# Evaluation of Hydrologic Alteration to Inform Flow Management Decisions in South Orange County Coastal Watersheds


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Southern California Coastal Water Research Project
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# 1. INTRODUCTION

The Flow Ecology Special Study (also known as the "Evaluation of Baseline and Reference In-Stream Flow Conditions Special Study") is outlined in Section 4.1.5.2 of the South Orange County Watershed Management Area (SOC WMA) Water Quality Improvement Plan (WQIP). The primary goal of the Flow Ecology Special Study (Study) is to develop ecologically based flow recommendations for waterbodies across the SOC WMA. This will shed light on how to manage water to promote streamflow enhancement and environmental restoration while balancing the needs of the communities of South OC.

The Study includes four major components:

- Stakeholder Coordination and Engagement
- Hydrologic Assessment
- Ecological Assessment and Synthesis
- Development of Flow Ranges to Support Focal Species

The Study team is made up of OC Public Works (on behalf of the municipalities of South OC), the Southern California Coastal Water Research Project (SCCWRP), and Geosyntec Consultants.

## 1.1. Contents and Purpose

This is the final report on the Study. It summarizes the overall results of the study as well as the intermediate and final data products produced from the Study. This report also outlines potential uses of these data products to support additional analyses. This report is organized into the following sections:

**Stakeholder Coordination and Engagement:** This section contains a record of the stakeholder meetings and includes links to meeting materials, recordings, comments, and responses associated with each meeting.

**Hydrologic Assessment:** This section contains summaries of the hydrologic assessment, including supporting data files and model results.

**Ecological Assessment and Synthesis:** This section contains summaries of a multi-level flow ecology assessment with a focus on answering the key questions laid out in the WQIP Special Study description (Level 1 to 2) and the results of a focal species analysis (Level 3). All supporting data files, alteration maps, and results referenced in this report can be downloaded at: https://ocgov.box.com/s/9rql69l3tvq96w88qh50b3axkeefvv1v.

**Special Study Summary:** This section provides a summary of the overall study findings, responses to the special study research questions, and discussion of potential uses of the study results.

## 2. STAKEHOLDER COORDINATION AND ENGAGEMENT

### 2.1. Overview

We[1] have solicited input on this study through two groups: (1) the Stakeholder Advisory Group (SAG), which provides input on the overall study process and (2) the Technical Advisory Group (TAG), which provides technical input on the approach, methods, and study endpoints.

To date, we have hosted nine (9) meetings with these groups including in-person and webinar formats (listed chronologically). Each date below links to associated meeting materials, recordings, comments, and responses:

1) **July 17, 2019**
   **SAG Webinar Workshop**
   Focus: Introduce the special study

2) **August 5, 2019**
   **SAG In-person Workshop**
   Focus: Discuss the study and opportunities for SAG input

3) **October 22, 2019**
   **TAG In-person Workshop**
   Focus: Discuss technical processes within the study and opportunities for TAG input

4) **January 8, 2020**
   **SAG/TAG In-person Workshop**
   Focus: Update on study progress and address action items from previous meetings

5) **June 3, 2020**
   **TAG Webinar Workshop**
   Focus: Hydrologic model, its calibration, and its output

6) **June 16, 2020**
   **SAG/TAG Webinar Workshop**
   Focus: Hydrologic assessment results and the proposed flow ecology evaluation approach

7) **November 12, 2020**
   **SAG/TAG Webinar Workshop**
   Focus: Isotope study findings, hydrologic model recalibration, and water conservation and climate change scenario analysis.

8) **December 2, 2020**
   **SAG/TAG Webinar Workshop**
   Focus: Flow ecology analyses and synthesis

[1] In this progress report, the use of "we" or "our" is intended to refer to the study team, including OC Public Works, SCCWRP, and Geosyntec.

9) **November 2, 2021**
**SAG/TAG Webinar Workshop**
Focus: Flow ecology conclusion and potential applications of results

We have also facilitated individual meetings with stakeholders who have requested additional detail and discussion on a variety of topics (e.g., data and model sharing and collaboration, clarifying technical discussions, water conservation plans). Such stakeholders included representatives from San Juan Basin Authority (SJBA), Santa Margarita Water District (SMWD), Wildermuth Environmental (WEI)[2] (hydrologic consultant for SJBA and SMWD), Metropolitan Water District of Orange County, Rancho Mission Viejo, South Orange County Wastewater Authority, San Diego Regional Water Quality Control Board (Water Board), CA Department of Fish and Wildlife, and US Fish and Wildlife Service.

## 2.2. Summary of Resolutions

Through the stakeholder process, we have gained concurrence on several key policy and technical topics.

### Overall Study Domain

The study domain began as the watersheds of the six major creeks in the South OC Watershed Management Area: Laguna Canyon Creek, Aliso Creek, Salt Creek, San Juan Creek (including tributaries Oso Creek and Arroyo Trabuco Creek), Prima Deshecha Creek, and Segunda Deshecha Creek. Based on input from the SAG, we narrowed the study domain to areas that have significant urban influences and are not already covered by a flow management agreement or plan. This resulted in exclusion of a few reaches from the study. These are:

- Mainstem San Juan Creek (covered by the SJBA Adaptive Pumping and Management Plan)
- Chiquita Canyon (covered by the Rancho Mission Viejo Ranch Plan)
- Lower Gobernadora Creek (covered by the Gobernadora Ecological Restoration Area)

### Hydrologic Assessment Methods

We obtained the following primary resolutions pertaining to hydrologic model development and calibration:

- *Model construction.* Beginning in October 2019 (meeting #3), we provided progressive updates of the construction of the hydrologic model to be used for the study, including the key processes modeled and the features represented. We presented the model in detail in June 2020 (meeting #5).
- *Primary calibration locations and metrics.* In January 2020 (meeting #4), we presented the proposed calibration approach, locations, and metrics. We followed this in June 2020

[2] Wildermuth Environmental is now part of West Yost Associates.

(meeting #5) and November 2020 (meeting #7) with summaries of the calibration process and results.

- *Priorities for improvement of calibration.* Following the initial presentation of model calibration results in June 2020 (meeting #5), we gained concurrence on priorities for improvement of the calibration. These included (1) incorporation of isotope monitoring results to help quantify and classify dry weather flow sources, and (2) improving the goodness of fit between modeled and gauged stream flows during dry periods, post-storm recession periods, and spring recession periods.

- *Modeled conditions.* In January 2020 (meeting #4), we outlined the conditions to be modeled (reference, current, future climate change, and future water conservation). We further detailed these conditions in June 2020 (meeting #5) and presented results in November 2020 (meeting #7).

- *Modeling program for San Juan basin.* Following the November 2020 workshop, we coordinated with Santa Margarita Water District regarding the modeling approach to use for parts of the study area within the San Juan basin. Based on this coordination, we decided to extend the Loading Simulation Program in C++ (LSPC) model to cover this area instead of relying on a GSFLOW model of the basin. This allowed each scenario to be run in the same program, improving comparability between scenarios.

- *Final model results presentation.* We presented the final model results in November 2021 (meeting #9). This was primarily informational. Following this workshop, we learned of the presence of some flow data from the 1970s for lower Aliso Creek.

**Ecological Analysis**

We obtained the following primary resolutions pertaining to the flow ecology analysis and synthesis:

- *Overall multi-level process.* In October 2019 (meeting #3) and January 2020 (meeting #4), we provided an overview of the tiered evaluation approach to the TAG and SAG, respectively. We presented further details on the approach and expected outcomes from Level 1 and 2 in June 2020 (meeting #6). We illustrated the overall analysis from Level 1 to 3 and presented preliminary findings in December 2020 (meeting #8) and summarized key findings in November 2021 (meeting #9)

- *Prioritization approach (Level 1 and 2).* In October 2019 (meeting #3), the TAG recommended that we implement an initial stream characterization and prioritization on an example subbasin to illustrate the process. We provided further details on initial stream characterization combining flow alteration (Level 1) and effects on biology (Level 2) in January 2020 (meeting #4) and illustrated the process using an example application in June 2020 (meeting #6).

- *Analysis domain for Level 3:* In June 2020 (meeting #6), the SAG and TAG agreed that the focused analysis on focal species (Level 3) would be conducted on a constrained set of sub-basins based on screening criteria laid out in the meeting #6 presentation.

- *Focal species to be modeled (Level 3).* We compiled an extensive database of species observations in the region and presented species observation maps and data sources to the SAG and TAG to identify and fill missing data gaps in October 2019 (meeting #3). SAG and TAG members shared missing data to add to the species database. We subsequently met with resource agency representatives and Water Board staff to identify a proposed subset of focal species to be modeled in Level 3. The SAG and TAG agreed upon the three focal species proposed and the screening criteria for species selection in June 2020 (meeting #6). We did not develop species models for Arroyo Toad because we did not have the species data or resolution in the hydraulic data available (meeting #9).

- *Focal species model approach (Level 3).* In December 2020 (meeting #8), we discussed the focal species response curves. We gained valuable input regarding the species model development and options for determining flow ranges and presented our final species response curves, thresholds, and example data products in November 2021 (meeting #9)

# 3. HYDROLOGIC ANALYSIS

## 3.1. Overview

The purpose of the hydrologic analysis was to characterize continuous, long-term flow regimes to support calculation of key functional flow metrics (FFM) for reference, current, and future conditions (defined in **Section 3.2**). FFM are summarized in **Section 4.2**, including metrics pertaining to each part of the annual hydrograph.

This analysis included the following steps:

- Define conditions to be modeled (**Section 3.2**)
- Compile and obtain data (**Section 3.3**)
- Develop a conceptual model (**Section 3.4**)
- Develop and calibrate a hydrologic model using LSPC (**Section 3.5** and **3.6**)
- Develop and evaluate scenarios (**Section 3.7**)

This section includes a summary of each of these steps. It provides links to reference directories that contain various supporting files and documentation. Each reference folder includes metadata documentation to explain the contents and sources of the files and/or provide more detailed documentation of key analyses or datasets.

## 3.2. Model Conditions

The conditions of interest are defined as follows:

**Current condition:** Defined as the land use conditions, slopes, soils, climate, water impoundments, water usage, and water extraction associated with the current conditions. Climate was simulated from 1993 to 2019. Outdoor water usage was estimated based on data from the more recent post-drought period (2015-2019), which accounts for current levels of water efficiency measures.

**Reference condition**: The reference condition in this study 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 or to define a restoration goal, but it allows assessment of current alteration of flow regimes. Additional information on this condition is contained in **Section 3.7**.

**Potential future conditions:** We evaluated potential future scenarios including enhanced water conservation (through approximately 2045) and climate change (for a future period centered at 2045). See **Section 3.7** for additional details.

Collectively, these conditions allow an assessment of the current degree of alteration compared to a hypothetical reference condition and potential future shifts in flow regime over a 20- to 30-year planning horizon.

## 3.3. Hydrologic Data

We developed several key hydrologic-related datasets as part of this study to serve as inputs to the model or support model calibration.

**Precipitation data:** We developed 16 continuous precipitation records spanning a consistent period from 1989 to 2019 at hourly resolution. The locations of these precipitation records provide relatively good spatial coverage of the WMA. Data sources, methods, and resulting model input datasets are documented at: https://ocgov.box.com/s/nusmzojqhp9uutljccev10o0r3a34m8s.

**Evapotranspiration data:** We developed two continuous evapotranspiration records spanning a consistent period from 1989 to 2019 at hourly resolution. These records were applied to zones within the study area. Data sources, methods, and resulting model input datasets are documented at: https://ocgov.box.com/s/nusmzojqhp9uutljccev10o0r3a34m8s.

**Impoundments:** We researched and compiled information on major water impoundments that have a significant effect on either low flow or storm flow regimes. These primarily included major water quality basins, flood control basins, and reservoirs. Impoundments are reflected in the LSPC model as storage-discharge tables, with optional water withdrawal or loss. Key impoundment information is documented at: https://ocgov.box.com/s/xzby5geodtyouxr0lq6yn0gvchnzcsar.

**Water diversions/withdrawals:** There are 4 significant low flow diversions in the study domain that affect streamflow regime in inland waters: Oso Barrier, Horno Basin, Gobernadora Basin, and Dove Canyon Barrier. We obtained records of diverted flows at Oso Barrier, Horno Basin, and Gobernadora Basin from SMWD. We used the time series from Oso Barrier and Horno Basin as inputs to LSPC. We used data from Gobernadora Basin as a line of evidence to validate dry weather flow from the upstream watershed, but this diversion was not modeled because the lower Gobernadora Creek reach (below Gobernadora Basin) is not part of the study area. Additionally, records of diversions from the Dove Canyon Basin were obtained from the Trabuco Canyon Water District. We used this to simulate a full low flow cutoff of the area draining from Dove Canyon.

**Application of water to developed areas:** Application of water to developed pervious land for the purpose of irrigating turf or landscaping is an important part of the water balance in the SOC WMA. We estimated rates of water application to land surfaces by using times series records of the total water deliveries and sewer return flows within the Moulton Niguel Water District (MNWD) service area. This calculation is described at: https://ocgov.box.com/s/qnm7j2ftlaaqvyu4yd315pdn3fm9m3bq.

**Outfall flow data:** Outfall flow data are available from three primary monitoring programs:

- Visual estimates of outfall flows are obtained as part of twice-yearly outfall field screening. The feature service here includes outfall characteristics and field screening estimates: https://ocgis.com/arcpub/rest/services/Environmental_Resources/Outfall_Locations_Observations_Combined/FeatureServer

- High resolution dry weather flow monitoring was conducted at around 65 outfalls in 2016 for two-week periods. A summary of data we utilized is provided in Appendix J (2019) of the WQIP. https://ocgov.box.com/v/WQIP-2019-Appendix-J

- High resolution dry weather flow monitoring was conducted at 20 outfalls in 2018 and 2019 as part of Outfall Capture Feasibility Studies (OCFS) (submitted as part of the 2019-2020 Annual Report: https://ocgov.box.com/v/2019-20WQIPAnnualReport). These mostly overlap with the 65 outfalls monitored in 2016 and include some wet weather periods.

Outfall flow data represent the discharge from the storm drain system from primarily urban areas. However, they also can include seepage from springs and hillslopes.

We compiled outfall flow data to determine typical dry weather runoff rates from urban areas as a basis for dry weather model calibration. We also used selected wet weather outfall records from 2018-2019 as a basis to evaluate the wet weather model calibration.

**Streamflow data:** The County's streamflow monitoring program includes monthly site visits to obtain direct discharge measurements (aka wading measurements) at 7 sites relevant to the Study. It also includes high resolution continuous data at 3 sites (Aliso Creek at the Sewage (Coastal) Treatment Plant, Aliso Creek at Jeronimo Road, and Lower Oso Creek near Crean Bridge) which are developed based on water level measurement and stage-discharge rating tables. We also obtained USGS gauge data for Arroyo Trabuco near San Juan Capistrano (U.S. Geological Survey Gauge 11047300). We used the continuous datasets as the primary basis for model calibration. We used the direct wading measurements to evaluate and improve low flow calibration at remaining stations and to evaluate the reliability of continuous datasets. Data are available at: https://ocgov.box.com/s/yabdq79q4cqoacsrax8lxqge8z2tkpqp.

Late in the Study, we also obtained a limited set of point-in-time flow observations in lower Aliso Creek from around 1973 to 1987, with a few observations in the 1990s. These data include about 8 observations per year on average, including typically 2 to 3 per year during dry months. We conducted a preliminary assessment of these data as part of this study. The data indicate that the system appeared to be perennial in the 1970s prior to significant development in the watershed, with late spring and summer baseflows typically between 0.25 cfs and 2 cfs. Qualitatively, this aligns with the results of the reference condition model (discussed later). The data do not support a direct comparison to model results as we did not model the 1970s climatic period. Data are available at: https://ocgov.box.com/s/sk8ux9hqdm5ig73ee7oewpix58dinnym.

**Isotope data:** In 2019, stable water isotope samples were obtained at 20 outfalls in the WMA as part of the OCFS. Additionally, as part of the Flow Ecology Special Study, samples were collected at 20 in-stream locations in March, May, and July 2020. Additionally, control samples were collected to characterize the isotopic signature of know sources of potable water, reclaimed water, groundwater seeps, and rainwater. We used these control samples as "endmembers" in a linear analysis that sought to determine the composition of mixed samples. The specifics of this analysis are provided in the technical report linked below. This analysis indicated that dry weather flow in stream channels contains a significant volume of rainfall-derived groundwater. In most streams, imported water (i.e., potable water used for turf irrigation that has been transported to OC from the State Water Project or the Colorado River Project for consumptive uses) accounts for less than half of dry-weather streamflow (**Table 3-1**). Minor variation occurred within separate reaches of individual streams (c.f. **Table 3-2**). Groundwater seeps typically contain 20 to 35% imported water (data not shown), and outfalls range from < 10% to > 90% groundwater with an average around 60% (data not shown). Therefore, rainfall-derived groundwater recharge is an important process in the model calibration of summertime stream flow. These results are summarized from isotope technical reports prepared by San Diego State University; additional detail is available at https://ocgov.box.com/s/5zbp7ikgtpk2p8mmimf2tups14czziac5.

**Table 3-1. Summary of Stream Composition Based on Isotope Data.**

| Stream | Contribution of Imported Water to Dry-Weather Streamflow | |
|---|---|---|
| | March 2020 | July 2020 |
| Laguna Canyon | 12% | 20% |
| Aliso Creek, Main Channel | 19% | 29% |
| Aliso Creek, Tributaries | 24% | 19% |
| Salt Creek | 33% | 43% |
| Oso Creek | 32% | 34% |
| Horno Creek | 36% | 68% |
| Trabuco Creek | <20%[a] | <20%[a] |
| Prima Deshecha | 33% | 60% |
| Segunda Deshecha | 30% | 43% |
| **Average** | **22%** | **32%** |

[a]Different rainwater end member used due to higher average elevation; less certainty in interpretation.

**Table 3-2. Stream Composition Based on Isotope Data in Separate Reaches of Aliso Creek.**

| Reach | Contribution of Imported Water to Dry-Weather Streamflow | |
|---|---|---|
| | March 2020 | July 2020 |
| Upper Aliso at El Toro | 22% | 19% |
| Mid Aliso near I-5 | 23% | 27% |
| Mid Aliso near 73 | 17% | 31% |
| Mid Aliso at Awma Rd. | 15% | 33% |
| Lower Aliso above Wood Canyon | 19% | 33% |
| Lower Aliso at Sewage (Coast) Treatment Plant | 24% | 27% |
| Lower Aliso above Lagoon | 11% | 32% |
| **Average** | **19%** | **29%** |

## 3.4. Conceptual Model

As an intermediate step, we developed a preliminary draft conceptual model of dry season hydrologic process (i.e., "the Conceptual Model") for the streams in South Orange County. It is intended to support preliminary interpretations about streamflow conditions and dominant hydrologic processes in major reaches of the watershed. It also serves as a tool to identify data gaps and areas where there is greater uncertainty in conditions.

The Conceptual Model is a living draft intermediate work product. Certain watersheds are further detailed than others. The Conceptual Model can be accessed at: https://ocgov.box.com/s/15ymjmqvdei9jd3u83dzpi9c5r9h6ldl.

## 3.5. LSPC Model Development

This section provides an overview of the development of the model of the existing condition of the Study area. Within this section, we aim to provide a moderate level of detail intended for a technical audience. Additional details of model development are contained in the data directories referenced in the respective sections below. LSPC model development was also summarized in the following workshop presentations and recordings:

- **January 8, 2020** – Introduction to model development.
- **June 3, 2020** – Presentation on model development and initial calibration.
- **November 12, 2020** – Presentation on updated calibration, with minor changes to model development.
- **November 2, 2021** – Presentation including hydrology overview and key findings.

The two fundamental components of the LSPC model are:

- *Pervious and impervious land areas*. Precipitation and irrigation are applied to pervious and impervious land. These segments produce surface runoff, interflow, and active groundwater discharge.

- *Reaches and reservoir routing*. These receive flow from pervious and impervious land segments and route this flow through a hydrologic and hydraulic routing network. They can also receive point source inflows or withdrawals.

