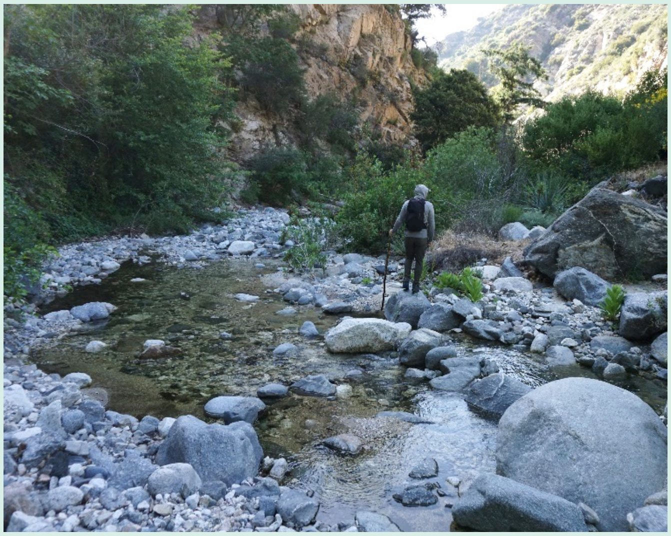
FINAL TECHNICAL MEMORANDUM ◦ SEPTEMBER 2020

Conceptual Ecological Model and Limiting Factors Analysis for Steelhead in the Los Angeles River Watershed



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Cover photos:
Clockwise from upper left: perennial stream habitat in the upper Arroyo Seco; juvenile steelhead; mainstem Los Angeles River at the 7th Street Bridge looking upstream; adult steelhead.

EXECUTIVE SUMMARY

The LA River watershed historically supported a population of steelhead (*Oncorhynchus mykiss*) belonging to the Southern California Steelhead Distinct Population Segment (DPS), which is listed as endangered under the federal Endangered Species Act. Steelhead, the anadromous[1] life history form of rainbow trout, are no longer present due to physical, chemical, and biological changes associated with urbanization of the LA River watershed. Restoring a steelhead population to the LA River watershed is a conservation goal that is consistent with the City of Los Angeles Mayor's Office biodiversity goals, the National Marine Fisheries Service's (NMFS) recovery goals for the DPS, County of Los Angeles biodiversity goals, U.S. Army Corps of Engineers (USACE) LA River and Arroyo Seco Watershed goals, and with the goals of numerous other agency and conservation organizations.

A major challenge for recovery of steelhead is providing access to suitable spawning and rearing habitat that exists in the upper tributaries. The LA River Fish Passage and Habitat Structures (LAR FPHS) design project is intended as a first step in surmounting these challenges. The LAR FPHS design project includes preparation of designs to modify a 4.8-mile section of the existing concrete-lined LA River flood control channel to improve fish passage for steelhead migration to soft-bottom reaches of the LA River and upper tributaries and provide important habitat features to benefit steelhead and other native fish. The LAR FPHS design project and its proposed concepts are fully consistent with design recommendations included in Alternative #20 of the USACE Integrated Feasibility Report for the LA River Ecosystem Restoration Project. In particular, the specific location of the LAR FPHS Project and its objective to redesign the channel bed are compatible with the proposed alternative to modify the existing mainstem channel of the LA River within a section that flows from Taylor Yard to the Union Pacific LA Trailer and Container Intermodal Facility (LATC, also known as Piggyback Yard). The LAR FPHS also aligns with the USACE Arroyo Seco Watershed Ecosystem Restoration Study, which is entering the Feasibility Study Design phase, focusing on opportunities for fish passage, stream naturalization, and overall habitat restoration along the Arroyo Seco from its confluence with LA River to the central Arroyo Seco reach just below Devil's Gate Dam.

This document is intended to provide the ecological basis for the steelhead passage and habitat improvements that are central to the LAR FPHS design project. It provides an overview of the current and historical riverine habitat conditions in the LA River watershed, the processes that create(d) and maintain(ed) these conditions, and the influence of these conditions and processes on the historical and potential future population of steelhead in the watershed. The document also describes our understanding of the life cycle and ecological interactions of the steelhead population that formerly occupied the LA River watershed, based on data from other steelhead populations in California and the Pacific Northwest and current and historical information for the LA River watershed. This information is presented in the form of a conceptual ecological model that describes steelhead freshwater life history and the primary ecological influences on these life history events, and identifies the habitat constraints most likely to affect the success of each life stage and limit productivity of the population.

The LA River occurs in a Mediterranean climate characterized by a wet and a dry season. Steelhead migrations (juvenile and adult) in the LA River would occur mainly during the wet season from approximately February through May when rain events and associated high flows

[1] Anadromous fish migrate to the ocean as juveniles and return to freshwater as adults to reproduce.

provide connectivity between the ocean and upstream habitat. Juvenile rearing would occur throughout the year in the watershed but would be limited to locations with suitable habitat and perennial flows (e.g., in the upper tributaries including the Arroyo Seco and Big Tujunga Creek). Under existing conditions, upstream migration of adults (and to a lesser extent downstream migration of juveniles) during the wet season is prevented due to the presence of numerous migration barriers. Major physical barriers (e.g., dams) prevent access to the tributaries of the LA River that contain the best habitat for spawning and rearing. Velocity barriers arise from concrete channelization of the LA River mainstem. These channelized sections create hydraulic conditions in which water velocity is too high for adults to migrate when water depth is suitable for migration, and vice versa, when water velocity is low enough for adult upstream migration, water depths are too shallow. Urbanization and associated modification of the natural drainage system has also reduced the duration of flow events large enough to support migration. Thus, the presence of migration barriers and altered flow patterns in the LA River are perhaps the most critical limiting factors for steelhead recovery.

Water quality is another potential limiting factor identified for steelhead in the LA River. Stressful and even lethally high water temperatures in the LA River mainstem largely preclude steelhead rearing opportunities and could disrupt migration and hinder the physiological transition to salt water. Urbanization and wastewater treatment inputs contribute to high water temperatures within the mainstem. Suitable temperatures for spawning, early life stage development, and rearing occur within tributaries, which suggests that steelhead could successfully spawn and rear in these locations if access were provided.

Other potential limiting factors include the amount of rearing habitat, the presence of non-native species, and artificial lighting. Rearing habitat is mostly absent or unsuitable in the mainstem LA River, lower tributaries, and the LA River estuary but suitable rearing habitat is present above barriers in the major tributaries. Non-native species in the mainstem and lower tributaries could act as predators or competitors with young steelhead, but the presence of non-natives generally decreases further upstream in the watershed where spawning and rearing would occur. Artificial lighting, especially in more urbanized areas such as the mainstem LA River, could disrupt life history transitions and behavioral patterns and result in increased predation of juveniles during their downstream migration. Under existing conditions, the mainstem LA River is not suitable for steelhead rearing but conditions improve in an upstream direction, with the best conditions in upper tributaries. Suitability of conditions in upper tributaries is further supported by recent surveys that found resident rainbow trout at several locations.

Although resident rainbow trout may exist in some locations within upper tributaries, their low abundance combined with the high likelihood that these fish are of hatchery descent (and thus may not have genes associated with anadromy) is another major limiting factor for steelhead population viability and recovery within the watershed. Small population sizes and the presence of barriers limit the ability of these fish to move and colonize new habitats. This in turn makes the populations less resilient to ecological disturbances, such as droughts and floods, that are projected to increase in severity and frequency with climate change.

Based on the limiting factors identified above and known life history patterns of Southern California steelhead, we propose a conceptual ecological model for steelhead in the LA River. If adults were provided passage to spawning habitat within tributaries, which is not currently accessible, the number of spawning adults would not be considered a major limiting factor to the population because adult steelhead have high fecundity relative to the amount of rearing habitat. Consequently, even a few reproducing adults could produce enough offspring to fully occupy available rearing habitat. Fish passage improvements facilitating upstream and downstream migration between the ocean and tributary habitats would restore genetic exchange between anadromous and resident life history types, likely improving population viability and reducing extinction risk. Juveniles would rear for up to two years in tributaries near where they spawned, during which time the amount of suitable rearing habitat in the dry season (i.e., deep pools that provide perennial habitat and refuge from predators and high temperatures) and wet season (i.e., structure that provides shelter from high flows) would be the primary limiting factors for the population, especially for older, larger juveniles that require more resources and thus larger territories to meet their metabolic demands. Anadromous juveniles would migrate downstream during winter high flows when water temperature and quality are most suitable. Under existing conditions there would be no opportunities to rear in the LA River mainstem or estuary prior to entering the ocean, which could result in low ocean survival.

To improve our understanding of steelhead dynamics within the LA River and for prioritizing restoration actions, we recommend additional data collection in the form of watershed-wide barrier assessments, habitat surveys, *O. mykiss* population surveys, and water temperature monitoring. We conclude that recovery of steelhead in the LA River is possible if key limiting factors are addressed. Immediate establishment of resident subpopulations could be achieved through translocations of *O. mykiss* from existing populations with predominantly native steelhead ancestry to locations with suitable spawning and rearing conditions (e.g., upper Arroyo Seco and Big Tujunga). If upstream and downstream passage were provided, recovery of an anadromous life history could also be achieved.

It is our hope that the next steps for steelhead recovery in the LA River watershed will benefit from and build upon the information in this Conceptual Ecological Model and Limiting Factors Analysis through pilot projects, planning and implementation of recommendations and priorities, and strategic funding partnerships to build momentum and support implementation of long-term sustainable actions for steelhead recovery. Specifically, the watershed-wide steelhead recovery actions, data gaps, and priority actions are currently linked to the overall City and County biodiversity action plans which include monitoring and adaptive management actions tracked against performance metrics as well as other statewide performance metrics associated with grants and fish passage programs such as the Wildlife Conservation Board fish passage program and California Department of Fish and Wildlife fish passage program. The envisioned timeline for implementation of these steelhead recovery actions would see completion of immediate LA River steelhead passage and subpopulation expansion and translocation projects in the next 10 years, with more extensive barrier removal and habitat improvement in the next 20 years.

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1 INTRODUCTION AND APPROACH

1.1 Introduction

Anadromous fish like steelhead (*Oncorhynchus mykiss*) serve as an indicator of aquatic habitat connectivity and quality at the watershed scale. While steelhead no longer occur in the Los Angeles (LA) River watershed, their reestablishment is a lofty but attainable goal that is consistent with the City of Los Angeles Mayor's Office biodiversity goals and with the National Marine Fisheries Service's (NMFS) recovery goals for the regional steelhead population group (NMFS 2012). The goal of steelhead reestablishment is also shared by other adopted sustainability, resiliency, and biodiversity policies and plans on federal, state, regional, and local levels. Among the most significant challenges in this effort will be providing successful passage between the ocean and the steelhead's mountain spawning and rearing habitat. Adult and juvenile steelhead formerly navigated the LA River and tributaries during the migratory freshwater phases of their life cycle. While suitable spawning and rearing habitat still exists in some mountain tributary streams within the watershed, extensive urbanization, flood control infrastructure, and water uses have severely altered the intervening reaches of the LA River and portions of the tributaries, effectively preventing upstream and downstream migration. Multiple funding opportunities and multi-benefit watershed projects are aligning to allow for planning and implementation of steelhead recovery actions that not only address many challenges associated with recovery of this keystone species, but also provide opportunities to address other integrated water management objectives and needs in the urban communities within the watershed and the LA region.

The LA River Fish Passage and Habitat Structures (LAR FPHS) design project is intended as a first step in surmounting these challenges. The LAR FPHS design project includes preparation of designs to modify a portion of the existing concrete-lined LA River flood control channel to improve fish passage for steelhead migration to soft-bottom reaches of the LA River and upper tributaries and provide important habitat features to benefit steelhead and other native fish. The LAR FPHS design project reach starts at the downstream end of the Glendale Narrows soft-bottom reach and extends downstream to Washington Boulevard, a total of 4.8 miles of the concrete-lined LA River through downtown LA (Figure 1-1). The proposed design process for the 4.8-mile project reach will evaluate fish-friendly design alternatives for the concrete-lined channel and connections to related restoration opportunities such as Piggyback Yard, the confluence of the Arroyo Seco, and the upstream soft-bottom reach of the LA River. Fish passage and habitat improvements may involve cutting and modifying the concrete channel bottom and low-flow notch to enhance habitat and provide suitable migration conditions for steelhead and ancillary benefits for other native fish while maintaining flood control capacity.

The LAR FPHS design project will link to other biodiversity projects within the City of Los Angeles (City), the LA River watershed, and its upper tributaries (Arroyo Seco and Tujunga watersheds). The LAR FPHS design project is consistent with the LA River Revitalization Master Plan (LARRMP) adopted by the City in May 2007 (City of LA 2007). Similarly, the LAR FPHS Project is meant to implement other relevant existing adopted plans, policies, and recommendations from federal, state, regional, and local authorities within the LA River watershed, including the NMFS Southern California Steelhead Recovery Plan (NMFS 2012), the Greater Los Angeles County (GLAC) Integrated Regional Water Management Plan (IRWMP) (GLAC IRWM Region 2014), the Los Angeles County LA River Master Plan (LACDPW 2019), the Mayor of LA's Sustainability City Plan (City of LA, Mayor of LA 2019), and the City of LA Biodiversity Report (City of LA 2018).

While focused on providing fish passage and habitat structures to address limiting factors to steelhead, the LAR FPHS design project also addresses watershed-wide data gaps and opportunities to promote future projects and address other limiting factors to steelhead and native fish recovery from coast to mountain crest.

This document is intended to provide the ecological basis for the steelhead passage and habitat improvements that are central to the LAR FPHS design project. It provides an overview of the current and historical riverine habitat conditions in the LA River watershed, the processes that create(d) and maintain(ed) these conditions, and the influence of these conditions and processes on the historical and potential future population of steelhead in the watershed. The document also describes our understanding of the life cycle and ecological interactions of the steelhead population that formerly occupied the LA River watershed, based on current and historical information for the LA River watershed and data from other steelhead populations in California and the Pacific Northwest. This information is presented in the form of a conceptual ecological model that describes steelhead freshwater life history and the primary ecological influences on these life history events and identifies the habitat constraints most likely to affect the success of each life stage.

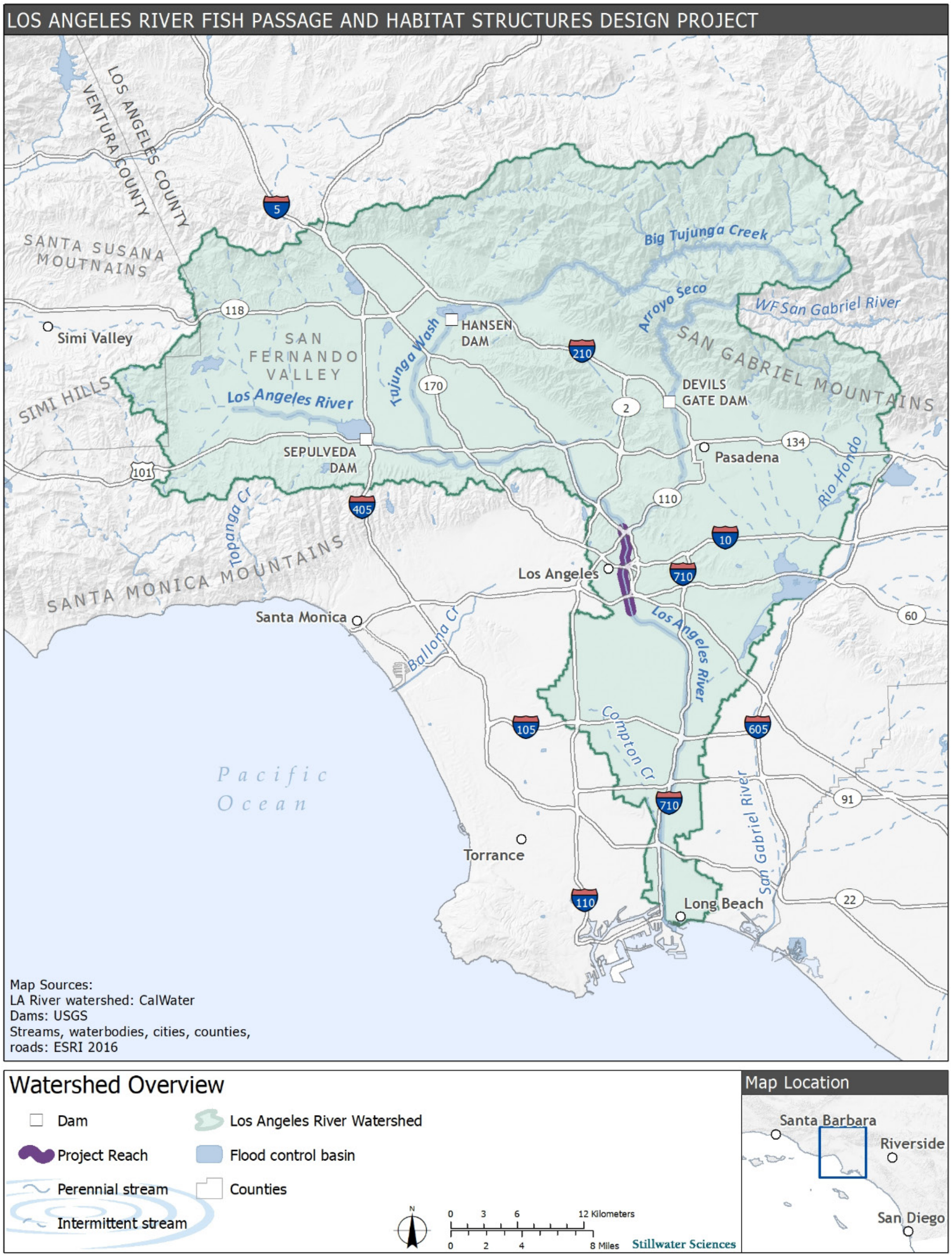

Figure 1-1. The LA River watershed showing the 4.8-mile LAR FPHS design project reach.

1.2 Approach to the Analysis

For this analysis we evaluated and synthesized historical and current information to explore factors that likely limited steelhead abundance and production in the LA River watershed under historical conditions and to identify which factors are likely to limit the successful reestablishment of steelhead under current and potential future conditions. Because steelhead no longer occur in the watershed, the analysis included an assessment of historical conditions using available information to document changes that have occurred in stream habitat conditions, particularly those most likely to affect steelhead. Where information is lacking or uncertainties remain, we developed hypotheses regarding potential limiting factors for steelhead using the best available information. The analysis and hypotheses were developed for each steelhead freshwater life stage to help understand how factors acting at each life stage could pose limitations at the population level. The results and hypotheses generated through the limiting factors analysis provide the basis for a conceptual ecological model that describes our knowledge and hypotheses regarding past, present, and future steelhead life history and ecology in the LA River watershed.

The limiting factors analysis and conceptual ecological model provide information to help identify and prioritize future management and restoration actions that will support the reestablishment of steelhead in the LA River and enhancement of biological diversity and habitat connectivity throughout the watershed. We begin with a description of steelhead life history and population status, followed by a description of conditions in the LA River watershed.

2 LIFE HISTORY AND STATUS OF SOUTHERN CALIFORNIA STEELHEAD

2.1 Life History Overview

Steelhead is a species of Pacific salmon that can migrate to the ocean, referred to as anadromous, or complete its life cycle entirely in freshwater, referred to as resident. Steelhead is the term used to describe the anadromous life history type, whereas freshwater residents are generally referred to as rainbow trout. The factors influencing life history strategies (e.g., resident versus anadromous) of the species are complex and not well-understood, but are likely related to a combination of genetics, internal conditions (e.g., growth rate), and environmental factors (Kendall et al. 2015, Boughton et al. 2006, Sogard et al. 2012, Satterthwaite et al. 2010, Mills et al. 2012). The two life history forms are capable of interbreeding and current evidence suggests that, under some conditions, either life history form can produce offspring that exhibit the alternate form (i.e., resident rainbow trout can produce anadromous progeny and vice-versa) (Burgner et al. 1992, Hallock 1989, Donohoe et al. 2008, Zimmerman et al. 2009, Courter et al. 2013), although in some watersheds, such as those where barriers largely isolate subpopulations, the two life histories are distinct (Pearse et al. 2009). Due to these complexities, the term *O. mykiss* is generally used when life history types are indistinguishable, such as when they are juveniles, or when referring in general terms to a population whose life history type expression is uncertain.

Steelhead in Southern California express a ‘winter-run’ life history type, meaning adults enter freshwater during winter and spawn shortly thereafter (as opposed to ‘summer-run’ steelhead that enter freshwater in the summer and spawn in the following winter/spring). Steelhead enter freshwater in their fourth or fifth year of life as sexually mature adults with males typically returning to fresh water earlier than females (Shapovalov and Taft 1954, Behnke 1992, Busby et al. 1996). Steelhead in Southern California are highly adapted to the flashy flow regime characteristic of rivers in this region, and river entry is associated with high flow events during the wet season (winter and spring) that provide connectivity through intermittent river sections. Steelhead typically enter rivers from January through May, but earlier and later migrations may sometimes occur (Table 2-1). Spawning can occur from late fall into spring, with peak spawning activity between January and March. Female steelhead construct redds in suitable gravels, often in pool tailouts and heads of riffles, or in isolated patches in cobble-bedded streams. Steelhead are an iteroparous species, meaning after spawning, adult steelhead can return to the ocean as kelts and have the potential to then return to freshwater to reproduce multiple times in a lifespan (as opposed to semelparous species of Pacific salmonids that die shortly after spawning).

Table 2-1. Migration timing of juvenile and adult steelhead in Southern California. Darker shading indicates months in which a higher proportion of migrants are expected. Figure based on data collected from the Santa Ynez (COMB 2011) and Santa Clara Rivers (Booth 2016, 2020).

Steelhead life history type	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
juvenile migrations												
adult migrations												

Steelhead eggs incubate in the redds for 3–14 weeks, depending on water temperatures (Shapovalov and Taft 1954, Barnhart 1991). After hatching, alevins remain in the gravel for an additional 2–5 weeks while absorbing their yolk sacs, and then emerge in spring or early summer (Barnhart 1991). After emergence, steelhead fry move to shallow, low-velocity habitats such as stream margins and low-gradient riffles, and forage in open areas lacking instream cover (Hartman 1965, Fontaine 1988). As fry grow and improve their swimming abilities in late summer and fall, they increasingly use areas with cover and show a preference for higher velocity, deeper mid-channel areas near the thalweg (the deepest part of the channel) (Hartman 1965, Everest and Chapman 1972, Fontaine 1988).

Juvenile steelhead (parr) rear in freshwater before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

Juvenile steelhead occupy a wide range of habitats during rearing, preferring deep pools as well as higher velocity riffle and run habitats (Bisson et al. 1982, Bisson et al. 1988). During periods of low temperatures and high flows that occur in winter months, steelhead prefer low-velocity pool habitats with large rocky substrate or woody debris for cover (Hartman 1965, Raleigh et al. 1984, Swales et al. 1986, Fontaine 1988). During high winter flows, juvenile steelhead seek refuge in interstitial spaces in cobble and boulder substrates (Bustard and Narver 1975, Meyer and Griffith 1997). Generally speaking, juvenile steelhead prefer cool, flowing waters with riffle-pool complexes in stream reaches that have adequate riparian shading. However, juveniles can also rear in estuaries demonstrating the complexity and plasticity in their life cycle. Resident *O. mykiss* (including juveniles and adults) occupy similar habitats as anadromous juvenile steelhead.

Juvenile emigration (i.e., outmigration) in Southern California typically occurs from March to June, but can occur as early as January and as late as July (Table 2-1) (Booth 2020). Emigration appears to be more closely associated with size than age, with a body length of 6–8 inches (in)

(15–20 centimeters [cm]) being most common for downstream migrants. Varying life history strategies for outmigration include freshwater potamodromous, ocean anadromous, and estuary anadromous life history types. Freshwater potamodromous fish migrate entirely within freshwater (i.e., they are considered freshwater resident fish), and these fish can migrate within tributaries or to mainstem rivers (i.e., fluvial) or can migrate to lakes (i.e., adfluvial) before migrating back upstream (Moyle 2002). Ocean anadromous fish migrate downstream and either enter the ocean immediately or rear in estuaries for a month to a year prior to entering the ocean (Shapovalov and Taft 1954, Barnhart 1991). In locations where sandbars are present in the estuary, ocean entry of juveniles is only facilitated when flows are high enough to connect estuaries with the ocean. Estuarine anadromous migrations culminate when the smolt reaches the estuary, where individuals may utilize the resources within this environment to feed at an elevated metabolic rate. These individuals then forgo migration into the ocean and return to upstream habitat (Hayes et al. 2011). Estuary rearing is more common in southern populations of steelhead compared to northern populations and is thought to confer a growth advantage compared to rearing in upper watersheds (Hayes et al. 2008, Satterthwaite et al. 2010). An estuarine anadromous life history has been shown for *O. mykiss* in central California (Hayes et al. 2011), and based on size data from upstream-migrating fish captured in the Santa Ynez river, an estuary anadromous life history may also occur in Southern California rivers (COMB 2011). The age of outmigration depends partly on growing conditions in their rearing habitat, but steelhead leaving freshwater may migrate downstream to estuaries as age 0+ juveniles or may rear in streams for up to four years before outmigrating to the estuary and ocean (Shapovalov and Taft 1954). Variability in rearing locations and ocean entry decisions exhibited by *O. mykiss* exemplifies the diversity in life history expression of *O. mykiss* and contributes to their success across a wide range of conditions.

2.2 Population Status

Anadromous and resident *O. mykiss* formerly occupied most of the rivers and streams draining Southern California's coast ranges, including the LA River and its major tributaries (NMFS 2012, Becker and Reining 2008, Swift et al. 1993). Steelhead populations in the LA River likely began declining rapidly in the early 20th century as a result of dramatic changes in land and water use (e.g., urbanization, channelization of rivers, dams, groundwater pumping, and water diversions) associated with the rapid human population growth in the Los Angeles area that was occurring at the time. The last documented steelhead in the LA River was caught near Glendale in January 1940 (Figure 2-1; Gumprecht 2001). While anadromous *O. mykiss* (i.e., steelhead) no longer occur in the LA River watershed, resident populations still exist in some of the mountain tributaries (SRMA 2020).

Figure 2-1. Steelhead caught in the LA River near Glendale, January 1940. Photo: family of Dr. Charles L. Hogue (Gumprecht 2001).

Historical population sizes for individual watersheds are not known, but total abundance in Southern California was estimated to be 32,000–46,000 returning adults annually (NMFS 2012). Abundance in some mountain watersheds in the LA River basin was supplemented by stocking to help support recreational angling but stocking no longer occurs in the basin (NMFS 2012, Becker and Reining 2008). Recent stream survey results summarized by SRMA (2020) provide qualitative abundance estimates for *O. mykiss* in several tributaries within the LA River basin based on visual estimates that included categories of "common" (many fish observed across habitats), "uncommon" (a few fish observed across an entire reach), and "rare" (only a single fish observed in an entire reach). The surveys documented *O. mykiss* in the following LA River tributaries: the Arroyo Seco upstream of Hahamongna Watershed Park ("uncommon;" surveyed in December 2010); lower Big Tujunga Creek ("uncommon;" surveyed in October 2018); upper Big Tujunga Creek ("rare;" surveyed in August 2019); and lower Alder Creek ("uncommon;" surveyed in November 2012). These fish have no known contribution from or to anadromous populations of *O. mykiss* and are therefore considered isolated resident populations. No *O. mykiss* were reported by SRMA (2020) from surveys conducted in Haines Creek, a tributary to Big Tujunga Creek (surveyed in September 2016) or Pacoima Creek (Wash) (surveyed in September 2017).

2.2.1 Listing status

Steelhead from the LA River belong to the Southern California Steelhead Distinct Population Segment (DPS), which includes coastal streams and rivers from the Santa Maria River south to the Tijuana River near the U.S.-Mexico border (NMFS 2012). The Southern California Steelhead DPS is an ecologically distinct population which was first listed as endangered under the federal

Endangered Species Act (ESA) in 1997 (62 FR 43937). An endangered species is a species considered to be in danger of extinction throughout all or a significant portion of its range. Critical habitat for Southern California steelhead, designated in 2005 (70 FR 52488), does not include any rivers or streams in the LA River watershed. The federal endangered listing was reaffirmed in 2006 (71 FR 834). In 2014, NMFS updated the listing to include only naturally-spawned populations originating below natural and manmade impassable barriers (79 FR 20809), which specifically excludes *O. mykiss* populations in the upper LA River tributaries, all of which exist upstream of impassable dams. The Southern California Steelhead DPS is not listed under the California Endangered Species Act (CDFW 2020).

2.2.2 Recovery planning

The Southern California Steelhead Recovery Plan (NMFS 2012) provides a strategy and recommended actions intended to meet the overall goal of preventing extinction of Southern California steelhead in the wild and ensuring the long-term persistence of viable, self-sustaining steelhead populations across the range of the Southern California Steelhead DPS. In the Recovery Plan, NMFS divides the DPS into distinct Biogeographic Population Groups (BPGs). The LA River is part of the Mojave Rim BPG. The Recovery Plan includes recommended recovery actions for individual watersheds within the BPG, including the LA River and the Arroyo Seco. Recovery actions for the LA River and the Arroyo Seco include habitat restoration, remediation of passage barriers, control of non-native species, and other actions that address the major stressors and limiting factors for steelhead identified in the Recovery Plan (NMFS 2012). The analysis of limiting factors in this document (Sections 4 and 6) and recommendations for future actions (Section 7) are intended to support the NMFS recovery goals and help meet objectives for steelhead recovery in the LA River watershed and the Mojave Rim BPG.

One of the objectives of the Recovery Plan, which is also the goal of the LAR FPHS design project, is to restore steelhead to some of the watersheds they previously occupied. The Recovery Plan (NMFS 2012) notes that relatively large areas of high-quality *O. mykiss* habitat exist above the many passage barriers in the river systems within the Southern California Steelhead DPS. This includes habitat in the upper reaches of the Arroyo Seco and the Big Tujunga system (Boughton et al. 2006). While these areas are upstream of impassable barriers and are therefore not currently included within the DPS, they are nonetheless considered a major focus of recovery actions because these habitat areas comprise most of the suitable steelhead spawning and rearing habitat within the species' historical range.

