Assessment of Aquatic Life Use Needs for the Los Angeles River

Los Angeles River Environmental Flows Project

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Southern California Coastal Water Research Project

SCCWRP Technical Report #1154

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Executive Summary

The State Water Board, in coordination with City of Los Angeles, Los Angeles County Department of Public Works, and Los Angeles County Sanitation Districts, initiated *the Los Angeles River Environmental Flows Project* (Project) to provide a toolset to evaluate a series of flow reduction scenarios for the LA River. These tools will be used to inform development of flow criteria that sustain specific species, habitats, and beneficial uses. This toolkit may be used to develop policies on how to balance the need for local water supply and still support beneficial uses. In the near term, the outcomes of this analysis can inform decisions associated with proposed wastewater change petitions and stormwater management programs. In the longer term, the outcomes could inform decisions regarding the ability to support beneficial uses not currently supported, in combination with broader restoration planning efforts. The study area for the project includes the mainstem of the LA River (from the DC Tillman water reclamation plant to the Pacific Ocean), plus two LA River tributaries (Rio Hondo and Compton Creeks). The goals of the project are to:

- Develop a process for establishing flow criteria
- Apply the process to provide recommendations for flow criteria in the LA River
- Produce tools and approaches to evaluate management scenarios necessary to achieve recommended flow criteria.

This report presents the results of the aquatic life beneficial use assessment. The goals of the aquatic life use assessment are:

1. Assess current hydrologic conditions
2. Identify priority ecological endpoints of management concern (e.g., species or habitats)
3. Determine flow-ecology relationships for priority ecological endpoints
4. Determine appropriate hydrologic and ecologic tools for analysis

A series of models was developed to assess the ability of the LA River to provide aquatic life uses (Figure ES-1).

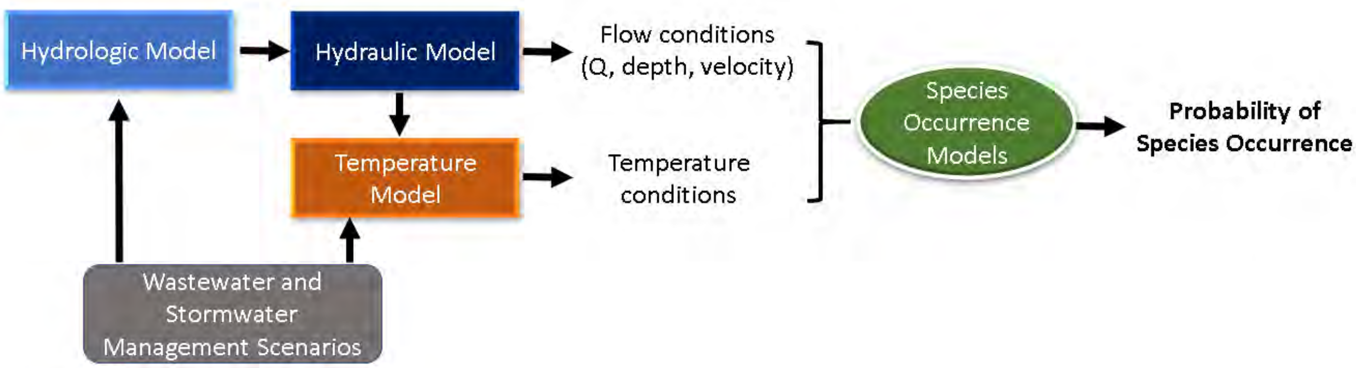


Figure ES-1. Overview of modeling framework.

Current Baseline Physical Conditions

We estimated current flow condition in the study area using a coupled hydrologic-hydraulic model created in EPA SWMM and HEC-RAS (ES-2). Current hydrologic conditions are defined as the flows and operations that occurred during water year (WY) 2011 to 2017.

The hydrologic model produces discharge on the mainstem of the LA River, Compton Creek, and Rio Hondo at an hourly time step from WY 2011 to 2017. The model was calibrated from WY 2014 to 2017 and validated from WY 2011 to 2013 at seven locations throughout the watershed (4 on the mainstem, 3 on tributaries) by comparing daily discharge values. The hydraulic model was created for a subset of this spatial domain — the mainstem of the Los Angeles River from Sepulveda Basin to the outlet to the harbor, and for Compton Creek and Rio Hondo (Figure ES-2).

The hydraulic model was created by combining existing HEC-RAS models for the river and updating channel geometry and Manning's roughness based on field observations. The hydraulic model was run under steady state conditions, which were used to develop rating curves to apply to the simulated hydrographs, producing time series hydraulic data for velocity, channel depth, and shear stress. The final SWMM model comprises 77 catchments, and 78 channels and nodes. The final HEC-RAS model contains over 1,600 cross sections. The coupled hydrologic-hydraulic model was used as a base for the temperature model, created in i-Tree Cool River and the water quality model, created using EPA SWMM. All models were calibrated and validated using local data sources from a variety of ongoing monitoring programs.

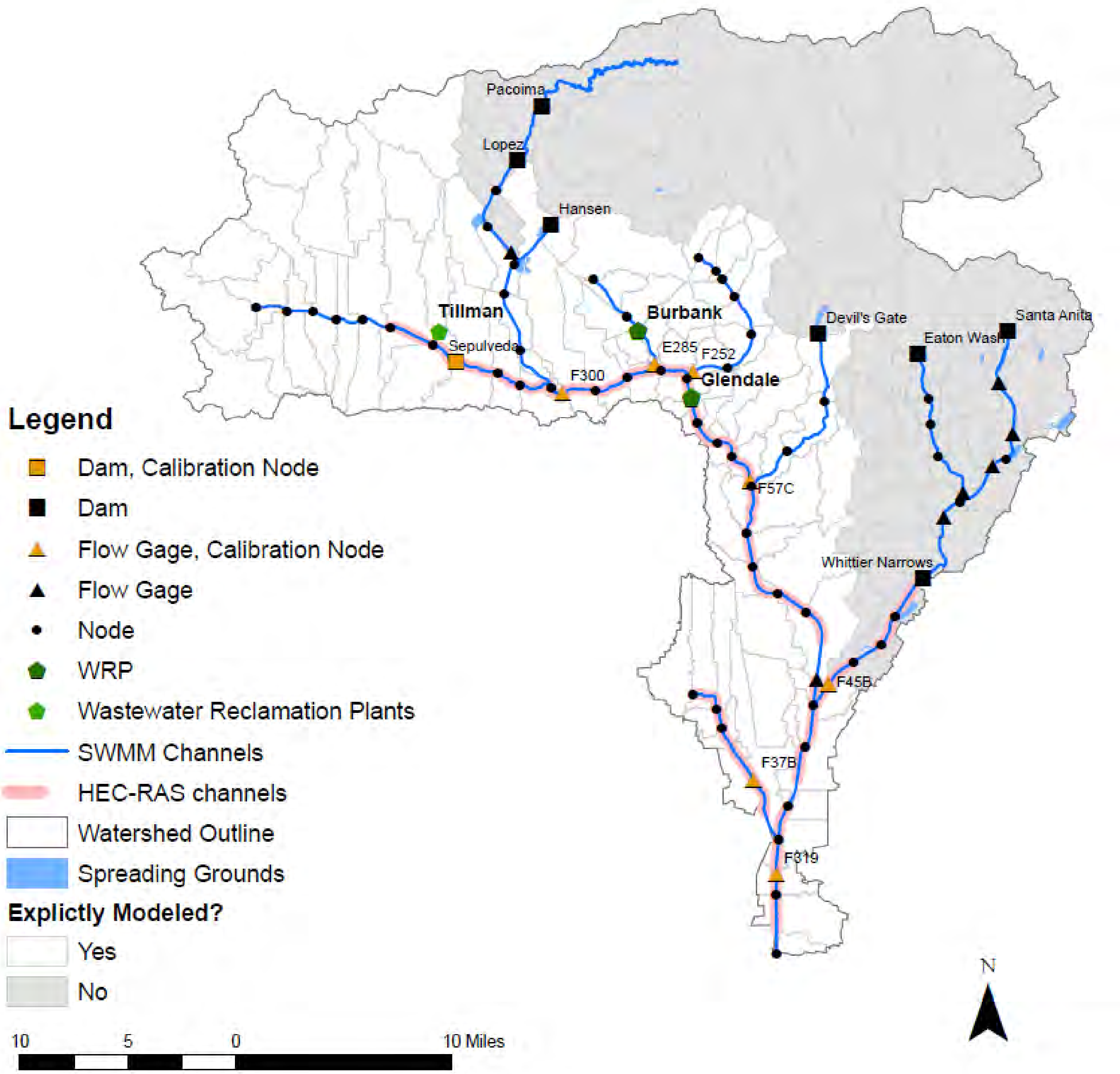


Figure ES-2. Hydraulic and hydrologic model domain. The hydraulic model was developed in HEC-RAS and paired with a hydrologic model created in SWMM.

Modeled median annual non-storm flows in the mainstem of the Los Angeles River across all reporting nodes range between 0.21 and 3.9 cms (7.5 and 138 cfs). Non-storm flows are defined as any flows not generated by rainfall in the model. Non-storm flows in Compton Creek and Rio Hondo are minimal, with medians of 0 and 0.0014 cms (0 cfs and 0.05 cfs), respectively (Figure ES-3).

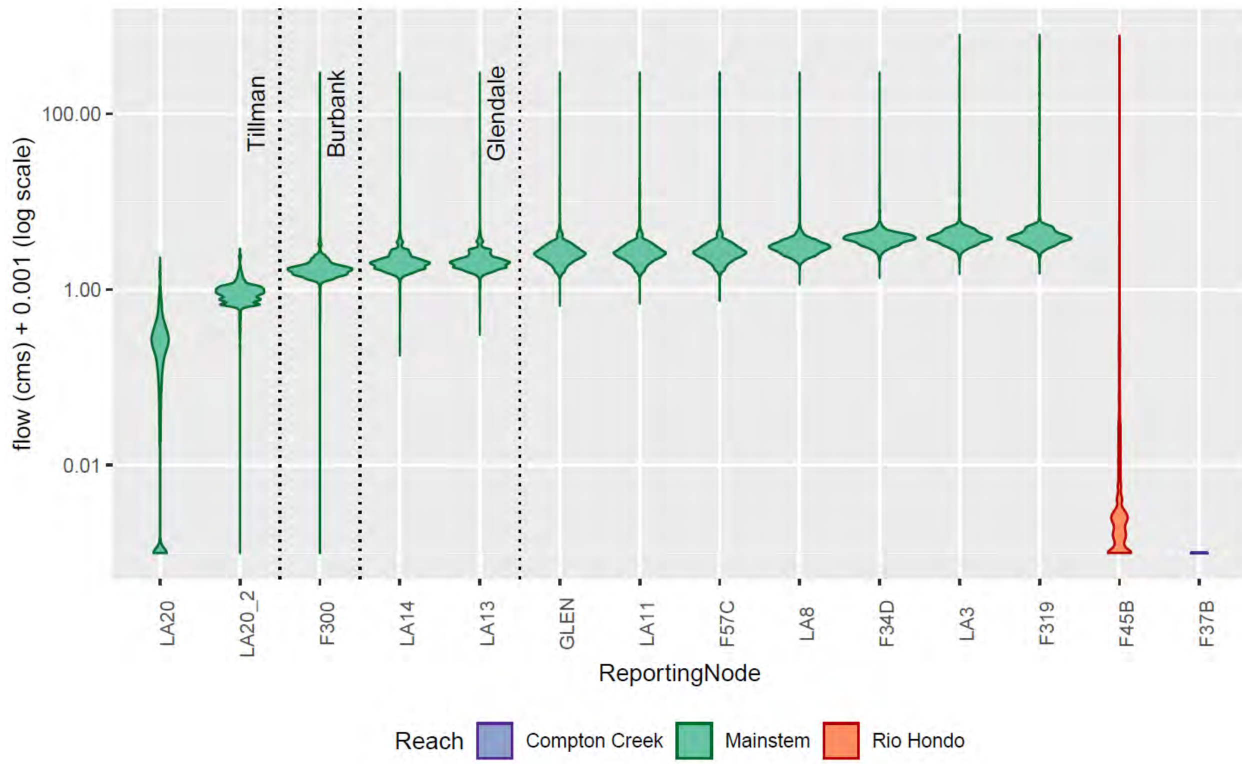
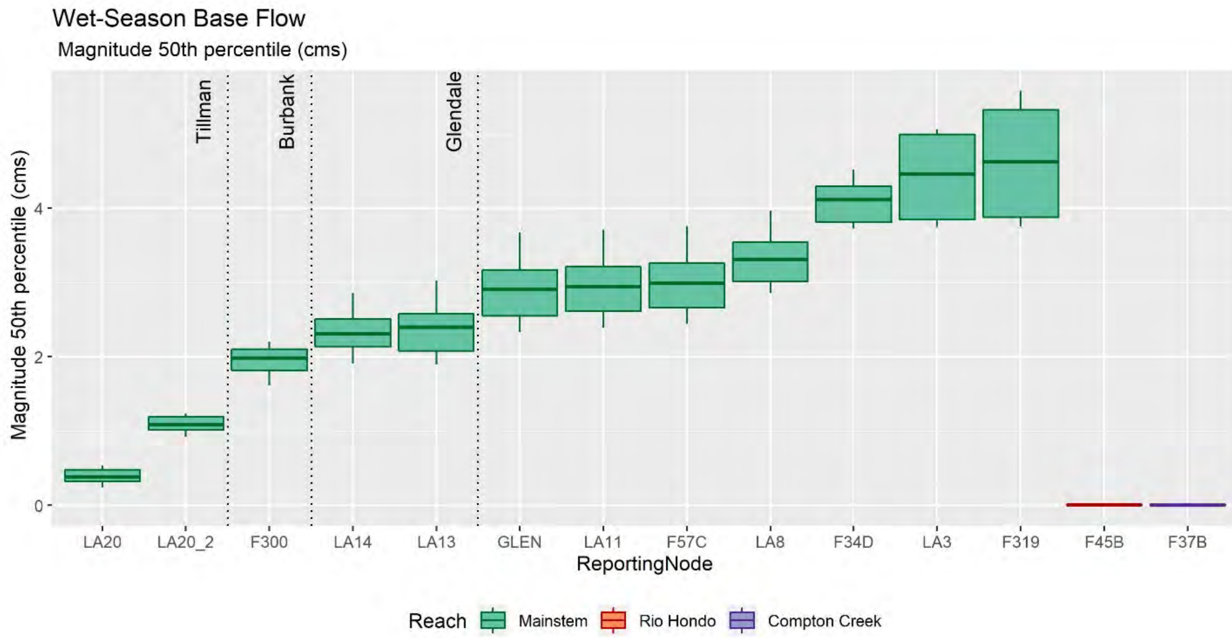


Figure ES-3. Violin plots of model simulated non-storm discharge for the reporting nodes under current conditions. Gage F45B is on the Rio Hondo tributary. Gage F37B is on Compton Creek. Note the y-axis is a log scale.

Calculated ranges for the wet season and dry season baseflow metrics increase downstream of the three water reclamation plants, illustrating the contributions of discharges from the water reclamation plants (Figure ES-4). The wet season metrics, baseflows from the start of the storm season to the start of the dry season, and dry season metrics, base flows from the start of the dry season to the start of the following wet season, are calculated on an annual basis. Typically, the start of the wet season is between November to January and the start of the dry season is between May to July depending on the climatic conditions for a given water year. The broader ranges and higher values of wet season baseflow metrics reflects the contribution of residual stormdrain discharge following storm events. Rio Hondo and Compton Creek both have the lowest wet season and dry season baseflow magnitudes compared to all other reporting nodes on the mainstem.



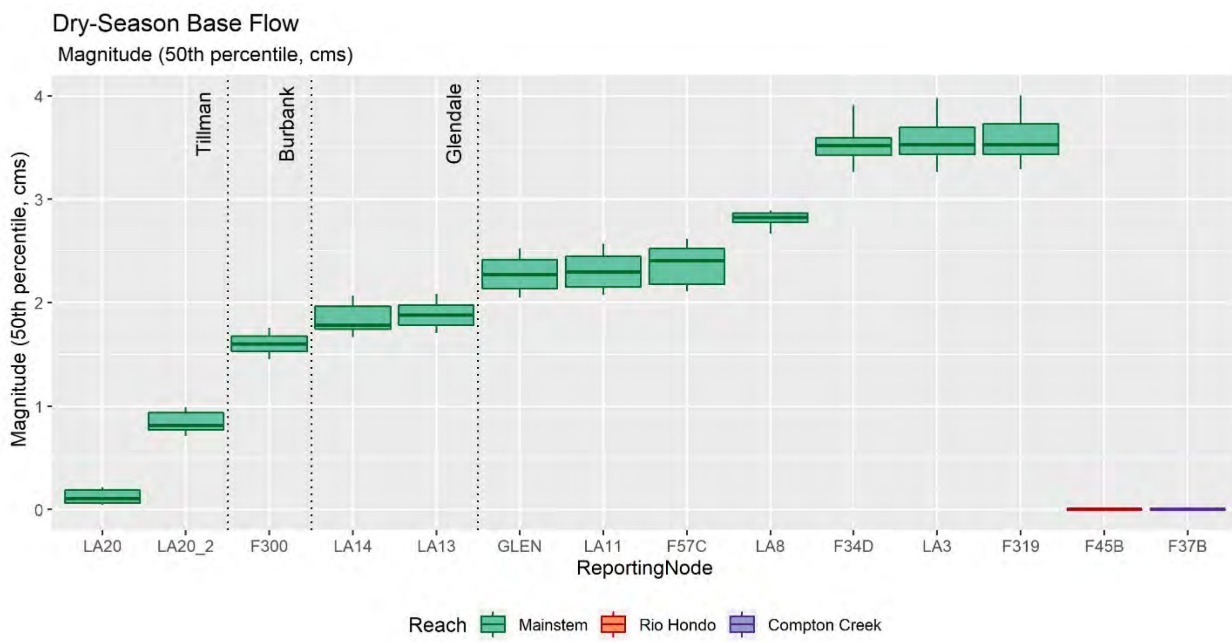


Figure ES-4. 50th percentile wet-season baseflow (top) and dry-season baseflow (bottom). Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10^{th} and above the 90^{th} percentile are not shown.

Main channel depths are generally less than 0.3 m (1 ft) with depth generally increasing downstream. Depths in Rio Hondo and Compton Creek are generally an order of magnitude less than in the mainstem (Figure ES-5). Similar spatial patterns are observed for velocity and shear stress.

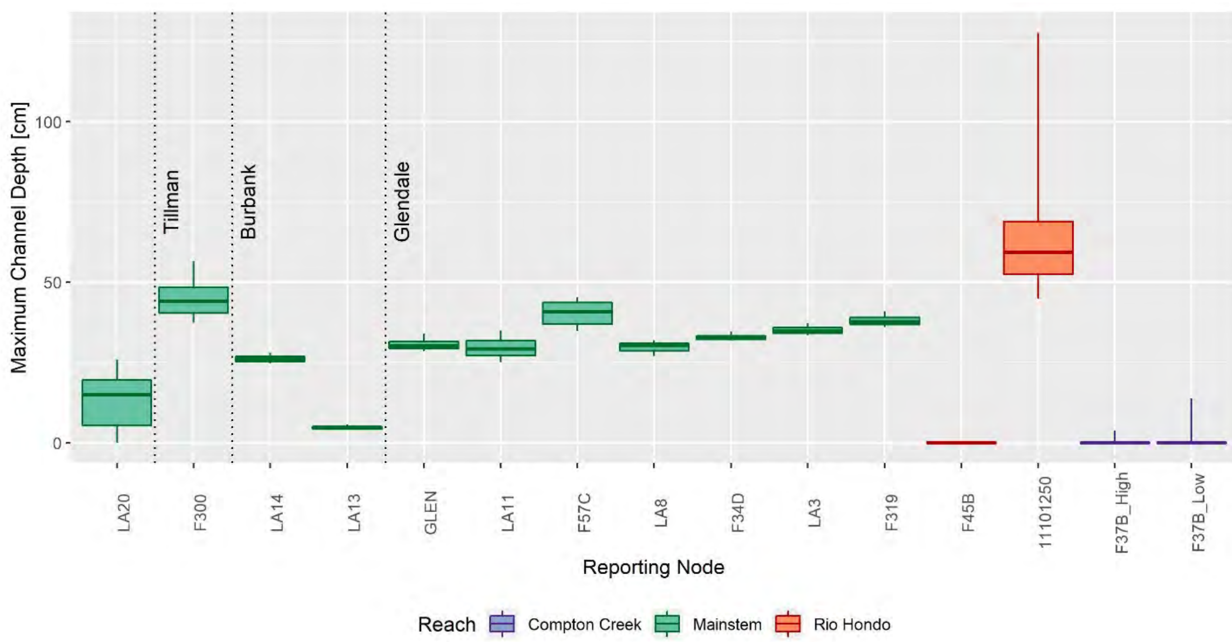


Figure ES-5. Box plots of maximum channel hourly depths as simulated by the HEC-RAS model. Midline of the box represents the median of observed values; bottom and top of the box represent the 25th and 75th percentiles, respectively. Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10th and above the 90th percentile are not shown.

Modeled baseline temperature estimates where used to calculate the following three ecologically meaningful temperature metrics for inclusion in the species occurrence analysis: Maximum Weekly Maximum Temperature (MaxWMT), Maximum Weekly Average Temperature (MaxWAT), and Minimum Weekly Minimum Temperature (MinWMT). Median values for these three metrics are summarized in Table ES-1.

Table ES-1. Ecologically relevant thermal metrics for the LA River's downstream segment (from Arroyo Seco confluence) and its two major tributaries, Compton Creek and Rio Hondo, based on the validation process and the reach averaged values.

Monitoring station	Temperature (C)	MaxWMT	MaxWAT	MinWMT
Station 2C (Upper LA River)	Observed	30.8	30.0	26.0
	Simulated	30.8	30.3	26.3
	ΔT (Sim. – Obs.; |% to obs.|)	0.8 (2.6%)	0.3 (1%)	0.3 (1.1%)
Station 3E (Upper LA River)	Observed	36.5	35.3	19.9
	Simulated	34.5	33.3	18.4
	ΔT (Sim. – Obs.; |% to obs.|)	-2 (5.4%)	-1.8 (5.1%)	-1.5 (-7.5%)
Station 4A (Upper LA River)	Observed	31.4	31.0	23.4
	Simulated	33.7	32.6	19.2
	ΔT (Sim. – Obs.; |% to obs.|)	2.3 (7.3%)	1.6 (5.1%)	-4.2 (17.9%)
Station 4D	Observed	34.7	34.2	21.1

Monitoring station	Temperature (C)	MaxWMT	MaxWAT	MinWMT
(lower LA River)	Simulated	34.0	33.5	21.9
	∆T (Sim. – Obs.; |% to obs.|)	-0.7 (2%)	-0.7 (2.0%)	0.8 (3.8%)
Station 5A (lower LA River)	Observed	34.4	33.9	20.7
	Simulated	34.7	34.2	21.5
	∆T (Sim. – Obs.; |% to obs.|)	0.3 (0.9%)	0.3 (0.9%)	0.8 (3.9%)
Compton Creek	Observed	24.9	22.8	20.0
	Simulated	23.8	22.9	20.2
	∆T (Sim. – Obs.; |% to obs.|)	-1.1 (4.4%)	0.1 (0.5%)	0.2 (1%)
Rio Hondo	Observed	26.3	23.7	13.3
	Simulated	25.8	24.3	11.8
	∆T (Sim. – Obs.; |% to obs.|)	-0.5 (1.9%)	0.6 (2.5%)	-1.5 (11.2%)

Current Baseline Ecological Conditions

For the purposes of this study, aquatic life beneficial uses in the LA River are being defined based on the ability of the river and its tributaries to support characteristic aquatic plant and animal communities. The overarching goal of this project is to consider potential effects of reduced WRP discharge and increased stormwater capture on existing and potential future beneficial uses. Therefore, our analysis included characterizing species and habitats that current occur and those that could reasonably occur in the future (based on a comparison to similar southern California watersheds). Current beneficial use designations for the mainstem of the LA River, Compton Creek, and Rio Hondo are set forth in the *Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties*, adopted by the Los Angeles Regional Water Quality Control Board. Our analysis focuses on the current beneficial uses but also considers support for species and habitats that are not currently supported in study area. The intent is to evaluate whether proposed management actions would influence flow conditions that could potentially support other beneficial uses in the future (e.g., COLD, MIGR), recognizing that there are many other factors that currently limit or preclude the ability to support these uses (e.g., channelization, lack of vegetative cover, lack of suitable substrate). The intent is not to propose management recommendations specifically aimed at supported species or habitats associated with beneficial uses not currently designated.

The aquatic life use assessment began with a compilation of observational data from the LA River and surrounding watersheds which was used to identify priority focal habitats and endmember species that represent a range of tolerances for each habitat. We then determined the flow conditions necessary to support the life history needs of each species and used those to create “flow-ecology” curves or models relating key hydrologic, hydraulic, and temperature conditions to the probability of occurrence for each focal species, or the probably of being able to complete specific life-history requirements.

We identified six major habitat types for the LA River, five of which currently exist (Table ES-2). For each habitat, we selected one or two representative species to represent the range of flow tolerances for each habitat.

Table ES-2. Habitats and representative end member species. Shaded cells represent habitats and species not currently supported in the entire mainstem LA River, Compton Creek, or Rio Hondo.

Habitat	End member species	Description
Cold water habitat	Santa Ana Sucker	Not currently present
	Unarmored threespine stickleback	
Migration habitat	Steelhead/Rainbow trout	Currently, only designated for Reach 1. Overlays with other habitats
Wading shorebird habitat	Cladophora spp	Green algae to support prey of wading birds
Freshwater marsh habitat	Typha	Dominant plant species used to represent overall habitat
	Duckweed	
Riparian habitat	Black Willow	
Warm water habitat	African clawed frog	Surrogate for invasive spp. habitat
	Mosquitofish	

Species habitat suitability under current conditions was assessed for each reporting node based on the probability that key life stages could be supported under current hydrologic and hydraulic conditions, using the flow-ecology relationships developed for this study.

Habitat models and suitability criteria were ultimately used to estimate the probability that each of the focal habitats and species can be supported under current flow conditions. This provides a baseline for assessing the potential effects of proposed changes in flow associated with reduced wastewater discharge or increased stormwater capture. Major findings of the baseline analysis suggest:

- Flow conditions are at least partially suitable to support freshwater marsh habitat, as indicated by *Typha*, which is consistent with field observations. This is not surprising given that marsh habitat is generally an early successional habitat when water (and substrate) are present and velocities are sufficiently low. Furthermore, these habitats rapidly recover following disturbance from high flows or mechanical clearing.

- Flows can generally support riparian habitat along the LA River, as indicated by the high suitability for willow seedlings and adults. However, the current model suggests that reproduction of willows is not supported. This result could be related to the location of germinating willows in the cross section, which may not be fully represented in the HEC-RAS output (i.e., willow germination may be located at a higher elevation, and hence shallower depth than the model describes).

- The lower LA River is characterized by flows that have a high probability to support wading shorebirds based on suitable flows for Cladophora. Although flows that can support Cladophora are present throughout the study area, for this study, we are specifically interested in Cladophora as an indicator of the ability to support foraging shorebirds in the tidal portions of the river.

- Although temperatures are too warm to support coldwater fish species, such as the Santa Ana Sucker, the river currently has flows that are at least partially suitable for coldwater fish (adult and juvenile).

- Conditions are generally not conducive to steelhead migration past Glendale Narrows.

ACKNOWLEDGMENTS

This project was conducted through a collaboration with the State Water Resources Control Board, the Los Angeles Regional Water Quality Control Board, and local municipalities and stakeholders. Principle funding was provided by the City of Los Angeles, Department of Water and Power (DWP) and Bureau of Sanitation (BoS). Additional funding was provided by Los Angeles County Public Works (LADPW), Los Angeles County Flood Sanitation Districts (LACSD), the Watershed Conservation Authority (WCA), a joint powers authority between the Rivers and Mountains Conservancy (RMC) and the Los Angeles County Flood Control District, and the Mountains Recreation and Conservation Authority (MRCA), a joint power of the Santa Monica Mountains Conservancy, the Conejo Recreation and Park District and the Ranch Simi Recreation and Park District. We thank all members of the Stakeholder Workgroup and the Technical Advisory Group who provided critical input, advice, and review over the course of this project. Additional project information is available at https://www.waterboards.ca.gov/water_issues/programs/larflows.html.

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INTRODUCTION AND BACKGROUND

Increasing water scarcity associated with population growth, drought, and climate changes has led to expanded effort to conserve and reuse wastewater and other discharges, particularly in drier regions of California, such as the greater Los Angele area. Water reuse is encouraged by the State's recycled water policy which calls for diversification of local water supplies to mitigate the effects of short-term drought and long-term climate change through the safe use of recycled water from wastewater sources. The state policy also requires that reuse programs ensure the protection of existing water rights and beneficial uses.

Wastewater reclamation plants (WRPs) statewide have expanded their capabilities to treat wastewater, making the resulting recycled water a valuable reusable resource. Recycled water has been used for irrigation and industrial applications in lieu of using potable drinking water. Municipalities can now use advanced treated recycled water from the WRPs to recharge groundwater basins (via percolation and spreading basins). Groundwater recharge serves as a management tool for basin users and managers and can allow cities to rely more on groundwater. Higher reliance on groundwater can help reduce the municipalities' demand from other stressed water systems, such as the Bay Delta and Colorado River.