**Figure 3-1** illustrates the key processes represented in the LSPC model.

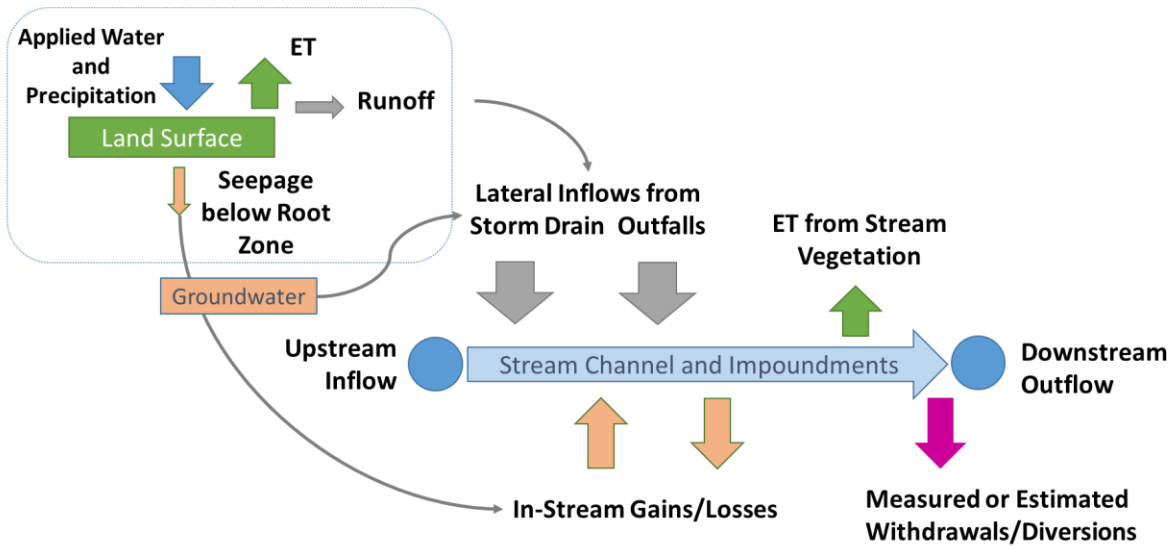


**Figure 3-1. Hydrologic processes in the LSPC model.**

The following paragraphs outline the key features represented in the model with links to where more detailed information can be found. The term "cards" refers to discrete sections of the LSPC model input file. We are providing this for reference, but the reader's knowledge of these cards is not necessary.

**Subbasins** serve as the primary spatial element for organizing the hydrologic processes in the watershed. A subbasin is a discrete land area that receives precipitation and experiences evaporation as quantified by specified meteorological stations. Surface runoff and subsurface flow is then delivered to an associated reach or reservoir. The subbasin is the reporting unit for land-based processes in LSPC. A subbasin has a collection of pervious and impervious land segments known as hydrologic response units (HRUs). See documentation of subbasin delineations at https://ocgov.box.com/s/0v3oc0p6md3njb48cz8frokynxfa4nua. Subbasin IDs and their linkages are defined in Cards 40, 60, and 90.

**HRUs** were developed based on intersecting subbasin boundaries with the HRU geoprocessing service maintained by OC Survey. This geoprocessing service is based on HRU feature class layers. HRUs are defined in Card 70. An HRU is generally present for all combinations of land use, soil, slope class, and pervious versus impervious cover. The spatial distribution of HRUs in each subbasin are represented in the model (Card 90). A given HRU can be found in multiple subbasins. Wherever it is found, it has the same hydrologic parameters, which are represented in Card 70 and Cards 92-200. Pervious HRUs (HRU ID

102-206) are named using land type, soil type, and slope class separated by underscore characters; impervious HRUs (HRU ID 1-70) lack soil types. Slope class 0 implies a slope between 0% and 5% with a slope of 2.5 percent assigned to those HRUs, slope class 5 implies a slope between 5% and 10% with a slope of 7.5 percent assigned to those HRUs, and slope class 10 implies a slope > 10% with a slope of 15% assigned to those HRUs.

**Reaches** can represent flow through streams or pipes. Each reach has a downstream reach that receives reach outflow. Reaches primarily serve a hydrologic purpose to define connections in the watershed and attenuate the flow response. LSPC is not a hydraulic model, and is not intended to be used to define specific hydraulic conditions. See documentation of development of reach parameters here: https://ocgov.box.com/s/fc5wajntfmwg3wvsqbnzccako03hvcoz. Hydrologic reach parameters are assigned in Cards 401 through 410.

**Impoundments** are represented by replacing stage-storage-discharge relationships (termed "FTables" in LSPC) calculated by the LSPC executable based on reach parameters with relationships based on as-built drawings of impoundments found in the SOC WMA. See https://ocgov.box.com/s/xzby5geodtyouxr0lq6yn0gvchnzcsar for documentation of major modeled impoundments. FTables for impoundments in LSPC are assigned in Card 415.

**Precipitation and evapotranspiration** are applied at the subbasin level. Evapotranspiration (ET) coefficients are varied at HRU levels based on land cover. See https://ocgov.box.com/s/nusmzojqhp9uutljccev10o0r3a34m8s for development of meteorological data. Meteorological data were assigned to subbasins based primarily on proximity to gauges. Cards 10 through 40 and Card 60 are used to specify meteorological time series that will be used in the model and assign them to subbasins. Card 70 includes the ET coefficients by HRU.

**Irrigation**, the application of water to developed land areas, is applied based on HRU-level parameters. See https://ocgov.box.com/s/qnm7j2ftlaaqvyu4yd315pdn3fm9m3bq for development of irrigation rate assumptions. Cards 201 through 205 include the parameters that pertain to irrigation. Water was applied to developed pervious land, irrigated agricultural land, irrigated open space, and 10% of impervious land as an approximation of irrigation water that is intended for pervious land but delivered to impervious land via imprecise irrigation practices.

**Stream losses** due to ET and seepage were modeled as negative point source flows. Point sources are described in Cards 420 through 430 of the LSPC input file. Daily negative point source flows used to represent ET are specified in the database table "PS_Timeseries". These negative point source flows were determined based on area of riparian vegetation, ET rates, and professional judgement. They varied seasonally and ranged from 0 to 1.45 cubic feet per second (cfs) per stream reach.

**Flow diversions** were represented using the capabilities of LSPC to model point sources as described above for stream losses. Oso Barrier, Horno Basin, and Dove Canyon were included in the model. Gobernadora Basin is outside our study area.

The final files of the LSPC model that simulate existing conditions are posted here: https://ocgov.box.com/s/ce7zjq7mrnssj5rit1ofpa1xy1gwnpf4.

## 3.6. Model Calibration

### 3.6.1. Calibration Approach

As part of model calibration, we sought to achieve agreement with various lines of evidence across the full range of hydrologic regimes. The following paragraphs provide an overview of the calibration approach. The following subsections provide additional details.

**Targets and constraints**. We first developed calibration targets and constraints for dry and wet weather based on available monitoring and supporting data. Targets and constraints included volumes of applied water, composition of typical dry weather streamflow (imported vs. local water), typical dry weather urban flowrates and composition, and measured flow patterns (both dry and wet) at streamflow gauges. These are described in **Section 3.6.2**.

**Initial parameterization.** We initially parameterized the model based on ranges of recommended parameter values (U.S. EPA 2000) for models created in the Hydrological Simulation Program – Fortran (variables and algorithms are much the same as LSPC) and an existing calibrated model of the Los Peñasquitos watershed in San Diego County (Tetra Tech 2016). We then checked the initial parameters against calibration targets to evaluate overall biases and errors.

**Calibration of Aliso and Oso Creeks**. We first focused on Aliso and Oso Creeks. Through iterative evaluation of parameter effects and sensitivities, we improved the calibration of the model to fit the targets for Aliso Creek and Oso Creek. In the course of this process, new isotope data of stream water in the Study domain were obtained to help fill gaps. We incorporated this new information at an intermediate step to refine the calibration. A primary tool for refining the calibrations at these locations was iteration on key model parameter values, which LSPC allows to vary across the model domain through the use of parameter groups. The first parameter group, encompassing Aliso, and the second parameter group, encompassing Oso, are identical except for variation in the interception storage capacity of impervious area. Interception storage pertains to the amount of water that is held on the landscape in vegetation canopy, puddles, and other features before runoff occurs. It is often used as a calibration parameter. See https://ocgov.box.com/s/onmy5ygv1d5l68jkyeeesnlb46b0u3ho for the parameter group extents and the parameter values for each group. The calibrated parameter groups for these watersheds then became the starting point for additional watersheds.

**Refinement of Low Flow Calibration in Laguna Canyon Creek, Salt Creek, Prima Deshecha Creek**, **and Segunda Deshecha Creek**. We then extended the model evaluation to other parts of the Study domain that have similar geology to Aliso Creek, but do not have continuous stream gauge data. This included Laguna Canyon Creek, Salt Creek, Prima Deshecha Creek, and Segunda Deshecha Creek. We compared the modeled baseflows to the values obtained from wading streamflow measurements. This supported minor adjustments of stream loss parameters to better fit the measured flows.

**Calibration at Arroyo Trabuco.** We next focused on calibration to the USGS gauge in Arroyo Trabuco. We started from the Oso Creek modeling parameters and made selected changes to reflect the somewhat different geologic characteristics of Trabuco Creek. Specifically, this system is underlain by a more significant alluvial aquifer that supports greater subsurface flow of water. It also has various groundwater extractions via the riparian rights of adjacent land owners. Therefore, we assigned greater groundwater loss parameters. Through iterative evaluation of parameter effects and sensitivities, we improved the calibration for Arroyo Trabuco to better fit the USGS streamflow monitoring data. This involved the development of the third and fourth parameter groups, which encompass the developed and undeveloped portions of Trabuco, respectively. The third parameter group, representing developed Trabuco, includes greater groundwater losses than the fourth group, representing undeveloped Trabuco, to account for greater pumping and evaporation from the alluvial aquifer in the lower reaches. See https://ocgov.box.com/s/onmy5ygv1d5l68jkyeeesnlb46b0u3ho for the parameter group extents and the parameter values for each group.

**Evaluation of Low Flow Calibration at Horno Creek, Upper Gobernadora Creek, Wagon Wheel Creek, and Dove Canyon**. We then extended the model evaluation to other parts of the Study domain that have similar geology to Trabuco Creek, but do not have reliable continuous stream gauge data. This included Horno Creek, Upper Gobernadora Creek, Wagon Wheel Creek, and Dove Canyon Creek. They were assigned to the third and fourth parameter groups based on relative development of the overall watershed. We evaluated the calibration of Horno Creek and Upper Gobernadora Creek by comparing dry weather modeled flows to values estimated from miscellaneous data sources (e.g., monitoring at Horno as part of a 2019-2020 outfall study, or low flow diversions and minimum downstream flow requirements at Gobernadora Basin). Finally, we checked Wagon Wheel Creek and Dove Canyon for reasonable average flow regimes compared to anecdotal evidence (e.g., expected relative dryness).

### 3.6.2. Calibration Targets and Constraints

In addition to rainfall, the water applied to the watershed as irrigation during dry weather has a significant effect on hydrology. The model calibration was guided and constrained by three key goals that pertain to water sources and flow composition:

- Application of water via the irrigation module within LSPC needed to match the estimate of applied water to developed areas using data from the Moulton Niguel Water District. This estimate was 2.5 to $3.8 \cdot 10^{-3}$ cfs per developed acre in the summer.

- Monthly average dry weather surface runoff from developed land areas matched a range of $2 \cdot 10^{-4} \pm 1 \cdot 10^{-4}$ cfs per developed acre, which was based on an average of outfall flow monitoring measurements at approximately 120 sites in the SOC WMA (see outfall flow references in **Section 3.3**) combined with isotope data regarding flow composition at 20 of these sites.

- Imported water generally comprised less than half of spring and summertime streamflow in most streams, as indicated by 2020 stable isotope data from streams in the study area (see isotope references in **Section 3.3**). This implies that groundwater recharge is an important factor in the watershed, and the model must allow active groundwater discharge to decline yet continue from spring through summer.

Calibration was assessed based on comparison of results to these goals. We also assessed the model calibration by comparing model simulations of hourly flow rates at stream gauge locations to the gauged flows at those locations. Calibration locations were:

- Aliso Creek at the Sewage (Coastal) Treatment Plant (also called Aliso@STP)
- Aliso Creek at Jeronimo Road in Lake Forest
- Oso Creek near Crean Bridge in Laguna Niguel
- Arroyo Trabuco USGS Gauge near San Juan Capistrano

Of these, we used the entire available record from the Aliso Creek at the Sewage (Coastal) Treatment Plant and Arroyo Trabuco gauges. The flow record measured at the Oso gauge showed a significant, abrupt decrease in flow rate in mid-summer 2017, indicating a potential data quality issue with this gauge. Therefore, we removed the gauge record after 17 July 2017 from this analysis. The Aliso Creek gauge at Jeronimo Road was used as a secondary calibration location.

**Table 3-3** summarizes the calibration targets used for comparison to flow monitoring data in Aliso, Oso, and Trabuco Creek.

**Table 3-3. Statistical targets for assessment of hydrologic model calibration.**

| Statistic[a,b] | Description | Target |
|---|---|---|
| Nash-Sutcliffe Efficiency (NSE) | Comparison of relative magnitude of variance in model output and data | > 0.5 |
| Logarithmic NSE | NSE using log-transformed model output and observed data | > 0.5 |
| Ratio of root-mean-square error to the standard deviation of measured data | Incorporates benefits of error index statistics and includes a normalization factor | ≤ 0.7 |
| Percent bias | Average tendency of the model output to be larger or smaller than observed data | ± 25 |

[a]Moriasi et al. 2007; Singh et al. 2005

[b]Each statistic was calculated for daily average flow rates

Dry weather flow calibration was assessed and adjusted based on comparison to dry weather wading streamflow measurements at four locations:

- Laguna Canyon Creek at Woodland Drive in Laguna Beach
- Salt Creek at Pacific Coast Highway in Dana Point
- Prima Deshecha Creek at Calle Grande Vista in San Clemente
- Segunda Deshecha Creek at Calle de Los Molinos in San Clemente

Finally, dry weather flow calibration was assessed and adjusted based on estimates from miscellaneous data and anecdotal evidence at four additional locations:

- Upper Horno Creek at the Horno Basin Project

- Upper Gobernadora Creek at the Gobernadora Basin Project
- Dove Canyon Creek at the Dove Canyon Barrier
- Wagon Wheel Creek

Calibration locations and streamflow files are outlined in **Section 3.3** and available at: https://ocgov.box.com/s/yabdq79q4cqoacsrax8lxqge8z2tkpqp. Parameters were adjusted to match calibration data sets during the period 1 October 2014 through 20 May 2019. After calibration, the model was run from 1 October 1989 through 20 May 2019 and model output was reported starting on 1 October 1993 to allow for a four-year model spin-up period.

The model was run with a four-year "spinup" period to decrease the influence of assumed initial conditions (i.e., the meteorological record extends from the middle of 1989 through 20 May 2019, but the reporting of results began on 1 October 1993 for consistency with the start of the water year). Model input files and time series output files are available at: https://ocgov.box.com/s/ce7zjq7mrnssj5rit1ofpa1xy1gwnpf4.

### 3.6.3. Summary of Calibration Performance

The calibration achieved very good agreement between observed and modeled streamflow in Aliso Creek at the Sewage (Coastal) Treatment Plant streamflow monitoring location, which was the primary location used to evaluate calibration. Comparison of time series plots of modeled and observed flows (example in **Figure 3-2**) indicates agreement in declining streamflow from spring to summer. Agreement between model and data is reasonable during both summer and winter base flow as well. Scatter plots (example in **Figure 3-3**) show a good fit to measured data over multiple orders of magnitude with limited discernable bias.

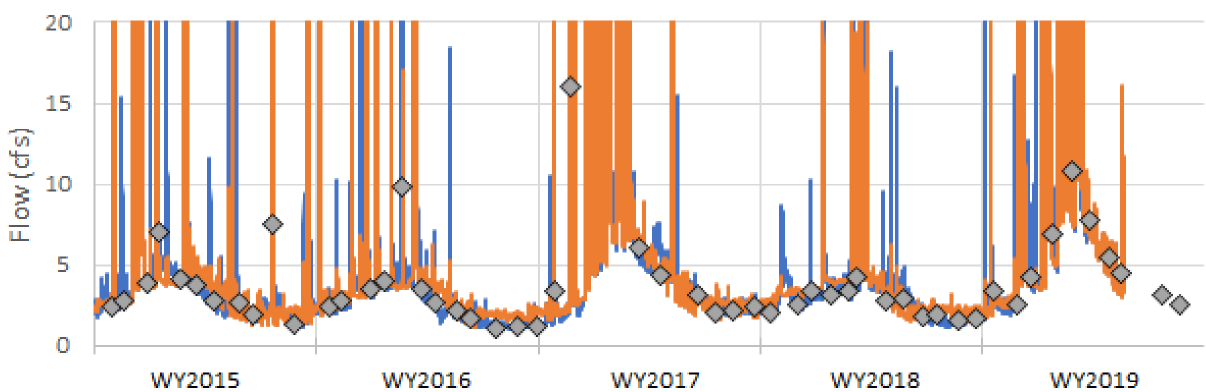


**Figure 3-2. Comparison of observed and modeled flow time series at Aliso Creek at the Sewage (Coastal) Treatment Plant between 1 October 2014 and 20 May 2019. Model output (orange) is shown as a 24-hour moving average on top of gauged flows (blue). Gray symbols depict monthly flow measurements assessed manually by wading.**

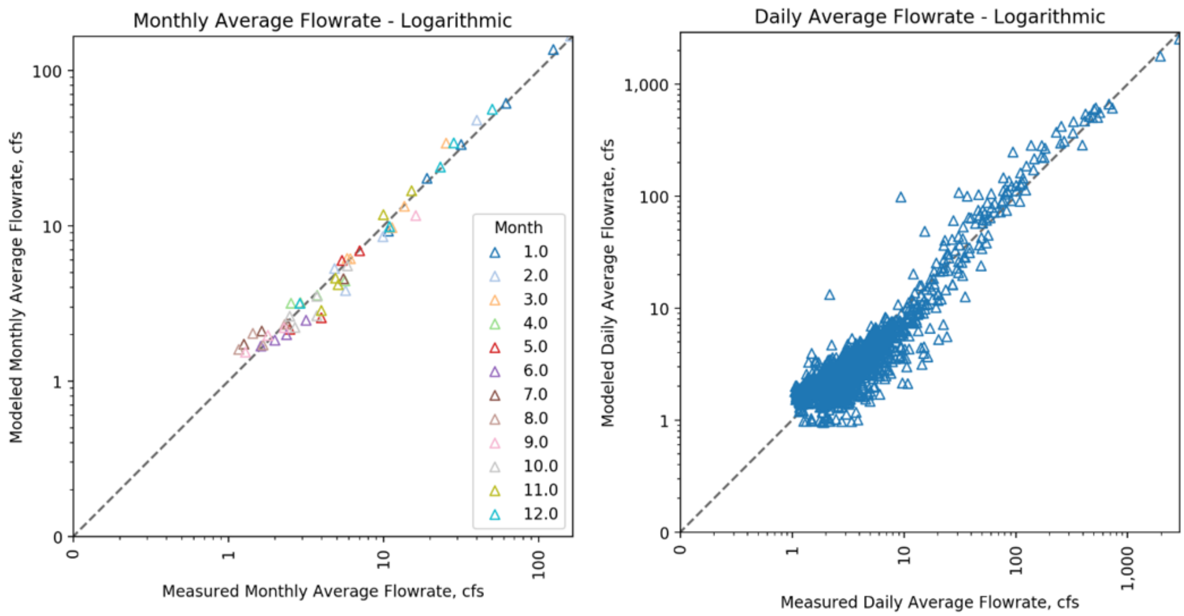


**Figure 3-3. Comparison of monthly and daily average simulated streamflow to observed streamflow at Aliso Creek at the Sewage (Coastal) Treatment Plant between 1 October 2014 and 20 May 2019.**

**Table 3-4** provides a summary of model performance at Aliso Creek at the Sewage (Coastal) Treatment Plant for each of the constraints and targets established. The calibration met all targets and constraints.

**Table 3-4. Model performance for Aliso Creek at Coastal Treatment Plant.**

| Constraint | Target | Model Performance | Assessment |
|---|---|---|---|
| Irrigation application to developed areas | 2.5 to $3.8 \cdot 10^{-3}$ cfs/ac | $3.8 \cdot 10^{-3}$ cfs/ac in developed subbasins | Pass |
| Dry weather surface runoff | $2 \cdot 10^{-4} \pm 1 \cdot 10^{-4}$ cfs/ac | $1 \cdot 10^{-4}$ cfs/ac in developed subbasins | Pass |
| Streamflow composition | 30% imported water in July (25% – 35%) | 32% | Pass |
| NSE | > 0.5 | 0.97 | Pass |
| Logarithmic NSE | > 0.5 | 0.89 | Pass |
| RSR | ≤ 0.7 | 0.17 | Pass |
| Percent bias | ± 25 | 4.1% (all); 0.3% (flows < 10 cfs); 16% (10-100 cfs); 6% (> 100 cfs) | Pass |

At the Jeronimo Road gauge on Aliso Creek, the model represented flows above 3 cfs with a low bias of 3.1% but considerably more scatter about a 1:1 line than at the Aliso@STP gauge, which led to a decreased NSE of 0.84 and a higher RSR of 0.39 (**Figure 3-4**). Flows below approximately 1 cfs were overestimated by model output. In subbasins nearer the headwaters of streams (such as the area above Jeronimo Road), the model lacked adequate resolution to define baseflow and stream loss behavior, tending to cause a small flow to occur despite reasonable calibration adjustments.

