Southern California River and Stream Habitats

Climate Change Vulnerability Assessment Synthesis

An Important Note About this Document: *This document represents an initial evaluation of vulnerability for river and stream habitats based on expert input and existing information. Specifically, the information presented below comprises habitat expert vulnerability assessment survey results and comments, peer-review comments and revisions, and relevant references from the literature. The aim of this document is to expand understanding of habitat vulnerability to changing climate conditions, and to provide a foundation for developing appropriate adaptation responses.*

Executive Summary

Rivers and streams are powerful drivers of landscape patterns and ecological communities, and provide California's most valuable forest resource: water. Rivers and streams in southern California are primarily fed by precipitation, surface runoff, and groundwater discharge; historically, peak flows and flooding occur in winter and spring, and low- or no-flow conditions often occur in the summer and fall (Gasith and Resh 1999; Stephenson and Calcarone 1999). This assessment includes both perennial and ephemeral systems, as well as riparian vegetation commonly associated with rivers and streams.[1]

The relative vulnerability of river and stream habitats in southern California was evaluated to be moderate[2] by habitat experts due to moderate-high sensitivity to climate and non-climate stressors, moderate exposure to future climate changes, and moderate adaptive capacity.

Sensitivity and Exposure	Climate sensitivities: Precipitation, drought, low streamflows Disturbance regimes: Wildfire, flooding Non-climate sensitivities: Dams and water diversions, invasive and other problematic species

Rivers and streams are sensitive to climate drivers that alter hydrology, water temperature, and water quality. Patterns of high and low streamflows, flooding, and drying are primarily responsible for the dynamic nature of lotic systems. Rivers and streams in southern California already reflect highly variable flow regimes; however, extreme flooding and/or drought events may magnify many processes in the system (e.g., channel incision). Extensive habitat alteration due to non-climate stressors such as dams and water diversions is likely to exacerbate the impacts of climate change.

Adaptive Capacity	Habitat extent, integrity, and continuity: Moderate-high geographic extent, low integrity (i.e., degraded), moderate continuity Resistance and recovery: Low resistance potential, moderate recovery potential

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[1] Climate change vulnerability alluvial fans will be discussed in the Alluvial Scrub section of this report.

[2] Confidence: High

Habitat diversity: Moderate-high overall diversity
Management potential: High societal value, moderate management potential

Rivers and streams are considerably degraded throughout most of the region, and hydrologic connectivity is low. This habitat type is adapted to high levels of variability and frequent disturbances, and can recover relatively quickly under natural conditions. However, highly modified streams are slow to recover and are vulnerable to impacts from additional stressors (e.g., invasive species). Overall, rivers and streams are diverse habitats and host many threatened, endangered, and endemic species. Stream improvements and restoration activities could reduce the impact of climate and non-climate stressors and enhance habitat quality.

Sensitivity

The overall sensitivity of river and stream habitats to climate and non-climate stressors was evaluated to be moderate-high by habitat experts.[3]

Sensitivity to climate and climate-driven changes
Habitat experts evaluated river and stream habitats to have moderate sensitivity to climate and climate-driven changes,[4] including: precipitation, drought, and low streamflows.[5] Habitat experts also identified high water temperatures, extreme heat events, snowpack depth, timing of snowmelt and runoff, soil moisture, and air temperature as additional climate and climate-driven stressors that may impact river and stream habitats.[6]

Precipitation and drought
Rivers and streams are primarily dependent upon precipitation to maintain flow, as well as to recharge soil moisture and groundwater systems. Franco-Vizcaino et al. (2002) found that roughly 15% of rainfall contributes to streamflow in forested watersheds of Baja California, which are characterized by extreme water deficits. As climatic water deficit increases over the course of the summer, evapotranspiration accounts for a greater proportion of precipitation and progressively less water is available as runoff from the forest floor into streams (Franco-Vizcaino et al. 2002). However, in areas where full groundwater recharge is possible, such as in fractured-rock aquifers (often associated with springs), a greater amount of water is available as runoff after a precipitation event, resulting in increased and sustained streamflow (P. Taber, pers. comm., 2015).

Drought intensifies normal patterns of flooding and drying, contributing to more frequent and/or longer periods of low or no flow conditions in stream reaches (Gasith and Resh 1999). Multiyear droughts may cause longer-term changes to rivers and streams by altering channel and bank characteristics (Gasith and Resh 1999). For example, sediment accumulation may

[3] Confidence: High
[4] Confidence: Moderate
[5] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.
[6] Not all habitat experts agreed on these climate and climate-driven stressors.

occur in the absence of occasional scouring events (Gasith and Resh 1999). The current drought (2011-present) has severely decreased flows in California streams; as of Oct. 19, 2015, 61% of gaged rivers within the state were flowing at conditions below normal, and 4% of rivers are experiencing flow conditions at new recorded lows (The Nature Conservancy 2015).

Reduced water availability and increasingly intermittent flows also affect riparian plant communities. Under drought conditions, species diversity and cover decline, and species composition shifts towards more drought tolerant shrubs such as sweetbush (*Bebbia juncea*) and saltcedar (*Tamarix* spp.; Stromberg et al. 2007). These changes can impact organic matter inputs into rivers and streams (e.g., leaf litter and woody debris) that support benthic invertebrates, a primary food source for many aquatic species such as steelhead (*Oncorhynchus mykiss*; Griggs 2009).

In addition to the direct contribution of precipitation to water availability and streamflow, changes in precipitation amount and/or timing can impact biological communities. For instance, communities of benthic macroinvertebrates, often used as indicators of health in aquatic systems, shift at the genera and species level in response to changes in precipitation and temperature (Lawrence et al. 2010). The impact of these two factors is often difficult to separate, given that they have a strong inverse correlation (i.e., conditions tend to be warm and dry or cool and wet). However, within genera that consistently respond to climate variables, precipitation is more strongly associated with shifts in community composition compared to changes in temperature (Lawrence et al. 2010).

