Central Valley Landscape Conservation Project

Climate Change Vulnerability Assessment (January 2017 version)

Stream Channels

Vulnerability Assessment Summary

Overall Vulnerability Score and Components:

Vulnerability Component	Score
Sensitivity	High
Exposure	High
Adaptive Capacity	Low-moderate
Vulnerability	**High**

Overall vulnerability of stream channels was scored as high. The score is the result of high sensitivity, high future exposure, and low-moderate adaptive capacity scores.

Key climate factors for stream channels include altered streamflow regimes, warming water temperatures, increased storms, changes to the amount and timing of precipitation, and earlier snowmelt and runoff. For example, precipitation changes affect streamflow volume and velocity, which can subsequently affect channel topography and substrate. Reduced snowpack and earlier and faster snowmelt could lead to decreases in mean annual flow and warmer stream temperatures especially during the summer months.

Key non-climate factors for stream channel habitats include dams, levees, and water diversions, groundwater overdraft, land use change, and agricultural and rangeland practices. These non-climate factors will likely interact with climate factors and disturbances, potentially resulting in streambed degradation and reduced aquatic habitat quality and biota.

Streams are sensitive to changes in disturbance regimes such as wildfire, flooding, and changes to sedimentation. More frequent and severe fires may burn more streamside vegetation and lead to warmer stream temperatures and change the pH of aquatic systems. Increased frequency and magnitude of floods could also result in stream bank scouring and the removal of riparian vegetation. Increased sediment delivery following a flood can affect concentrations of contaminants and potentially the abundance of disease-bearing organisms in streams.

Management potential for stream channel habitats was scored as moderate. The Sacramento and San Joaquin Rivers are unique in regards to the continuity of stream habitats, which has large implications for the structural and functional integrity of streams. Instream flows for channel maintenance and habitat creation are dependent on sufficient magnitude and duration of winter and spring flows. Flood control and water storage projects on both rivers have promoted urban and agricultural development and have led to stream channelization. Dams, levees, and water diversions can make streams homogenous with negative impacts to connectivity for biodiversity. Flow regulation has reduced the natural spatial and temporal variability of floods, thereby impeding sediment movement. These structures also break up the connectivity of stream systems and prevent some species from migrating. However, there is significant management potential for conserving habitat and restoring stream processes and functions.

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Introduction

Description of Priority Natural Resource

Streams and rivers support a wide range of social, cultural, and ecological values, including plant and wildlife diversity, water quality, water quantity, cultural values, aesthetic values, agricultural and urban uses, fishing, and tourism (Hunsaker et al. 2014a).

As part of the Central Valley Landscape Conservation Project, workshop participants identified stream channels as a Priority Natural Resource for the Central Valley Landscape Conservation Project in a process that involved two steps: 1) gathering information about the habitat's management importance as indicated by its priority in existing conservation plans and lists, and 2) a workshop with stakeholders to identify the final list of Priority Natural Resources, which includes habitats, species groups, and species.

The rationale for choosing stream channels as a Priority Natural Resource included the following: the habitat has high management importance, and because the habitat is important for fish and fish passage. Please see Appendix A: "Priority Natural Resource Selection Methodology" for more information.

Vulnerability Assessment Methodology

During a two-day workshop in October of 2015, 30 experts representing 16 Central Valley resource management organizations assessed the vulnerability of priority natural resources to changes in climate and non-climate factors, and identified the likely resulting pressures, stresses, and benefits (see Appendix B: "Glossary" for terms used in this report). The expert opinions provided by these participants are referenced throughout this document with an endnote indicating its source[1]. To the extent possible, scientific literature was sought out to support expert opinion garnered at the workshop. Literature searches were conducted for factors and resulting pressures that were rated as high or moderate-high, and all pressures, stresses, and benefits identified in the workshop are included in this report. For more information about the vulnerability assessment methodology, please see Appendix C: "Vulnerability Assessment Methods and Application." Projections of climate and non-climate change for the region were researched and are summarized in Appendix D: "Overview of Projected Future Changes in the California Central Valley".