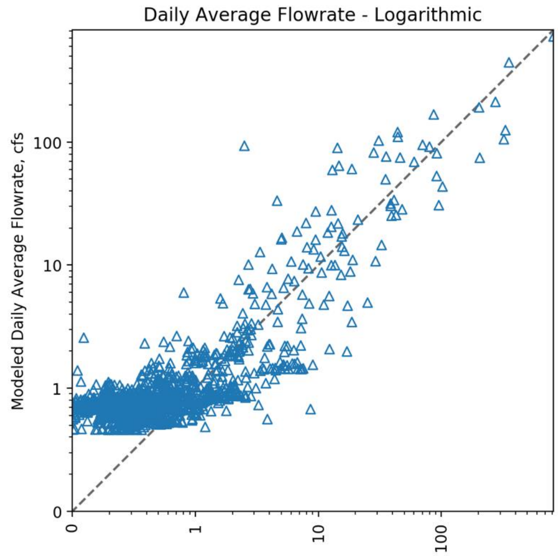


**Figure 3-4. Agreement of modeled and observed flow at the Aliso Creek gauge at Jeronimo Road.**

The calibration was also reasonable in Oso Creek. At the Oso Creek continuous monitoring station, gauge data showed several unexplained instances of changing flow between 1 October 2014 and 11 June 2017. Because they did not relate to events in the watershed (e.g., precipitation patterns), it is possible that moving sediment in the streambed may have disrupted the relationship between water level and flow upon which the flow records are based. After 11 June 2017, they dropped to near zero for nearly all times. Because this drop in gauged flows was not reflected in the direct wading streamflow estimates performed at this time, we disregarded gauged flows after this date because we suspect a long-term impairment to gauge function. Agreement between model output and wading streamflow was reasonable (**Figure 3-5**). When compared to only the reliable flow monitoring data, model performance was generally acceptable. The model showed a somewhat higher water application than target and a somewhat greater fraction of imported water than the calibration target (**Table 3-5**).

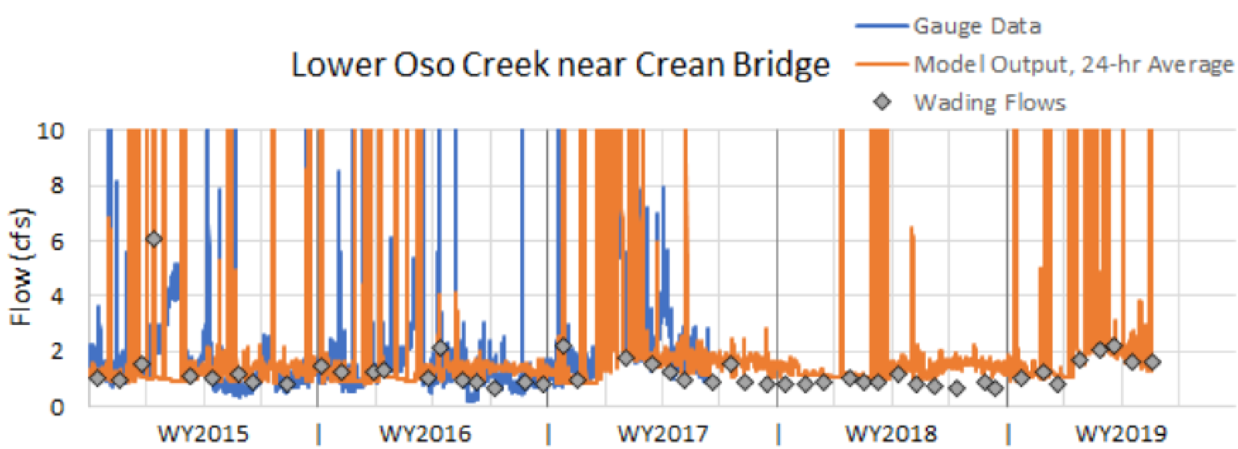


**Figure 3-5. Flow timeseries at Lower Oso Creek, including gauge measurements, wading measurements, and model output.**

**Table 3-5. Model performance for Oso Creek near Crean Bridge.**

| Constraint | Target | Model Performance | Assessment |
|---|---|---|---|
| Irrigation application to developed areas | 2.5 to $3.8 \cdot 10^{-3}$ cfs/ac | $4.1 \cdot 10^{-3}$ cfs/ac in developed subbasins | High |
| Dry weather surface runoff | $2 \cdot 10^{-4} \pm 1 \cdot 10^{-4}$ cfs/ac | $1 \cdot 2^{-4}$ cfs/ac in developed subbasins | Pass |
| Streamflow composition | 30% imported water in July (25% – 35%) | 49% | High |
| NSE | > 0.5 | 0.91 | Pass |
| Logarithmic NSE | > 0.5 | 0.71 | Pass |
| RSR | ≤ 0.7 | 0.31 | Pass |
| Percent bias | ± 25 | 10.2% (all); -3.4% (flows < 10 cfs); 9.5% (10-100 cfs); 18.6% (> 100 cfs) | Pass |

Through iteration within a reasonable range of input parameter, we achieved an acceptable calibration in Arroyo Trabuco. Scatter plots (example in **Figure 3-6**) show a good fit to measured data over multiple orders of magnitude. The LSPC model does not distinguish between surface flow and subterranean flow. The modeled discharge at the subbasin effectively includes both components of flow. However, the USGS streamflow monitoring station only measures surface flow. Therefore, it is inappropriate to compare the model to the gauge data for low flows. To account for this, we did not consider measured flows smaller than 3 cfs in evaluation of the calibration.

Calibration statistics for flows above 3 cfs (**Table 3-6**) showed generally acceptable model performance. Both isotope data and the calibrated model indicated that imported water constitute a relatively low fraction of streamflow; however, there is considerable uncertainty in the isotope analysis due to the relatively high elevation of the headwaters of the watershed. The isotopic composition of rainwater tends to vary with elevation and distance from the coast, which may lead to a different isotopic signature of the precipitation falling in the headwaters of Trabuco Creek relative to the precipitation reaching other parts of the study area. The control samples and reference data we had available to define isotopic endmembers did not span the higher elevation, leading to the greater uncertainty stated above. A previous study performed by SMWD (personal communication, Don Bunts) found that about half of the summer streamflow in Arroyo Trabuco was imported.

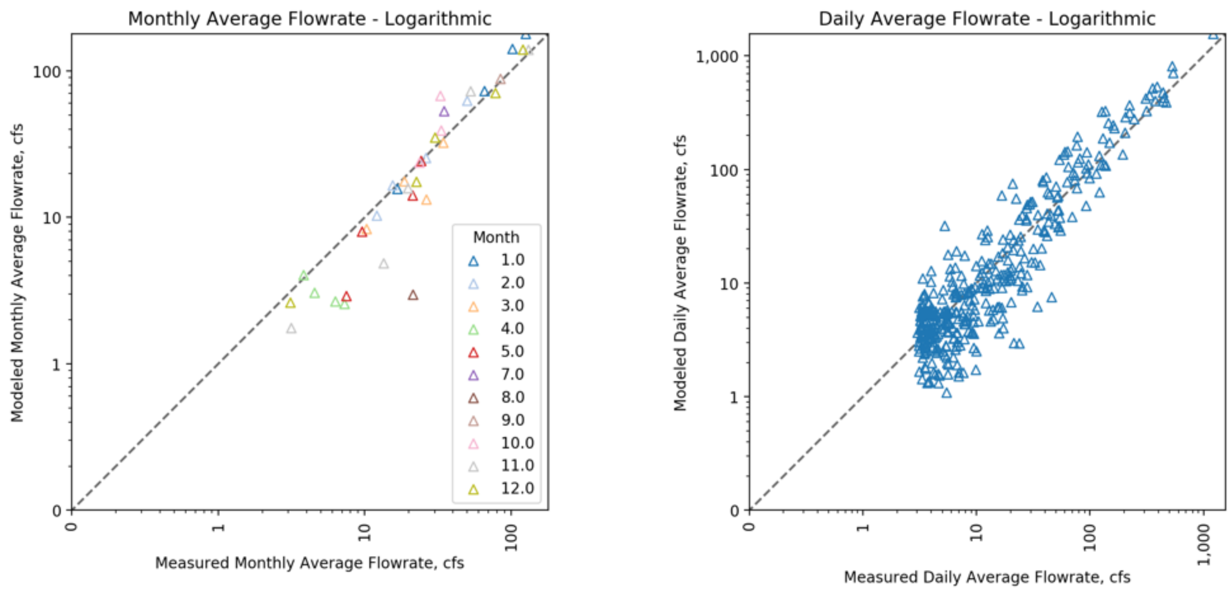


**Figure 3-6. Comparison of monthly and daily average simulated streamflow to observed streamflow at Arroyo Trabuco USGS gauge between 1 October 2014 and 20 May 2019.**

**Table 3-6. Model performance for Trabuco Creek at the USGS Arroyo Trabuco Gauge.**

| Constraint | Target | Model Performance | Assessment |
|---|---|---|---|
| Irrigation application to developed areas | 2.5 to $3.8\cdot10^{-3}$ cfs/ac | $3.8\cdot10^{-3}$ cfs/ac in developed subbasins | Pass |
| Dry weather surface runoff | $2\cdot10^{-4} \pm 1\cdot10^{-4}$ cfs/ac | $1\cdot3^{-4}$ cfs/ac in developed subbasins | Pass |
| Streamflow composition | < 20% imported water in July | 15% | Pass |
| NSE | > 0.5 | 0.87 | Pass |
| Logarithmic NSE | > 0.5 | 0.88 | Pass |
| RSR | ≤ 0.7 | 0.36 | Pass |
| Percent bias | ± 25 | -4.8% (3-10 cfs); 10.4% (10-100 cfs); 23.2% (> 100 cfs) | Pass |

The dry weather flow calibration was reasonable for the smaller watersheds based on the data available for comparison. At the points where wading streamflow measurements were available, the agreement of the modeled and observed flow is shown in

**Figure 3-7**. In Laguna Canyon, we were unable to achieve a model calibration that matched the frequent dry (no flow) conditions, indicating that there are low flow loss processes in this watershed that are different than other watersheds. Only estimated flows greater than 0.5 cfs were considered to be an indication of actual flow.

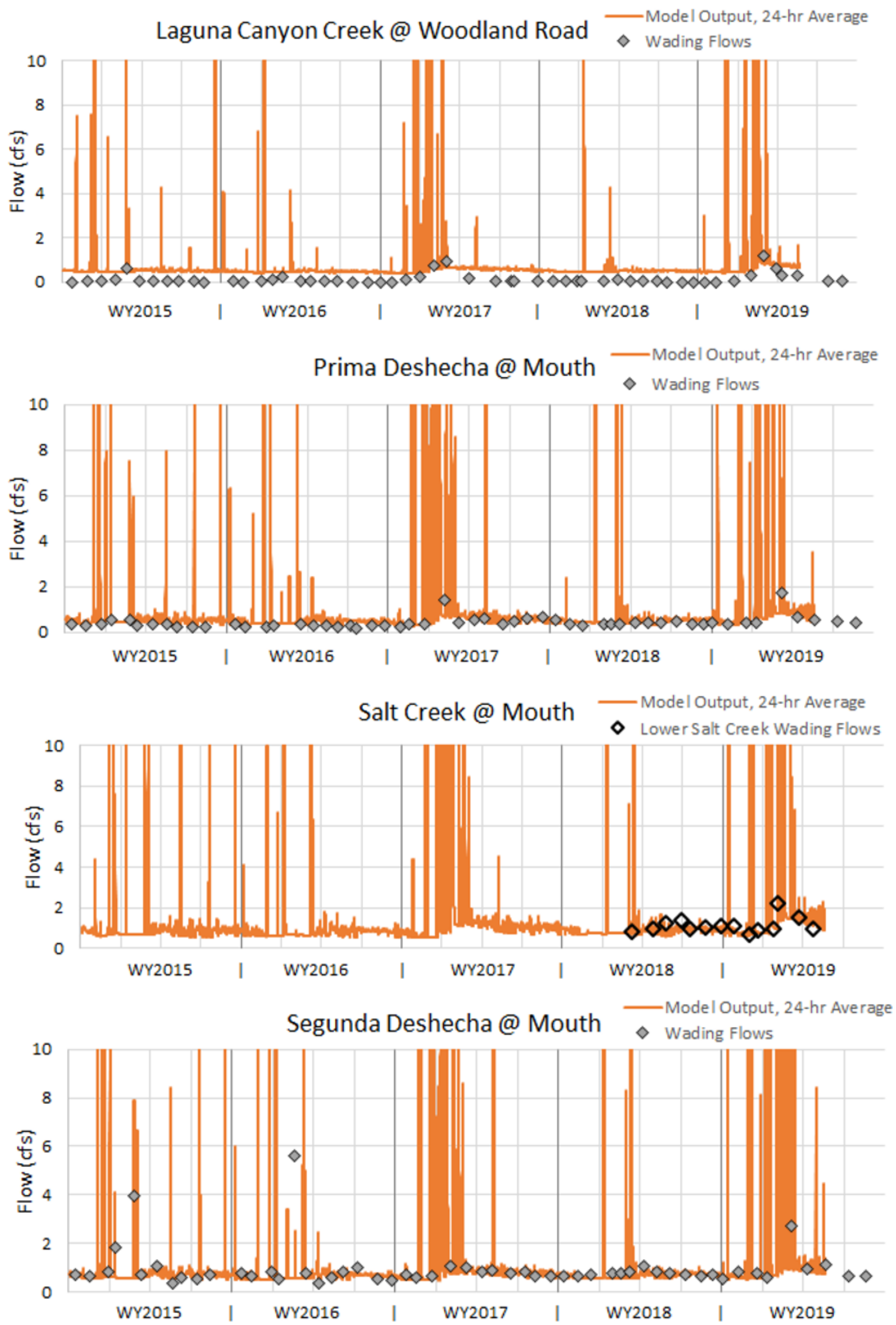


**Figure 3-7. Flow calibration for Laguna Canyon Creek, Salt Creek, Prima Deshecha, and Segunda Deshecha. Wading streamflow measurements (diamonds) are overlain on model output (orange).**

Where wading streamflow measurements were not available, we referenced miscellaneous data and anecdotal evidence to assess the calibration. For example, we determined that the average modeled late-summer flows at Horno Basin (approximately 0.54 cfs) were similar to the median flow monitored from September through November of 2019 (0.59 cfs ).[3] Additionally, average modeled late-summer flows at Gobernadora Basin (approximately 1.1 cfs) were similar to the estimated dry weather flows in the reach before the low flow diversion (1.08 cfs).[4] Finally, average modeled late-summer flows in Wagon Wheel Creek and Dove Canyon Creek were relatively low (approximately 0.1 cfs in each case), as expected based on anecdotal evidence that these systems are often dry in some reaches during summer months. In each of these cases, the calibration was found to be reasonable.

Additional calibration results (crossplots, flow duration curves, time series plots, summary statistics and parameter values) are available at: https://ocgov.box.com/s/onmy5ygv1d5l68jkyeeesnlb46b0u3ho.

### 3.6.4. Calibration Summary and Limitations

Overall, the calibration performance was very good and showed strong agreement with a wide range of calibration constraints and criteria. There are a few notable limitations:

- Confidence is greatest in the Aliso Creek watershed because the greatest amount of high-quality calibration data was available in this watershed.
- Flows less than about 0.5 to 1 cfs were difficult to model accurately, resulting in occasional high bias. In reaches that may exhibit periods of drying or subsurface flow, the model may not have adequate resolution to account for these conditions. Additional lines of evidence such as visual observations were used to determine flow regime.
- The LSPC model does not account for subsurface flow in a stream channel. This may be a significant fraction of flow in lower Trabuco Creek. Therefore, model output is not reported for Trabuco Creek below 3 cfs.
- The model is informed significantly by isotope findings. However, these are available only for 2019 and 2020. Therefore, we have less confidence in how the composition of streamflow varies over time and through long-term wetter and drier periods. Additionally, isotope findings are less certain for Trabuco Creek due to the much higher elevation of the headwaters of this watershed compared to other streams.
- Portions of the model domain lack calibration data (i.e., upper Trabuco Creek, Bell Canyon and Dove Canyon Creeks, Upper San Juan Creek) and thus the model results in these reaches are estimated based on the calibration of nearby reaches.

Overall, the model is considered to be reliable for assessing each part of the long-term hydrograph in key receiving water locations throughout the modeling domain. Additional data obtained in ongoing or future monitoring programs can help improve the calibration in areas that currently lack site-specific data.

[3] Value obtained from the 2019-2020 OCFS Outfall Summary Sheets developed by Geosyntec Consultants and Orange County Public Works, pg. 78.
[4] Value obtained from estimate of 0.78 cfs low flow diversion with a minimum of 0.3 cfs left in the creek for downstream ecosystem needs.

## 3.7. Scenario Analysis

### 3.7.1. Reference Condition

We developed and modeled a reference condition scenario to serve as a point of reference for analyses of hydrologic and ecologic alteration (discussed below). In general, development of this scenario sought to remove anthropogenic influences from the model representation of the SOC WMA. However, this scenario was not representative of any specific time, and it was not an attempt to define or recreate "natural" conditions.

We developed the reference condition by modifying the model of current conditions (described above) in the following ways:

- Developed land in each subbasin was reassigned to open space (i.e., open space, shrubland, forest, and wetlands) based on the distribution of scrub and forested areas found in that subbasin (example in
- Figure **3-8**). For subbasins lacking open space land uses, the average distribution of the respective watershed was used. Developed areas were assigned to the middle slope class of the respective open space land uses that they were reassigned to.
- Application of water to the land surface was turned off in the model.
- Flow control structures and channel modifications were removed.

Figure **3-8** illustrates an example of how we changed the modeled land uses changed between the current condition and the reference condition for the Aliso Creek watershed. We made analogous changes throughout the study area to define the reference condition.

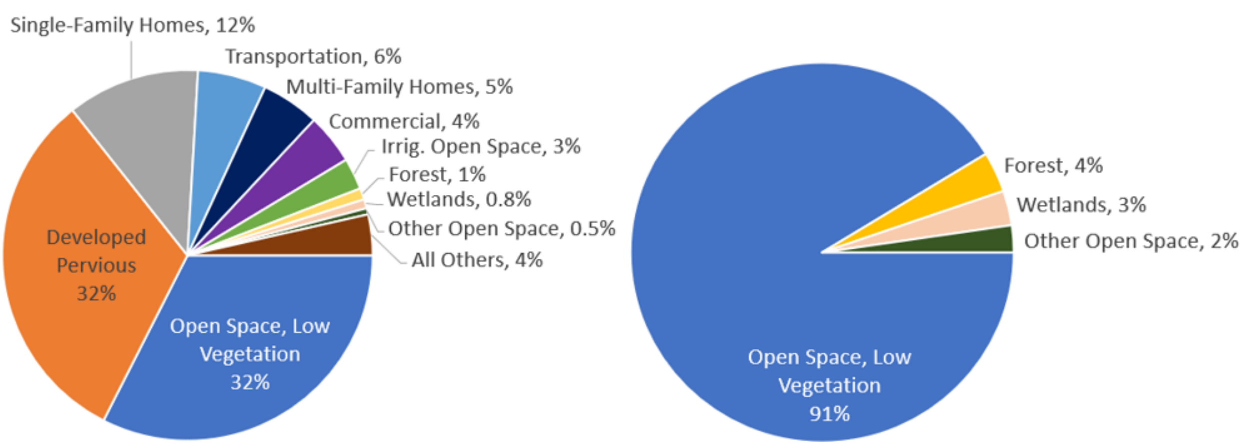


**Figure 3-8. Land uses in the LSPC representation of the Aliso Creek watershed in current conditions (left panel) and the reference condition (right panel).**

For Aliso Creek, Oso Creek, and Coastal Streams, we left the stream losses unchanged between current and reference conditions. Based on review of historical aerial photographs, we found that there were greater lengths of soft-bottomed stream reaches prior to development but with lower density of vegetation in stream corridors. This has an offsetting effect, and there was insufficient information to determine the direction or magnitude of change in losses. In these reaches, the riparian losses modeled were entirely based on evapotranspiration as there are limited subsurface flow pathways and no significant groundwater extractions.