As municipalities use more recycled water, the WRPs discharge less to waterways. Water conservation in the region has also reduced the volume of wastewater available for recycling. Reductions in discharges to waterways can have unintended consequences affecting fish, wildlife, or other public resources (such as access to recreation) that have come to rely on WRP discharges. To balance these interests and minimize impacts, wastewater dischargers who want to reduce their discharges to streams to allow reuse and recycling of the water need approval from the Water Boards under Water Code Section 1211. The Water Boards require that the wastewater discharger demonstrate that a change in flow will not unreasonably harm beneficial uses.

The Los Angeles (LA) River is at the forefront of this need to better understand and quantify potential impacts from changes in flow regimes. The cities of Burbank, Glendale, and Los Angeles have been beneficially reusing and recycling wastewater for decades and plan to recycle more wastewater. They have petitioned, or are planning to petition, the State Water Board to reduce their discharges to the LA River for this purpose. The LA River also serves as an important stormwater management system. The potential reduction in wastewater discharge, along with plans to better manage stormwater, would reduce or potentially eliminate flows in certain stretches of the LA River during the dry season. The Water Boards are currently supporting the development of technical tools to help balance the needs of municipal water users and other beneficial uses.

The State Water Board, in coordination with City of Los Angeles, Los Angeles County Department of Public Works, and Los Angeles County Sanitation Districts, initiated *the Los Angeles River Environmental Flows Project* (Project) to provide a toolset to evaluate a series of flow reduction scenarios for the LA River. These tools will be used to inform development of flow criteria that sustain specific species, habitats, and beneficial uses. This toolkit may be used to develop policies on how to balance the need for local water supply and groundwater recharge, and still support beneficial uses. In the near term, the outcomes of this analysis can inform decisions associated with proposed wastewater change petitions and stormwater management programs. In the longer term, the outcomes could inform decisions regarding the ability to support beneficial uses not currently supported, in combination with broader restoration planning efforts. The goals of the project are to develop a process for establishing flow criteria, to apply the process to provide recommendations for flow criteria in the LA River, and to produce tools and approaches to evaluate management scenarios necessary to achieve recommended flow criteria. The project also serves as an important pilot application of the California Environmental Flows Framework (CEFF)[1] by demonstrating how CEFF can be applied in a highly urbanized watershed where flow alteration is primarily caused by wastewater and stormwater discharges. The outcomes of this project may also serve as a model for assessing similar situations in other river systems.

All phases of the project beginning with initial project scoping have been coordinated through both a Stakeholder Working Group (SWG) and a Technical Advisory Committee (TAC). Additional project information including meeting notes and presentations are available on the project website at https://www.waterboards.ca.gov/water_issues/programs/larflows.html#background.

Study Area

The study area for the project includes the mainstem of the LA River (from the DC Tillman water reclamation plant to the Pacific Ocean), plus two LA River tributaries (Rio Hondo and Compton Creeks). Areas within the River (i.e., between the banks) are also covered by this study (Figure 1). The upper tributaries of the LA River are included in the Project's hydrologic modeling component to more accurately characterize the watershed. The models produced could be used in the upper reaches to support future studies. Additionally, restoration in portions of the upper tributaries will be evaluated as possible offsets to potential impacts along the mainstem of the river.

[1] The California Environmental Flows Framework provides a set of reference-based ecological flow criteria for each stream reach in the state and provides guidance for developing refined flow criteria when appropriate.

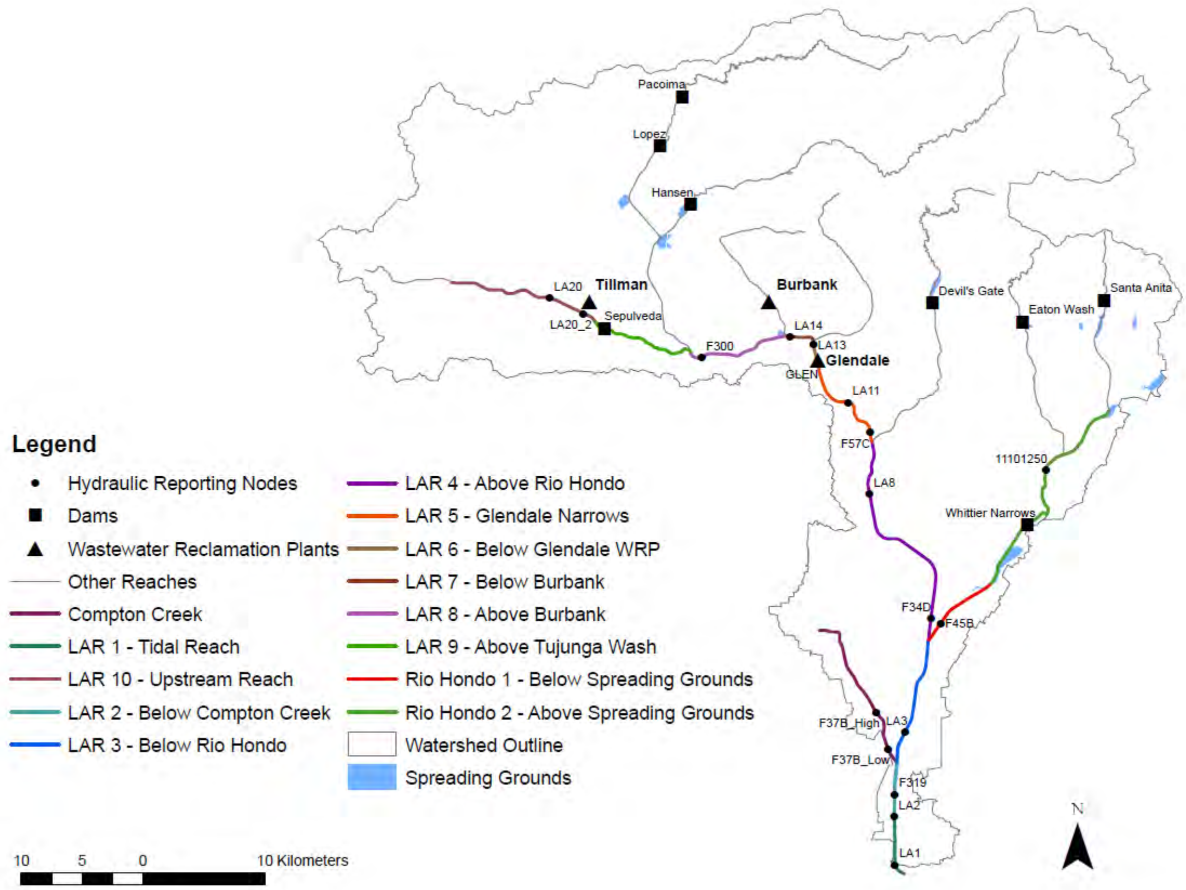


Figure 1. Project study area showing the major study reaches, locations of major dams and wastewater reclamation plants (WRPs). Hydrologic Reporting Nodes (circles) represent locations where the effect of various discharge scenarios on instream flows will be evaluated.

Organization of this Report

The project consists of seven activities, each with a series of tasks:

- Activity 1 - Stakeholder coordination
- Activity 2 - Non-aquatic Life Use Assessment
- Activity 3 - Aquatic Life Beneficial Use Assessment
- Activity 4 - Apply Environmental Flows and Evaluate Scenarios
- Activity 5 - Monitoring and Adaptive Management Plan
- Activity 6 - Summary of results/reporting
- Activity 7 - Water Quality Assessment

Non-aquatic life beneficial uses (e.g., recreation) were previously assessed and reported (Stein and Sanchez 2019). This report presents the results of the aquatic life beneficial use assessment (Activity 3). The goals of the aquatic life use assessment are reflected by the organization of this report:

1. Assess hydrologic and hydraulic baseline conditions
2. Identify priority ecological endpoints of management concern (e.g., species or habitats of concern)
3. Determine flow-ecology relationships for priority ecological endpoints
4. Determine appropriate hydrologic and ecologic tools for analysis

A series of models were developed to assess the ability of the LA River to provide aquatic life uses (Figure 2).

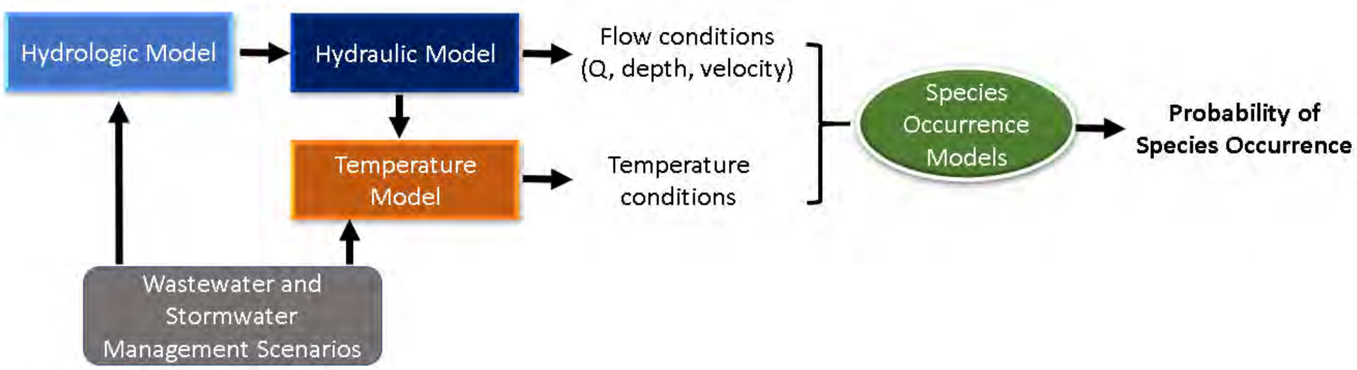


Figure 2. Overview of modeling framework.

In activity 4, the hydrology, hydraulic and temperature models will be used to evaluate a series of management scenarios involving different amounts of wastewater discharge and stormwater capture. The species occurrence models will be used to evaluate the potential effect of the management scenarios on aquatic life beneficial uses, which can in turn be used to inform development of flow criteria necessary to protect those uses.

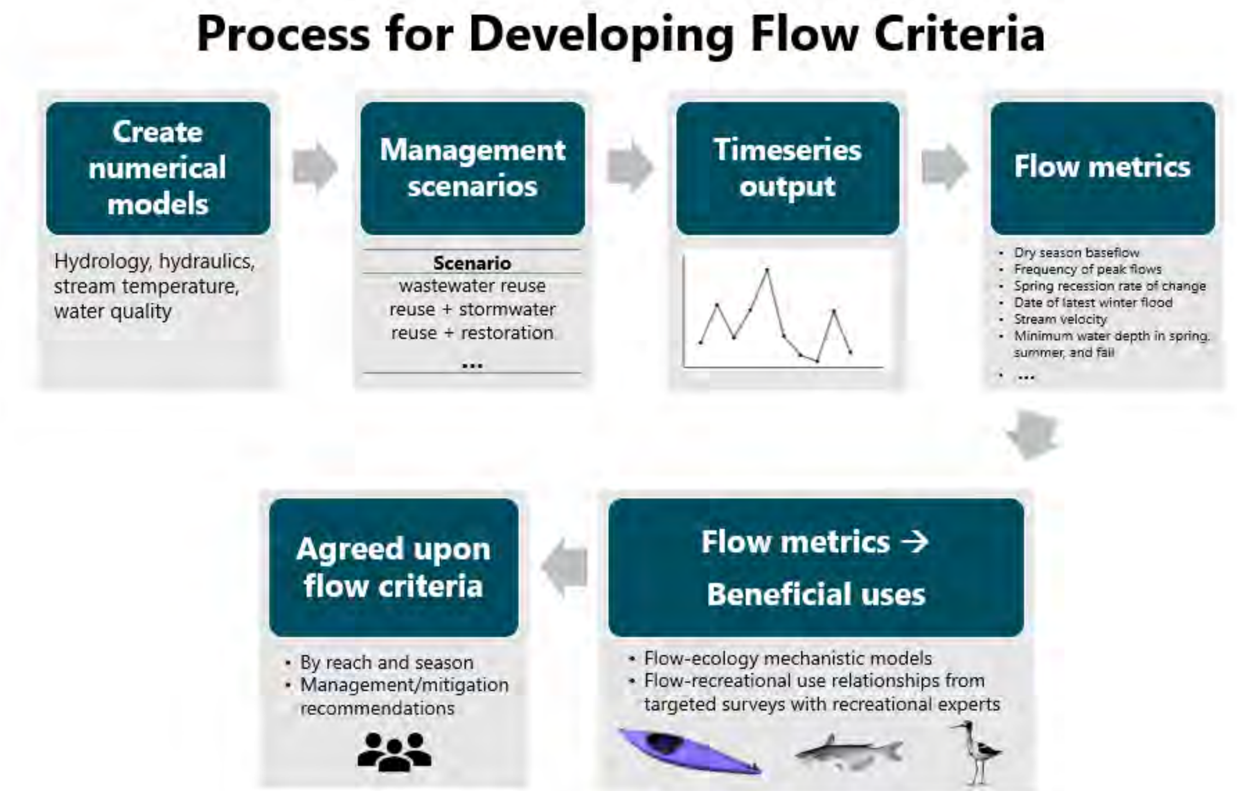


Figure 3. Process used to develop flow criteria recommendations.

Evaluation of Physical Conditions

Overall Approach

We estimated baseline flow condition in the study area using a coupled hydrologic-hydraulic model created in EPA SWMM and HEC-RAS (Figure 4). The hydrologic model produces discharge on the main stem of the LA River, Compton Creek, and Rio Hondo at an hourly time step from water year (WY) 2011 to 2017, was calibrated from WY 2014 to 2017 and validated from WY 2011 to 2013 at seven locations throughout the watershed (4 on the mainstem, 3 on tributaries). The hydraulic model was created for a subset of this spatial domain—the mainstem of the Los Angeles River from Sepulveda Basin to the outlet to the harbor, and for Compton Creek and Rio Hondo (Figure 4). The hydraulic model was run under steady state conditions and calibrated at 5 locations (3 on the mainstem, 2 on tributaries). The final SWMM model comprises 77 catchments, and 78 channels and nodes. The final HEC-RAS model contains over 1,600 cross sections.

The coupled hydrologic-hydraulic model was used as a base for the temperature model, created in i-Tree Cool River and the water quality model, created using EPA SWMM.

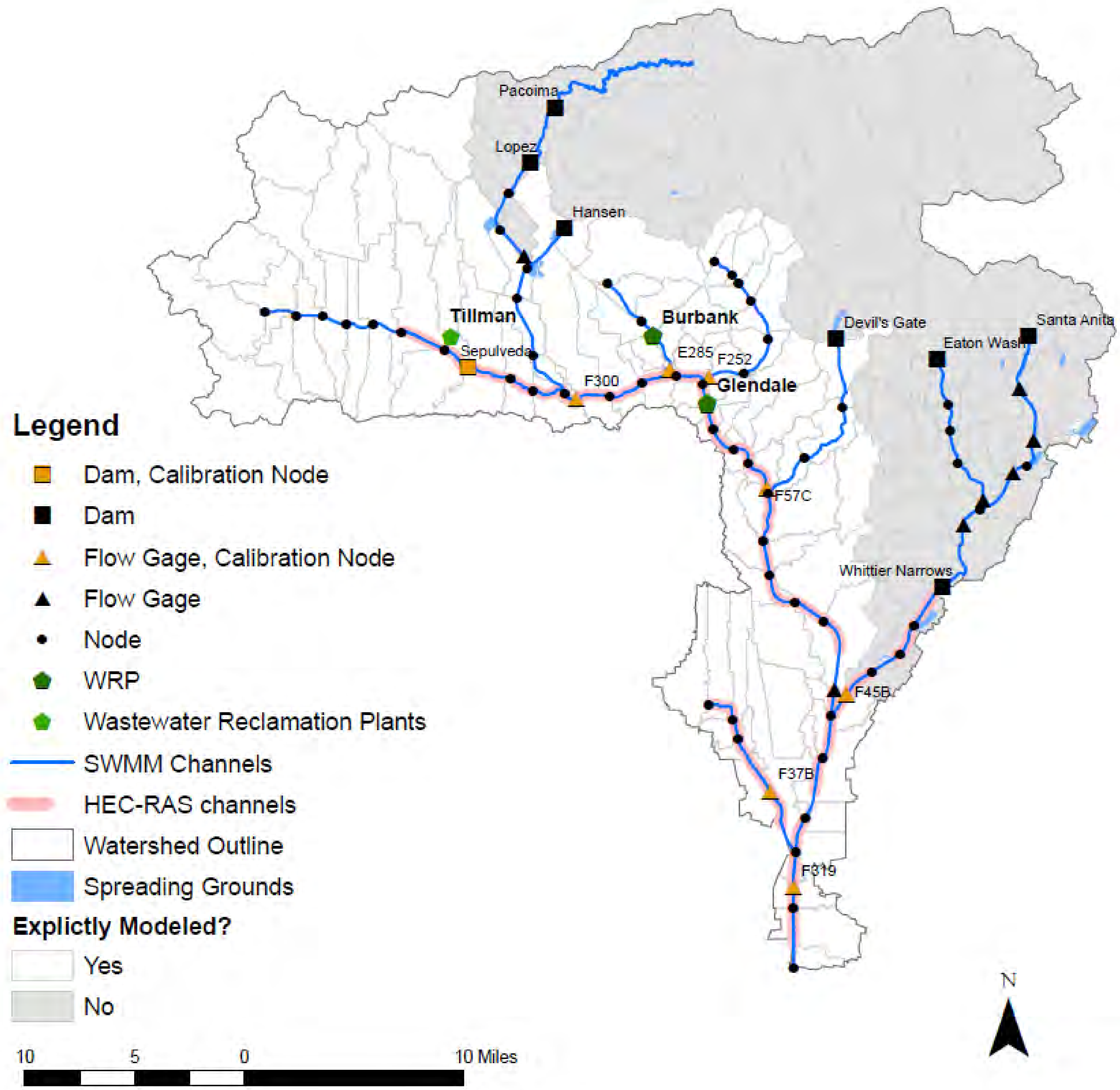


Figure 4. Hydraulic and hydrologic model domain. The hydraulic model was developed in HEC-RAS and paired with a hydrologic model created in EPA SWMM.

Reporting Nodes

Reporting nodes were selected to represent specific reaches of the river where the effect of various discharge scenarios on instream flows will be evaluated (Figure 1). The reporting nodes were selected to represent a range of different hydraulic and hydrologic conditions, prioritizing cross sections in soft bottom reaches such as within Glendale Narrows. Hydrologic outputs from the SWMM model are paired with hydraulic outputs from the HEC-RAS model for the evaluation at these nodes. The selection of the reporting nodes was reviewed and coordinated with both the project SWG and TAC.

Hydrologic Model

Spatial data

Sewersheds were downloaded from the LA County Watershed Management and Modeling System (Tetra Tech 2020). These 1,001 catchments were merged to 147 catchments with an average size of 3,600 ac (14.7 km^2). The storm sewer network, retrieved from LA County GIS data portal (County of Los Angeles 2020), as well as National Hydrography Dataset (U.S. Geological Survey 2019) flowlines were used to confirm the drainage network. A Digital Elevation Model (DEM) was retrieved from the USGS 3D Elevation Program at 1/3 arcsecond resolution and processed to find average slope for each subcatchment (U.S. Geological Survey 2016a). Total imperviousness for each catchment was estimated from the National Land Cover Database (U.S. Geological Survey 2016b). Soils data was downloaded the Natural Resources Conservation Service, United States Department of Agriculture Soil Survey Geographic Database (Natural Resources Conservation Service 2019). Green-Ampt infiltration parameters (hydraulic conductivity, suction head, moisture deficit) were initially estimated by matching Natural Resources Conservation Service hydrologic soil groups to typical values and spatially averaging. Areas with no hydrologic soil information were assumed to be Group D, as these soils are typically in urban areas with low infiltration capacity (National Resources Conservation Service 2007). Channel geometry was not included in the hydrology model but was included in the hydraulic model created with HEC-RAS.

Table 1. Table of raw spatial data used and sources.

Data	Primary Source
Sewersheds	Los Angeles County Watershed Management and Modeling System (WMMS)
Digital Elevation Model	USGS 3D Elevation Program
Soils	USDA Soil Survey Geographic Database
Imperviousness	National Land Cover Database
Channels	National Hydrography Dataset
Dams, Spreading Grounds, Discharge, WRP Timeseries	Los Angeles County, Army Corps of Engineers
Precipitation	Los Angeles County
Evaporation	CIMIS

Time series data

Potential evapotranspiration (PET) data was downloaded from the California Irrigation Management Information System (CIMIS), which are a collection of autonomous weather stations that make real-time observations (California Department of Water Resources 2019). The inverse-distance square weighing method was used to combine the reference PET time series from the nine closest CIMIS stations into one for the centroid of LA River watershed. This PET time series was applied to subcatchments throughout the watershed.

Precipitation data was retrieved for 72 of the Los Angeles County Automatic Local Evaluation in Real Time (ALERT) rain gages. Precipitation was spatially interpolated for each catchment by kriging using the krige function from the R package gstat, with a variogram generated through fit.variogram from the same package, using a spherical variogram for the best fit.

Flow data at 29 gaging stations was retrieved from the Los Angeles County Department of Public Works and downloaded from the USGS for six gaging stations. Spreading basin data was retrieved from the Los Angeles County Department of Public Works for 15 facilities. These facilities recharge a mix of imported, recycled, and stormwater. Because the distribution of these water sources changes year to year, existing conditions at spreading basins were not modeling explicitly but used to inform the spatial extent of the model.

Data was retrieved from the City of Los Angeles for discharges from the Tillman Water Reclamation Plant. WRP effluent is discharged into Balboa Lake, Wildlife Lake, the Japanese Gardens, or directly to the LA River (Figure 5). Timeseries data was received from the City of Los Angeles for the Glendale WRP. Timeseries discharge for Burbank WRP to the LA River was retrieved from the State Water Resources Control Board. Inflow and outflow data for five dams within the watershed were retrieved from the Los Angeles County Department of Public Works: Eaton Wash, Devil's Gate, Big Tujunga, Pacoima, Santa Anita. Whittier Narrows Dam and Sepulveda Dam data were downloaded from USGS website.

Figure 5. Schematic of discharges from Donald Tillman Water Reclamation Plant within and below Sepulveda Basin. Wildlife Lake and Lake Balboa discharge to the Los Angeles River above Sepulveda Dam (blue lines). Discharge from the Japanese Garden and weir at the reclamation plant discharge to the Los Angeles River below Sepulveda dam (yellow line). Note the discharge infrastructure in blue and yellow is not to scale. Base map imagery from Google Maps.

Most of the dams are in the upper reaches of the LAR watershed, and capture runoff from primarily open space or undeveloped land. Because we were primarily interested in management scenarios in the urbanized parts of the catchment, dams were included in the model as nodes with inflow time series. The catchments above the dams were not explicitly modeled (Figure 4). Because of the complex water management along the Rio Hondo tributary, *observed* discharge below above Whittier Narrows dam (USGS Gage #11101250) and observed discharge at the Los Angeles County gage on Rio Hondo above Stuart and Gray Road (Gage #F45B) were paired with the HEC-RAS hydraulic model.

Baseflow was separated using the USGS hydrograph separation program (HYSEP) and disaggregated across each reach based on contributing catchment area (Sloto and Crouse 1996). The exception for this was in the Glendale Narrows area where baseflow was disaggregated to include groundwater upwelling, WRP discharge, and channel evaporation. Groundwater upwelling in the Glendale Narrows was assumed to be a constant discharge over the course of the year at around 3,000 acre-ft/yr (0.12 cms) (ULARA 2018). Groundwater upwelling was equally distributed across the Glendale Narrows reach. Evaporation within the channel was estimated by multiplying monthly pan evaporation data collected at Long Beach, CA by a coefficient of 0.75.

Calibration and Validation

The hydrology model was calibrated for mean daily discharge at seven gage stations from upstream to downstream using an automated calibration tool to optimize the calibration parameter set with 500 – 1000 trials (Alamdari 2016). Nash Sutcliffe Efficiency (NSE) was maximized, and percent bias was minimized to select the best calibration parameter set. Calibration parameters include subcatchment width, hydraulic conductivity, depression storage, Manning's roughness coefficients, and percent directly connected impervious area. Calibration was considered good to very good (Moriasi et al. 2007) with NSE between 0.67 and 0.94 and percent bias between -20% and 17.3% (Table 2). Example calibration and validation plots are shown as Figure 6 and Figure 7. Overall, calibration captured high flows relatively well, with some disagreement between observations and the model in 2015 (Figure 7). The low flows were also captured relatively well except for some disagreement between 2012–2014 (Figure 7). Validation was satisfactory to very good (Moriasi et al. 2007) with NSE between 0.66 and 0.92 and percent bias between -19.9% and 17.3% (Table 2).

Table 2. Calibration and validation statistics for the hydrologic model of the Los Angeles River watershed.

Gage ID	Gage Description	Drainage Area (mi^2)	Calibration (WY 2014–2017)			Validation (WY 2011–2013)		
			NSE	% Bias	R^2	NSE	% Bias	R^2
F37B	Compton Creek	23	0.70	-14.9	0.72	0.66	17.3	0.81
E285	Burbank Western Channel	25	0.72	3.3	0.75	0.73	-9.1	0.85
F252	Verdugo Wash	27	0.67	2.6	0.69	0.75	-19.9	0.75
11092450	LAR above Sepulveda	158	0.92	-2.9	0.92	0.86	-3.5	0.88
F300	LAR below Tujunga Wash	401	0.94	0.9	0.94	0.90	-14.4	0.91
F57C	LAR above Arroyo Seco	511	0.76	-9.7	0.76	0.92	13.8	0.94
F319	LAR below Wardlow Rd.	815	0.80	-11.9	0.81	0.90	-5.4	0.91

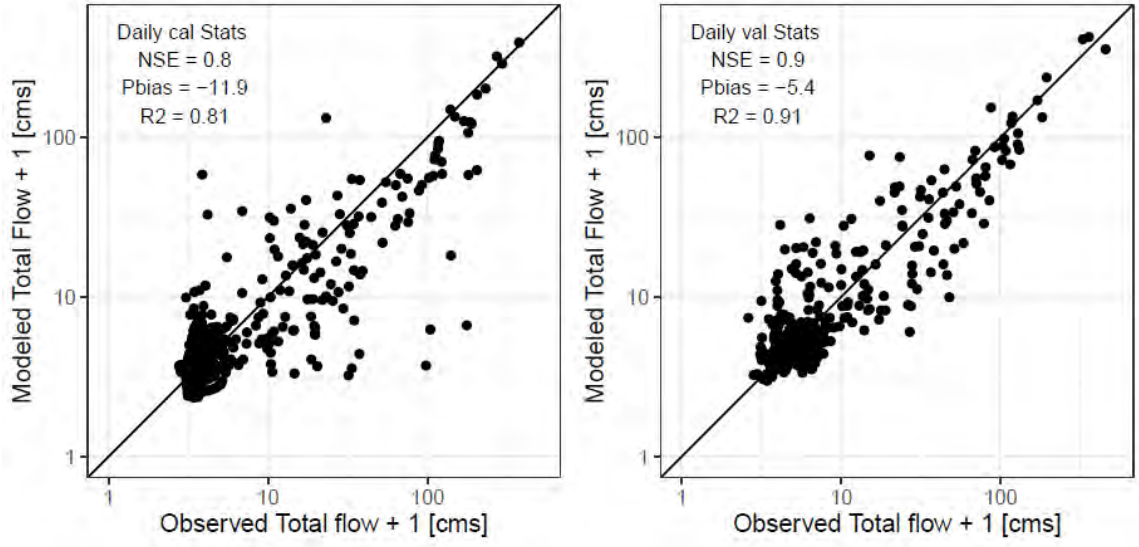


Figure 6. Calibration (left) and validation (right) performance of the SWMM hydrologic model at the LA County flow gage F319 (Los Angeles River below Wardlow Rd.).