Low streamflows

Variability in annual flow regimes (e.g., high/low flows) is perhaps the most significant driver of dynamics in lotic ecosystems within Mediterranean climate regions (Gasith and Resh 1999; Meffe 1984). In southern California, peak flows and flooding fed by increased precipitation and snowmelt historically occur during winter and spring, while low flows and/or drying occur in summer and fall (Stephenson and Calcarone 1999). During periods of late-summer drought, the upper- and lower-most portions of rivers typically run dry, while some middle portions retain flow due to groundwater discharge (Stephenson and Calcarone 1999).

Over the last 20 years researchers have documented a decline in streamflow volumes throughout California, and peak flows in spring have been occurring earlier in the year (Vicuna and Dracup 2007). Declining streamflow volumes and earlier onset of spring snowmelt and runoff have been attributed to increasing temperatures (Hamlet et al. 2007; Hayhoe et al. 2004; Stewart et al. 2005), as have reduced winter snowfall and snowpack (Knowles et al. 2006; Mote et al. 2005; Vicuna and Dracup 2007). While rivers and streams in southern California are not typically dominated by snowmelt (P. Taber, pers. comm., 2015), snowpack reductions are a significant driver of streamflow declines for much of the western U.S. (Hayhoe et al. 2004; Stewart et al. 2005). This may have indirect implications for rivers and streams in the study region, possibly by forcing increased local water withdrawals because of reductions in the water supply from outside southern California. For instance, reduced snowpack in the Sierra

Nevada is likely to affect the availability of water for the State Water Project (Vulnerability Assessment Reviewers 2015).

Periods of low flow and drying may lead to a contraction of riparian and aquatic habitat, increased salinity, greater isolation of pools and stream reaches, and channel entrenchment due to encroaching vegetation (Gasith and Resh 1999). Macroinvertebrate communities are sensitive to the harsh conditions found in streams with increasingly intermittent flows, and changes in precipitation may drive changes in community composition toward species and genera better adapted to extreme conditions (Lawrence et al. 2010).

Water temperature

Water temperature affects water quality (U.S. EPA 2012), and is determined by a number of factors including air temperature, precipitation, snowmelt, groundwater input, runoff, water depth, flow volume and velocity, riparian shading, and human activity (Poole and Berman 2001; U.S. EPA 2012; Webb et al. 2008). High stream temperatures also affect other aspects of water quality, contributing to decreases in dissolved oxygen (Morrill et al. 2005; Poff et al. 2002) and shifts in microbial communities found in warmer water that may exacerbate the toxicity of pollutants (e.g., bacteria that create methylmercury; Ficke et al. 2007).

In the United States, increases in water temperature over the last century are correlated with rising air temperatures, with the strongest relationships occurring on monthly or decadal scales (Hill et al. 2014; Marion et al. 2014; Webb and Nobilis 2007). Weaker relationships on an annual scale are likely related to variability in precipitation patterns caused by the El Niño Southern Oscillation (ENSO; Webb and Nobilis 2007). Water temperature has increased on a global scale, with the greatest rates of increase occurring in urban areas (Kaushal et al. 2010). This is due in part to reduced riparian cover and the replacement of natural stream bottom communities with engineered stream channels (K. Klose, pers. comm., 2015).

During extreme heat events and/or periods of very low flow or drought, reduced river discharge can contribute to increased water temperature (van Vliet et al. 2011). For instance, a 40% decrease in river discharge may drive an additional 3.8°C increase in water temperature (van Vliet et al. 2011). Historical patterns suggest that warming may affect maximum stream temperatures more than average stream temperatures, creating greater extremes in stream conditions (Marion et al. 2014).

Changes in the temperature of rivers and streams can have a large effect on the distribution and composition of biotic communities (Beakes et al. 2014; Ebersole et al. 2003; Nelson and Palmer 2007; U.S. EPA 2012; Webb et al. 2008). Cool- and cold-water fish are particularly vulnerable to increasing stream temperatures that are typical of sustained periods of low flow conditions (Beechie et al. 2012; Nelson and Palmer 2007). For instance, steelhead (*O. mykiss*) exposed to warmer water temperatures showed decreased rates of maturation and increased rates of smoltification, with repercussions for both anadromous and resident life histories (Sloat and Reeves 2014). Significant variations in water temperature occur within rivers and streams, both along a vertical depth profile and from the headwaters to the mouth (Webb et al.

2008). Patches of cold water created by groundwater influx, shading, and deep pools can offer thermal refugia to coldwater fish (Ebersole et al. 2003; Matthews and Berg 1997).

Sensitivity to disturbance regimes
Habitat experts evaluated river and stream habitats to have low-moderate sensitivity to disturbance regimes,[7] including: wildfire and flooding.[8] Some habitat experts included disease as an additional disturbance regime, which is supported by the scientific literature (Cairns et al. 2005).

Wildfire

Wildfires impact rivers and streams by affecting water quality, sedimentation, light levels, riparian cover, leaf litter input, invertebrate populations, and algal community structure (Cooper et al. 2014; Morrison and Kolden 2015). Wildfires also release nutrient pulses from ash and increase the risk of fire retardants entering rivers and streams, where the ammonia content may lead to fish kills and invertebrate mortality (Cooper et al. 2014; Morrison and Kolden 2015). The impacts of wildfire may be particularly severe when coupled with early spring storms (Morrison and Kolden 2015).

Wildfire may be exacerbated by unnaturally high fuel loads from invasive species such as giant reed (*Arundo donax)* and saltcedar (*Tamarix* spp.), which form dense thickets on stream banks (Brooks et al. 2004). These shrubs can act as ladder fuels, increasing wildfire severity and contributing to the spread of fire into the riparian canopy (Brooks et al. 2004). *Arundo* is also highly flammable and may cause more intense wildfires (Stephenson and Calcarone 1999).

Morrison and Kolden (2015) found that increased erosion during post-fire precipitation events increased phosphorus concentrations in lotic and coastal ecosystems by 161%, and total suspended solids by 53%. The loss of riparian vegetation following a fire is also associated with an increase in stream temperature (Beakes et al. 2014; Cooper et al. 2014). This increase, along with increases in light levels (due to decreased shading), sediment loading, and altered nutrient regimes, can increase algal communities and invertebrate biomass, altering stream food webs (Cooper et al. 2014; Klose et al. 2015). Hypoxic or anoxic conditions are also more likely to occur following a wildfire, further altering the structure and function of the system (J. Weigand, pers. comm., 2015).