In the developed subbasins in Lower/Middle Trabuco-Tijeras, Horno, Gobernadora, Wagon Wheel, and Dove Canyon, the calibrated stream losses for the current condition are a bulk parameter that accounts for current vegetation density as well as groundwater withdrawals. This has limited bearing on what may have occurred in reference conditions. Therefore, to estimate reference condition stream losses, we estimated vegetated riparian area and the ET demand exerted by the vegetation types. This same method was used for both the current and reference condition in the undeveloped subbasins of Upper Trabuco, Bell Canyon, and San Juan.

In all months over a long-term simulation, the reference condition model had lower streamflow at the Aliso Creek at the Sewage (Coastal) Treatment Plant and Trabuco Creek gauge locations relative to the models of current conditions. A plot demonstrating this trend for Aliso Creek is provided in **Figure 3-9**. Example summary statistics for both gauge locations are included in **Table 3-7**. The lower flows in the reference condition are attributable to the much greater area of pervious land and its capacity to infiltrate rainwater before it reaches stream channels. However, the presence of significant local rainwater-derived baseflow in both creeks in the current conditions suggests that perennial baseflow would be expected in the reference condition. It is unknown how much of the low flow in Trabuco Creek in the reference condition would occur as surface flow versus subterranean flow.

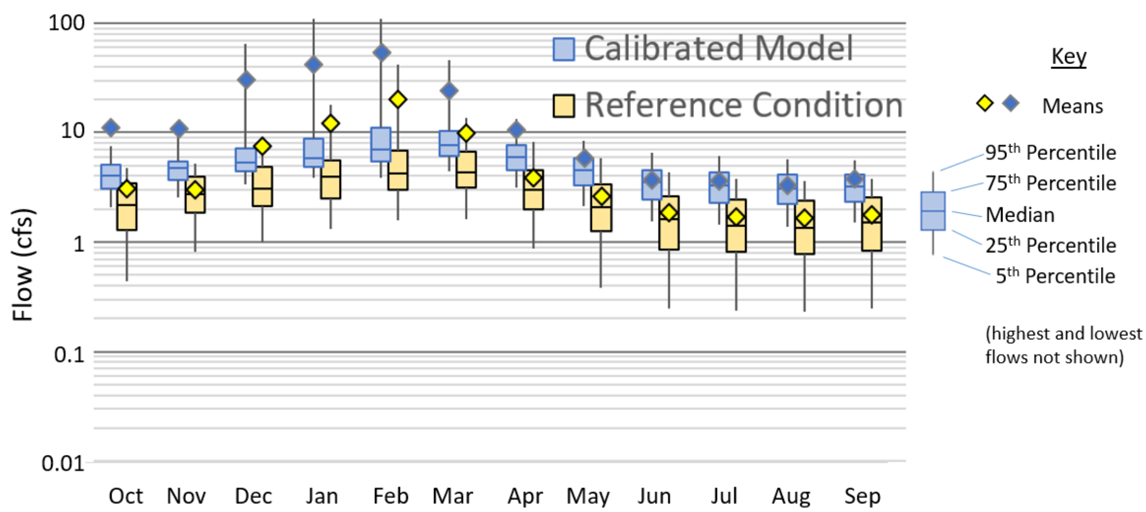


**Figure 3-9. Monthly distribution statistics of streamflow for the calibrated model of current conditions and the reference condition at the Aliso Creek @ STP stream gauge location in a long-term simulation.**

**Table 3-7. Comparison of selected metrics between reference and current conditions.**

| Metric | Reference Condition | Calibrated Current Condition | Percent Change (Reference to Current) | Reference as Fraction of Current |
|---|---|---|---|---|
| Aliso Creek at the Sewage (Coastal) Treatment Plant | | | | |
| Average Annual Discharge Volume, ac-ft/yr | 3,861 | 11,144 | 188% | 0.35 |
| Median Summer Streamflow[a], cfs | 1.98 | 3.50 | 77% | 0.57 |
| 2-year Peak Flowrate[b], cfs | 447 | 1,045 | 134% | 0.43 |
| 10-year Peak Flowrate[c], cfs | 1,073 | 1,840 | 71% | 0.58 |
| **Trabuco Creek** | | | | |
| Average Annual Discharge Volume[d], ac-ft/yr | 4,981 | 12,870 | 158% | 0.39 |
| Median Summer Streamflow[a,d], cfs | 2.33 | 3.47 | 49% | 0.67 |
| 2-year Peak Flowrate[b,d], cfs | 583 | 1156 | 98% | 0.50 |
| 10-year Peak Flowrate[c,d], cfs | 1,164 | 1,651 | 42% | 0.70 |

[a]Summer = May-October
[b]Daily average flow exceeded 13 times in 26-year period
[c]Daily average flow exceeded 3 times in 26-year period
[d]Estimates of discharge volume and streamflow in Trabuco Creek include both surface flow and subterranean flow. These two pathways are not distinguished by the LSPC model. During dry weather periods, it is believed that a significant fraction of streamflow occurs via subterranean flow.

Historical data from the early 1970s for lower Aliso Creek provides an indication of measured flows prior to significant urbanization of the watershed. While these data are relatively sparce and coarse, the observed baseflow in dry season months appears to range from around 0.25 cfs to 2 cfs. This range overlaps with the box plots shown in **Figure 3-9** and qualitatively supports the assessment that the stream was likely normally perennial in a reference, non-urbanized condition. These data are too limited to serve a calibration or validation purpose.

Model input files and model output time series for the reference condition are found at: https://ocgov.box.com/s/hlef1oms6z7osentx46mo55h5xucpnty.

### 3.7.2. Water Conservation

We developed a water conservation scenario for the model domain to study the potential response of streamflow to a future scenario in which water conservation practices have become more widespread in the SOC WMA. The development, model files, and model output of the

water conservation scenario are described at:
https://ocgov.box.com/s/6qvmo164narhn74o7nezvotrnm3bq3ln.

Based on analysis of water conservation projections and discussion with MNWD, a 14 percent reduction in water application was modeled in LSPC. This corresponds to “Scenario 3” within the water conservation description accessed at the link above, which was judged as most likely following consultation with the MNWD. We implemented this scenario in LSPC by uniformly reducing irrigation water application to the watershed while preserving seasonal trends. No other changes were made. **Table 3-8** provides a summary of results for two example locations. We applied the same scenario throughout the developed land uses in the model domain.

**Table 3-8. Summary of key metrics from water conservation scenario results.**

| Metric | Current Conditions Calibrated Model | Water Conservation | Percent Change |
|---|---|---|---|
| **Aliso Creek at the Sewage (Coastal) Treatment Plant (14 percent reduction in applied water)** | | | |
| Average Annual Runoff Volume, ac-ft/yr | 11,144 | 10,207 | -8% |
| Median Summer[a] Flowrate, cfs | 3.50 | 2.42 | -31% |
| 25$^{th}$ Percentile Summer[a] Flowrate, cfs | 2.73 | 1.77 | -35% |
| **Trabuco Creek (14 percent reduction in applied water)** | | | |
| Average Annual Runoff Volume[b], ac-ft/yr | 12,870 | 11,403 | -11% |
| Median Summer Flow Rate[a,b], cfs | 3.47 | 1.85 | -47% |
| 25th Percentile Summer Flow Rate[a,b], cfs | 2.51 | 1.21 | -52% |

[a]Summer = May-October

[b]Estimates of discharge volume and streamflow in Trabuco Creek include both surface flow and subterranean flow. These two pathways are not distinguished by the LSPC model. During dry weather periods, it is believed that a significant fraction of streamflow occurs via subterranean flow.

### 3.7.3. Climate Change

To evaluate the effect of future changes in climate, we performed a case study of the Aliso Creek Watershed. The effects of climate change on other South Orange County creeks are expected to be similar to Aliso Creek. We developed two sets of model scenarios for comparative purposes: the historical period from WY 1975 – 2005 and the future (RCP85) period from WY 2030-2060. The primary factor differentiating the two sets of models were the climate variables precipitation and ET. Timeseries for each of these climate variables for both model periods were obtained or derived from a series of four Global Climate Models (GCMs) representing a range of future projections with respect to change in precipitation and temperature. Note that this is only a direct evaluation of how climatic variables change runoff and streamflow. There are likely indirect impacts of climate change such as changes in water use patterns that may also influence streamflow.

Due to availability of climate projections, these models were run at a daily resolution. This does not allow results to be compared to hourly models but does allow comparison between historic and future conditions with the same modeling assumptions (**Table 3-9**).

The climate scenarios reference directory (https://ocgov.box.com/s/rkswfvhgl7gpx7g3v711lzkqsfcov1yb) provides a more detailed description of scenario analysis and provides input datasets, model files, and results.

Overall, climate change has the potential to result in moderate changes in streamflow metrics. However, the different GCMs provided different projections that spanned both negative and positive changes in streamflow metrics. Given the disagreement among models, we are not able to draw clear conclusions about the effects of climate change on stream flows, and therefore, climate change was not carried through the ecological analysis explicitly. However, it is acknowledged as a key point of uncertainty.

**Table 3-9. Summary of selected results from climate change scenario.**

| GCM | 1975-2005 | 2030-2060, RCP8.5 | Percent Change |
|---|---|---|---|
| **Average Annual Discharge Volume, ac-ft/yr** | | | |
| CanESM2 | 10,500 | 12,100 | +15% |
| CCSM4 | 10,300 | 9,500 | -8% |
| CNRM-CM5 | 10,100 | 12,100 | +21% |
| MIROC5 | 11,300 | 8,100 | -28% |
| Average: | 10,500 | 10,450 | -1% |
| **Median Summer Streamflow, cfs (May – October)** | | | |
| CanESM2 | 6.5 | 7.4 | +14% |
| CCSM4 | 6.4 | 5.7 | -11% |
| CNRM-CM5 | 6.7 | 7.2 | +8% |
| MIROC5 | 6.9 | 5.2 | -25% |
| Average: | 6.6 | 6.4 | -3% |
| **2-year Peak Flow, cfs (Peak daily flowrate exceeded 17 days in 35 years)** | | | |
| CanESM2 | 507 | 621 | +22% |
| CCSM4 | 502 | 561 | +12% |
| CNRM-CM5 | 450 | 522 | +16% |
| MIROC5 | 540 | 435 | -19% |
| Average: | 500 | 535 | +7% |
| **10-year Peak Flow, cfs (Peak daily flowrate exceeded 3 days in 35 years)** | | | |
| CanESM2 | 712 | 953 | 34% |
| CCSM4 | 785 | 783 | 0% |
| CNRM-CM5 | 785 | 739 | -6% |
| MIROC5 | 762 | 684 | -10% |
| Average: | 761 | 790 | +4% |

Note: Climate change assessment results are based on daily resolution modeling. Absolute values are different than hourly simulation values. Hourly values are more reliable. This analysis is intended to focus primarily on the relative change.

## 3.8. Hydrology Analysis Summary

The primary objective of the hydrologic analysis was to characterize streamflow regimes across the study area to support the ecological analysis described in **Section 4.** To meet this objective, we:

- Compiled hydrologic and watershed data relevant to defining and modeling streamflow regimes.

- Developed a continuous simulation LSPC model of the study area accounting for rainfall, irrigation, ET, flow diversions and controls, land uses, soils, and surface slopes.
- Defined calibration targets and constraints.
- Collected water isotope monitoring data to better understand the sources of streamflow and support model calibration.
- Performed model calibration to achieve reasonable alignment with targets and constraints.
- Defined and analyzed scenarios, including a reference condition and water conservation condition.
- Conducted a case study analysis of potential climate change effects on streamflow regimes in Aliso Creek.

This has produced a consistent model across the study area that is reliable for assessment of current conditions and relative comparisons between scenarios. As with any model, various uncertainties and limitations exist. Inputs and outputs from this model are available at the links referenced in this section.

Key findings from the hydrologic analysis are summarized in **Section 5.**

# 4. ECOLOGICAL ANALYSIS

## 4.1. Overview

The primary purpose of the flow ecology analysis is to prioritize areas where actions to restore more natural flow conditions will benefit the ecology and desired species and habitats and to identify the flow conditions necessary to support desired conditions. The intent is NOT to recommend flow criteria, but to inform restoration and watershed and water resource management planning.

### 4.1.1. Multi-tiered Analysis Approach

A multi-tiered approach was developed to support prioritization and provide flow ranges to inform restoration and management. This approach includes the following steps:

- Assess hydrologic alteration (Level 1; **Section 4.2**)
- Determine where hydrologic alteration is likely affecting biological communities and identify priority locations for addressing alteration (Level 2; **Section 4.3**)
- Identify flow ranges to support focal species and inform restoration and management (Level 3; **Section 4.4**)

The ecological analysis herein focused on subbasins of the LSPC model (

**Figure 4-1**).

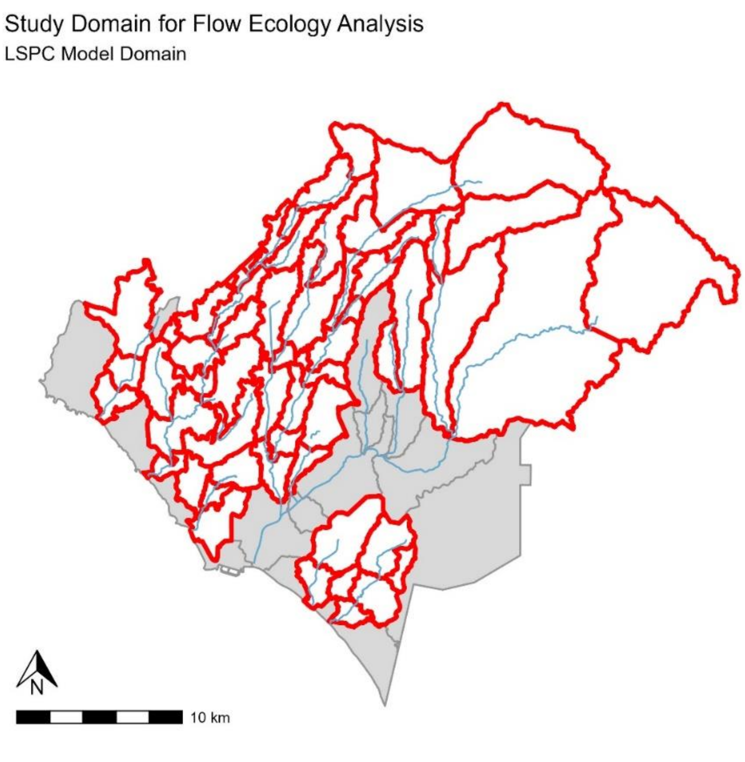


**Figure 4-1. Study domain of the multi-tiered flow ecology analysis is focused on the LSPC model domain (red).**

## 4.2. Level 1 - Hydrologic Alteration based on Deviation from Reference

Level 1 analysis evaluates hydrologic alteration based on the deviation of current flow conditions from modeled reference conditions. Modeled reference and current hydrology, documented in **Section 3.7**, were characterized by quantifying key components of the annual hydrograph that support a broad suite of ecological functions, referred to as functional flow metrics (FFM). An alteration assessment comparing FFM from reference to current conditions was conducted to identify in which seasons (i.e., wet or dry) and direction (i.e., augmented or depleted) are flows likely altered and in what locations. This analysis does not provide a management target or an expectation of achievable flow conditions, but instead serves as context to evaluate the current alteration status of hydrology across the SOC WMA as it relates to the ability to support stream functions, habitats, and species.

### 4.2.1. Functional Flow Metrics

Hydrology can be characterized by hundreds of flow metrics that span across variable timescales, flow characteristics, and seasons. This study evaluated current and reference hydrology across a suite of 24 FFM that represent multiple aspects of the annual hydrograph, consistent with the California Environmental Flows Framework (CEFF) (https://ceff.ucdavis.edu/). Functional flows are the components of the annual hydrograph that support a broad suite of ecological functions and support a characteristic set of aquatic and riparian plants and animals (Yarnell et al. 2015). In California, functional flow components include the fall pulse flow, winter baseflows, peak flows, spring recession flows, and summer baseflows (Yarnell et al. 2020). FFM are quantifiable flow characteristics that describe the timing, magnitude, duration, and frequency of these functional flow components and are calculated annually from daily flow timeseries. Additional details on the FFM, references, and tools are archived at: https://ocgov.box.com/s/jlksoi9yr85iho5do8560zy2tp6qsncn

Current and reference hourly flow timeseries from water year 1993 to 2019 (LSPC) were post-processed to mean daily flow and FFM were calculated 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 could not be 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.

Calculated flow metrics and metadata for all subbasins modeled with LSPC can be found at: https://ocgov.box.com/s/l66wvrexbdmt7endumu0pkxao0flq89p.

### 4.2.2. Alteration Assessment

An alteration assessment was conducted to determine where, when, and in what direction are functional flows likely altered across the SOC WMA. Following the guidelines presented in CEFF, we assessed alteration across all FFM by comparing the distribution of metric values under current and reference conditions. Utilizing the distribution of flows across the full period of record, as opposed to a year-by-year comparison, allowed evaluation of the general trends in flow conditions over time. We only assessed alteration if the FFM had at minimum 5 metric values calculated across the period of record under the current and reference scenarios. Functional flow components such as the peak flow and fall pulse flow may not be observed every water year and their corresponding FFM may be excluded from the alteration assessment. The peak magnitude metrics (2-year, 5-year, and 10-year flood magnitude) only have one value calculated across the period of record and were excluded from the alteration assessment. Instead, we used the 99th percentile of daily flow each year, referred to herein as the magnitude of the largest annual storm, as our peak magnitude flow metric which was found to have strong importance to CSCI (Mazor et al. 2018). First, the 10$^{th}$, 50$^{th}$ (median), and 90$^{th}$ percentiles were calculated for both reference and current FFM values. Next, we applied the criteria illustrated in **Figure 4-2** to assign an alteration status for each metric by comparing the current median to the reference 10$^{th}$ and 90$^{th}$ percentile range. The three alteration categories were likely altered, likely unaltered, and indeterminate.

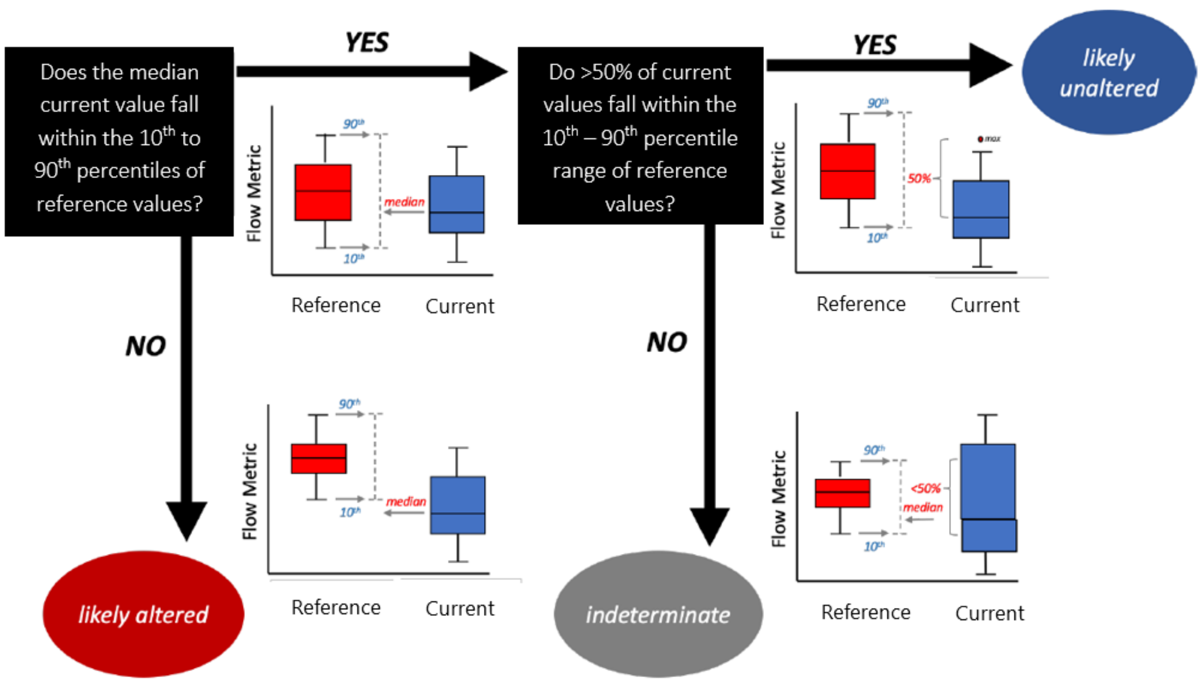


**Figure 4-2. Criteria for assigning alteration status adapted from CEFF Appendix J (in review).**

Additionally, alteration was synthesized at the flow component (or season) level. For each functional flow component, if one metric was likely altered, the entire component was considered likely altered. A synthesis map was produced to visualize alteration across the wet-season and dry-season flow components and evaluate seasonal trends observed across the region. All alteration data, maps, and metadata can be found at: https://ocgov.box.com/s/h2woo67dod0jtb9uis6upaw7vhzjkmu8.