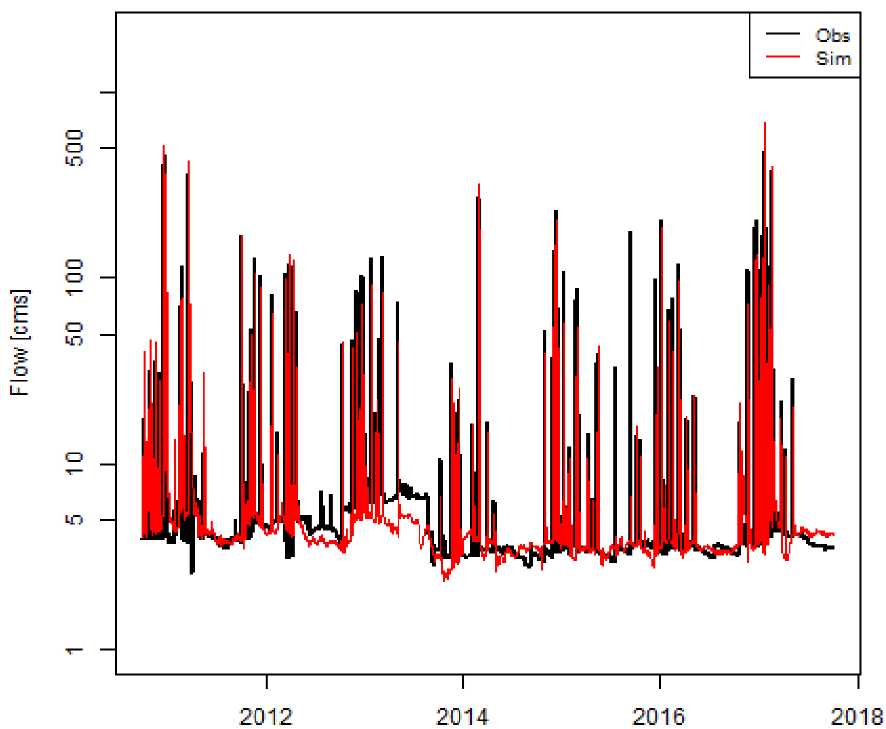


Figure 7. Observed (black) versus simulated (red) daily time series of flow in the Los Angeles River at Wardlow Road (LA County gage F319). Note discharge is reported on a log scale.

Baseline Hydrologic Conditions

Median annual non-storm flows in the mainstem of the Los Angeles River across all reporting nodes (Figure 1) range between 7.5 and 138 cfs. Non-storm flows are defined as any flows not generated by rainfall in the model. Non-storm flows in Compton Creek and Rio Hondo are minimal, with medians of 0 cfs and 0.05 cfs, respectively (Figure 8).

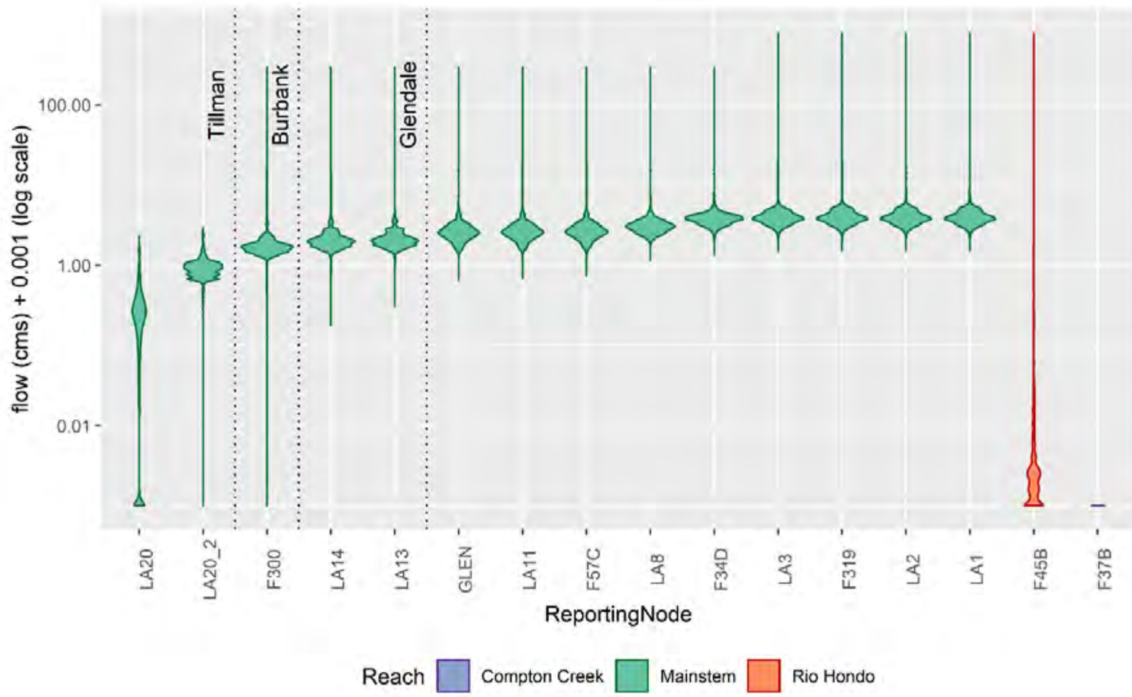


Figure 8. Violin plots of simulated non-storm discharge for the reporting nodes under baseline conditions. Gage F45B is on the Rio Hondo tributary. Gage F37B is on Compton Creek. Note the y-axis is a log scale.

Flow was summarized using a series of 24 functional flow metrics that are used to quantify aspects of the annual hydrograph that support a broad suite of ecological functions. These metrics aggregate flow data into five flow components representing different aspects of the annual hydrograph. Ranges of values for the 24 functional flow metrics can be used to determine the degree to which each flow component is able to support characteristic biological communities (see Appendix A for additional background on functional flows and all calculated flow metric values). Wet season (base flows from the start of the storm season to the start of the dry season) and dry season (base flows from the start of the dry season to the start of the following wet season) metrics are calculated on an annual basis. Typically, the start of the wet season is between November to January and the start of the dry season is between May to July depending on the climatic conditions for a given water year. Calculated ranges for the wet season and dry season baseflow metrics increase downstream of the three water reclamation plants, illustrating the contributions of discharges from the water reclamation plants (Figure 9 and Figure 10). The broader ranges and higher values of wet season baseflow metrics reflects the contribution of residual stormdrain discharge following storm events. Rio Hondo and Compton Creek both have the lowest wet season and dry season baseflow magnitudes compared to all other reporting nodes on the mainstem.

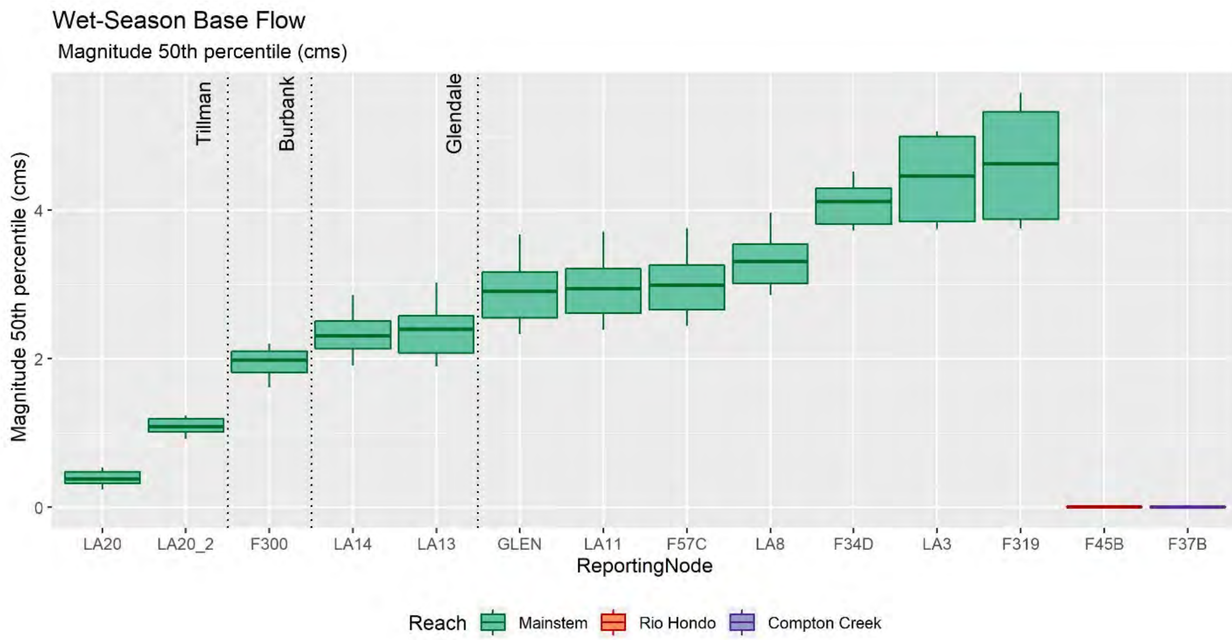


Figure 9. 50th percentile wet-season baseflow as determined from the functional flows calculator. Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10th and above the 90th percentile are not shown.

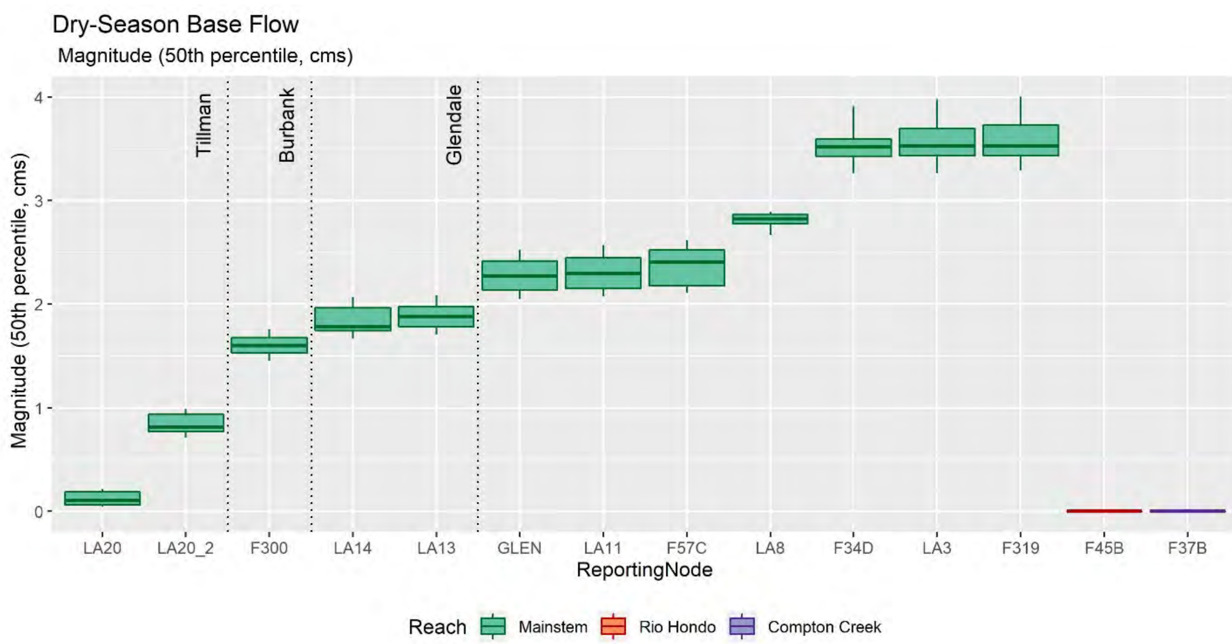


Figure 10. 50th percentile dry-season baseflow, as determined by the functional flows calculator. Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10th and above the 90th percentile are not shown.

Hydraulic Model

Existing 1-D HEC-RAS models were compiled from various sources (U.S. Army Corps of Engineers 2004; Environmental Science Associates 2018; HDR CDM 2011; U.S. Army Corps of Engineers 2005) and then the channel geometry was validated with LiDAR data, as-builts, and Google Earth to ensure that it included the low-flow channel. The stitched existing models were expanded to include Sepulveda Basin and upper Rio Hondo using LiDAR data; the model domain is shown in Figure 4. The model includes about 3,000 nodes over both channelized and soft-bottomed portions of the Los Angeles River between the estuary and Sepulveda Dam, Compton Creek, and Rio Hondo up to Whittier Narrows Dam. Manning's roughness coefficient (n) for concrete was determined by calibrating simulated maximum channel depth to observed channel depth at USGS gage 11102300 (Rio Hondo below Whittier Narrows Dam). The optimal Manning's n of 0.017 (Root-Mean-Square-Error = 0.081 ft, Nash Sutcliffe Efficiency (NSE) = 0.998) was used for concrete sections throughout the river system. Manning's n for soft-bottom reaches were updated in sections of the model where observational data was collected from field surveys (see below).

The model was run for flows ranging from 0.1 cfs to 150,000 cfs, depending on the reach. See Table 3 for maximum flows for each reach; for low flows, simulated results were considered unreliable if the predicted depth was less than 0.1 ft due to the inherent uncertainty of the model at this resolution. The maximum flows were set based on where the flow exceeded the banks, with a maximum cutoff of 150,000 cfs. Rating curve functions were created based on the model outputs for maximum channel depth, average velocity, shear stress (calculated by HEC-RAS as a function of hydraulic channel radius and slope), and stream power (calculated by HEC-RAS as a function of average velocity and average shear stress).

For each variable, rating curve functions were determined based on a least-squares fit. In many cases, the hydraulic behavior in lower and higher flows were substantially different, so low and high flows were fit with curves separately and joined at a specified threshold. An example comparison of the function fit to the model output is shown in Figure 11. In that example, the threshold was set at 1,000 cfs to best fit the slightly different curve shapes that can be seen above and below the threshold. Once the rating curve functions were generated, they were used to predict hydraulic behavior for the baseline flow timeseries and the flow scenarios.

Note that the hydraulic model is being refined in Sepulveda Basin (node LA20_2) and in the tidal reach (nodes LA1 and LA2) so results for these nodes are not included in this report.

Table 3. Maximum flow rates used to develop rating curves at each reporting node.

Node	**Maximum flow (cfs)**	**Maximum flow (cms)**
F319	150,000	4,248
LA3	52,500	1,487
F34D	150,000	4,248
LA8	150,000	4,248
F57C	150,000	4,248
LA11	150,000	4,248
GLEN	150,000	4,248
LA13	150,000	4,248
LA14	46,500	1,317
F300	40,500	1,147
LA20_2	52,500	1,487
LA20	34,600	980
F37B	12,000	340
F45B	50,000	1,416
11101250	760	22

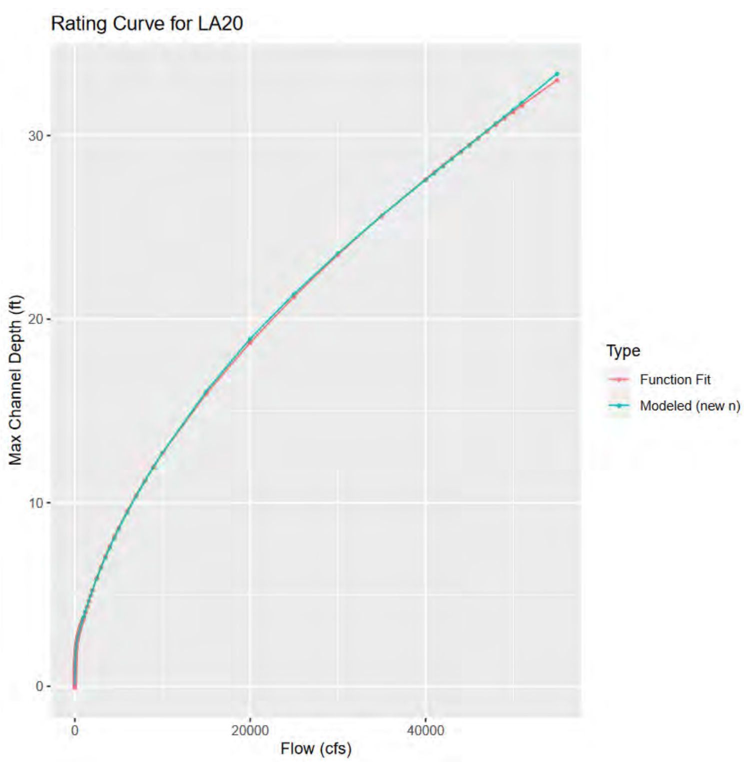


Figure 11. Example rating curve function. The low-flow/high-flow threshold for this node is 1,000 cfs.

Soft-bottom reach characterization

A detailed cross-sectional analysis of soft-bottom channel geometry was conducted to characterize the representative stream habitat features (i.e., pools, split channels, depositional islands, side channels, floodplains) in each of the soft-bottom reaches of the mainstem and Compton Creek. The goal of this analysis was to qualitatively and semi-quantitively describe the microhabitats observed in the Long Beach estuary, Glendale Narrows, Compton Creek, and Sepulveda Basin to ensure that the selected model output nodes were representative of conditions in each reach. Channel hydraulics (i.e., maximum channel depth, velocity, and shear stress) can vastly differ across different sections of the channel at a single site. For every soft-bottom output node in the HEC-RAS model, three output locations were selected at the three most significant morphological zones to capture the variability in hydraulics for each node and were designated as left overbank (LOB), center channel (Main), and right overbank (ROB). Note that these results are derived from a one-dimensional model and may differ from a fully resolved two-dimensional model. Due to this limitation, we cannot fully capture the hydraulics of certain microhabitat features including edgewater conditions and vernal pools. Three laterally varying locations were selected for consistency between cross sections and are not intended to represent all significant morphologic and hydraulic variation. See Figure 12 for an example of how cross sections were sub-divided.

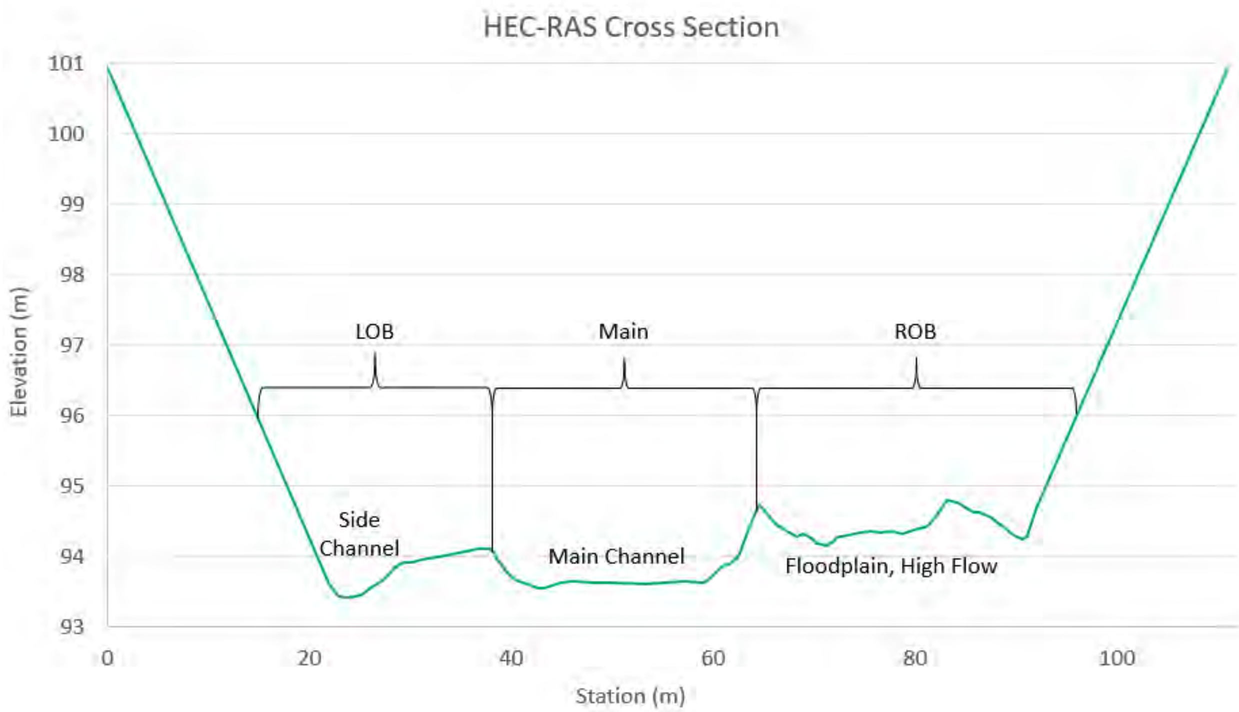


Figure 12. Illustration of a soft-bottom cross section and how the channel was split up to get hydraulic outputs in three locations: the side channel (LOB), main channel (Main), and high flow floodplain (ROB).

Additionally, a field survey was conducted in July 2020 to validate channel geometry in the soft-bottom reaches and provide additional details for the Sepulveda Basin model nodes. A total of six sites were surveyed including two soft-bottom cross sections in Sepulveda Basin, one cross section upstream of Sepulveda Dam, and three in Glendale Narrows (Figure 13). The average width of the active channel within the concrete banks surveyed in Sepulveda Basin was 28 m and average channel depth of the active channel was 3.1 m. For Glendale Narrows, two sites had split channels with widths ranging from 33 m to 12 m at the time of survey, and the average depth of the split channels was 0.9 m. The third site in Glendale Narrows had a uniform, flat and wide bed with a v-shaped concrete side channel. The entire channel bed from concrete wall to concrete wall was 60.5 m wide and the v-shaped inset channel was 0.77 m deep and 7 m wide. Field surveys in Glendale Narrows indicated that channel geometry in the existing HEC-RAS model matched fairly well with the channel geometry observed in July 2020 (Figure 14). In Sepulveda Basin, the field survey indicated that the LiDAR data (Los Angeles County Public Works) does not penetrate through the water surface and does not fully characterize the bathymetry of the main channel (Figure 15). The model was updated with the field-surveyed geometry. The field survey in Sepulveda Basin was challenging due to dense vegetation and errors in the GPS in certain areas, deep water depths, and limited access due to steep erodible slopes and homeless encampments. Additional field surveys are warranted to further characterize the channel geometry in Sepulveda Basin.

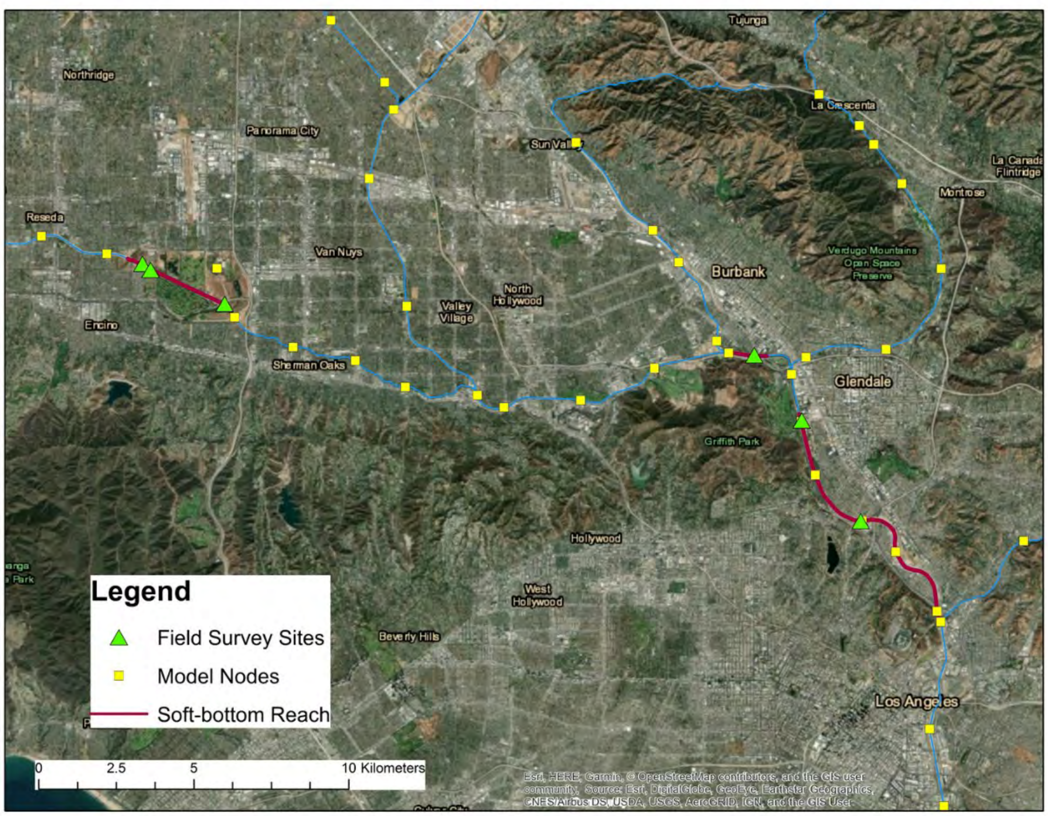


Figure 13. Cross sectional survey locations in the soft-bottom reaches of Sepulveda Basin and Glendale Narrows conducted in July 2020.

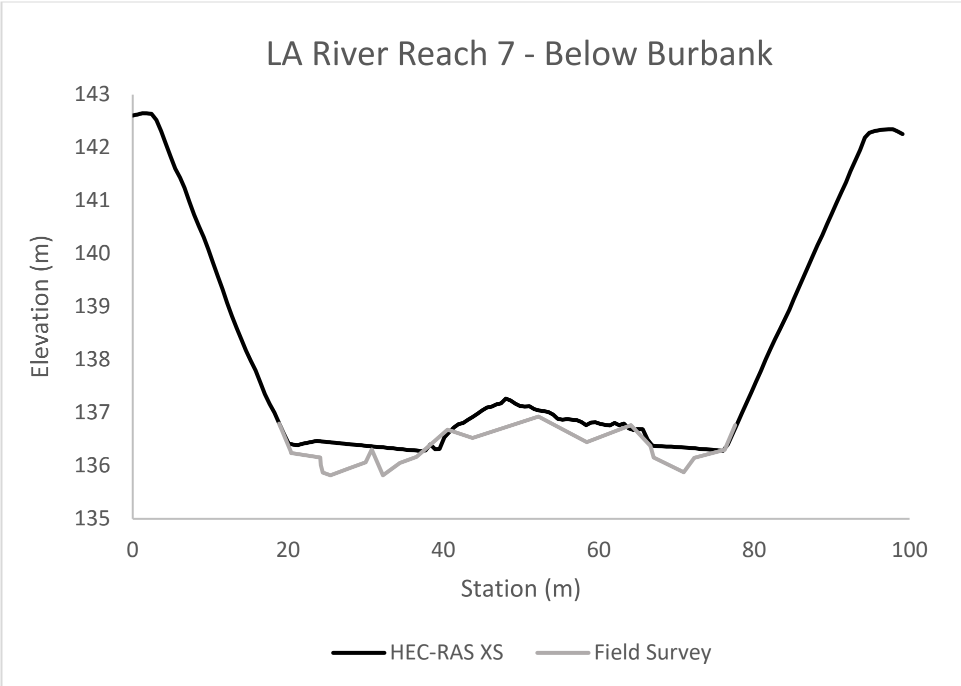


Figure 14. Representative cross section comparison from the soft-bottom LA River Reach 7, upstream Glendale Narrows, below Burbank WRP. The HEC-RAS cross section matched the surveyed cross section well, validating the channel geometry used in the HEC-RAS model.

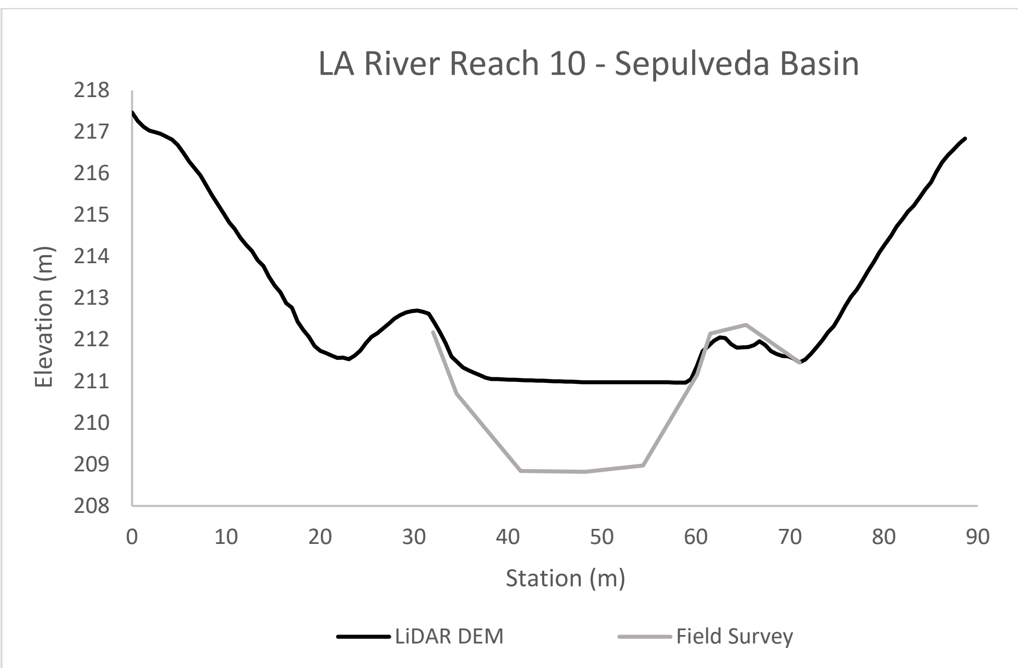


Figure 15. Representative cross section from Sepulveda Basin, soft-bottom LA River Reach 10. Field survey indicates that the LiDAR-DEM does not penetrate the water surface and does not fully characterize the bathymetry of the main channel.

Baseline Hydraulic Conditions

Maximum channel depths are generally less than 0.3 m (1 ft) over the range of modeled flows with depth generally increasing downstream. Channel depths in lower Rio Hondo and Compton Creek are generally an order of magnitude less than in the mainstem (Figure 16). Similar spatial patterns are observed for velocity (Figure 17) and shear stress (Figure 18).