Recovery of steelhead in the Southern California DPS will require careful consideration of population genetics and the role of *O. mykiss* populations in upper portions of the watersheds that may be reproductively isolated from anadromous populations for considerable periods of time between anadromous spawning events. Because resident *O. mykiss* can produce anadromous progeny and therefore contribute to the maintenance of the steelhead genetic component, preservation of both life history forms is considered a high priority in the Recovery Plan (NMFS 2012). Recent genetic research indicates that historical stocking with introduced lineages, primarily from the Central Valley DPS, has reduced or eliminated native *O. mykiss* lineages in the Mojave Rim BPG, posing a substantial risk to recovery and viability of steelhead in the Southern California DPS (NMFS 2016). Translocation of native *O. mykiss* from remaining native populations, which include those in the headwaters of the San Gabriel, Santa Ana, and San Luis Rey rivers, would help reestablish critical native-lineage subpopulations and may be an important part of the recovery strategy for the LA River and other watersheds in the Mojave Rim BPG and the Southern California Steelhead DPS. By increasing spatial structure and genetic diversity of the overall population and ameliorating the effects of hatchery influence, this approach would help reduce extinction risk by addressing two critical parameters of the viable salmonid population (VSP) concept: spatial structure and diversity (McElhany et al. 2000). Expansion of the steelhead population via reestablishment of subpopulations at multiple locations throughout the BPG and the DPS ("subpopulation expansion") would spread risk and help improve viability of the population by providing multiple sources for genetic mixing and increasing the chances of reestablishment (e.g., via straying) of subpopulations that may become extirpated as a result of relatively localized catastrophic events such as extreme fires, toxic spills, or other risks (McElhany et al. 2000, Lindley et al. 2007).

3 THE LA RIVER WATERSHED

In this section, we describe current conditions in the LA River watershed and, when known, how they compare to historical conditions. Where appropriate data are available and relationships to the habitat requirements and physiological tolerances of steelhead are known, we have attempted to relate watershed conditions to steelhead suitability. More detailed discussion of how conditions would likely influence steelhead population success and implications for steelhead ecology and life history is provided in Sections 4 and 5, respectively.

3.1 Physical Setting

The LA River watershed drains 834 square miles (mi^2) (2,160 square kilometers [km^2]) of land (CWH 2018) stretching from the San Gabriel Mountains on the northern end of the Los Angeles Basin to the Pacific Ocean (Figure 1-1). The watershed is bounded by three mountain ranges, alluvial fans, fluvial valleys, and a broad coastal plain. The northern boundary is demarked by the drainage divide of the San Gabriel Mountains. South of the San Gabriel range, the west-east trending Santa Monica Mountains define the southern boundary of the San Fernando Valley, provide the distinctive shape of the Los Angeles watershed, and influence the west-east orientation of the upper LA River. The third mountain range, composed of the Santa Susana Mountains and Simi Hills, provides the northwest boundary of the watershed. The topography of the watershed is dramatic, with elevations ranging from 7,100 feet (ft) (2,164 meters [m]) in the northwestern San Gabriel Mountains to sea level over a mere 51 miles (mi) (82.1 km) (CWH 2018).

3.2 Climate

The LA River is located in a region with a Mediterranean climate characterized by warm, dry summers, and cool, wet winters with short, sometimes intense, winter storm events. Air temperatures in the region are moderate in the winter (40–69°F [4–21°C]) and there is little variability across locations within the watershed. Air temperatures in the summer are higher (56–93°F [13–34°C]) with more variability across locations. Air temperature in coastal areas in the summer is approximately 10°F (5°C) cooler compared to more inland locations. Precipitation in the region is also variable. This is due, in part, to the rain shadow effect, which traps moist ocean air against the mountains and creates spatial variation in precipitation as elevation increases. For example, Altadena, located at 1,300 ft (396 m) along the foothills of the San Gabriel Mountains, receives 10 more in (25.4 cm) of annual precipitation, on average, than Los Angeles, located at 285 ft (86.9 m) (CWH 2018, WRCC 2020).

Despite a warm climate that is moderated by a maritime effect, the region is also naturally prone to climatic extremes and oscillations between wet and dry periods. Precipitation varies considerably from year to year due to drought and climate phenomena, such as the El Niño Southern Oscillation (ENSO) (WRCC 2020). Intense storm events, particularly over the San Gabriel Mountains, are, in part, due to atmospheric rivers. These bands of moisture originate in the tropics, akin to a river in the sky, and deliver 30–50% of California's precipitation over short time spans. Atmospheric rivers have been responsible for historic megafloods (Dettinger and Ingram 2013). Additionally, multi-year droughts, lasting a decade or more have been noted in California's paleohydrological record and are a looming possibility (Griffin and Anchukaitis 2015, MacDonald 2007). The most recent drought, beginning in 2012, was record setting because it coincided with record warmth, low streamflow, enhanced wildfire risk, and overdrafting of the state's groundwater resources (DWR 2015, Diffenbaugh et al. 2015).

Climate change is already affecting the region and will exacerbate climatic extremes. Between the years of 1950 and 1999, climate-influenced changes in hydrology resulted in more precipitation falling as rain instead of snow, earlier timing of snow melt, and increased river flows during the spring and decreased flows in the summer (Barnett et al. 2008). Record highs for average annual temperatures have all occurred in the last decade and temperature maxima are projected to increase by 4 to 5°F (2.2 to 2.8°C) by mid-century (Hall et al. 2018). Scenarios modeled on business as usual assumptions predict that the region will experience extreme dry and wet events more frequently (Aghakouchak et al. 2018, Swain et al. 2018). Droughts, for example, are predicted to become more frequent, intense, and to last for longer periods of time, ushering an era of persistent aridity (Cook et al. 2015, MacDonald 2008). Additionally, despite uncertainties in modeled scenarios, California is also expected to experience more frequent fires and larger burned areas under a business as usual scenario (Jin et al. 2015). Based on statistical models that account for climate and land use change, fires are projected to burn an additional 2000 hectares annually by the mid-21st century (Hall et al. 2018, Westerling et al. 2018, Wilhelm et al. 2018). The destructive cycle of drought, fires, and large storm events in addition to the impact increased temperatures and low precipitation have on the state's water resources will stress ecosystems, infrastructure, and human communities.

3.3 Hydrology

The hydrology of the LA River is characteristic of its Mediterranean climate, with relatively steady low flows during the summer-fall dry period and higher winter flows punctuated by large, storm-driven peaks that recede quickly (Figure 3-1). Historically, summer flows may have been intermittent or ephemeral in some locations (Figure 3-2), but now flow occurs year-round due to urban runoff, reclaimed water discharges, and lack of infiltration in the concrete-lined channel network. Summer flows are low and consistent, while winter storms produce runoff that routes efficiently through the heavily urbanized watershed and flood conveyance system, resulting in large, rapid increases in river flows and equally rapid decreases (i.e., "flashy" storm flows). The entire watershed has been modified to move water efficiently away from urban areas to the detriment of natural ecological function. As a result, there are few natural sections of the mainstem LA River and tributaries to dissipate storm flows.

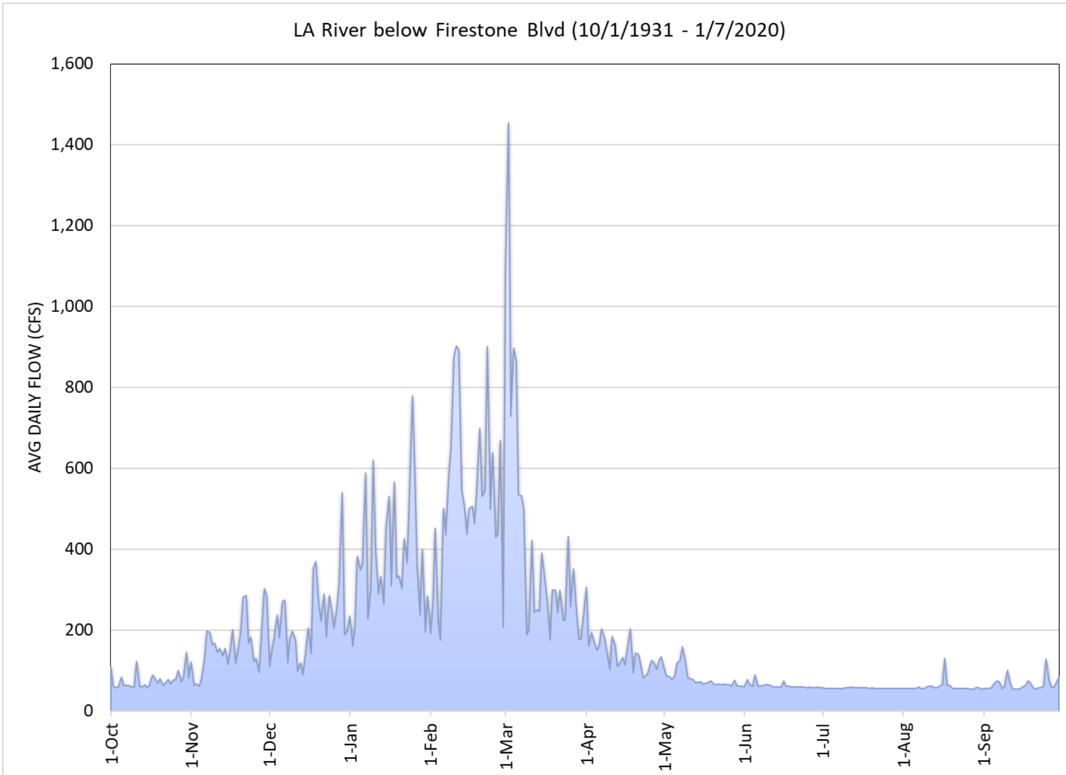

Figure 3-1. Average daily flow in the LA River below Firestone Blvd (LACDPW Station F34D-R), 1931–2020. Source: LA County Department of Public Works.

Figure 3-2. Assumed natural flow patterns for the LA River prior to urbanization and modification of the drainage system.

3.3.1 LA River tributaries

The highly modified condition of each tributary's watershed results in changes to the LA River's hydrology downstream of each tributary confluence. The mainstem LA River originates in the Simi Hills and Santa Susana Mountains of the western San Fernando Valley. The Arroyo

Calabasas and Bell Creek flood control channels converge to form the official "start" of the LA River on its 51-mi (82.1 km), mostly channelized, course to the Pacific Ocean. The western San Fernando Valley tributaries also include, in order from west to east, Browns Canyon Wash, Aliso Creek, and Caballero Creek, all concrete flood control channels at their confluence with the LA River and for many miles upstream. Roughly one mile downstream of its confluence with the Caballero Creek flood control channel, the LA River transitions to a soft-bottom flood control channel and enters the Sepulveda Basin, a 22,493 acre-ft (AF) (27.7 million cubic meters [m^3]) flood control basin maintained by the U.S. Army Corps of Engineers (USACE). The LA River at Sepulveda Dam has a drainage area of 152 mi^2 (394 km^2), or about 18% of its total drainage area (Table 3-1). Downstream of Sepulveda Dam there are no flood control basins or major diversions to impede or attenuate the LA River's storm flows; only the flood control channel itself to direct the remaining tributary inflows to the Pacific Ocean.

Downstream of Sepulveda Dam, the LA River continues its course across the southern San Fernando Valley where it joins the Tujunga Wash near Studio City (Figure 1-1). Tujunga Wash is the largest tributary of the LA River by drainage area, and includes Big Tujunga Creek, Little Tujunga Creek, Pacoima Wash, and many smaller tributaries. At its confluence with the LA River, Tujunga Wash has a greater drainage area (225 mi^2 [583 km^2]) than the LA River to that point (176 mi^2 [456 km^2]) (Table 3-1). Little Tujunga Creek joins Big Tujunga Creek at the site of Hansen Reservoir (28,380 AF [35 million m^3]) and Pacoima Wash joins the Tujunga Wash roughly three miles farther downstream. Tributaries draining the San Gabriel Mountains are subject to greater precipitation than lower-elevation parts of the LA River basin. As a result, and due to the relatively large size of the Tujunga-Pacoima subwatershed, the majority of flood flows and sediment supply to the lower LA River would have historically originated from the Tujunga Wash drainage (Lavé and Burbank 2004).

Downstream of the confluence with Tujunga Wash, the LA River continues to flow east along the northern toe of the Santa Monica Mountains and past its confluence with the urbanized Burbank Western Channel watershed and transitions to a 0.75-mi (1.2 km) soft-bottom flood control channel before joining Verdugo Wash, where it turns south and transitions again to a soft-bottom flood control channel as it enters the Glendale Narrows. The south-flowing LA River is subsequently joined by the Arroyo Seco (47 mi^2 drainage area [122 km^2]) near Elysian Park. The Arroyo Seco upstream of Devil's Gate Dam (1,928 AF [2.4 million m^3]) and the Hahamongna Reservoir is virtually unaltered except for the defunct Brown Mountain Dam (600 AF [740,000 m^3]), which was installed as a debris dam by the USDA Forest Service in 1942 and filled to capacity with sediment within a few seasons (Arroyo Seco Foundation). Downstream of Devil's Gate Dam the Arroyo Seco channel is lined with concrete for 9.6 mi (15.4 km) to its confluence with the LA River except for two short soft-bottom reaches totaling 0.5 mi (0.8 km). There are no major tributaries downstream of the Arroyo Seco through downtown Los Angeles, only local stormwater discharges, until the Rio Hondo (142 mi^2 drainage area [368 km^2]) confluence near the City of South Gate and Compton Creek (42 mi^2 drainage area [109 km^2)] at the City of Carson. The LA River watershed contains approximately 225 mi (362 km) of constructed flood control channel (USACE 2015a).

Table 3-1. Drainage areas of major tributaries to the LA River[1].

Tributary	Drainage area	
	(mi^2)	**(km^2)**
LA River Upstream of Sepulveda Dam	152	394
Tujunga Wash	225	588
Burbank Western Channel	26	67
Verdugo Wash	30	78
Arroyo Seco	47	122
Rio Hondo	142	368
Compton Creek	42	109
Other	170	440
Total	**834**	**2160**

[1] Source: CWH (2018).

3.3.2 Hydromodification

The hydrology of the LA River has been highly altered by tributary dams, water diversions, urban stormwater development, groundwater extraction, and discharge from water treatment facilities. Deadly floods in 1914 and 1938 led to implementation of comprehensive flood control from the mountain tributaries to the mainstem LA River. Devil's Gate Dam on the Arroyo Seco was completed in 1920 and was the first built by the Los Angeles County Flood Control District, formed in 1915 (CWH 2018). Pacoima Dam and Reservoir (3,929 AF [4.8 million m^3)] was completed in 1929, Big Tujunga Dam (6,027 AF [7.4 million m^3]) in 1931, and Hansen Dam in 1940. The Flood Control Act of 1936 authorized funding for "reservoirs and principal flood channels" across the nation, including the LA River, and initiated construction of the network of concrete flood control channels that now define the LA River's course from coast to crest.

In addition to flood control facilities, there are also groundwater recharge facilities, or spreading grounds, downstream of Hansen Dam on Tujunga Wash, along Pacoima Wash, in Hahamongna Reservoir behind Devil's Gate Dam on the Arroyo Seco, downstream of Whittier Narrows along the Rio Hondo, and at Dominguez Gap along the lower LA River. These recharge facilities divert and infiltrate stormwater, as well as base flows, into groundwater basins to increase local water supply resiliency. This capture of stormwater prevents significant portions of the river's flow from moving downstream. For example, roughly half of the inflow to Hansen Dam is diverted to the Hansen Spreading Grounds (USACE 1998). However, the original sediment storage capacity at these facilities has been exceeded and their ability to attenuate peak flows and trap sediment has been diminished (USACE 2015a).

From 1966 to 1985, three water reclamation plants were brought on line and began discharging effluent into the LA River at the Burbank Western Channel approximately 2.3 mi (3.7 km) upstream from its confluence with the LA River (Burbank Water Reclamation Plant in 1966), the Glendale Narrows (Los Angeles-Glendale Water Reclamation Plant in 1976), and Sepulveda Basin (D.C. Tillman Water Reclamation Plant in 1985). As a result, average monthly flows in the mainstem LA River, including winter and summer base flow levels, have increased in recent decades (Figure 3-3). The higher base flows and lack of seasonal drying provide suitable habitat for non-native and invasive species which can outcompete or prey on native species, resulting in a lower level of biological diversity and resiliency than what would exist under lower (historical) base flow rates, particularly during dry weather conditions (TNC 2016). Increased demand for reclaimed or recycled water, to offset domestic water imports and increase local water supply resiliency, has the potential to reduce this source of base flows and change the LA River flow regime once again. The Southern California Coastal Water Research Project (SCCWRP) is currently conducting an environmental flows study to determine impacts of diverting discharges from the LA River that includes steelhead as one of the sensitive species evaluated.

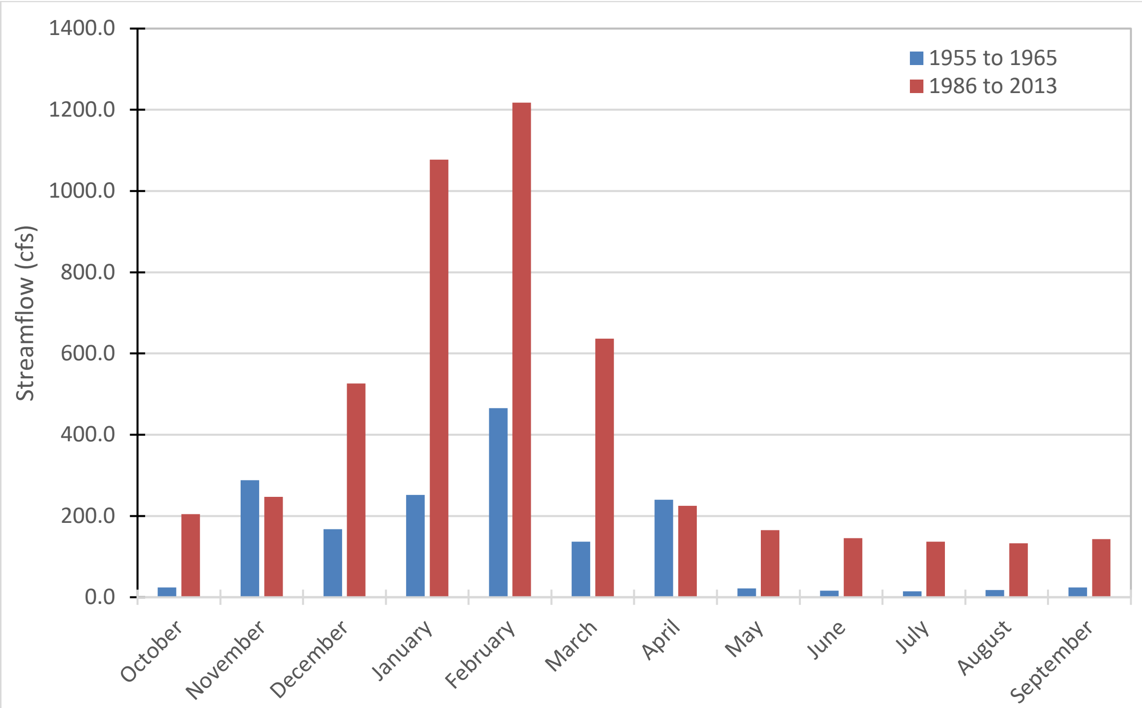

Figure 3-3. Average monthly flow in the LA River below Firestone Boulevard (LACDPW Station F34D) for the periods 1931–1965 and 1986–2013. Increases in monthly average streamflow for the period of 1986-2013 can be attributed primarily to urbanization and wastewater treatment plant effluent. Source: LA County Department of Public Works.

3.3.3 Spatial hydrologic patterns

Altered hydrologic patterns in the major LA River tributaries (e.g., Tujunga Wash and the Arroyo Seco) are largely attributable to dams and urban stormwater development in their lower reaches. The upper reaches of the Arroyo Seco and Big Tujunga Creek above the major dams feature perennial flow and stream habitat conditions suitable for *O. mykiss* spawning and year-round rearing (e.g., Figure 3-4). Historically, these perennial reaches would have provided abundant coldwater habitat for steelhead and resident trout. Flow in the lower reaches of these tributaries is regulated by dams and diversions, with variable flow conditions affected by a concrete-lined channel and numerous inputs of concentrated stormwater runoff.

Figure 3-4. Perennial coldwater habitat in the Arroyo Seco, upstream of Devil's Gate Dam and Hahamongna Watershed Park, May 2020.

The Arroyo Seco was depicted on early maps as a seasonally intermittent stream in its lower reaches (USGS 1897) and early accounts characterize it as flowing each winter but dry during summer and fall (e.g., Reid 1895). Flow in the Arroyo Seco downstream of Devil's Gate may have been perennial in certain locations along its course where groundwater, springs, or small tributaries contributed flow, but the Arroyo Seco was likely connected to the LA River for its entire length only during winter and spring. The resulting habitat connectivity during winter and spring would have allowed adult steelhead to migrate upstream to perennial habitat in the San Gabriel Mountains upstream of Devil's Gate. Historical accounts of steelhead in the upper Arroyo Seco (e.g., Holder 1906) suggest that this occurred frequently, possibly on an annual basis, and thus the Arroyo Seco may have provided the most important steelhead spawning and rearing habitat in the entire LA River basin. Since completion of Devil's Gate Dam in 1930, flows in the Arroyo Seco have shown a seasonal pattern similar to the LA River, with very low summer baseflows and higher winter flows punctuated by large storm-driven peak flows (Figure 3-5). The Arroyo Seco downstream of the Jet Propulsion Laboratory (JPL) and Hahamongna Watershed Park in Pasadena experiences very low flows during the summer-fall dry season and may dry completely at times. However, at its confluence with the LA River the Arroyo Seco likely remains flowing throughout the dry season in most years due to accretion from small tributaries and urban runoff.

The Big Tujunga Creek watershed upstream of Hansen Dam is largely undeveloped, with the exception of Big Tujunga Dam and Reservoir, and has no appreciable urban runoff to maintain dry season base flows. Water released from Big Tujunga Dam, roughly 15 mi (24.1 km) upstream of Hansen Dam, typically percolates into the alluvial sediments as Big Tujunga Creek emerges from the mountains into the San Fernando Valley, thus the lower reaches of Big Tujunga Creek and Tujunga Wash are typically dry during the summer and fall and have intermittent storm-driven flows during the winter and spring (Figure 3-6). Historical maps and accounts indicate that Big Tujunga Creek did not have a perennial connection to the LA River, and Tujunga Wash is mapped as dry on 1900-era USGS topographic maps (USGS 1897). Consequently, its main function for the historical steelhead population in the LA River may have been as habitat for *O. mykiss* that occupied perennial reaches in its upper watershed and exhibited a largely resident (i.e., non-anadromous) life history. These fish may have contributed to the anadromous steelhead population only when sufficient flow allowed juveniles/smolts to outmigrate and reach the ocean and when flow conditions provided winter-spring connectivity from the mainstem LA River to upstream perennially-flowing spawning and rearing habitat.

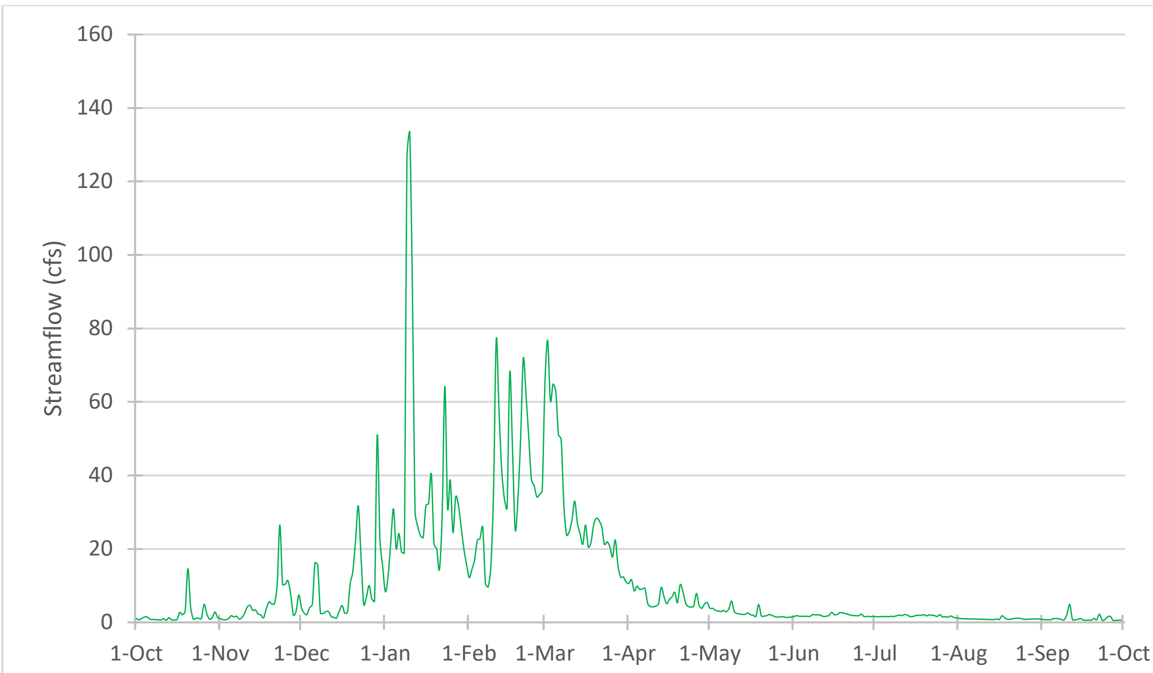

Figure 3-5. Average daily flow (cfs) in the Arroyo Seco below Devil's Gate Dam (LACDPW Stations P277-R and F277) for the period of record (1942–2020). Source: LA County Department of Public Works.

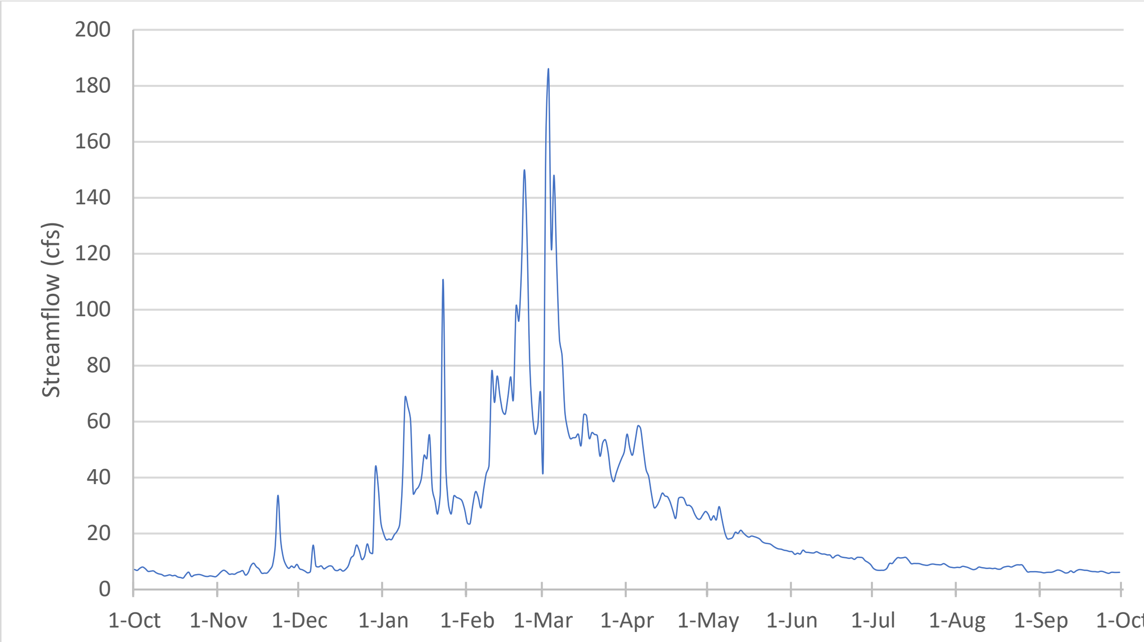

Figure 3-6. Average daily flow (cfs) in Big Tujunga Creek below Big Tujunga Dam (LACDPW Station F168-R) for the period of record (1932–2020). Source: LA County Department of Public Works.

Downstream of the upper tributary reaches, the hydrology of the LA River is heavily influenced by water resource facilities as discussed in the preceding section. Debris basins and flood control reservoirs along the mountain front are designed to trap sediment and decrease flood peaks (see Section 3.4.3). The effects of these facilities are counteracted somewhat by increased runoff from the almost entirely urbanized lowlands. For example, the 1991 Los Angeles County Drainage Area (LACDA) Review concluded that new dams in the upper LA River watershed would "have only minor impacts on downstream flows because local runoff increases flow in the mainstem" (USACE 1991).

Climate change impacts to temperature and precipitation will have a direct influence on LA River streamflow. Effects of climate change are projected to include more extremes, with longer dry and wet periods in California resulting in increased drought and flood frequency (DWR 2015). Increased air temperatures will cause more precipitation to fall as rain than snow and cause earlier snowmelt in the higher elevation zones. This warming will lead to an earlier shift in the timing of peak flows and increased water temperatures (DWR 2015). Climate change will also potentially lead to more frequent storms, with shorter receding limbs and overall higher maximum flows (Taylor et al. 2019). Projections suggest that climate change may also reduce the range and probability of occurrence of *O. mykiss* in Los Angeles and Ventura counties due to increased water temperatures in the higher elevation streams they occupy (Taylor et al. 2019).

3.4 Geology, Geomorphology, and Sediment Processes

The LA River watershed comprises three mountain ranges that form the boundary of the watershed within which sit a series of fluvial landforms that define and characterize the river network. These landforms include alluvial fans at the fringes of the mountain ranges, fluvial valleys bounded by mountain ranges (the San Fernando and Crescenta valleys), and the broad coastal plain that makes up the downstream portions of the watershed. A series of low elevation hills along the Newport-Inglewood Fault Zone separates the LA River Watershed from the smaller watersheds including the Dominguez Channel and Ballona Creek that drain directly to the Pacific Ocean between Santa Monica and Long Beach. The watershed is tectonically active which, along with factors such as climate and wildfire, influence rates of erosion and so the natural sediment regime and dynamics of the river network.

3.4.1 Geology and tectonics

The watershed's northern boundary is formed by the San Gabriel Mountains. The San Gabriel Mountains are made primarily of Mesozoic granitic rocks with small areas of undifferentiated Precambrian metamorphic and sedimentary rocks (Figure 3-7).