### 4.2.3. Water Conservation

Functional flow metrics were calculated for the water conservation scenario following the methods described in **Section 4.2**. We assess alteration across all FFM by comparing the distribution of metric values under the water conservation scenario and reference conditions following the methods described in **Section 4.2.2**. We mapped the change in alteration status from the current to water conservation scenarios as likely degradation (change from likely unaltered or indeterminate to likely altered), likely improvement (change from likely altered or indeterminate to likely unaltered), no change, and indeterminate (if alteration status from current changed to indeterminate).

## 4.3. Level 2 – Biologic Flow Alteration based on CSCI and ASCI

Level 2 analysis provides a way to prioritize streams for further analysis in order to be considered for flow management consideration. The prioritization is achieved by identifying areas where flow alteration is sufficient to be associated with a decline in biological condition as indicated by the standard statewide biological indices, the California Stream Condition Index (CSCI, Mazor et al. 2016) for benthic invertebrates and the Algal Stream Condition Index (ASCI, Theroux et al. 2020) for benthic algae. We prioritized subbasins based on biotic alteration by relating biotic indices and FFM using flow ecology curves (described in **Section 4.2** and below).

The following sections in the Level 2 analysis are summarized below:

- **Section 5**: We developed regional flow ecology curves based on observed bioassessment scores in southern California and modeled change in FFM (Delta H) from regional hydrologic models (HEC-HMS). We used these curves to identify Delta H limits for each FFM. Delta H from regional hydrologic models were used in a Boosted Regression Tree (BRT) analysis to evaluate relative importance of the FFM on CSCI and ASCI.
- **Section 4.3.2**: The FFM were filtered based on the relative importance and a filtering process.
- **Section 4.3.3**: We compared the Delta H for the FFM from LSPC to the Delta H limits from **Section 5** to determine if flows in SOC WMA were biologically altered. We prioritized subbasins for flow management consideration based on biologically-relevant flow alteration.
- **Section 4.3.4**: While some observed bioassessment scores were located within SOC WMA, predicted scores at all study reaches were used to answer the questions in **Section 5.2**.
- **Section 4.3.5**: We determined biologically-relevant flow alteration under the water conservation scenario following the methods described in **Section 4.3.3.**

### 4.3.1. Flow Ecology Curve Method

Observed CSCI and ASCI bioassessment data from Southern CA (**Figure 4-3**) were modeled with the change in FFM from regional hydrologic models. At each bioassessment site, reference and current flow conditions were modeled with an ensemble of regional HEC-HMS[5] rainfall-runoff models developed for southern California in a previous study (Sengupta et al. 2018). FFM were calculated under reference and current conditions using the regional models. Note that the peak magnitude metrics (i.e., 2-year, 5-year, and 10-year flood magnitude, timing, frequency, and duration) that were identified in the suite of functional flow metrics for California (Yarnell et al. 2020) were not utilized in this analysis because 242 bioassessment sites had modeled flow timeseries with less than 20 years, primarily due to gaps in the rainfall data. Instead, we used the 99th percentile of daily flow each year, referred to herein as the magnitude of the largest annual storm, as our peak magnitude flow metric which was found to have strong importance to CSCI (Mazor et al. 2018). Therefore, we used a total of 16 FFM in our flow ecology curve analysis. At each bioassessment site, the change in flow metrics from reference to current (hereafter referred to as Delta H) were determined for the 16 FFM. The change value was applied in logistic regression to predict the probability of a healthy CSCI/ASCI score based on the currently accepted threshold values, providing relationships between the indices and FFM. These relationships were used to define Delta H limits and perform subsequent analysis in the biologically-relevant alteration process (described below). The logistic regression process modelled each FFM individually. To understand the relative influence of all FFM on each biological index, BRTs were performed on the full set of FFM and the relative importance determined and ranked. This ranking process aided the FFM filtering process outlined below.

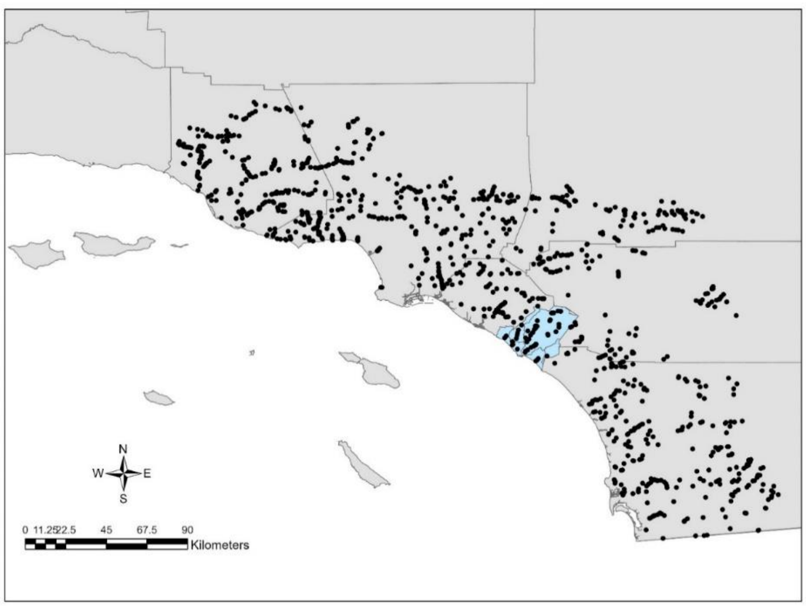


**Figure 4-3. Bioassessment sites across southern California used to develop flow ecology curves. The SOC WMA is highlighted in blue.**

An example flow ecology curve for spring timing is shown in **Figure 4-4**. All flow ecology curves can be viewed at: https://ocgov.box.com/s/r8uv4puero3lp65fmxe68hu2pt0k47ro.

[5] US Army Corps of Engineers Hydrologic Engineering Center Hydrologic Modeling System

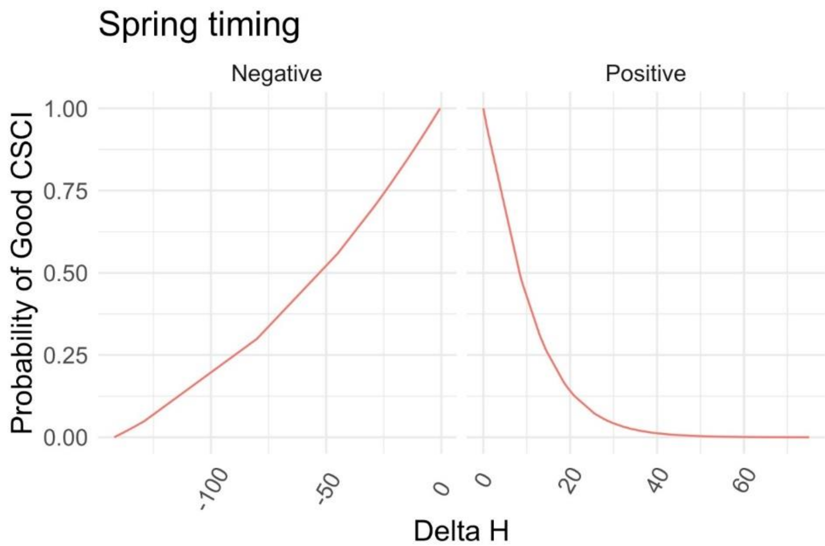


**Figure 4-4. Example flow ecology curve for CSCI and spring timing. Delta H is measured as the change in spring timing from reference to current in days.**

### 4.3.2. Process to Filter Functional Flow Metrics

To attain a manageable subset of the 16 FFM, the metrics were prioritized based on relevancy and amenability to management actions. The FFM were filtered based on the following criteria:

- Can be modeled with confidence through the regional flow models
- Not highly correlated with other FFM
- High relative importance from BRT assessment
- Strong relationship through logistic regression analysis
- High data density to ensure relationships not driven by only 1 or 2 points
- Can be influenced through management

Selected Metrics for CSCI:

- Magnitude of largest annual storm ($99^{th}$ percentile of annual flow)
- Spring recession start timing (start date of spring recession)
- Dry-season duration (summer flow duration in days from start of summer to start of wet-season)

Selected metrics for ASCI:

- Magnitude of largest annual storm

- Spring recession flow duration (number of days from start of spring recession to start of summer baseflow period)
- Dry-season duration

### 4.3.3. Biologically-Relevant Flow Alteration Process

Defining biologically relevant flow alteration requires a series of decisions on thresholds, frequencies and magnitudes of alteration. To be useful, the assessment should have sufficient discriminatory power to allow locations to be prioritized. All decisions regarding the alteration assessment approach were discussed with the TAG and SAG. For each chosen FFM we identified Delta H limits based on specific index and probability thresholds for both CSCI and ASCI. To ensure discriminatory power, we performed a sensitivity analysis on threshold combinations of index score; 1) Likely altered (ASCI: 0.75, CSCI: 0.63), 2) possibly altered (ASCI: 0.86, CSCI: 0.79), 3) likely intact (ASCI: 0.94, CSCI: 0.92), and probability of a achieving a healthy score (0.25, 0.50 and 0.75). Biological alteration was calculated (as below) for every LSPC model subbasin using the Delta H values from every threshold combination. Overall percentage of alteration (throughout the study area and over time) was compared and the final combinations chosen based on proximity to the median percentage of alteration and consistency between FFM (Irving et al. 2022). The final combinations were: CSCI (index = 0.92, probability = 0.25), ASCI (index = 0.94, probability = 0.50).

Applying these limits, the FFM were annually classified at each LSPC subbasin using the following criteria:

- **Biologically Altered**: if change in subbasin FFM falls *outside* of Delta H limits
- **Biologically Unaltered**: if change in subbasin FFM falls *within* Delta H limits

Biologically altered years were summarized as a percentage, which was then used to synthesize alteration across all FFM within the subbasin. The subbasin hydrology was classified as “likely altered” if two FFM were biologically altered for > 50% of years, a time threshold determined to give the greatest discriminatory power for prioritization. For prioritization, the following criteria was applied to synthesize alteration across biological indices:

- High priority: Both indices have biologically altered flow
- Medium priority: One index has biologically altered flow
- Low priority: Both indices have biologically unaltered flow

Outputs were tested using a range of thresholds and choices. The thresholds applied above (probability thresholds, percentage of years, number of FFM) were chosen to provide highest discriminatory power for prioritization.

A web-based application to explore the data products and alteration maps from Level 1 and 2 was developed using R Shiny and can be viewed at: https://sccwrp.shinyapps.io/socfess_shinyapp/. This application allows the users to explore how the various thresholds of alteration, including the number of FFM altered and the percent of years altered, can change overall prioritization.

### 4.3.4. Relationship to Observed and Predicted Bioassessment Data

In the SOC WMA, there were a total of 38 bioassessment sites with observed data; however, only sites with co-located modeled flow from LSPC were evaluated. For CSCI, there were 36 sites where modeled flow and calculated Delta H were co-located and 32 sites for ASCI[6]. At each site, management recommendations for each index were assigned based on combining observed biological condition and biologically-relevant hydrologic alteration (**Figure 4-5**). Observed biological condition for CSCI and ASCI were determined as biologically healthy if index scores fell in the "likely intact" or "possibly altered" categories (i.e., scores greater than or equal to 0.79 for CSCI and 0.86 for ASCI) and biologically degraded if they fell in the "likely altered" and "very likely altered" categories (i.e., scores less than 0.79 for CSCI and 0.86 for ASCI). Biologically-relevant hydrologic alteration was determined using Level 2 data, described in **Section 4.3.3.**

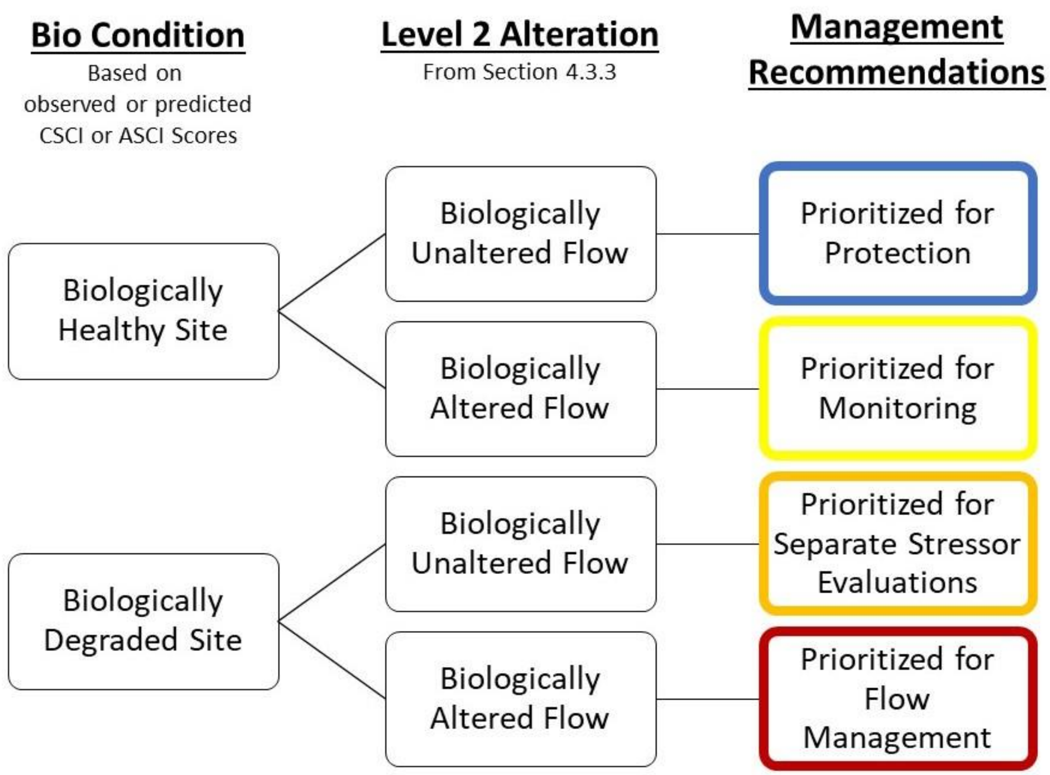


**Figure 4-5. Illustration of how management recommendations were assigned to each LPSC subbasin based on biological condition (first column) and biologically-relevant flow alteration from Section 4.3.3 (second column).**

As mentioned above, not all modeled subbasins in LSPC had observed bioassessment data. To fill in these gaps, the evaluation was expanded to include predicted CSCI and ASCI scores at reaches that lacked observed data. We used a random forest landscape model for California

[6] Not every bioassessment site had both CSCI and ASCI scores reported

(Beck et al. 2019) that estimates ranges of CSCI scores from watershed and landscape characteristics (StreamCat) to extrapolate scores across unsampled stream reaches. A random forest landscape model for ASCI was developed for California, following the methods of Beck et al. (2019), and validated in southern California and additional regions across the state with observed ASCI scores from the Stormwater Monitoring Coalition's (SMC) data portal and California Environmental Data Exchange Network (CEDEN). Management recommendations outlined in **Figure 4-5** were assigned to all but four LSPC model subbasins and were used to answer Questions 4 to 7 in **Section 5.2**. A total of four subbasins, located in Prima Deshecha and Segunda Deshecha, did not have predicted bioassessment scores and were excluded from this analysis.

Where possible, model performance was evaluated by comparing the management recommendation category using predicted biological scores versus observed biological scores (**Table 4-1**). Overall, recommendations using predicted and observed biological scores had strong agreement for CSCI and ASCI. Recommendation categories were the same when using predicted and observed scores for 75% and 85% of sites for CSCI and ASCI, respectively. Therefore, the answers to Questions 4 to 7 in **Section 5.2** utilized the predicted scores to cover the entire LSPC model domain. Summary tables, maps, and metadata are located at: https://ocgov.box.com/s/lyev77zfp8ny5wmoe389xf81npn9i1cq. Additional details on the random forest landscape models, data, and maps using predicted data can be viewed at: https://ocgov.box.com/s/9ry4yg5qukoh1wp18v72hkahdlnd9p40.

**Table 4-1. Contingency table comparing the proportion of reaches in each management recommendation category using predicted versus observed CSCI and ASCI scores.**

| | | Observed CSCI | | | |
|---|---|---|---|---|---|
| | | Flow Management | Separate Stressor Evaluation | Monitoring | Protection |
| Predicted CSCI | Flow Management | 88% (7 reaches) | 0% | 100 % (4 reaches) | 0% |
| | Separate Stressor Evaluation | 0% | 92% (12 reaches) | 0% | 33% (1 reach) |
| | Monitoring | 12% (1 reach) | 0% | 0% | 0% |
| | Protection | 0% | 8% (1 reach) | 0% | 67% (2 reaches) |

| | | Observed ASCI | | | |
|---|---|---|---|---|---|
| | | Flow Management | Separate Stressor Evaluation | Monitoring | Protection |
| Predicted ASCI | Flow Management | 100% (13 reaches) | 0% | 0 % | 0% |
| | Separate Stressor Evaluation | 0% | 90% (9 reaches) | 0% | 100% (3 reaches) |
| | Monitoring | 0% | 0% | 0% | 0% |
| | Protection | 0% | 10% (1 reach) | 0% | 0% |

### 4.3.5. Water Conservation

We determined biologically-relevant flow alteration under the water conservation scenario following the methods described in **Section 4.3.3.** Delta H for the water conservation scenario was determined as the change in FFM from the reference condition to the water conservation scenario. Biologically-relevant flow alteration maps for CSCI and ASCI and prioritization maps for the water conservation scenarios were developed. We evaluated the change in the number of subbasins in each prioritization category from the current condition to water conservation scenario.

## 4.4. Level 3 – Higher Trophic Level Species

Level 3 analysis provides ranges of flows necessary to support key stream functions, habitats, or species. These ranges can be used to inform management decisions at agreed upon locations and as measures to assess performance of implemented restoration and management actions . We assessed flow ranges that support focal species, with the aim to answer the following questions:

- What types of flows do focal species need?
- Where can we provide those flows, if desired?

The focal species chosen in coordination with the TAG were Arroyo toad, Arroyo chub, and willow (as a surrogate for Least Bell's Vireo). However, there was insufficient species data to develop models for arroyo toad. The general approach for each species follows the same process:

1. Important life stages for each species are identified together with associated hydraulic variables vital for habitat support.
2. Species habitat curves are created by applying statistical models appropriate to the data (e.g., species life stage abundance in response to depth), or critical thresholds identified where data are insufficient for statistical analysis.
3. Species habitat curves are applied to hydraulic data at each subbasin, from which a rating curve was used to define flow ranges for each species life stage and associated variables.
4. Species-based flow ranges are related back to the FFM. Reference based flow ranges are applied for any metrics not represented by the species-based curves/ranges, under the assumption that the reference range of flows would provide critical stream functions needed to support a broad range of species (Poff et al. 1997; Yarnell et al. 2015).

The above process was completed for Arroyo chub and willow. Refinement of species habitat curves and thresholds was conducted in coordination with the SAG/TAG. Final curves and habitat criteria were used to develop recommended flow ranges. An illustrative application of CEFF to develop flow ranges for focal species in lower Aliso Creek was conducted by Taniguchi-Quan et al. (2022).

### 4.4.1. Arroyo chub (*Gila orcuttii*)

Following the procedure for developing fish species models in Stein et al. (2021), input data describing fish abundance and habitat variables velocity and depth were collated from Wulff et al. (2017a, 2017b). Each hydraulic variable was modeled separately with either fish abundance or presence/absence. In brief, habitat suitability models were developed for chub response to velocity through a probability density curve, and for chub response to depth though Generalized Linear Models (GLMs). The habitat suitability models are shown in **Figure 4-6** and described in detail in Taniguchi-Quan et al. (2022) and in the documentation found here: https://ocgov.box.com/s/yt0jxjzxmj8p2selkv93ctah1ja7cf6n.