Flooding

Floods and high-flow events are an important part of the disturbance regime for rivers and streams in southern California. In addition to providing water to maintain flow, intermittent flooding may restore successional cycles for riparian and aquatic biota by scouring accumulated sediment and redistributing streambed and bank substrate and organic matter (Gasith and

[7] Confidence: Moderate
[8] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

Resh 1999). Periods of high flow restore channel connectivity, homogenize water quality, and alter channel morphology (Gasith and Resh 1999).

Brief, intense storms can cause very rapid rises and falls in streamflow, and this ‘flashy’ hydrology is most common in small, high-gradient systems with steep banks (Gasith and Resh 1999). Desert streams, which typically descend from mountainous areas and are constrained within high canyons, are particularly prone to flash floods, which are exacerbated in deserts by the lack of vegetation to absorb water (Gasith and Resh 1999). Flash floods can be associated with mudslides and debris flows, and can cause extensive damage in developed areas (Carpenter et al. 2007). More frequent floods also increase the amount of silt and pollutants in rivers and streams, affecting ecosystem services and biological communities (Poff et al. 2002).

Severe floods, such as those that follow wildfire, can wipe out communities of vertebrates and invertebrates (K. Klose, pers. comm., 2015). However, organisms that are native to regions that experience frequent flow extremes and flooding may be more suited to survival under these conditions, and, in some cases, populations of invasive species may be reduced or removed after a flood (Doubledee et al. 2003; Gamradt and Kats 1996; Meffe 1984). Invertebrates return to affected areas by drifting and/or through terrestrial movement, and diverse invertebrate communities are able to recover through the gradual downstream movement of sediment and the return of complex substrates (K. Klose, pers. comm., 2015). However, vertebrates return to affected areas slowly, and may be extirpated from severely flooded areas (K. Klose, pers. comm., 2015).

Disease

As water temperature increases, fish and invertebrates become more physiologically stressed and susceptible to disease and parasites (Cairns et al. 2005). For instance, black spot disease is more common among trout and salmon during warmer summers, and is seen more frequently in warm main stem rivers, as opposed to cooler tributaries and headwaters (Cairns et al. 2005). Warmer temperatures may also contribute to increased parasites within river and stream systems (Cairns et al. 2005). Parasites may be introduced by invasive species such as the red swamp crayfish (*Procambarus clarkii*), a generalist that is able to thrive in warm water (K. Klose, pers. comm., 2015). Pests and disease may also target riparian vegetation, and loss of cover may decrease shading and reduce stream bank stability (P. Taber, pers. comm., 2015).

Sensitivity and current exposure to non-climate stressors

Habitat experts evaluated river and stream habitats to have moderate-high sensitivity to non-climate stressors[9] and to have an overall moderate-high exposure to these stressors within the study region.[10] Key non-climate stressors identified by habitat experts for river and stream habitats include dams and water diversions and invasive and other problematic species.[11]

[9] Confidence: High
[10] Confidence: High
[11] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

Habitat experts also identified management emphasis on water as a significant additional stressor, and the literature suggests that pollution, groundwater pumping, development, agriculture, grazing, recreation, and transportation corridors also impact rivers and streams heavily (Gasith and Resh 1999; Griggs 2009; Morrison and Kolden 2015; Nelson and Palmer 2007; Nelson et al. 2009; Stephenson and Calcarone 1999; Stromberg et al. 2007).

Dams and water diversions

Most rivers and streams in southern California have been dammed or diverted for water supply and/or flood control at some point along their reaches (Stephenson and Calcarone 1999). Low-elevation sites are particularly susceptible to fragmentation or altered streamflow due to their proximity to population centers (Stephenson and Calcarone 1999). Rivers and streams continue to be developed because of current water shortages, as well as for renewable energy features such as upstream reservoirs that release water during the evening for power generation (P. Taber, pers. comm., 2015).

Dams and diversions cause habitat loss due to a change in the volume, duration, timing, and variability of streamflows (Stephenson and Calcarone 1999). Water releases below dams tend to be high volume/short duration or continuous low volume, and these significantly alter downstream flow regimes (Stephenson and Calcarone 1999). Consequently, sediment transport is reduced, leading to channel entrenchment. Altered flow regimes also favor the establishment and persistence of invasive flora and fauna, reducing the abundance of native species (Stephenson and Calcarone 1999). Vegetative structure in impounded streams is less diverse and much more likely to be dominated by very few species (namely, invasive and drought-tolerant species like *Tamarix*; Stromberg et al. 2007). Decreased flow velocity, low dissolved oxygen, and reduced habitat heterogeneity resulting from lack of sediment and woody debris transport also threaten species such as freshwater mollusks and fish (Beechie et al. 2012; Furnish 2007).

Upstream from dams, reservoirs inundate riparian areas and may eliminate flow regimes entirely. Historically, deep-water ponds or reservoirs were nonexistent in southern California, with the exception of a few natural basins (Stephenson and Calcarone 1999). Native species did not evolve in these environments, and, consequently, invasive species represent the dominant flora and fauna in these areas (Stephenson and Calcarone 1999). Man-made lakes also facilitate the spread of invasive species to adjacent streams and rivers (Stephenson and Calcarone 1999). Finally, engineered structures (e.g., dams, culverts) negatively affect connectivity between stream habitats and fish populations, acting as barriers to migratory species such as steelhead that depend on upstream habitats for spawning and rearing grounds (Beechie et al. 2012; Poff et al. 2002).