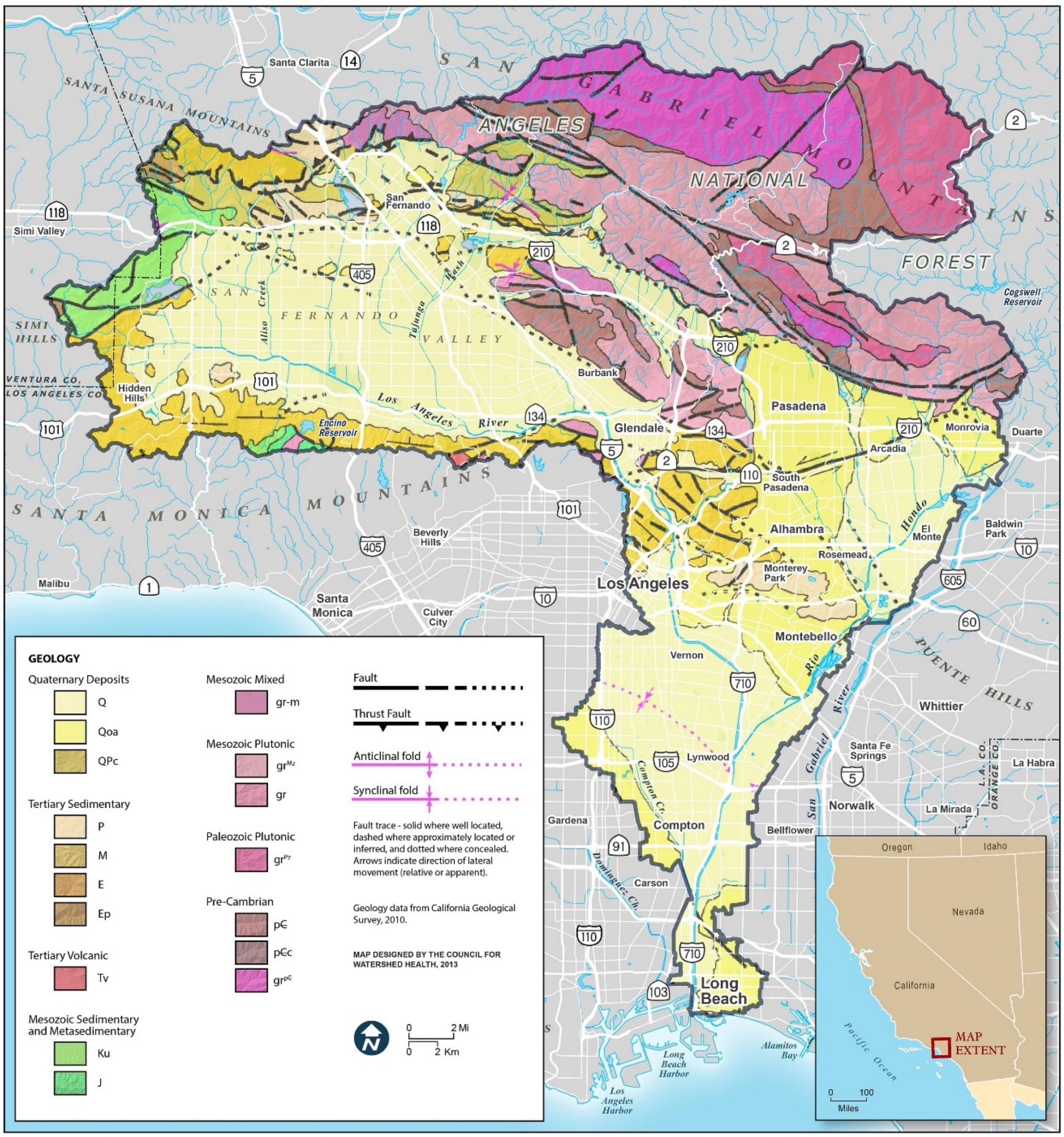

Figure 3-7. Geology of the Los Angeles River Basin and surrounding areas. Source: CWH (2018).

The topography originates due to a restraining bend in the San Andreas Fault which led to uplift of the San Gabriel Mountains and numerous strike-slip and reverse faults beginning 5–7 million years ago (Spotila et al. 2002). The San Andreas fault lies outside the watershed and forms the northeastern margin of the NW-SE trending San Gabriel Mountains, while the southwest margin of the mountains is provided by the series of reverse faults related to the Sierra Madre Fault Zone.

South of the San Gabriel range, the west-east trending Santa Monica Mountains are an anticline that defines the southern boundary of the San Fernando Valley, provide the distinctive shape of the Los Angeles watershed, and influence the west-east orientation of the upper LA River. The left-reverse Santa Monica Fault demarks the southern boundary of the Santa Monica Mountains. There are no mapped faults along the northern margin of the Santa Monica Mountains and consequently the southern margin of the range is much steeper. The Santa Monica Mountains are made up of Tertiary marine sediments, metasediments and volcanic rocks (Meigs et al. 1999). These mountains are about 1,000–3,000 ft (305–914 m) in elevation and uplift of the mountains began approximately 5 million years ago.

The Santa Susana Mountains and Simi Hills are lower elevation than the other bounding ranges with elevations ranging up to 2,300 ft (701 m). They are composed of upper Cretaceous and Tertiary marine sediments (Figure 3-7) and that were uplifted starting approximately 0.7–0.6 million years ago (Levi and Yeats 2003).

Within the watershed, the Verdugo Mountains and San Rafael Hills range in elevation from 1,000–3,000 ft (305–914 m) above sea level. They are bounded by the Verdugo and Pasadena Faults and are composed primarily of the same granites as the San Gabriel Mountains with some additional Tertiary sediments. Uplift of these mountains likely corresponds with regional uplift over the last 6 million years. The 1–2-mi (1.6–3.2-km) wide Crescenta Valley lies between the Verdugo and San Gabriel mountains. The Newport-Inglewood Fault Zone lies along a series of low hills within the coastal plain.

The LA River watershed is tectonically active with long-term uplift rates for the San Gabriel Mountains of about 0.02 to 0.039 in/yr (0.5 to 1 mm/yr) (DiBiase and Lamb 2013), while the millennial erosion rate of the San Gabriel Mountains ranges from 0.014 to 0.043 in/yr (0.35 to 1.1 mm/yr) (DiBiase et al. 2010). Recent, short-term erosion rates estimated from sediment accumulation in numerous debris basins in the foothills of the San Gabriel Mountains range from approximately 0.035 to 0.063 in/yr (0.9 to1.6 mm/yr) (Lavé and Burbank 2004). The rate increase over the long-term average is likely due in large part to human activities—erosion in the San Gabriel Mountains is correlated strongly with the occurrence of wildfires and large storm events generated mostly by the ENSO. Lavé and Burbank (2004) estimated that anthropogenic increases in fire frequency have caused erosion rates to increase by approximately 60%. For instance, the 2009 Station Fire burned 650 mi^2 (1683 km^2) of the San Gabriel mountains and sediment eroded after the fire filled many of the debris basins in the watershed. Eroded sediment was historically delivered from the mountains via debris flows and floodwaters during large storm events to the LA River and its tributaries in the lowlands. Coarser sediments were deposited closer to the mountain front with finer sediments carried further downstream. The eastern portions of the San Fernando Valley therefore have coarser soils, with finer soils farther from the mountain source. In the Santa Monica Mountains, data from sedimentation basins and river incision analyses suggest approximately 0.02±0.012 in/yr (0.5±0.3 mm/yr) (Meigs et al. 1999). The northern part of the Santa Monica Mountains along the San Fernando Valley is uplifting at 0.0094±0.0047 in/yr (0.24±0.12 mm/yr), while the southern portion of the range outside of the LA River Basin is uplifting at 0.02±0.016 in/yr (0.5±0.4 mm/yr) (Meigs et al. 1999).

Between outside of the mountain ranges and hills, the valleys and coastal plain are typified by very deep sediments reflecting subsidence of these basins. The Los Angeles Basin formed due to lithospheric stretching initiated as the Pacific-Juan de Fuca-North American triple plate junction migrated north of Southern California (Ingersoll and Rumelhart 1999), the basin has been subsiding through rotation and stretching for some 18 million years. Sediments in the coastal plain are up to 5 mi (8 km) thick (Ma and Clayton 2016) but can be thin in areas of shallow bedrock such as the Glendale Narrows.

3.4.2 Fluvial geomorphology

The LA River watershed was formed by the uplift of the San Gabriel and Santa Monica Mountains over the last 6 million years and currently has a drainage area of 834 mi^2 (2,160 km^2). The river and its tributaries can be subdivided into four zones that define their fluvial geomorphology and sediment transport. In the mountains, the tributaries are confined within steep canyons. Depending on their drainage area and water source, the tributaries in the mountains are often perennial. At the mountain front, the alluvial and debris flow fans represent a transition from the steep, confined channels to the broad valleys upstream of downtown Los Angeles. The mainstem LA River is the only perennial stream in this section.

Downstream of downtown Los Angeles, the river enters a broad coastal plain. The dynamic, flashy nature of the LA River's flow regime and the relatively flat topography of the coastal plain led to broad avulsing channels under historical conditions that would repeatedly change their course and intermix with channels from the neighboring San Gabriel River (draining 689 mi^2 [1,785 km^2]). For example, prior to a large flood event in 1825, the LA River discharged to the Pacific Ocean through what is now Ballona Creek, but was diverted south following the flood event, joining the San Gabriel River about seven miles (11.3 km) north of San Pedro Bay. Floods in 1862 and 1884 saw the San Gabriel River itself diverted at the Whittier Narrows, eventually settling into a new course that entered the ocean six miles (9.7 km) east of its old course (Kenyon 1951, as cited in Taylor 1981). The former lower San Gabriel River became known as the LA River, with Rio Hondo henceforth serving to divert a portion of San Gabriel flows into this former course during large flood events. The Los Angeles, San Gabriel and Santa Ana rivers discharge to the ocean within 18 mi (29 km) of one another (Long Beach to Huntington Beach) and their outlet positions have moved and coalesced as the channels avulsed throughout recent history (Gumprecht 2001), together providing the sediments that make up the broad coastal plain that extends through Los Angeles and Orange counties.

Taylor (1981) postulated that the LA River today may have the most extensive system of controls for any river of its size in the world. The extensive spread of Los Angeles since the early twentieth century in conjunction with devasting flood damage resulting from large floods in 1914 and 1938 prompted a series of initiatives intended to manage flows and sediment supplies to protect residents and industries located on the watershed's floodplains and foothills. Actions included the construction of numerous check dams by the U.S. Forest Service (USFS) to stabilize creeks emanating from the San Gabriel Mountains (especially in the 1950s; Brownlie and Taylor 1982), debris dams to intercept large pulses of sediment during flood events (especially life-threatening debris flows, as part of LA County's sediment management strategies beginning after the 1914 flood), and various dams intended for flood storage (flood control basins) and water supply to groundwater infiltration 'spreading ponds' (Figure 3-8). The dams include two larger flood control basins constructed by the USACE in 1940 (Hansen Dam, a 97-ft high [29.6-m] structure on Tujunga Wash) and 1941 (Sepulveda Dam, a 57-ft [17.4-m] high structure on the LA River mainstem] (Figure 3-8). Each dam regulates approximately 152 mi^2 (394 km^2) of upstream drainage area (USACE 2015a).

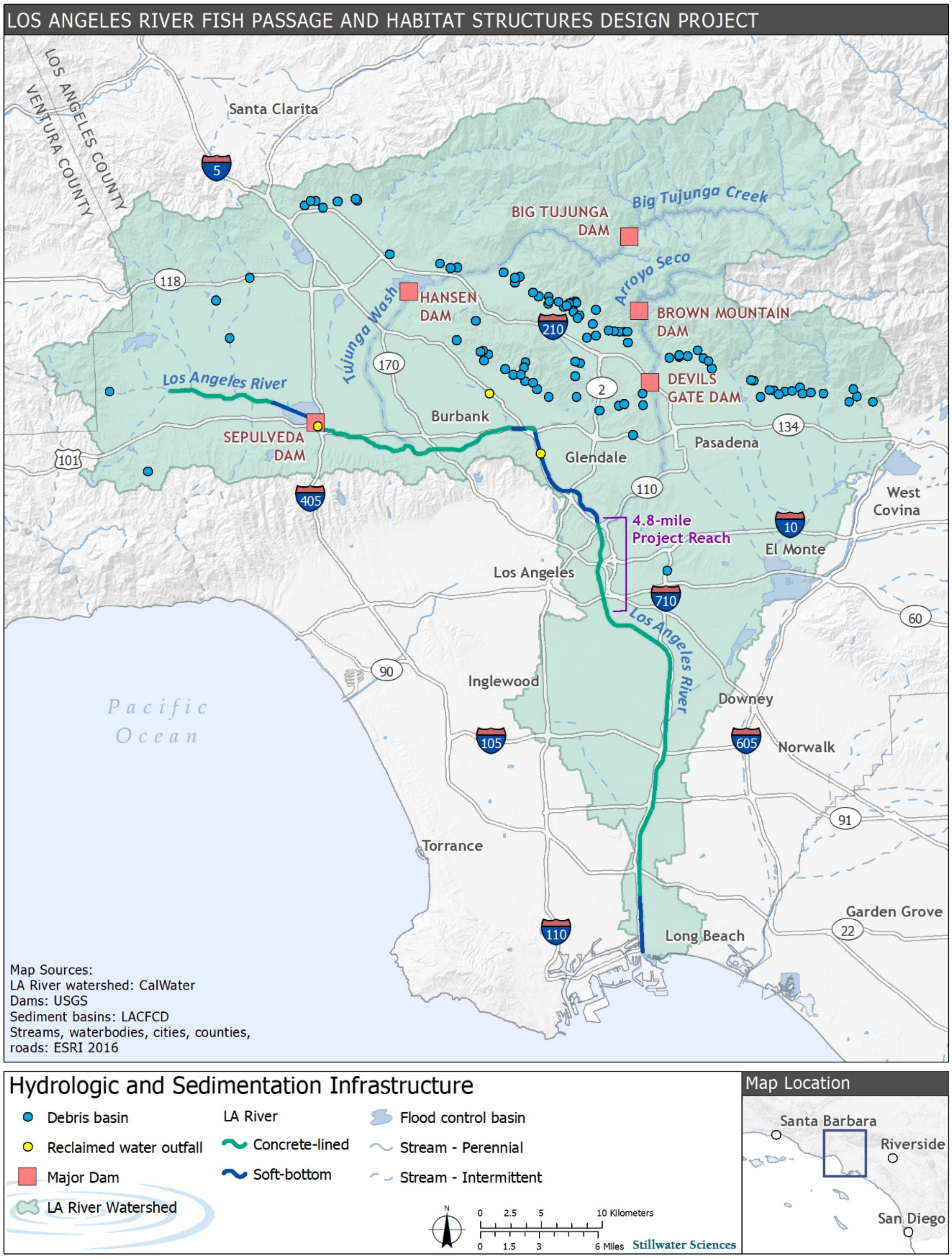

Figure 3-8. Dams and debris basins in the Los Angeles River Watershed.

Most iconic of the human interventions has been the extensive channelization of the river designed to accelerate flood flows to the Pacific Ocean: outside of the mountains and alluvial fan areas of the watershed, nearly all of the LA River and its tributaries now flow through trapezoidal or rectangular concrete channels. Channelization began following the 1914 flood with relocation of the lowest 5 mi (8 km) of the river into a 525-ft wide (160-m) (bed width) trapezoidal channel through the City of Long Beach (Taylor 1981). Channelization peaked with Federal activity in the 1930s to 1950s (prompted by Flood Control Acts of 1936, 1937 and 1938) and was completed by 1970 (USACE 2015a). The only exceptions to a fully concreted design occur in those locations inherently subject to rising groundwater where conditions were too wet to allow the river bed to be covered in concrete. Such 'soft-bottom' reaches occur on the mainstem LA River in the Sepulveda Flood Control Basin upstream of Sepulveda Dam, Glendale Narrows, and the estuary below Willow Street. Unlike the remainder of the mainstem river network, the soft-bottom reaches are characterized by dense vegetation growth along the river bed and towards the channel margins, creating a far higher roughness in flood flows and thus reducing flood flow velocities. Although the soft-bottom reaches generally lack a concrete bed, numerous check dams are present through the soft bottom reach of the Glendale Narrows. The channel bed slope of the LA River through the soft-bottom reach through the Glendale Narrows is approximately 0.004. From the 1st Street Crossing to E 26th Street the LA River slope is 0.0045. Channelization also resulted in far narrower channel widths relative to the historical braided channel. These measures, combined with a period of 20 years following the end of World War II in which there were no significant flood events, permitted intensive development of the floodplain consistently up to the channel's edge.

Tujunga Wash downstream of Hansen Dam has also been subject to extensive channelization, resulting in a rectangular concrete channel that is 60 ft (18.3 m) wide upstream of the confluence with Pacoima Wash and 70 ft (21.3 m) wide downstream of the confluence with a channel slope of 0.0078 (The River Project et al. 2002). Water and sediment are caught in Lopez Dam on Pacoima Wash and Big Tujunga Dam and Hansen Dam on Big Tujunga Creek. In 1999 the trap efficiency of Hansen Dam was estimated at 100% for bedload and 84% for fine sediment (USACE 1999), although the trap efficiency varies through time as sedimentation occurs within the reservoir and when sediment is excavated.

Arroyo Seco is also concrete-lined downstream of Devil's Gate Dam except for two short sections near the 210 Freeway and 134 Bridge. To reduce the amount of sediment removal required behind Devil's Gate Dam, low-elevation gates on Devil's Gate Dam are operated to flush sediment downstream as the water level in the reservoir increases, although to our knowledge the volume of sediment sluiced downstream during recent storms has not been assessed. The Los Angeles County Department of Public Works (LACDPW) initiated sediment removal at Devil's Gate Reservoir in May 2019 as part of the Devil's Gate Reservoir Restoration Project, which will remove up to 1.7 million cubic yards (yd^3) (1.3 million m^3) of sediment from behind Devil's Gate Dam over a four-year period. As of May 28, 2020 more than 445,000 yd^3 (340,227 m^3) of sediment has been removed as part of the Devil's Gate Reservoir Restoration Project (LACDPW 2020).

Flood flows in the LA River remain predominantly supplied by Big Tujunga Creek, Arroyo Seco, and other smaller tributaries draining the San Gabriel Mountains, but such flows are now extensively regulated upstream of Los Angeles by debris basins and flood control dams, and accelerated within populated areas through the narrow, smooth, concrete channels. Consequently, flood flow velocities are extremely high, modeled in excess of 25 ft/sec (7.6 m/sec) in some locations (USACE 2015a). Riparian vegetation is largely absent, so too is vegetation along the river bed except in the soft-bottom reaches.

3.4.3 Sediment connectivity and routing

The system of fluvial sediment erosion, transport, and deposition in the LA River watershed can be divided into four zones in which certain processes dominate. The zones encompass mountains and canyons, alluvial fans, fluvial valleys and the coastal plain. As a consequence of the flashy flow regime, ENSO-driven large flood events, and high sediment loads resulting from the steep (uplifting) terrain, tectonic activity and wildfire, there are naturally extreme differences between rates of sediment transport in low and high flows. Further, transport processes have been dramatically altered because of the extensive human alteration of the river network. A summary of sediment process expectations under historical and current conditions follows as context for efforts in aquatic habitat rehabilitation.

Historical conditions

1. *Mountains and canyons*. In its natural condition, sediment production in the watershed occurs in the mountains. Brownlie and Taylor (1982) categorized 56% of the watershed area as the sediment production zone. This area includes the upland mountain ranges (especially the San Gabriel Mountains) whose combination of uplift-induced erosion, susceptibility to wildfire, and steep slopes makes it the primary sediment production and export area. Water and sediment in this region are transported through confined channels to the fans downstream. Sediment is transported by fluvial flows and debris flows.
2. *Alluvial fans*. Where the steep upland tributaries meet the lower gradient valley, a system of debris and alluvial fans developed in the foothills as a result of coarse sediment deposition, resulting in the series of ephemeral braided channels (e.g., Tujunga Wash) that characterized large areas of the San Fernando Valley. Reflecting such depositional processes, aggregate mining for sand and gravel started on the Tujunga Fan in 1908 (but reserves were dwindling by the 1970s, Kolker 1982). It is likely that under baseflow and moderate high flow events, flows emanating from the mountain ranges seeped into the ground and any sediments transported during these flows would be deposited. But, during annual flow events, and especially under ENSO-driven floods with a 5- to 8-year recurrence interval, a large volume of sediment up to and including cobbles was likely transported to the Los Angeles mainstem channel.
3. *Fluvial Valleys*. The third natural zone includes zones of intermittent and perennial flow along the San Fernando and Verdugo fluvial valleys, with the former including the LA River from its natural source to the 'Glendale Narrows'. The sediment character of this zone is not well documented but, subject to periodic sediment supply from the alluvial fans during large flow event, this was presumably a zone of sedimentary transfer and 'exchange' with erosion, transport and depositional processes all in evidence.
4. *Coastal plain*. Finally, as the LA River enters the coastal plain, sediment processes would have been dominated by losses (i.e., deposition) caused by periodic avulsions and overbank flood events. Over geological time frames, these sedimentary losses helped to more than offset the natural tectonic subsidence of the coastal plain. Using the surrogate of the neighboring Santa Clara River, the likelihood is that in-channel transport rates would still have been considerable in this zone and sufficient to eject significant quantities of sediment to the Pacific Ocean.

Throughout these zones, the semi-arid climate and ENSO-driven large flood regime of the Los Angeles watershed means the sediment process dynamics were concentrated into several days of highly intense activity every 5–8 years rather than being metered out in 'average annual' increments, such as in temperate climates where rainfall is more consistent and 'bankfull' processes dominate. To illustrate, surveys of delta accumulation (i.e., sediment export) at the mouth of the newly channelized LA River at Long Beach from 1927–1938 indicated that approximately 60% of the 11 million yd^3 (8.4 million m^3) of total deposited sediment probably resulted from one single event, the large flood of March 1938. Likewise, in Devil's Gate Dam on Arroyo Seco, 42% of the sediment accumulation from 1920–2012 occurred after two fires in the watershed (the 1934 Brown Mountain Fire and the 2009 Station Fire). The Brown Mountain Fire was followed four years later by the 1938 flood (a 50-year recurrence interval for the LA River).

Current conditions

Under current conditions most of the channels in the lower watershed have been lined with concrete and numerous small check dams have been built to control channel gradient and trap sediment in the mountains, numerous water supply reservoirs were built on small tributaries, three large sedimentation dams were constructed in the upper watershed, intermediate-size debris basins were constructed at the outlet of the canyons throughout the watershed, and three large flood control and sedimentation reservoirs were constructed in the valleys downstream of the mountain outlets. As a consequence, the function of the four sediment 'zones' has altered greatly under current watershed conditions as described below.

1. *Mountains and canyons*. Sediment production from the mountain ranges probably increased subsequent to Euro American arrival in the watershed (see Lavé and Burbank 2004, data above), due to a combination of vegetation changes resulting from initial cattle grazing, and the inadvertent increase in wildfire frequency caused by human actions. The mountain zones now contain an estimated 290 small check dams constructed by the USFS (particularly in the 1950s) to reduce upland channel incision (Brownlie and Taylor 1982). These small structures (generally 10–16 ft [3–5 m] high) are designed to fill with sediment (hundreds or thousands of cubic meters) after which they are ineffectual at reducing sediment throughput. As such, they may have affected sediment exports rates for a short period in the 1950s and 1960s (a period characterized by few storm events) but were almost certainly filled by or during the large flood of 1969, and have had little impact on sediment export since. Conversely, several large sedimentation dams were also constructed in the uplands including Tujunga Dam on the Big Tujunga, Brown Mountain Dam on Arroyo Seco, and Pacoima Dam on Pacoima Creek with the intent purpose of intercepting mountain-derived sediment. While Brown Mountain Dam is now full, Tujunga and Pacoima dams still operate and are part of Los Angeles County's sediment management strategy (LADPW/LAFCD 2013).
2. *Alluvial fans*. The role of the alluvial fan zone in intercepting mountain sediment has been markedly changed by the construction of an estimated 95 debris basins (Taylor 1981), eight large flood control and sediment storage reservoirs, and the Hansen and Devil's Gate dams on Tujunga Wash and Arroyo Seco, respectively. The mid-size debris basins are generally significantly larger than the check dams, capable of storing tens to hundreds of thousands of cubic meters of sediment, on average (Brownlie and Taylor 1982), and they are designed to be periodically excavated to enable perpetual sediment storage. Unlike the smaller check dams, periodic excavation is required to ensure that the debris basins do not lose their effectiveness in time and they are a key part of LA County's sediment management strategy (LADPW/LAFCD 2013). These debris basins in the Los Angeles watershed directly regulate sediment discharge from about 12% of the watershed's erosional area.
3. Most of the sediment emanating from the mountain range is thus no longer deposited across alluvial fans by braided channels subject to periodic avulsion. Sediment is instead disconnected through the action of these various structures. Downstream of the flood control basins, Tujunga Wash and Arroyo Seco have been subject to the same channelization as the mainstem channel. As such, during large flood events when the

trapping efficiency of the various structures is reduced, some sediment transfer through the regulating structures does occur into the channelized reaches downstream, upon which the sediment is transferred rapidly through the remainder of the channel network. No floodplain deposition occurs.

4. *Fluvial valleys*. The former ‘exchange’ zone along the LA River mainstem probably now operates in the same manner as the Tujunga Wash and Arroyo Seco, due to a combination of the Sepulveda flood control basin and extensive channelization of the river, including upstream of the river’s original source. There is presumably little sediment exchange, rapid transport of flood sediments through the reach, and no floodplain deposition. Instead, a small volume of sediment is retained in the ‘soft bottom’ reaches of the mainstem, where a combination of greater flow roughness and woody vegetation causes a small amount of channel bed deposition. Some of this sediment is periodically cleared from the channel (USACE 2015a).
5. *Coastal plain*. The furthest downstream sediment zone has also had its functional role altered radically from the natural condition. There is no longer floodplain deposition or avulsion occurring on the coastal plain, with the channelized reaches permitted no overbank flow. Any sediment that escapes the retention structures in the remainder of the LA River network will be transferred rapidly through the coastal zone to the Pacific Ocean.

3.5 Land Use and Land Cover

Along its route from headwaters to ocean, the LA River traverses, in descending order of land coverage, medium to high density residential, industrial, open space, and commercial land uses (CWH 2018). The historical broad, braided channels of the LA River have been completely converted to concrete lined channels in lower reaches. A few remaining soft-bottom sections are also concrete lined on the banks, but include vegetated and riverwash land cover in the channel bed. Associated ongoing management activities in these sections include management of invasive giant reed (*Arundo donax*), homeless encampments, vector control, and vegetation, sediment, trash, and debris removal for water quality and flood control.

The mountainous headwaters of the LA River are predominantly undeveloped, with large natural areas of forest, chaparral, and shrub-scrub that lie in stark contrast to the heavily urbanized lower watershed which is home to more than 4.5 million people (CWH 2018, Sheng and Wilson 2008). The Los Angeles-Long Beach-Anaheim metropolitan statistical area (MSA) is the most densely developed of any MSA in the United States at 2,699 people per square mile (1,046 people per square kilometer) (Dillinger 2017). The contrast between mountains and lowlands is further illustrated by the vastly different proportions of impervious area in the upper and lower portions of the watershed. Impervious area in downtown Los Angeles ranges from 56–74%, compared to 5–15% impervious area in the foothills of the San Gabriel Mountains (Ackerman and Stein 2008). Associated impervious surfaces and engineered drainage systems result in very rapid runoff rates, high pollutant loading, and reduced groundwater infiltration within these reaches. Cummings (2016) evaluated changes to the impermeable surface coefficient (ISC) on urban discharges from the LA River Watershed from 1930–2012. The average ISC value increased more than 100% (0.193 to 0.438) over the time period. These results also suggest that urbanization is the primary driver of changes in discharge in the LA River, as opposed to changes in precipitation. Impervious surfaces, combined with a substantial urban heat island effect across the Los Angeles basin, may also contribute to increased surface water and discharge temperatures (Taha 2017).

Hilly terrain in the lower watershed is less densely developed and still maintains some patches of the chaparral, coastal sage scrub, and woodlands that were prevalent prior to large scale development. Flatter terrain that historically was composed of grasslands, coastal sage scrub, and wetland and riparian vegetation types has been nearly completely developed (Ethington et al. 2020). Remaining patches of natural vegetation and urban landscapes in the City also provide habitat for common and rare biodiversity and support regional habitat connectivity. The City of Los Angeles recently mapped urban habitat quality for the City and surrounding areas, and connectivity for the Elysian Valley, including northern portions of the 4.8-mile project reach. The Elysian Valley represents a key area for enhancing urban habitat connectivity between the Santa Monica, San Gabriel Mountains, and Repetto Hills (and Puente Hills and Santa Ana Mountains further to the south) (LA Sanitation and Environment 2020, in press). LA River revitalization is also envisioned to enhance riparian connectivity along the river corridor itself, providing connected habitat for both resident and migratory species along the entire 51-mi (82.1-km) river mainstem and tributaries, including habitat for bird populations that use the Pacific Flyway. Habitat enhancement of the river corridor is also intended to support improved access to nature for underserved neighborhoods in more densely developed parts of the City (County of Los Angeles 2020, in press).

Despite the intensive land use in lower reaches of the watershed, areas within the City of Los Angeles adjacent to the River are the focus of initiatives to improve water quality and multiple benefits of the LA River. The River Improvement Overlay (RIO) District and associated River Design Guidelines focus on “options, solutions, and techniques to improve the aesthetic quality of the River and its surrounding communities; increase the availability of publicly accessible open space; and effectively utilize public rights-of-way as locations to capture and treat stormwater” within approximately ¼ to ½ mile (0.4 to 0.8 km) of the River mainstem within the City (Los Angeles Urban Design Studio 2015). These and other watershed-wide water quality and river-access strategies are increasingly being implemented and will likely improve water quality and use of the river corridor over time. Improvements to water quality would benefit steelhead migration. Implications to steelhead of increased public access and other multi-benefit demands of the river corridor will be considered when developing restoration design strategies.

Except for a few areas of limited developed land uses, hiking trails, and minor roads, land cover in upper portions of the watershed that feed reaches suitable for steelhead spawning and rearing, remain largely composed of natural vegetation types (USDA Forest Service 2020). Wildfires in these fire-prone vegetation types cause periodic inputs of fine sediment to the streams resulting from runoff following fires. Little evidence exists to suggest substantial changes to wildfire regimes in these specific vegetation types over the past century, nor are changes currently projected in the future as result of climate change or other drivers (Keeley and Syphard 2017).

3.6 Water Temperature and Quality

3.6.1 Water temperature

Water temperature in the LA River and its tributaries varies considerably depending on location, elevation, channel condition, local inputs, and other factors. Although continuous, long-term water temperature measurements could not be located for this analysis and may be unavailable, the small amount of available data suggest that water temperature during summer is unsuitable for all steelhead life stages in the mainstem LA River but potentially suitable at some higher-elevation tributary locations (Mongolo et al. 2017). At sites monitored by Mongolo et al. (2017) in summer 2016, the highest water temperatures occurred in the most heavily developed portions of the watershed while temperatures were lowest at sites in the relatively undeveloped, higher-elevation San Gabriel Mountains. Notably, water temperature in the natural bottom section of the Arroyo Seco downstream of the Rose Bowl in Pasadena was among the lowest at any site within the urbanized portion of the watershed. This site, which despite its location in an urbanized portion of the watershed has well developed riparian vegetation shading the channel and bedrock outcroppings that may indicate the potential for groundwater inputs to the stream, had an average maximum water temperature for the monitoring period (June–October 2016) of 71.2°F (21.8°C) which is below the critical thermal maximum reported for *O. mykiss* in Southern California streams (Sloat and Osterback 2012, Mongolo et al. 2017). Water temperature was not monitored in Big Tujunga Creek or other mountain tributaries of the LA River during the Mongolo et al. (2017) study.