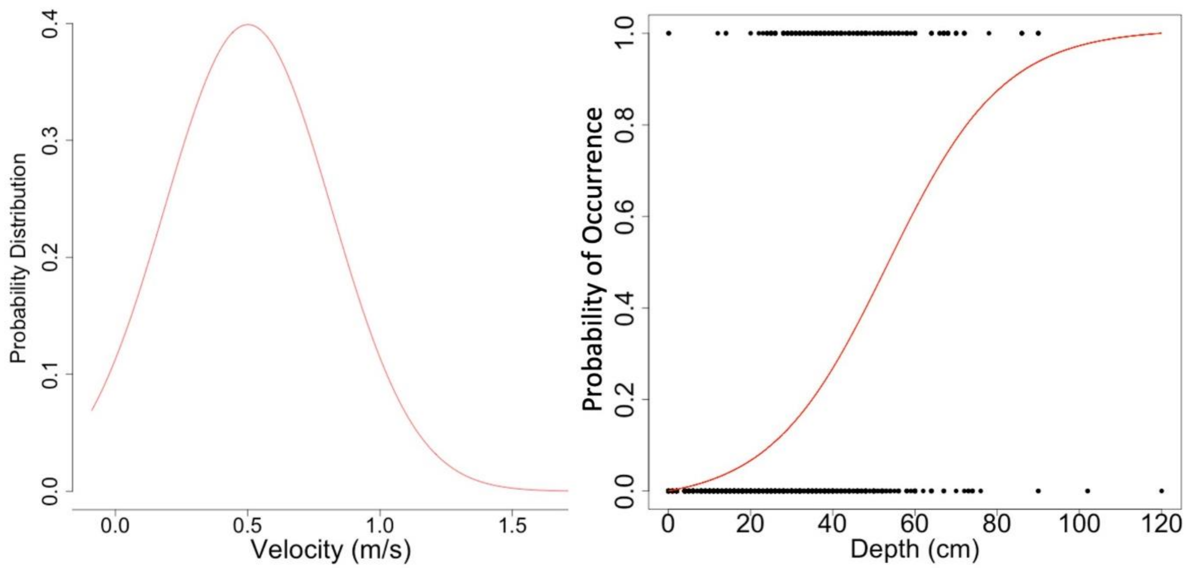


**Figure 4-6. Suitability models for Arroyo chub occurrence with hydraulics: velocity (left panel), and depth (right panel) using Wulff et al. (2017a & 2017b).**

### 4.4.2. Goodding's black willow (*Salix gooddingii*)

We developed a suite of habitat rules used to identify ecological flow ranges for willow seedlings and adults. Adult willows require flows to inundate the overbank area seasonally. For adult willows, we used a wet-season and dry-season baseflow lower 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. We also used a maximum flow threshold at the channel capacity to limit overbank inundation and oversaturated soils in the overbanks. For both adult willows and willow seedlings, we developed habitat criteria for the spring recession start magnitude to ensure that the lower limit 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 flow ranges by applying a suite of rules developed (**Table 4-2**).

Current distributions of both chub and willow are located at: https://ocgov.box.com/s/peptsds1jq8kbmjxwil3sz0bcz8pw2h5.

**Table 4-2. Habitat criteria used to determine ecological flow needs for willow adult and seedling.**

| Life Stage | Functional Flow Metric | Lower Limit | Upper limit |
|---|---|---|---|
| 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 value > lower limit (only refined the lower limit to ensure overbank inundation at the start of spring recession) |

### 4.4.3. Stream hydraulics

Stream hydraulics (depth, velocity, shear stress, and stream power) were estimated for 51 subbasins where flow was modeled with LSPC and channel geometry was readily available. Channel hydraulics were not simulated in reaches where flow is conveyed via underground storm drains or impoundments. Rating curves were developed to apply to the simulated flow timeseries to produce timeseries of hydraulic data at discrete channel sub-sections. First, channel geometry and reach characteristics, including slope and field-verified Manning's roughness n, were taken from Orange County's LiDAR-derived channel geometry cross sectional dataset 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 (**Figure 4-7**). 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 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 (see black points in **Figure 4-7**). 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. All timeseries of hydraulics for the current and water conservation scenarios are located at: https://ocgov.box.com/s/an5arzidp4pcymtu1f217lycraclta3j.

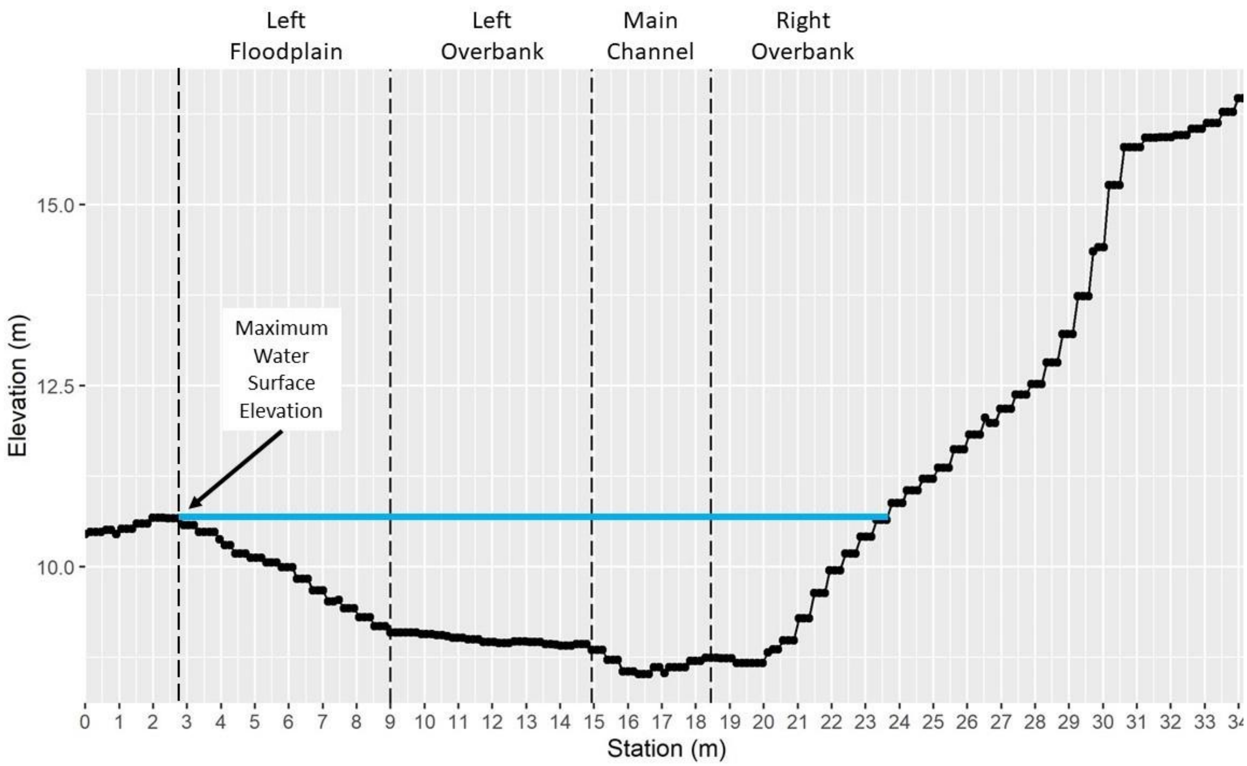


**Figure 4-7. Example cross-section at Aliso Creek at the Sewage (Coastal) Treatment Plant. Vertical dashed lines represent geomorphically distinct sub-section splits and the black points represent micro-sections of the channel geometry. The blue horizontal line represents the maximum water surface elevation simulated for this cross section, which corresponds to the floodplain elevation at capacity.**

### 4.4.4. Suitability

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 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 SAG/TAG, 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. Annual suitability for each subbasin was determined using the following criteria:

- High suitability - conditions met for at least 75% of time
- Partial suitability - conditions met for 25-75% of time
- Low suitability - conditions met less than 25% of time with the exception of Willow Spring Recession, where a binary High/Low suitability was assigned depending on whether or not the flow range was met, i.e., 1 = overbanks were inundated, 0 = overbanks were not inundated anytime in spring.

To estimate suitability over the period of record, annual suitability classes were counted, and the majority class taken as overall suitability for each subbasin. Willow suitability was determined for each season separately. Arroyo Chub suitability was determined per subbasin by synthesizing hydraulic suitability. Here, flow conditions based on both hydraulics (depth, velocity) had to be met 75% of the time for the subbasin to be classified as high suitability, if flow ranges for one hydraulic variable were lower than 75% of the time then the subbasin was classified at the lower classification.

### 4.4.5. Water Conservation

We determined focal species suitability under the water conservation scenario following the methods described in **Section 4.4.4**. Suitability maps for Arroyo chub and Willow were developed. We evaluated the change in the number of subbasins in each suitability category from the current condition to water conservation scenario.

## 4.5. Future Climate

Given the disagreement among GCMs, we are not able to draw clear conclusions about the effects of climate change on stream flows (see **Section 3.7.3**). For example, percent change in median summer streamflow from current to future conditions were from -25% to 14%, depending on the GCM. Given the uncertainty in GCMs, we did not carry the climate change analysis forward to the ecological analysis.

## 4.6. Results

The flow-ecology results presented in **Section 4.6** are based on one representative point within each subbasin: Levels 1 & 2 - LSPC pour points located at the downstream outlet of each subbasin and Level 3 – representative cross-section near the subbasin pour point. Further site-specific analyses would be necessary before restoration is initiated as flow, channel morphology, and hydraulics may vary upstream of the pour point location.

### 4.6.1. Level 1 – Hydrologic Alteration based on Deviation from Reference

Pervasive hydrologic alteration was observed across the study domain. Spring recession rate of change was altered high for 83% of subbasins (n=50) and dry-season baseflow magnitude was altered high for 38% (n = 23) of the subbasins evaluated (**Figure 4-8**). The synthesized alteration map that considers component alteration of dry-season baseflow, wet-season baseflow, and peak flows shows pervasive alteration in Prima and Segunda Deschecha (**Figure 4-9**). Additionally, there were no subbasins with all three components classed as unaltered, as at least one of the components were classed as indeterminate – these basins were classed as “Unaltered, Indeterminate”. However, many subbasins in the undeveloped, upper reaches of San Juan Creek had 1 to 2 unaltered components.

Alteration maps for all FFM are located at:
https://ocgov.box.com/s/d0q5r82xvhdaauxwjadpknzg52jsut3a

The synthesized alteration map is located at:
https://ocgov.box.com/s/0l2k70r0o1xzu1t9zptc6dzz2xw98fsi

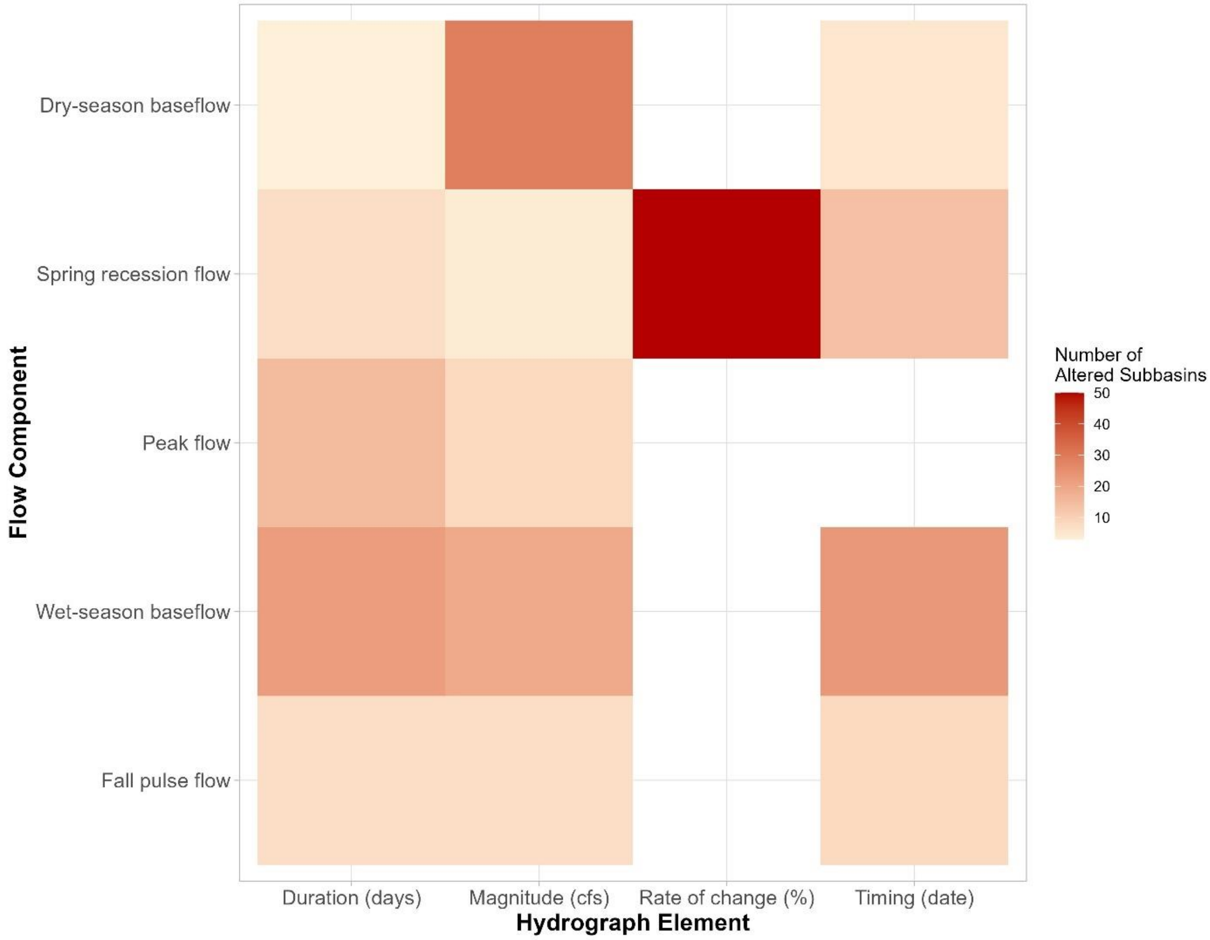


**Figure 4-8. Heat map showing the number of subbasin altered by hydrograph element and seasonal flow component. White boxes were not considered.**

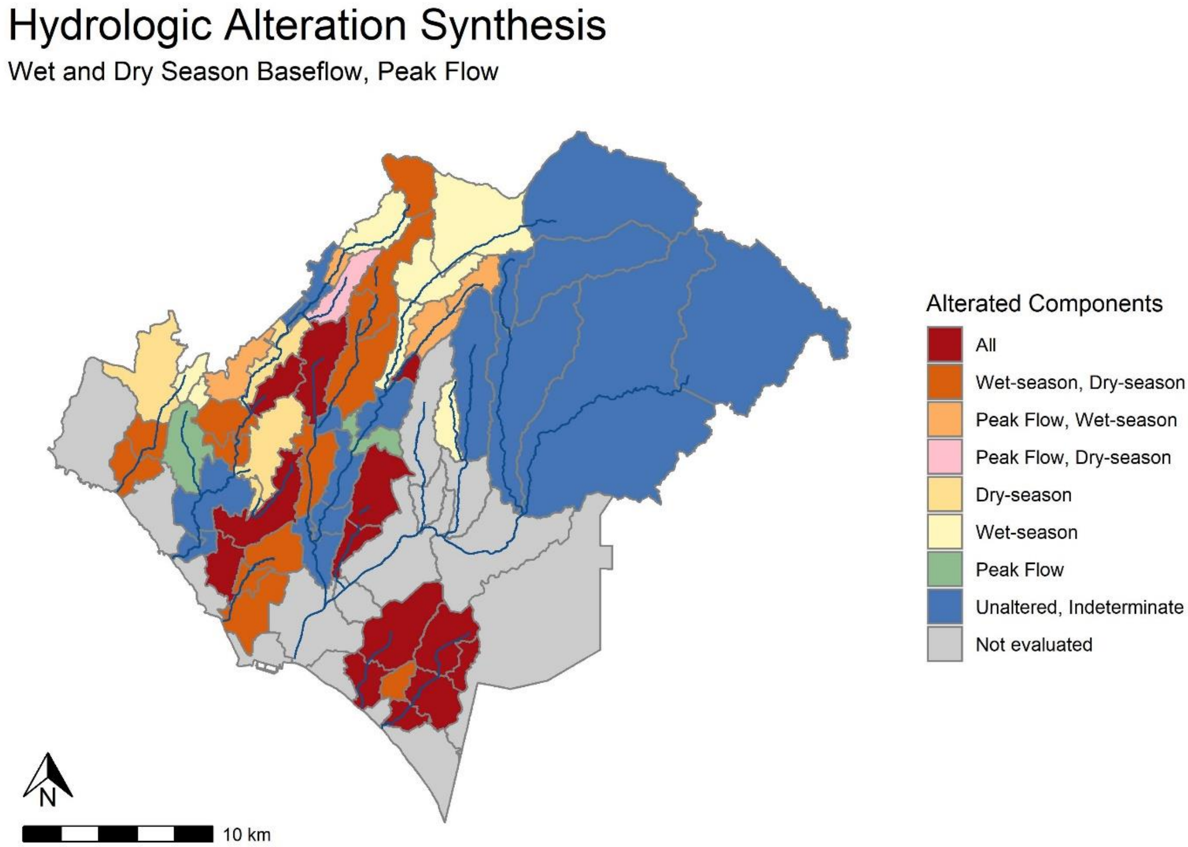


**Figure 4-9. Current hydrologic alteration synthesis map across wet-season baseflow, peak flow, and dry-season baseflow components. All represents component alteration for wet-season baseflow, dry-season baseflow, and peak flows.**

Water conservation could improve dry-season baseflow magnitude in stream reaches along the mainstem of Aliso Creek that were currently classed as augmented (**Figure 4-10**), while conditions for the wet-season baseflow magnitude could degrade in reaches along Trabuco Creek where current flow conditions were depleted (**Figure 4-11**).

Water conservation alteration change maps for all FFM are located at: https://ocgov.box.com/s/d0q5r82xvhdaauxwjadpknzg52jsut3a.