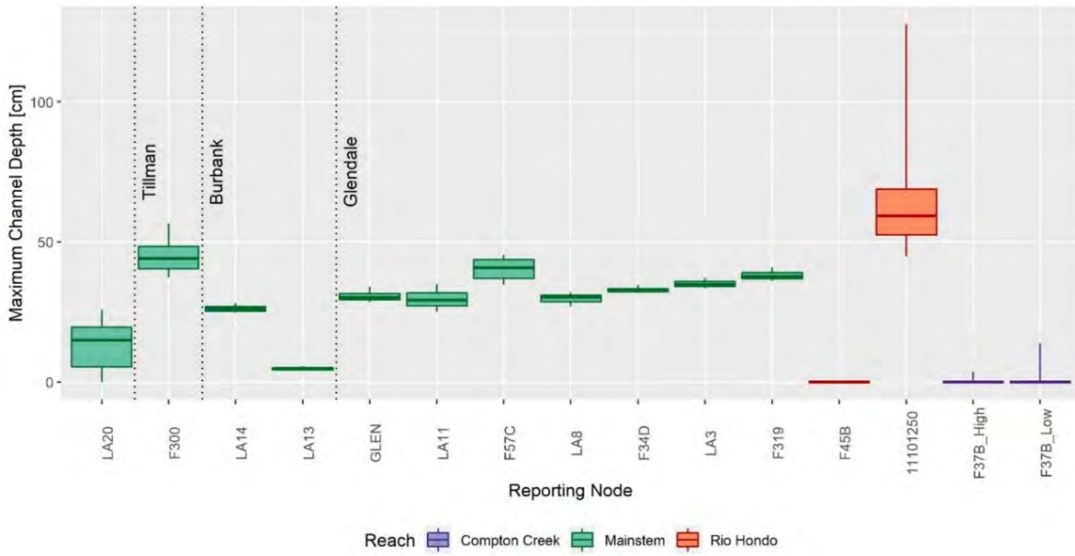


Figure 16. Box plots of maximum channel hourly depths as simulated by the HEC-RAS model. Midline of the box represents the median of observed values; bottom and top of the box represent the 25th and 75th percentiles, respectively. Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10th and above the 90th percentile are not shown.

Figure 17. Box plots of main channel hourly average velocity as simulated by the HEC-RAS model. Midline of the box represents the median of observed values; bottom and top of the box represent the 25th and 75th percentiles, respectively. Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10th and above the 90th percentile are not shown.

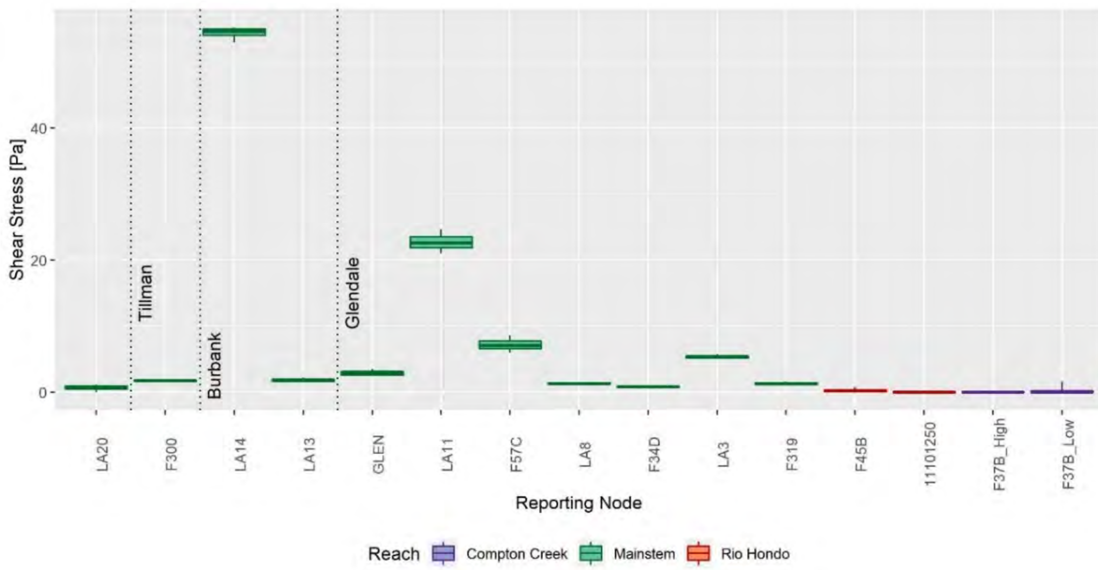


Figure 18. Box plots of main channel hourly shear stress as simulated by the HEC-RAS model. Midline of the box represents the median of observed values; bottom and top of the box represent the 25th and 75th percentiles, respectively. Bottom and top whiskers represent the 10th and 90th percentiles, respectively. Data below the 10th and above the 90th percentile are not shown. Note the y-axis is a log scale.

Temperature Model

Temperature effects the occurrence of many aquatic species in addition to flow. Because treated effluent is typically warmer than ambient water temperature, it is important to assess how changes in effluent discharge may affect in-stream temperature and in turn the probability of occurrence of focal species. To help answer this question, we simulated river temperature using the mechanistic model, i-Tree Cool River (Abdi and Endreny 2019; Abdi et al. 2020a, 2020b). The model applies the standard advection, dispersion, reaction equation coupled with the HEC-RAS (USACE 2016) model outputs of water surface profiles to simulate river water temperature. The model considers a combination of heat balance parameters, acquired from different sources including longwave and shortwave radiation, latent heat, sensible heat, and sediment heat (Figure 19). We added a retention time parameter to the model equations to allow us to apply velocity and discharge data from the HEC-RAS model. We also updated the i-Tree Cool River model to use a time series of sediment temperature data in place of fixed values to capture the diurnal effect of substrate temperature on the heat budget during the low flow periods.

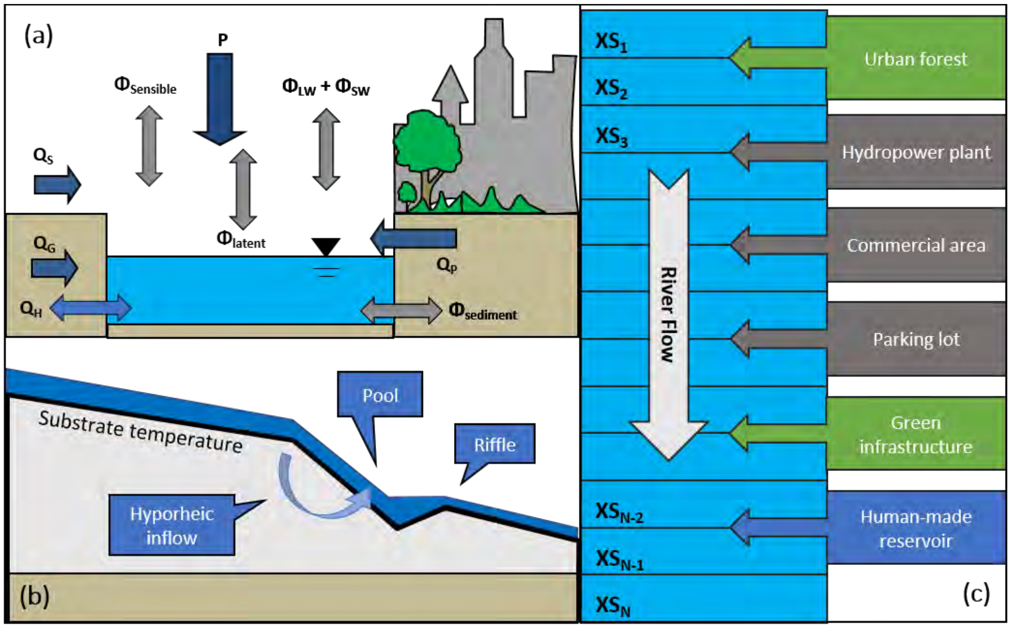


Figure 19. Schematic of the i-Tree Cool River model: (a) River cross-section view, demonstrating the energy and water balances. In this figure, P represents precipitation, and Q_S, Q_G, and Q_P represent the surface flow, groundwater flow, and pipe flow, respectively. Φ is the heat flux, and subscripts $_{LW}$ is longwave radiation flux, $_{SW}$ is shortwave radiation flux, $_{latent}$ is latent heat flux, $_{sensible}$ is sensible heat flux, and $_{sediment}$ is bed sediment heat flux; (b) River longitudinal section for a riffle-pool bedform. The hyporheic inflow pathways around the riffle-pool and substrate temperature are shown in the panel; and (c) River plan view demonstrating the potential lateral inflows that can be added to the river flow in either dry or wet weather. XS represents the cross-section of the river reach.

Calibration and Validation

As the initial step in simulating river temperature, we calibrated and validated the baseline river temperature model for Compton Creek during both the low flow and high flow periods. We selected two time periods, June 5 to September 5, 2016, and January 10 to April 10, 2016, for low flow and high flow simulations, respectively. Considering solar radiation data and sediment temperature and assuming that there was no subsurface inflow due to the concrete bedform, we calibrated the i-Tree Cool River model in low flow condition with an R^2 of 0.71 for the observed temperatures and the reach-averaged simulated temperatures. The validation R^2 for the low flow using the varying sediment temperatures was 0.68. The calibration and validation R^2 values in the high flow period were 0.86 and 0.78 respectively. For the high flow condition, we applied all the possible modification options on the simulations including sediment temperature, cloudiness, shade effect, and solar radiation. Variations in the simulated river temperature were negligible, suggesting that in high flow conditions, the thermal impact from the upstream boundary in Compton Creek was dominant and the only way of modifying temperature was by changing inflow temperatures at the upstream boundary condition by applying management scenarios on the exterior floodplain in the upstream area. Given that the mentioned stressors weren't effective on high flow condition in the Compton Creek, low flow periods were determined to have a more important role for habitat modeling.

Baseline Temperature Conditions

Both observed and simulated river temperature variations are available for the LA River's mainstem and its major tributaries (Figure 20). Observed baseline data for the monitoring reaches in LA River and Compton Creek is available from Mongolo et al. (2017) (see Table 4 for the statistical details of the monitoring stations on the mainstem).

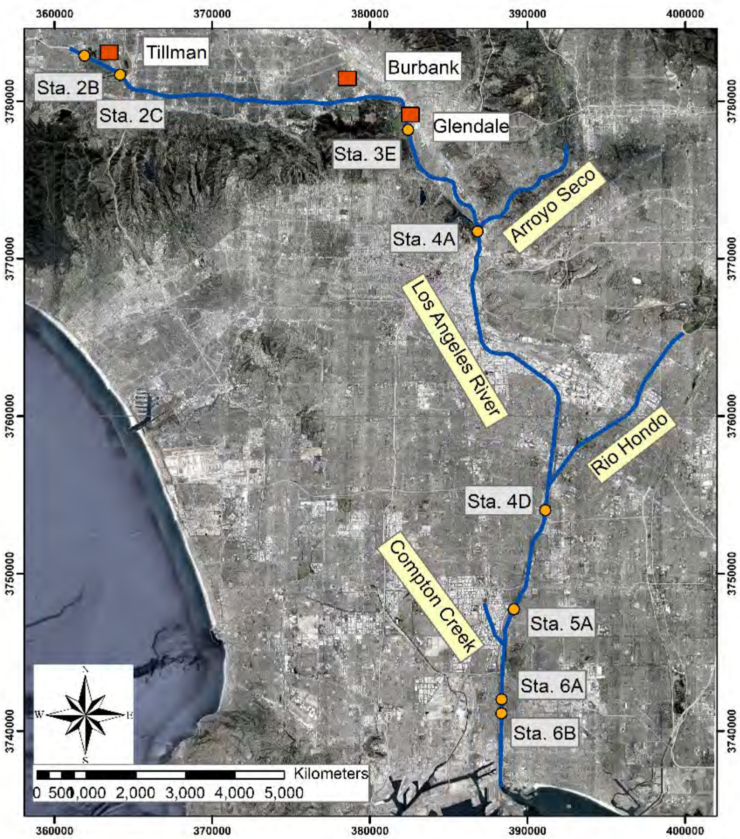


Figure 20. River temperature monitoring stations on LA River's mainstem for May to October 2016 obtained from Mongolo et al. (2017).

Table 4. Statistical properties of the monitored river temperature data by Mongolo et al. (2017) on LA River's mainstem (℃).

	2B	2C	3E	4A	4D	5A	6A	6B
mean	25.7	26.8	25.5	26.5	25.4	25.5	24.6	26.9
std	1.8	1.6	5.1	2.8	4.9	4.9	2.9	3.2
min	21.3	22.9	17.1	20.0	17.2	16.7	20.9	21.4
25%	24.6	25.8	21.3	24.6	21.7	21.6	22.5	24.3
50%	26.2	27.0	24.1	26.2	23.8	24.4	23.6	26.4
75%	27.1	28.1	30.0	28.7	29.5	30.0	26.0	29.1
max	28.4	29.9	36.9	33.1	35.7	35.6	34.1	34.4

The i-Tree Cool River model was applied to LA River's mainstem (downstream of the Arroyo Seco confluence), and its two major tributaries, Compton Creek and Rio Hondo. Calibration and validation results for these segments are presented in Table 5 and Figure 21 through Figure 25. In general, the model performed better in the concrete sections than the vegetated reaches, e.g., Glendale Narrows and Sepulveda Basin, likely because the model has difficulty simulating complex interactions with vegetation. There is more model scatter in the mid temperature ranges; however, since the biological models are most concerned with the extreme ends of the range, this is acceptable. We didn't include the results for the stations 6A and 6B as these two stations are close to the estuary and affected by the tidal impacts which will be modeled separately.

Table 5. Calibration and validation results (%pbias and R^2) for the LA River and its two major tributaries, Compton Creek and Rio Hondo based on the reach averaged values.

	Sta. 2C (Upper LA River)		**Sta. 3E (Upper LA River)**		**Sta. 4A (Upper LA River)**		**Sta. 4D (Lower LA River)**	
	Calibration	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**	**Calibration**	**Validation**
Simulation period	6/05 - 6/30	7/01 - 8/17	6/05 – 6/30	7/01 - 8/17	6/05 – 6/30	7/01 - 8/17	6/10 - 6/30	7/01 - 7/18
Avg. Observed	26.5	28.1	25.2	26.7	26.2	26.8	24.5	26.5
Avg. Simulated	26.9	28.4	25.0	25.0	25.3	25.5	25.8	26.6
∆T sim. - Obs.	0.4	0.3	-0.2	-1.7	-0.9	-1.3	1.3	0.1
%pbias	1.5	1.2	-0.4	-6.5	-3.5	-5.0	5.3	0.05
R^2	0.68	0.68	0.51	0.42	0.65	0.63	0.57	0.79

	Sta. 5A (Lower LA River)		**Compton Creek**		**Rio Hondo**	
	Calibration	**Calibration**	**Calibration**	**Validation**	**Calibration**	**Validation**
Simulation period	6/10 - 6/30	6/10 - 6/30	6/05 - 7/31	8/01 - 9/16	6/05 - 7/31	8/01 - 9/16
Avg. Observed	24.5	24.5	21.1	21.2	21.1	18.9
Avg. Simulated	25.7	25.7	21.5	21.5	21.5	18.6
∆T sim. - Obs.	1.2	1.2	0.4	0.3	0.4	0.3
%pbias	4.8	4.8	1.5	1.2	1.5	1.9
R^2	0.55	0.74	0.73	0.60	0.75	0.70

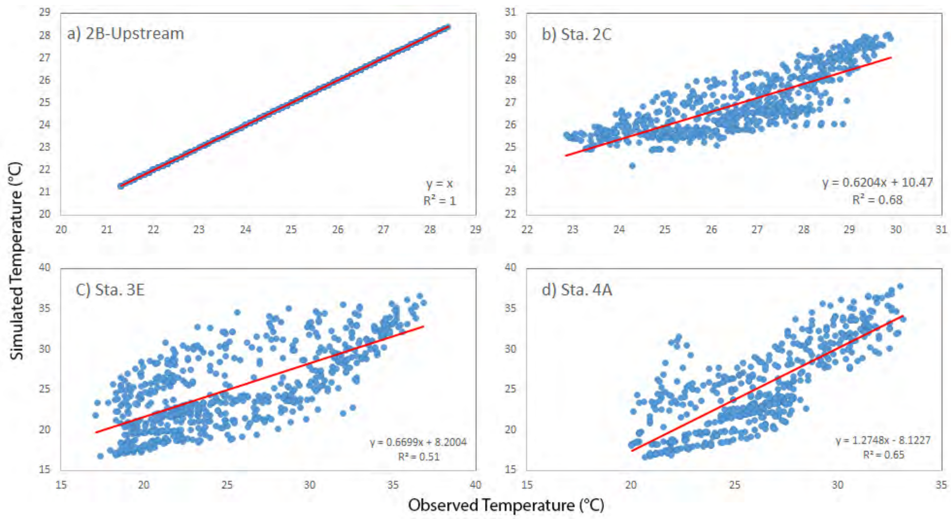


Figure 21. Scatter plots displaying the calibration of the LA River's upper segment (from upstream of Tillman WRP to the Arroyo Seco confluence) including the station 2B as the upstream boundary condition station (a), station 2C, immediately downstream of the Tillman WRP (b), station 3E in the downstream of the Glendale WRP (c), and station 4A in the downstream of the Glendale Narrows soft bottom (d). The R^2 value of 1 for the panels (a) indicates that there was no computation instability in the simulation process.

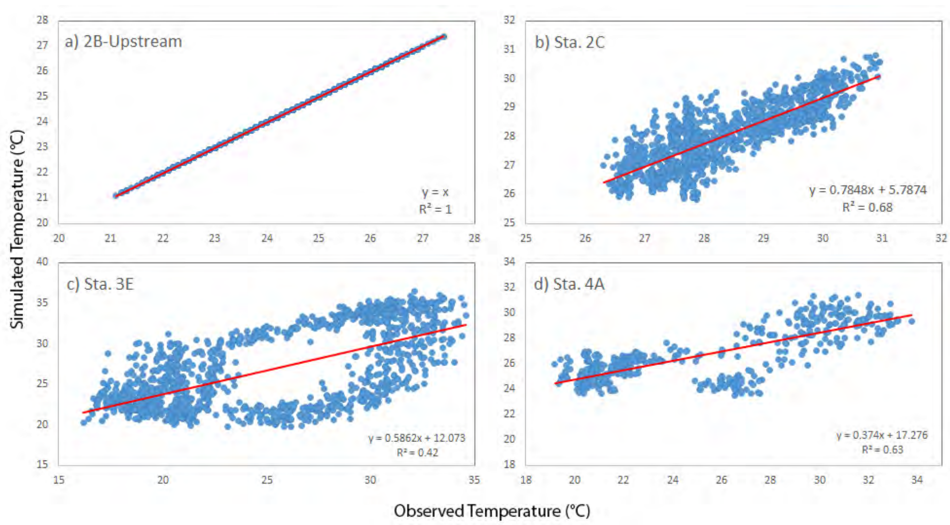


Figure 22. Scatter plots displaying the validation of the LA River's upper segment (from upstream of Tillman WRP to the Arroyo Seco confluence) including the station 2B as the upstream boundary condition station (a), station 2C, immediately downstream of the Tillman WRP (b), station 3E in the downstream of the Glendale WRP (c), and station 4A in the downstream of the Glendale Narrows soft bottom (c).

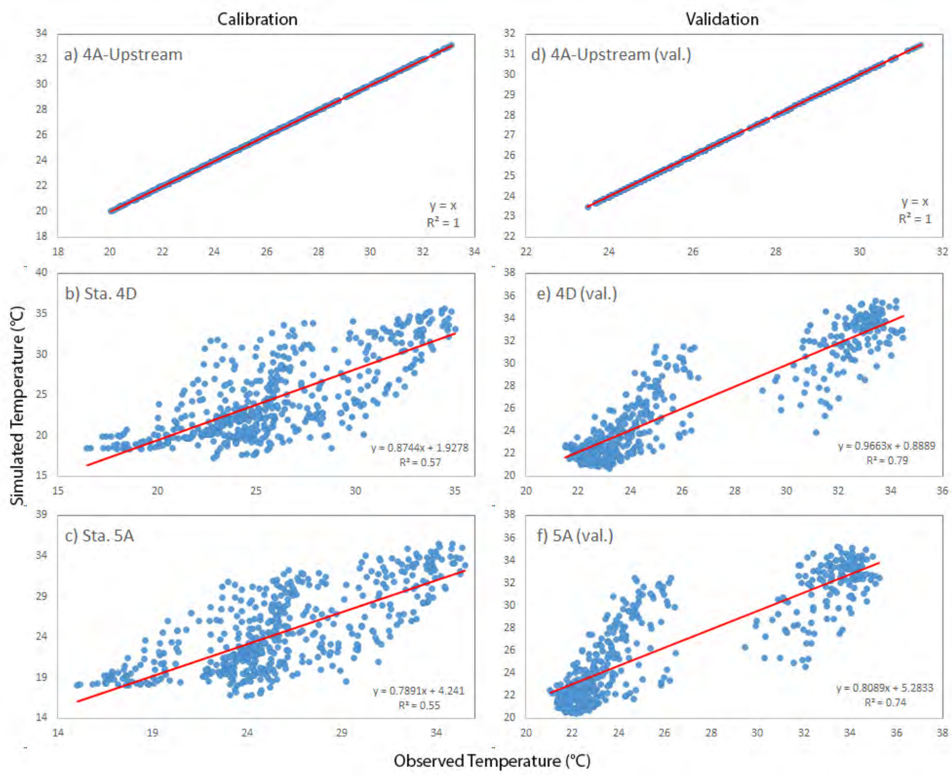


Figure 23. Scatter plots displaying the calibration and validation process for the LA River's lower segment (from Arroyo Seco confluence to the downstream of the Compton Creek confluence) including the station 4A as the upstream boundary condition station (a and d), station 4D, after the Rio Hondo tributary confluence (b and e), and station 5A before the Compton Creek confluence.

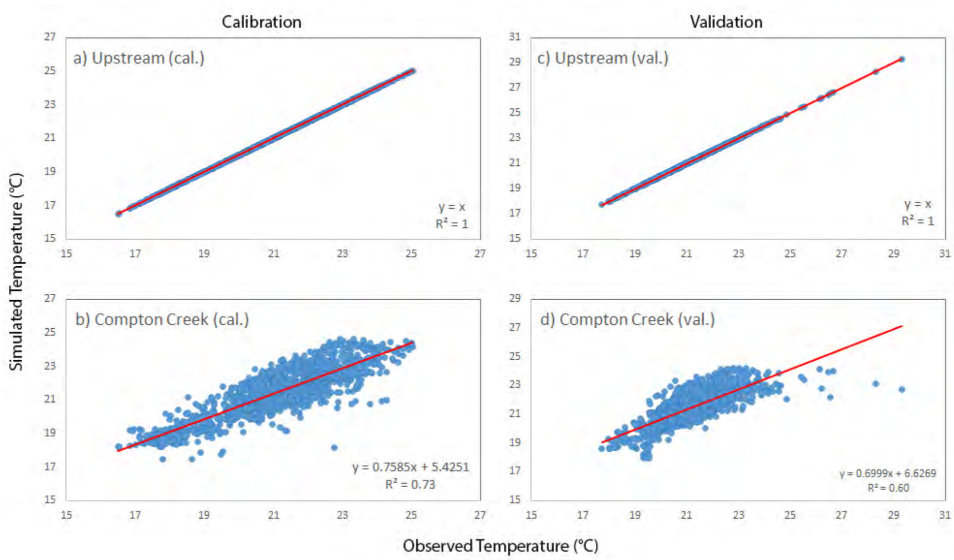


Figure 24. Scatter plots displaying the calibration and validation process of the river temperature simulation for the Compton Creek in the upstream boundary condition monitoring station (a and c) and reach averaged values (b and d).

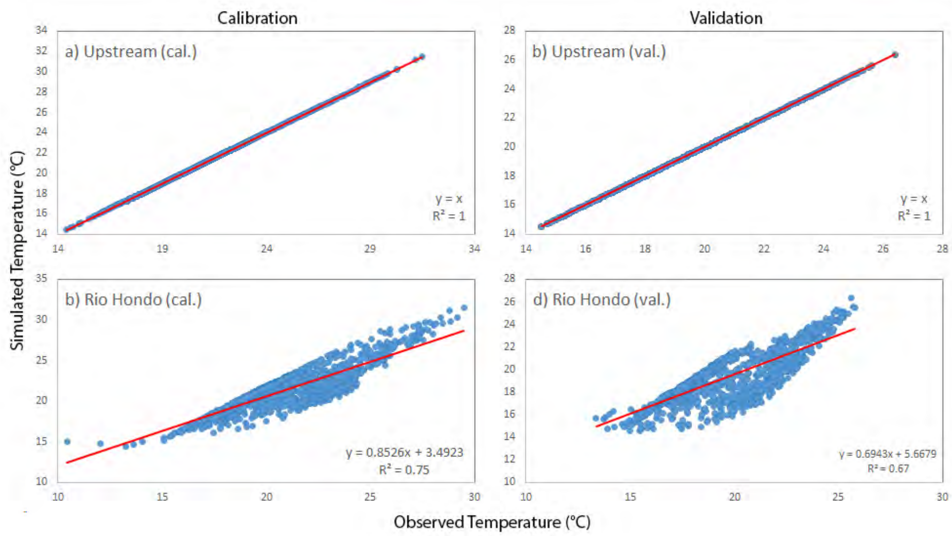


Figure 25. Scatter plots displaying the calibration and validation process of the river temperature simulation for the Rio Hondo in the upstream boundary condition monitoring station (a and c) and reach averaged values (b and d).

We also considered the following ecologically relevant temperature metrics for assessing our simulations (see Figure 26):

- Maximum Weekly Maximum Temperature (MaxWMT)
- Maximum Weekly Average Temperature (MaxWAT)
- Minimum Weekly Minimum Temperature (MinWMT)

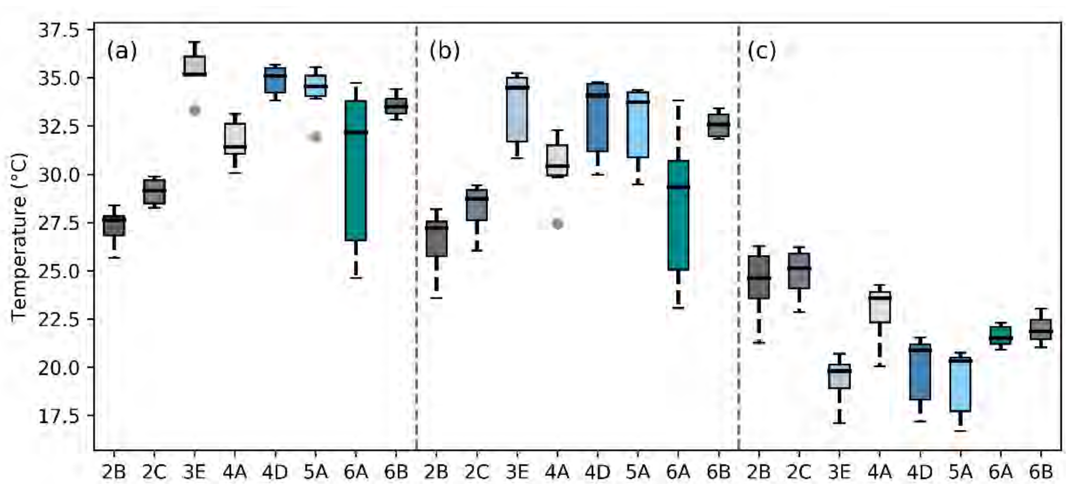


Figure 26. Box plots of the observed data showing the variation of the calculated metrics for the base case with no treatment. The figure shows the box plots for three metrics MaxWMT (a), MaxWAT (b), and MinWMT (c).

The baseline medians of the MaxWMT, MaxWAT, and MinWMT metrics for the LA Rivers two monitoring stations in the lower segment as well as Compton Creek, and Rio Hondo tributaries are shown in Table 6.

Table 6. Ecologically relevant thermal metrics for the LA River and its two major tributaries, Compton Creek and Rio Hondo based on the validation process based on the reach averaged values.