Vulnerability Assessment Details

Climate Factors

Workshop participants scored the resource's sensitivity to climate factors and this score was used to calculate overall sensitivity. Future exposure to climate factors was scored and the overall exposure score used to calculate climate change vulnerability.

Climate Factor	Sensitivity	Future Exposure
Altered stream flow	High	High
Extreme events: drought	-	High
Extreme events: storms	High	-
Increased flooding	-	High
Increased wildfire	-	Moderate
Precipitation (amount)	Moderate-high	High
Precipitation (timing)	Moderate-high	High
Timing of snowmelt/runoff	Moderate-high	High
Water temperature	High	High
Overall Scores	**High**	**High**

Streamflow

Sensitivity: *High (high confidence)*
Future exposure: *High (high confidence)*

Extremely dry periods may occur more frequently over the next century, especially in the San Joaquin Valley (Null et al. 2013). Streamflow will likely be impacted by reduced snowpack and more rapid snowmelt runoff, which could manifest in decreases in mean annual flow, especially during the summer months (Knowles & Cayan 2002; Miller et al. 2003; Medellín-Azuara et al. 2007; Vicuna et al. 2008). Total annual water year runoff has increased for the Sacramento River basins and decreased for the San Joaquin River basins, but both areas experienced decreases in spring runoff (April-July), which declined by 9% for the Sacramento River basins and declined by 7% for the San Joaquin River basins in the 20th century; these trends may continue through 2050 (Hunsaker et al. 2014b). Stream discharge is also projected to increase by 30–90% for the Northern Sierra Nevada and 50–100% for Southern Sierra by end of century (Das et al. 2013).

Stream channels are highly sensitive to changes in flow regimes, which drive sediment transport, channel migration, floodplain access or accretion, the development of riparian zones, and instream bedload quality (Poff et al. 1997; Stromberg et al. 2007; Perry et al. 2012; Wohl et al. 2015). Changes in precipitation impact flow volume and velocity (Meyers et al. 2010), which influences channel topography and substrate (Yarnell et al. 2010) and impacts stream habitat for invertebrates, fish, amphibians, and reptiles (Meyers et al. 2010). Drier conditions could cause some streams to transition from perennial to intermittent or even to ephemeral channels, drastically reducing habitat suitability for species that are dependent on streamflow (Myrick & Cech 2004). Adequate flow volume is important for stream channel connectivity, allowing sediments and biological material to move downstream (Yarnell et al. 2015). Streamflow can be a surrogate for water quality conditions if it is protected from heating/pollutants[1].

Water temperature

Sensitivity: *High (high confidence)*
Future exposure: *High (high confidence)*

Streams on the west slopes of the Sierra Nevada at middle elevations are extremely sensitive to warming temperatures (Null et al. 2013), and water temperatures may increase by 1.6°C for each 2°C rise in air temperature, with most of the warming occurring during the spring months (Null et al. 2013). Reduced snowpack and earlier timing of peak flows may affect stream temperatures by reducing flow volume (Yarnell et al. 2010).

Stream temperatures have a direct influence on dissolved oxygen levels, nutrient cycling, productivity, and the metabolic rates and life histories of aquatic organisms (Vannote & Sweeney 1980; Poole & Berman 2001). Warmer water temperatures also affect the distribution and abundance of organisms, leading to local extinctions for species with low thermal thresholds (e.g., salmonids), and potentially facilitating the introduction of invasive species (Eaton & Scheller 1996; Moyle 2002; Hari et al. 2006; Rahel & Olden 2008).

Storms

Sensitivity: *High (high confidence)*

More intense winter rainstorms could result in more flooding (Vivoni et al. 2009).

Stream channels are sensitive to extreme precipitation events that occur within Central Valley, as well as those that occur at high elevations at higher points of the watershed. In semiarid and arid areas, where most recharge occurs through dry streambeds after heavy rainfalls and floods, increased extreme precipitation events could increase groundwater recharge (Karl et al. 2009).