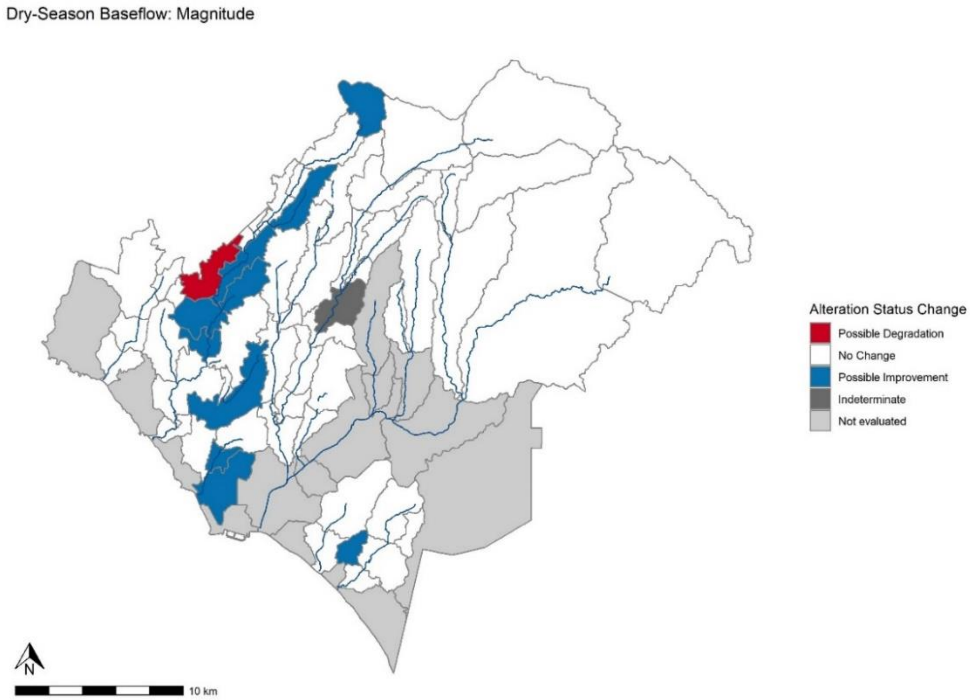


**Figure 4-10. Change in alteration status from current conditions to the water conservation scenario for the dry-season baseflow magnitude.**

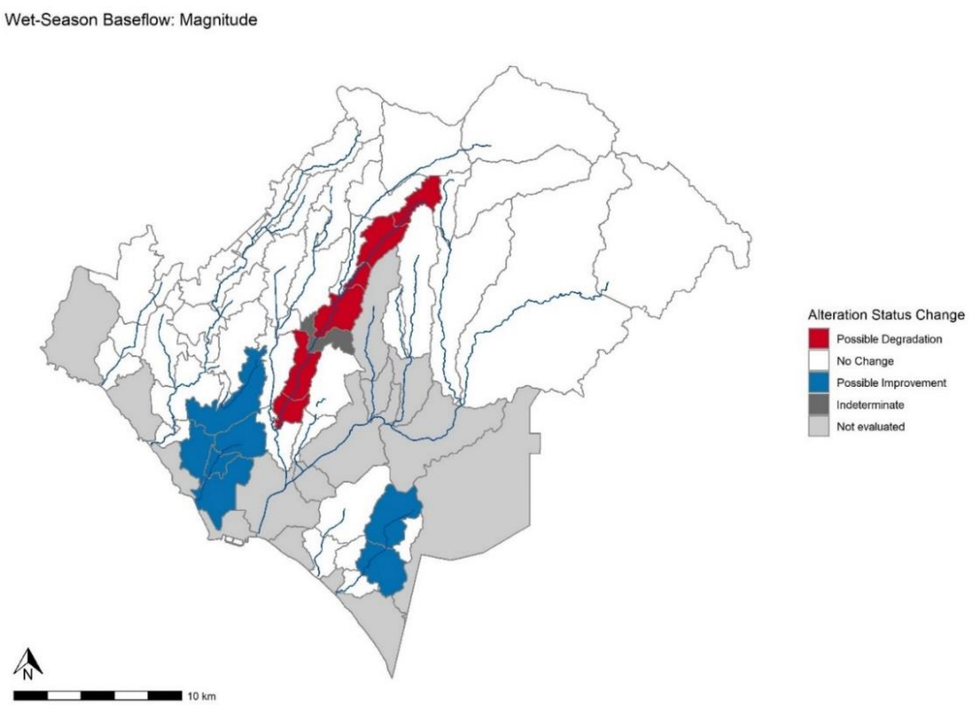


**Figure 4-11. Change in alteration status from current conditions to the water conservation scenario for the wet-season baseflow magnitude.**

### 4.6.2. Level 2 – Biologic Flow Alteration based on CSCI and ASCI

**Biologically-Relevant Flow Alteration:** Overall, flow alteration is more associated with the effect on the algal community than benthic invertebrates. Biologically-relevant flow alteration for both CSCI and ASCI were observed in reaches of Trabuco Creek under current conditions (**Figure 4-12**). In Aliso Creek, reaches along the entire mainstem were altered for ASCI as opposed to the lower Aliso Creek for CSCI. Flows were likely unaltered based on CSCI and ASCI in reaches of Oso Creek, the undeveloped upper reaches of San Juan and upper Trabuco Creeks. Water conservation had a minimal impact on biologically-relevant flow alteration (**Figure 4-13**), with flow conditions for ASCI and CSCI improving from likely altered to likely unaltered for two and three subbasins, respectively, and conditions degrading for four subbasins for ASCI and one subbasin for CSCI.

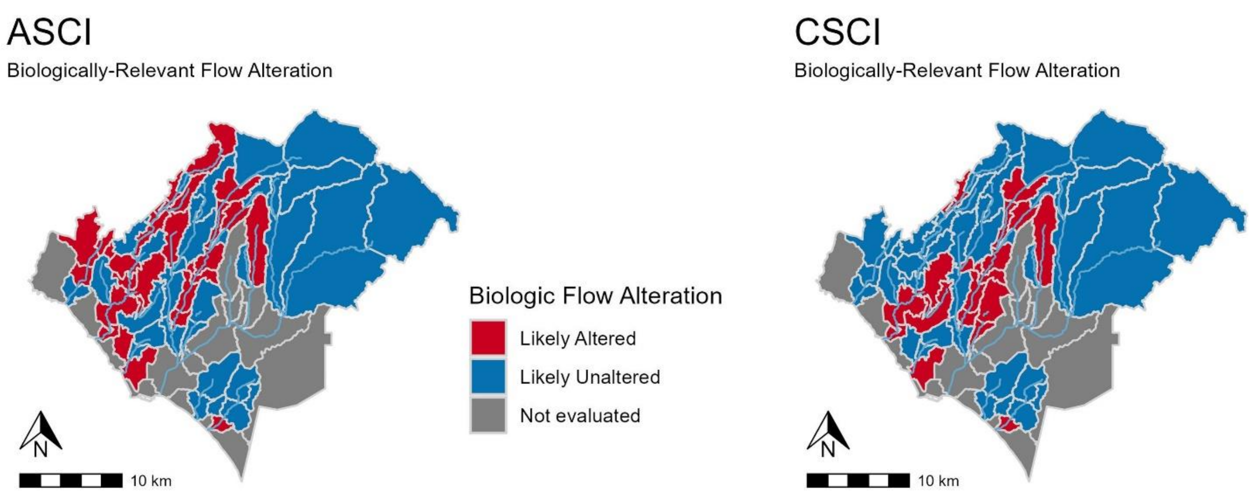


**Figure 4-12. Biologically-relevant flow alteration for ASCI and CSCI for current conditions.**

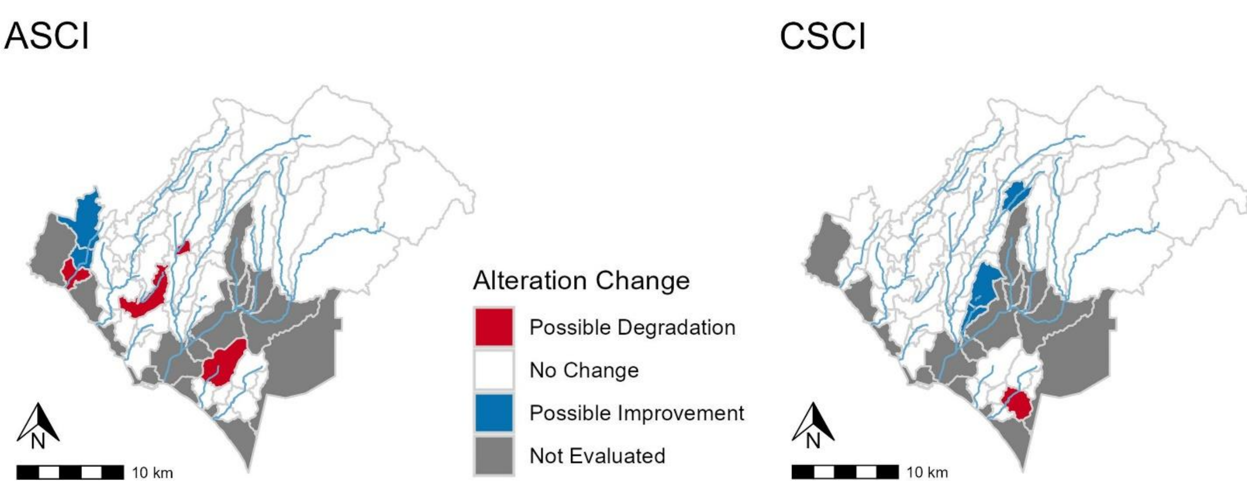


**Figure 4-13. Change in biologically-relevant flow alteration for ASCI and CSCI from current conditions to the water conservation scenario.**

**Prioritization for Additional Analysis based on Biologically-Relevant Flow Alteration:** Lower Aliso and portions of Trabuco Creek are priorities for additional analysis under Level 3 based on biologically-relevant flow alteration (**Figure 4-14**). The less developed upper reaches of Trabuco and San Juan Creeks were classed as low priority. Overall, 45% of subbasins were classed as low priority, 28% were classed as medium priority, and 27% were classed as high priority (**Table 4-3**). Prioritization maps combining both indices and summary data tables can be found at: https://ocgov.box.com/s/18c3jg317ik18e1xdafomujbh0gfcrel.

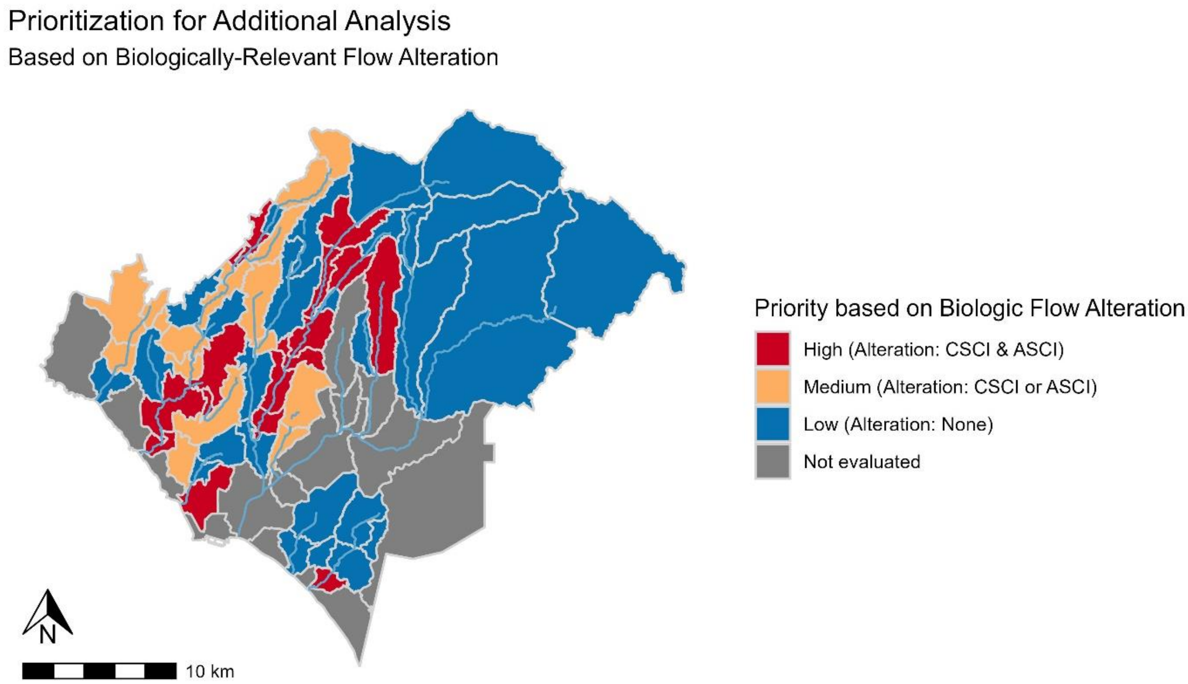


**Figure 4-14. Prioritization for additional analysis based on biologically-relevant flow alteration for CSCI and ASCI for current conditions.**

Water conservation tended to have a minimal impact on overall prioritization based on biologically-relevant flow alteration for CSCI and ASCI (**Figure 4-15** and **Table 4-3**). Overall, 83% of subbasins (n=50) stayed the same and approximately 17% of subbasins (n=10) changed priorities, with 5 subbasins degrading from medium to high priority (n=2) and low to medium priority (n=3) and 5 subbasins improving from medium to low (n=4) and high to medium (n=1).

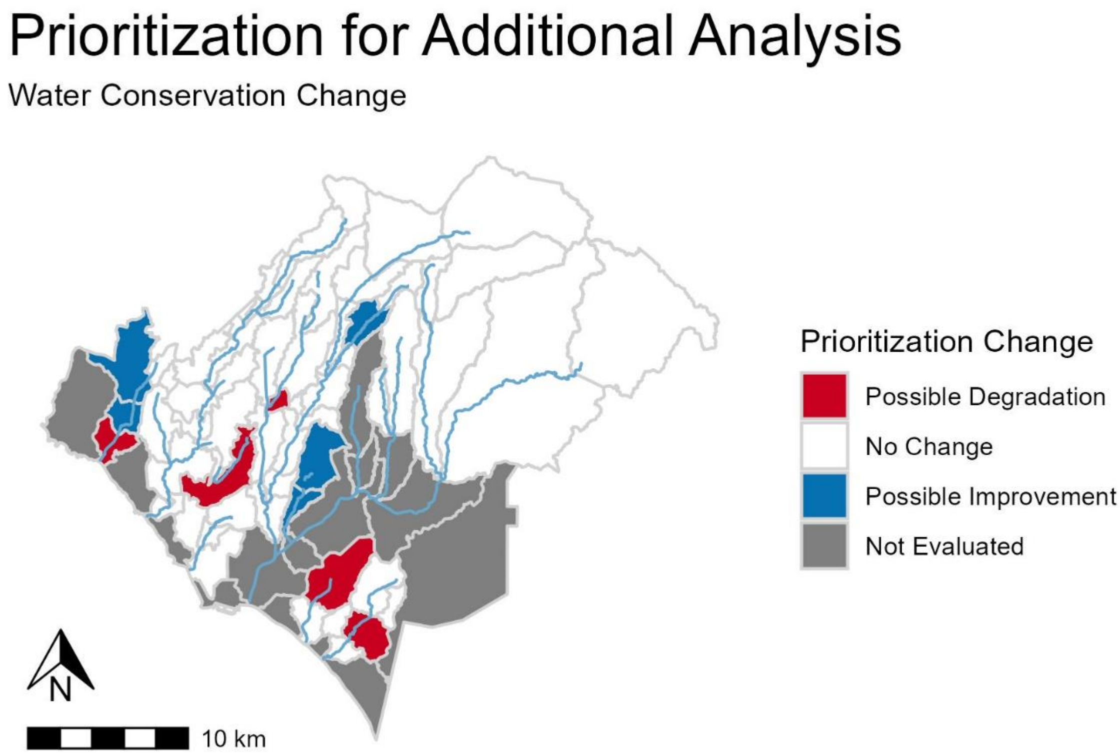


**Figure 4-15. Change in overall synthesis prioritization based on biologically-relevant flow alteration for CSCI and ASCI from current conditions to the water conservation scenario.**

**Table 4-3. Subbasin prioritization based on biologically-relevant flow alteration under current conditions and the water conservation scenario.**

| Priority | Number of Subbasins (Current) | Number of Subbasins (Water Conservation) |
|---|---|---|
| High | 16 | 17 |
| Medium | 17 | 15 |
| Low | 27 | 28 |

### 4.6.3. Level 3 – Higher Trophic Level Species

**Ecological flow ranges and habitat suitability:** Flow ranges for Willow and Arroyo chub were developed based on the Willow habitat suitability rules and the probability of occurrence curves for Arroyo chub. An example table that includes the natural range of flow metrics and ecological flow ranges for lower Aliso Creek at the Sewage (Coastal) Treatment Plant are presented in

**Table** 4-4 for illustrative purposes. In this example, both the wet-season and dry-season baseflow magnitude need to be at least 120 cfs to provide suitable depths for Arroyo chub with the existing channel morphology. The minimum flow of 120 cfs is well beyond the baseflow flow ranges under current and reference conditions, 2 to 5 cfs and 0.5 to 3 cfs, respectively, and are only observed during storm events. If restoring flow and hydraulic conditions to support Arroyo chub is a priority in this reach, non-flow actions, such as channel rehabilitation, are likely necessary in addition to flow management. For other stream reaches where the channel may be enlarged, the ecological flow ranges may be well beyond the current and reference conditions, and channel rehabilitation may also be necessary to provide suitable flow conditions. Additionally, consideration of in-stream habitat heterogeneity for fish including availability of low-flow refugia are of importance. In intermittent streams, for example, fish can oversummer in perennial pools that provide suitable refugia. In addition to the flow ranges, further analysis would be essential to fully understand how to restore specific reaches sufficiently to support Arroyo chub habitat. All flow ranges for Willow and Arroyo chub can be found at: https://ocgov.box.com/s/s6twithu1prm3x0vqxdg9int58a3mkkq.

**Table 4-4. Natural range of flow metrics and habitat suitability needs for Black Willow and Arroyo Chub at example subbasin location, Aliso Creek at the Sewage (Coastal) Treatment Plant. Bolded values were determined using the reach-specific channel morphology and habitat suitability criteria and unbolded values were the reference ranges.**

| Flow Component | Flow Metric | Reference Range of Flow Metrics median (10th - 90th percentile) | Habitat Suitability Needs: Black Willow | Habitat Suitability Needs: Arroyo Chub |
|---|---|---|---|---|
| Fall pulse flow | Fall pulse magnitude | 2.4 (1.7 - 5) cfs | Same as reference range | Same as reference range |
| | Fall pulse timing | Nov 29 (Oct 24 - Dec 3) | Same as reference range | Same as reference range |
| | Fall pulse duration | 11 (3 - 16) days | Same as reference range | Same as reference range |
| Wet-season baseflow | Wet-season baseflow magnitude | 3 (2 – 5) cfs | **0.1 – 12 cfs** | **> 120 cfs** |
| | Wet-season timing | Dec 15 (Oct 10 – Jan 25) | Same as reference range | Same as reference range |
| | Wet-season duration | 67 (30 - 133) days | Same as reference range | Same as reference range |
| Peak flows[a] | 2-year peak flow magnitude | 31 cfs | Same as reference range | Same as reference range |
| | 2-year peak flow duration | 4 (1 – 25) days | Same as reference range | Same as reference range |
| | 2-year peak flow frequency | 2 (1 – 8) | Same as reference range | Same as reference range |
| | 5-year peak flow magnitude | 423 cfs | Same as reference range | Same as reference range |
| | 5-year peak flow duration | 3 (1 - 6) days | Same as reference range | Same as reference range |
| | 5-year peak flow frequency | 3 (1 - 4) event(s) | Same as reference range | Same as reference range |
| Spring recession flows | Spring recession start magnitude | 15 (3 - 528) cfs | **35 -** 528 cfs | Same as reference range |
| | Spring timing | Mar 3 (Feb 22 - Mar 18) | Same as reference range | Same as reference range |
| | Spring duration | 109 (76 - 125) days | Same as reference range | Same as reference range |
| | Spring rate of change | 1.4 (0.9 – 1.9) % decline per day | Same as reference range | Same as reference range |
| Dry-season baseflow | Dry-season baseflow magnitude | 2 (0.5 – 4) cfs | **0.1 – 12 cfs** | **> 120 cfs** |
| | Dry-season timing | June 20 (May 9 - Jul 10) | Same as reference range | Same as reference range |
| | Dry-season duration | 198 (116 - 220) days | Same as reference range | Same as reference range |

[a]The 10-year peak flow metrics are not shown

Flow conditions for Arroyo chub were classed as low suitablility in all subbasins, and did not change under the water conservation scenario. All suitability figures can be found at: https://ocgov.box.com/s/52ddxfplj64p65icl2oyemlm9ahm6axz

Arroyo chub hydraulic needs extracted from the suitability curves for medium probability were: Depth > 53 cm, Velocity 0.2 to 0.8 m/s. Velocity conditions were highly suitable over space and time. Depth was the limiting factor in all subbasins with maximum 13% of time where depth conditions were met throughout the entire study area. Depth was overall too shallow to support Arroyo chub. Flow ranges for Arroyo chub can be found at https://ocgov.box.com/s/s6twithu1prm3x0vqxdg9int58a3mkkq.

In contrast to our estimated suitability, Arroyo chub have been observed in some subbasins in the study area (https://ocgov.box.com/s/peptsds1jq8kbmjxwil3sz0bcz8pw2h5). It is important to note that although a low suitability reduces the likelihood of supporting chub populations, it does not restrict the fish entirely. Additionally, our study utilizes one representative cross-section within each subbasin on which to estimate suitability. This coarse resolution is not sufficient to understand the habitat suitability of specific reaches, for which further analysis is necessary.

Suitability for Willow was more variable throughout the study area. The majority of subbasins during dry (n=29) and wet (n=33) season baseflow were classed as high suitability, improving slightly under water conservation scenario (dry; n=32, wet; n=34, **Figure 4-16**, **Table 4-5**); however, two subbasins became less suitable (Figure 4-17) . The majority of subbasins for Willow during the Spring recession were classed as low (n=26) with no change in suitability under the water conservation scenario (**Table 4-5**, **Figure 4-18**). Flow ranges for Willow can be found at: https://ocgov.box.com/s/s6twithu1prm3x0vqxdg9int58a3mkkq.