Invasive and other problematic species

Invasive species are a major threat to river and stream ecosystems, causing a decline in native flora and fauna and preventing the recovery of endemic and threatened/endangered species (Doubledee et al. 2003; Gamradt and Kats 1996; Klose and Cooper 2012; Stephenson and Calcarone 1999; Riley et al. 2008). Warmer temperatures, reduced high flows, and extended periods of drying are contributing to an increase in invasive species well-suited to these conditions, altering interspecies competition and predation (Gasith and Resh 1999; Doubledee et al. 2003; Klose and Cooper 2012). For example, Doubledee et al. (2003) found that river reaches with reduced flood events harbored high abundances of invasive predatory bullfrogs (*Lithobates catesbeianus*), and lower abundances of the threatened California red-legged frog (*Rana draytonii*). In areas where floods occurred more than once every five years, however, bullfrog mortality was sufficient to allow coexistence between both bullfrogs and red-legged frogs (Doubledee et al. 2003).

Additional invasive wildlife species in southern California rivers and streams can include predatory fish, crustaceans, amphibians, and reptiles, and include green sunfish (*Lepomis cyanellus*), bluegill (*Lepomis macrochirus*), bullfrogs, red swamp crayfish, mosquitofish (*Gambusia affinis*), brown trout (*Salmo trutta*), bass (*Micropterus* spp.), bullheads (*Ameiurus* spp.), red-eared sliders (*Trachemys scripta elegans*), and African clawed frogs (*Xenopus laevis*; Doubledee et al. 2003; Gamradt and Kats 1996; Meffe 1984; Stephenson and Calcarone 1999). These species have varying effects on individual systems, depending on factors such as food availability and trophic cascades (Klose and Cooper 2012).

Invasive plants, such as saltcedar and giant reed, are prolific in riparian areas, transpiring large amounts of soil moisture and lowering the water table (Stephenson and Calcarone 1999). Their effect on native vegetation can be exacerbated under changing climate conditions, including reduced streamflows and increased water temperature (Stephenson and Calcarone 1999). For instance, increased intermittent flows and decreased flooding in the Sonoran Desert was associated with reduced cover, lower species diversity, and shifts in species composition towards drought-tolerant, generalist shrubs such as *Tamarix* (Stromberg et al. 2007). Invasive riparian plants likely contribute to the relatively high abundance of threatened and endangered plants in river and stream habitats (Stephenson and Calcarone 1999).

<u>Pollution</u>

Pollutants are very common in southern California rivers and streams, where they are then transported to coastal areas (Gasith and Resh 1999; Morrison and Kolden 2015). Wildfire and flooding can increase contaminated runoff, resulting in very high levels of sediment, nutrients, and pollutants being washed into waterways (Morrison and Kolden 2015; Poff et al. 2002). For instance, wildfire alters overland flow for at least two to three years following the event, which increases sediment, total suspended solids, and phosphorus running off into rivers and streams (Morrison and Kolden 2015). These components are carried downstream and deposited in coastal environments, where they can affect the structure and function of coastal wetlands and the health of marine wildlife (Morrison and Kolden 2015). Wildfire can also release heavy metals sequestered in terrestrial sediments, either directly through combustion of organic matter or indirectly through accelerated weathering and erosion processes in deforested areas (Odigie 2014). Finally, while frequent and/or severe flooding can introduce significant levels of pollutants into rivers and streams, drought and extended periods of low flow can concentrate toxic substances (Gasith and Resh 1999).

Although point source pollution from sources such as industrial or mining sites has been significantly reduced in recent years, ongoing sources of pollution include agricultural activity and urban stormwater runoff (Poff et al. 2002; Walsh et al. 2005). Non-point source pollution is relatively high in southern California due, in part, to intensive urban development and high population densities (Peterson et al. 1995). Atmospheric deposition of nitrogen is concentrated near urban centers in coastal regions, and decreases on a west to east gradient as winds blow inland (Fenn et al. 2010). In most southern California forests, nitrogen deposition rates over 17 kg per ha/year may cause excess nitrates to leach into streams; in chaparral habitats, this can occur when rates over 10-14 kg per ha/year (Fenn et al. 2010). Over the course of several decades, nitrogen-saturated sites begin to leach nitrates at lower thresholds. Given that nitrogen deposition has already been very high for 60-70 years, it is likely that the threshold of 17 kg per ha/year in forested areas will drop to 13 kg per ha/year in the future (Fenn et al. 2008). Currently, nitrogen deposition rates are particularly high within the San Bernardino Mountains, ranging between 6.1 and 71.1 kg per ha/year at nine test sites (Fenn et al. 2008). Sites along the southern face of the San Gabriel Mountains in the Los Angeles Air Basin have similarly high rates of deposition, as do many other areas within southern California mountain ranges (Fenn et al. 2008).

Warm temperatures can alter the toxicity of pollutants and how they are metabolized, which may increase both sub-lethal effects (e.g., reduced reproductive success) and direct mortality in wildlife (Ficke et al. 2007). For instance, under warm anaerobic conditions, sulfur-reducing bacteria convert inactive mercury contained within sediment to methylmercury, a bioavailable compound that can cause physical, neurological, developmental, reproductive, and behavioral impacts on wildlife (Compeau and Bartha 1985; Wolfe et al. 1998). Additional contaminants of emerging concern include endocrine-disrupting compounds estradiol, estrone, and testosterone (K. Klose, pers. comm., 2015).

Groundwater pumping

Groundwater pumping is one of the primary anthropogenic causes of low streamflow and lowered water tables in the Southwestern United States (Stromberg et al. 2007). Increasing demand for water has also led to high rates of water mining, spring water extraction, and illegal water withdrawals (MacDonald et al. 2008; Stephenson and Calcarone 1999; Vulnerability Assessment Reviewers, pers. comm., 1999). In addition to reducing water supply, groundwater overdraft can cause reductions in water quality, increased land subsidence, and saltwater intrusion into aquifers (California Department of Water Resources 2015).

Development

Development pressure in southern California is extremely high, and streambank terraces are particularly in demand for agriculture and development (Stephenson and Calcarone 1999). Alterations can include the removal of riparian vegetation, channel modification, increased stormwater runoff from paved surfaces, and increased amounts of trash and pollutants in the system (Griggs 2009; Nelson et al. 2009), impacting the health of aquatic systems. Interest in renewable hydropower energy and a growing need for water storage and delivery infrastructure will likely lead to the creation of additional small reservoirs, further impacting lotic systems (P. Taber, pers. comm., 2015).