Precipitation (amount)

Sensitivity: *Moderate-high (moderate confidence)*
Future exposure: *High (high confidence)*

Although precipitation models for California are highly uncertain, some projections suggest that annual precipitation will remain quite variable over the next century, and may increase slightly in the Sacramento River Basin and decrease slightly in the San Joaquin River Basin by 2050

(Bureau of Reclamation 2015), and precipitation extremes may increase (Toreti et al. 2013). There has been a slight trend towards decreased and more variable precipitation in central and southern California over the last 100 years (Hunsaker et al. 2014a).

The frequency, magnitude, and nature of precipitation events directly affect stream hydrology and geomorphology by altering streamflow and potentially causing floods and associated scouring (Meyers et al. 2010; Null et al. 2013). Increased precipitation amounts, especially in the form of rain instead of snow, could lead to substantial changes in stream morphology, channel location, sediment movement, and bank stability (Yarnell et al. 2010; Null et al. 2013).

Precipitation (timing)

> ***Sensitivity:*** *Moderate-high (moderate confidence)*
> ***Future exposure:*** *High (high confidence)*

Increased intensity and frequency of winter rainfall would be likely to result in “quick pulses” in streamflow and more scouring of stream substrate (Yarnell et al. 2010). Increased rain-on-snow events may translate into high winter flows and more flashy hydrographs (Hamlet & Lettenmaier 2007).

Timing of snowmelt & runoff

> ***Sensitivity:*** *Moderate-high (moderate confidence)*
> ***Future exposure:*** *High (high confidence)*

Warmer temperatures and reduced snowpack may contribute to earlier snowmelt and timing of peak spring runoff, which may decrease the magnitude of streamflow at the start of the snowmelt recession (Yarnell et al. 2010). This would likely shorten the duration of cold water within the system and contribute to a longer period of low summer flow, which could shift the species composition of amphibians and fish and potentially facilitate an increase in invasive species (Marchetti & Moyle 2001).

Although earlier snowmelt may lead to higher peak flows in many cases, drastically reduced snowpack may ultimately lower the magnitude of spring flows.

Drought

> ***Future exposure:*** *High (high confidence)*

Over the coming century, the frequency and severity of drought is expected to increase due to climate change (Hayhoe et al. 2004; Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015), as warming temperatures exacerbate dry conditions in years with low precipitation, causing more severe droughts than have previously been observed (Cook et al. 2015; Diffenbaugh et al. 2015). Regardless of changes in precipitation, warmer temperatures are expected to increase evapotranspiration and cause drier conditions (Cook et al. 2015). Recent studies have found that anthropogenic warming has substantially increased the overall likelihood of extreme California droughts, including decadal and multi-decadal events (Cook et al. 2015; Diffenbaugh et al. 2015; Williams et al. 2015).

Non-Climate Factors

Workshop participants scored the resource's sensitivity and current exposure to non-climate factors, and these scores were then used to assess their impact on climate change sensitivity.

Non-Climate Factor	Sensitivity	Current Exposure
Agriculture & rangeland practices	Moderate-high	High
Dams, levees, & water diversions	High	High
Groundwater overdraft	High	High
Land use change	High	High
Urban/suburban development	Moderate	High
Overall Scores	**High**	**High**

Dams, levees, & water diversions

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape.*

Dams, levees and water diversions for agriculture and other human uses directly impact streamflow by limiting flow variability and creating a deficit or surplus sediment, which creates more homogenous river morphology and negatively impacts biodiversity (Moyle & Mount 2007; Wohl et al. 2015). For instance, upstream sediment supply is often trapped behind dams in regulated rivers, creating sediment deficits downstream (Yarnell et al. 2015). Water releases that do not contain enough sediment may cause extreme stream scour and bed degradation during downstream flooding (Grams et al. 2007). By contrast, sediment may over-accumulate in some regulated rivers that have large sediment inputs from unregulated tributaries, or where flow is not strong enough to flush sediment because of diversions (Yarnell et al. 2015). Nevertheless, it is generally agreed that floods of short duration are insufficient to transport large volumes of residual sediment downstream (Yarnell et al. 2015), and the overall impact of dams, levees, and water diversions on stream channels is likely to limit geomorphic diversity and the maintenance of associated instream channel habitats[1].