Summer 2016 water temperatures in the mainstem LA River within the 4.8-mile LAR FPHS design project reach (Figure 1-1) were among the highest in the watershed, with a June–October average maximum temperature of 86.9°F (30.5°C), exceeding the tolerance of *O. mykiss* and other native fishes (Mongolo et al. 2017). Other sites in the concrete-lined portion of mainstem Los Angeles River also had average maximum water temperatures exceeding 86°F (30°C) during summer 2016, (see Section 4.2.3 and Mongolo et al. 2017) presenting thermal barriers to steelhead movement and survival during summer. Other sites in the concrete-lined portion of mainstem LA River also had average maximum water temperatures exceeding 86°F (30°C) during summer 2016. The concrete river channel lacks structural heterogeneity and riparian vegetation that would otherwise serve as natural insulators and thermal buffers (Poole and Berman 2001) and is disconnected from groundwater that would typically provide inputs of cool water to the river. The concrete channel also absorbs the sun's energy and radiates heat more efficiently than a natural streambed and banks, directly warming the river water (Hester and Doyle 2011). As a result, water temperature in the simplified, concrete-lined sections of the channel is heavily influenced by fluctuations in ambient air temperature and solar radiation (Mongolo et al. 2017).

Non-continuous water temperature data for the mainstem LA River were also recorded by USGS at two gages near Long Beach for the period 1973–1992 (USGS #11103000 and #11103010). Daily maximum water temperatures at these locations ranged from 55.4 to 93.2°F (13 to 34°C) during summer (June–November) and 46.4 to 89.6°F (8 to 32°C) during winter and spring (December–May). Daily maximum water temperatures during the primary steelhead adult and juvenile migration season (February–May; see Table 2-1) occasionally exceeded 86°F (30°C) during the spring months, but were most frequently below 80.6°F (27°C). Since juvenile steelhead can survive at water temperatures between 77 and 80.6°F (25°C and 27°C) for short periods (Moyle 2002), these data suggest that water temperature would not typically preclude upstream or downstream steelhead migration during the coolest portion of the peak migration season. Summer water temperatures in the lower river, however, would almost certainly pose a thermal barrier to movement and could be acutely lethal to all steelhead life stages.

More detailed analysis and inferences on the effects of water temperature in the LA River watershed on steelhead are provided in Section 4.2.3

3.6.2 Water quality

All the reaches of the LA River are water quality impaired in some form. Some impairments in the watershed can be limited to a specific reach, like the legacy of organochlorines in the LA River estuary. Some impairments are discontinuous, such as dissolved metals and nutrients, and some are more widespread, like trash (Table 3.2). Regional stream assessments employing multiple indicators have revealed that biologically healthy streams are a limited resource in the region (Mazor 2015). Mazor (2015) also found significant associations between poor biological condition and high priority stressors, which include nutrients, physical habitat, sulfates, and dissolved solids. A significant source, by mass, of one of those classes of priority pollutants are wastewater treatment plants. Wastewater plants contribute to upwards of 70% of dry-weather flows to the river and, by mass, are the largest contributors of nutrients (Ackerman et al. n.d.). Dry weather flows from storm drains are the largest contributors of low priority pollutants like lead and copper (Stein and Ackerman 2007).

Table 3-2. Select 303(d) listed reaches of the LA River watershed and pollutants responsible for impairments (SWRCB 2020).

Water body	Size affected	Pollutant
Los Angeles River Estuary	207 acres	Chlordane, PCBs, trash, DDT, toxicity
Los Angeles River Reach 1	3.37 mi	Dissolved copper, dissolved zinc, cadmium, cyanide, pH, ammonia, algae (nutrients), trash, lead, indicator bacteria
Los Angeles River Reach 2	18.8 mi	Trash, ammonia, algae (nutrients), copper, lead, indicator bacteria, oil
Los Angeles River Reach 3	7.94 mi	Trash, ammonia, copper, algae (nutrients), toxicity, indicator bacteria
Los Angeles River Reach 4	11.06 mi	Trash, indicator bacteria, algae (nutrients), toxicity
Los Angeles River Reach 5	1.9 mi	Ammonia, copper, lead, trash, oil, algae (nutrients), toxicity, benthic community effects
Los Angeles River Reach 6	6.99 mi	Selenium, indicator bacteria, toxicity, copper
Arroyo Seco Reach 1	5.15 mi	Indicator bacteria, trash
Arroyo Seco Reach 2	4.42 mi	Indicator bacteria, trash
Tujunga Wash (below Hansen Dam)	9.68 mi	Ammonia, trash, copper, indicator bacteria

Much of the water quality data collected in the watershed has resulted from the sustained efforts of the LA River Watershed Monitoring Program (LARWMP). LARWMP's activities are motivated by regulatory monitoring requirements for dischargers and the concerns of watershed managers and the public. LARWMP monitoring efforts that generated the data discussed herein were conducted from 2007–2018 and include:

- Water quality monitoring using grab sampling and laboratory analysis for general chemistry, nutrients, dissolved metals, and algal biomass.
- Transect based assessments of physical habitat condition, parameters include macrophyte cover, substrate, embeddedness, bank stability, and shading (Ode et al. 2016).
- Assessments of riparian habitat condition using the California Rapid Assessment Method (CRAM). This method is based on visual assessment and scoring of sub-metrics related to buffer landscape context, hydrology, physical structure, and biotic structure (California Rapid Assessment Method for Wetlands 2013).
- Assessment of benthic macroinvertebrate community using the California Stream Condition Index (CSCI). The index measures taxonomic completeness and structure of benthic macroinvertebrate communities (Rehn et al. 2015).
- Assessment of algal communities, specifically soft algae and diatoms, using the Southern California Algal index of biotic integrity (IBI) (Ode et al. 2016).

LARWMP assesses stream conditions in the LA River watershed at sites that capture common stream typologies. These typologies include natural stream sites, located in the forest of the upper watershed, urban stream sites, located along urbanized tributaries of the lower watershed, and the effluent dominated sites along the LA River. The condition of sites found along urban and effluent dominated stream typologies are comparable to each other and significantly more degraded than natural stream sites. For example, natural stream sites have greater canopy cover, a higher percentage of cobble/gravel and epifaunal substrates, greater amounts of organic particulate matter, and greater macrophyte cover than urban or effluent dominated stream sites (Table 3-3). These conditions contribute to greater habitat suitability in natural stream sites for *O. mykiss* and other native fishes, whereas urban and effluent dominated sites generally have unsuitable conditions for native fish and aquatic species. Physical habitat conditions along urban stream sites are similar to effluent sites because, like the effluent dominated portions of the river, streams along urban tributaries vary between soft bottom and channelized, have high algal cover, low epifaunal substrates, and few macrophytes. However, in contrast to effluent dominated sites, urban sites have lower discharge rates and greater canopy cover, on average. The differences in physical habitat condition are also mirrored in water quality, whereby the concentration of nutrients, dissolved solids, and metals are significantly lower in natural stream sites compared to urban and effluent dominated sites. Dissolved oxygen, an important water quality constituent for steelhead and other coldwater fishes, also differs according to location in the watershed. Dissolved oxygen concentrations were relatively high (often at or near 100% saturation) and exhibited less variability at natural stream sites compared to urban and effluent dominated sites, generally meeting water quality objectives and providing suitable conditions for native fishes at the natural sites (CWH 2018). Dissolved oxygen concentrations at urban and effluent dominated sites showed considerable variability, with minimum values sometimes below water quality objectives and maximum values exceeding 100% saturation, likely due to high levels of algal photosynthesis at urban and effluent dominated sites. Temperature and conductivity are also, on average, 1.3 to 2.2 times lower, respectively, in natural streams compared to lower watershed sites.

Table 3-3. Physical habitat conditions at stream sites in the LA River Watershed. Data summarized from raw data collected by the LARWMP from 2009 to 2018. Unitless metrics are a score based on visual assessments. Source: LARWMP (2018).

Metric	Watershed wide				Urban				Effluent				Natural			
	mean	stdev	min	max	mean	stdev	min	max	mean	stdev	min	max	mean	stdev	min	max
Eroded (%)	3.27	9.49	0.00	50.00	1.02	4.83	0.00	27.78	0.21	0.97	0.00	4.55	6.57	13.03	0.00	50.00
Stable (%)	64.50	42.77	0.00	100.00	93.31	23.04	0.00	100.00	94.01	20.01	18.18	100.00	27.03	32.83	0.00	100.00
Vulnerable (%)	32.23	39.14	0.00	100.00	5.67	19.15	0.00	72.73	5.79	19.55	0.00	81.82	66.41	30.91	0.00	100.00
Fast Water (%)	52.18	36.24	0.00	100.00	35.70	38.39	0.00	100.00	73.98	28.39	10.00	100.00	54.59	32.15	0.00	94.50
Slow Water (%)	47.16	35.98	0.00	100.00	64.01	38.17	0.00	100.00	25.75	28.25	0.00	89.50	44.27	31.70	5.50	97.50
Channel Alteration	8.09	8.22	0.00	20.00	1.67	3.34	0.00	19.00	0.82	1.92	0.00	9.00	16.78	2.91	10.00	20.00
Epifaunal Substrate	6.83	6.51	0.00	18.00	1.86	2.46	0.00	10.00	1.55	2.70	0.00	11.00	13.38	3.45	4.00	18.00
Sediment Deposition	15.21	4.14	4.00	20.00	17.14	4.12	4.00	20.00	17.55	1.92	14.00	20.00	12.53	3.38	4.00	20.00
Slope (%)	1.70	1.51	0.05	7.70	1.14	1.06	0.11	5.20	1.06	1.64	0.05	5.02	2.49	1.42	0.85	7.70
Discharge (m^3/sec)	0.78	1.73	0.00	11.50	0.28	1.03	0.00	5.55	2.28	1.75	0.00	7.96	0.42	1.77	0.00	11.50
Wetted Width (m)	12.21	21.99	1.08	98.50	5.80	5.86	1.21	29.26	40.20	35.87	3.64	98.50	4.02	1.96	1.08	9.67
Microalgae Thickness (mm)	0.80	4.38	0.00	39.60	0.12	0.12	0.00	0.44	0.37	0.62	0.00	2.97	1.53	6.50	0.00	39.60
Macrophytes (%)	3.03	6.14	0.00	31.43	1.14	3.45	0.00	18.10	1.36	2.31	0.00	8.57	5.26	8.03	0.00	31.43
Macroalgae (%)	35.51	30.09	0.00	100.00	43.43	28.24	0.00	87.62	65.55	25.29	10.48	100.00	15.39	15.93	0.00	69.52
Cover (%)	36.32	37.49	0.00	100.00	17.48	25.36	0.00	97.39	6.15	11.79	0.00	52.06	64.87	32.85	0.00	100.00
CPOM (%)	14.76	15.01	0.00	61.90	11.16	14.33	0.00	61.90	4.84	4.89	0.00	13.46	22.16	15.12	1.90	53.47
Sand Fines (%)	14.98	17.22	0.00	80.00	10.65	19.65	0.00	79.05	4.59	5.72	0.00	17.14	23.17	15.06	4.76	80.00
Concrete/Asphalt (%)	47.62	47.23	0.00	100.00	85.32	28.90	0.00	100.00	87.53	22.10	7.62	100.00	0.06	0.24	0.00	1.05
Cobble Gravel (%)	27.21	30.51	0.00	93.33	2.85	9.02	0.00	48.89	6.10	13.45	0.00	58.10	55.75	21.21	3.81	93.33

Biological communities respond to this variability in water chemistry and physical habitat. Algal communities, more closely associated with water quality conditions, and benthic macroinvertebrate communities, more associated with physical habitat, are healthier in natural stream sites. More than 50% of sites along natural streams are likely intact based on CSCI scores and upwards of 85% of sites are in reference condition based on algal IBI scores (CWH 2018). In contrast, no single urban or effluent dominated site is considered "intact" based on CSCI scores and only 3% of urban sites are in reference condition based on algal IBI scores. Unsurprisingly, riparian habitat conditions are also healthier in natural sites. This is because habitat conditions, which include increased habitat complexity, wide, vegetated buffers, and a more natural flow condition, can create refugia, provide diverse food sources, and buffer aquatic communities from stressful conditions (Lancaster and Hildrew 1993, Rios and Bailey 2006).

While the heavily urbanized portions of the Arroyo Seco and Tujunga Wash tributaries reflect many of the same patterns described above, these tributaries are unique. The Tujunga Wash is home to the rare alluvial scrub plant community, with high species richness and a relatively large number of special-status species. The Arroyo Seco consistently has CSCI scores that are among the highest for Southern California (CWH 2018). The upper, mountainous reaches of both tributary systems have perennial streamflow. As a result, the more natural reaches of the Tujunga system and the Arroyo Seco provide food web support for native fishes including *O. mykiss*, as well as other native aquatic species (native aquatic species are described below in Section 3.8.2).

Aquatic and terrestrial habitat conditions in both tributaries suffered from the effects of the 2009 Station Fire, one of the largest fires in the LA Region to date, which burned considerable portions of both watersheds in the San Gabriel Mountains. Their recovery has been continuously monitored by LARWMP since the fire. Both CRAM scores and CSCI scores at these sites declined immediately after the Station Fire. Aquatic and riparian habitat conditions, though highly variable, have improved overall since the post-fire decline. Benthic macroinvertebrate communities recovered within 3–4 years after the fire (CWH 2018).

3.7 Historical Ecology

Southern California has a rich diversity of plant cover and is designated a biodiversity hotspot (CWH 2018). The diversity is in part due to the diverse topographic features, microclimates, and soils of the region (CDFW 2015). Many natural communities that once occurred in the watershed and along the LA River's extensive floodplain, and that were adapted to natural flow regimes that included cycles of flood and drought, have been lost, particularly near the coast. These communities include willow woodlands, valley marsh, alkali meadows, palustrine wetlands, and coastal prairie habitats (Mattoni and Longcore 1997, Longcore 2016, Stein and Ackerman 2007). However, fragments of riparian wetland and woodland habitats still exist along the soft bottom sections of the LA River. Patches of coastal sage scrub, coast live oak woodlands, walnut woodlands, and mixed coniferous forest can also still be found along the less heavily developed portions of the river's tributaries, such as the Arroyo Seco (CWH 2018).

This section provides a brief summary of the historical ecological conditions in the LA River watershed, organized by ecological subregion (ecotype), and with a focus on dominant vegetation types and aquatic habitat. Likely implications for the historical and potential future steelhead/*O. mykiss* population are included where information is sufficient to support assumptions and hypotheses.

3.7.1 San Gabriel Mountains

The success of steelhead in the LA River, as in other watersheds with a hot, dry summer climate, was dependent on the availability of coldwater spawning and rearing habitat in the higher elevation upper reaches of the watersheds. In the LA River watershed, this habitat occurs in tributary streams originating in the San Gabriel Mountains. The Arroyo Seco and Big Tujunga Creek, the two main perennial tributaries to the upper LA River, likely provided the most important steelhead habitat in these areas. Cool groundwater, combined with dense vegetation and steep canyon walls that shade these streams, continue to support water temperatures in some areas that are favorable for steelhead spawning and rearing (Mongolo et al. 2017). Streams in the foothill and mountain regions are also dominated by riffle and step-pool bed morphology and relatively coarse substrates including gravel, cobble, and boulder that provided spawning and rearing habitat for steelhead (and some other native fishes). Much of the historical vegetation of the upper watershed portions of the San Gabriel Mountains remains intact.

3.7.2 Upper San Fernando/La Crescenta Valley Alluvial Fans

The relatively flat alluvial fans where tributary streams leave the San Gabriel mountains were characterized by warmer year-round temperatures, coarse, porous soils, seasonally ephemeral surface flow, and flood-driven disturbance regimes. These areas historically supported alluvial scrub on drier microsites, with willow riparian scrub and riparian woodlands on wetter sites along the rivers and streams. Some of this vegetation is still present within the Hansen Dam area along Big Tujunga Creek/Tujunga Wash (Hanes et al. 1989). Due to their ephemeral flow regime and high flood disturbance frequency, the stream channels in this area likely lacked suitable habitat for rearing by steelhead or other native fishes and were probably used by steelhead only as a migration corridor during high winter flows.

3.7.3 San Fernando Valley Alluvial Plain

Sections of LA River tributaries within the flat, open alluvial plains of the San Fernando Valley floor, including Big Tujunga Creek, often exhibited surface flow only during wet periods (Gumprecht 2001). As a result, Big Tujunga Creek in this section would have most likely only been used during migration of adult and juvenile steelhead between the mountains and the ocean. The Valley exhibits very hot temperatures in summers and somewhat cooler temperatures in winter due to valley cooling and stronger continental climate influence compared to alluvial plains closer to the coast (Sunset Magazine 2020). Dry coastal sage scrub and herbaceous vegetation was likely dominant adjacent to dry stream beds in this reach. However, areas with seasonal stream flow or shallow groundwater would have supported riparian woodlands and willow scrub alliances, as mapped along Big Tujunga Wash below Hansen Dam by Ethington et al. (2020). Some sections of the LA river mainstem at the foot of the north slope of the Santa Monica Mountains in the eastern San Fernando Valley may have also exhibited perennial flow. Oak and riparian woodlands were present along stream terraces here and on northerly aspects that predominate along the foot of the Santa Monica Mountains (Ethington et al. 2020). Whether flow here was historically perennial is currently unknown, but reaches with shallow, interconnected groundwater may have had perennial flow and relatively cool water temperatures that could have supported habitat for resident rainbow trout and juvenile steelhead, but spawning by steelhead was probably unlikely here.

3.7.4 Elysian Valley Narrows and Lower Arroyo Seco

Below the confluence of Big Tujunga Creek in the Elysian Valley, bedrock near the surface results in shallow groundwater that feeds the LA River. Historically, this resulted in perennial flow and relatively cool water temperatures. These conditions may have supported year-round populations of rainbow trout and juvenile steelhead rearing. Early accounts by Fr. Juan Crespi on August 1st, 1769 suggest a “very full flowing, wide river”, about seven yards wide, just below the Arroyo Seco confluence (Brown 2001, Gumprecht 2001). August is also typically the driest time of year with the lowest flows (Figure 3-3). This information suggests that perennial flow was likely substantial here prior to water diversions to supply the downstream agricultural lands and the growing Pueblo de Los Angeles during the 19th century.

Dense riparian forests and willow scrub within the active alluvial plain, and coast live oak woodlands on adjacent stream terraces, likely contributed to shading of the river and cooler water temperatures. Extensive areas of freshwater marshes were also present along this section of the riparian corridor (TNC 2016). Areas of the river that passed close to the steep Elysian Hills and Santa Monica Mountains near Griffith Park also exhibited more shaded conditions, and potentially cooler water temperatures, due to the favorable position of slopes to the southwest and west reducing solar loading during the hottest afternoon hours. The last documented steelhead caught in the River occurred here in 1940 (Gumprecht 2001).

After leaving the San Gabriel Mountains, the Arroyo Seco travels along the eastern foot of the San Rafael Hills below the Devil’s Gate Dam. It then turns west through the Repetto Hills to its confluence with the LA River at the lower end of the Elysian Valley. Historical accounts suggest the possibility of perennial flow through this reach. Like the nearby Elysian Valley, any deeper, shaded pools with cool groundwater may have provided some year-round habitat value for juvenile steelhead, but steelhead likely used the reach mainly for migration. Vegetation was likely similar to the Elysian Valley with riparian forest and woodlands along the valley bottom and oak woodlands on slopes and canyon walls.

3.7.5 Lower LA River Alluvial Plain

The LA River leaves the Elysian Valley just downstream of the Arroyo Seco confluence, forming a relatively flat alluvial fan between the Downtown and Boyle Heights Neighborhoods that transitions into a broad, flat alluvial plain that is now home to South Los Angeles, Compton, portions of Long Beach, and the “gateway cities” of South Gate, Paramount, Lakewood, and others. Here, meandering, braided channels transported and deposited alluvium from the San Gabriel and Eastern Santa Monica Mountains along the river banks and floodplain. Historically, large storms would often breach the banks resulting in flooding of relatively lower adjacent areas, sometimes allowing the channel to shift miles east or west during a single storm event. A well-known example of this occurred when the river shifted its course in 1825 from emptying into Santa Monica Bay, via what is now Ballona Creek, to its present outlet in Long Beach. There is also evidence that the river would occasionally merge with the San Gabriel River in north Orange County and enter the ocean near Seal Beach (Gumprecht 2001).

Historical accounts and soil data indicate the past presence of vast, verdant plains comprising wet meadows, marshes, riparian forests, and willow thickets in this area of the watershed, interspersed with drier areas of coastal sage scrub away from more recent river alignments (Gumprecht 2001, Dark et al. 2011, Ethington et al. 2020). The water table in many areas was likely shallower historically, but extensive groundwater extraction, subsurface infiltration galleries, and diversion of surface flow for irrigation during the 19th and early 20th centuries contributed to the drawdown of the shallow groundwater table over time (Gumprecht 2001, TNC 2016). Subsequent development and expansion of impervious surfaces may have further exacerbated the drawdown, contributing to loss of much of the native riparian and wetland vegetation.

The historical occurrence of seasonally wet herbaceous meadows, marshes, ponds, and willow thickets was documented by Dark et al. (2011) in what is now the Ballona Creek Watershed near the historical "La Cienegas" wetlands upstream of the Baldwin Hills. Historical mapping and soils data indicate that similar wetland ecosystems were also likely present near the confluence of the LA River and Compton Creek just upstream of the Dominguez Hills and Bixby Knolls area of Long Beach (Ethington et al. 2020). This higher terrain and associated narrows in the alluvial plain were formed by the Newport Inglewood Fault. Backup of runoff behind the Dominguez Hills, along with relatively shallow bedrock under the alluvial plain associated with the Fault, may have also resulted in rising groundwater, supporting wetlands and perennial LA River flow in this area. This may have provided conditions suitable for juvenile steelhead rearing in some areas, most likely during cooler times of the year. The stronger maritime climate influence here may have also supported cooler overall water temperatures than more inland, "valley" reaches of the river that are substantially hotter during summer months.

Drier shrublands and seasonally dry herbaceous meadows were likely interspersed with wet areas and higher, adjacent coastal terraces and low hills may have also exhibited herbaceous prairies similar to those described by Mattoni and Longcore (1997) near the LAX dunes and Baldwin Hills, along with coastal sage scrub vegetation (Ethington et al. 2020).

3.7.6 LA River Lagoon Area

The historical LA River estuary and brackish wetlands, and extensive areas of freshwater wetlands and water bodies, occurred below the Dominquez Hills Narrows where the Los Angeles River, Dominguez Channel, and Wilmington Drain now meet (Ethington et al. 2020). The area included an expansive lagoon protected by a sand spit near San Pedro (Gumprecht 2001). The estuary was critical for juvenile steelhead rearing prior to ocean entry (see Sections 2.1 and 5.4). Most of this area has since been filled and channelized to make way for the Ports of Los Angeles and Long Beach (Figure 3-9). Historical vegetation likely included willow thickets, tule, and other perennial and ephemeral freshwater marsh vegetation, interspersed with coastal sage scrub and grasslands on higher terrain. Salt marsh and pickleweed alliances likely dominated brackish intertidal areas (Ethington et al. 2020).

Figure 3-9. Historical aerial photo comparison at the LA River estuary from 1928, 1960, and 2007.

3.8 Aquatic Habitats and Species

The LA River watershed was once home to a variety of native fish species that were of ecological and social importance. Over time, human influences in the watershed have dramatically altered natural processes and degraded habitat and water quality conditions. These human induced changes to rivers and streams in the watershed have led to extirpation or severe range contraction of many native fish species and reduction of biodiversity within the region. In this section, we summarize the existing habitat and species in the LA River and provide insights into changes relative to historical conditions.

3.8.1 Habitat conditions

As previously discussed, the LA River is a highly modified system, which has resulted in fragmentation and degradation of aquatic and riparian habitats. For example, numerous barriers and impediments occur throughout the LA River and its tributaries that prevent or limit movements of fish between habitats, reduce the total amount of available habitat, and disrupt habitat forming processes. We include a detailed discussion of barriers in Sections 4 and 5 of this document. Generally, aquatic habitat becomes less modified as distance upstream from the ocean increases. Below we describe current habitat in the LA River starting from the river's mouth and moving in an upstream direction. We focus on habitat conditions in general with specific references to steelhead when applicable.

In many rivers in central and Southern California, seasonally closed estuaries and lagoons serve as important rearing habitat for juvenile steelhead and other species because they provide thermal refuge and opportunities for enhanced feeding and growth. Effectively, the estuary no longer exists in the LA River in a capacity to support native fish rearing. There is no sandbar formation at the mouth of the LA River, resulting in continuous connection with the ocean. Water quality is also poor with high temperatures throughout the year but especially during the summer (see Section 3.6). Thus, conditions at the mouth of the LA River are considered largely unsuitable for native freshwater and anadromous fishes of any life stage (e.g., steelhead, Pacific lamprey, unarmored threespine stickleback), although steelhead could still use the estuary as a migratory corridor. In five fish surveys conducted by the Resource Conservation District of the Santa Monica Mountains (RCDSMM) and Friends of the LA River (FoLAR) in the lower LA River between May 2014 and August 2015, only a single native fish—a California killifish (*Fundulus parvipinnis*)—was documented (FoLAR 2016).

The lower LA River mainstem, which was historically an extensive alluvial floodplain (see Section 3.7), now contains little suitable habitat for native aquatic species because its banks and bottom consist of mostly channelized concrete designed to contain and efficiently distribute runoff to the ocean and not to provide habitat for aquatic species. These concrete sections are homogenous, can have high temperatures (>86°F [>30°C] based on USGS data from Long Beach) and are largely devoid of vegetation and fish (i.e., there is little or no suitable habitat for fish). With the exception of three natural, soft-bottom reaches the LA river is entirely channelized with concrete (Figure 3-8). Soft-bottom reaches near the river's mouth in Long Beach, in the Glendale Narrows upstream of the Arroyo Seco confluence, and in Sepulveda Basin Recreation Area have heterogeneous bottom substrate, riparian and aquatic vegetation, and complex aquatic habitat. These locations may provide some suitable habitat conditions for native fish including cover from predators, shading by riparian vegetation to moderate water temperature, and aquatic invertebrate production to provide food resources. However, the presence of non-native species and poor water quality (e.g., high temperatures, low dissolved oxygen, pollutants) likely preclude the occurrence of most native aquatic species. Historically, the LA River mainstem likely provided little quality habitat for coldwater fishes such as steelhead and Pacific lamprey, but did serve as a crucial migration corridor and may have provided seasonal habit such as access to floodplains that fish could take advantage of for feeding opportunities.

Further upstream in tributaries to the LA River, habitat conditions begin to improve. Temperatures are cooler (Mongolo et al. 2017) and the streams have more natural bed materials and physical structure. Riparian vegetation becomes more consistent, providing shading and allochthonous inputs into the streams that promote productivity. However, lower tributaries are still influenced by urbanization (e.g., runoff, water quality) and the presence of dams upstream that prevent movement of materials and natural habitat forming processes in downstream reaches. For example, Devil's Gate Dam on the Arroyo Seco acts a sediment sink and prevents movement of sediment and large woody material downstream. Downstream of Hansen Dam in the lower reaches of Big Tujunga (i.e., Tujunga Wash), habitat conditions are also not generally suitable for aquatic species due to channelization and the ephemeral nature of the stream as it enters the valley.

Upstream of barriers in the upper reaches of the tributaries, habitat closely resembles historical conditions (SRMA 2020). Cool groundwater inputs, combined with dense vegetation and steep canyon walls that shade these streams, continue to support water temperatures and habitat that are suitable for native fish species (Mongolo et al. 2017, BonTerra Consulting 2011). Streams in the foothill and mountain regions are typically dominated by riffle and step-pool bed morphology and relatively coarse substrates including gravel, cobble, and boulder that provided high quality rearing and spawning habitat for native fishes. Much of the historical vegetation of the upper watersheds in the San Gabriel Mountains remains intact and continues to provide ecosystem support and suitable habitat conditions for native fishes.

The LA River was historically subjected to extremes, however, recent drought conditions such as from 2012–2017 combined with more frequent and severe wildfires has further impacted habitat. For example, high debris loads are predicted following wildfires (e.g., the 2009 Station Fire, Cannon et al. 2010) that can inundate suitable rearing and spawning habitat with debris and sediment. Scouring associated with post-wildfire debris flows widens stream channels, reduces water retention, reduces riparian vegetation, and homogenizes habitat into continuous shallow riffles (Lamberti et al. 1991). More intense and frequent ecological disturbances such as drought and wildfires are predicted with climate change and may have severe impacts on aquatic habitat. Due to predicted impacts associated with climate change, there is even greater need to protect and maintain suitable aquatic habitat in multiple locations that will promote long-term resiliency for native fish populations.

Finally, the creation and maintenance of in-stream habitat is necessarily dependent on hydrological and geomorphic processes such as scouring and movement of sediment and bed load materials along a longitudinal gradient. As described in sections above, these conditions have been heavily altered and thus, these habitat forming processes are no longer intact across much of the LA River watershed, especially within the LA River mainstem and below dams in the tributaries. Restoration of these habitat forming processes would promote long-term resiliency of restored habitats and minimize the need for ongoing interventions such as gravel augmentation, riparian revegetation, and channel maintenance.

3.8.2 Fish and aquatic species

There are seven species of native fish that occur or have the potential to occur in the LA River watershed (Swift et al. 1993), all of which are considered special-status species[2] with either state or federal protections (CNDBB, CNPS, USFWS) (Table 3-4). Native fish have different habitat associations and therefore their presence would not have been evenly distributed within the LA River watershed. For example, Arroyo chub (*Gila orcuttii*) prefer slow water streams with mud or sand bottoms and therefore would not be likely to occur in fast moving, headwater streams that have cobble and boulder substrates (Moyle 2002). Instead, they would be more likely found in slower moving pools and runs in tributaries lower in the watershed or even in perennial pools within the mainstem LA River.

[2] Special-status fish species are defined as species listed, proposed, or under review as endangered or threatened under ESA or CESA, and/or designated as a species of special concern by CDFW.

Table 3-4. Special-status fish species with potential to occur in the LA River watershed. SSC denotes a California species of special concern. Note that *O. mykiss* are separated into two groups, coastal rainbow trout and steelhead, based on life history differences, management implications, and the focus of this document.