The impacts of development and urbanization are likely to interact strongly with climate change, exacerbating the effects of both factors (Nelson et al. 2009). For instance, increased storms and heavy precipitation events could create large amounts of runoff and manufactured debris, while increased development could create a greater amount of impervious surface to absorb heat and rapidly channel the warmed water into streams, increasing stream temperature and flow velocity (Nelson and Palmer 2007).

Agriculture and grazing

Agriculture is a primary stressor for many rivers and streams. Livestock grazing may also be an issue in some watersheds, although this practice has been reduced in many areas of the region (Griggs 2009; D. Jacobs, pers. comm., 2015). Agriculture and grazing activities may increase runoff and introduce large amounts of nutrients and sediment into systems (Griggs 2009). Grazing livestock may also compact soils and trample sensitive riparian vegetation, leading to the loss of vegetative cover and increased erosion (Griggs 2009). Water contamination can occur when nutrients and bacteria are introduced through the feces and urine of livestock (Craun et al. 2005; K. Klose, pers. comm., 2015). Eutrophication in rivers and streams resulting from agricultural and grazing practices may have additional impacts on water quality (e.g., reducing dissolved oxygen) and may lead to the loss of species diversity and shifts in community composition (Ficke et al. 2007; Poff et al. 2002).

Recreation

Water and riparian resources are very attractive for recreational use in southern California, and many parks and campgrounds are located in these areas (Stephenson and Calcarone 1999). The use of rivers and streams for recreation may lead to construction of additional dams (K. Klose, pers. comm., 2015), and lagoons may be breached in coastal areas, negatively affecting the lower reaches of streams (D. Jacobs, pers. comm., 2015). High recreational use may also increase bacterial densities (e.g., *E. coli*; Craun et al. 2005). Illegal recreational use of riparian habitats, including the use of unpermitted sites for RV and off-highway vehicle use and the creation of new hiking paths, may increase erosion and sedimentation, while the illegal impoundment of water for recreational activities may alter water flow patterns (L. Jurkevics, pers. comm., 2015). Although regulated activities such as hunting, trapping, and fishing are generally less harmful than unregulated activities (D. Jacobs, pers. comm., 2015), fishing can further stress populations of threatened and endangered species, and in some areas poachers have already extirpated these species (K. Klose, pers. comm., 2015).

Transportation corridors

The construction and use of roads, highways, and trails impacts almost all streams and rivers, as well as sensitive riparian habitats and associated wetlands (Stephenson and Calcarone 1999; Vulnerability Assessment Reviewers, pers. comm., 2015). The heaviest use of rivers and streams is often concentrated around roads, and many transportation corridors are associated with bridges and stream crossings, which may alter normal flow regimes and sedimentation processes and limit aquatic connectivity for species dispersal and migration (Stephenson and Calcarone 1999). Roads may also be associated with direct wildlife mortality (Stephenson and Calcarone 1999); this can be a particularly large concern near streams and riparian areas, where slow-moving reptiles and amphibians frequently cross roads (Stephenson and Calcarone 1999).

Future Climate Exposure

Habitat experts evaluated river and stream habitats to have moderate exposure to future climate and climate-driven changes,[12] and key climate variables to consider include: altered streamflows, changes in precipitation, increased air temperature, and decreased soil moisture (Table 1).[13] For a detailed overview of how these factors are projected to change in the future, please see the Southern California Climate Overview (http://ecoadapt.org/programs/adaptation-consultations/socal).

Higher-elevation sites may be less affected by factors such as increased temperature and drought (P. Taber, pers. comm., 2015). The presence of riparian vegetation also affects water temperature and microclimate characteristics that influence habitat suitability for wildlife (Seavy et al. 2009). Thermal refugia may occur in rivers and streams, especially near seeps and springs, shaded areas, and deep pools that can offer shelter for cool- and cold-water organisms (Ebersole et al. 2003; Matthews and Berg 1997; Webb et al. 2008). However, rivers and streams are, by nature, connected, and upstream changes in streamflow are likely to affect the ecosystem, regardless of local conditions.

Table 1. Anticipated response of river and stream habitats to climate and climate-driven changes.

Climate and climate-driven changes	Anticipated river and stream habitat response
Precipitation and drought *Variable annual precipitation volume and timing; longer, more severe droughts with drought years twice as likely to occur*	• Decreased flow volumes and prolonged duration of low- and no-flow conditions • Altered stream morphology and habitat complexity • Reduced water availability for riparian vegetation and corresponding increase in drought-tolerant shrubs such as *Tamarix* spp. • Shifts in the composition of macroinvertebrate communities, primarily at the genera and species level
Low streamflows *More extreme low flows and increased duration of low- or no-flow conditions*	• Reduced water quality, including increased salinity and/or alkalinity and increased concentrations of pollutants • Increased water temperature and associated declines in cool- and cold-water aquatic species • Altered channel structure due to sediment and

[12] Confidence: High
[13] Factors presented are those ranked highest by habitat experts. A full list of evaluated factors can be found at the end of this document.

	vegetation encroachment • Increased isolation of pools and stream reaches • Decreased extent of riparian and aquatic habitats • Shifts in the composition of macroinvertebrate communities
Water temperature *Increase of 2-3°C in the United States by 2100 (local conditions may vary)*	• Reduced water quality, including low dissolved oxygen • Increased toxicity of pollutants • Loss of stream habitat complexity, including loss of thermal refugia • Expanding distributions of warmwater species and contraction of coldwater species • Reduced spawning and rearing grounds for native fish • Changes in metabolic requirements, growth rate, and other physical processes of aquatic organisms (e.g., fish)
Wildfire *Increased fire size, frequency, and severity*	• Increased concentrations of ammonium, nitrate, dissolved organic nitrogen, phosphate, sediment, and total suspended solids • Reduced riparian canopy and increased water temperature due to loss of shade • Increased occurrence of hypoxic/anoxic conditions • Altered composition of macroinvertebrate communities, including reductions in detritivores and shredders and increases in algivores • Altered structure and function of food web • Possible extirpation of local fish populations
Flooding *30-40% increase in flash floods in small river/stream basins*	• Increased flash floods, mudslides, debris flows, and extended damage • Increased erosion, with episodes of more powerful sediment scour and transport • Increased pollutants washed into streams • Changes in riparian vegetation, including species composition, distribution, and loss • Extirpation of local populations of vertebrates and invertebrates (including invasive species) • Altered structure and function of food web