Groundwater overdraft

Sensitivity: *High (high confidence)*
Current exposure: *High (high confidence)*
Pattern of exposure: *Consistent across the landscape.*

Large-scale groundwater extraction may cause adverse environmental impacts on stream systems because of the close linkages between groundwater and biogeochemical cycles and ecological processes (Loáiciga 2002, 2003). For instance, groundwater overdraft can lead to declines in surface-water levels, decreased recharge of aquifers, declines in streamflow, and changes in riparian vegetation (Zektser et al. 2004). Where groundwater is withdrawn from deep aquifers unconnected with surface water, streams may still be indirectly impacted by land subsidence[1]. Changes in precipitation and increased drought may increase groundwater overdraft due to increased water demands and decreased aquifer recharge, compounding the negative impacts on stream channels.

Land use change

> ***Sensitivity:*** *High (high confidence)*
> ***Current exposure:*** *High (high confidence)*
> ***Pattern of exposure:*** *Consistent across the landscape, although there may be greater threat from crop conversion in the foothills where more precipitation falls.*

The population of California is expected to increase by 19–30% by the year 2025 (Public Policy Institute of California 2006), which will likely lead to a substantial increase in the demand for water for both agriculture and urban area use (Duffy & Kahara 2011).

Land use change, especially crop conversion, impact streams directly when crops go right up to the stream edge[1]; however, they may also increase the runoff of nutrients and pesticides, water diversions for irrigation, and the introduction of alien species (Duffy & Kahara 2011).

Agriculture and rangeland practices

> ***Sensitivity:*** *Moderate-high (moderate confidence)*
> ***Current exposure:*** *High (high confidence)*
> ***Pattern of exposure:*** *Localized, concentrated around current development.*

The Central Valley is dominated by agricultural development, which has been possible due to a massive water distribution system that transfers water from the north to arid central and southern parts of the state (Duffy & Kahara 2011). Nearly 93% of all water used in the region is for agricultural production, and changes in how this water is managed would likely decrease streamflow (Perry et al. 2012). For instance, earlier and/or larger irrigation water withdrawals could substantially reduce late spring and summer flows (Eheart & Tornil 1999), compounding climate-projected reductions in streamflow and causing further stress to plants and animals (Perry et al. 2012). Drought, wildfire, and extreme precipitation events can also interact with agricultural and rangeland practices to exacerbate impacts on stream channel habitats[1].

Rangeland grazing practices have direct and indirect effects on stream ecosystems (Ohmart 1996). Livestock favor riparian areas because they have productive herbaceous species, as well as water and shade; heavy grazing in riparian areas can lead to soil compaction, bank erosion, deterioration of vegetative cover, destabilization of channel banks, and an increase in streamflow sediment concentrations (Lusby et al. 1971; Kauffman & Krueger 1984; Ohmart 1996; Scott et al. 2003).

Urban/suburban development

> ***Sensitivity:*** *Moderate (high confidence)*
> ***Current exposure:*** *High (high confidence)*
> ***Pattern of exposure:*** *Consistent across the landscape.*

Urban/suburban development is likely to exacerbate the impacts of climate change on stream channels, contributing to warmer water temperatures, altered flooding regimes, and heavy erosion and/or sedimentation (Nelson & Palmer 2007; Nelson et al. 2009). Development significantly changes the timing, quality, and volume of runoff in watersheds where urban areas are located (Nelson et al. 2009). Development is also associated with removal of riparian vegetation, channel modification, and increased pollution (Griggs 2009).

Disturbance Regimes

Workshop participants scored the resource's sensitivity to disturbance regimes, and these scores were used to calculate climate change sensitivity.

> ***Overall sensitivity to disturbance regimes:*** *High (high confidence)*

Flooding

> ***Future exposure:*** *High (high confidence)*

Floods are projected to become more frequent and severe, and to potentially occur over a longer season (Dettinger 2011).

