., 2017a, 2017b).

Goodding's black willow (*Salix gooddingii*)

We developed a suite of habitat rules used to identify ecological flow ranges for willow seedlings and adults. Seedling mortality increases in both very wet and very dry conditions (Stein et al., 2021; Tallent-Halsell & Walker, 2002; Vandersande, Glenn, & Walworth, 2001) and with increased shear stress (Pasquale, Perona, Francis, & Burlando, 2014). Seedlings are dependent on soil water availability until their roots can reach the water table. Periodic high flows are important drivers of soil water content but are most suitable for seedling establishment early in the growing season as large floods can scour the soil resulting in mortality (Woods & Cooper, 2005). However, the peak flow metrics that are related to scour do not typically occur during the critical growing period of April to September. We did not develop ecological flow needs for willow that correspond to the peak flows, assuming that the reference-based values will be a suitable flow target. Adult willows require flows to inundate the overbank area seasonally. Although they can withstand some large floods, these areas should not remain inundated for prolonged periods which may result in mortality or impaired growth (Bendix, 1999; Hosner & Boyce, 1962; Nilsson, 1987). For adult willows, we used a wet-season and dry-season baseflow minimum threshold necessary to maintain at least 3 cm of depth of flow in the active channel, under the assumption that roots can reach the water table, and used a maximum flow threshold at the channel capacity to limit overbank inundation and oversaturated soils in the overbanks. We also developed habitat criteria for the spring recession start magnitude to ensure that the lower flow criteria threshold will provide flows that will inundate the overbank to provide soil moisture in the overbanks prior to the start of the dry-season and ensure lateral connectivity to the floodplain for riparian seed dispersal. With these factors in mind, we determined suitable flow ranges by applying a suite of rules developed in consideration of the current channel morphology (Table 6).

Table 6. Habitat criteria used to determine ecological flow needs for willow adults and seedlings.

Life Stage	Functional Flow Metric	Lower Flow Threshold	Upper Flow Threshold
Adult	Wet-Season Baseflow Magnitude	Discharge necessary to maintain at least 3 cm depth of flow in the river, under the assumption that roots can reach water table	Maximum flow that would not inundate the overbank area to limit oversaturated soils in the overbanks
	Dry-Season Baseflow Magnitude		
Adult & Seedling	Spring Recession Start Magnitude	Discharge necessary to inundate 10 cm depth in the overbank areas for seed dispersal and to provide soil moisture in the overbanks prior to the start of the dry-season	No upper limit, used the reference 90th percentile if > lower limit (only refined the lower limit to ensure overbank inundation at the start of spring recession)

Stream hydraulics

A one-dimensional hydraulic analysis, rather than a data- and resource-intensive two-dimensional analysis, was implemented to allow for flexibility in applying these methods across a multitude of reaches in the study region. Overall, the hydraulic analysis was conducted to evaluate whether altered habitat conditions would provide suitable habitat for the focal species under various flow conditions and to validate if the natural range of flows are supportive for species of concern or if they need to be adjusted**.** Rating curves were developed in R statistical programming version 4.0.2 (R Core Team 2020) to apply to the simulated flow timeseries to produce timeseries of hydraulic data for depth and average velocity at discrete channel sub-sections. First, channel geometry and reach characteristics, including slope (0.01) and field-verified Manning's roughness n (0.035), were taken from Orange County's LiDAR-derived channel geometry cross sectional dataset[1] near the outlet of the model subbasins. The channel cross section was split into geomorphically-distinct sub-sections (e.g., left floodplain, left overbank, main channel, right overbank) where channel hydraulics were estimated. To build the rating curves, hydraulic variables need to be estimated for a range of flows at various water surface elevations. We identified 200 water surface elevations, using the minimum bed elevation and the maximum floodplain elevation at capacity as the range, that were used to calculate discharge, ranging from 0 to 101 cfs, and associated hydraulics. For every water surface elevation, velocity and discharge were estimated across hundreds of micro-sections of the channel geometry using Manning's equation. Micro-sections were defined by the change in topography in the cross-sectional profile. Total discharge was determined by summing the discharges from each channel sub-section. For each channel sub-section, maximum and average depth and mean velocity were determined for every water surface elevation. Rating curve functions were determined for each hydraulic variable based on a least-squares fit. We used the rating curves to determine the suitable flows under current channel conditions for each of the species of management concern and identified the associated ecological flow criteria.