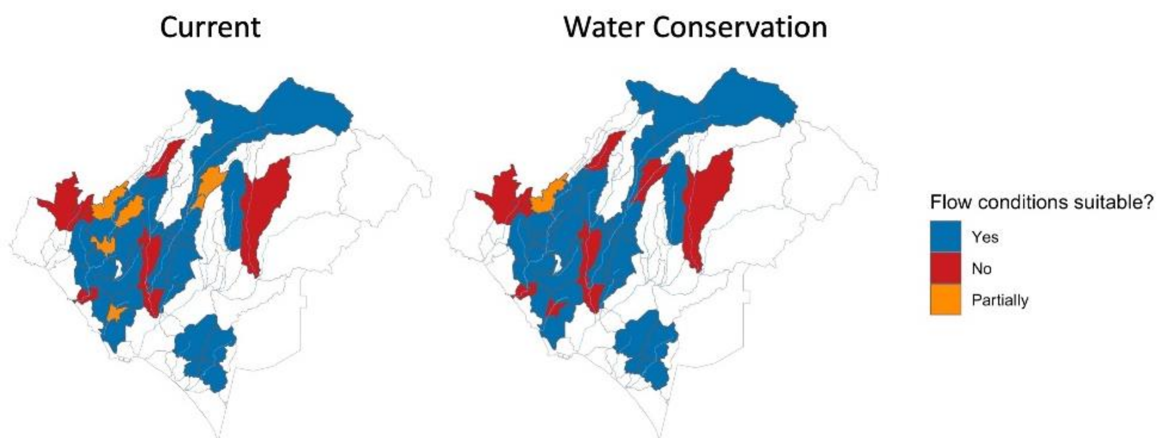


**Figure 4-16. Willow adult dry season suitability under current flow conditions and water conservation. All white subbasins were not evaluated in Level 3 analysis.**

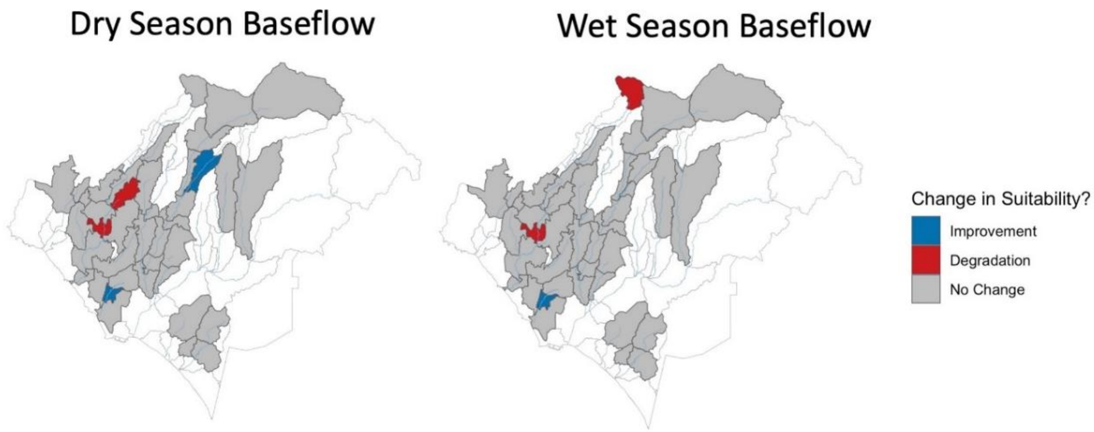


**Figure 4-17. Change in Willow suitability from current conditions to water conservation scenario conditions. All white subbasins were not evaluated in Level 3 analysis.**

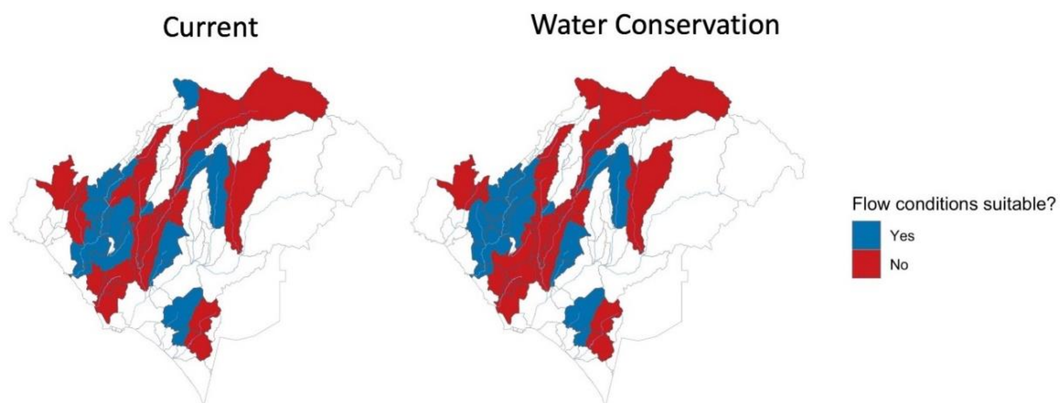


**Figure 4-18. Willow adult and seedling spring recession suitability under current flow conditions and water conservation. All white subbasins were not evaluated in Level 3 analysis.**

**Table 4-5. Subbasin suitability based on Willow flow ranges under current conditions and the water conservation scenario for each season.**

| Flow Metric | Suitability | Current | Water Conservation |
|---|---|---|---|
| Dry-season Baseflow Magnitude | High | 29 | 32 |
| | Partial | 6 | 1 |
| | Low | 10 | 12 |
| Spring Recession Flow Magnitude | High | 19 | 19 |
| | Low | 26 | 26 |
| Wet-season Baseflow Magnitude | High | 33 | 34 |
| | Partial | 4 | 3 |
| | Low | 8 | 8 |

# 5. SPECIAL STUDY SUMMARY

## 5.1. Summary of Study Scope and Findings

### Hydrologic Analysis

The hydrologic analysis primarily served as an input to the ecological analysis. However, several standalone findings can be distilled from this analysis.

- Based on monitoring of water isotopes, we found that imported water accounts for around 30% of streamflow on average in the WMA. This varies by receiving water and by season. More urbanized streams tend to have a higher fraction of imported water. The fraction also tends to increase between spring and summer as rainfall-derived baseflow recedes. Dry weather flows from stormwater outfalls contain around 50% imported water on average, with wide variability by outfall. Overall, this suggests that rainfall-derived groundwater seepage is an important process for dry weather streamflow in many streams in the WMA. This also suggests that many streams may be normally perennial in their lower reaches in the absence of urbanization.

- In comparison to a reference condition with urbanization removed, various types of hydrologic alteration were observed across the Study domain. The results of the flow alteration assessment are included in **Section 1**. Dry-season and wet-season baseflow magnitude and annual peak storm magnitude were altered high in some reaches. These correspond to the effects of urbanization, including irrigation water application and impervious cover. Spring recession rate of change was altered high for 83% (n=50) of subbasins, dry-season baseflow magnitude was altered high for 38% (n =23) of the subbasins evaluated, and wet-season baseflow magnitude was altered high for 28% (n=17) subbasins evaluated. Annual storm magnitude (Q99) was altered high for 13% (n=8) of the subbasins evaluated.

- In locations where low flow diversions are in place, these tend to offset the increase in dry season baseflow magnitude and result in lesser alteration of this metric.

- There is significant residual uncertainty in low flow conditions in several stream systems, particularly in systems where granular alluvial soils supports some level of subterranean flow. The fraction of subterranean flow may vary longitudinally along a reach corresponding to changes in geomorphology and geology, resulting in some segments that are flowing and some that are dry. This level of understanding is not currently supported by available data and observations. This indicates the need for site-specific monitoring to support project development in cases where low flow conditions are important.

- Future water conservation is projected to have a significant effect on dry season baseflow magnitude (reduction) and a more limited effect on annual discharge volumes (reduction). It is expected to have limited effect on wet season metrics.

- Climate change may result in increases or decreases in key flow metrics depending on the GCM used. Therefore, the direct effects of climate change on streamflow are uncertain.

**Ecological Analysis**

- Hydrologic alteration affects biological condition to varying degrees
    - CSCI and ASCI show similar patterns in some but not all cases
- Flow ecology tools can be used to prioritize subbasins for management
    - Approximately 40% of subbasins were prioritized for flow management
    - Approximately 50% of subbasins were prioritized for separate stressor evaluations
- Flow ranges necessary to support focal species can inform flow management actions
    - Channel rehabilitation combined with flow management may be necessary in certain reaches
- Water conservation will likely reduce the extent of hydrologic alteration during the dry-season
    - However, water conservation may have a minimal effect on biologically-relevant flow alteration based on CSCI and ASCI with priorities staying the same for majority of reaches (83%), improving for ~8% of reaches, and degrading for ~8% of reaches.
    - Overall, flows are too shallow for Arroyo chub, but most are suitable for Willow under current and water conservation conditions.
- Direct effect of climate change is highly uncertain

## 5.2. Special Study Research Questions

The original special study description in the SOC WMA WQIP outlined a set of conceptual research questions. The paragraphs below discuss responses to these research questions and/or how they have been reframed through the course of stakeholder input and study execution.

1. **What are the expected reference conditions of streams within the SOC WMA assuming complete elimination of urban discharges?**

   This analysis is complete for all study reaches including Laguna Canyon, Aliso Creek, Oso Creek, Salt Creek, Horno Creek, Prima Deshecha Creek, Segunda Deshecha Creek, Trabuco Creek, and San Juan Creek tributaries of interest.

   We have used the characterization of reference condition hydrology to support the Level 1 Alteration Assessment outlined in this Final Report. In general, hydrology is altered in many areas, including augmented baseflows and storm flows. However, multiple lines of evidence suggest that groundwater derived from local rainwater is a significant component of stream flow in current conditions. This suggests that reference conditions would likely be perennial in many reaches. However, it is unclear how geomorphic changes, such as erosion of alluvial soils, may affect the portion of flow that is present in the stream channel versus in shallow alluvial aquifers below the stream.

2. **What are the specific instream flow requirements necessary to meet ecological benchmarks?**

   Levels 1 & 2 assess alteration both hydrologically and biologically to identify recommended priority sites for future management and restoration efforts. Recommended flow ranges for focal species were defined through the Level 3 assessment and can be found at: https://ocgov.box.com/s/s6twithu1prm3x0vqxdg9int58a3mkkq.

3. **Where is additional stream/reach data needed to close gaps related to the degree of hydrologic alteration?**

   This effort has developed a relatively good understanding of overall flow regimes at the subwatershed scale. It is more vetted near streamflow gauges than at intermediate points in the watershed, but often supported by other lines of evidence at intermediate points. A few key data gaps have been identified:

   - In systems with significant groundwater-surface water interaction, such as Trabuco Creek, there is less understanding of the portion of flow that is present in the stream channel versus in shallow alluvial aquifers below the stream, and how this varies over the stream length.

   - The composition of water in streams has been evaluated using water isotope methods. This has helped to improve understanding of the relative importance of irrigation-derived runoff, irrigation-derived recharge, and rainfall-derived recharge in the water balance of the system, and partially filled a key gap. However, these data are a snapshot in time. Additional isotope monitoring is recommended to evaluate how flow composition changes over time with longer-term climatic cycles and trends and water usage trends.

4. **Where are there biologically healthy sites (e.g., CSCI scores > 0.79) that are also hydrologically unaltered sites, so they may be prioritized for protection?**
5. **Where are there biologically healthy sites (e.g., CSCI scores > 0.79) that are hydrologically altered, so they can be prioritized for monitoring?**
6. **Where are there biologically degraded sites that are hydrologically altered, so they should be prioritized flow management (such as increased stormwater detention or groundwater infiltration)?**
7. **Where are there biologically degraded sites that are hydrologically unaltered, so they can be prioritized for separate stressor evaluations?**

   **Questions 4 to 7** were answered using the predicted CSCI and ASCI scores to cover all subbasins modeled with LSPC. A total of 4 subbasins, located in Prima Deshecha and Segunda Deshecha, did not have predicted bioassessment scores and were excluded from this analysis. A summary of reaches that fall within each recommendation category are presented in **Table 5-1** and a map of the categories for CSCI and ASCI are presented in **Figure 5-1**. Six unique reaches were classified as biologically healthy based on predicted CSCI (n=6) and ASCI (n=2) scores. Overall, 5 reaches were prioritized for protection (biologically healthy sites that are hydrologically unaltered; **Question 4**) for CSCI, located in the underdeveloped portions of the San Juan and Trabuco watershed and 2 reaches were prioritized for protection for ASCI which were located in upper Trabuco Creek and Upper Bell Canyon. Only 1 reach was prioritized for monitoring which was located in upper Trabuco Creek (biologically healthy sites that are hydrologically altered; **Question 5**) based on CSCI.

Based on CSCI, 18 reaches were prioritized for flow management (biologically degraded sites that were hydrologically altered; **Question 6**) and these reaches were generally located in lower Aliso Creek, Trabuco Creek, and upper Gobernadora. For ASCI, 28 reaches were prioritized for flow management, and they were generally located in Aliso Creek, Trabuco Creek, Laguna coastal draining creeks, and upper Gobernadora watersheds. Additionally, 32 reaches were prioritized for separate stressor evaluations based on CSCI (biologically degraded sites that were hydrologically unaltered; **Question 7**), including reaches in mid to upper Aliso, Oso, Segunda Deshecha, Laguna and Dana coastal draining creeks. For ASCI, 26 reaches were prioritized for separate stressor evaluations and they were located in Oso Creek, Segunda Deshecha, and portions of upper San Juan Creek watersheds.

**Table 5-1. Number of sites for CSCI and ASCI that fall within each management recommendation category corresponding to Questions 4 to 7.**

| Recommendation Category | Number of Reaches (CSCI) | Number of Reaches (ASCI) |
|---|---|---|
| Prioritized for Protection | 5 | 2 |
| Prioritized for Monitoring | 1 | 0 |
| Prioritized for Flow Management | 18 | 28 |
| Prioritized for Separate Stressor Evaluations | 32 | 26 |

Recommendation maps and data tables based on observed and predicted bioassessment data can be found at: https://ocgov.box.com/s/lyev77zfp8ny5wmoe389xf81npn9i1cq.

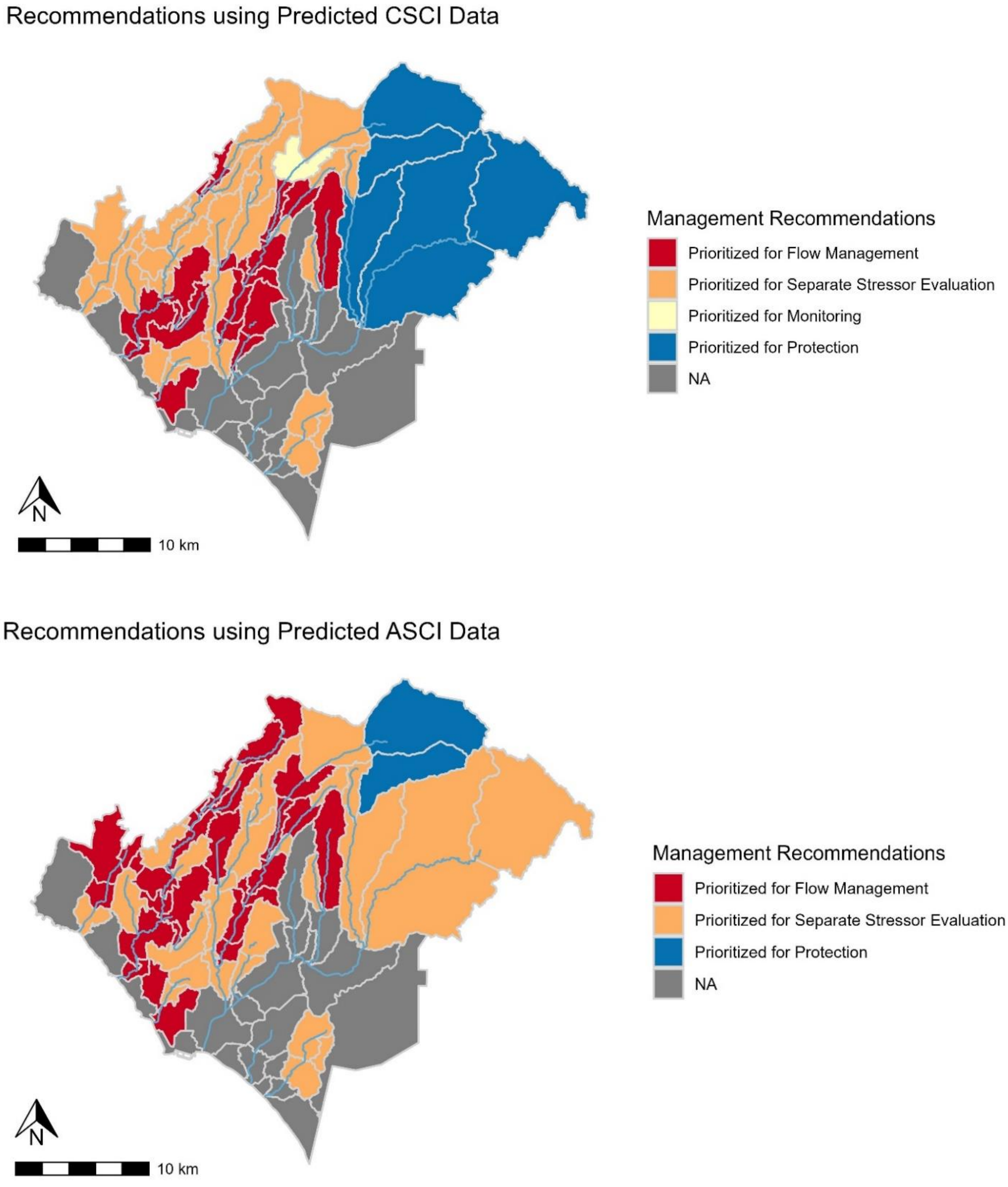


**Figure 5-1. Management recommendations based on predicted biologic condition for CSCI and ASCI and biologically-relevant flow alteration from Level 2. Note: flow data is only available at the terminal node of each subbasin, so the corresponding recommendation category associated with that flow is assigned to the entire catchment. NA means subbasins were not evaluated.**

## 5.3. Potential Uses of Study Results

This study is intended to serve as a resource to support implementation and adaptation of WQIP strategies and support development of multi-benefit watershed and water resource projects. In general, the results of this study and the associated tools can be used to (1) better understand flow regimes throughout the study area, (2) prioritize areas for potential flow management, including potential changes in flow management priorities in the future considering increased water conservation and climate change, (3) support the design of flow management projects, and (4) support the design of stream rehabilitation projects. The sections below provide more information about potential uses of these study results.

**Prioritization of areas for potential flow management**: MS4 Permittees can use Level 1 and 2 prioritization maps and the R shiny dashboard to help understand where flow alterations may be most biologically significant. This can help prioritize certain subwatersheds for more targeted flow management actions. These datasets do not specify a certain management action or target. However, the maps indicate the direction of alteration that may be contributing to biological alteration, which provides a reference point for what types of actions may be effective (e.g., reduction or augmentation, wet and/or dry).

**Evaluation of the benefit and feasibility of outfall diversions or other runoff capture strategies:** Many outfalls have rainwater-derived dry weather flow that contributes to rainwater-derived baseflow in receiving streams. This suggests that outfall low flow diversion strategies may be less applicable for these outfalls than previously thought as the interception of rainwater-derived flow sources could impact streamflow regimes. However, where an outfall dry weather flow is found to be predominantly imported water, a strategy involving diverting this water for water recycling may have limited negative effect on streamflow. Additionally, where water quality from the outfall is poor, the minor reduction in flow may have an overall beneficial effect. Level 1 and 2 prioritization maps and alteration assessment can help determine the potential effect of outfall flow reduction on downstream flow regimes. The study products, combined with OCFS, provide helpful datasets to support these decisions.

**Identification of areas for other stressor evaluation.** Tentative findings from Level 1 and 2 suggest that other stressors may be responsible for depressed biological integrity in some reaches. These findings could help support shifts in focus from water balance management to geomorphic rehabilitation and/or pollutant source control and treatment in these reaches.

**Figure 5-2** provides an example process flow for how the Flow Ecology Study work products could support the identification, prioritization, and design of flow management and/or stream rehabilitation projects.

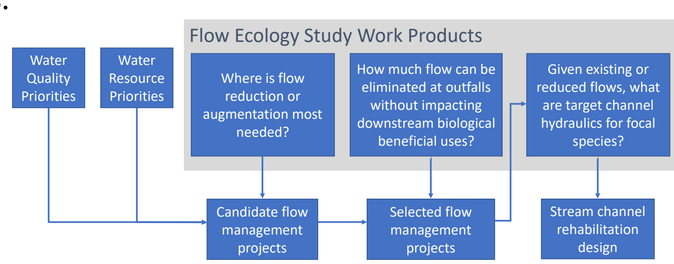


**Figure 5-2. Example process flow for use of Flow Ecology Study work products in project identification and development.**

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