Common name Scientific name	Query sources	Status[a] Federal/ State	Distribution in California	Habitat associations	Likelihood to occur in the watershed
Arroyo chub *Gila orcuttii*	CNDDB	–/SSC	Native to streams from Malibu Creek to San Luis Rey River basin; introduced into streams in Santa Clara, Ventura, Santa Ynez, Mojave & San Diego river basins	Slow water stream sections with mud or sand bottoms	Present (upper watersheds only); limited by habitat availability and presence of non-native predatory species
Pacific lamprey *Entosphenus tridentatus*	N/A	–/SSC	Coastal rivers and stream with access to the ocean	Spawning in gravel riffles with fast moving currents and rearing in soft sand or mud	Not documented. Moderate potential to occur; limited by habitat availability and barriers
Santa Ana speckled dace *Rhinichthys osculus*	CNDDB	–/SSC	Headwaters of the Santa Ana and San Gabriel rivers. May be extirpated from the LA River system	Shallow cobble and gravel riffles in permanent flowing streams with summer water temps of 62.6–68°F (17–20°C)	Present (upper watersheds only); summer water temperatures and non-native predatory species likely preclude occurrence/persistence throughout year
Santa Ana sucker *Catostomus santaanae*		FT/SSC	Endemic to Los Angeles Basin south coastal streams, but also occur in Santa Clara River watershed.	Habitat generalists, but prefer sand-rubble-boulder bottoms, cool, clear water, and algae.	Present (upper watersheds only); limited by habitat availability and presence of non-native predatory species
Steelhead, Southern California DPS *Oncorhynchus mykiss*	CNDDB, NMFS	FE/–	Federal listing refers to populations from the Santa Maria River in San Luis Obispo County south to the U.S-Mexico border	Flowing waters, riffles and pools in streams and rivers that connect with the ocean and have high dissolved oxygen	Not documented. Moderate potential to occur; limited by habitat availability, water conditions and barriers, and predatory non-native species.
Coastal rainbow trout *Oncorhynchus mykiss*	CNDDB	FE (below barriers only)/ –	Western slopes of the Sierra Nevada in waters draining to the Pacific Ocean. Below barriers are considered steelhead in Southern California	Flowing waters, riffles and pools in streams and rivers that connect with the ocean and have high dissolved oxygen	Rare or extirpated from much of watershed but observed recently or have potential to occur in tributaries.

Common name Scientific name	Query sources	Status[a] Federal/ State	Distribution in California	Habitat associations	Likelihood to occur in the watershed
Tidewater goby *Eucyclogobius newberryi*	CNDDB, USFWS	FE/SSC	San Diego County north to the mouth of the Smith River in Del Norte County	Coastal lagoons and uppermost zone of brackish large estuaries consisting of fairly still but not stagnant water and high oxygen levels; prefer sandy substrate for spawning, but can be found on silt, mud, or rocky substrates; can occur in water up to 4.6 m in lagoons and within a wide range of salinities (0–42 ppt)	Not documented. Low potential to occur; too far from suitable coastal habitats and fish barriers that preclude movement upstream to project area
Unarmored threespine stickleback *Gasterosteus aculeatus williamsoni*	CNDDB	FE/SE	Federal listing refers to Upper Santa Clara River, Bouquet Creek and Soledad Canyon Creek.	Cool (<75.2°F [24°C]), clear water with abundant vegetation.	Not documented. Moderate potential to occur

There have been few extensive surveys to determine species presence in the LA River watershed. Based on recent surveys conducted by SRMA (2020) the arroyo chub, rainbow trout, Santa Ana speckled dace (*Rhinichthys osculus)*, Santa Ana sucker (*Catostomus santaanae)* are the only native freshwater fishes that presently occur in the watershed. All of these species were detected in lower Big Tujunga Creek, and all species were uncommon except for arroyo chub, which were common. In addition to being present in lower Big Tujunga, rainbow trout were also detected in Upper Big Tujunga, lower Alder Creek, and the Arroyo Seco, but in all locations rainbow trout were considered uncommon or rare (SRMA 2020). Santa Ana suckers were commonly observed in Haines Creek, a tributary to Big Tujunga Creek. Arroyo chub were uncommon in Haines creek and rarely observed in the Arroyo Seco (SRMA 2020). Previous surveys from Big Tujunga Creek also confirmed the presence of all species except rainbow trout (ECORP 2010, BonTerra Consulting 2011, Stein et al. 2018). SRMA (2020) noted that disturbances, such as debris flows associated with wildfires and drought, may have reduced or eliminated native aquatic species from some of their survey locations. Extirpation of species following disturbances is problematic when there is limited ability for recolonization due to the presence of downstream barriers.

Based on results from fish surveys largely conducted in Big Tujunga Creek and the LA River at the Sepulveda Basin and the Glendale Narrows (FoLAR 2008, BonTerra Consulting 2011, CDFW 2014, FoLAR 2015, SRMA 2020), present day aquatic species assemblages are dominated by non-natives such as common carp (*Cyprinus carpio*), mosquitofish (*Gambusia affinis*), tilapia *(Oreochromis* sp*.)*, fathead minnow (*Pimephales promelas*), black bullhead (*Ameiurus melas*), yellow bullhead (*Ameiurus natalis*), channel catfish (*Ictalurus punctatus*), common goldfish (*Carassius auratus*), and centrarchids such as largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), and green sunfish (*Lepomis cyanellus*). Other non-native aquatic species that presently occur within the LA River basin include red-swamp crayfish (*Procambarus clarkia*) and American bullfrogs (*Lithobates catesbeianus*). Many of these species compete with or are predators of native fish species.

Non-native aquatic species are persistent in the LA River because they take advantage of altered habitat and conditions such as warmer temperatures, low dissolved oxygen, and reduced flows. Channelization has homogenized or eliminated habitat altogether from many locations within the LA River. Urban and flood control structures such as bridges and levees have also created artificial environments such as pools that provide refuge for non-natives which tend to prefer deeper, slow moving waters. Larger barriers, such as dams and spillways also create lentic habitat upstream that provides refuge for non-natives and acts as a source population for the continued spread of non-natives throughout the watershed. Most non-natives have been found in lower elevation water bodies and are not typically observed in higher elevation, upper tributaries.

4 LIMITING FACTORS ANALYSIS

In this section, we identify the range of potential factors that could limit the ability of steelhead to complete the freshwater portions of their lifecycle within the LA River watershed. We then screen these potential limiting factors to identify limiting factors of greatest importance to steelhead in the LA River. Qualitative and when possible, quantitative assessments are used to evaluate limiting factors thought to be of specific importance and to develop hypotheses that: a) inform the conceptual ecological model for LA River steelhead in Section 5 of this report; and b) support recommendations for additional studies and restoration actions. We begin with a brief description of limiting factors that were considered (Section 4.1), followed by a detailed discussion of limiting factors that are perceived to be of high importance (Section 4.2).

4.1 Potential Limiting Factors

Aquatic resources within LA county have been under increasing pressure from humans as a result of urban expansion and associated increases in water demands. These have resulted in a wide range of factors that may limit the viability of steelhead in the LA River. Habitat loss, habitat fragmentation, and altered hydrologic regimes are some of the most common overarching limiting factors for fishes in general (Magurran 2009). Reduced habitat, which is perhaps the largest limiting factor for native fish globally, can occur through a number of mechanisms such as channelization, water diversions that reduce flows, and increased sedimentation, but habitat loss can also occur as a result of sub-optimal conditions that make habitat unsuitable. Regardless of the cause, reductions in the amount or quality of available habitat, or an inability to consistently access suitable habitat, reduce the likelihood that a species can successfully fulfill life history needs such as migration, foraging, reproduction, and sheltering. The consequences may include reductions in population size, population growth rate, spatial distribution, and genetic diversity, potentially making species more vulnerable to disturbances and reducing population resilience and viability (McElhany et al. 2000).

Steelhead spend a considerable portion of their life cycle in fresh water. This period includes several of the most vulnerable life stages. During this time they are subject to a variety of physical and biological factors that influence fitness and may cause direct or indirect mortality, thereby limiting the size and health of the population. Because environmental requirements change for each salmonid life stage, different factors are important during different life stages. Accordingly, we organized the analysis of potential limiting factors by life stage.

This analysis is focused on the freshwater phase of the steelhead life cycle. Factors affecting the amount and quality of available estuary rearing habitat are also briefly addressed. Ocean harvest and other factors affecting growth and survival of steelhead during the ocean phase of their life cycle may also be very important limiting factors but were beyond the scope of this study.

The following list includes the factors believed to be potentially limiting during one or more steelhead life stages. These factors are generally applicable to steelhead and salmon populations throughout the species' range. In Section 4.2 we identify the factors most likely to limit a future population of steelhead in the LA River watershed.

4.1.1 Adult upstream migration

The initiation of upstream migration by adult salmonids, including steelhead, generally requires an environmental cue in the form of an "attraction flow," which provides a chemical or other type of signal to the fish that upstream conditions are suitable for migration and spawning (Keefer and Caudill 2014). Alterations in the timing, duration, or magnitude of attraction flows may delay or prevent the spawning migration by anadromous salmonids.

As adult salmonids migrate upstream to spawn, they frequently must overcome a variety of natural and anthropogenic obstacles before reaching suitable spawning areas. These include:

- *Physical migration barriers.* Natural or man-made features such as dams, weirs, inadequate flows, natural falls, grade control structures, or culverts may compromise the success of spawning salmonids by preventing access to spawning habitat, or, in the case of partial barriers, by depleting the fish's energy reserves as it attempts to get past the obstacle. In highly modified river channels like the LA River, hydraulic conditions such as prohibitively high water velocities or shallow water depths resulting from channelization and concentrated, laminar flow may pose physical barriers to migration.

- *Environmental migration barriers*. Upstream migration by adult salmonids to their spawning grounds may also be blocked or curtailed by environmental conditions, such as poor water quality, elevated water temperatures or high suspended sediment loads. If water temperatures remain prohibitively high, spawning may not occur or may take place in suboptimal habitats.
- *Migration corridor hazards*. Other hazards that may be encountered by adult salmonids as they migrate upstream include poaching and false migration pathways presented by bypasses, diversions, tributaries, and storm drains. These hazards can interfere with spawning migrations and limit the success of salmonid populations.

4.1.2 Spawning and incubation

Environmental conditions play a crucial role in successful salmonid spawning, egg incubation, and survival to emergence. The range of environmental tolerance of salmonids during this life stage is narrow, and many factors may limit survival. These factors include:

- *Spawning gravel quantity and redd superimposition*. Limited spawning gravels may occur naturally or where access to spawning habitat has been blocked or suitable substrates have been dewatered. This problem can be further exacerbated in areas where limited habitat availability can result in competition for space that leads to redd superimposition (i.e., excavation of a salmonid spawning nest, or redd, on top of an existing redd, partially or completely destroying the eggs of the previous spawner).
- *Spawning gravel quality*. Suboptimal spawning gravel quality (related to gravel size distribution and/or presence of fine sediment) can limit spawning and incubation success by rendering gravel unusable by spawning fish, creating unsuitable incubation conditions, or preventing fry from emerging after hatching.
- *Water quality and temperature.* Survival to emergence is dependent on successful incubation of eggs, which are especially vulnerable to low dissolved oxygen levels and high water temperature. Excessive sediment deposition during incubation also can reduce egg survival by inhibiting gravel permeability (thereby reducing both oxygen delivery and removal of metabolic wastes) and can trap (or "entomb") emerging alevins.
- *Substrate mobility/scouring.* Successful hatching and emergence require stable gravels in and around the egg pocket. Scouring of redd gravels can alter redd hydraulics resulting in reduced egg survival rates or cause abrasion and displacement of eggs resulting in direct mortality.
- *Redd dewatering.* Partial or complete dewatering of redds can result in low survival rates due to reduced delivery of water and oxygen and buildup of toxic metabolic byproducts, and may cause egg mortality due to desiccation.

4.1.3 Juvenile rearing

Following emergence from the gravel, juvenile salmonids must begin feeding and competing for resources under varying environmental conditions. Factors that may limit survival of rearing juvenile salmonids include:

- *Availability of summer rearing habitat.* During summer, when flows are typically lowest and water temperatures highest, pools, substrate interstices, and other complex habitats provide rearing salmonids with important refugia from high temperatures and predation. A lack of summer rearing habitat can reduce the success of juvenile salmonids, especially in populations subject to other stressors such as reduced food availability, increased competition for food and space, and increased predation.

- *Availability of overwintering habitat.* Displacement or mortality caused by high winter flows frequently limits production of juvenile salmonids that do not have access to refuge habitat associated with large woody material, large substrates such as boulders, interstitial spaces among coarse substrates, off-channel habitat, or other features that provide velocity refuge.
- *Stranding by low flows.* Stranding can cause direct mortality of juvenile salmonids when low flows or rapidly receding water levels isolate fish in disconnected or dewatered habitats, subjecting them to predation, desiccation, high water temperature and low dissolved oxygen concentrations, or other hazards.
- *Displacement by high flows.* Extremely high flows, especially in areas devoid of bed or bank roughness elements, can displace rearing salmonids and lead to low survival, injury, or mortality. Without complex habitats (e.g., deep pools, large woody debris, or interstitial spaces between cobble/boulder) to provide refuge from high water velocities, salmonid fry and juveniles are likely to be displaced downstream and experience higher rates of injury and mortality from physical trauma, predation, or other causes. Those that survive displacement and end up prematurely in the estuary or ocean are at increased risk of predation due to their relatively small size and poor swimming ability.
- *Predation.* Predation limits population success through direct mortality. Predation pressure on rearing salmonids may be increased by removal of instream and overhead cover, low flows, migration barriers, and changes in channel geometry. Predation is a particular problem for salmonids where non-native piscivorous fishes are abundant.
- *Food availability.* An inadequate food supply can cause increased interspecific and intraspecific competition, and may lead to reduced fitness and, in some cases, mortality.
- *Interspecific interactions between native species.* Interspecific interactions between native species, which include competition for food and space, are usually related to reduced availability of food and suitable habitat. These interactions may result in reduced fitness or survival.
- *Competition with non-native species.* Non-native species can compete for food and space with native salmonids, reducing access to these important resources and potentially limiting fitness and survival.
- *Water quality/temperature.* The quality and temperature of stream water has a direct impact on the success of rearing juvenile salmonids. Short term exposure to lethal or near lethal temperatures or prolonged periods of elevated water temperature, as well as acute or chronic water pollution, can lead to direct and indirect mortality or physiological impairment of juvenile salmonids.

4.1.4 Outmigration

A variety of internal fish and external environmental factors may serve as outmigration cues to juvenile salmonids in streams. Outmigrating fish are subject to a range of conditions that influence their ability to successfully reach the ocean. These include:

- *Physiological and genetic.* The smoltification process, which prepares migrants for life in saltwater, initiates while fish are still rearing, and the process continues over the course of downstream migration. Initiation of smoltification is associated with changes in photoperiod (Boothe 2020) but fish size also plays a key role in the decision to migrate to the ocean (Kendall et al. 2015). Genetic factors also play a role in outmigration (Pearse et al. 2014).

- *Adequate flows for outmigration.* After undergoing smoltification, juvenile salmonids initiate outmigration when adequate river flows occur, usually during spring. Reduced flow duration or magnitude during the outmigration period can render some portions of the river corridor impassable and may subject emigrating juveniles to increased predation, stress, or mortality due to high temperatures, thereby reducing the chances of successful outmigration.
- *Water quality and temperature*. Water quality and temperature may be especially important to outmigrating salmonids during low-flow periods. Lethal or sublethal effects may result from pollutants or prolonged exposure to high water temperatures.
- *Predation*. Predation, especially by non-native warmwater, piscivorous fish, is believed to be a significant source of mortality of outmigrating salmonids in some rivers. Outmigrant juveniles may also be subject to predation by terrestrial or avian predators.
- *Diversion hazards*. Water diversions, such as canals, pumps, and bypasses, can act as "blind pathways," preventing fish from reaching the ocean. They may also be directly lethal to fish or may expose them to high water temperatures, pollutants, predation, or desiccation.

4.2 Evaluation of Watershed-specific Limiting Factors

The potential limiting factors described above are relevant to steelhead in the LA River and were considered in the development of the Conceptual Ecological Model described in Section 5. The scope of our analysis was limited to desktop evaluation of existing data, but limited information was available to evaluate in detail many of these potential limiting factors for the LA River watershed. For example, there are currently no steelhead in the watershed and thus no ability to monitor or collect population data, and much of the information on LA River steelhead is from historical accounts summarized in publications by Gumprecht 2001, Becker and Reining 2008, and Tomlinson 2014. For these reasons, our assessment of steelhead life history patterns is based largely on steelhead in systems whose size, climate, upper watershed hydrology, and ecoregional context most closely resemble the LA River such as the Santa Clara and Santa Ynez rivers, both of which are California watersheds that support steelhead populations within the Southern California DPS.

We found few data on environmental conditions in the LA River, particularly for physical habitat conditions, water temperature, and sediment concentrations. Inferences about physical habitat features, including barriers, were largely made through review of aerial imagery combined with field reconnaissance and historical accounts. Temperature monitoring data were available through two primary sources including a USGS monitoring site in the lower LA River near Long Beach, and a temperature monitoring study that collected continuous temperature data from a single summer at multiple locations within the watershed (Mongolo et al. 2017). Temperature monitoring data at the USGS Long Beach gages were not continuous. Suspended sediment data were also collected at the Long Beach USGS site, and thus, there were some temperature and sediment data to inform our desktop review, as presented below. The following sections describe the factors most likely to limit a future population of steelhead in the LA River watershed, based largely on available data from the LA River and similar river systems and our understanding of *O. mykiss* life history and habitat requirements.

4.2.1 Flow

The timing, frequency, duration and magnitude of flow in the LA River are critical factors affecting steelhead across their freshwater life stages. Flow is probably the single most important limiting factor for steelhead in the LA River because it also influences many other environmental factors such as water quality (e.g., temperature), migration barriers/impediments (limitations imposed by depth and velocity are functions of flow), habitat (flow controls formation and availability of habitat), and sediment. Due to the effects of flow on abiotic and biotic factors, discussions of flow are incorporated throughout this document and within sections describing other limiting factors (e.g., migration barriers, temperature, sediment). In this section, we provide an overview of the effects of flow on steelhead and how flow potentially limits steelhead viability within the LA River watershed.

Adequate flow at the time of the year when steelhead would migrate is required for steelhead to move between the ocean and freshwater spawning and rearing locations. Unlike perennial rivers further north, rivers in Southern California often have intermittent flow regimes resulting in periodic drying and hydrologic disconnection between river reaches, as well as between the estuary and ocean. Rain events create flows that provide connectivity along longitudinal gradients, and these rain events occur during the wet season when steelhead migration occurs. For adult steelhead to access most Southern California rivers, flows must be high enough to breach sandbars, but sandbars are absent from the LA River estuary and thus flows are not limiting to river entry.

Flows, however, can be limiting to upstream migration within the LA River. Depth and velocity conditions must be met for both upstream and downstream migration, but flows are thought to be particularly limiting to upstream migration because adult migrants are larger, and thus require greater water depths, and upstream migrants must swim against the water current, which becomes more challenging as the water velocity increases (also see Section 4.2.2 for additional details on how flows create barriers or impediments to steelhead migration). Adult salmonids have three modes of swimming: sustained, prolonged and burst (Beamish 1978). Sustained swimming can be maintained indefinitely and relies solely on aerobic metabolic activity. Prolonged swimming is a combination of aerobic and anaerobic metabolic activity and can be maintained for extended periods of time (minutes to an hour) before reaching fatigue. Burst swimming can only be maintained for seconds before fatigue and almost exclusively uses anaerobic muscles. Thus, if water velocities exceed burst swim speeds, flow prevents migration. Flows can also impede migration when velocities exceed the prolonged swimming capacity over large reaches with no suitable velocity refuge habitat. Recommendations and standards for velocity and depth passage criteria for salmonids are provided by Bell (1991), Flosi et al. (2010) and NMFS (2001, 2019). Velocities that can impede migration are dependent on the distance the fish needs to travel, but adult steelhead can swim for prolonged periods of time when water velocity is between 6 and 12 ft/s (1.8 – 3.7 m/s) (Bell 1991). High water velocities over large spatial scales can also deplete energy reserves needed for spawning and gamete development, and tradeoffs exist between energetic expenditure during migration and reproductive fitness. Bioenergetic modeling would be required to estimate how much energy is required to complete migration in the LA River. Depths that facilitate upstream migration are considered suitable when they exceed the body depth of fish, and 1 ft (0.3 m) depth is recommended.

Channelization of the mainstem LA River has created a major challenge for upstream migrating fish. When flows are too low, water depth is insufficient at most locations for adults to migrate upstream and pass obstacles. When flows increase, the shape of the channelized concrete river bed and banks creates velocities that are too high for adults to swim upstream against. This has been demonstrated by 1-D hydraulic modeling in a representative segment of the 4.8-mile LAR FPHS design project reach (Table 4-1; also see Reclamation 2019). When compared to the aforementioned recommendations for depth and velocity criteria, results from this model indicate that upstream migration is limited by depth at flows < 600 cfs (Table 4-1). Furthermore, velocity is limiting to upstream migration when flows are > 300 cfs (Table 4-1) because, despite these velocities being within the prolonged swimming ability of steelhead, the distances over which these swimming speeds would need to be maintained in the LA River surpass the amount of time which steelhead could maintain these swimming speeds and there is no resting habitat available for fish to recover along the way. Effectively, the channelized structure within the LA River results in hydraulic conditions that are unsuitable for upstream passage. Furthermore, the duration of flow events has been shortened from historical conditions due to channelization, loss of connection to groundwater, reduced storage of overbank flows on floodplains and in wetlands, and rapid stormwater runoff and recession caused by the largely impervious urbanized landscape.

Table 4-1. 1-D hydraulic modeling results for the LA River in the 4.8-mile LAR FPHS project reach, showing the relationship between discharge and water depth and velocity in a straight section of the concrete-lined channel. Red text indicates depth thresholds considered unsuitable for upstream migration by adult steelhead and velocity thresholds for prolonged swimming which could not be maintained over long distances.

Discharge (cfs)	Depth (ft)	Velocity (ft/s)
100	0.59	4.76
200	0.74	5.16
300	0.81	5.88
400	0.88	6.49
500	0.93	7.08
600	0.98	7.57
700	1.02	8.05
800	1.06	8.49
900	1.11	8.87
1,000	1.15	9.23

Steelhead at the southern extent of their range are adapted to flashy and seasonal flows (Shapovalov and Taft 1954, Moyle 2002, NMFS 2014, Stillwater and Kear 2012), but there is no historical data on flows or steelhead migration in the LA River prior to urbanization to characterize historical flow conditions that facilitated upstream migration. Under historical conditions it is assumed that flow that provided migration opportunities would have occurred in most years. Under current conditions, flows that allow upstream migration would not be expected to be more infrequent than historical due to the system being more flashy. Although adequate flows are needed during the juvenile/smolt outmigration period to provide longitudinal habitat connectivity between tributary habitat and the ocean, outmigration can be facilitated under a much wider range of flow conditions and flow alone is not considered limiting to smolt outmigration.

Flow is not thought to be limiting to spawning, egg incubation, or early life development of *O. mykiss* in the LA River watershed. These life stages require adequate flow to provide suitable conditions such as dissolved oxygen and temperature (higher flows are associated with increased dissolved oxygen and lower temperatures), and flows within tributaries where these events occur are perennial and not likely to be limiting. The existence of self-sustaining *O. mykiss* populations in the Arroyo Seco and the Big Tujunga drainage (SRMA 2020) provide evidence that flows are not limiting to spawning and early life development for resident fish. Flow would, however, influence the total area available for spawning, but it is assumed that there is more than adequate availability of spawning habitat for the expected low numbers of anadromous adults that would return to the LA River watershed. The issue of spawning habitat availability on the life history of steelhead is discussed further in Section 5 below.

Juvenile rearing during the summer and fall is a challenging life history phase for steelhead in Southern California due to low flows that can result in marginal habitat conditions. Infrequent rainfall events during these months result in reduced flows and potentially sub-optimal water quality such as low dissolved oxygen and higher temperatures. Lower flows also reduce the total amount of habitat available for rearing and the availability of many types of macroinvertebrate prey within streams. Thus, flow is a major factor associated with habitat availability and suitability for rearing. Due to the associations between flow and habitat, flow could be a limiting factor for juvenile rearing, depending on the location in the watershed. In the major tributaries that currently support resident *O. mykiss* and where the offspring of anadromous (i.e., steelhead) spawners are expected to rear, flows are likely adequate to support this life stage. However, low flows may limit rearing in other locations within the watershed, such as in the mainstem LA River and the lower reaches of the tributaries. The effects of habitat availability on juvenile rearing is discussed in more detail in the habitat section below.

4.2.2 Migration barriers

Barriers and impediments to fish movement can cause significant adverse impacts on anadromous fish populations by restricting the ability of fish to leave and return to the basin and the ability of rearing juveniles and resident adults to access habitat and track resources within the system. By disrupting habitat connectivity, even a small number of barriers can have a disproportionately large impact on a population if the barriers obstruct access to large amounts of habitat or habitat of critical importance. Barriers also impact the ability of fish to respond to disturbances. For example, barriers can prevent fish from recolonizing an area following extirpation by wildfires and subsequent debris flows, which are common in Southern California rivers. Resilience of a population to changing conditions is also reduced when barriers prevent the sharing of genetic material between populations or subpopulations, thereby reducing genetic diversity. Indeed, barriers that result in habitat fragmentation can increase the risk of extirpation or even extinction of populations, which is why increasing habitat connectivity is a focus of many restoration activities.

Barriers can be natural (e.g., waterfalls) or anthropogenic (e.g., dams, culverts, road crossings), structural or hydraulic, or caused by water temperature or chemistry, but in all cases they result in habitat fragmentation. A hydraulic barrier (also referred to as a ‘velocity barrier’) occurs when water velocities exceed the swimming capabilities of fish. Velocity barriers occur frequently in channelized sections of rivers because the simplified channels lack physical structures that displace the force of water. Low flows can also result in passage barriers at locations where rivers become dry or when water is too shallow for fish to move between habitats. Locations that become impassable during low flows are sometimes referred to as ‘critical riffles.’ Section 4.2.1 provides specific details on depth and velocity criteria for fish passage. In addition to structural and velocity barriers, sub-optimal water quality conditions such as high temperature or low dissolved oxygen concentrations can also act as barriers to movement.

We identified potential structural and hydraulic barriers in the LA River watershed by searches on the California Passage Assessment Database (PAD) combined with desktop and field observations. Barriers were characterized as either structural (e.g., a dam, weir, or natural waterfall) or hydraulic, and whether barriers would likely prevent upstream migration, downstream migration, or both (Figure 4-1). Note that additional data gathering would be needed to fully evaluate many of these barriers, and there may be additional barriers that were either not identified or that were identified but might require additional evaluation.

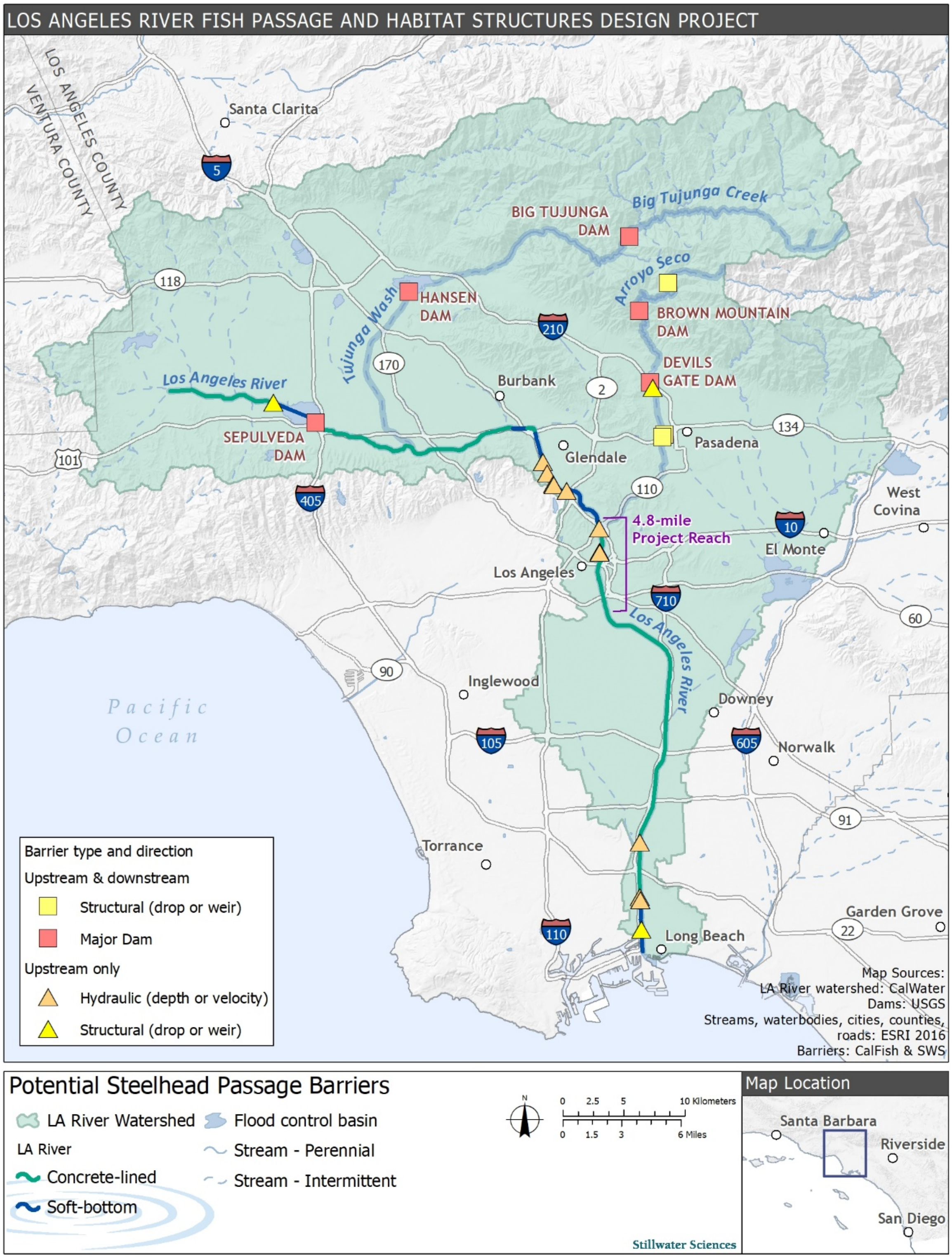

Figure 4-1. Potential steelhead migration barriers identified within the LA River watershed. Colored symbols indicate the type of barrier and whether it would limit upstream passage, downstream passage, or both.

Moving from the estuary upstream, several hydraulic or structural upstream barriers exist within the concrete and soft-bottom reaches in the lower LA River. These barriers may depend on flows and are only identified as barriers to upstream migrating fish. Additional upstream passage barriers (all hydraulic) exist further upstream in the LA river mainstem within the 4.8-mile LAR FPHS project reach (Figure 4-1), as well as upstream of the project reach within the soft-bottom channel near Glendale. Sepulveda Dam is a complete barrier (both upstream and downstream) and marks the furthest upstream adult migrants could reach in the LA River mainstem.