Streamflow projections in the Colorado River Basin suggest that water availability will likely decrease over the coming century due to multiple hydrological factors including snowpack, runoff, soil moisture, and evapotranspiration, among others (Christensen and Lettenmaier 2007; Ficklin et al. 2013. Under climate scenarios predicting decreased precipitation, these factors contributed to even greater decreases in water yield (Ficklin et al. 2013). Furthermore, precipitation increases did not create comparable changes in water yield due to the increased evapotranspiration and decreased snowpack associated with warming temperatures (Ficklin et al. 2013). In the future, annual low flow volumes are projected to decrease and the frequency of low-flow/no-flow periods is expected to increase, resulting in extended summer drought periods (Perry et al. 2012). Flash floods are projected to increase 30-40% by the end of the 21st century, due to less frequent but more extreme precipitation events in the study region (Modrick and Georgakakos 2015).

In the United States, stream temperatures are expected to increase 2-3°C by the end of the century (Hill et al. 2014; Morrill et al. 2005), roughly corresponding to a 0.6-0.8°C increase in water temperature for every 1°C in air temperature (Morrill et al. 2005). However, factors such as flow volume and urbanization can strongly influence water temperature at the watershed scale (Nelson and Palmer 2007; Poole and Berman 2001; van Vliet et al. 2011; Webb et al. 2008).

Researchers anticipate a shift of cool- and coldwater species (particularly fish) upward in elevation and northward in latitude (Nelson and Palmer 2007). Warmwater species will likely outcompete and displace cool- and coldwater species in areas close to declining species' critical thermal maximum (Nelson and Palmer 2007). An east to west shift in species distribution may also occur, as Mediterranean-climate vegetation contracts coastward in forests that border the driest environments (e.g., San Gabriel, San Bernardino, deserts; J. Weigand, pers. comm., 2015).

Adaptive Capacity

The overall adaptive capacity of and stream habitats was evaluated to be moderate by habitat experts.[14]

Habitat extent, integrity, continuity and landscape permeability
Habitat experts evaluated river and stream habitats to have moderate-high geographic extent (i.e. habitat occurs across state[s]),[15] low integrity (i.e. habitat is degraded),[16] and feature moderate continuity (i.e. patches with connectivity between them).[17] Habitat experts identified dams and water diversions as the primary barrier to habitat continuity and dispersal in river and stream habitats. Some habitat experts also identified land-use conversion, agriculture, transportation corridors, and energy production and mining as additional barriers.[18]

Aquatic ecosystems have become highly degraded as a result of alterations in streamflow coupled with anthropogenic stressors (Stephenson and Calcarone 1999). Habitat loss in

[14] Confidence: High
[15] Confidence: High
[16] Confidence: High
[17] Confidence: High
[18] Barriers presented are those ranked most critical by habitat experts (not all habitat experts agreed on these barriers). A full list of evaluated barriers can be found at the end of this document.

southern California rivers and streams has been extensive, and may be one of the most disturbed habitats within the study region, especially in lower elevations (Stephenson and Calcarone 1999). Almost all major streams originating in southern California mountains have had dams or diversions placed at some point along their reaches (Stephenson and Calcarone 1999).

Resistance and recovery

Habitat experts evaluated river and stream habitats to have low resistance to climate stressors and maladaptive human responses,[19] and moderate recovery potential.[20]

Southern California rivers and streams are well-adapted to variable conditions and flow regimes, and systems recover quickly from extreme conditions within the natural range of variability (P. Taber, pers. comm., 2015). Native plants can be used to restore riparian areas in a relatively short time frame, and native wildlife will readily recolonize these areas (Seavy et al. 2009). However, native plants may not be able to withstand increasingly powerful or frequent flash floods, despite their adaptations to fill this niche (J. Weigand, pers. comm., 2015). In addition, high population densities and development/recreation pressure around rivers and streams may slow natural recovery of these systems (R. Taylor, pers. comm., 2015). Eventually all aquatic organisms are likely to be impacted by changes in the quality and extent of available habitat, with fish, amphibians, and aquatic insects likely to respond most rapidly (R. Mazor, pers. comm., 2015).

Habitat diversity

Habitat experts evaluated river and stream habitats to have high physical and topographical diversity,[21] moderate component species diversity,[22] and moderate functional group diversity.[23]

Rivers and streams are some of the most diverse habitat types in California, playing a large part in harboring 3,906 plants and animals dependent on freshwater systems at some point within their lifecycle (Howard et al. 2015). Nearly a quarter of these are endemic to the state, and most of these are at risk of extinction (90%) – a percentage much higher than the overall number of species at risk (48%). However, many species have not yet been evaluated for extinction risk (including 69% of invertebrates), and only 6% of at-risk species have been given federal or state protection (Howard et al. 2015). Many threatened or endangered species are found at lower elevations, probably due to the greater anthropogenic stressors faced in more populated areas (Stephenson and Calcarone 1999). Rivers and streams also support a wide range of terrestrial birds, mammals, and amphibians because they are adjacent to a variety of terrestrial habitats (Grenfell 1988).

[19] Confidence: High
[20] Confidence: Moderate
[21] Confidence: High
[22] Confidence: High
[23] Confidence: High

Healthy rivers and streams have high structural diversity, with variable flows and heterogeneous site conditions based on factors such as gradient, substrate, water quality, temperature, and frequent disturbance (Gasith and Resh 1999; Grenfell 1988). In fast-moving stream sections characterized by riffles, common associates include water moss, filamentous algae, invertebrates such as mayflies (*Ephemeroptera*), caddisflies (*Trichoptera*), alderflies (*Sialidae*), and stoneflies (*Plecoptera*), and temperature-appropriate fish species (Grenfell 1988). In areas with slow-moving currents, mollusks and crustaceans can be found along with emergent bank vegetation (Grenfell 1988). High seasonal and inter-annual variation in discharge and nutrient fluxes can foster high accumulations of algae during the dry season, generating nuisance algal blooms (e.g., *Cladophora*) and ultimately leading to reduced concentrations of dissolved oxygen (Klose et al. 2012).