[1] Dataset available at: https://www.ocgis.com/ocpw/IllicitDischarge/

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

Outcome of Step 7:

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

Based on the information gathered in steps 5 and 6, ecological flow criteria were defined for each focal flow component. These new criteria were then combined with those defined in step 4 to develop a comprehensive set of criteria for all five functional flow components (and their associated functional flow metrics).

Ecological flow needs were determined for the functional flow components based on the habitat ruleset for willow and the habitat suitability relationships for arroyo chub and compared to the reference ecological flows identified in CEFF Section A. Habitat suitability curves for depth and velocity for arroyo chub were related to the flow at each cross-sectional sub-section by applying the rating curve for each hydraulic variable in the habitat suitability curve and flow in the stream. The flow associated with the hydraulic value for a medium probability threshold of 50%, which was an agreed-upon criteria by the stakeholder and technical advisory groups, was determined for each hydraulic variable to create a target flow range. Hydraulic flow ranges were combined for each sub-section to develop ranges of integrative ecological flow needs. On occasions where flow ranges for depth and velocity did not overlap, the range of the variable least supported by the current flow range (limiting hydraulic factor) was used. The flow ranges developed for willow and arroyo chub represent the refined ecological flow needs.

The refined ecological flow needs, from CEFF Section B, and the natural range of the flow metrics for the remaining components that were not refined, from CEFF Section A, were combined to make up the overall ecological flow needs for all functional flow components. In developing the overall ecological flow needs, we evaluated whether the natural range of flow metrics will be suitable for the indicator species, to ensure that the holistic functional flow needs will be supportive of the ecological management goals for the region.

Refined ecological flow needs were developed for the dry-season and wet-season baseflow magnitudes and the spring recession start magnitude based on the habitat suitability requirements for willow and arroyo chub (Table 6). Together, the natural and refined ranges of flow metric values represent the ecological flow criteria, or the suite of functional flow metrics that can serve as a management goal. Under the current channel morphology, the flow at the active channel capacity was 12 cfs. For willow adult, the ecological flow needs for wet-season and dry-season baseflow magnitude were 0.1 to 12 cfs. The natural range of the wet- and dry-season baseflow magnitude, 2 to 5 cfs and 0.5 to 4 cfs, respectively, would be suitable for willow adult. For willow adult and seedling, the ecological flow needs for the spring recession start magnitude was 33 to 528 cfs. Under the existing channel morphology, the reference lower limit of 5 cfs would not provide ecosystem functions associated with floodplain inundation and would need to be increased to 33 cfs to provide such functions. For arroyo chub, depth was the limiting hydraulic factor under the existing channel morphology. Both the wet-season and dry-season baseflow magnitude need to be at least 120 cfs to provide suitable depths in the existing channel morphology for arroyo chub. The minimum flow of 120 cfs is well beyond the baseflow ranges under current and natural conditions, 2 to 4.9 cfs and 0.3 to 3 cfs, respectively, and are only observed during storm events. Overall, the natural range of flow metrics would provide suitable conditions for willow but not for arroyo chub. We therefore slightly adjusted the refined ecological flow criteria for willow to ensure that willows are supported during baseflows and increased the range of magnitudes during the spring recession by increasing the lower flow threshold (Table 7). Given that the refined ecological flow criteria for arroyo chub were unrealistic management goals, we evaluated whether channel restoration could provide suitable habitat for chub under both natural and current flow conditions (see results in step 10).

Table 7. Ecological Flow Criteria for Lower Aliso Creek (LOI 1). Values reflect medians and 10^{th} – 90^{th} percentiles in parentheses of functional flow criteria for all water year types combined. Values determined in steps 5 and 6 are bolded, while all other values were determined in step 2.

Flow Component	Flow Metric	**Ecological Flow Criteria at LOI 1** median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	2.4 (1.7 - 5) cfs
	Fall pulse timing	Nov 29 (Oct 24 - Dec 3)
	Fall pulse duration	11 (3 - 16) days
Wet-season baseflow	Wet-season baseflow magnitude	3 (**0.1 – 12**) cfs
	Wet-season timing	Dec 15 (Oct 10 – Jan 25)
	Wet-season duration	67 (30 - 133) days
	Wet-season median magnitude	6 (4 – 11) cfs
Peak flows	2-year peak flow magnitude	31 cfs
	2-year peak flow duration	4 (1 – 25) days
	2-year peak flow frequency	2 (1 – 8)
	5-year peak flow magnitude	423 cfs
	5-year peak flow duration	3 (1 - 6) days
	5-year peak flow frequency	3 (1 - 4) event(s)
	10-year peak flow magnitude	981 cfs
	10-year peak flow duration	1 (1 – 1) days
	10-year peak flow frequency	1 (1 – 1) events(s)
Spring recession flows	Spring recession start magnitude	**33** – 528 cfs
	Spring timing	Mar 3 (Feb 22 - Mar 18)
	Spring duration	109 (76 - 125) days
	Spring rate of change	1.4 (0.9 – 1.9) % decline per day
Dry-season baseflow	Dry-season baseflow magnitude	2 (**0.1 – 12**) cfs
	Dry-season timing	June 20 (May 9 - Jul 10)
	Dry-season duration	198 (116 - 220) days
	Dry-season high magnitude	5 (3 – 6) cfs