Structural barriers also occur within the major tributaries that could support steelhead and resident *O. mykiss*. In the Arroyo Seco, Devil's Gate Dam limits upstream migrants from accessing some of the highest quality spawning and rearing habitat in the upper Arroyo Seco. Devil's Gate Dam also prevents juveniles produced by resident *O. mykiss* from the upper Arroyo Seco from migrating downstream as anadromous smolts and prevents resident *O. mykiss* from accessing downstream habitat. Brown Mountain Dam, upstream from Devil's Gate Dam on the Arroyo Seco, also prevents upstream and possibly downstream migration. On Big Tujunga Creek, Hansen Dam and Big Tujunga Dam, also prevent upstream-migrating fish from accessing the highest quality habitat in the Big Tujunga system in the San Gabriel mountains, and prevent downstream migration of any resident *O. mykiss* or their progeny. Overall, numerous migration barriers exist within the LA River watershed that would limit or completely block migrations, and thus barriers may be the single most critical factor limiting steelhead viability in the LA River.

4.2.3 Water quality

Habitat loss can also effectively occur when sub-optimal conditions exist such as poor water quality or altered resources. Poor water quality includes increased temperatures, reduced dissolved oxygen, and increased nutrient or toxicant concentrations. As discussed in Section 3.6.2, much of the LA River estuary and the mainstem are water quality impaired, which would further limit suitability for rearing *O. mykiss*. However, water quality improves with distance upstream in the watershed. Sites in lower reaches of the major tributaries show varying degrees of impairment that would not likely limit the success of *O. mykiss* in these locations compared to physical habitat or water temperatures. The upper tributary reaches are relatively unimpaired, underscoring the importance of these habitats for spawning, rearing, and year-round residence by *O. mykiss*.

O. mykiss require suitable temperature and dissolved oxygen concentrations, and these two factors are related. Colder water can hold more dissolved oxygen compared to warmer water, and as such, high temperatures are typically associated with low dissolved oxygen concentrations. In streams, low dissolved oxygen and high water temperatures are also associated with low flows. Data on dissolved oxygen concentration in the LA River watershed are limited (see Section 3.6.2) but generally indicate suitable conditions for *O. mykiss* in the upper tributaries and variable but potentially unsuitable conditions occurring periodically in the mainstem LA River. These limited data suggest that dissolved oxygen could be a limiting factor for steelhead in the mainstem during certain times of year, but the available data do not indicate the date of collection (only the year) which is a critical gap for our ability to assess steelhead limiting factors. However, there was limited temperature data available to evaluate water temperature as a limiting factor. Below we include quantitative and qualitative analysis of temperature as a potential limiting factor for steelhead in the LA River.

Increased temperature is especially problematic for coldwater fish because they have limited thermal tolerances. Reduced shading of streams after removal of riparian vegetation, shallow water depths, and reduced flows due to water diversions can increase water temperature above that which fish are adapted to handle. Reduction in food quality or mismatches in the timing of resource availability due to altered thermal regimes can also occur in disturbed aquatic systems and thus act as limiting factors. Many urbanized streams have reduced amounts of riparian vegetation, which expose streams to increased amounts of solar radiation and decreased allochthonous inputs, which in turn changes the food web structure in streams and often reduces the abundance of benthic macroinvertebrates that form the primary prey base for many fish species (Karr and Chu 2000, Walsh et al. 2005).

Most fish maintain body temperatures that closely match their environment (Moyle 1993). As a result, water temperature has a strong influence on almost every salmonid life history stage (Berman 1998), including metabolism, growth and development, timing of life history events such as adult migration and emergence from the redd, and susceptibility to disease (Groot et al. 1995). Temperature can also affect fish through indirect effects on food availability and species interactions.

Temperature influences fish across life stages, and temperatures above or below optimum can adversely impact growth, immune responses, and life history decisions (Brett 1971, Elliot 1981, Sullivan et al. 2000, Sogard et al. 2012). There have been several reviews on temperature tolerance of steelhead (e.g., McCollough et al. 1999, 2001; Sullivan et al. 2000; Myrick and Cech 2001, 2004), but much of the literature has focused on northern populations due to limited studies on southern populations. The few studies conducted on steelhead populations in Southern California suggested that these populations have higher temperature tolerance than northern populations due to either acclimation or adaptation to higher temperatures (Boughton et al. 2007, Myrick and Cech 2000, Myrick and Cech 2005). For example, studies conducted on wild steelhead in Southern California reported critical thermal maxima between 73.4°F (23°C) and 88.7°F (31.5°C) (Bell 1986; Boughton et al. 2007, 2015; Spina 2007; Dagit et al. 2009; Sloat and Osterback 2013), whereas the critical thermal maximum for northern populations has been reported as 75.2°F (24°C) (Richter and Kolmes 2005). Because the LA River is near the southern extent of the steelhead's distribution, steelhead in the watershed would encounter some of the highest temperatures throughout their range, which could be a limiting factor for migration, rearing and spawning.

To fill current knowledge gaps in the potential limiting impact of temperature for steelhead in the LA River watershed, information on steelhead thermal tolerance was compared and contrasted with available water temperature data from two existing data sets—the only temperature monitoring data sets we could locate. The first data set included temperature data collected from 1973–1992 in the LA River at two U.S. Geological Survey (USGS) gage sites (USGS #11103000 and #11103010) near Long Beach. These two sites are located approximately 16 miles (25.7 km) downstream of the lower terminus of the 4.8-mi LAR FPHS design project reach. We used this data set to test our initial hypothesis that temperatures in the lower LA River would preclude juvenile rearing (i.e., non-migratory use of the river for foraging and sheltering outside the core downstream migration period), and to assess the potential for temperature-related limitations on adult and juvenile/smolt migration. Data were combined from the two gage sites, after which the maximum temperature for any given day of the year was identified. Figure 4-2 shows daily maximum temperatures by day of the year and colored based on the assumed steelhead migration season (December–May) and non-migration season (April–November) for adult and juvenile steelhead. All measurements shown in Figure 4-2 were taken between 12:00 pm and 8:00 pm to reflect, as much as possible, the daily period during which LA River water temperatures are reportedly warmest (Mongolo et al. 2017).

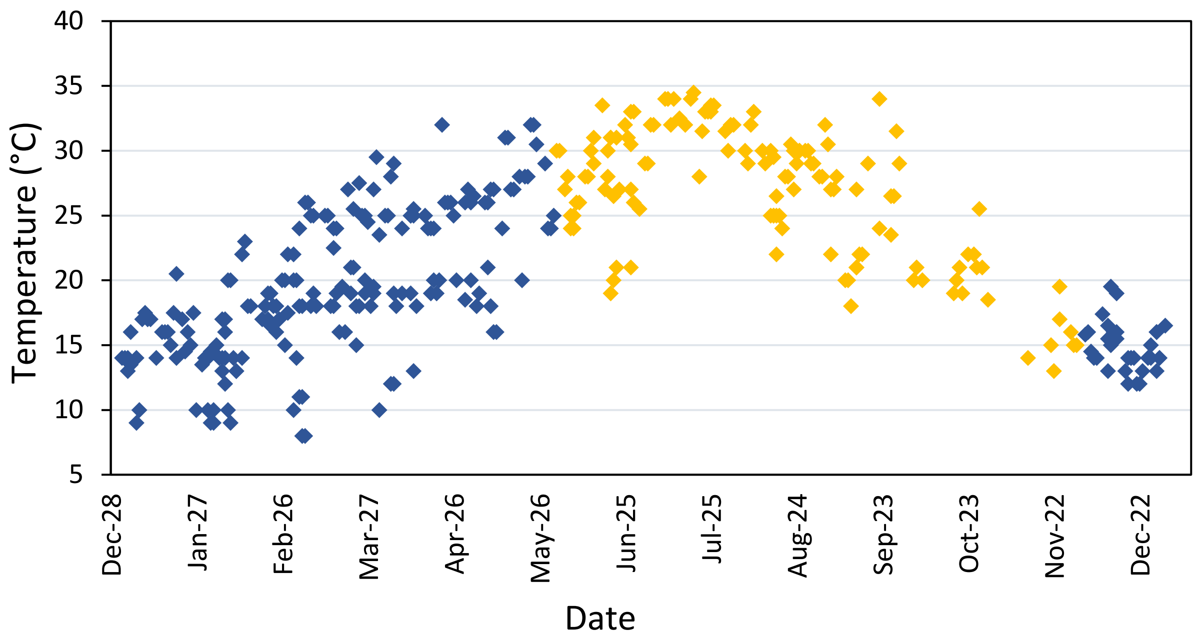

Figure 4-2. Daily maximum water temperature in the LA River recorded at Long Beach between Feb. 6, 1973 and Sep. 22, 1992 for the presumed steelhead migration season (December-May: blue diamonds) and non-migration season (June-November: orange diamonds). Measurements shown here were taken between 12:00 pm and 8:00 pm. (Source: USGS Water Resources, https://nwis.waterdata.usgs.gov/ca/nwis/si).

The results suggest that water temperature in the lower mainstem LA River during the non-migration season (orange diamonds in Figure 4-2) can be a critical limiting factor for juvenile steelhead. Although juveniles can survive at water temperatures between 77°F (25°C) and 80.6°F (27°C) for short periods (Moyle 2002), many (53%) recorded observations for daily maximum temperature during the non-migration season showed that temperatures warmer than 80.6°F (27°C) are frequent during this period at the two sites, with a peak of 93.2°F (34°C) recorded on two separate days in July and September. Therefore, these exceedingly high summer water temperatures would likely preclude successful juvenile rearing in the lower mainstem LA River, although it is recognized that steelhead populations in Southern California might have the capacity to acclimate to high temperatures more easily compared to northern populations (Boughton et al. 2007; Myrick and Cech 2000, 2005). Under the recent water temperature regime, the lower LA River would provide very limited, if any, rearing opportunities for juveniles.

Similarly, water temperature during the migration season (blue diamonds in Figure 4-2) can be limiting for smoltification and downstream migration of juvenile steelhead, particularly in the spring when water temperatures in April and May at the USGS Long Beach gages were often higher than 73.4–77°F (23–25°C) (smoltification is impaired when temperatures are consistently greater than > 54°F (12°C); EPA 2003, Myrick and Cech 2001). Furthermore, water temperature above 69.8°F (21°C) is considered stressful for migrating adult steelhead (Lantz 1971, as cited in Beschta et al. 1987), and water temperatures in the lower LA River were often higher than 69.8°F (21°C) during the primary adult upstream migration window from February through May. Exposure to these high temperatures could result in acute and chronic stress for migrating adults, which can lead to secondary stress effects such as increased energy use, immunosuppression, depressed reproductive maturation, and overall could reduce reproductive fitness and lead to mortality if exposure is prolonged. Assuming a lethal temperature threshold of 75.2°F (24°C) for steelhead (Myrick and Cech 2000, 2005; Spina 2007; Sloat and Osterback 2013; Boughton et al. 2015), water temperatures in the lower reaches of the LA River would be physiologically challenging and may present a thermal barrier for steelhead migration and rearing, especially during late spring and summer. However, migrating adult steelhead may be able to avoid high temperatures by migrating only when water is cooler (such as during high flow events) or by locating thermal refuges that might exist at tributary outlets or groundwater inputs that may occur in natural soft-bottom reaches such as the Glendale Narrows.

Absent substantial changes to the water temperature regime, the available water temperature data suggest that the thermally suitable migration period for a reestablished steelhead population in the LA River would likely occur earlier in the year than the typical migration season for steelhead in more northerly rivers and those in less urbanized watersheds. However, the lack of historical temperature data precludes a more in-depth understanding of whether urbanization and associated changes in water temperatures have created phenological mismatches. For example, if initiation of migration is driven by photoperiod as shown for steelhead smolts in Southern California (Booth 2020), there may not be phenotypic plasticity for selection to act upon to make fish physiologically able to migrate if early season conditions were more suitable for migration.

While water temperature in the lowermost portion of the LA River may present thermal challenges to migrating steelhead, the data from the USGS Long Beach gage site is not representative of conditions steelhead would encounter more broadly in the watershed. To investigate further how water temperature could influence dry season thermal suitability for steelhead, including juvenile rearing, at other locations within the LA River watershed, we examined available data collected by Mongolo et al. (2017) that included maximum daily water temperatures measured in summer 2016 at various mainstem and tributary sites. For this analysis we focused on three sites in the mainstem LA River (Site F2 at the Willow St. Bridge, Site D1 at Atwater Park, and Site D2 at the Los Angeles State Historic Park), one site in Compton Creek (Site E1), and two sites located within the Arroyo Seco (Sites C1 and C2). The Willow Street Bridge is located in the lower mainstem LA River approximately 3.6 mi (5.8 km) upstream from the ocean near the Long Beach USGS gauge. The Atwater Park site is located just upstream of the 4.8-mile LAR FPHS project reach, approximately 31 mi (49.9 km) upstream from the ocean, while the Los Angeles State Historic Park is within the 4.8-mile LAR FPHS project reach, approximately 23 mi (37 km) from the ocean. Compton Creek is a small tributary to the lower LA River with a natural (soft) channel bottom and well-developed riparian vegetation. Arroyo Seco is a primary LA River tributary with suitable *O. mykiss* habitat in its relatively unaltered headwater reaches and two short soft-bottom reaches lined with riparian forest in its urban extent in the city of Pasadena. For the exact location of each site see Mongolo et al. (2017). Water temperature was recorded at sites F2, E2, C1, and C2 from June 4 through October 30, 2016, while data for site D2 was only available from June 9 through July 19, 2016. Temperature at Site D1 was recorded from June 4 through August 18, 2016. We analyzed the data to calculate the seven-day average of the daily maximum temperature (7-DADM) at each site (Figure 4-3) to provide a preliminary assessment of locations where high temperatures (i.e., temperatures >75.2°F [24 °C]) during summer could be considered a limiting factor for steelhead in the LA River watershed.

Results from analysis of 7-DADM for summer 2016 support our hypothesis that the mainstem LA River is not suitable for juvenile rearing due to excessively high water temperature throughout the summer (see 7-DADMs for site F2, D1, D2 in Figure 4-3). However, water temperatures are likely not a limiting factor for *O. mykiss* juvenile rearing and year-round residence in the Arroyo Seco (although, at site C2, 7-DADMs were consistently greater than

75.2°F (24°C) between late June and mid-July) and Compton Creek (see 7-DADMs for sites C1, C2, and E1 in Figure 4-3), and possibly other tributaries where water temperatures may remain relatively cool by virtue of riparian shading, connection to shallow groundwater through a natural channel bottom, or other factors. These results suggest that water temperatures are likely limiting for rearing of juvenile steelhead during the summer months throughout the mainstem LA River, but most likely not in some of the tributaries, including the Arroyo Seco. This finding supports our hypothesis that steelhead rearing would only occur in the mountain tributaries and is consistent with available information on steelhead life history in other Southern California rivers such as the Santa Clara River (Boughton and Goslin 2006).

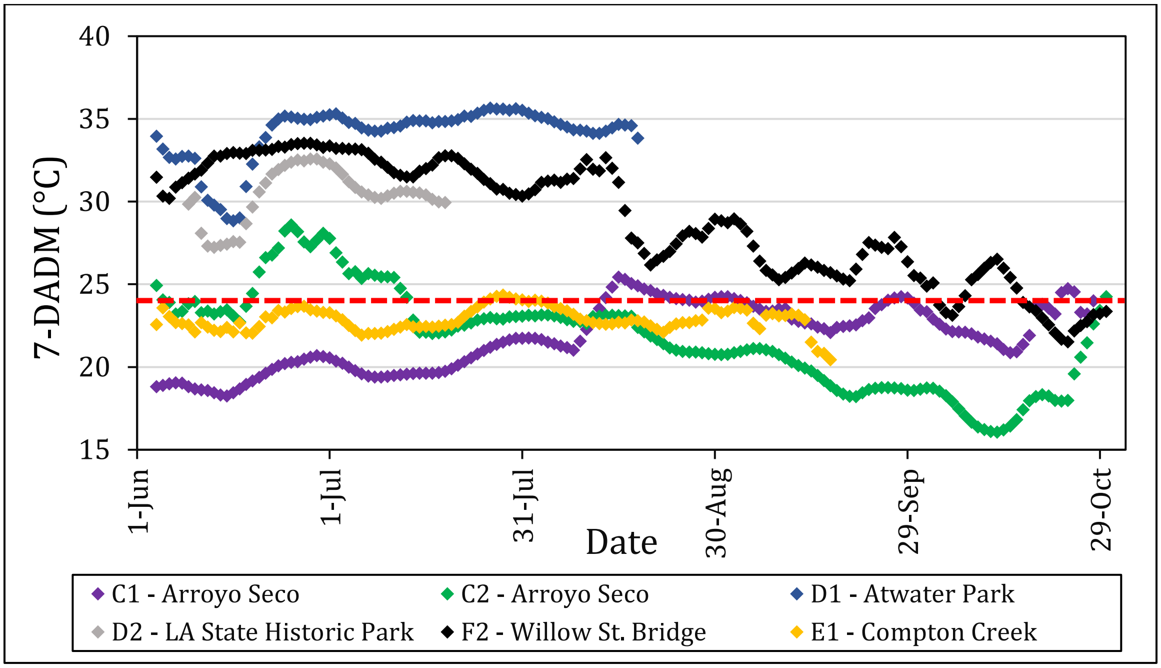

Figure 4-3. Summary of 7-day average of the daily maximum temperatures (7-DADM) recorded at three sites located within the mainstem LA River (F2, D1 and D2), two sites in the Arroyo Seco (C1 and C2), and one site in Compton Creek (E1) in summer 2016. The red dashed line indicates a potential threshold of critical thermal stress for steelhead. Site names follow the same coding as Mongolo et al. (2017). Raw data was kindly provided by the Resource Conservation District of the Santa Monica Mountains (RCDSMM).

4.2.4 Habitat

Suitable habitat is a requirement for all steelhead life stages. Migrating fish require habitat that provides refuge from predators and from low and high flows, spawning fish require suitable gravel sizes to deposit eggs, and juvenile fish require habitat that provides cover and suitable conditions for feeding and growth. As previously described, habitat in the LA River watershed has been highly altered and the availability of suitable habitat is likely a major limiting factor for steelhead viability in the system. Suitable water quality can be viewed as a component of habitat, but this specific factor is discussed in more detail in the following section.

Upstream migrating steelhead would require habitat for avoiding high flows, resting during migration, and for holding if fish are stranded between flow events. Currently, there is no good holding habitat in lower LA River below project site because it is entirely a channelized concrete river. The closest holding habitat is upstream of the project site in the soft-bottom Glendale Narrows reach. Due to the lack of refuge and holding habitat, if upstream migration through the lower LA River takes longer than a single storm event, or if water velocity during a storm exceeds the steelhead's swimming ability, there is little chance an adult could successfully complete its migration. Thus, holding habitat for upstream migrating steelhead is a critical liming factor in the LA River. Holding habitat is not thought to be limiting for smolt migration because smolts can likely reach the ocean during a single storm event and can continue migration even in low flows because baseline flows in the LA River, which are higher than historical flows due to wastewater discharge inputs, provide suitable depths and velocities for smolt migration. It is also possible that outmigrating smolts could find suitable habitat for sheltering, and potentially feeding and rearing, in some of the soft-bottom reaches located along the route they must take between their natal headwaters and the ocean.

The amount of available spawning habitat is not thought to be limiting due to high fecundity of steelhead (adult female can deposit > 3,000 eggs; Moyle 2002) and the low numbers of anadromous adults that are expected to return in any single year. For reference, based on 25 years of monitoring in 30 streams within the Southern California Steelhead DPS, an average of seven adult steelhead per year returned to rivers across the entire DPS (i.e., each stream saw less than one adult return on average) (Dagit et al. 2020). In the Santa Ynez and Santa Clara rivers that have consistent monitoring, an average of fewer than two and fewer than one adults per year, respectively, have been detected over the last 25 years (Dagit et al. 2020). Thus, there is likely enough available spawning habitat to support the few anadromous adults expected to return to the LA River. Adult spawning would take place in tributaries that have relatively abundant amounts of complex habitat and gravel substrate. Suitable spawning habitat also occurs above major barriers in upper tributaries where resident *O. mykiss* populations spawn. There are no habitat surveys quantifying the amount of suitable spawning habitat within the LA River watershed. Spawning habitat is limited below barriers, but some high-quality spawning habitat exists in the central Arroyo Seco that would support spawning for the low numbers of expected returning adults.

The amount of rearing habitat can be limiting because of competition between juveniles for limited resources. The amount of rearing habitat can be used to estimate the carrying capacity of a stream (Cramer and Ackerman 2009). Potentially suitable rearing habitat in the mainstem LA River is limited to soft-bottom reaches in the Sepulveda Basin, Glendale Narrows, and at the river's mouth downstream of the Willow Street Bridge, but rearing suitability is likely limited to winter months due to prohibitively high water temperature in the mainstem during the remainder of the year (Section 4.2.3). Most rearing habitat exists in the Arroyo Seco, Big Tujunga Creek, and tributaries to Big Tujunga Creek. Much of the highest quality rearing habitat exists above major barriers within these tributaries and thus the habitat is not currently accessible for steelhead spawning and rearing. Resident *O. mykiss* still occur in these locations (SMRA 2020) and habitat is not thought to be limiting for these resident populations. However, few residents are observed in tributaries, so additional habitat assessments are required to understand what factors may limit resident *O. mykiss* in these tributary locations where most suitable habitat is located.

Habitat is influenced by other factors such as flow, geology, water quality, and physical features such as availability of complex habitat in the channel and in adjacent floodplains and wetlands. Altered conditions in the LA River watershed have changed natural habitat-forming processes and the alteration of these processes is likely limiting to the formation and persistence of suitable habitat, especially below barriers in the mainstem LA River and major tributaries.

4.2.5 Suspended sediment effects

Another consideration for steelhead migration in the LA River is the effects of suspended sediment. Deriving from its climate context, geology, and tectonics, the LA River in its natural state was characterized by very high sediment loads delivered from rapidly eroding mountain ranges during large flood events. Exposure to suspended sediment can result in behavioral and physiological effects depending on concentration and duration of exposure (Newcombe and Jensen 1996). Physiological responses range from sublethal to lethal with sublethal effects having been detected in adult steelhead exposed to suspended sediment concentrations (SSCs) of 500 mg/l for three hours (Redding and Schreck 1982). Behavioral responses, such as avoidance, have been detected in juvenile steelhead at suspended sediment levels <100 mg/L (Madej et al. 2007). Few studies have estimated the lethal threshold of suspended sediment for steelhead, but Newcombe and Jensen (1996) cite unpublished study results showing that steelhead fry exposed to SSCs >5,000 mg/L for 96 hours experienced zero mortality. However, lethal levels of suspended sediments for salmonids have been reportedly as low as <500 mg/L (Newcombe and Jensen 1996).

The effects of SSC on salmonids are dependent on life stage and exposure duration. Based on the predictive relationships developed by Newcombe and Jensen (1996), adult steelhead exposed to SSC of approximately 8,000 mg/L for as little as one day would experience up to 20% mortality, and adult steelhead exposed to approximately 1,100 mg/L SSC for one day would experience major physiological stress. Thus, it can be reasonably assumed that adult steelhead would attempt to avoid or minimize prolonged exposure to SSC concentrations >1,100 mg/L. The SSC tolerance of juvenile steelhead is approximately twice as high as the tolerance of adults. For example, 20% mortality is predicted in juvenile steelhead exposed to SSC of approximately 8,000 mg/L for 2 days compared to one day for adults.

In the LA River, instantaneous suspended sediment concentrations have been recorded as high as 4,500 mg/L (Figure 4-4). Based on predictive relationships from Newcombe and Jenson (1996), this concentration of suspended sediment could result in mortality if steelhead were exposed to this concentration for more than one day. It is generally thought that discharge and SSC are closely related, and although there is a positive relationship between SSC and flow in the LA River based on data limited to the USGS Long Beach gages, flow explains a modest amount (~26%) of the variability in SSC concentrations (Figure 4-4). SSC concentrations likely peak and decline relatively quickly, so it is possible that exposure duration to high SSC would be brief and thus, not a significant limiting factor. Additional data on relationships between SSC and flow in the LA River and how SSC differs throughout the watershed would improve our ability to predict effects of SSC on migration.

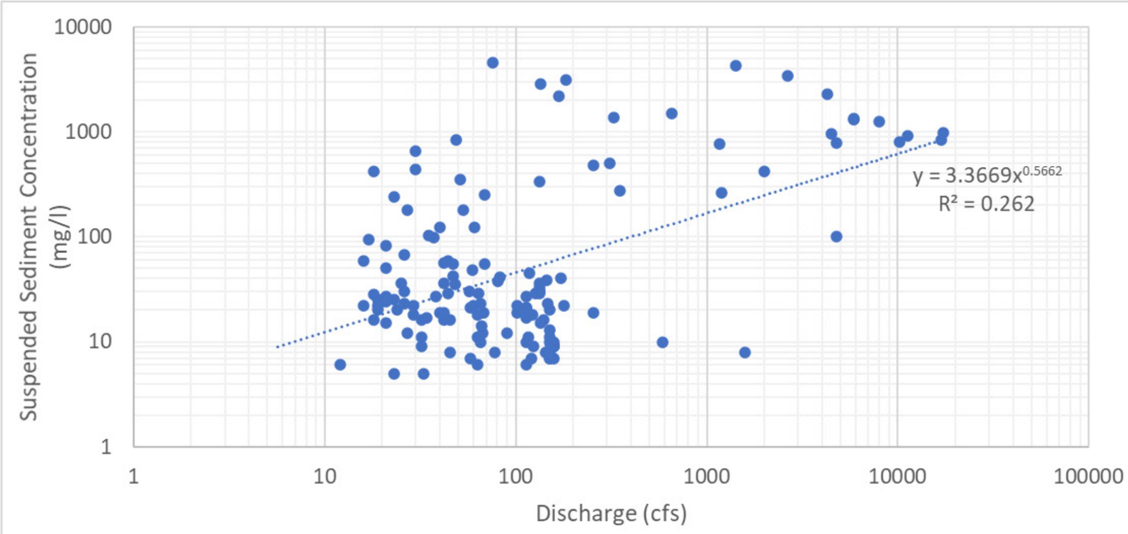

Figure 4-4. Suspended sediment concentration in the mainstem LA River at Long Beach (USGS 11103010) from 1973–1980 and (USGS 11103000) from 1979–1992.

4.2.6 Non-native species

The presence of non-native species in aquatic systems is an important factor limiting native species in Southern California and globally. In many cases, these species thrive in the conditions that exist following anthropogenic alteration. For example, largemouth bass can tolerate warmer waters and prefer slower moving waters compared to native trout and steelhead (Stuber et al. 1982, Moyle 2002). Non-native fishes and other exotic aquatic species can directly compete for resources with native fish or act as predators. Control of non-native species is a major component of many restoration strategies for improving conditions for native fish species in Southern California (e.g., USFWS 1985, Moyle et al. 2017, USFWS 2017). The Southern California Steelhead Recovery Plan (NMFS 2012) includes non-native species control among the recommended recovery actions for the mainstem LA River and Arroyo Seco.

As described in Section 3.8, there are numerous non-native species that occur within the LA River watershed. Some of these species (e.g., common carp, fathead minnow) pose relatively little threat to steelhead because they tend not to occur within similar habitats and the non-natives would not act as a predator or competitor during the life stage when they would typically interact (i.e., during migration). However, other species such as centrarchids (e.g., largemouth bass, green sunfish) would act as both predators and competitors for early life stages of *O. mykiss* including during egg incubation. Because *O. mykiss* did not co-evolve with these predatory species, they lack morphological defenses (e.g., spines), which makes them extremely susceptible to predation. Since the size of prey consumed by predators is limited by the predator's gape size, once *O. mykiss* reach a larger size they would no longer be susceptible to predation, but may still compete with non-natives for resources including habitat and food.

Non-natives typically occur at lower elevations because these habitats are more degraded and have conditions that are more suitable for non-natives. For example, in soft-bottom reaches of the lower LA River, warm water and deep pools with slow moving water create conditions that favor non-native fishes. Overall, the presence of non-natives is a factor that likely contributes to the exclusion of juvenile *O. mykiss* from the lower reaches of the watershed or limits their ability to rear in these altered habitats, but it should be noted that poor habitat conditions may limit *O. mykiss* rearing in many locations even in the absence of non-natives. Eradication of non-native aquatic species is not possible and even population control measures are rarely effective, especially when there are source populations for non-natives such as reservoirs where non-natives can be intentionally stocked. Consequently, habitat improvement is likely the best approach for creating conditions that favor steelhead and other native species.

4.2.7 Artificial lighting

In highly urbanized systems like the LA River Watershed, artificial lighting (e.g., public street lighting, billboards) can be a form of "light pollution" with adverse impacts to wildlife (Perkin et al. 2011). In fish, behavioral responses to artificial lighting differ considerably among species, age classes, and type of habitat, with effects reported to include disruption of natural biorhythms, life cycle transitions, foraging behavior, spatial distribution, predation risk, migration, and reproduction (Becker et al. 2013). In addition, the presence of artificial lights during night hours could potentially alter fish communities through enhanced opportunities for predation and alterations of predator-prey relationships, which has been suggested in estuarine fish communities (Becker et al. 2013).

For steelhead in the LA River, life stage transitions related to photoperiod, such as early development and smoltification, could be influenced by artificial light. Artificial light could also influence rearing juveniles if they are nocturnally active. Increased nocturnal behavior has been reported during winter in juvenile rainbow trout in the wild (Riehle and Griffith 1993) and year-round in some juvenile steelhead (Bradford and Higgins 2001). Nocturnal behavior in rainbow trout may be a combination of an adaptive response to decreased swimming performance at colder water temperatures (Rimmer et al. 1985) or a strategy to avoid predators (Riley et al. 2013) as has been shown in studies on juvenile Atlantic salmon. Results from a study conducted on age-0 juvenile rainbow trout in the wild found a negative relationship between light intensity and the number of fish emerging from the substratum in the winter (Contor and Griffith 1995). Similarly, the number of juveniles observed at night decreased in the presence of moonlight, with fish emerging out of their concealment when light intensity was lower than 4.5×10^{-3} W m-2 (Contor and Griffith 1995). Additionally, experimental evidence suggests that exposure to artificial light of an intensity comparable to street lamps can cause both a delay and disruption of emergence and dispersal in Atlantic salmon fry from redds (Riley et al. 2013), which is a behavior that occurs primarily at night in this species (Riley and Moore, 2000) and is commonly considered a predator avoidance strategy (Fraser et al. 1994, Tabor et al. 2004). Any alteration or disruption of this behavior could potentially affect recruitment in the population (Riley et al. 2013).

Based on this information, artificial lighting might be a potential limiting factor for steelhead fry emergence and rearing juveniles. However, under current conditions in the LA River watershed, all life stages other than adult and juvenile migrants would occur within upper tributary reaches that are much less urbanized and have little artificial light pollution, and thus artificial light is expected to have little effect on steelhead in these locations. If future restoration actions improved conditions in the mainstem LA River and provided opportunities for juvenile rearing, artificial light could cause increased predation risk at night and alter behavioral patterns with fitness consequences.