Monitoring station	Temperature (C)	MaxWMT	MaxWAT	MinWMT
Station 2C	Observed	30.8	30.0	26.0
(Upper LA River)	Simulated	30.8	30.3	26.3
	∆T (Sim. – Obs.; |% to obs.|)	0.8 (2.6%)	0.3 (1%)	0.3 (1.1%)
Station 3E	Observed	36.5	35.3	19.9
(Upper LA River)	Simulated	34.5	33.3	18.4
	∆T (Sim. – Obs.; |% to obs.|)	-2 (5.4%)	-1.8 (5.1%)	-1.5 (-7.5%)
Station 4A	Observed	31.4	31.0	23.4
(Upper LA River)	Simulated	33.7	32.6	19.2
	∆T (Sim. – Obs.; |% to obs.|)	2.3 (7.3%)	1.6 (5.1%)	-4.2 (17.9%)
Station 4D	Observed	34.7	34.2	21.1
(lower LA River)	Simulated	34.0	33.5	21.9
	∆T (Sim. – Obs.; |% to obs.|)	-0.7 (2%)	-0.7 (2.0%)	0.8 (3.8%)
Station 5A	Observed	34.4	33.9	20.7
(lower LA River)	Simulated	34.7	34.2	21.5
	∆T (Sim. – Obs.; |% to obs.|)	0.3 (0.9%)	0.3 (0.9%)	0.8 (3.9%)
Compton Creek	Observed	24.9	22.8	20.0
	Simulated	23.8	22.9	20.2
	∆T (Sim. – Obs.; |% to obs.|)	-1.1 (4.4%)	0.1 (0.5%)	0.2 (1%)
Rio Hondo	Observed	26.3	23.7	13.3
	Simulated	25.8	24.3	11.8
	∆T (Sim. – Obs.; |% to obs.|)	-0.5 (1.9%)	0.6 (2.5%)	-1.5 (11.2%)

To simulate water temperature in the reporting nodes for the rest of the 2016 year, where observed data was not available, we developed and trained a multilayer linear regression machine learning algorithm. We used Google's TensorFlow and Keras packages on Python 3 for the process. Using this method, we predicted upstream river temperature boundary conditions and used the mechanistic water temperature model to propagate the upstream boundary condition temperature downstream. For the model training process, we used the hourly observed temperature data obtained from Mongolo et al. (2017) as the dependent variable and hourly air temperature, relative humidity, wind speed, and station pressure parameters as the independent (predictor) variables. Based on the watershed domain on mechanistic river temperature model, we predicted water temperature in 4 stations including: 1) Upstream of the Tillman WRP, 2) Downstream of the LA River and Arroyo Seco confluence, 3) Upstream of the Compton Creek tributary, and 4) Upstream of the Rio Hondo tributary. We used 80% of the observed data for the training process and 20% of the observed data for the testing. For the training process, we used the weather data from the Burbank Airport weather station and National Renewable Energy Laboratory's (NREL) National Solar Radiation Database (NSRDB; Sengupta et al. 2018). Table 7 shows the results for the loss function we calculated based on the mean absolute error and Figure 27 shows the variation of the mean absolute error in 100 iterations of running the machine learning algorithm in the training phase.

Table 7. The mean absolute error values for the upstream stations of the river reaches on LA River watershed.

	Upper LA River	Lower LA River	Compton Creek	Rio Hondo
Mean absolute error (℃)	1.8	1.7	0.9	1.0

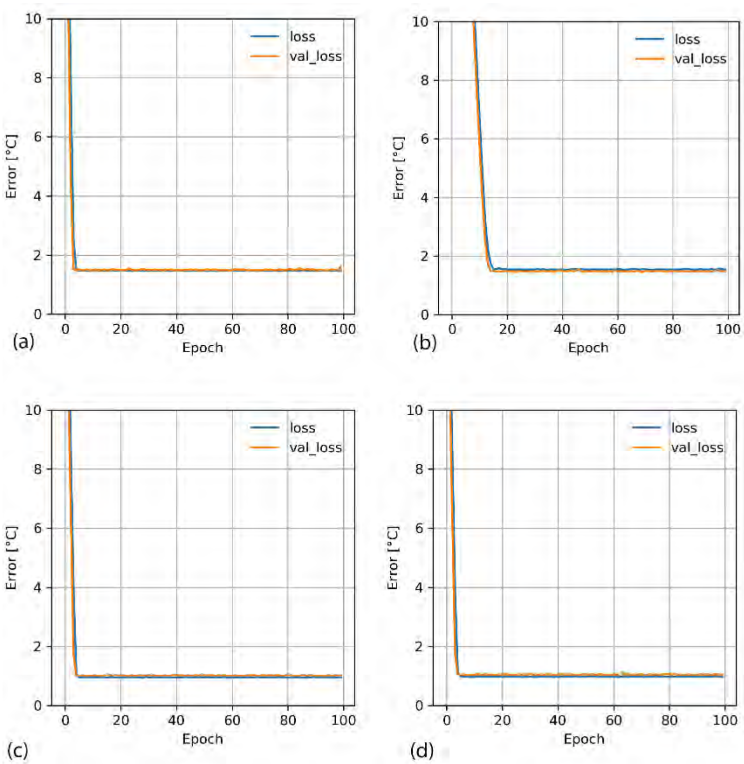


Figure 27. Loss function variation based on the mean absolute error (℃) parameter for the trained reaches a) Upper LA River, b) Lower LA River, c) Compton Creek, and d) Rio Hondo. The figure shows the variation of the mean absolute error for the training and validation datasets.

We simulated the river temperature based on the trained and tested multilayer linear regression machine learning algorithm for hourly time steps. Figure 28 shows the portion of the year 2016 our simulations were based on observed and predicted boundary conditions. As presented in the previous section, the simulated river temperatures in the dry weather of 2016 (the thermally critical period) were based on observed data.

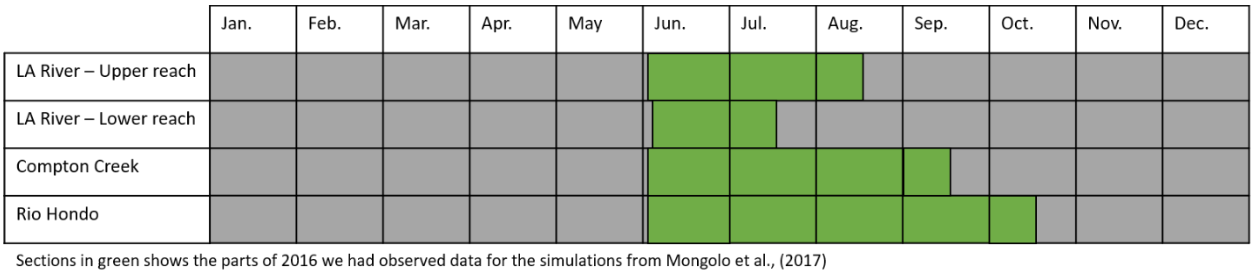


Figure 28. Distribution of the observed and machine learning-based predicted boundary conditions for water temperature mechanistic model in the year 2016 for the 4 reaches of the project domain.

We simulated water temperature in daily time steps for 2016 using the mechanistic model based on the upstream water temperature boundary conditions obtained from a machine learning algorithm. The results then were combined with the simulated water temperature for the determined reporting nodes altogether made daily water temperature time series for the reporting nodes (Figure 29). The results showed generally average water temperature in the main stem was almost 20% warmer (23.5℃ compared to 19℃) than the studied tributaries. One reason could be the warm water temperature releases from the WRPs throughout the year. For example, the annual average of effluent from the Tillman WRP was 26.1℃ in 2016. There was a 2.8℃ (11%) change moving from LA River’s soft bottom (F57C) to the hard bottom downstream (LA8). Part of this warming in the water temperature could be because of the cooling impact of the upwelling in the Glendale Narrows soft bottom and part of that could be an urban warming impact, as Station LA8 is located close to downtown LA and phenazones like urban heat island could impact water temperature in this area.

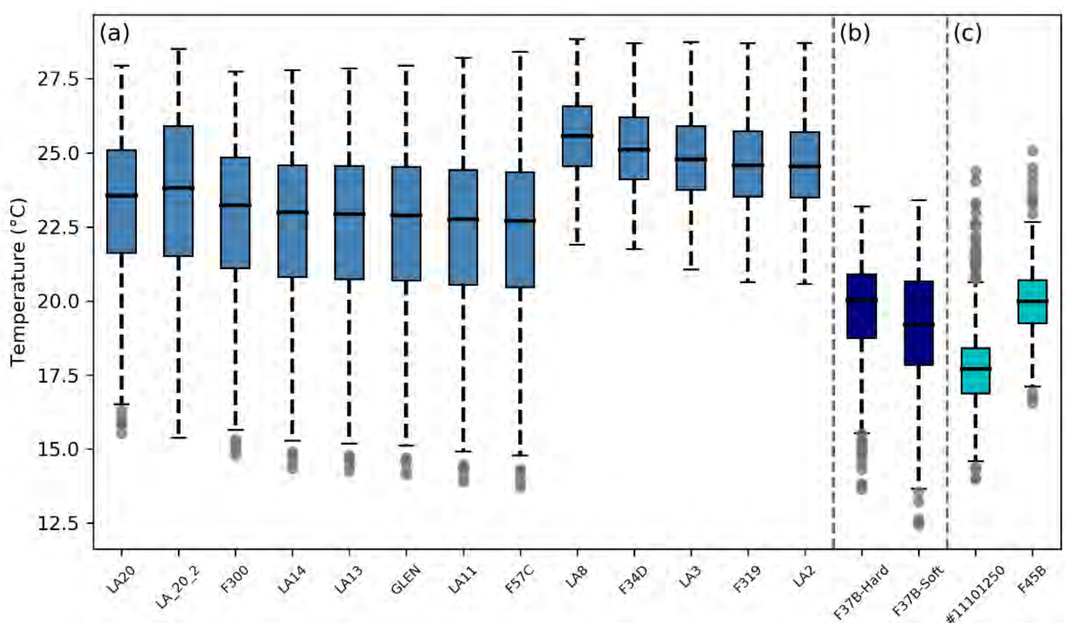


Figure 29. Boxplots show the variation of the simulated daily water temperature for the year 2016 in the LA River’s main stem (a), Compton Creek (b), and Rio Hondo (c).

Based on the simulated daily data, we calculated three thermal metrics (see the previous section for more details) for the reported nodes. The thermal matrices included 1) maximum weekly maximum temperature (MaxWMT), 2) maximum weekly average temperature (MaxWAT), and 3) minimum weekly minimum temperature (MinWMT). Table 8 shows the average values based on the data were calculated for the year 2016.

Table 8. Annual average temperatures for three calculated thermal metrics in the reporting nodes for the year 2016 (℃).

River reach	Reporting node	MaxWMT	MaxWAT	MinWMT
LA River main stem	LA20	24.8	23.2	21.6
	LA_20_2	25.0	23.6	22.1
	F300	24.3	22.7	21.1
	LA14	24.1	22.5	20.8
	LA13	24.0	22.4	20.7
	GLEN	24.0	22.4	20.7
	LA11	23.9	22.3	20.6
	F57C	23.9	22.2	20.5
	LA8	26.6	25.6	24.6
	F34D	26.2	25.1	24.2
	LA3	25.9	24.8	23.8
	F319	25.7	24.6	23.6
	LA2	25.7	24.6	23.5
Compton Creek	F37B-Hard	20.7	19.6	18.5
	F37B-Soft	20.1	19.0	17.9
Rio Hondo	#11101250	18.7	17.9	17.0
	F45B	20.7	20.0	19.2

Water Quality Assessment

Changes in discharge of stormwater and treated wastewater effluent can affect instream water quality by either reducing contaminant loading or altering concentrations through changes in dilution. Changes in concentration of water quality constituents can influence achievement of water quality targets and may affect habitat suitability for focal species through either toxicological response or changes in conductivity. Current water quality conditions were assessed using local water quality observations. Seven tributaries and all six reaches of the main stem in the Los Angeles River watershed are listed on the 303(d) list. Total maximum daily loads (TMDLs) for dry and wet weather days were established to meet water quality targets. Dry weather and wet weather days are defined by the maximum daily flow located at Wardlow (F319). The threshold for a dry vs wet weather day is 500 cfs. Established TMDLs in the Los Angeles River watershed include trash, metals, nitrogen-based nutrients, and bacteria. While copper and lead have dry weather TMDL locations throughout the Los Angeles River watershed zinc has only one established dry weather TMDL location, Rio Hondo. Numeric targets for copper and lead range from 12.5 ug/L to 125.97 ug/L and 37 ug/L to 170 ug/L, respectively. The zinc dry weather numeric target at Rio Hondo is 131 ug/L. Copper, lead, and zinc have one established wet weather TMDL located at Wardlow. The numeric target for copper, lead, and zinc are 67.49 ug/L, 84 ug/L, and 159 ug/L, respectively.

Water Quality data

The study focused on the following water quality parameters: total and dissolved copper, total and dissolved lead, total and dissolved zinc, total suspended solids, and specific conductance. Observed water quality data were collected from the California Environmental Data Exchange Network (CEDEN), Mass Emissions (ME) Stations, Los Angeles River Watershed Monitoring

Program (LARWMP), and Municipal Separate Storm Sewer System (MS4) Reports. The data were compiled into a single database and cleaned by combining similar values in each field and removing unusable records in R Studio (R Core Team 2020). Any samples recorded outside of the watershed boundary were removed. Detected samples make up 89% of the cleaned database while non-detect (ND) and detected, not quantified (DNQ) samples, or censored data, make up 10%. Roughly 1% of samples are not recorded and are consequently removed. ND and DNQ samples in the database indicate that the concentrations fall somewhere between 0 and the reporting limit or the method detection limit. The data from the database spans from the years 2000 through 2019. Due to recent regulatory requirements requiring additional monitoring, 79% of the data spans between 2015 through 2019 and 21% spans between 2000 through 2014. Figure 30 and Figure 31 below shows the number of observations for each constituent and data source in the database. Total suspended solids (TSS) have the most observation between constituents and MS4 data have the most observations between data sources. The database is used to determine the observed water quality baseline.

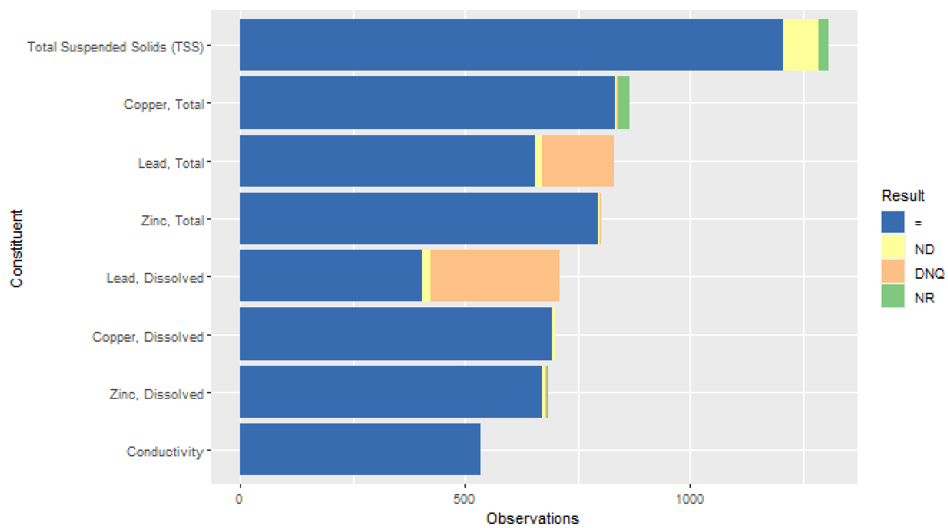


Figure 30. Bar plot summarizing the number of observations for each constituent. The equal sign stands for detected samples, ND stands for non-detects, DNQ stands for detected but not quantifiable, and NR stands for not recorded.

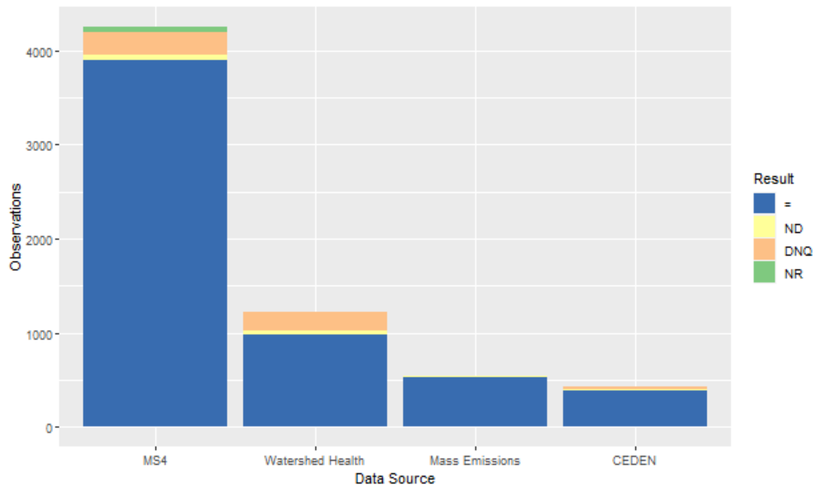


Figure 31. Bar plot summarizing the number of observations for each data source.

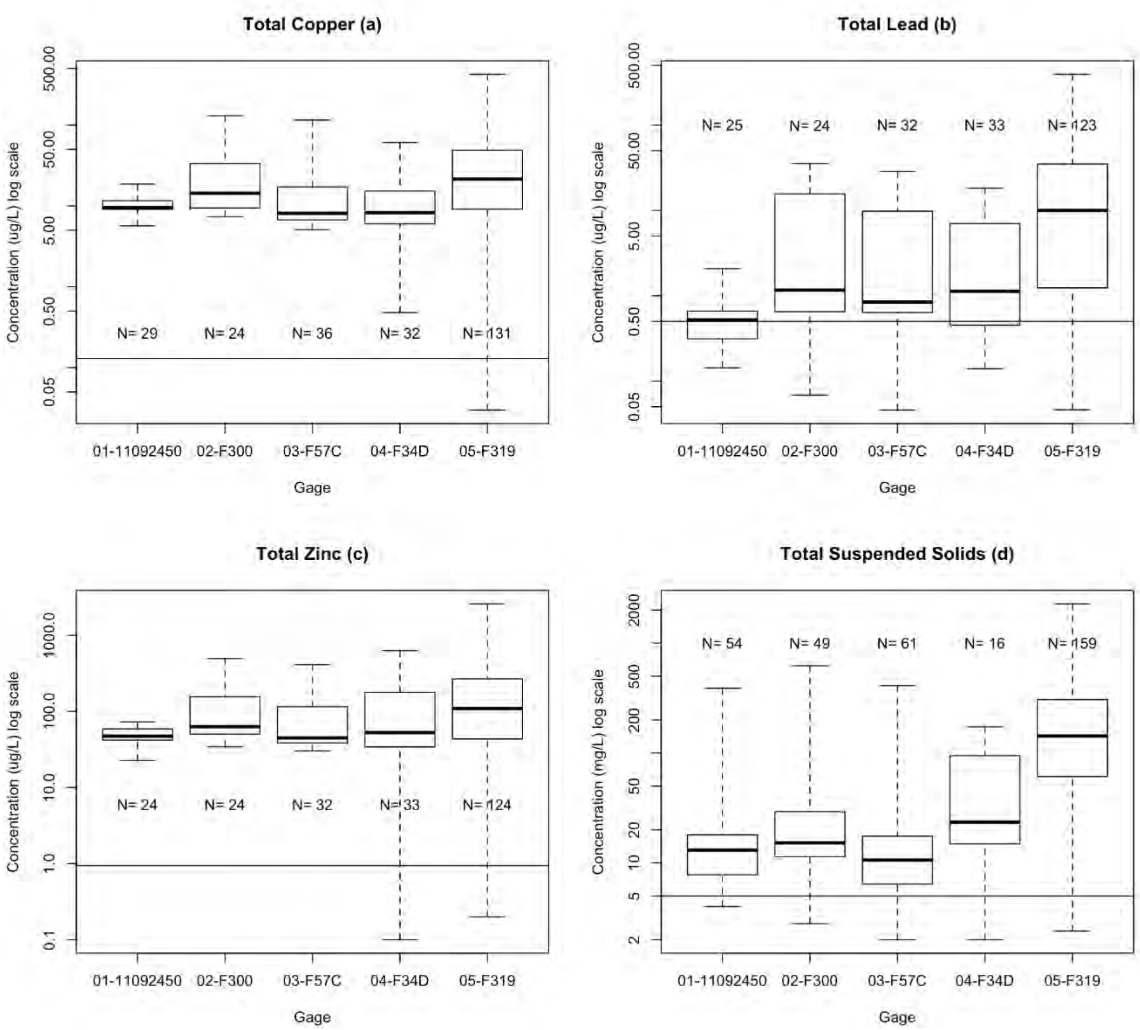
Observed Water Quality Baseline Conditions

To establish a reliable water quality baseline with NDs and DNQs, statistical methods laid out in *Statistics for Censored Environmental Data Using Minitab® and R* are used (Helsel 2012). The parameters and their corresponding median, minimum, and maximum concentrations are presented in Table 9. Summary statistics and EPA aquatic life criteria in LAR mainstem. Total and dissolved lead have the lowest median concentrations for the metal parameters at 1.7 and 0.33 ug/L, respectively. Total and dissolved zinc have the highest median concentrations for the metal parameters at 63 and 39 ug/L. Total zinc and TSS have the highest range between their median and maximum concentrations, suggesting that these parameters vary the greatest within the watershed. The spatial boxplots for the main LAR stem in Figure 32 (a-h), created using statistical methods by Helsel (2012) to include ND and DNQ data, show the largest concentration distribution at gage F319 at Wardlow. Gages correspond to the gage locations on Figure 1. The large distribution of data is likely due to the amount of monitoring in that location. Dissolved lead concentrations were 100% DNQ samples (n=13) at gage 11092450 near Tillman WRP, so data cannot be estimated at that location. The median concentrations are generally higher at Wardlow for every constituent, indicating that concentration increases near the estuary of the channel. Total lead and total suspended solids present the clearest trend of increasing concentration upstream to downstream. Specific conductance is the exception, where the median measurements decrease as they are transported downstream.

Table 9. Summary statistics and EPA aquatic life criteria in LAR mainstem.

Analyte	Median	Minimum	Maximum	Unit	Acute	Chronic
Copper, Dissolved	7.27	0.01	155	µg/L	NA	NA
Copper, Total	11.45	0.01	424	µg/L	NA	NA
Lead, Dissolved	0.342	0.01	88	µg/L	65	2.5
Lead, Total	1.44	0.01	393	µg/L	NA	NA
Total Suspended Solids (TSS)	29.3	0.50	2280	mg/L	NA	NA
Zinc, Dissolved	38.5	0.02	988	µg/L	120	120
Zinc, Total	63.1	0.02	2590	µg/L	NA	NA
Specific Conductance	33.5	947	1450	uS/cm	NA	NA

The EPA aquatic life criteria values for both acute and chronic levels for dissolved lead and dissolved zinc are also presented in Table 9 (U.S. Environmental Protection Agency 2019). The median is below the acute and chronic criteria for dissolved lead and zinc, but in both cases the maximum concentrations exceed the acute and chronic levels. In the spatial boxplots in Figure 32, some high dissolved lead (f) concentrations exceed the chronic aquatic life criteria at gages F300 (near Tujunga Avenue) and F319 (near Wardlow Street). The concentrations are below the acute criteria except for one outlier event at F319. Dissolved zinc maximum concentrations (c) exceed the acute and chronic criteria levels at F34D (near Rio Hondo confluence) and F319.



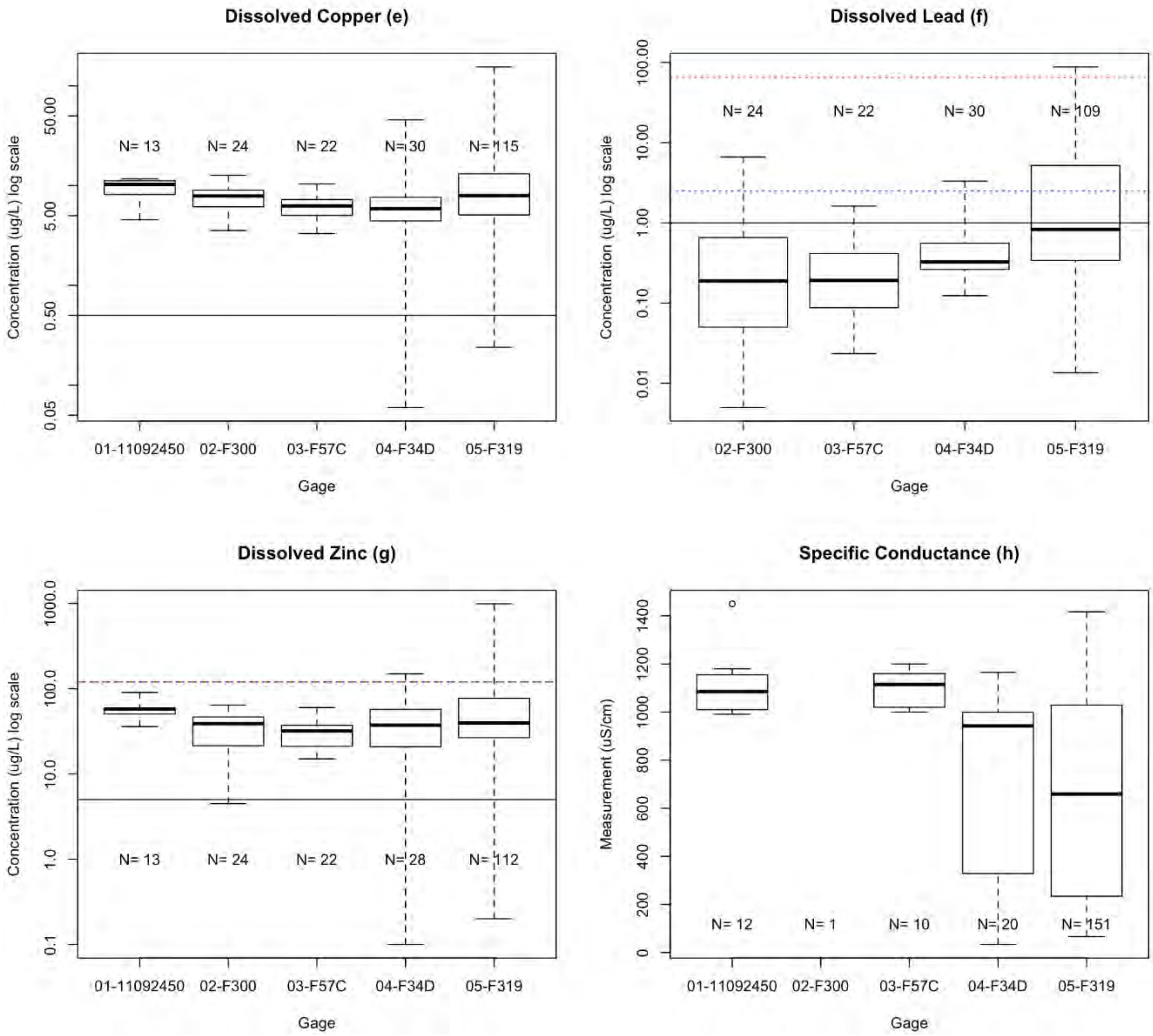


Figure 32. Censored boxplots of each gage on the LAR mainstem, upstream (11092450 at Sepulveda) to downstream (F319 at Wardlow) (a-h). A black horizontal line is drawn at the highest reporting limit to indicate that distributions below this line are estimated based on the ND and DNQ values. The red dotted lines on the boxplots for dissolved lead (f) and dissolved zinc (g) represent the acute and blue dotted lines represent chronic EPA aquatic life criteria values. The boxes represent the 25th percentile through the 75th percentile of the data and the whiskers represent the absolute minimum and maximum values. Note that (a-g) is on log scale.

EVALUATION OF ECOLOGICAL CONDITIONS

Overall Approach

For the purposes of this study, aquatic life beneficial uses in the LA River are being defined based on the ability of the river and its tributaries to support characteristic aquatic plant and animal communities. The overarching goal of this project is to consider potential effects of reduced WRP discharge and increased stormwater capture on existing and potential future beneficial uses. Therefore, our analysis included characterizing species and habitats that currently occur and those that could reasonably occur in the future (based on a comparison to similar southern California watersheds). Current beneficial use designations for the mainstem of the LA River, Compton Creek, and Rio Hondo are set forth in the *Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties*, adopted by the Los Angeles Regional Water Quality Control Board (Table 10). Our analysis focuses on the current beneficial uses but also considers support for species and habitats that are not currently supported in study area. The intent is to evaluate whether proposed management actions would influence flow conditions that could potentially support other beneficial uses in the future (e.g., COLD, MIGR), recognizing that there are many other factors that currently limit or preclude the ability to support these uses (e.g., channelization, lack of vegetative cover, lack of suitable substrate). The intent is not to propose management recommendations specifically aimed at supported species or habitats associated with beneficial uses not currently designated.

Table 10. Beneficial uses of the main stem of the LA River, Compton Creek, and Rio Hondo as set forth in the Los Angeles Region Basin Plan for the Coastal Watersheds of Los Angeles and Ventura Counties.

Waterbody	Beneficial Uses						
	WARM	EST	MAR	WILD	RARE	MIGR	SPWN
Estuary		E	E	E	Ee	Ef	Ef
Los Angeles River Reach 1	E		E	E	E	P	P
Compton	E			E			
Los Angeles River Reach 2	E			P			
Rio Hondo Reach 1	P			I			
Rio Hondo Reach 2	P			I			
Rio Hondo Reach 3	P			I	E		
Los Angeles River Reach 3	E			E			
Los Angeles River Reach 4	E			E			
Los Angeles River Reach 5	E			E			
Los Angeles River Reach 6	E			E			

E – Existing beneficial use
P – Potential beneficial use
I – Intermittent beneficial use
e – One or more rare species utilizes all ocean, bays, estuaries, and coastal wetlands for foraging and/or nesting.
f – Aquatic organisms utilize all bays, estuaries, lagoons, and coastal wetlands, to a certain extent, for spawning and early development. This may include migration into areas which are heavily influenced by freshwater inputs.