Importance of physical habitat on developing ecological flow criteria

In highly altered systems where channel morphology has been altered via excess incision or widening, for example, the relationship between physical habitat characteristics such as depth, velocity, and shear stress, and flow will change, making it critical to consider altered channel morphology when developing ecological flow criteria. Ecological flow criteria based solely on the natural flow regime may not provide suitable physical habitat conditions to support species in areas where stream channel alterations have occurred. In this study, the natural range of baseflows and peak flows would provide suitable conditions for willow adult, even with the widened channel morphology. However, the natural lower limit of the spring recession start magnitude would not support seasonal floodplain inundation. In highly incised streams, the natural ranges of peak flows, for example, may not inundate the floodplain (Edwards et al., 2016) and important floodplain functions and processes associated with lateral connectivity such as seed dispersal and spawning (Hayes et al., 2018; Yarnell & Thoms, 2022), may not be supported.

In this study, we use a functional flows approach that is broadly protective of ecosystem functions, considers altered channel morphology, and could be applied to other modified systems. Although our hydraulic analysis to develop ecological flow needs for arroyo chub is similar to more traditional environmental flow methods, such as PHABSIM, the functional flows approach goes beyond specifying flow needs that correspond solely to baseflows by encompassing the natural range of flow variability across multiple seasonal flow components that are tied to a range of ecosystem functions (see Table 2). Moreover, we illustrated how designing flow targets based solely on a single species, may negatively impact other species. For example, baseflow targets for arroyo chub under the widened channel morphology would be too high for willow and could lead to excess sediment transport that could negatively impact macroinvertebrates and algae. Channel restoration may be necessary so that the natural, current, or future range of flows can be functional for chub, willow, and other species of management concern. The approach we utilized in Section B was designed to be simplistic enough, in terms of data requirement and computing power, to be implemented across multiple stream reaches, inclusive of all seasonal flow components that are broadly protective of overall stream health, and takes special consideration of the landscape and the species in it.

Section C – Developing environmental flow recommendations

Step 8: Identify management objectives

The ecological flow criteria developed in Steps 1-7 represent the ecological objectives for the study area. For this study, the main goal was to determine ecological flow needs (Sections A and B), to assess flow alteration (Section C, step 9), and explore an alternative non-flow management scenario (Section C, step 10 consideration). In this report, we summarize considerations for Section C, however, additional work in collaboration with the stakeholder group should be implemented if the goal is to develop final environmental flow recommendations.

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

Outcome of Step 8:

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

Management Objectives and Measures

Development of environmental flow recommendations requires consideration of non-ecological objectives, which for Lower Aliso Creek may include satisfying stormwater permits that require that all nuisance dry-weather discharges into streams be eliminated under the Clean Water Act, limiting water use via conservation measures which could decrease dry weather flows, flood and hydromodification management of peak flows, and meeting municipal water demands. Stakeholders should be consulted to determine the full suite of desired non-ecological management objectives and any potential mitigation measures that might be needed to achieve the ecological management goals.

Stakeholder Process

The existing stakeholder advisory group developed through this application (Table 1) should be used for ongoing stakeholder engagement and consultation on the steps of Section C.

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

Outcome of Step 9:

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

The extent of current hydrologic alteration was evaluated based on deviation from the reference ranges and deviation from the refined ecological flow needs developed. Note that we did not see visual differences in the dimensionless hydrographs between modeled reference and current conditions due to scaling the flow timeseries by the mean annual flow. Instead, we evaluated alteration of current conditions to reference ranges in addition to ecological flow criteria.