Artificial lighting in the mainstem LA River could represent a limiting factor for juveniles during their outmigration. However, outmigration would occur primarily in the winter and early spring when river flows are characterized by high sediment load and turbidity, helping to conceal juveniles from predators. Although less common, smolts migrating downstream under lower sediment concentrations would be expected to migrate at night to avoid predators during the day, and in this case, artificial light could increase predation risk or alter diel migration patterns. Overall, the effects of artificial lighting on freshwater fish and habitats have not been fully studied and many knowledge gaps remain. In particular, it is difficult to disentangle the effects of artificial lighting from those of other urban stressors that interact with each other (Ormerod et al. 2010). Thus, the negative impacts of artificial lighting may become clearer only in the absence of other major urban stressors or limiting factors (Perkin et al. 2011).

4.2.8 Existing *O. mykiss* population

A parent population of native steelhead ancestry *O. mykiss* in the LA River is needed to produce steelhead smolts that can return as adults and contribute to the population. Currently, the majority of *O. mykiss* in the LA River are present above major barriers (SRMA 2020) and therefore are not capable of producing successful anadromous offspring. *O. mykiss* populations above and below barriers in some watersheds have been shown to be genetically similar (Clemento et al. 2009), which demonstrates the importance of resident populations above barriers for steelhead recovery. There are some resident *O. mykiss* in LA River tributaries upstream of barriers based on recent surveys (SRMA 2020), but these populations are likely small and are unable to contribute to the anadromous life history component due to barriers that prevent juvenile/smolt emigration (Shapovalov and Taft 1954, Ward et al. 1989, Bond et al. 2008). Small and isolated populations are at risk of loss of genetic diversity through inbreeding depression and genetic drift and are more susceptible to disturbances.

Stocking of hatchery rainbow trout in headwaters has historically occurred throughout range of steelhead in Southern California, which may have already compromised the genetic integrity of native *O. mykiss* including resident and anadromous populations (e.g., Moyle et al. 2017). Few genetic assessments of resident *O. mykiss* in the LA River watershed have been made; however, individual resident *O. mykiss* within the Rio Hondo tributary were shown to be derived primarily from hatchery rainbow trout (Abadía-Cardoso et al. 2016). In addition, recent genetic research indicates the occurrence of historical stocking with Central Valley *O. mykiss* lineages (NMFS 2016). The influences of stocking practices on population genetics can be very site specific, especially when barriers are present, but overall resident *O. mykiss* in LA County rivers (including in the neighboring San Gabriel River) and further south tended to have more hatchery influence compared to more northern populations (Jacobson et al. 2014, Abadía-Cardoso et al. 2016).

Additional genetic sampling within the LA River watershed may be necessary to fully understand the influence of stocking on the current resident *O. mykiss* population. If resident *O. mykiss* in the LA River are largely derived from non-native stocks, and especially those of non-anadromous lineage, it is unlikely that they would contribute to an anadromous life history type. In this case, translocations from populations outside of the LA River watershed that have documented native coastal steelhead ancestry (e.g., within the San Gabriel River; Abadía-Cardoso et al. 2016) should be considered as an approach for restoring native genetics to the LA River. When combined with restoration of habitat and connectivity within the LA River watershed, translocations would provide opportunities for recolonization of additional habitat and restoration of native genetic diversity. However, if *O. mykiss* of native ancestry were translocated to areas where hatchery ancestry fish are present, interbreeding would reduce the frequency of alleles (i.e., Omy5) related to anadromy within the population (Pearse et al. 2014) and cause reduced fitness and maladaptation. Hatchery ancestry fish could also compete with or even prey upon native fish. The level of introgression of native genetics by hatchery fish would be dependent on the abundance of translocated native fish relative to hatchery fish already present at the sites. For these reasons, population surveys at translocation sites and potential removal of hatchery ancestry fish should be considered prior to translocations to avoid competition between native and hatchery fish. Finally, despite the low numbers of *O. mykiss* in the LA River watershed, the existence of persistent populations of *O. mykiss* in some of the upper tributaries demonstrates there are suitable conditions in some locations and these populations could contribute to the diversity and resiliency of *O. mykiss* in the LA River. Overall, however, the dearth of *O. mykiss* in the watershed is a major limiting factor for the viability of an anadromous steelhead life history type. Studies to improve our understanding of the current population dynamics of *O. mykiss* in the LA River are recommended.

4.2.9 Cumulative watershed effects and climate change

Many of the factors described above overlap in time or space or can otherwise act in combination to produce cumulative adverse effects. Interactions among water temperature and food availability, for example, can strongly influence *O. mykiss* growth and population productivity. When water temperature is warmer, fish experience increased metabolic demands. When food is plentiful, fish can also increase feeding to meet increased metabolic demands imposed by warmer temperatures, and growth rates can be higher under warmer conditions (Wurtsbaugh and Davis 1977). However, if prey availability does not meet increased metabolic demands in warmer temperatures, fish would suffer from reduced growth, potentially resulting in reduced freshwater and marine survival. Additional discussion of how temperature and food availably can interact is provided in section 5.4.1.

Climate change is expected to further exacerbate the effects of these limiting factors. For example, increased summer temperatures and potentially reduced summer flows under future climate change conditions could lead to a bioenergetic bottleneck in juvenile growth during summer months if food supply becomes limiting due to reduced invertebrate drift as metabolic demands increase with increasing water temperatures. Due to the number and complexity of the potential limiting factors, it is extremely challenging to identify the most important factors to prioritize for restoration. Specific restoration actions should be dependent on location and in reference to particular fish species and life-stages.

Finally, long-term viability of a steelhead population in the LA River is dependent on creating a resilient system that has multiple locations for spawning and for resident populations (e.g., McElhany et al. 2000). Even if they rarely contribute to the anadromous population, resident populations help maintain genetic diversity within the system and can act as source populations for recolonization of habitat following localized extirpation from catastrophic events such as extreme drought (Dagit et al. 2017), floods (Bell et al. 2011a) or debris flows following wildfires. Establishing multiple *O. mykiss* subpopulations (i.e., a metapopulation) within the LA River watershed and across the Mojave Rim BPG and the full range of the Southern California DPS is essential to the recovery and persistence of steelhead in the face of the increased frequency and severity of extreme weather and ecological disturbances projected under most climate change scenarios (NMFS 2012, Moyle et al. 2017). Critical to steelhead recovery in the LA River watershed is the reestablishment of native lineage *O. mykiss* populations at multiple locations including the upper Arroyo Seco watershed and other suitable tributaries. Planning and workplan development are underway for subpopulation expansion efforts, which will address full lifecycle needs for native *O. mykiss* populations in the LA River watershed and elsewhere in the Mojave Rim BPG and the Southern California DPS.

5 CONCEPTUAL ECOLOGICAL MODEL

The majority of Southern California's river systems are defined by high seasonal and inter-annual variability in flows, high water temperatures, and frequent isolation from the Pacific Ocean due to sandbar development at the river mouth. Few aquatic species are adapted to these conditions. However, *O. mykiss*, more than any other Pacific salmonid, exhibits extreme phenotypic and life history variability allowing the species to persist where other salmonids would perish. Here we provide an initial conceptual model for LA River *O. mykiss* that describes a species adapted to conditions at the southern extent of its range. We begin by describing the expected life history expression of anadromous and resident *O. mykiss*, after which we describe physical habitat controls on steelhead. We then progress through each life stage beginning with upstream migration of adults and ending with marine survival.

5.1 Anadromous and Resident *O. mykiss* Dynamics

As described in Section 2.1, steelhead is the term commonly used for the anadromous life history form of *O. mykiss*, and rainbow trout (or resident *O. mykiss*) is the term for the resident life history. Both anadromous and resident life histories are expressed by *O. mykiss* populations in Southern California watersheds, although detailed information on the relative proportion of each ecotype is rarely available. While there is little information on *O. mykiss* life history from the LA River watershed, it is assumed that life history was similar to other steelhead populations in the Southern California Steelhead DPS, and thus, both anadromous and freshwater resident life history types would have played an important role in maintaining an *O. mykiss* population in the LA River watershed (Moyle 2002, Bell et al. 2011a).

Due to the episodic nature of streamflow and river connectivity in the LA River watershed, the relationship between a resident rainbow trout life history strategy and an anadromous steelhead life history strategy was very likely a key driver of the historical *O. mykiss* population dynamics. Accordingly, this relationship is a focus of this conceptual model and numerous investigations of *O. mykiss* population dynamics in other steelhead watersheds at the southern end of their distribution (Bell et al. 2011a; Satterthwaite et al. 2009, 2010; Kendall et al. 2015).

5.2 Upstream Migration

Adult steelhead upstream migration is dependent on suitable conditions that provide migration opportunities for steelhead to reach spawning locations in perennial habitats, which in the LA River is assumed to be located within tributaries. Below we describe how current conditions in the LA River watershed might influence upstream migration behavior of steelhead in the LA River.

5.2.1 Upstream migration timing and conditions

Historically, prior to their extirpation from the system, steelhead would enter the LA River when flows and passage conditions allowed. Based on adult migration timing data from other populations of Southern California steelhead, adult steelhead enter freshwater during high flow events that occur in winter and spring with most migrations occurring January through March (Booth 2016, COMB 2011). Earlier (December) and later (April–May) migrations are possible if conditions are appropriate. In many Southern California coastal rivers, sandbars block connection with the ocean, and thus, steelhead can only enter rivers when high flows provide migration opportunities by breaching sandbars. Sandbar formation and breeching may have historically been the case in the LA River prior to urbanization. Currently, sandbar formation does not occur at the mouth of the LA River and adults could feasibly enter the lower river at any time but may have to wait for storm flows to provide passage upstream of the tidally influenced lower segment.

Once the decision to enter freshwater has been made, successful in-river migration is once again contingent upon suitable flows that provide upstream passage. Flows must provide adequate hydraulic conditions[3] to migrate upstream. Typical of lower reaches of Southern California rivers, intermittently dry sections in the lower LA River would have historically prevented upstream migration when flows were low, even during the migration season. High flows associated with storms would have connected these dry sections and provide upstream passage to perennial flows within spawning tributaries. For example, the Arroyo Seco was likely connected to the LA River for its entire length and passable by steelhead only during storm flows of sufficient duration to allow adult steelhead to move upstream to perennial habitat in the San Gabriel Mountains upstream of Devil's Gate. Historical accounts of steelhead in the upper Arroyo Seco (e.g., Holder 1906) suggest that this was a relatively frequent occurrence and thus the Arroyo Seco may have provided the most important steelhead spawning and rearing habitat in the LA River basin. Current channelized concrete sections that include a low flow channel do not facilitate upstream movements under low flows due to shallow depths, and passage is also not facilitated during high flows due to high water velocities resulting from the channelized, homogeneous physical structures.

Historically, spawning migrations probably occurred in most years but may not have been possible in years when winter precipitation was low and river flow was insufficient to provide passage from the ocean to the spawning tributaries. For this reason, resident populations are a critically important component of a successful life history strategy to maintain viability of steelhead populations in the LA River. Under current conditions, successful passage to upstream spawning and rearing habitat may be limited or completely prevented due to the presence of barriers in the mainstem LA River and tributaries. A detailed field assessment of potential passage barriers and impediments is needed to identify locations and conditions that impede or prevent passage throughout the basin and to provide the information needed for restoration and passage improvement efforts. This assessment should include an evaluation of opportunities and constraints for improving or providing fish passage at barriers and impediments throughout the watershed, including channelized concrete reaches where hydraulic conditions inhibit or prevent passage and structures including dams (e.g., Hansen Dam and Big Tujunga Dam in the Tujunga system, Sepulveda Dam on the mainstem LA River, and Devil's Gate Dam and Brown Mountain Dam in the Arroyo Seco), none of which currently have fish ladders or other passage facilities.

Provided suitable passage conditions, upstream migrants would reach perennial habitat in tributaries where they would spawn. Much of the suitable spawning habitat exists upstream of barriers in the tributaries, including Big Tujunga Creek upstream of Hansen Dam and upstream of Big Tujunga Dam and the Arroyo Seco upstream of Devil's Gate Dam. Suitable spawning habitat may also be present in a few tributaries below dams, including soft-bottom reaches of the Arroyo Seco upstream and downstream of the Rose Bowl in Pasadena. A major question is how long would adult steelhead take to migrate upstream to perennial waters in tributaries and could fish reach perennial habitat during a single storm event? If migration takes longer than a typical storm

[3] Depths of 0.5–1 ft (0.2–0.3 m) (Thompson 1972, Bell 1991, ODFW 2004, NMFS 2001), and velocities 6–12 ft/s (1.8–3.7 m/s) (Bell 1991, Caltrans 2007) are among the recommended passage guidelines for adult steelhead upstream passage. These guidelines generally apply to the design of bridges, culverts, and other structures.

event, upstream migrants would have to hold and wait for the next flow event that provides upstream passage, which has important implications for the design and placement of fish passage and habitat improvement projects in the LA River and its major tributaries. To help answer these questions, we evaluated migration rate of steelhead across their range.

5.2.2 Upstream migration rate

Migration rate is a function of the physical conditions of a river (e.g., slope, water velocity, resting locations, etc.) and fish morphometrics, physiology and energetic state. As mentioned previously, energetic tradeoffs exist between the amount of energy expended during migration and energy available for gamete development and reproductive behaviors. Thus, fish should attempt to minimize energy use during migration by selecting pathways with lower water velocities while maximizing migration rate.

Migration rates reported for adult steelhead in rivers are highly variable, ranging from less than 0.6 mi/d (1 km/d) to more than 25 mi/d (40 km/d) (Keefer et al. 2004, Salinger and Anderson 2006, English et al. 2006, Jepsen et al. 2012). Differences in migration rate among river systems are a result of environmental complexity along migratory routes (e.g., variable flows, physical structure), differences in run timing (i.e., winter versus summer-run fish), and variation in individual fish condition and physiology. The most extensive data on adult steelhead migration rates are from tagging studies in the Columbia River basin, but these data include migration rate estimates from fish migrating through heavily altered systems with regulated flow patterns due to hydropower infrastructure. Comparisons of steelhead migration rates between the Columbia River and naturally flowing rivers indicated that Columbia River steelhead generally migrate faster compared to steelhead from naturally flowing rivers (English et al. 2006). English et al. (2006) noted that migration rates among rivers are inversely related to channel gradient because gradient controls water velocity, and hence faster migration rates are observed in impounded rivers that have lower gradients and lower flows (i.e., fish don’t have to swim against higher flows in lower gradient rivers). Many studies report that across life stages and environments, salmonids tend to migrate at an average speed of one body length per second (Drenner et al. 2012, Salinger and Anderson 2006), which is associated with a minimum gross cost of transport (Brett 1995).

Little data exists on migration rates and behavior of steelhead at the southern extent of their range. Compared to northern populations, adult steelhead migrating in southern locations contend with different challenges, such as flashy flows, high suspended sediment loads and high temperatures, making it challenging to infer migration rates based on data from northern rivers. For example, and as described in Section 2.1, steelhead in Southern California evolved in river systems characterized by high seasonal flow variability and rapidly rising and falling (‘flashy’) storm flows. Steelhead enter these rivers in the winter and spring when storms create pulses of high flows that breach sandbars causing rivers mouths to connect with the ocean, providing migration opportunities. Periods of low flows can occur between flow pulses in these rivers with sections becoming dry in some locations depending on river geomorphology. This contrasts with northern river systems that have perennial flows that provide continuous longitudinal habitat connectivity to facilitate steelhead migration. Interrupted migration and isolation in disconnected habitats in low flow conditions is a major risk to steelhead in southern rivers because it would expose fish to poor water quality (high temperature and low dissolved oxygen), increased predation risk, and overall increased risk of physiological stress and mortality. In addition, holding habitat is limited in lower river sections, especially in extensively channelized rivers with little habitat complexity such as the LA River. Due to the risks associated with migrating in southern rivers, it is generally assumed that steelhead in Southern California have evolved directed (and relatively fast) upstream migration behaviors to avoid stranding and increase reproductive success.

In the absence of data on southern steelhead behavior, migration rates for steelhead in the LA River are assumed to be similar to steelhead migrating in naturally flowing rivers. Steelhead migration rate averaged 7.3 mi/d (11.8 km/d) (sdev = ± 4.5 mi/d [7.3 km/d]; range = 0.56–17.7 mi/d [0.9 – 28.5 km/d]) in naturally flowing rivers in British Columbia, Canada (English et al. 2006). Based on this average migration rate applied to adult steelhead in the LA River, it is expected that adult steelhead would take 2.7 days on average to reach the LAR FPHS project reach 20 mi (32.2 km) upstream from the ocean (Figure 1.1) and four days to reach perennial habitat in the central Arroyo Seco 30.5 mi (49.1 km) upstream from the ocean. Using the first (3.7 mi/d [6.0 km/d]) and third (11 mi/d [17.75 km/d]) quartiles of migration rate from English et al. (2006), steelhead would take a maximum of five days and a minimum of two days to reach the LAR FPHS project site. Similarly, steelhead would take a maximum of eight days and a minimum of three days to reach perennially-flowing, soft-bottom habitat in the central Arroyo Seco. It remains uncertain whether the duration of a typical storm flow event is long enough for steelhead to reach these locations in a single event, or if multiple storm flow events are needed.

The magnitude and duration of migration flow events in Southern California rivers is highly unpredictable, and is dependent on the magnitude and duration of the storm event as well as the amount of recent precipitation which affects the amount and rate of soil infiltration and losses to groundwater. Typically, high flows from storm events in the LA River last from less than a day to two days with extremely rare high flows lasting for up to a week (Section 3.3). It is generally thought that adult steelhead in Southern California migrate upstream during the falling limb, and to a lesser extent, the rising limb of a storm hydrograph, and that migration may not occur at peak flows due to high water velocities, high suspended sediment concentrations, and/or high debris loads associated with peaks in the hydrograph. Based on these assumptions, the migration rate estimates described above, and considering the duration of a typical storm event, it is feasible that adult steelhead could reach the 4.8-mile LAR FPHS project reach within a single storm event, but it is unlikely that fish could reach perennial habitat in either the Arroyo Seco or Big Tujunga Creek during a single storm event (in the absence of existing migration barriers and impediments). Steelhead that do not reach perennial habitat within a single storm event would need to locate suitable holding habitat to wait for the next storm event or abandon their migration and return to the ocean.

It should be noted that the average migration rate of 7.3 mi/d (11.8 km/d) is from data collected on summer-run steelhead stocks (English et al. 2006), whereas steelhead in Southern California are considered winter-run stocks. As their name implies, summer-run steelhead enter rivers during the summer months and then overwinter prior to spawning in the spring. In contrast, winter-run steelhead enter rivers in winter and spawn shortly thereafter. Due to differences in river entry versus spawning time, summer-run steelhead may migrate at slower rates than winter-run steelhead. There is little data on migration rates of winter-run steelhead, but winter-run steelhead in the Willamette River, Oregon averaged approximately 18.6 mi/d (30 km/d) (Jepsen et al. 2012), which is substantially higher than our estimate of 7.3 mi/d (11.8 km/d). Similar to the Columbia River where migration rates are higher, flows in the Willamette River are modified by dams and thus may not be truly representative of free-swimming fish in river that experiences episodic high flow events. In the study by English et al. (2006) the highest gradient river was approximately 11.6 ft/mi (2.2 m/km), and median migration rate in this river was 2.2 mi/d (3.5 km/d), significantly lower than in other lower gradient rivers. The average gradient of the LA River is 21.1 ft/mi (4 m/km), which is nearly double that of the highest gradient river studied by English et al. (2006), and thus it is possible that steelhead in the LA River would migrate at slower rates. While it is possible that steelhead in the LA River could migrate faster or slower than 7.3 mi/d (11.8 km/d), the lack of data for winter-run steelhead in comparable river systems precludes a more reliable estimate. Additional studies using mark-and-recapture or radio telemetry are needed to better understand adult steelhead movements in Southern California rivers.

An additional consideration is the effect of altered hydraulic and hydrologic conditions in the LA River on adult steelhead migration. Channelization of the river for flood control was intended to move water quickly to the ocean, which truncates the duration of storm flows available for migration compared to historical conditions. Thus, faster-migrating steelhead would typically be more successful at reaching spawning habitat during storm flows under current and future conditions in the watershed. Rapid migration rates would therefore be selected for over time. Wastewater treatment effluent has increased winter baseflows from historical levels, which could increase migration opportunities despite truncated storm flows. Future recycling plans for wastewater treatment effluent could reduce winter baseflows. The SCCWRP is currently conducting environmental flow studies to investigate flow requirements of steelhead and other native fish in the LA River and the potential effects of wastewater treatment effluent reductions.

5.2.3 Temperature

As discussed in Section 4.2.3, high temperatures in the mainstem LA River could influence adult upstream migrations. Based on our analysis of temperatures, sub-lethal (assumed 69.8°F [>21°C]; Sullivan et al. 2000) and even lethal (assumed >75.2°F [24°C]; Sullivan et al. 2000) temperatures can occur throughout the migration season in the lower LA River, but especially during the later portion of the migration window in April and May. The frequent occurrence of high temperatures later in the migration season favors early migration of adult steelhead (i.e., prior to April). We hypothesize that, in addition to temperature increasing over the course of the migration season, high temperatures can also occur during winter baseflows. Steelhead would be assumed to migrate during high flow events, which would be associated with lower temperatures. However, available data on flow and temperature in the LA River are not adequate to test these relationships. Prohibitively high-water temperatures during winter baseflow periods could cause physiological stress or preclude holding by adult steelhead between winter storms.

Our analysis of migration rates suggests that, despite migration being associated with high flow events, adults would have to hold in the lower LA River between storm events and thus, there is the potential for these fish to be exposed to stressful temperatures during baseflow conditions, especially later in the migration season. Holding adults could avoid exposure to high temperatures if they are able to access thermal refugia such as at confluences with cooler tributaries (e.g., Compton Creek, see Section 4.2.3). The use of similar thermal refugia has been demonstrated for juvenile steelhead in warm, mainstem rivers (Wang et al. 2020). We assume that increased baseflows from wastewater discharge could improve hydrologic and hydraulic passage conditions between storm events, but if baseflows are too warm, migration might not be possible. Additional investigation of flow-water temperature relationships during winter baseflow periods, and the potential for reduced winter baseflows, is needed to improve our understanding of this potential limiting factor.

5.2.4 Upstream migration conclusions

Adult steelhead have continuous access to the LA River during the migration season (December–June) due to the lack of sandbar formation at the river's mouth, but upstream migration success would be greatest during flow events of intermediate magnitude, such as the falling limb of the storm hydrograph, that provide suitable depths and velocities for upstream passage. Multiple high flow events are likely needed for adults to reach perennial habitat located in tributaries, and thus steelhead would require access to holding habitat between storm events. High temperatures could pose a major challenge for migrating adults later in the season or for migrating or holding adults during winter baseflows. For these reasons, successful upstream migration is more likely early in the migration season (December–March) due to the occurrence of high temperatures. Numerous passage barriers exist that could limit or altogether prevent upstream migration in both the mainstem LA River and in the major tributaries.

5.3 Spawning and Incubation

Adult steelhead spawning, egg incubation and early life development are influenced by physical habitat features, hydraulic and hydrologic conditions, and water quality. Suitable conditions for spawning and incubation are assumed to only occur in perennial tributaries. Below we relate the existing conditions in the LA River to spawning and early life stages.

5.3.1 Spawning habitat quantity and quality

Historically, LA River steelhead had access to spawning habitat in several tributaries including the Arroyo Seco, Big Tujunga Creek and others. Migration barriers, urbanization, habitat alteration, and poor water quality have greatly reduced the amount and accessibility of spawning habitat in the watershed. There are no detailed assessments of spawning habitat within the LA River watershed, which limits our ability to predict availability and locations of suitable spawning habitat. Under present conditions, the soft-bottom reach of the Arroyo Seco under the Ventura Freeway contains potentially suitable *O. mykiss* spawning habitat that is perhaps the most accessible spawning habitat in the LA River basin by virtue of its location downstream of any major structural migration barriers. However, passage and habitat improvements are likely still needed for steelhead to access the habitat in the central Arroyo Seco downstream of Devil's Gate Dam. Suitable spawning habitat exists upstream of Devil's Gate Dam in the Arroyo Seco and upstream of Hansen Dam and Big Tujunga Dam in the Big Tujunga watershed, but passage would need to be provided. Habitat forming processes and materials (e.g., gravel, large wood) are not intact or available through much of the LA River watershed, and thus mechanisms may not exist to promote formation and maintenance of spawning habitat, especially downstream of dams. Sedimentation of spawning habitat is also a concern, especially after wildfires and sluicing of sediment through dams, as is the case at Devil's Gate Dam. Although the amount and quality of available spawning habitat is a concern, it is more likely that other factors such as migration barriers, water temperature and available rearing habitat would limit population productivity.

5.3.2 Fecundity

Because of the large fecundity differences between anadromous and resident *O. mykiss* (greater than 3,000 eggs for anadromous female *O. mykiss* compared to fewer than 1,000 eggs for resident females) (Moyle 2002), population dynamics are potentially very different in years with anadromous production versus only resident production. In the LA River, anadromous *O. mykiss* would not be expected to spawn every year (as discussed in Section 4.2.1), and in years when it does not occur production would only be from resident females. Therefore, *O. mykiss* production in years when anadromous adults can access and spawn in the LA River watershed may be far greater than in years when they do not spawn. This phenomenon may have a disproportionate influence on the population and age structure of *O. mykiss* in a given year and between years. Currently, anadromous individuals do not contribute reproductively to the *O. mykiss* population in the LA River, and all reproductive contribution is from the few existing resident fish. Additional studies into the population size of residents is needed to understand their reproductive potential.

We hypothesize that population growth of future LA River *O. mykiss*, both resident and anadromous, will be limited by physical habitat constraints, particularly in years of anadromous production. For anadromous *O. mykiss* populations (as well as other Pacific salmon populations such as coho salmon), the average fecundity is high relative to the amount of suitable juvenile rearing habitat usually available within a stream. Rather than being controlled by reproductive success, growth of anadromous populations tends to be limited by physical habitat constraints during the juvenile freshwater rearing stage. The degree of juvenile habitat constraints can differ between watersheds. For example, in some coastal California watersheds lagoons and other estuarine habitats provide key rearing habitat for *O. mykiss*, although this is not the case for the LA River due to loss of estuary habitat and poor water quality in the lower portion of the river. Rearing habitat is discussed in more detail below.

In the absence of migration passage, resident *O. mykiss* populations that fully complete their life cycle above barriers within tributaries may be critical for maintaining the *O. mykiss* population and conserving wild LA River steelhead genetics (Courter et al. 2013, Kendall et al. 2015). As discussed in Section 4.2.8, the few genetic assessments of resident *O. mykiss* in the LA River watershed indicated these fish were derived from hatchery populations (Jacobsen et al. 2014; Abadía-Cardoso et al. 2016), but additional genetic studies would be needed to understand the genetic ancestry of existing LA River *O. mykiss*. Regardless of their genetic origins, both resident O. *mykiss* and steelhead would spawn in the spring. As noted above, high temperatures later in the migration season could select for earlier migrations and thus earlier spawning time of anadromous fish compared to residents.

5.3.3 Incubation

The duration of egg incubation is influenced by temperature with higher temperatures resulting in shorter incubation times (Myrick and Cech 2001). There is little temperature data from tributaries over the egg incubation period to understand how temperature might influence egg incubation in the LA River watershed, but given the observation that mainstem LA River temperatures increase throughout the migration and spawning season, earlier hatching times are possible.

Eggs require adequate flow and oxygen during incubation, conditions which are generally expected in spawning locations in the LA River watershed. However, increased sedimentation from dam sluicing events or from wildfires could adversely impact conditions for egg incubation. Redd scouring during high flow events is also a concern, but flow conditions in the tributaries are not expected to have changed significantly from historical conditions.

Redd predation by non-natives is also a concern in the LA River. Historically, there would have been few predators for steelhead redds, but several non-native predators, such as centrarchid species and American bullfrogs, would likely target steelhead redds. For the most part, non-natives are associated with habitats that would not be suitable for spawning and incubation, especially in upper tributaries.

5.4 Juvenile Rearing

Under historical conditions, juvenile steelhead rearing would have taken place in multiple locations throughout the watershed including within tributaries, the estuary, and even in some mainstem locations. Juvenile steelhead typically rear for one to two years in fresh water before migrating downstream as age 1+ and 2+ fish. In rivers with estuaries, there is typically an important distinction between age 1+ smolts and age 1+ downstream migrants. It is a common life history strategy for juvenile steelhead to migrate downstream in the spring but rear for an additional year before smolting in an estuary when one is present (Hayes et al. 2008). This is true of all age classes of juvenile steelhead but especially common at age 1+. Age 1+ steelhead that rear in the estuary will then smolt at age 2+ the following spring and, because they may be larger as a result of greater food supply in the estuary, they may experience higher ocean survival than stream-reared age 2+ smolts (Bond et al. 2008). Therefore, both in instances of stream rearing and estuary rearing, production of adult steelhead depends greatly on the size of the smolts produced and advantageous smolt size is most often reached by age 2+. However, age 1+ fish can reach adequate sizes if the system is productive (Booth 2020). Overall, growth rates and size of emigrant fish is an important component influencing life history decisions and marine survival rates.

The extensive estuarine habitat that was present in the lower reaches of the LA River prior to urbanization (Gumprecht 2001) provided high quality rearing habitat for steelhead and supported the estuarine rearing strategy, likely resulting in rapid growth and high ocean survival. An estuary rearing life history strategy is not currently viable due to poor rearing conditions (e.g., high temperature) and the nearly complete lack of typical estuarine habitat at the mouth of the LA River. In the absence of significant restoration to the LA River estuary, juveniles must complete rearing solely within freshwater, which would impact the size of fish at ocean entry and thus marine survival rates.

The maximum number of juvenile steelhead that a stream can support is limited by food and space through territorial behavior, and this territoriality is necessary to produce steelhead smolts that are large enough to have a reasonable chance of ocean survival. Because of these habitat requirements, the number of age 0+ fish that a reach of stream can support is typically small relative to the average fecundity of an adult female steelhead. For example, a small to medium-sized female steelhead may produce 3,000–5,000 eggs (Moyle 2002). Typical age 0+ densities in some of the most productive California steelhead streams (e.g., tributaries to the South Fork Eel River) have been around 0.10 fish/ft^2 (1.1 fish/m^2) (Connor 1996). Even at relatively low survival-to-emergence rates of 25%, the number of fry produced from one medium-sized anadromous female (5,000 x 0.25 = 1,250) may be sufficient to fully seed most of the available rearing capacity in the soft-bottom section of the Arroyo Seco downstream of the Rose Bowl, although habitat surveys would be needed to confirm the amount of suitable habitat for rearing. Thus, it is assumed that the amount of available rearing habitat, particularly during the summer due to lower flows and warmer temperatures, would limit steelhead production in the LA River.