- **Warm Freshwater Habitat (WARM):** Uses of water that support warm water ecosystems including, but not limited to, preservation or enhancement of aquatic habitats, vegetation, fish, or wildlife, including invertebrates.
- **Estuarine Habitat (EST):** Uses of water that support estuarine ecosystems including, but not limited to, preservation or enhancement of estuarine habitats, vegetation, fish, shellfish, or wildlife (e.g., estuarine mammals, waterfowl, shorebirds).
- **Marine Habitat (MAR):** Uses of water that support marine ecosystems including, but not limited to, preservation or enhancement of marine habitats, vegetation such as kelp, fish, shellfish, or wildlife (e.g., marine mammals, shorebirds).
- **Wildlife Habitat (WILD):** Uses of water that support terrestrial ecosystems including, but not limited to, preservation and enhancement of terrestrial habitats, vegetation, wildlife (e.g., mammals, birds, reptiles, amphibians, invertebrates), or wildlife water and food sources.
- **Rare, Threatened, or Endangered Species (RARE):** Uses of water that support habitats necessary, at

least in part, for the survival and successful maintenance of plant or animal species established under state or federal law as rare, threatened, or endangered.

- **Migration of Aquatic Organisms (MIGR):** Uses of water that support habitats necessary for migration, acclimatization between fresh and salt water, or other temporary activities by aquatic organisms, such as anadromous fish.
- **Spawning, Reproduction, and/or Early Development (SPWN):** Uses of water that support high quality aquatic habitats suitable for reproduction and early development of fish.

The aquatic life use assessment began with a compilation of observational data from the LA River and surrounding watersheds, which, together with advice from the project's Technical Advisory Committee (TAC) and Stakeholder Working Group (SWG), was used to identify priority focal habitats and endmember species to represent a range of flow tolerances for each habitat. We then determined the conditions necessary to support the life history needs of each species and used those to create "flow-ecology" curves or models relating key hydrologic, hydraulic, and temperature variables to the probability of occurrence for each focal species, or the probably of being able to complete specific life-history requirements. Potential effects associated with changes in water quality conditions will be assessed in a subsequent phase of this project.

Characterization of Species and Habitats in the LA River

We compiled all readily available species and habitat data from a variety of sources, including surveys and species/habitat databases, to broadly characterize the ecology of the LA River. We mapped the habitat locations and species observations, compiled data on and mapped species that occur in each habitat, and identified endmember species that represent species that occur within the range of flow or temperature tolerances for each habitat. The choice of endmember species was coordinated and reviewed by the project's TAC and SWG.

Table 11. Biological data sources.

SPECIES
Center for Biological Diversity
California Natural Diversity Database (CNDDB)
Nature Conservancy/Aquarius/Nature Serve
USFWS – threatened and endangered species
eBird
Global Diversity Information Facility (GBIF)
HerpNET – Natural History Museums
iNaturalist
CDFW Wildlife Action Plan
Various species survey reports
HABITATS
Significant ecological areas
National wetlands inventory
California Native Plant Society
CalVeg

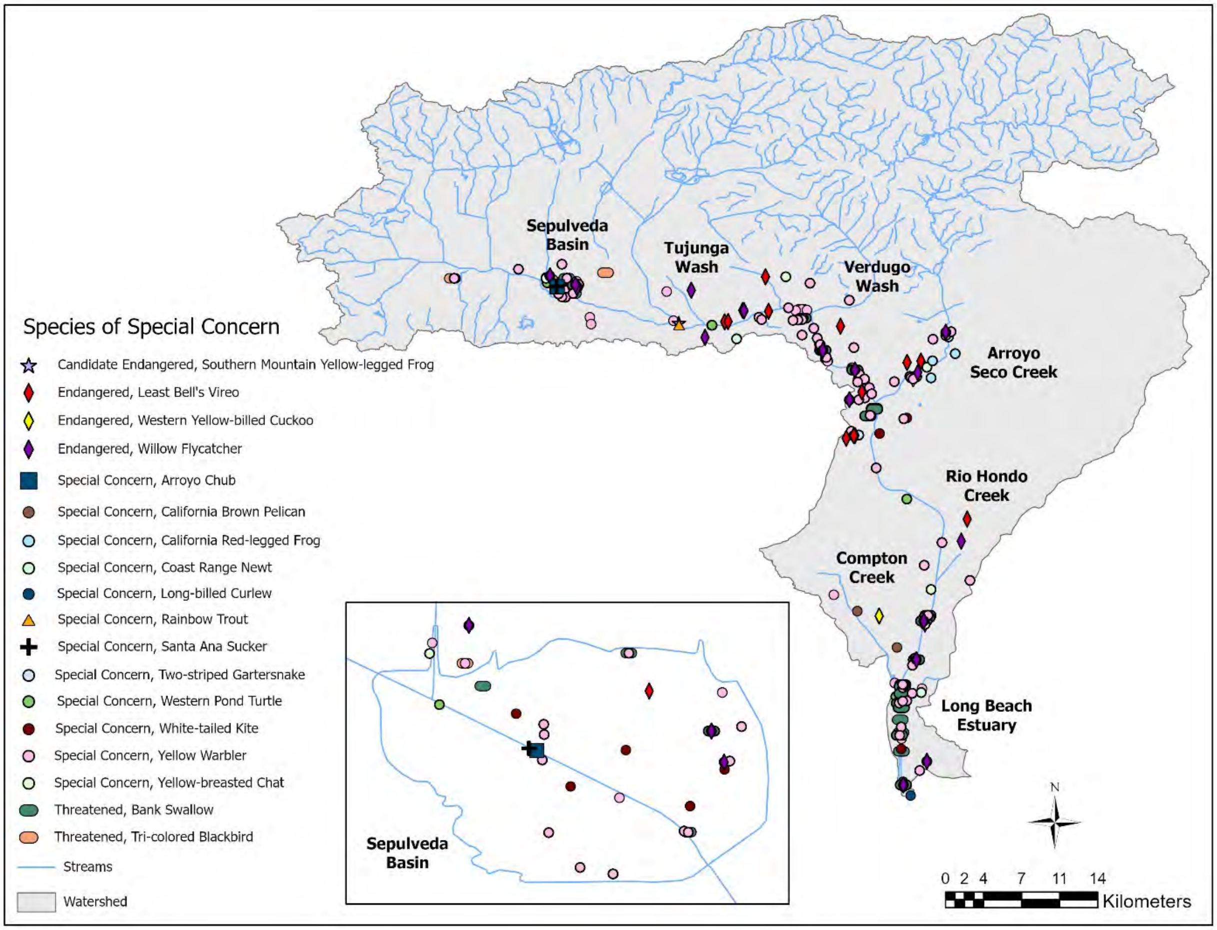


Figure 33. Species observations along the mainstem of the LA River and tributaries included in this study.

Selection of Endmember Species

To fully describe the study area, six representative habitats were chosen and defined in consultation with the TAC and SWG (Table 12). We mapped the potential habitats that are currently supported or could be supported in the future for every study reach along the LAR mainstem, Rio Hondo, and Compton Creek (Figure 34). Endmember species were selected to represent the range of flow tolerances for each habitat. The main criteria for species selection were:

- Present or potentially present in the study area
    - Observed within past ten years
    - Occur in comparable habitats in similar watersheds in the region
- Representative of the range of conditions within the habitat

- Representative of diversity of species
- Mix of sensitive and more common species
- Life history traits fairly well understood
- Dependent on aquatic habitats for key life history stages
- Sensitive to changes in flow, temperature, and hydraulics

Three of the habitats (cold water, freshwater marsh, and warm water) contain two endmember species chosen to represent the gradient of requirements of each habitat. For the migration, wading shorebird and riparian habitats, one endmember species was considered sufficient to depict these habitat gradients fully. For species and habitat information, we compiled all readily available data from surveys and species/habitat databases.

Table 12. Habitats and representative end member species. Shaded cells represent habitats and species not currently supported in the entire mainstem LA River, Compton Creek, or Rio Hondo.

<table>
<tr><th>Habitat</th><th>End member species</th><th>Description</th></tr>
<tr><td rowspan="2">Cold water habitat</td><td>Santa Ana Sucker</td><td rowspan="2">Not currently present</td></tr>
<tr><td>Unarmored threespine stickleback</td></tr>
<tr><td>Migration habitat</td><td>Steelhead/Rainbow trout</td><td>Currently, only designated for Reach 1. Overlays with other habitats</td></tr>
<tr><td>Wading shorebird habitat</td><td>Cladophora spp</td><td>Green algae to support prey of wading birds</td></tr>
<tr><td rowspan="2">Freshwater marsh habitat</td><td>Typha</td><td rowspan="3">Dominant plant species used to represent overall habitat</td></tr>
<tr><td>Duckweed</td></tr>
<tr><td>Riparian habitat</td><td>Black Willow</td></tr>
<tr><td rowspan="2">Warm water habitat</td><td>African clawed frog</td><td rowspan="2">Surrogate for invasive spp. habitat</td></tr>
<tr><td>Mosquitofish</td></tr>
</table>

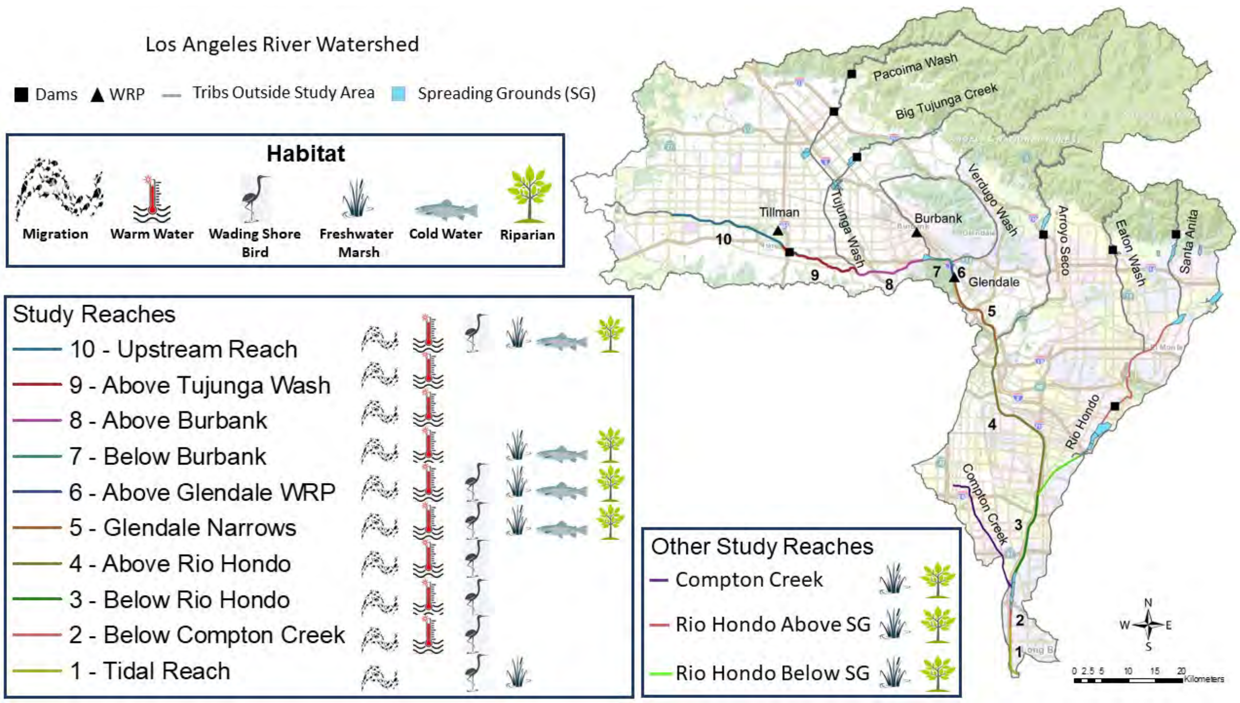


Figure 34. Map of study reaches with identified habitats that could potentially be supported in each reach.

Flow-ecology Relationships for Focal Species

Flow-ecology models were built for five of the nine endmember species. Four endmember species were not modeled for various reasons:

- <u>Unarmored threespine stickleback</u> – data on habitat requirements was not sufficiently different from the Santa Ana Sucker to allow development of a distinct model
- <u>Duckweed</u> – inclusion of this species does not provide additional relevant information than what is already included for Typha
- <u>African clawed frog and mosquitofish</u> – developing flow ecology relationships for these invasive species was difficult due to their broad habitat tolerances. Therefore, they were given a lower priority for inclusion in the analysis

The modeling approach varied by species, but all were used to evaluate the species ecological response to changes in flow. The aim is to apply the output data from the coupled SWMM-HEC-RAS model and i-Tree Cool River to each flow ecology relationship to assess the habitat suitability based on current conditions.

Summary of life history needs for each focal species

The individual life stages of a species often requires distinctive habitat. It is therefore important to consider the habitat needs of each life stage for a habitat to support a species successfully. For this reason, the response of species life stage to their environment were considered separately. Literature reviews for life stage habitat requirements were performed in two phases. The objective was to understand the life history of each species in relation to their habitat requirements and identify their tolerance to certain habitat variables. A summary of each species' life history needs, and tolerance limits is provided in Appendix B. We identified the most influential habitat variables (e.g., depth, velocity), and the knowledge gained was used to refine the literature search of phase two. We then compiled datasets describing species' occurrence in association with measured habitat variables. The data were obtained from a range of sources (survey reports, peer-reviewed journals, online databases) and included a variety of types (field surveys, observations, lab experiments).

Approaches to developing flow-ecology response relationships

The general approach for the response relationships between endmember species and habitat followed four stages:

1. Compile habitat requirements for life history phases
2. Coalesce available data for each life stage and habitat variable
3. Create species' habitat suitability curves: life stage ~ habitat variable
4. Apply management scenarios to response curves to estimate habitat suitability

The flow-ecology models were first developed conceptually for each species based on their habitat requirements and life stages. Data that describe life stage response to the identified habitat variables were compiled and cleaned. Habitat suitability curves for each species life stage were developed from the compiled data and the type of curve applied varied per species, depending on 1) the relationship of the life stage and habitat variable, and 2) the type of data available and means by which it was compiled. The goal of the species habitat suitability curves is to evaluate habitat conditions and associate those with hydrologic or hydraulic conditions that provide the greatest probability of occurrence of the end member species. An appropriate ecological response (e.g., probability of occurrence, probability of mortality/survival) for each species was determined depending on the species/life stage, data availability and type of relationship between life stage and habitat variable reported (e.g., biomass decline in response to increasing depth).

Flow-ecology relationships for endmember species associated with current beneficial uses

Goodding's black willow (Salix gooddingii)

Goodding's Black Willow (*Salix gooddingii*) are important riparian forest species found throughout western North America and native to California. They currently occur in some areas of the LA River including Sepulveda Basin and Glendale Narrows. Goodding's Black Willow was the focal willow species; however, due to data availability, related Salix species (e.g., *S. alba* and *S. viminali*, Appendix C) were, on occasion, used as a substitute. Three life stages were identified for the Willow, namely germination, seedling and adult, with three habitat variables: inundation/depth, shear stress and stream power (Table 13).

Due to the Willow's ecological response and hence the types of empirical data available, depth in the willow suitability model was used to describe inundation. Here, inundation is defined as surface water depth over time.

Inundation data for germination life stage was limited. Therefore, the following rules to describe inundation were applied over each year to determine suitability (Nakai and Kisanuki 2007):

1. IF depth exceeds 5 cm for less than 85 days, Unsuitable
2. IF depth exceeds 5 cm for greater than 280 days, Unsuitable
3. IF depth exceeds 5 cm for > 85 and < 280 days, Suitable

Seedling life stage was modeled with two hydraulic variables: inundation and shear stress. The relationship between willow seedling and inundation was produced using a linear model with a quadratic term (Figure 35). The probability of mortality was calculated from different water depths ranging from -20 cm (20 cm below surface) and 35 cm (35 cm above surface) that were collected from two sources (Tallent-Halsell and Walker 2002; Vandersande et al. 2001). These experimental studies reported the probability of mortality at depths over a duration of 58 days and 105 days, the latter reported 92% mortality in the first half of the experiment, i.e., 53 days, deeming both studies of approximate equal length. The resulting relationship illustrates that both very dry and very wet conditions can cause mortality.

The relationship between seedling mortality and shear stress was adapted from Pasquale et al. (2014; Figure 11a) and was calculated using a linear regression model (Figure 36).

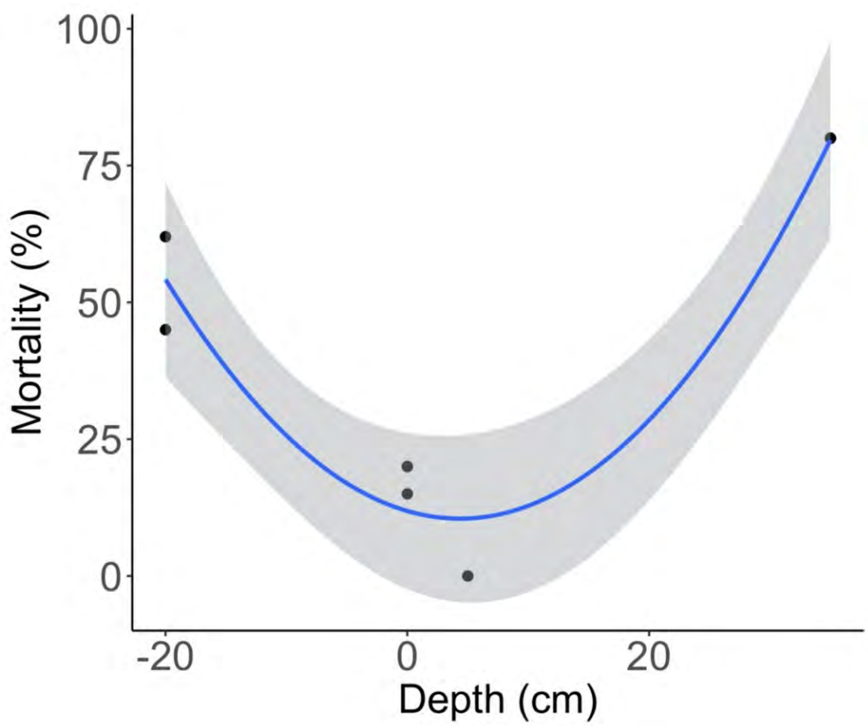


Figure 35. Habitat suitability curve of seedling mortality as a function of inundation/depth from water surface of Salix Gooddingii calculated through quadratic linear regression. Depth is defined as depth from surface i.e., -20 cm = 20 cm below surface, 20 cm = 20 cm above surface. Mean = 5 cm, p = 0.002, n=5.

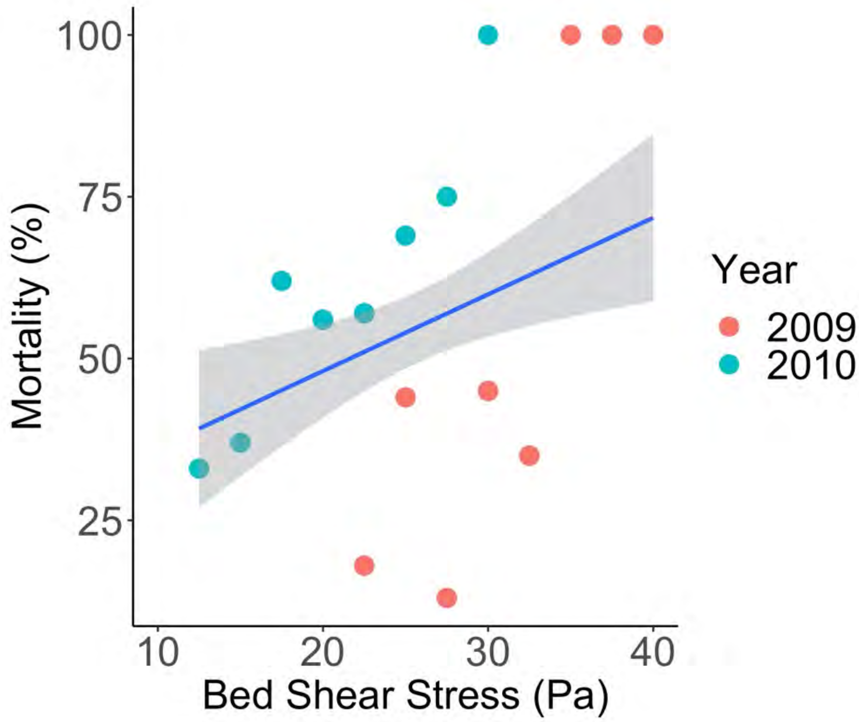


Figure 36. Habitat suitability curve of seedling mortality of Salix Gooddingii as a function of shear stress, calculated through linear regression. Mean = 25.3 Pa, p = 0.03, n = 58.

For adult willow, there was a lack of available data describing their response to hydraulic conditions. Therefore, we assigned a suitability threshold of stream power less than 4000 W/m^2 based on the analysis provided by Bendix (1999).

Table 13. Identified Willow life stage, habitat variables and model applied.

Life Stage	Habitat Variable	Model Component
Germination	Inundation/depth	Threshold
Seedling	Shear stress	Linear model
	Inundation/depth	Linear model with quadratic term
Adult	Stream Power	Threshold

Cattail Marsh (*Typha spp.*)

Typha spp are a riparian perennial reed species commonly found in lakes and freshwater marsh areas, important food source and habitat for many faunae. Data were collected on several species of *Typha* (Appendix C) of which three life stages were identified: seedling, germination and adult patch, with habitat variables: depth, velocity and temperature (Table 14).

Table 14. Identified *Typha spp* life stage, habitat variables and model applied.

Life Stage	Habitat Variable	Model Component
Seedling	Depth	Linear model with quadratic term
Germination	Temperature	Multivariate linear regression
Adult patch	Depth	Linear model with quadratic term
	Velocity	Logistic regression

Seedling survival was modeled through a linear regression with quadratic term in relation to water depth. The two species from Grace et al. (1985) were combined to produce one relationship. Depths ranged from -18 cm (18 cm under surface) to 20 cm (20 cm above surface), with depth above surface considered as saturated. Both seedling and germination have a similar relationship with water depth (Figure 37).

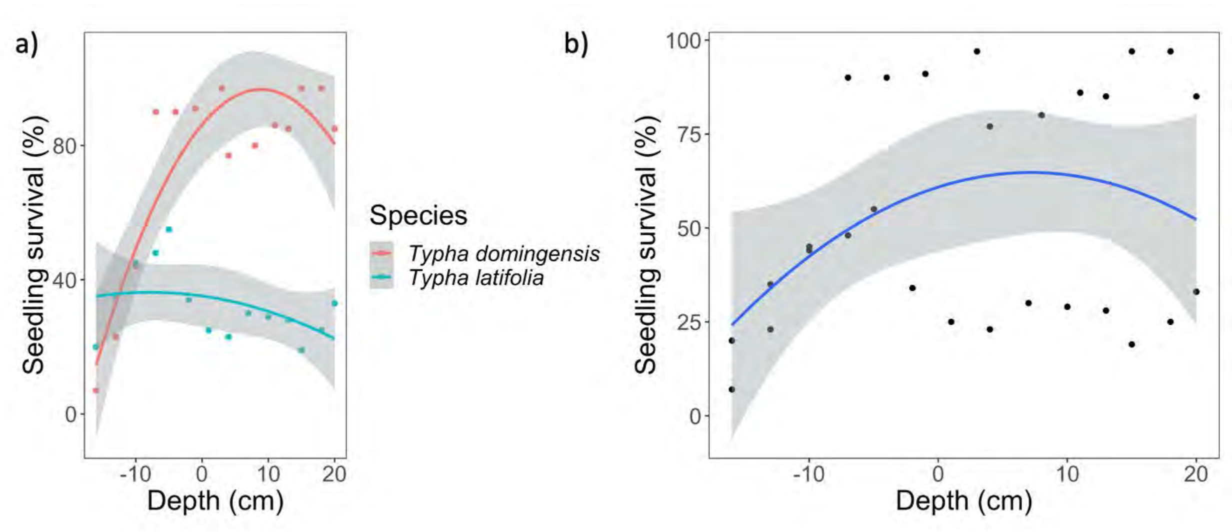


Figure 37. Habitat suitability curve of seedling survival in relation to water depth from Grace et al. (1985) of Typha latifolia, Typha domingensis; a) seedling survival of both species, and b) seedling survival of both species, calculated through linear regression. Water depth is measured from soil surface (-18 cm to 20 cm).

A multivariate linear model was built to evaluate the probability of germination as a function of temperature using data from five controlled experiment studies (Appendix C). A percentage of germination was measured at either constant temperatures e.g., 10°C, 20°C and 30°C, or a temperature cycle to imitate photoperiod e.g., 10/20°C, 10/30°C cycles. The temperature range of photoperiod (i.e., on a 10/20 cycle, temperature range = 10°C) and the high temperature value (i.e., on a 10/20 cycle, high temperature = 20°C) were applied as separate variables in the multivariate linear model (Figure 38). Constant measurements of temperature were included in the high temperature variable. The duration of the experiments ranged between 7 and 35 days, with the majority of measured germination occurring within 7-10 days. All studies consistently reported limited germination at 10°C, and higher temperatures were optimum (approx. 25 - 30°C, max 35°C).

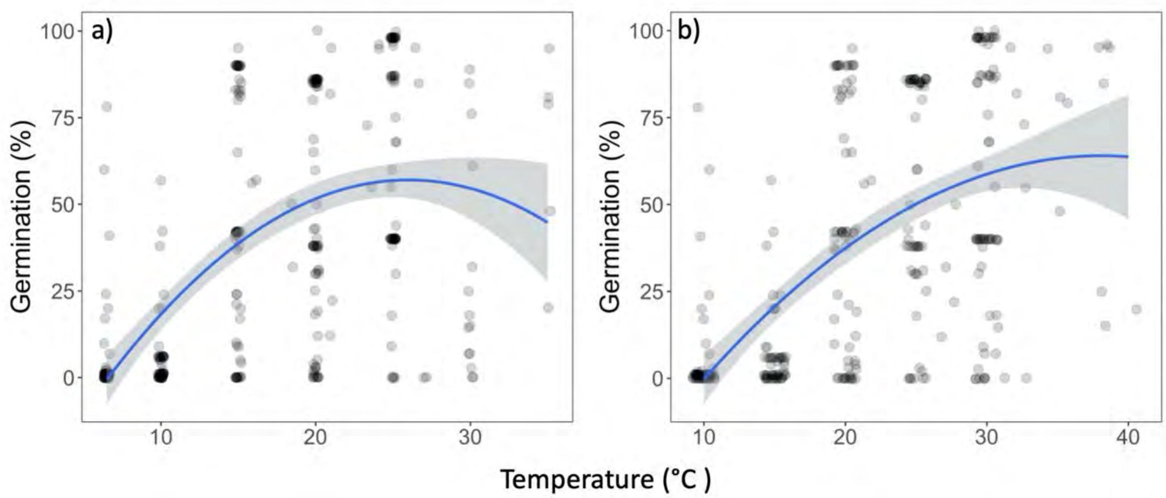


Figure 38. Habitat suitability curve of Typha spp germination as a function of temperature calculated through multivariate linear regression (p < 0.001). Each box represents the two variates; a) mid-range temperature (mean = 17.8°C, n= 316) and b) high temperature (mean = 22.2°C, n= 316).

The probability of occurrence of *Typha* adult patch in relation to velocity was calculated through logistic regression (Figure 39). Data were adapted from systematic field survey studies (Appendix C) into presence only (Asaeda et al. 2005) or presence/absence (Jones Jr 2003). Probability of occurrence is high at low velocities and low at high velocities.

Data from same two studies were used to calculate the probability of occurrence of *Typha* adult patches in response to depth, plus four additional studies (7 in total, Appendix C). Depth ranged from -15 cm (15 cm below surface) to 120 cm above surface. The data were a mix of categorical information (pond experiments) and spot measurements (field surveys) and adapted to produce presence/absence of *Typha* in relation to depth and linear regression with quadratic term was applied to produce the relationship (Figure 39). Both very dry and very wet conditions will reduce the probability of occurrence.

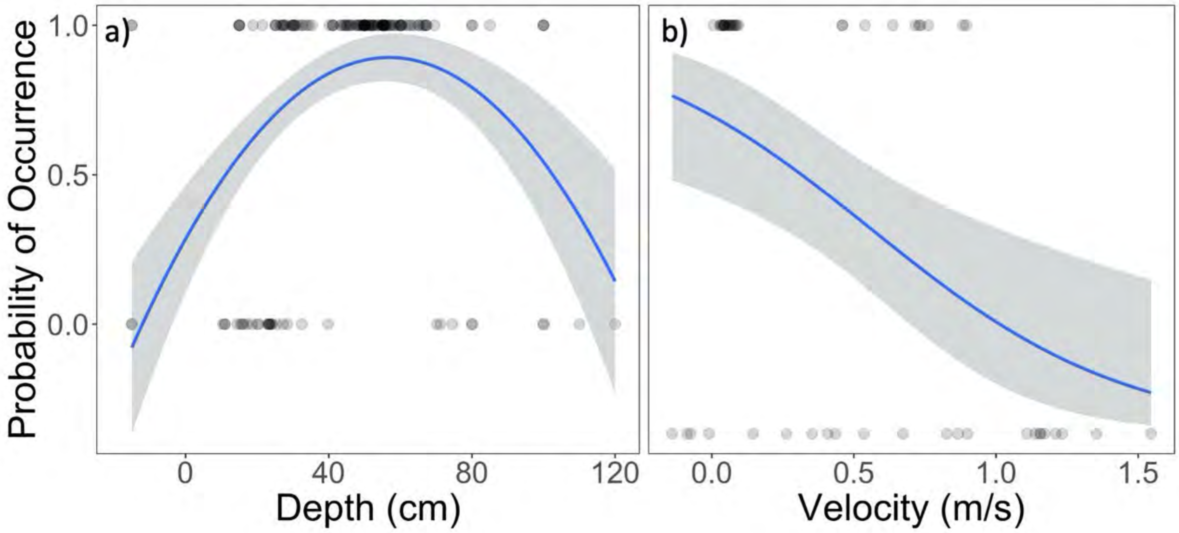


Figure 39. Habitat suitability curve of Typha spp adult patch as a function of a) depth (mean = 33.5 cm, p < 0.001, n= 194) and b) velocity (mean = 0.47 m/s, p = 0.003, n = 51) and calculated through linear model with quadratic term and logistic regression, respectively.