Alteration was assessed across all functional flow metrics by comparing the distribution of metric values under current and reference conditions. By utilizing the distribution of functional flows across the full period of record, as opposed to a year-by-year comparison, this approach evaluated the general trends in flow conditions over time. First, the 10th, 50th (median), and 90th percentiles were calculated for both reference and current functional flow metric values. Next, we applied the criteria illustrated in Figure 7 to assign an alteration status for each metric by comparing the median current value to the 10th and 90th percentile range of reference values and evaluating the percentage of years that current flow metric values fall within the 10th and 90th percentile range of reference values. The three alteration categories assigned were likely altered, likely unaltered, and indeterminate and the direction of alteration was categorized as high or low and early or late. For the focal flow components with specific flow needs for willow and arroyo chub, we utilized the same alteration criteria but used the refined ecological flow needs instead of the reference ranges.

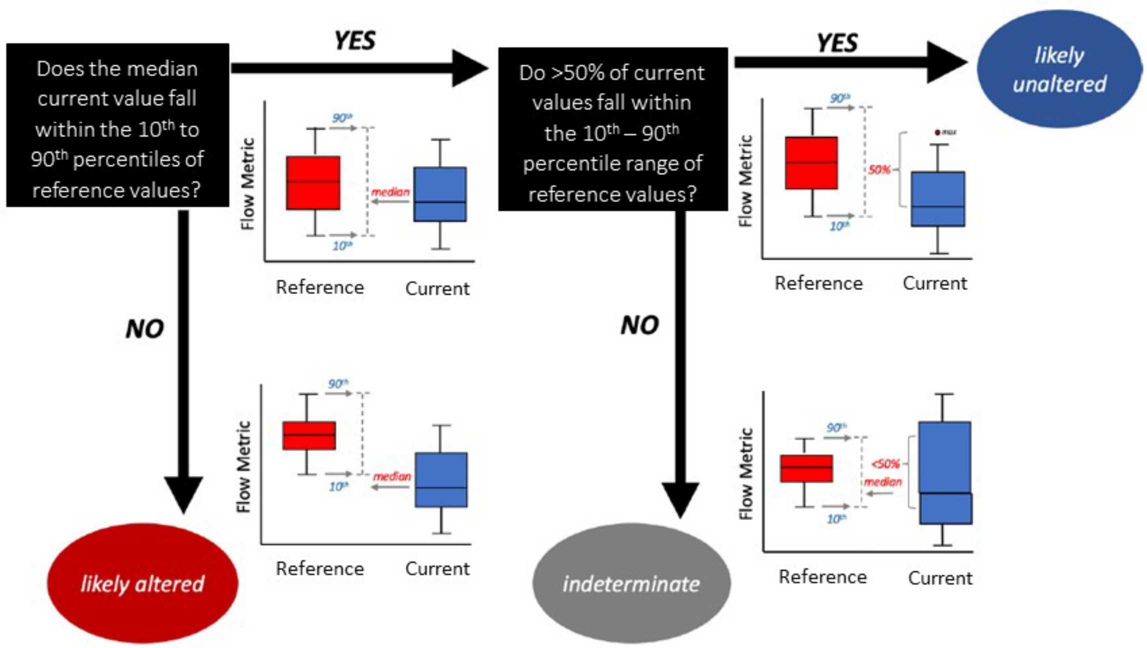

Figure 7. Criteria for assigning alteration status adapted from CEFF Appendix J (in review). Alteration was evaluated based on the deviation of current flows from reference conditions and the deviation of current flows from refined ecological flow needs identified.

Overall, the fall pulse flow and spring recession flow components had more than one flow characteristic that were likely altered compared to natural conditions (Table 8, Table 9). Although the spring recession start magnitude was classed as likely unaltered compared to reference conditions and the ecological flow needs for willow, the spring flow recession was quicker and had a larger rate of change compared to the natural range. The flashier spring recession flow may be due to increases in impervious cover in the contributing watershed and upstream concrete channelization that more efficiently move water through the system compared to natural conditions. Alteration based on the ecological flow needs for willow were likely unaltered for all relevant flow metrics, indicating that current flow conditions are suitable for willow. In contrast, the current flow conditions for the wet- and dry-season baseflow magnitude were determined as altered low based on the flow needs for arroyo chub, as the current baseflows were too shallow for chub due to the widened channel morphology. Although there was not enough data to determine an alteration status for the peak magnitude metrics based on the alteration criteria, all current peak magnitudes were larger than the ecological flow criteria based on reference expectations. The 2-year flood magnitude was 660 times greater than the reference prediction and the 5-year flood magnitude was nearly three times greater than the reference prediction. Augmented peak flows are also likely due to upstream urbanization.