5.4.1 Summer habitat

Summer rearing likely occurred only in the upper tributaries where reliable perennial flows occurred. It is possible, however, that suitable rearing conditions were present in portions of the lower mainstem LA River and in floodplain wetlands that were perennial as a result of shallow groundwater, which would have kept water temperatures low year-round. Summer rearing habitat has been posited to limit *O. mykiss* production in some other California coastal streams where a lack of habitat complexity, low pool volume, low food availability, and excessive water temperatures reduce rearing success (e.g., Stillwater Sciences and Dietrich 2002, Stillwater Sciences 2007, Harvey et al. 2006). The mainstem LA River and the lower elevation reaches of its tributaries do not currently provide suitable rearing habitat for *O. mykiss*, but limited data on temperature and physical habitat suggest anadromous adult steelhead offspring could rear in the

Arroyo Seco and the Big Tujunga system if passage to these areas was provided. Interestingly, water temperatures in Compton Creek appear to be suitable, but physical habitat and water quality conditions have not been documented in this tributary and could be limiting for steelhead production.

The interaction between food availability and temperature in Southern California is a key consideration during summer rearing. The ability of fish to convert energy sources to physical growth is a function of their food intake and metabolic rate. Consumed food sources have varying energetic value, which are first allocated to catabolic processes (maintenance and activity metabolism), then to waste losses (feces, urine and specific dynamic action). Any leftover energy is allocated to somatic storage (body growth and gonad development). Because fish are poikilothermic, their metabolic rate is determined by the water temperature. High water temperatures increase energy allocated to catabolic processes, and thus less energy remains to allocate to growth. Therefore, the key environmental parameters that potentially affect growth are food availability (e.g., invertebrate drift) and water temperature. Flow delivers invertebrate drift downstream, and low flows during the summer could decrease prey transport, especially from riffle habitats.

Since summer water temperature in the LA River watershed is warmer than the thermal tolerance of steelhead (see section 4.2.3), fish would experience increased metabolic demands and reduced growth if sufficient prey were not available. In tributaries to the Napa River, California, steelhead that experienced reduced growth during the summer due to high temperatures and low prey availability were able to compensate through increased feeding and growth during other seasons when flows and prey delivery were higher and water temperature was lower (Stillwater Sciences 2007). In Topanga Creek, another Southern California steelhead stream, growth of juvenile steelhead was observed year-round despite high water temperatures (Bell et al. 2011b) suggesting Southern California steelhead have thermal physiology that is acclimated/adapted to high water temperatures. Macroinvertebrate sampling, additional water temperature monitoring, and growth monitoring of existing resident *O. mykiss*, during the summer would improve our understanding of seasonal influences of temperature on growth in the LA River.

Summer habitat likely supports more age 0+ steelhead compared to age 1+. In watersheds where, as a result of anthropogenic disturbance, there are increased inputs of coarse and fine sediment to the stream channel and decreased large wood, the disparity between the amount of summer habitat for age 0+ steelhead and age 1+ steelhead is often increased. Pool frequency is reduced with the removal of large wood, especially in forced pool-riffle and plane-bed stream reaches. The remaining pools may become shallower as a result of aggradation and the lack of scour-forcing features such as large wood. There is a lack of large wood in the LA River, particularly below major dams, and thus pools are likely fewer and shallower compared to upstream tributaries which tends to favor age 0+ fish.

5.4.2 Winter habitat

In addition to winter rearing within tributaries, winter rearing habitat was likely also historically available in some mainstem and lower tributary sections due to increased flows and lower water temperatures in the winter. For example, in the coastal plain downstream of Elysian Park, the mainstem was a multi-threaded channel with wide floodplains and wetlands connected to the channel in many places (see Section 3.7.5). Studies have shown that seasonal floodplain access can provide excellent feeding and growth opportunities for rearing salmonids (e.g., Sommer et al. 2001).

As with summer habitat, a reach of stream will typically support far fewer age 1+ than age 0+ *O. mykiss* in the winter. Overwintering *O. mykiss* may suffer high mortality when they are displaced by winter floods, which are common in the inherently flashy LA River watershed. Refuge from flood events requires a similar type of habitat as concealment cover, but may require access deeper into the streambed to avoid turbulent conditions near the surface or even within the first layer of substrate (the implications of this for embeddedness are discussed later). Similar to other watersheds supporting *O. mykiss* populations, the LA River has a relatively low gradient in the mainstem while the tributaries are much steeper (e.g., 4% or greater), with no remaining floodplains or other off-channel habitat due to channelization and adjacent urbanization in the mainstem and narrow valleys and canyons in the upper watershed. In general, *O. mykiss* show less propensity than other species (e.g., coho salmon) for using off-channel slackwater habitats in winter, and a greater propensity for using in-channel cover provided by cobble and boulder substrates, which are common in tributaries such as the Arroyo Seco and Big Tujunga and usually immobile at all but the highest flows.

The upper watersheds within the LA River basin were (and mostly still are) forested and likely had abundant large wood inputs to promote pool formation and sediment sorting. Hillslopes in the lower watershed were (and still are) vegetated with chapparal and scrub and never provided great amounts of large wood to the streams. The San Gabriel Mountains are steep and highly erosive (see Section 3.4) so sediment inputs would have been high. Because the upper watershed is largely undeveloped, anthropogenic changes in the upper watershed have been minimal, with the exception of fire which now results in large, episodic sediment inputs, and dams which trap almost all sediment (except Devil's Gate, where sediment is sluiced through periodically). Fire occurred historically too, but was likely more frequent and thus less severe, with more moderate effects on sediment input and stream biota.

In contrast to upper watersheds that are mostly natural, anthropogenic influences have altered natural habitat processes in lower tributaries and within the LA River mainstem. Other than sediment sluicing events from Devil's Gate Dam, there are few sediment sources lower in the watershed, and sources of large wood are extremely limited. Pool frequency is reduced with the removal of large wood, especially in forced pool-riffle and plane-bed stream reaches (Montgomery and Buffington 1997). The remaining pools may become shallower as a result of aggradation and the lack of scour-forcing features such as large wood, and cover may also be reduced. The filling of interstitial spaces of cobble/boulder substrates by gravels and sand can affect rearing habitat for both age 0+ and age 1+ *O. mykiss*. At higher levels of embeddedness, substrate will become unsuitable for both summer and winter rearing, but it will often be more limiting in winter because refuge from entrainment during winter freshets typically occurs deeper within the substrate. Typically, sediment supply to LA River tributaries is limited to inputs from hillslopes, small tributaries, and the channel itself. Larger inputs of sediment also occur infrequently from events such as erosion following wildfires and floods, and on the Arroyo Seco from the sluicing of sediment through Devil's Gate Dam. As a result, it is likely that embeddedness is generally low and interstitial spaces among cobble/boulder habitat are probably abundant throughout much of the tributaries. Under these typical conditions it does not appear that winter habitat would be a limiting factor for the LA River *O. mykiss* population. However, sediment deposition in the streambed can be substantial following events such as the 2009 Station Fire and sluicing events at Devil's Gate Dam, resulting in extremely high embeddedness and nearly complete lack of accessible interstitial space among coarse substrates. After these events, the lack of winter habitat for *O. mykiss* would likely limit juvenile survival and production until fine sediments are flushed from the streambed by high winter flows.

5.5 Downstream Migration

The decision to migrate downstream is related to a combination of genetics, intrinsic fish condition (e.g., growth) and environmental factors (Kendall et al. 2015) and is the subject of ongoing research. Some key factors influencing smoltification include photoperiod, fish size, and temperature. For example, juvenile steelhead typically must reach a particular size to initiate migration (Beakes et al. 2010) with fish migrating at younger ages when growth rate is higher. Thus, in systems that are productive during the winter, fish can typically achieve greater sizes and migrate sooner. There are two competing hypotheses for age (and thus size) of outmigrating smolts. If summer/winter habitat is unsuitable for larger age 1+ juveniles compared to age 0+ juveniles, we might expect more fish to migrate as age 1+ smolts to avoid spending and an additional season in adverse conditions. However, if growth potential is low due to high temperatures or low prey availability, we might expect age 0+ juveniles to require an additional year to reach sizes associated with smoltification. Like all other aspects of the life history of steelhead, temperature is a primary factor that influences growth rate directly, as well as indirectly by influencing food availability. In productive systems, increased steelhead growth rates have been observed at high, 'above-optimal' temperatures as long as there is enough food available to offset the increased metabolic costs from temperatures (Bell et al. 2011b). Temperature is also known to influence the physiological process of smoltification, and temperatures above 54°F (12°C) are shown to impair smoltification (USEPA 2003, Myrick and Cech 2001). It is possible that steelhead in Southern California have adapted to achieve smoltification at higher temperatures, but water temperatures in the LA River mainstem under current conditions would likely preclude smoltification during summer and successful smoltification may only be possible during cooler winter periods, as discussed in Section 4.2.3.

Successful smolt outmigration in Southern California necessarily depends on adequate flow conditions to provide a migration corridor that connects intermittent stream sections and to breach sandbars, if present, at the river mouth (e.g., Smith 1990). Although adequate flows are necessary to facilitate fish passage, the initiation of downstream migration has recently been shown to be primarily related to photoperiod for smolts in Southern California (Booth 2020). Booth (2020) related smolt arrival at a diversion dam in the Santa Clara River to several factors including photoperiod and flow. The results from this study showed that migration could occur as early as January and as late as June, but over 95% of smolt migration occurred over a relatively consistent window from mid-March to late-May regardless of the occurrence of early season flows that could have facilitated downstream migration. Photoperiod is understood to be the key factor initiating smoltification in more northern populations, but it had been hypothesized that flows would be a primary cue for migration in Southern California due to the flashy and intermittent nature of Southern California rivers. However, based on results from Booth (2020), photoperiod may be the initial cue for the smoltification process, and only during the seasonal occurrence of the appropriate day length will smolts take advantage of high flows to migrate downstream.

In the LA River, high flows are likely still necessary to facilitate migration from tributaries to the mainstem, but once fish reach the mainstem, consistent baseline flows from wastewater discharge and the lack of a sandbar at the river's mouth would result in fairly consistent downstream migration opportunities. However, migrating during baseflows would pose significant risks to migrants including exposure to above optimal temperatures and increased susceptibility to predators. Thus, in the LA River, smolt migration success would be greatest during winter and spring high flow events that are associated with cooler temperatures and better cover (i.e., higher turbidity) from predators.

As discussed previously, some steelhead are known to rear in upstream reaches before outmigrating as smolts, and some outmigrate to the lower river reaches and estuary at smaller sizes/younger ages to rear before migrating to the ocean (Hayes et al. 2008). Estuarine rearing may be more important for steelhead populations in the southern half of the species' range due to greater variability in ocean conditions and lack of high-quality nearshore habitats in this portion of their range (NMFS 1996). However, the estuary of the LA River is heavily modified and is likely unsuitable for rearing, so all downstream migrants are expected to leave their tributary rearing habitats as smolts.

Steelhead are iteroparous and capable of repeat spawning. Post-spawn steelhead (kelts) would be expected to migrate downstream soon after spawning unless conditions and available resources (primarily space and prey) in the spawning tributaries were suitable for adults to survive over the summer. Downstream migration by kelts would typically be coincident with smolt migrations (i.e., from March–May) and during high flow events that provide passage. Temperature could be a limiting factor for these migrations especially later in the season, but since downstream migrations are comparatively much shorter in duration than upstream migration, encountering above optimal temperatures during outmigration may only be stressful and not lethal.

5.6 Marine Survival

In California, it is widely accepted that most adult *O. mykiss* returns are from fish that smolted at age 2+ or older. For example, in Waddell Creek, Shapovalov and Taft (1954) found that 69% of the adult returns were from fish that smolted at age 2+, and 19% were from fish that had outmigrated at age 3+. Only 10% of the returning adults were from fish that outmigrated at age 1+. However, these relationships between age at outmigration and survival are from systems in Central California and may not apply to Southern California rivers. Generally, the reason for greater survival of fish that outmigrate at older age is due to size at outmigration.

The size of outmigrating *O. mykiss* smolts is positively correlated with marine survival, with smolts greater than 6.7 in (170 mm) typically having high (>10%) survival in the marine environment (Ward et al. 1989). Similarly, Bond et al. (2008) found that adult *O. mykiss* returning to Scott Creek (central California coast) had entered the ocean as juveniles when their average fork length was just over 7.1 in (180 mm). In contrast, Kelley (2008) found that while migrating through the Santa Clara and Santa Ynez estuaries, smaller smolts had higher survival than larger ones, which may be attributable to disproportionate avian predation rates, and may not be indicative of marine survival success.

Due to limited rearing habitat and likely unsuitable rearing conditions in the LA River estuary, it is uncertain whether LA River smolts would achieve sizes associated with higher marine survival. As discussed previously, smolts could migrate downstream at age 1+ or age 2+. If more age 1+ smolts migrate to the ocean compared to age 2+, lower marine survival would be expected. The absence of information on growth and age structure of *O. mykiss* in the LA River limits our ability to make predictions about marine survival.

6 SUMMARY OF LIMITING FACTORS AND CONCEPTUAL MODEL

In the preceding sections, we described how current conditions in the LA River watershed may limit different life stages of *O. mykiss* including for both resident and anadromous life history types. Based on our evaluation of historical versus current conditions, we developed a preliminary conceptual ecological model for steelhead in the LA River. Below we summarize key aspects of both the limiting factors analysis and the conceptual ecological model. Table 6-1 provides a synthesis of historical and current conditions related to steelhead, as well as priorities for restoration.

Major findings from our evaluation of limiting factors related to steelhead life history include:

- Altered flow patterns present challenges for migrating steelhead due to truncation of flow events associated with storms.
- Barriers limit upstream (and sometimes downstream) migration of anadromous individuals and prevent resident populations from expanding their distribution and exchanging genetic materials.
- Water temperature in some locations, mainly the mainstem LA River and the estuary, limits juvenile rearing opportunities and potentially precludes smoltification in fresh water during all but the coolest winter periods.
- Suitable spawning and rearing habitat exists in the tributaries, nearly all of which occurs in the upper tributary reaches above major barriers.
- Stocking practices have introduced non-native *O. mykiss* genetics within the LA River, which is associated with loss of genetic diversity and reduction of native phenotypic expression.
- The limited numbers of resident *O. mykiss* in the watershed combined with barriers may limit recovery of steelhead.
- Increased summer temperatures and potentially reduced summer flows under future climate conditions could lead to a bioenergetic bottleneck in juvenile growth during summer months if food supply becomes limiting as metabolic demands increase with increasing water temperatures.
- Additional data collection in the form of barrier assessments, habitat surveys, *O. mykiss* distribution and population surveys, and water temperature/quality monitoring is needed to improve our understanding of steelhead dynamics within the LA River and for prioritizing restoration actions.
- Expansion of the spatial structure and diversity of the *O. mykiss* population in the LA River and the Mojave Rim BPG via reestablishment of multiple native-lineage subpopulations is an important component of a recovery strategy that would reduce extinction risk and improve population viability.

Table 6-1. Summary of conceptual models and hypotheses regarding historical and current conditions in the LA River watershed and their potential effects on different life stages of steelhead, with priorities for restoration and recovery.

Life history event	Hypothesized historical condition	Current condition	Priorities for restoration/recovery
Upstream migration	Timing and success of upstream migration was dependent on winter-spring connectivity in the mainstem LA River, as determined by magnitude and duration of precipitation and streamflow. Breaching of the sandbar at the river's mouth, if present, occurred when storm flows reached sufficient magnitude, thus determining the beginning of the upstream migration window. The river entry window closed when the sandbar reformed. Winter-spring flow was likely perennial in the mainstem and tributaries, providing continuous connectivity to/from the ocean. Holding habitat was present at various locations in the mainstem and tributaries, providing refuge and resting locations during low-flow periods between winter storms. Successful spawning migrations probably occurred in most, but not all years. Suspended sediment concentrations (SSC) were high during winter storms but in most reaches rarely or never reached levels that would impair steelhead and hinder migration, in part because high flows were able to overtop the channel and deposit sediment across floodplains and wetlands in the valleys and coastal plain.	A sandbar no longer occurs at the river's mouth and river entry is possible year-round. Winter-spring flows still needed to provide in-river connectivity, but numerous passage barriers exist including hydraulic barriers in channelized concrete reaches and dams and other structural barriers in the mainstem and tributaries. Multiple high flow events are likely needed for adults to reach perennial habitat located in tributaries (if passage barriers were absent), and thus steelhead would require access to holding habitat to hold between storm events. High water temperatures could pose a major challenge for migrating adults later in the season or during holding between storm events. Successful migration more likely earlier in the wet season due to increasing temperatures beginning in spring. Most sediment is captured by dams but suspended sediment passes dams during high storm flows. Current SSC possibly higher than historical SSC in the mainstem LAR and channelized tributary reaches due to highly efficient fluvial transport and lack of floodplain/wetland connection to dissipate flow and deposit sediment. SSC not sufficient to cause acute physiological stress to adult steelhead.	In-depth assessment of potential migration barriers and remediation (i.e., passage solutions) to provide unimpeded steelhead passage under an appropriate range of winter-spring flow conditions. Provide suitable holding habitat at appropriate intervals along the mainstem LA River and channelized reaches of major tributaries, determined through detailed evaluation of storm flow duration compared with adult steelhead migration rate. Conduct continuous water temperature monitoring in the mainstem and major tributaries to identify relationships between flow and temperature and identify suitability for each freshwater life stage. Conduct continuous SSC monitoring at multiple locations in the mainstem and major tributaries to identify relationships between flow and SSC and conditions, if any, under which SSC is likely to hinder migration.

Life history event	Hypothesized historical condition	Current condition	Priorities for restoration/recovery
Spawning and incubation	Spawning by anadromous steelhead probably occurred in most, but not all years, increasing productivity and maintaining genetic diversity of resident *O. mykiss* populations in upper tributaries. Spawning habitat was abundant in tributaries, mainly the Arroyo Seco and Big Tujunga but spawning may have occurred in other tributaries with suitable habitat. Spawning gravel was abundant in upper tributaries and gravel quality was high. As a result, incubation and emergence success was generally high, resulting in fry density that exceeded rearing habitat capacity in tributaries.	Limited access to spawning habitat due to barriers, but available rearing habitat likely limiting to production rather than spawning habitat due to high fecundity. Location of most spawning habitat is relatively unchanged (mainly in Arroyo Seco upstream of Devil's Gate and Big Tujunga upstream of Hansen Dam and Big Tujunga Dam). Warmer temperatures due to climate change could favor earlier spawning and hatching. Prevalence of hatchery genetic ancestry may be influencing genetic diversity and life history expression of existing populations and compromising population viability.	Remove barriers or provide passage across barriers to increase access to spawning habitat. Sediment management and gravel augmentation in upper tributaries where water temperature and other habitat conditions are suitable for spawning and rearing. Implement basin-wide water quality monitoring and improvements. Additional genetic studies to identify the presence of wild coastal steelhead genetics and locations with hatchery ancestry to guide reestablishment of subpopulations.

Life history event	Hypothesized historical condition	Current condition	Priorities for restoration/recovery
Juvenile rearing	Rearing, potentially year-round, took place in abundant estuary habitats near the river's mouth. Estuary-reared smolts entered the ocean at larger sizes than stream-reared smolts, likely resulting in high ocean survival. Winter rearing occurred in suitable habitat in tributaries, floodplain wetlands along the mainstem LA River, and the estuary. Relatively low frequency of catastrophic events (e.g., wildfire) and resulting sedimentation and reduction of winter habitat quality. Suitable summer rearing habitat was present in the upper tributaries, supporting rearing by juveniles and year-round resident populations, but high water temperatures and partial summer drying may have limited growth and survival. Summer rearing habitat quantity and limited summer growth opportunities in tributaries likely limited production of juveniles and smolts.	Lack of suitable estuary and mainstem rearing habitat such as floodplain wetlands would result in smaller smolts and relatively low ocean survival, likely limiting productivity of the population. Processes and materials for creating habitat not intact, except in upper tributaries. Winter rearing habitat is available only in upper tributaries. Increased frequency of catastrophic events and introduction of sediment sluicing, resulting in longer periods of sedimentation and poor winter rearing habitat conditions. Summer habitat and resident *O. mykiss* populations still present in upper tributaries, with growth and survival likely still limited by high water temperatures and partial drying. Summer habitat limitations likely exacerbated by episodic sedimentation and limited access to suitable habitat due to barriers. More downstream migrants expected at age 1+ than at age 2+ due to limited habitat available for larger juveniles.	Restore access to additional rearing habitat by providing passage. Restore natural processes for habitat creation (e.g., comprehensive sediment management, large wood recruitment) and/or implement habitat enhancement projects. Document current habitat conditions in watershed, particularly in tributaries; use data to model population production potential. Assess measures to reduce stream temperatures (such as increased riparian shading and increased groundwater inputs). Survey *O. mykiss* presence/absence throughout the watershed and sample for genetic analysis. Develop and implement a basin-wide plan for aquatic invasive species removal and management.

Life history event	Hypothesized historical condition	Current condition	Priorities for restoration/recovery
Outmigration	Successful outmigration associated with high flow events that provided connectivity and suitably cool water temperatures. No barriers to outmigration when flows provided connectivity. Timing of ocean entry dependent on breaching of sandbar by high flows. Some downstream migration and estuary rearing of age 1+ *O. mykiss*.	High flow events needed to connect tributaries to mainstem LA River. Dams prevent or impede outmigration during most flow conditions. Elevated baseflows in LA River mainstem create potentially year-round downstream migration connectivity to the ocean. High temperature in LA River mainstem may inhibit smoltification, especially later in the migration season or if fish migrate during baseflows, and may truncate the outmigration window. Estuary rearing strategy not viable due to poor rearing conditions in estuary. Predation by introduced piscivores may limit rearing and outmigration success during periods of low flow, effectively shortening the suitable outmigration window.	Monitor and improve water quality, especially temperature in the mainstem LA River. Remove or modify dams to provide unimpeded downstream passage during appropriate seasonal time period. Restore estuarine habitat to provide suitable *O. mykiss* rearing conditions. Develop and implement a basin-wide plan for aquatic invasive species removal and management.

Life history event	Hypothesized historical condition	Current condition	Priorities for restoration/recovery
Summary of steelhead production potential	Reproduction of anadromous adults expected in most years, with juvenile outmigration to the ocean or estuary in every year. Rearing in tributaries and estuary (and possibly mainstem) with high growth potential in the estuary that would have resulted in high marine survival. Spatially distributed resident *O. mykiss* subpopulations (i.e., Arroyo Seco, Big Tujunga, and likely some smaller tributaries) helped maintain genetic diversity of the population and resiliency to disturbances and catastrophic events, conferring a relatively low risk of extinction and contributing to viability of the population. Unimpaired flow regime and lack of physical barriers allowed access by anadromous *O. mykiss* and possibly movement of resident fish within the watershed, facilitating connectivity among subpopulations. The population thus functioned as a viable metapopulation with low risk of extinction due in part to genetic exchange and reduced risk of population extirpation in the face of catastrophe. Diverse habitat features within the watershed combined with a lack of barriers allowed *O. mykiss* to take advantage of habitat and resources for rearing, migrating, and spawning.	Anadromous *O. mykiss* no longer occur in the watershed and there is no genetic exchange among remaining subpopulations, contributing to low diversity and viability (i.e., high extinction risk) of the population. Some suitable rearing habitat and possibly spawning habitat is present below barriers in the Arroyo Seco, but most suitable habitat exists above barriers in tributaries. Altered flow patterns, channelization, and physical barriers limit migration opportunities, especially upstream migration. A few resident *O. mykiss* subpopulations exist, but abundance and population growth appear low and genetic integrity may be compromised by hatchery stocking. These conditions contribute to low population viability and high extinction risk. High water temperatures in the mainstem may inhibit successful smoltification and limit migration.	Restore habitat connectivity and increase available habitat through barrier removals or fish passage solutions in mainstem and tributaries Conduct *O. mykiss* surveys to document distribution, quantify abundance, and perform genetic analysis to determine ancestry. Reestablish spatially dispersed subpopulations via translocation of appropriate native genetic stock to increase spatial structure and diversity of the population, helping reduce extinction risk and improve population viability. Inventory and restore/enhance migration and rearing habitat in the tributaries, mainstem, and estuary. Manage water, sediment, and wood to facilitate processes for habitat formation. Improve water quality, especially temperature in the mainstem LA River.

7 CONCLUSIONS AND RECOMMENDATIONS

Urbanization and other anthropogenic influences have greatly altered physical, chemical, and biological conditions in the LA River watershed, which in turn have limited steelhead (and resident *O. mykiss*) presence. Long-term recovery of steelhead in the LA River watershed will require a basin-wide effort to improve habitat, provide fish passage solutions, improve water quality, control non-native species, and wisely manage water, sediment, and other watershed inputs that create and maintain habitat for *O. mykiss* and other native aquatic and riparian species. Of note, immediate reestablishment of steelhead in the LA River could be achieved through translocations of fish with native coastal steelhead ancestry to existing suitable habitat in the Arroyo Seco or possibly other LA River tributaries in the San Gabriel Mountains. Providing upstream and downstream passage would then provide opportunities for reestablished steelhead to complete an anadromous life cycle. The following recommendations are focused on actions to lay the groundwork for reestablishment and eventual recovery of steelhead in the LA River watershed. These recommendations are presented as a roadmap for steelhead recovery.

1. **Additional investigations**
   Additional data gathering is needed to develop a more comprehensive understanding of limiting factors for steelhead within the LA River to ultimately inform and help prioritize restoration and recovery actions. Refer to earlier sections of this document for the latest progress on each of these priorities. Specific studies that are recommended as priorities include:
   - **Barrier assessments** – A comprehensive and detailed assessment is needed to fully evaluate many of the potential steelhead migration barriers. Additional barriers may exist that were either not identified or that were identified (in Section 4.2.2 and Figure 4-1) but might require additional evaluation.
   - ***O. mykiss* population surveys** – Quantitative fish population surveys in upper tributaries to document distribution and abundance and gather information on population demographics.
   - **Genetic inventory** – Additional genetic sampling of *O. mykiss* is needed to identify the presence of native steelhead genetics and help develop actions to improve or maintain genetic integrity.
   - **Habitat surveys** – Habitat inventories in upper tributaries would provide valuable mapping and quantification of spawning gravel, summer, and winter rearing habitat and document problems and stressors. These efforts should build on current plans for these types of assessments in the upper Arroyo Seco to support potential *O. mykiss* translocation. Surveys should be designed to collect data that can be used for population productivity modeling.
   - **Steelhead movement studies** – Additional studies using mark-recapture or radio telemetry are needed to better understand adult and juvenile steelhead movements in Southern California rivers. This should be done first in river systems with existing adult steelhead returns such as the Santa Ynez or Santa Clara rivers and later in the LA River to monitor movement and migration of reestablished *O. mykiss*.
   - **Temperature & dissolved oxygen monitoring** – Deployment of combined temperature and dissolved oxygen data loggers at multiple strategic locations throughout the watershed would help characterize these parameters and identify locations to target for restoration in partnership with those already engaged in

monitoring such as the Council for Watershed Health, Arroyo Seco Foundation, SCCWRP, and others.

- **Growth rate studies -** Document food supply, stream temperatures, and juvenile growth and condition during summer rearing in the primary headwater perennial reaches.
- **Flow regulation opportunities** – Evaluation of opportunities to regulate flows in the mainstem LA River and tributaries via re-operation of dams, wastewater treatment facilities, management of stormwater and water diversions/deliveries, or other means to improve passage and habitat conditions for steelhead and other native fishes such as through partnerships with SCCWRP on the 2-year State Water Resources Control Board LA River Environmental Flows Study, City of LA, City of Pasadena, and other similar partners.
- **Sediment studies –** Detailed investigation of current sediment loads and dynamics throughout the watershed with a focus on the supply of different grain size classes and sediment retention. This analysis is a crucial component of designing passage and habitat improvement for steelhead and other species to evaluate sediment-related effects on proposed design features and assess locations that are likely to require sediment augmentation.
- **Identify funding sources and high-priority restoration/enhancement projects –** Identify and leverage potential funding sources and specific projects aligned with scientific, regulatory, and socio-political priorities.

2. **Project Planning and Implementation**
   Planning and implementation of high-priority steelhead recovery actions, including additional fish passage and habitat improvement projects in the LA River mainstem and lower tributary reaches (e.g., the Arroyo Seco), are critical to steelhead recovery in the LA River watershed and will contribute to recovery efforts throughout the Mojave Rim BPG and the Southern California Steelhead DPS. Restoration projects can be prioritized based on the anticipated magnitude of benefits to steelhead and project feasibility (e.g., cost, stakeholder support, regulatory feasibility). Priority actions should be developed and implemented within an adaptive management framework. Broadly, implementation project categories would likely include:
   - **Barrier removal projects** to provide upstream and downstream passage between the ocean and suitable spawning and rearing habitat;
   - **Habitat restoration projects** to improve habitat conditions and increase available habitat within tributaries (and potentially the estuary);
   - **Subpopulation expansion via translocation** of genetically appropriate *O. mykiss* into upper tributaries or other priority locations (e.g., the Arroyo Seco upstream of Devils Gate Dam) to enhance native genetic stock and improve metapopulation viability; and
   - **Flow regulation/augmentation projects** to improve passage and habitat conditions for steelhead and other native fishes.

3. **Continued Monitoring**
   Following implementation of restoration projects, continued monitoring is needed to understand the effectiveness of restoration actions, identify future restoration projects, and adjust restoration strategies as part of an adaptive management framework. Some examples of monitoring include:

- *O. mykiss* population surveys;
- Habitat assessments;
- Temperature monitoring;
- Biotelemetry studies; and
- Food web studies.

4. **Continued steelhead planning and implementation of multi-benefit strategies**
   Continue steelhead-focused planning and assessment in coordination with other plans, projects, and initiatives and develop approaches to river-riparian restoration and enhancement that capitalize on synergies and multi-benefit strategies throughout the watershed and the region.

   Currently there is substantial alignment and funding to address steelhead recovery priorities and actions in the LA River and upper tributaries. The City of Los Angeles is taking a leadership role in implementing its adopted biodiversity action plan which includes the LA River FPHS design project and this Conceptual Ecological Model and Limiting Factors Analysis. Likewise, the County of Los Angeles has adopted its Sustainability Plan which includes biodiversity actions inclusive of aquatic, riparian, and terrestrial species recovery. The USACE has a Congressional Authorization to implement Alternative 20 as described in the LA River Ecosystem Restoration Integrated Feasibility Report (USACE 2015b) which includes the 4.8-mile LAR FPHS project area. A recent 2020 Settlement Agreement between the County and the Arroyo Seco Foundation has resulted in commitment by the County to complete the Arroyo Seco Watershed Feasibility Study by April 2021 which includes fish passage and stream naturalization as a major focus area. Planning and workplan development are progressing for steelhead subpopulation expansion efforts in the headwaters of the LA River watershed and many others throughout the Southern California Steelhead DPS. NMFS and CDFW are likewise addressing limiting factors to steelhead recovery in this and other watersheds.

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