Algae (Cladophora spp)

Cladophora spp are a filamentous alga that commonly occur in shallow freshwater and marine environments, including LA River estuary. The algae provide habitat and a food source for benthic invertebrates, which in turn, provide a vital food source for wading birds. The algae can, however, also become a nuisance by forming extensive mats, a common sign of eutrophication (Higgins et al. 2005). Growth of *Cladophora spp* is associated with many factors such as light and nutrients (Bach and Josselyn 1978; Salovius and Kraufvelin 2004); however, this study will only focus on flow related metrics i.e., depth, velocity and shear stress in addition to temperature. *Cladophora spp* reproduction can be sexual, asexual or vegetative, and therefore are treated as one life stage (see Table 15 for habitat suitability model components).

In general, *Cladophora spp* biomass declines with increasing depth, so data describing this relationship was extracted from Higgins et al. (2005). This field survey reports biomass values over seven depths ranging from 1m to 10m. For relative measurements, the biomass values reported in the study were converted to percentage and applied as the response variable in a linear model with quadratic term to predict habitat suitability (Figure 40).

Data describing *Cladophora spp* response to velocity was taken from Flynn et al. (2020). Here, presence and absence of *Cladophora spp* was determined for 25 m grids over 1 km from aerial surveys. Logistic regression was applied to determine the probability of occurrence in response to velocity (Figure 41). In Flynn et al. (2020) a lower limit of velocity was reported, but an upper limit could not be quantified. For this reason, a general value of shear stress (Table 15) for filamentous algae that is known to remove up to 73% (Biggs and Thomsen 1995) was applied in absence of an upper velocity limit. The shear stress limit also allows for a level of scour, without eliminating the algae entirely.

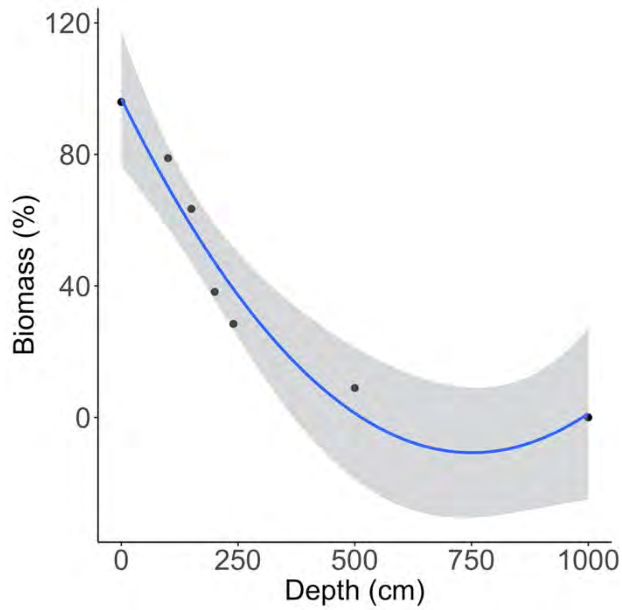


Figure 40. Habitat suitability curve of Cladophora spp as a function of depth (mean = 312 cm, p = 0.01, n = 7) calculated through linear regression with quadratic term.

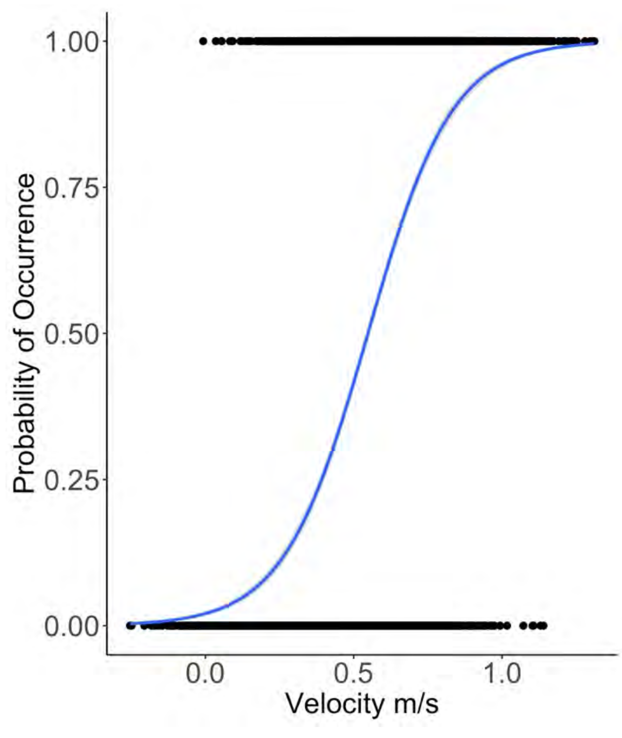


Figure 41. Habitat suitability curve of Cladophora spp as a function of velocity (mean = 0.55 m/s, p < 0.001, n = 8000) calculated through logistic regression.

To evaluate temperature suitability a temperature range of 15-30 (°C) was applied (Cambridge et al. 1987). Growth and reproduction are limited below 15 (°C) and mortality begins to occur above 30 degrees (Whitton 1970).

Table 15. Cladophora spp habitat variables and model applied

Habitat Variable	Model Component
Depth	Linear model with quadratic term
Velocity	Logistic regression
Shear Stress	Upper limit = 16.9 Pa
Temperature	Range = 15 – 30 (°C)

Flow-ecology relationships for endmember species NOT associated with current beneficial uses

Santa Ana Sucker (*Catostomus santaanae*)

Santa Ana Sucker (SAS) are native to Southern California and listed as threatened under Endangered Species Act of 1973, as amended (Act) (U.S. Fish and Wildlife Service 2000). SAS are found in the Santa Ana River, San Gabriel River and Big Tujunga creek, a tributary of the LA River (U.S. Fish and Wildlife Service 2014), but are not currently found in the study region of this project. Four life stages (adult, juvenile, fry and spawning) and three habitat variables (depth, velocity and temperature) were identified as important for habitat suitability (Appendix B). Spawning life stage lacked sufficient survey and observational data to create a reliable habitat suitability relationship, so it was omitted from the final model. Substrate was also identified as a vital habitat variable for SAS; however, the HEC-RAS hydraulic model would not provide sediment transport as output, and hence could not be included in the final model.

The habitat survey data (Appendix C) consisted of fish abundance and associated measurements of depth, velocity or temperature. The habitat suitability models for adult and juvenile SAS were built by first calculating a frequency histogram of fish abundance and habitat variable. A probability density curve was calculated from the histogram following a normal distribution probability function. To remove the accumulative probability values usually attained from this calculation, the habitat data were centered around the mean and scaled to 1 standard deviation. This technique resulted in a habitat suitability curve that produced non-accumulative probability values for each habitat variable value. To maintain intuitiveness of the curve, the scaled habitat data were transformed back to their raw values. This results in a maximum potential probability value of 0.4 (vs. 1.0) because the total area under the curve represents the full range of probabilities. Moreover, the lack of absence data from the surveys used to generate the curve means we cannot estimate a 100% probability of occurrence (i.e., a y-axis value of 1.0). This method was applied to all combinations of adult and juvenile SAS and habitat variables (Figure 42), except for juvenile and velocity where, due to insufficient data availability, the adult velocity curve was substituted. On advice from the TAC, the left and right tails of the depth curves (Figures 42d and 42e) were bound at 0.1 probability, to ensure less stringent low probability limits. The majority of habitat curves were created using several field survey datasets (Appendix C). Figure 43 details the data distribution of component datasets used to create each curve. The component datasets were a mix of both continuous and categorical data types. To combine both data types, categorical data was transformed to continuous by using the mid-point of each category (e.g., adult and juvenile depth; Haglund et al. 2003).

There was insufficient survey data to build habitat suitability curve for SAS fry. Therefore, this life stage was modeled on observational data. Also, the limited resolution of the available channel cross-sections means that microhabitats along channel margins are likely underrepresented in the analysis. An algorithm that determines suitable habitat through a series of suitability statements was created based on the criteria in Table 16.

Table 16. Santa Ana Sucker fry habitat criteria. Note that velocity reported in the literature as "negligible/undetectable." In this case, an upper limit of 0.05 m/s was applied.

Depth	3-10cm
Velocity	Negligible/undetectable (< 0.05 m/s)
Temperature	18-24℃

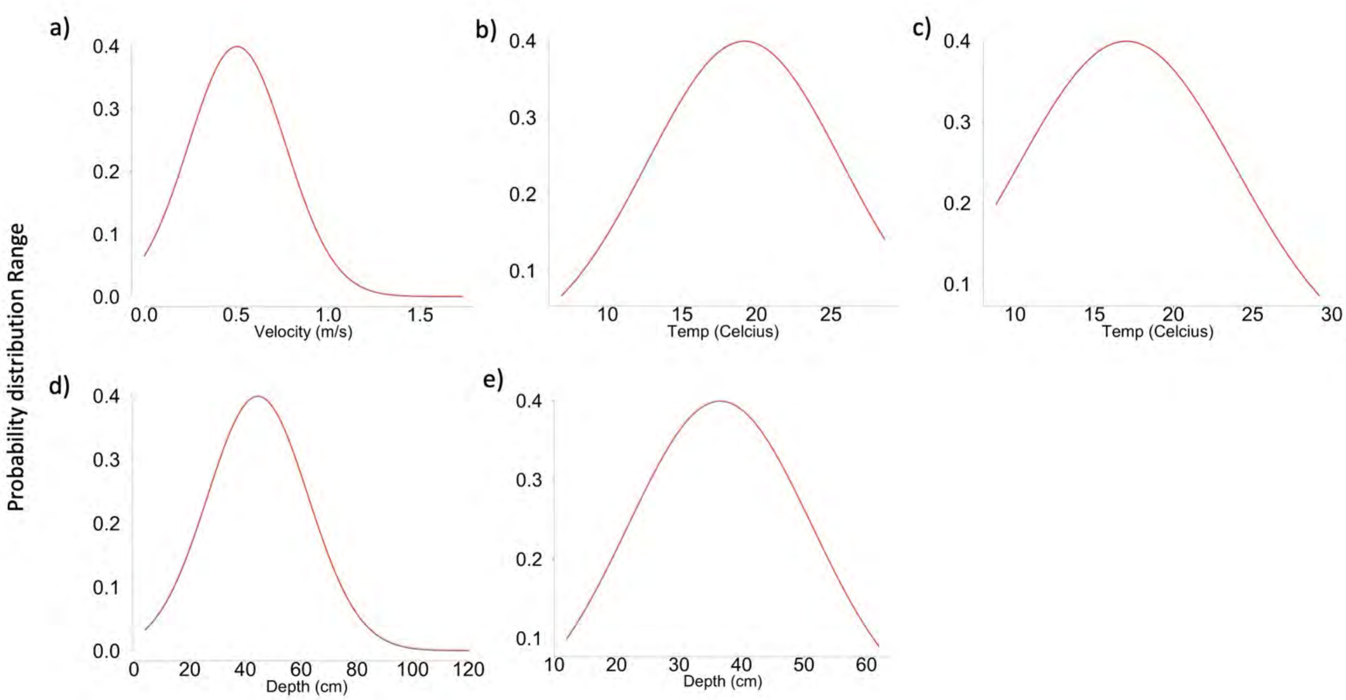


Figure 42. Habitat suitability curves for Santa Ana Sucker: a) adult velocity (mean = 0.61 m/s, n=1167), b) adult temperature (mean = 19.19℃, n = 963), c) juvenile temperature (mean = 17.02, n = 9), d) adult depth (mean = 44.4 cm, n =1 376), and e) juvenile depth (mean = 36.5 cm, n = 257).

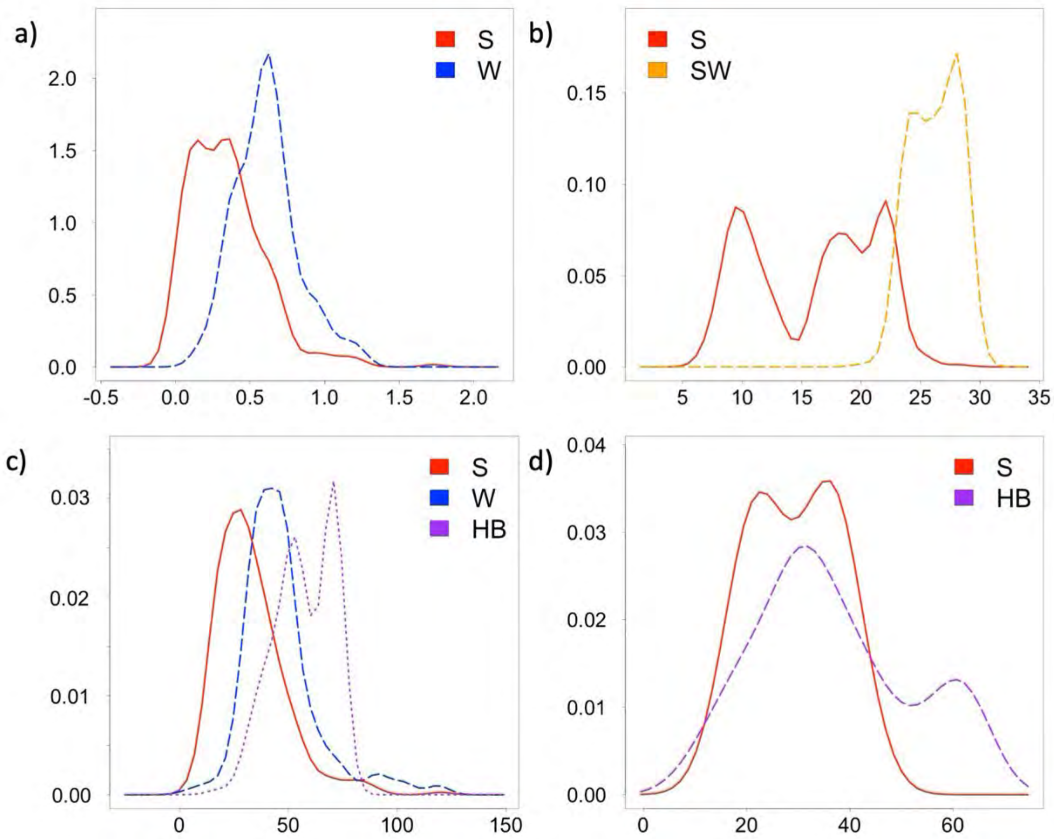


Figure 43. Data distribution curves for Santa Ana Sucker: a) adult velocity, b) adult temperature, c) adult depth, and d) juvenile depth. Note that juvenile temperature has only one component dataset, so the data distribution was not included. Legend are data sourced from: S (Saiki 2000), W (Wulff et al. 2017a, 2017b, 2018), HB (Haglund et al. 2003, 2004), and SW (SAWA 2014).

Steelhead Migration (*Oncorhynchus mykiss*)

Steelhead trout (*Oncorhynchus mykiss*) are an anadromous fish species that have historically utilized the mainstem of the LA River as a migratory passage to spawning grounds. Steelhead migration is not currently supported in the LA River mainstem. Migration of Steelhead consists of two main events: 1) adult passage from the ocean to freshwater tributaries, and 2) smoltification (juvenile) passage from freshwater nursing grounds to estuaries or the ocean. Critical values of habitat variables (velocity, depth and temperature) are well studied for both migration events; therefore, the criteria outlined in Table 17, were followed to assess habitat suitability. On advice from the project's TAC, included for adult migration are two depth values, one conservative threshold (high: 23 cm) and one more lenient threshold (low: 18 cm), in addition to two velocity thresholds in order to consider both burst (3.1 m/s) and prolonged (2 m/s) swimming speeds (Flosi et al. 2010). The values were modelled and reported in two combinations: burst velocity and low depth (burst threshold), and prolonged velocity and high depth (prolonged threshold).

Table 17. Steelhead migration habitat suitability criteria (see Appendix C for references)

Migration Event	Velocity (Burst/Prolonged)	Temperature	Depth (low/high)
Adult	< 3.1 m/s/< 2m/s	< 18°C	> 18 cm/> 23 cm
Smolt/juvenile	N/A	< 14°C	> 12cm

Current Baseline Ecological Conditions

Species habitat suitability for current conditions was assessed at each reporting node for every species life stage following a common procedure:

1. Habitat suitability curves were applied to hydrologic and hydraulic variables at the reporting node
2. A probability of occurrence was assigned based on the hydrologic or hydraulic value at each reporting node
3. Limits in physical conditions were determined using probability threshold for each species life stage
4. A percentage of time & number of days when conditions are likely to support occurrence were calculated based on each physical limit

The HEC-RAS model provided output for three positions (Left over bank, LOB; Main channel, MC; and Right over bank, ROB) in each cross-section. The habitat suitability curves outlined above were applied separately to the associated hydraulic variable at each cross-section position, which resulted in a probability curve unique to species life stage, hydraulic variable and cross-section position. The model components that were derived from predictive models e.g., linear model, Willow seedling and depth, were applied to the HEC-RAS model using the model prediction. As the SAS curve used a probability distribution as opposed to a predictive function, a smoothing spine was applied to interpolate the habitat suitability curve to the HEC-RAS data.

The probability associated with the habitat variable was then related to flow at each cross-section position using a rating curve (Figure 44a). Thresholds of probability were determined for every species life stage, SAS (0.1, Low; 0.2, Medium; 0.3, High), *Typha spp*, Willow & *Cladophora spp* (0.25/25, Low; 0.5/50, Medium; 0.75/75, High). Where suitability thresholds were applied in place of suitability curves (SAS fry, adult Willow/stream power and Willow germination/depth, Steelhead migration), the threshold of flow was determined from the suitable habitat variable value. Flow limits were then determined for each threshold using the probability ~ flow rating curve (Figure 44b). These limits were used to calculate the amount of time each cross-section position provided suitable conditions for each species life stage in 1) overall percentage of time, and 2) number of days per month.

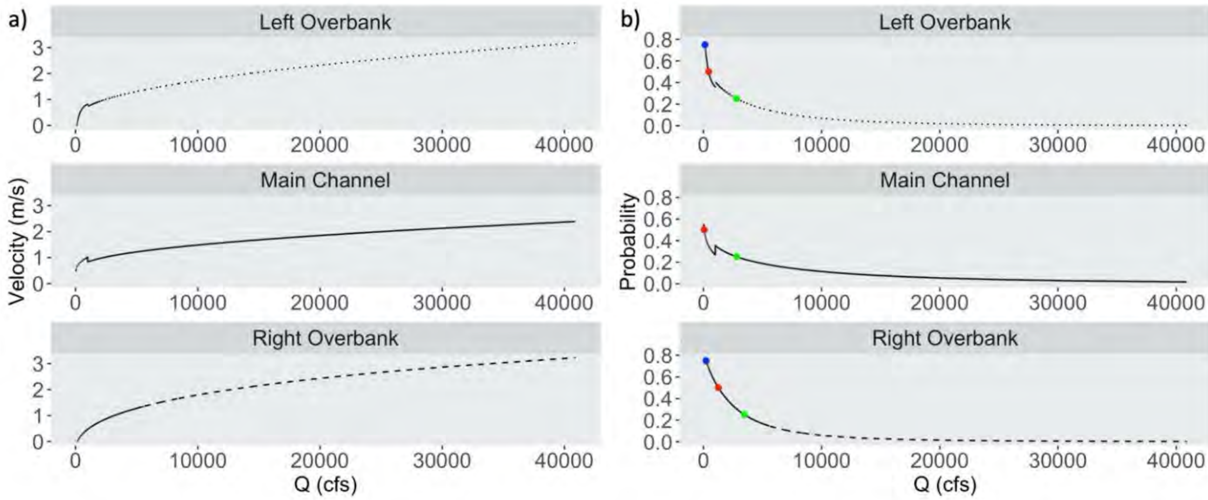


Figure 44. Conceptual example of a) hydraulic variable (velocity) ~ flow rating curve, and b) probability of occurrence ~ flow rating curve. Colored data points represent probability thresholds (green, low (0.25); red, medium (0.5); blue, high (0.75)).

Criteria outlined in Table 18 were used to determine the overall suitability of each node. The habitat suitability models for each species were separated into two suitability types: 1) adult survival (all adult life stages), and 2) growth (all other life stages; fry, juvenile, seedling, germination). Phenological life history events were incorporated into the suitability criteria by identifying critical time periods for each species, which correspond to life history events such as breeding season for SAS, or growing season for Willow (outlined in Table 19) In order for a node to be deemed suitable, it must provide suitable conditions during the critical time period. Only one cross-section position within the node would need to be classified as high suitability for the node to be classed as highly suitable. One exception to the suitability criteria rules was for Willow germination in response to depth, which included a time element in the habitat suitability threshold (see Willow section above). Here, the related timing was applied to determine suitability class. Because Willow seedling is dependent on the success of Willow germination, the suitability class for each was combined into “Willow Reproduction” for each node by taking the lowest rating as the final suitability class. The suitability criteria had to be met for both percentage time overall and number of days per month metrics as outlined in Table 18. On occasion, these two temporal metrics resulted in different outcomes, in such instances the lower suitability class was assigned. For any node rating of “Low”, the hydraulic variable that limits the suitability was identified and outlined in Table 20 and Table 21. These tables represent potential suitability based solely on flow irrespective of any physical/habitat conditions that may affect the probability of species occurrence.

Table 18. General suitability criteria for habitat suitability curves and statements.

General suitability criteria	Habitat suitability curves	Habitat suitability statements
Class	*Criteria*	
High	Probability values for every hydraulic variable are high for minimum 75% overall & 21 days of each month during critical period	All hydraulic variables are classed as suitable
Low*	Probability values for one hydraulic variable are low for maximum 25% overall & 7 days of each month during critical period	One hydraulic variable classed as unsuitable
Partial	All other combinations	All other combinations

*The limiting factors will be determined i.e., abiotically (hydraulic variable) and biotically (life stage)

Table 19. Critical phenological time period for each species

Species	Suitability Type	Critical period
Santa Ana Sucker	Adult survival	all year
	Growth	March – July
Willow	Adult survival	all year
	Growth	April – September
Typha spp	Adult survival	all year
	Growth	April – September
Migration*	Adult (in)	December – June
	Smoltification (out)	December – July
Cladophora	Growth	all year

*Migration suitability type based on the two Steelhead migration events (in and out)

Habitat models and suitability criteria were ultimately used to estimate the probability that each of the focal habitats and species can be supported under current flow conditions (Table 20). This provides a baseline for assessing the potential effects of proposed changes in flow associated with reduced wastewater discharge or increased stormwater capture. Major findings of the baseline analysis suggest:

- Flow conditions are at least partially suitable to support freshwater marsh habitat, as indicated by *Typha*, which is consistent with field observations. This is not surprising given that marsh habitat is generally an early successional habitat when water (and substrate) are present and velocities are sufficiently low. Furthermore, these habitats rapidly recover following disturbance from high flows or mechanical clearing.

- Flows can generally support riparian habitat along the LA River, as indicated by the high suitability for willow seedlings and adults. However, the current model suggests that reproduction of willows is not supported. This result could be related to the location of germinating willows in the cross section, which may not be fully represented in the HEC-RAS output (i.e., willow germination may be located at a higher elevation, and hence shallower depth than the model describes).

- The lower LA River is characterized by flows that have a high probability to support wading shorebirds based on suitable flows for Cladophora. Although flows that can support Cladophora are present throughout the study area, for this study, we are specifically interested in Cladophora as an indicator of the ability to support foraging shorebirds in the tidal portions of the river.

- Although temperatures are too warm to support coldwater fish species, such as the Santa Ana Sucker, the river currently has flows that are at least partially suitable for coldwater fish (adult and juvenile).
- Conditions are not conducive to steelhead migration past Glendale Narrows.

Table 20. Suitability of flow conditions for each species currently supported in the river and life stage per node according to the criteria outlined in Table 18. Steelhead migration reports values for burst swimming speeds with prolonged swimming speeds in parentheses if results differed. Cells that are grayed out represent nodes where the species is not expected to occur, according to Figure 34. Limiting factors are only listed for instances where suitability is low. Ratings pertain only to flow conditions and do not account for other potential limitations (e.g., temperature, substrate). The hydraulic model is being updated for the tidal reaches (LA1 and LA2) as well as Sepulveda Basin (LA20 2) and suitability estimates will be revised accordingly.

SPECIES ASSOCIATED WITH CURRENT BENEFICIAL USES
SPECIES CURRENTLY OBSERVED IN LA RIVER

		Riparian			Freshwater Marsh			Wading Birds	
Reach	**Node**	**Willow (Adult)**	**Willow (Reproduction)**	**Limiting Factor**	**Typha (Adult)**	**Typha (Seedling)**	**Limiting Factor**	**Cladophora**	**Limiting Factor**
LAR 10 - Upstream Reach	LA20							Partial	
LAR 10 - Upstream Reach	LA20 2	TBD	TBD		TBD	TBD		TBD	
LAR 8 - Above Burbank	F300								
LAR 7 - Below Burbank	LA14	High	Low	Depth/ Shear Stress	Partial	Partial			
LAR 6 - Above Glendale WRP	LA13							Low	Velocity
LAR 5 - Glendale Narrows	GLEN	High	Low	Depth	Partial	Partial		Low	Velocity
LAR 5 - Glendale Narrows	LA11	High	Low	Depth	Partial	Partial		Partial	
LAR 5 - Glendale Narrows	F57C	High	Low	Depth	Partial	Low	Depth	Partial	
LAR 4 - Above Rio Hondo	LA8							High	

		Riparian			Freshwater Marsh			Wading Birds	
Reach	**Node**	**Willow (Adult)**	**Willow (Reproduction)**	**Limiting Factor**	**Typha (Adult)**	**Typha (Seedling)**	**Limiting Factor**	**Cladophora**	**Limiting Factor**
LAR 4 - Above Rio Hondo	F34D							Partial	
LAR 3 - Below Rio Hondo	LA3							High	
LAR 2 - Below Compton Creek	F319							Partial	
LAR 1 - Tidal Reach	LA2				TBD	TBD		TBD	
LAR 1 - Tidal Reach	LA1				TBD	TBD		TBD	
Rio Hondo 1 - Below Spreading Grounds	F45B								
Rio Hondo 2 - Above Spreading Grounds	11101250	High	Low	Depth	Partial	Low	Depth	Low	Velocity
Compton Creek	F37B Low	High	Low	Depth/ Shear Stress	Low	Low	Depth & Velocity	Low	Depth & Velocity
Compton Creek	F37B High	High	Low	Depth	Low	Low	Depth & Velocity	Low	Depth & Velocity

Table 21. Suitability of flow conditions for each species <u>not currently supported</u> in the river and life stage per node according to the criteria outlined in Table 18. Steelhead migration reports values for burst swimming speeds with prolonged swimming speeds in parentheses if results differed. Cells that are grayed out represent nodes where the species is not expected to occur, according to Figure 34. Limiting factors are only listed for instances where suitability is low. Rating pertain only to flow conditions and do not account for other potential limitations (e.g., temperature, substrate). We cannot sufficiently model edgewater habitat conditions for Santa Ana Sucker (SAS) fry due to limitations in our hydraulic model. The hydraulic model is being updated for the tidal reaches (LA1 and LA2) as well as Sepulveda Basin (LA20 2) and suitability estimates will be revised accordingly.