Table 8. Observed functional flow metrics for Lower Aliso Creek (LOI 1). Values reflect median and 10th – 90th percentiles of functional flow criteria. Observed flows at the LOI reflect the simulation time period of 1993 to 2019. Note that both the wet-season and dry-season baseflow magnitude need to be at least 120 cfs to provide suitable depths in the existing channel morphology for arroyo chub.

Flow Component	Flow Metric	Ecological Flow Criteria at LOI 1	Observed Metrics at LOI 1
		median (10th-90th percentile)	median (10th - 90th percentile)
Fall pulse flow	Fall pulse magnitude	2.4 (1.7 - 5) cfs	51 (8 - 123)
	Fall pulse timing	60 (25 - 64) water year days	12 (4 - 37)
	Fall pulse duration	11 (3 - 16) days	4 (2-5)
Wet-season baseflow	Wet-season baseflow magnitude	3 (**0.1 – 12**) cfs	5 (4 - 6)
	Wet-season timing	77 (17 – 117) water year days	52 (22 - 10)
	Wet-season duration	67 (30 - 133) days	101 (72 - 174)
	Wet-season median magnitude	6 (4 – 11) cfs	53 (22 - 100)
Peak flows	2-year peak flow magnitude	31 cfs	660
	2-year peak flow duration	4 (1 – 25) days	2 (1 - 3)
	2-year peak flow frequency	2 (1 – 8)	1 (1 - 5)
	5-year peak flow magnitude	423 cfs	1092
	5-year peak flow duration	3 (1 - 6) days	2 (1 - 3)
	5-year peak flow frequency	3 (1 - 4) event(s)	2 (1 - 3)
	10-year peak flow magnitude	981 cfs	1753
	10-year peak flow duration	1 (1 – 1) days	-
	10-year peak flow frequency	1 (1 – 1) events(s)	-
Spring recession flows	Spring recession start magnitude	**33** – 528 cfs	130 (54 - 833)
	Spring timing	161 (145 - 169) water year days	172 (136 - 216)
	Spring duration	109 (76 - 125) days	62 (11 - 97)
	Spring rate of change	1.4 (0.9 – 1.9) % decline per day	7 (3- 11)
Dry-season baseflow	Dry-season baseflow magnitude	2 (**0.1 – 12**) cfs	3 (2 - 5)
	Dry-season timing	263 (221 - 284) water year days	229 (179 - 292)
	Dry-season duration	198 (116 - 220) days	281 (255-303)
	Dry-season high magnitude	5 (3 – 6) cfs	5 (3 - 6)

Table 9. Alteration status and direction for functional flow metrics comparing current flows to natural ranges and ecological flow needs for willow and arroyo chub. Likely altered cells are highlighted yellow. Greyed boxes indicate that refined flow needs for willow or chub were not identified.

Flow Component	**Flow Metric**	**Alteration Status and Direction Based on:**		
		Natural Range of Flow Metrics	**Ecological Flow Needs: Black Willow**	**Ecological Flow Needs: Arroyo Chub**
Fall pulse flow	Fall pulse magnitude	Likely Altered, High		
	Fall pulse timing	Likely Altered, Early		
	Fall pulse duration	Likely Unaltered		
Wet-season baseflow	Wet-season baseflow magnitude	Likely Unaltered	Likely Unaltered	Likely Altered, Low
	Wet-season timing	Likely Unaltered		
	Wet-season duration	Likely Unaltered		
Peak flows	2-year, 5-year, and 10-year peak flow magnitude	Not enough data for alteration status but all augmented		
	2-year, 5-year, and 10-year peak flow duration	Likely Unaltered		
	2-year, 5-year, and 10-year peak flow frequency	Likely Unaltered		
Spring recession flows	Spring recession start magnitude	Likely Unaltered	Likely Unaltered	
	Spring timing	Likely Altered, Late		
	Spring duration	Likely Altered, Short		
	Spring rate of change	Likely Altered, High		

Dry-season baseflow	Dry-season baseflow magnitude	Likely Unaltered	Likely Unaltered	Likely Altered, Low
	Dry-season timing	Indeterminate		
	Dry-season duration	Likely Unaltered		

Step 10. Evaluate alternative management scenarios and address tradeoffs

Alternative management scenarios

Given the possibility that altered channel morphology may limit ecological functionality of reference flows, we evaluated scenarios for channel rehabilitation that may better support ecologic functions under reference and current flow conditions. In this example, we designed an alternative channel geometry with a low-flow channel within the main channel to provide suitable depths for arroyo chub (depth of at least 0.53 m total in the main channel throughout the reach) and a top width (1.5 m) that allows for seasonal inundation of an inset floodplain for willow (Figure 8). This example is not meant to be a comprehensive restoration study, but instead, illustrate how changes to channel morphology can be made to provide more suitable habitat conditions and ultimately increase overall functionality given available water.