Several aquatic and riparian species are considered at-risk in southern California river and stream habitats, including steelhead, arroyo toads (*Anaxyrus californicus*), and red-legged frogs (K. Klose, pers. comm., 2015). These species are particularly sensitive to several aspects of the habitat likely to be affected by climate change, including water temperature and dissolved oxygen. Benthic macroinvertebrates, including mayflies, stoneflies, and caddisflies, are also sensitive to changes in water quality, and are often considered indicator species for the health of aquatic systems (P. Taber, pers. comm., 2015). Documented shifts in the composition of macroinvertebrate communities can occur in response to changing temperature and precipitation, with most changes occurring at the genus and species level (Lawrence et al. 2010).

Management potential

Habitat experts evaluated river and stream habitats to be of high societal value.[24] Rivers and streams are valued for camping and other recreational activities and as a water source for agriculture and human consumption, and they are heavily used for these purposes (Vulnerability Assessment Reviewers, pers. comm., 2015). River and stream habitats provide a variety of ecosystem services, including: biodiversity, flood and erosion protection, water supply/quality/sediment transport, recreation, grazing, carbon sequestration, air quality, nitrogen retention, fire regime controls, and public health (Vulnerability Assessment Reviewers, pers. comm., 2015). California Water Boards have designated 20 beneficial uses for waterbodies, which document the value of services provided by each waterbody in the region (e.g., California Regional Water Quality Control Board, Santa Ana Region 1995). Examples of these include recreation, municipal supply, groundwater recharge, and wildlife habitat, among others.

Habitat experts identified that there is moderate potential for managing or alleviating climate impacts in river and stream habitats.[25] While management has the potential to reduce the impact of both climate and non-climate stressors (R. Mazor, pers. comm., 2015), habitat experts commented that effective actions will depend largely on the direction and rate of

[24] Confidence: High
[25] Confidence: Moderate

climate changes. Habitat experts identified the following actions as potential management options for river and stream habitats:

- Reduce engineered channels and hard infrastructure, as addressed in the Los Angeles River Revitalization project. This and similar projects will help to restore the complex structure and function of lotic ecosystems, in part by reducing impermeable surfaces (e.g., concrete) that reduce groundwater recharge and decrease floodplain inundation and organic matter exchange. Although most local, state and federal agencies understand the importance of restoring degraded streams, an increasing demand for municipal and agricultural water use may make it more difficult to garner support for these restoration projects (K. Klose, pers. comm., 2015).
- Communicate information about flagship species that may benefit from management actions (e.g., steelhead); this could draw interest in recreational fisheries and aid in the prioritization of stream restoration (K. Klose, pers. comm., 2015).
- Implement restoration activities such as removing dams and impoundments to restore stream connectivity and natural flow regimes, control invasive plants and wildlife, and establish or expand riparian buffers that provide shade (Doubledee et al. 2003; Griggs 2009; Stromberg et al. 2007; Seavy et al. 2009). These activities would help to reduce water temperature, decrease sediment loading, and provide wildlife habitat and corridors for movement.
- Encourage sustainable management of groundwater (California Department of Water Resources 2015). The State of California recently passed the Sustainable Groundwater Management Act, which requires basin prioritization, the development of Best Management Practices, regulation of groundwater withdrawals, and data collection and monitoring efforts (California Department of Water Resources 2015). Groundwater must now be managed sustainably in all basins determined to be at medium or high risk of significant economic, social, and environmental impacts of groundwater extraction. If extraction exceeds recharge capability, changes to extraction will be required. The Act does not apply, however, to basins that have been adjudicated or are already sustainably managed (K. Klose, pers. comm., 2015; California Department of Water Resources 2015).
- Create land/watershed management plans and habitat recovery plans that consider climate change impacts on focal resources and ecosystem services (Blickenstaff et al. 2013; Griggs 2009; Seavy et al. 2009).

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Rivers and Streams – Overview of Vulnerability Component Evaluations

Overall Vulnerability Ranking:[1] **3 Moderate** **Overall Confidence:**[2] **3 High**

SENSITIVITY

Sensitivity Factor[3]	Sensitivity Evaluation[4]	Confidence[4]
Sensitivities to Climate & Climate-Driven Factors	**Overall: 3 Moderate**	**Overall: 2 Moderate**
• *Precipitation*	• 5 High	• 3 High
• *Extreme events: drought*	• 4 Moderate-High	• 2 Moderate
• *Low stream flows*	• 4 Moderate-High	• 3 High
• *Snowpack depth*	• 3 Moderate	• 2 Moderate
• *Timing of snowmelt & runoff*	• 3 Moderate	• 2 Moderate
• *Soil moisture*	• 3 Moderate	• 2 Moderate
• *Air temperature*	• 3 Moderate	• 3 High
• High lentic/lotic temperature[5]	• 5 High	• 3 High
• Extreme events: high temperature[5]	• 5 High	• 2 Moderate
• Extreme events: low temperature[5]	• 1 Low	• 2 Moderate
• Other (dissolved oxygen)[6]	• 3 Moderate	• No answer given
Disturbance Regimes	**Overall: 2 Low-Moderate**	**Overall: 2 Moderate**
• *Wildfire*	• 5 High	• 3 High
• *Flooding*	• 4 Moderate-High	• 3 High
• *Disease*	• 2 Low-Moderate	• 2 Moderate
• *Insects*	• 1 Low	• 1 Low
• Wind[5]	• 1 Low	• 1 Low
Non-Climate Stressors – Degree Stressor Affects Sensitivity	**Overall: 4 Moderate-High**	**Overall: 3 High**
• *Dams & water diversions*	• 5 High	• 3 High
• *Invasive & other problematic species*	• 4 Moderate-High	• 2 Moderate
• Agriculture & aquaculture[5]	• 5 High	• 3 High
• Land use conversion[5]	• 5 High	• 3 High
• Livestock grazing[5]	• 4 Moderate-High	• 3 High
• Recreation[5]	• 3 Moderate	• 2 Moderate
• Fire suppression practices[5]	• 3 Moderate	• 2 Moderate
• Pollution & poisons[5]	• 3 Moderate	• 2 Moderate

[1] Overall vulnerability is calculated according to the following formula: Vulnerability = Sensitivity * (0.5*Exposure) - Adaptive Capacity.
[2] Overall confidence is an average of the overall averaged confidences for sensitivity, exposure, and adaptive capacity.
[3] Factors with expert consensus are *italicized*; all other factors indicate the percentage of experts who identified that factor as important to consider for the habitat.
[4] Scores presented reflect an average of all scores given by habitat experts for a given factor.
[5] Identified by 75% of habitat experts.
[6] Identified by 25% of habitat experts.