SPECIES *NOT* ASSOCIATED WITH CURRENT BENEFICIAL USES
SPECIES *NOT* CURRENTLY OBSERVED IN LA RIVER

		Coldwater Fish				Migration		
Reach	**Node**	**SAS (Fry)**	**SAS (Adult)**	**SAS (Juvenile)**	**Limiting Factor**	**Smolt (Out-migration)**	**Adult (In-migration)**	**Limiting Factor**
LAR 10 - Upstream Reach	LA20							
LAR 10 - Upstream Reach	LA20 2	NA	TBD	TBD		TBD	TBD	
LAR 8 - Above Burbank	F300					High	High	
LAR 7 - Below Burbank	LA14	NA	Partial	Partial		High	High	
LAR 6 - Above Glendale WRP	LA13					Low	Low	Depth
LAR 5 - Glendale Narrows	GLEN	NA	Partial	Partial		High	High	
LAR 5 - Glendale Narrows	LA11	NA	Partial	Partial		High	High	
LAR 5 - Glendale Narrows	F57C	NA	Partial	Partial		High	High	
LAR 4 - Above Rio Hondo	LA8					High	High	
LAR 4 - Above Rio Hondo	F34D					High	High	
LAR 3 - Below Rio Hondo	LA3					High	High	

		Coldwater Fish				Migration		
Reach	**Node**	**SAS (Fry)**	**SAS (Adult)**	**SAS (Juvenile)**	**Limiting Factor**	**Smolt (Out-migration)**	**Adult (In-migration)**	**Limiting Factor**
LAR 2 - Below Compton Creek	F319					High	High	
LAR 1 - Tidal Reach	LA2					TBD	TBD	
LAR 1 - Tidal Reach	LA1					TBD	TBD	
Rio Hondo 1 - Below Spreading Grounds	F45B							
Rio Hondo 2 - Above Spreading Grounds	11101250							
Compton Creek	F37B Low							
Compton Creek	F37B High							

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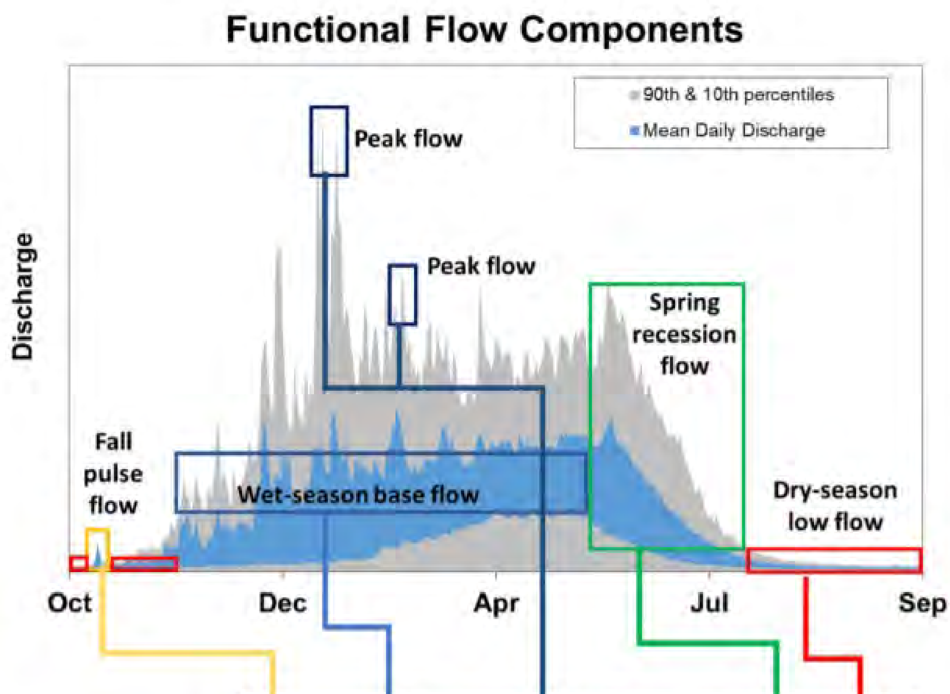
APPENDIX A: FUNCTIONAL FLOWS UNDER BASELINE CONDITIONS

What are functional flows?

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. In California, functional flow components include the fall pulse flow, winter baseflows, peak flows, spring recession flows, and summer baseflows (Figure A1). The timing, magnitude, duration, and frequency of these functional flow components under natural conditions can be used to estimate how much water is needed to support ecological functions throughout the year. The various flow characteristics can be quantified through calculating a suite of functional flow metrics (Table A1).



	Functional Flow Components				
Flow Characteristics	Fall Pulse	Wet Baseflow	Peak Flow	Spring Recession	Dry Low Flow
Magnitude	X	X	X	X	X
Timing	X	X	X	X	X
Duration		X	X	X	X
Frequency			X		
Rate of Change				X	X

Figure A1. Functional flow components (boxes) for a mixed rain-snowmelt runoff system (hydrograph) with key flow characteristics, or hydrograph elements, for each flow component (table). Not all flow components are equally important throughout different regions of California.

What functions are supported by each flow component?

1. Fall pulse flow, or the first major storm event following the dry season. These flows represent the transition from dry to wet season and serve important functions, such as transporting nutrients downstream, improving streamflow water quality, and providing cues for species to migrate or spawn.

    a) In southern California, fall pulse flows may not occur every single year. However, when present, these flows provide key functions for riparian habitat. The magnitude, duration, and timing of flows may be important to support riparian vegetation recovery following the dry summer season. Sufficient magnitudes will allow for the reconnection of the channel-riparian floodplain habitats, duration is important for the appropriate length of inundation of riparian vegetation (not too long but not too short, ~1-2 weeks), and timing should occur before the weather cools down to allow for growth of vegetation.

2. Wet-season base flows: support native species that migrate through and overwinter in streams and are important for nutrient cycling.

3. Peak magnitude flows: transport a significant portion of sediment load, inundate floodplains, and maintain and restructure river corridors. Peak flows also prevent vegetation encroachment through scour and can reduce the extent of invasion by exotic species not adapted to disturbance regime.

4. Spring recession flows: represent the transition from high to low flows, provide reproductive and migratory cues, and redistribute sediment.

    a) Spring recession flows have a strong influence in snowmelt systems but may not be as significant in southern California systems.

5. Dry-season base flows: support native species during the dry-season period when water quality and quantity limit habitat suitability

Further information on functional flows can be found at Yarnell et al. (2015), Yarnell et al. (2020), and https://ceff.ucdavis.edu/functional-flows-approach.

Table A1. Description of functional flow metrics.

Flow Component	Flow Characteristic	Flow Metric - Short	Flow Metric - Long	Description
Fall pulse flow	Magnitude (cfs)	FA_Mag	Fall Pulse Flow: Magnitude	Peak magnitude of fall season pulse event (maximum daily peak flow during event)
	Timing (date)	FA_Tim	Fall Pulse Flow: Timing	Start date of fall pulse event
	Duration (days)	FA_Dur	Fall Pulse Flow: Duration	Duration of fall pulse event (# of days start-end)
Wet-season base flow	Magnitude (cfs)	Wet_BFL_Mag_10	Wet-Season Base Flow: Magnitude 10th percentile	Magnitude of wet season baseflows (10th percentile of daily flows within that season, including peak flow events)
	Magnitude (cfs)	Wet_BFL_Mag_50	Wet-Season Base Flow: Magnitude 50th percentile	Magnitude of wet season baseflows (50th percentile of daily flows within that season, including peak flow events)
	Timing (date)	Wet_Tim	Wet-Season Base Flow: Timing	Start date of wet season
	Duration (days)	Wet_BFL_Dur	Wet-Season Base Flow: Duration	Wet season baseflow duration (# of days from start of wet season to start of spring season)
Peak flow	Magnitude (cfs)	Peak_10	Peak Flow: Magnitude (10-year flood)	Peak-flow magnitude (10% exceedance values of annual peak flow --> 10-year recurrence intervals)
	Magnitude (cfs)	Peak_5	Peak Flow: Magnitude (5-year flood)	Peak-flow magnitude (20% exceedance values of annual peak flow --> 5-year recurrence intervals)
	Magnitude (cfs)	Peak_2	Peak Flow: Magnitude (2-year flood)	Peak-flow magnitude (50% exceedance values of annual peak flow --> 2-year recurrence intervals)
	Duration (days)	Peak_Dur_10	Peak Flow: Duration (10-year flood)	Duration of peak flows over wet season (cumulative number of days in which a given peak-flow recurrence interval is exceeded in a year).
	Duration (days)	Peak_Dur_5	Peak Flow: Duration (5-year flood)	Duration of peak flows over wet season (cumulative number of days in which a given peak-flow recurrence interval is exceeded in a year).
	Duration (days)	Peak_Dur_2	Peak Flow: Duration (2-year flood)	Duration of peak flows over wet season (cumulative number of days in which a given peak-flow recurrence interval is exceeded in a year).
	Frequency	Peak_Fre_10	Peak Flow: Frequency (10-year flood)	Frequency of peak flow events over wet season (number of times in which a given peak-flow recurrence interval is exceeded in a year).
	Frequency	Peak_Fre_5	Peak Flow: Frequency (5-year flood)	Frequency of peak flow events over wet season (number of times in which a given peak-flow recurrence interval is exceeded in a year).

Flow Component	Flow Characteristic	Flow Metric - Short	Flow Metric - Long	Description
	Frequency	Peak_Fre_2	Peak Flow: Frequency (2-year flood)	Frequency of peak flow events over wet season (number of times in which a given peak-flow recurrence interval is exceeded in a year).
Spring recession flow	Magnitude (cfs)	SP_Mag	Spring Recession Flow: Magnitude	Spring peak magnitude (daily flow on start date of spring-flow period)
	Timing (date)	SP_Tim	Spring Recession Flow: Timing	Start date of spring (date)
	Duration (days)	SP_Dur	Spring Recession Flow: Duration	Spring flow recession duration (# of days from start of spring to start of summer baseflow period)
	Rate of change (%)	SP_ROC	Spring Recession Flow: Rate of Change	Spring flow recession rate (Percent decrease per day over spring recession period)
Dry-season base flow	Magnitude (cfs)	DS_Mag_50	Dry-Season Base Flow: Magnitude (50th percentile)	Base flow magnitude (50th percentile of daily flow within summer season, calculated on an annual basis)
	Magnitude (cfs)	DS_Mag_90	Dry-Season Base Flow: Magnitude (90th percentile)	Base flow magnitude (90th percentile of daily flow within summer season, calculated on an annual basis)
	Timing (date)	DS_Tim	Dry-Season Base Flow: Timing	Summer timing (start date of summer)
	Duration (days)	DS_Dur_WS	Dry-Season Base Flow: Duration	Summer flow duration (# of days from start of summer to start of wet season)

For more information on how the flow metrics are calculated, visit https://eflow.gitbook.io/ffc-readme/functional-flow-calculator/metrics.

For more information on the California Environmental Flows Framework (CEFF) and the tools and datasets developed, visit https://eflows.ucdavis.edu/.

Functional Flow Metrics: Baseline Conditions of the LA River

Functional flow metrics were calculated under the baseline scenario (WY 2011 – 2017) for all reporting nodes (Table A2). All of the metrics, with the exception of the peak magnitude flows, were calculated on an annual basis and summarized as percentiles across the period of record (i.e., 10^{th} percentile to 90^{th} percentile). These values broadly describe different aspects of the annual hydrograph to which future scenarios of wastewater recycling and stormwater capture will be compared to.

For percentiles of functional flow metrics calculated for baseline conditions at all model reporting nodes, see https://sccwrp-my.sharepoint.com/:x:/g/personal/kristinetq_sccwrp_org/EShSfNZLlipKtGWBCjkGb5sBu0Icdc8adP_MT2jju4hzKA?e=hSM3HE.

APPENDIX B: SPECIES LIFE HISTORY NEEDS

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
steelhead (rainbow) trout adult	optimal: 15-18, observed: 3-20; min-0, max-21.1	3-3.1 m/s, 2m/s	>0.18 m, 23 m/s	silt-free, gravel/rock					Bjornn and Reiser et al. 1991; Hofflander and Dagit et al. 2016; Raleigh et al. 1984, Flosi et al. 2010, USEPA 2003
steelhead (rainbow) trout migration	7.8-11.1, lethal: <4 & >23; summer run: can survive 25-27 for short term		>0.12 m	particles >7.6 cm, cobble boulders					Bjornn and Reiser et al. 1991; Oroville Facilities Relicensing 2004; Raleigh et al. 1984, USEPA 2003
unarmored threespine stickleback Fry	18-20; 17.4-20.9	slow flow	shallow edges of streams	dense vegetation, clear water, little turbidity; sand/gravel					U.S. Fish and Wildlife Service 2009; SMEA 1995; occurrence data sheet
unarmored threespine stickleback Juvenile	warmer water speeds up development; 16-27	slow/standing water	shallow water; 10-25 & 40-45 cm	clear water					Impact Sciences, Inc. 2003; Aquatic Consulting Services, Inc. 2002; occurrence data sheet

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
unarmored threespine stickleback Spawning	peak reproduction during the spring	low velocity	>40 cm	clear water, requires vegetation					U.S. Fish and Wildlife Service 2009; SMEA 1995; Aquatic Consulting Services, Inc. 2002
unarmored threespine stickleback Adult	min: 12.4, max: 30.4, preferred: 20-25	0.3-2.4	40-90, 180-200 cm	sand/gravel					SMEA 1995; Impact Sciences, Inc. 2003; Aquatic Consulting Services, Inc. 2002; occurrence data sheet; Shoken 1986
Santa Ana Sucker Fry	18-24 °C	low/negligible flow, next to faster flowing water	shallow; 5-10 cm	sand/silt					Santa Ana Water Project Authority 2014; Fish Wildlife Serv. 2010; Saiki 2000
Santa Ana Sucker Juvenile	11-29 °C	observed: 0.05-0.45 m/s average: 0.16 m/s	observed: 11-63 cm average: 29 cm	sand/gravel					Feeney and Swift 2008; Haglund et al. 2010; Moyle 2002; Greenfield et al. 1970; Saiki 2000
Santa Ana Sucker Spawning	14-22 °C	slow-flowing observed at 0.2 m/s	20-60 cm	gravel/sand					Feeney and Swift 2008; Moyle 2002; Haglund et al. 2003

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
Santa Ana Sucker Adult	16-29 °C	<1.7 m/s	observed: 4-120 cm average: 36 cm	gravel/cobble/sand					Feeney and Swift 2008; Haglund et al. 2010; Saiki 2000; Thompson et al. 2010; Wulff et al. 2018
cladophora all	average temperature 20 °C to 30 °C	average velocity 20 cm/sec to 80 cm/sec	shallow water around lake margins (range 0-3 meter(s))	Cladophora colonizes on attached rocks, attached to clams and fish in shallow water					Cambridge et al. 1987; Dodds and Gudder 1992; Herbst 1969; Flynn et al. 2020; Scott et al. 2005; Steven et al. 1978; Whitton 1970
Salix Gooddingii (Willow) germination	peak growth at 21°C-27°C	slow flow	along streamside; water levels maintained 10 cm below the soil surface to facilitate germination, High germination is associated with seeds saturated in soils kept moist by capillarity	moist, bare soils					Reed 1993; Siegel and Brock 1990; Stella et al. 2010; Stromberg 1997; Castro-Morales et al. 2014; California Native Plant Society

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
Salix Gooddingii (Willow) seedlings	mortality when >33°C		mortality increases when water levels > 0.5 m	moist, river margins	mortality is evident when bed shear stress reaches 30-42 Pa	NA			Siegel and Brock 1990; Quintana-Ascencio et al. 2013; Pasquale et al. 2014; Castro-Morales et al. 2014
Salix Gooddingii (Willow) Adult		withstand speeds <1.7 m/s	decline in survivorship where water is >1.5 m deep	moist, river margins		S. exigua and S. lasiolepis show ≥25% cover when median unit stream power is 300 (W/m^2) and when S. laevigata at medium unit stream power is 700 (W/m^2)			Stella et al. 2010; Stromberg 1997; Bendix 1999; Pitcher and McKnight
Typha germination	peak growth at 25-30 °C	no flow to slow moving stream	maximum germination levels at 7-10 cm above the water table no germination 18 cm above the water table	saturated soil					Bedish 1964; Sifton 2011; Lombardi et al. 1997; Jones 2003; Coops and Van Der Velde 1995
Typha seedlings	temperatures as high as 30	NA	seedlings can grow in	saturated soil, along river banks					Hall 1993; Beule 1979;

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
	°C are necessary for seedling establishment		water up to 40 cm deep, greater growth seen in water depth of -6 cm to 1 cm, poor growth from 1-8 cm						Coops and Van Der Velde 1995; USGS
Typha Adult	24-28°C	low water velocity (< 0.107 m/s)	can grow in at least 60-75 deep water, greater growth in shallow water, poor growth past 110 cm	river banks, along streams					Cary and Weerts 1984; Jones 2003; Beule 1979 ; Jones 2003; USGS
Lemna spp. all	17.5-30°C; thresholds <10 and >34 optimal range: 25-31°C	little to no flow; <0.3 m/s	optimal: 0.4-1 m reported: 0.2-2 m	fresh or brackish water; sand/silt			> thrives in water rich in nutrients > favors decaying organic material > growth inhibited by high metal concentrations	optimal: 5-7 reported: 3-10	Ali et al. 2016; Culley et al. 2009; Escobar and Escobar 2017; Van den Berg et al. 2015; Janauer et al. 2010; Iqbal 1999; Journey et al. 1993; Grinberga 2011; Leng 1999; Zirschky and Reed 1988; Lasfar et al. 2007; FAO 2009

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
Western mosquitofish Fry	observed in range 15-30		observed in shallow, vegetated areas; often occupying perimeter/ shoreline	sandy bottom					Maglio and Rosen 1969; Ayala et al. 2007
Western mosquitofish Adult	observed in range 1-40; prefer 31-35 in lab; can survive as low as 1 for brief periods; 40 likely lethal limit; growth may slow past 35 due to stress	0 - 0.385 m/sec (mean swimming failure velocity); prefer calm water over turbulent	>0.1 m ; prefer shallow water 8-15 cm; in streams ranging 0.4 - 1.3 m deep for example, found often along shallow, well vegetated edges	recorded substrates include sand, mud, silt					Ward et al. 2003; Cherry et al. 1976; Pyke 2005; Winkler 1979; Moyle and Nichols 1973
Western mosquitofish Spawning	>10; warmer waters			non-pregnant females prefer dark substrate; preference decreases with pregnancy					Pyke 2005
African clawed frog Tadpole	observed in temperatures 18 - 24	slow to stagnant (likely not strong swimmers)	shallow; early tadpoles avoid open water column more often	observed in sites with main substrate sand, cobble, silt. Also found in concrete locations					Golden et al. 2000; Moreira et al. 2017
African clawed frog Adult	<30 (no reports of lower than 20)	slow to stagnant, but permanent water in pond or close by; dispersal of young adults via	0.1 - 2 m (are completely aquatic, will migrate if pool/stream dries)	will burrow in mud substrate to avoid heat					Wishtoyo Foundation 2008; Moreira et al. 2017; McCoid and Fritts 1980

Species	Temperature	Velocity	Depth	Substrate	Shear Stress	Stream Power	Other Factors	pH	References
		flooding/heavy rain events							
African clawed frog Spawning	>20	lotic breeding sites more frequent than lentic though can produce tadpoles in both							McCoid and Fritts 1989; Moreira et al. 2017

Appendix B: Bibliography

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APPENDIX C: DATA SOURCES FOR HABITAT SUITABILITY CURVES

Data source	Study region	Type of study	Species	Data Type	Life stage	Habitat Variable
Wulff, M., L. Brown, J. May, and E. Gusto. 2018. Native Fish Population and Habitat Study, Santa Ana River, California, 2015:2017: U.S. Geological Survey data release. U.S. Geol. Surv. data release https://www.sciencebase.gov/catalog/item/5a837189e. doi:https://doi.org/10.5066/F7CJ8CR0.	Santa Ana River, California	field survey	*Catostomus santaanae*	abundance	adult	depth, velocity
Saiki - Saiki, M.K. 2000. Water quality and other environmental variables associated with variations of the Santa Ana Sucker. Natl. Fish Wildl. Found.	Santa Ana River & San Gabriel River, California	field survey	*Catostomus santaanae*	abundance	adult	depth, velocity, temperature
				abundance	juvenile	depth, temperature
SMEA - Haglund, T.R., J.N. Baskin, and T.J. Even. 2003. Results of the Year 3(2003) Implementation of the Santa Ana Sucker Conservation Program for the Santa Ana River. San Marino Environmental Associates, 9.	Santa Ana River, California	field survey	*Catostomus santaanae*	abundance	adult	depth
				abundance	juvenile	depth
				observation	fry	depth, velocity
SMEA - Haglund, T.R., J.N. Baskin, and T.J. Even. 2004. Results of the Year 4(2004) Implementation of the Santa Ana Sucker Conservation Program for the Santa Ana River. San Marino Environmental Associates, 9.	Santa Ana River, California	field survey	*Catostomus santaanae*	abundance	adult	depth
				abundance	juvenile	depth
SAWA - Habitat variability and distribution of the Santa Ana sucker , Catostomus santaanae , in the Santa Ana River from the confluence of the Rialto channel to the Prado Basin. Santa Ana Water Project Authority (SAWPA) (2014).	Santa Ana River, California	field survey	*Catostomus santaanae*	abundance	adult	temperature
Feeney, R.F. and C.C. Swift. 2008. Description and ecology of larvae and juveniles of three native cypriniforms of coastal southern California. *Ichthyol. Res.* **55**, 65–77.	California	observation	*Catostomus santaanae*	observation	fry	depth, velocity, temperature
Nakai, A., and H. Kisanuki. 2007. Effect of inundation duration on Salix gracilistyla density and size on a gravel bar. J For Res;12(5):365–70.	Miya River in	field survey	*Salix gooddingii*	germination (%)	germination	depth

Data source	Study region	Type of study	Species	Data Type	Life stage	Habitat Variable
	central Japan					
Tallent-Halsell, N.G., and L.R. Walker. 2002. RESPONSES OF SALIX GOODDINGII AND TAMARIX RAMOSISSIMA TO FLOODING. Wetlands, 22(4).	Lake Mohave	controlled experiment	*Salix gooddingii*	mortality (%)	seedling	depth
Vandersande, M.W., E.P. Glenn, and J.L. Walworth. 2001. Tolerance of five riparian plants from the lower Colorado River to salinity drought and inundation. Journal of Arid Environments, 49(1), 147\u0096159.	Colorado River, Mexico	controlled experiment	*Salix gooddingii*	mortality (%)	seedling	depth
Pasquale, N., P. Perona, R. Francis, and P. Burlando. 2014. Above-ground and below-ground Salix dynamics in response to river processes. Hydrological Processes, 28(20), 5189\u00965203	Thur river, Switzerland	field survey	*Salix alba, Salix viminalis*	survival (%)	seedling	shear stress
Bendix, J. 1999. Stream power influence on southern Californian riparian vegetation. Journal of Vegetation Science 10: 243–252.	California	field survey	*Salix gooddingii*	observation	adult	stream power
Grace, J.B. 1985. Juveniles vs. Adult Competitive Abilities in Plants: Size-Dependence in Cattails (Typha). Ecology, vol. 66, no. 5, pp. 1630–1638.	Arkansas	controlled experiment	*Typha latifolia, Typha domingensis*	germination (%)	seedling	depth
				germination (%)/survival (%)	germination	depth
Lombardi, T., T. Fochetti, A. Bertacchi, and A. Onnis. 1997. Germination requirements in a population of Typha latifolia. Aquatic Botany. 56. 1-10.	Italy	controlled experiment	*Typha latifolia*	germination (%)	germination	temperature
Morinaga, T. 1926. Effect of Alternating Temperatures Upon the Germination of Seeds. American Journal of Botany, vol. 13, no. 2, pp. 141–158.	not given	controlled experiment	*Typha latifolia*	germination (%)	germination	temperature
Sifton, H. 1959. The germination of light-sensitive seeds of Typha latifolia L. Canadian Journal of Botany. 37. 719-739. 10.1139/b59-057.	not given	controlled experiment	*Typha latifolia*	germination (%)	germination	temperature
Bonnewell, V., W. Koukkari, and D. Pratt. 1983. Light, oxygen, and temperature requirements for Typha latifolia seed germination. Canadian Journal of Botany. 61. 1330-1336.	Anoka County, MN	controlled experiment	*Typha latifolia*	germination (%)	germination	temperature
Ter Heerdt, G., C. Veen, W. Putten, and J. Bakker. 2016. Effects of temperature, moisture and soil type on seedling emergence and mortality of riparian plant species. Aquatic Botany. 136.	Netherlands	controlled	*Typha latifolia*	emergence (%)	germination	temperature

Data source	Study region	Type of study	Species	Data Type	Life stage	Habitat Variable
		experim ent				
Jones, C.E. 2003. Predicting Cattail responses to re-watering of a travertine stream: Decommissioning the Fossil Springs Dam. Masters Thesis. Northern Arizona University	Fossil creek, Arizona	field survey	*Typha domingens is*	presence/abs ence	adult	velocity, depth
Asaeda, T., T. Fujino, and J. Manatunge. 2005. Morphological adaptations of emergent plants to water flow: A case study with Typha angustifolia, Zizania latifolia and Phragmites australis. Freshwater Biology. 50. 1991 - 2001.	Lake Teganu ma, Tokyo	field survey	*Typha angustifoli a*	presence only, presence/abs ence	adult	velocity, depth
Grace, J.B. and R.G. Wetzel. 1981. Habitat Partitioning and Competitive Displacement in Cattails (Typha). Experimental Field Studies. American Naturalist, 118(4), 463.474.	Michigan	controlle d experim ent	*Typha latifolia, Typha domingens is*	abundance	adult	depth
Grace, J.B. and R.G. Wetzel. 1982. Niche differentiation between two rhizomatous plant species: Typha latifolia and Typha angustifolia. Canadian Journal of Botany. 60. 46-57.	Kalamaz oo County, Michigan	field survey	*Typha latifolia and Typha angustifoli ala*	abundance	adult	depth
Waters, I. and J. Shay. 1992. Effect of water depth on population parameters of a Typha glauca stand. Canadian Journal of Botany. 70. 349-351. 10.1139/b92-046.	Lake Manitoba , Canada	field survey	*Typha glauca*	presence only	adult	depth
Waters, I. and J. Shay. 1992. A field study of the morphometric response of Typha glauca shoots to a water depth gradient. Canadian Journal of Botany. 68. 2339-2343.	Lake Manitoba , Canada	field survey	*Typha glauca*	abundance	adult	depth
Bjornn, T.C. and D.W. Reiser. 1991. Habitat Requirements of Salmonids in Streams, Influences of Forest and Rangeland Management on Salmonid Fishes and Their Habitats. American Fisheries Society Special Publications 19: 83-138.	western North America	report	*Oncorhync hus mykiss*	presence only	adult	temperat ure, velocity, depth
U.S. Environmental Protection Agency. 2003. EPA Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality Standards. EPA 910-B-03-002. Region 10 Office of Water, Seattle, WA.	Pacific Northwe st	Guidanc e report	*Oncorhync hus mykiss*	review	smolts/ad ult	temperat ure
McEwan, D. and T.A. Jackson. 1996. Steelhead restoration and management plan for California. California Dep. Fish Game, 234 p. (Available from California Department of Fish and Game, Inland Fisheries Division, 1416 Ninth Street, Sacramento, CA 95814.)	Californi a	report	*Oncorhync hus mykiss*	presence only	adult/juve nile	temperat ure, velocity, depth

Data source	Study region	Type of study	Species	Data Type	Life stage	Habitat Variable
Dagit, R., N. Trusso, et al. 2016. The Long Beach Fish Study June 2016. Friends of LA River.	Middle and Lower Los Angeles River, California	report	*Oncorhynchus mykiss*	presence only	not specified	temperature
Flosi, G., S. Downie, J. Hopelain, M. Bird, R. Coey, and B. Collins. 2010. California Salmonid Stream Habitat Restoration Manual. Sacramento,	California	report	*Oncorhynchus mykiss*	Critical habitat threshold	Adult/juvenile	depth, velocity
Oroville Facilities Relicensing. 2004. Matrix Of Life History and Habitat Requirements for Feather River Fish Species – Steelhead.	Oroville, California	report	*Oncorhynchus mykiss*	presence only	adult/juvenile	temperature, velocity, depth
Raleigh, R.F., T. Hickman, R.C. Soloman, and P.C. Nelson. 1984. Habitat Suitability Information: Rainbow Trout. US FWS.	Pacific Coast	report	*Oncorhynchus mykiss*	presence/mortality data	adult/juvenile	temperature, velocity, depth
Higgins, S., R. Hecky, and S. Guildford. 2005. Modeling the Growth, Biomass, and Tissue Phosphorus Concentration of Cladophora glomerata in Eastern Lake Erie: Model Description and Field Testing. Journal of Great Lakes Research - J GREAT LAKES RES. 31. 439-455. 10.1016/S0380-1330(05)70275-6.	Lake Eerie	field survey	*Cladophora glomerata*	maximum biomass	N/A	depth
Flynn, K., M. Asce, S. Chapra, and F. Asce. 2020. Evaluating Hydraulic Habitat Suitability of Filamentous Algae Using an Unmanned Aerial Vehicle and Acoustic Doppler Current Profiler. Journal of Environmental Engineering. 146. 04019126. 10.1061/(ASCE)EE.1943-7870.0001616.	Clark Fork River, Montana	aerial survey	*Cladophora glomerata*	presence/absence	N/A	velocity
Biggs, B.J. and H.A. Thomsen. 1995. Disturbance of Stream Periphyton by Perturbations in Shear Stress: Time to Structural Failure and Differences in Community Resistance. Journal of Phycology, 31: 233-241. doi:10.1111/j.0022-3646.1995.00233.x	New Zealand	controlled experiment	*Filamentous algal community*	percentage removal	N/A	shear stress
Cambridge, M., A. Breeman, S. Kraak, and C. Hoek. 1987. Temperature responses of tropical to warm temperate Cladophora species In relation to their distribution m the North Atlantic Ocean. Helgoland Marine Research - HELGOLAND MAR RES. 41. 329-354. 10.1007/BF02366197.	Corsica, Brittany, Curacao	controlled experiment	*Cladophora submarina, Cladophora prolifera, Cladophora coelothrix*	relative growth rate	N/A	temperature