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.

Outcome of Step 10:

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

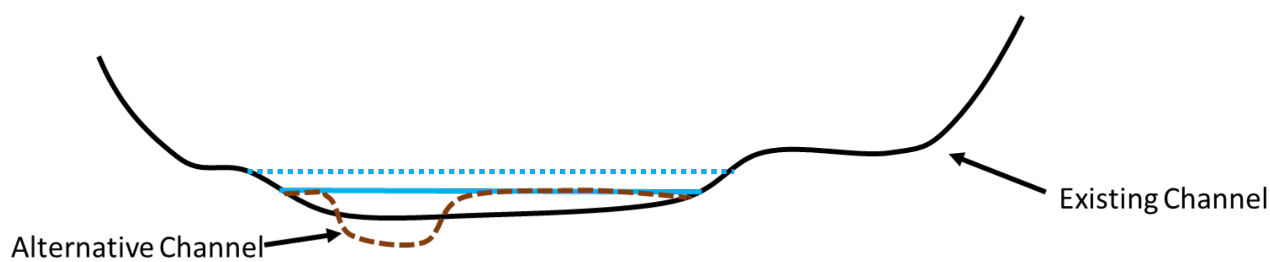

Figure 8. Illustration of the existing channel morphology (black line) and the alterative channel design (dashed brown line) explored in this example. Under the existing channel, for a given discharge, flow depths are shallower (solid blue line) compared to depths under the alternative channel design (dotted blue line). Figure is not drawn to scale.

We developed new rating curves for the alternative channel that were used to revise the flow-ecology relationships. With this information, we determined which flows provide suitable habitat conditions and translated that to revised ecological flow needs for willow and arroyo chub under the new channel. We compared the current and reference functional flow ranges with the refined ecological flow criteria under existing (current channel morphology) and “restored” channel morphology. We also evaluated the habitat suitability of hydraulic conditions under both the current geometry and the alternative channel design to illustrate how non-flow actions, such as channel rehabilitation, could be tailored to better achieve ecological flow needs.

Evaluating ecological flow criteria based on design of restored channel

With the alternative channel design, the ecological flow criteria for the wet- and dry-season baseflows will allow for slightly less water needed to support willow (Figure 9). The wet- and dry-season baseflow magnitude lower limit for willow adult decreased from 0.11 cfs under the existing channel morphology to 0.09 cfs under the alternative channel design. Both flow limits are below the current wet- and dry-season baseflow range of 3.6 to 6.3 cfs and 2.4 to 5 cfs, respectively. The ecological flow needs for willow spring recession start magnitude, which is defined by the flow associated with overbank inundation, decreased from 33 cfs under existing channel morphology to 18 cfs under the alternative channel design, which is closer to the natural median value of 15 cfs.