Sensitivity Factor[3]	Sensitivity Evaluation[4]	Confidence[4]
• Hunting, trapping & fishing[5] • Energy production & mining[7] • Transportation corridors[7] • Timber & wood harvesting[7] • Other (type conversion of lagoons to tidal systems)[6]	• 3 Moderate • 5 High • 5 High • 4 Moderate-High • 5 High	• 2 Moderate • 3 High • 3 High • 2 Moderate • 3 High
Non-Climate Stressors – Current Exposure to Stressor • *Dams & water diversions* • *Invasive & other problematic species* • Agriculture & aquaculture[5] • Land use conversion[5] • Livestock grazing[5] • Recreation[5] • Fire suppression practices[5] • Pollution & poisons[5] • Hunting, trapping & fishing[5] • Energy production & mining[7] • Transportation corridors[7] • Timber & wood harvesting[7] • Other (type conversion of lagoons to tidal systems)[6]	**Overall: 4 Moderate-High** • 5 High • 4 Moderate-High • 4 Moderate-High • 5 High • 3 Moderate • 3 Moderate • 3 Moderate • 3 Moderate • 2 Low-Moderate • 3 Moderate • 5 High • 1 Low • 5 High	**Overall: 2 Moderate** • 3 High • 3 High • 2 Moderate • 3 High • 2 Moderate • 2 Moderate • 2 Moderate • 2 Moderate • 2 Moderate • 2 Moderate • 3 High • 2 Moderate • 3 High
Other Sensitivities: • Management emphasis on water reuse, new dams, groundwater pumping, etc.	**Overall: 5 High** • 5 High	**Overall: 3 High** • 3 High

Overall Averaged Ranking (Sensitivity):[8] 4 Moderate-High

Overall Averaged Confidence (Sensitivity):[9] 3 High

EXPOSURE

Exposure Factor[3]	Exposure Evaluation[4]	Confidence[4]
Future Climate Exposure Factors • *Altered stream flows* • *Changes in precipitation* • *Increased air temperature* • *Decreased soil moisture* • Increased lentic/lotic temperatures[5] • Extreme events: increased drought[5]	**Overall: 3 Moderate** • 5 High • 5 High • 4 Moderate-High • 3 Moderate • 5 High • 5 High	**Overall: 3 High** • 3 High • 3 High • 2 Moderate • 2 Moderate • 3 High • 3 High

[7] Identified by 50% of habitat experts.

[8] Overall averaged ranking is an average of the sensitivity, adaptive capacity, or exposure evaluation columns above.

[9] Overall averaged confidence is an average of the confidence column for sensitivity, adaptive capacity, or exposure.

Exposure Factor[3]	Exposure Evaluation[4]	Confidence[4]
• Increased wildfire[5] • Extreme events: high temperatures[5] • Extreme events: high flows & runoff[5] • Decreased snowpack[5] • Earlier snowmelt & runoff[5] • Extreme events: low temperatures[5]	• 4 Moderate-High • 4 Moderate-High • 3 Moderate • 3 Moderate • 3 Moderate • 1 Low	• 3 High • 2 Moderate • 2 Moderate • 2 Moderate • 2 Moderate • 2 Moderate

Overall Averaged Ranking (Exposure):[8] 3 Moderate

Overall Averaged Confidence (Exposure):[9] 3 High

ADAPTIVE CAPACITY

Adaptive Capacity Factor	Adaptive Capacity Evaluation[4]	Confidence[4]
Habitat Extent, Integrity & Continuity • Geographic Extent • Structural & Functional Integrity • Habitat Continuity	**Overall: 3 Moderate** • 4 Moderate-High (Occurs across state) • 1 Low (Degraded) • 3 Moderate (Patches with connectivity between them)	**Overall: 3 High** • 3 High • 3 High • 3 High
Landscape Permeability[3] Key barriers: • *Dams & water diversions* • Land use conversion[5] • Agriculture[5] • Transportation corridors[5] • Energy production & mining[5] • Timber harvest & clear cuts[5] • Grazing[5] • Geologic features[7] • Other (groundwater pumping)[6]	**Overall: 2 Low-Moderate** Impact on landscape permeability: • High • High • High • Moderate-High • Moderate • Low-Moderate • Low-Moderate • High • High	**Overall: 3 High** • 3 High • 3 High • 3 High • 2 Moderate • 2 Moderate • 2 Moderate • 2 Moderate • 3 High • 3 High
Habitat Resistance & Recovery • Resistance • Recovery	**Overall: 2 Low-Moderate** • 1 Low • 3 Moderate	**Overall: 2 Moderate** • 3 High • 2 Moderate
Habitat Diversity • Physical/Topographical Diversity • Component Species Diversity • Functional Group Diversity	**Overall: 4 Moderate-High** • 5 High • 3 Moderate • 3 Moderate	**Overall: 3 High** • 3 High • 3 High • 3 High
Management Potential • Habitat Value • Likelihood of Managing or Alleviating Climate Impacts	**Overall: 4 Moderate-High** • 5 High • 3 Moderate	**Overall: 2 Moderate** • 3 High • 2 Moderate
Other Adaptive Capacities: None identified	N/A	N/A

Overall Averaged Ranking (Adaptive Capacity):[8] 3 Moderate

Overall Averaged Confidence (Adaptive Capacity):[9] **3 High**