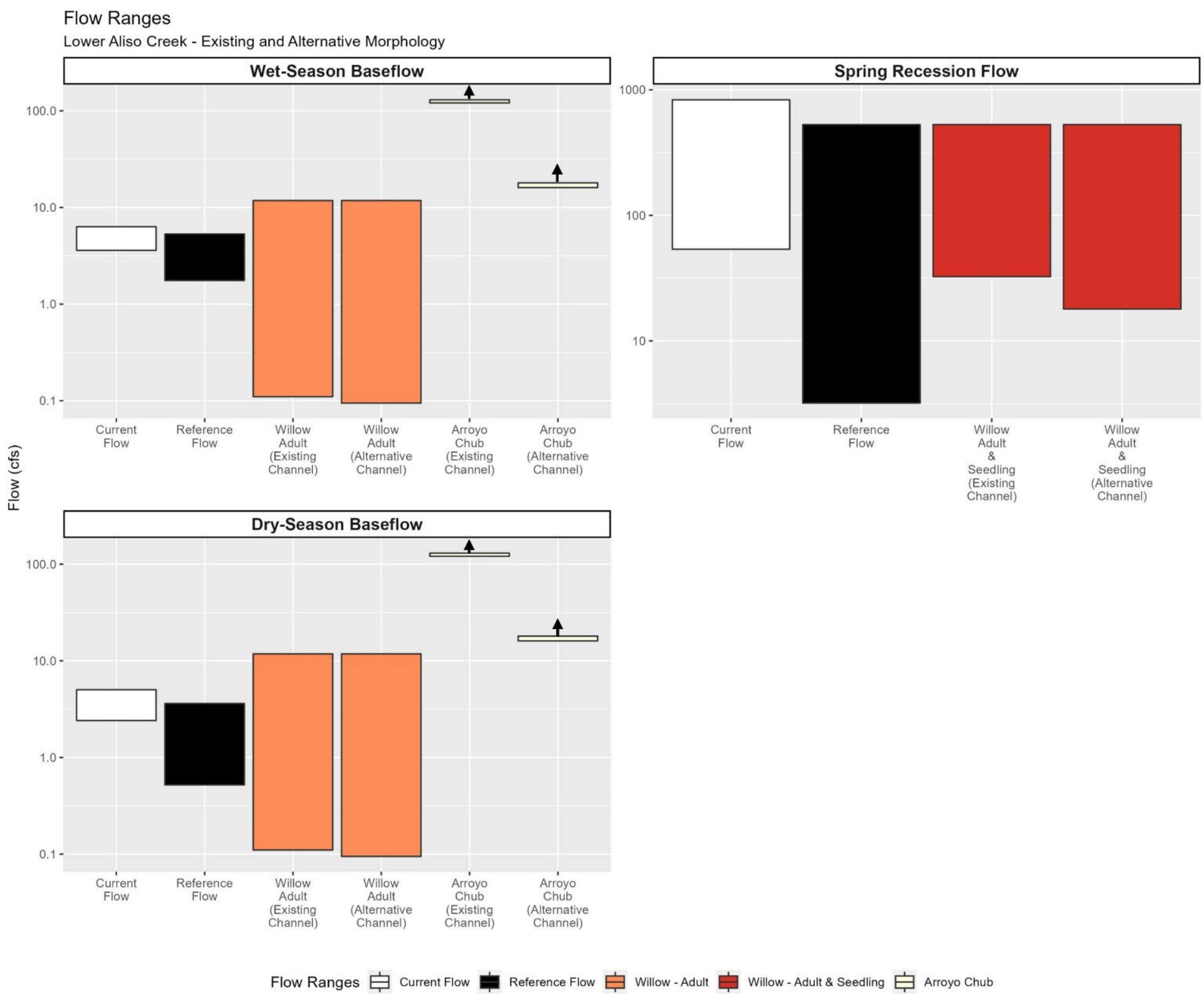

Figure 9. Flow ranges for dry-season baseflow, spring recession flow, and wet-season baseflow magnitudes under current and reference conditions and refined ecological flow criteria for focal species, willow and arroyo chub, developed for the existing channel morphology and a "restored" alternative channel design. Current flow conditions are suitable for willow seedling and adult under existing and alternative channel geometries but are too low for arroyo chub.

Changes to the channel morphology could substantially reduce the ecological flow needs to support arroyo chub for the wet- and dry-season baseflow magnitudes. Ecological flow needs would be reduced from >120 cfs under the existing channel morphology to >16 cfs under the alternative channel design. In the current widened channel, the natural ranges of baseflows would not provide suitable depths for arroyo chub in the main channel, even with the existing augmented baseflows. Moreover, current baseflow conditions would be too shallow to support arroyo chub with the alternative channel geometry. If restoring flow and hydraulic conditions for arroyo chub is a priority in this reach, channel rehabilitation, including provisions for suitable refugia under low-flow conditions, are likely necessary, in addition to flow management. Likewise, critical physical habitat features such as shallow edgewater habitats that provide slow moving, warmer water and refuge for tadpoles and other aquatic organisms may no longer be accessible or present in highly enlarged stream reaches (Wheeler, Bettaso, Ashton, & Welsh, 2015). In addition to the importance of lateral connectivity, longitudinal connectivity of the stream network and the availability of low-flow refugia, such as perennial pools, are important considerations.

Habitat suitability for arroyo chub with the existing channel occurred 0.25% (+/- 0.34) of time during summer and 3.48% (+/- 0.35) of time during winter. In the restored channel, current baseflows were still not high enough to provide suitable depths during the winter and summer, however, habitat suitability for chub increased to 0.88% (+/- 0.9) of time over the summer and 10.1% (+/- 0.91) of time over winter. The most limiting physical habitat requirements for arroyo chub survival was depth associated with the dry-season and wet-season baseflow magnitude, as velocity was suitable under existing and restored channel conditions.

Suitability for willow adult with the existing channel occurred 99.1% (+/- 0.3) of time during the summer and 85% (+/- 2.09) of time during the winter. In the restored channel, suitability for willow adult only minimally increased to 99.2% (+/- 0.23) of time during summer and increased to 88.6% (+/- 1.01) of time during the winter. The spring recession start magnitude was suitable for willow adult and seedling for 80.1% of the modeled years with the existing and the restored channels.

Study limitations and additional considerations

We provide a simplistic one-dimensional hydraulic analysis of physical habitat suitability at a high priority stream reach to develop ecological flow needs that could be implemented at other priority stream reaches, with the primary goal of illustrating the process and application of CEFF in an altered system. The alternative channel design evaluated here was not intended to be a recommended design for channel rehabilitation, but rather an illustration of how changes to the channel morphology could be tailored to provide more suitable physical habitat conditions for species of management concern, without substantial changes to the flow regime. A more detailed two-dimensional hydraulic model is recommended for the design of channel rehabilitation projects and to evaluate the spatial variability of hydraulics at larger spatial scales. Future evaluations should also consider the importance of in-stream habitat heterogeneity for fish including availability of low-flow refugia (Magoulick & Kobza, 2003). In intermittent streams or during times of drought, fish can oversummer in perennial pools that provide suitable refugia (Magoulick & Kobza, 2003). There may be other limiting factors including water quality and stream temperature, substrate composition, interactions with invasive species, food availability, upstream migration barriers, among others, that should be considered in a comprehensive habitat suitability analysis. Moreover, future research could couple a comprehensive population viability model (Anderson et al., 2006; Shenton, Bond, Yen, & Mac Nally, 2012; Tonkin, Merritt, Olden, Reynolds, & Lytle, 2018), models based on guilds of species that share similar flow needs (Merritt, Scott, Leroy Poff, Auble, & Lytle, 2010), or flow ecology models based on community responses (Irving et al., 2022; Mazor et al., 2018) with the eco-hydraulic analysis. Additionally, we utilized a more simplified hydraulic analysis to be applied at multiple high priority stream reaches in the South OC region. This approach allows for the development of ecological flow needs at the regional scale.

Although this CEFF application focuses on developing ecological flow criteria (Sections A and B), multiple additional steps need to be taken to develop balanced environmental flow recommendations that account for ecological and non-ecological water uses. Prior to implementation of flow management actions, a trade-offs analysis that considers the consequences of multiple alternative management scenarios on ecological and non-ecological management objectives from Step 8 is recommended. For example, a Multi-Criteria Decision Analysis (MCDA) could be used to quantify socio-economic and environmental tradeoffs of multiple management scenarios (Barton et al., 2020) and can form the basis for developing environmental flow recommendations among multiple stakeholders.

As discussion and evaluation of management actions by stakeholders in the basin continues, consideration of their potential effects on the ecological management goals identified in step 1 should be included. Additionally, further study and quantification of the ecological consequences of failing to satisfy the ecological flow criteria will help in evaluation of trade-offs inherent to meeting ecological and non-ecological management objectives.

Potential management actions and restoration projects

A high priority goal identified by the Aliso Creek Watershed stakeholders is to improve streamflow conditions, including fish passage, and rehabilitate physical habitat conditions to support riparian habitat and the reintroduction of sensitive native fish species. Several reaches in Lower Aliso Creek have been identified as candidate LOIs for future restoration projects to address the severe incision and widening and remove major in-stream migration barriers. Future project planning that seeks to manage the system to increase ecosystem functionality with available water should consider current and future functional flows and utilize and build from the tools and findings of this CEFF application, including a more detailed evaluation in step 10, using a collaborative stakeholder process.

Step 11. Define environmental flow recommendations

Once all analyses, studies, and discussions regarding ecological and non-ecological management objectives have been completed, stakeholders in the Aliso Creek watershed should establish their environmental flow recommendations and any associated non-flow management actions.

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

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)

Step 12. Develop implementation plan

An adaptive management plan for the Lower Aliso Creek coordinated with an implementation plan for actions identified in step 11 will be key for future management considerations related to climate change impacts. Plans that allow for ongoing assessment and support of ecosystem functions will be essential for maintaining and increasing climate resilience within the Aliso Creek ecosystem.

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

Outcome of Step 12:

- Implementation plan that includes mitigation measures and adaptive management
- Monitoring strategy that informs adaptive management

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