Major floods can result in stream bank scouring and the removal of riparian vegetation, thereby affecting stream temperature and sediment loads (Stromberg et al. 1993). Increased sediment delivery following a flood can affect stream channel stability (Perry et al. 2012), and can also increase concentrations of contaminants and potentially the abundance of disease-causing organisms in streams (Grimm et al. 2013), which can have serious impacts on ecosystems, organisms, and drinking water facilities (Semenza et al. 2012).

Many woody riparian plant species require periods of high flows for seed dispersal, and reduced flooding or changes in the timing of floods may limit recruitment success and riparian habitat extent (Rood et al. 2005; Stella et al. 2006), ultimately impacting vegetation diversity and abundance, as well as riparian arthropod and aquatic macroinvertebrate communities (Yarnell et al. 2010). These changes in the riparian and aquatic communities caused by changes in the flooding regime could have cascading impacts to the adjacent terrestrial ecosystem (Nakano et al. 1999).

Wildfire

Future exposure: *Moderate (moderate confidence)*

Large fire occurrence and total area burned in California are projected to continue increasing over the next century with total area burned projected to increase by up to 74% by 2085 (Westerling et al. 2011).

Riparian areas often have high stem densities, biomass, and fuel loads (Van de Water & North 2011) and these characteristics can predispose them to high-severity fire (Olson & Agee 2005). Fires that occur during extreme weather conditions (e.g., hot, dry wind storms) can be particularly severe (Van de Water & North 2011), and can cause substantial channel erosion and/or sedimentation, altering patterns of substrate distribution (Segura & Snook 1992; Skinner & Chang 1996; Camp et al. 1997; Olson & Agee 2005) and inputs of sediment and large woody debris (Miller et al. 2003; Barnett et al. 2008). Changes in wildfire regimes, such as more frequent and severe fires, may also lead to warmer stream temperatures by reducing the shade from woody vegetation, and can change the pH of aquatic systems (Dwire & Kauffman 2003; Pettit & Naiman 2007).

Disease

Warmer stream temperatures may magnify the distribution and virulence of disease organisms and parasites, increasing negative impact on fish and wildlife species, especially salmonids (Rahel & Olden 2008; Null et al. 2013). For some organisms, the combination of warm temperatures, low streamflow, and disease could cause mortality. For example, this combination of factors caused a substantial die-off of approximately 35,000 salmon in the Klamath River during 2002 (Fedor 2003). Mortality events such as these may be related to reduced disease resistance in organisms under climate-induced stress (Heino et al. 2009). Warmer stream temperatures may also affect aquatic parasites, directly altering their life cycles and transmission as well as host susceptibility (Marcogliese 2001, 2008).

Sedimentation

Streams are a product, in part, of historical disturbance regimes and physical processes (Lytle & Poff 2004; Perry et al. 2012). Changes to the rate and pattern of sediment flux will substantially affect stream hydrology and geomorphology (Naiman et al. 2008; Beechie et al. 2010). For example, higher spring peak flows could increase the amount of sediment movement and potentially flush the stream channel of fine sediments (Poff et al. 1997). Large surges in streamflow could also lead to large amounts of erosion and further sediment transfer (Perry et al. 2012). A “flashy” spring hydrograph may lead to a system dominated by two flow stages (i.e., flood stage and low-flow stage) rather than multiple stages, thereby affecting the distribution of sediments and resulting in a stream with greater habitat homogeneity and less overall biodiversity (Yarnell et al. 2010).

Adaptive Capacity

Workshop participants scored the resource's adaptive capacity and the overall score was used to calculate climate change vulnerability.

Adaptive Capacity Component	Score
Extent, Integrity, & Continuity	Moderate
Landscape Permeability	Low-moderate
Resistance & Recovery	Low-moderate
Habitat Diversity	Low-moderate
Overall Score	**Low-moderate**

Extent, integrity, and continuity

Overall degree of habitat extent, integrity, and continuity: *Moderate (high confidence)*
Geographic extent of habitat: *Transcontinental (high confidence)*
Structural and functional integrity of habitat: *Altered but not degraded (high confidence)*
Continuity of habitat:
- ***Sacramento River****: Continuous (high confidence)*
- ***Tulare River:*** *Isolated and/or quite fragmented (high confidence)*
- ***San Joaquin River:*** *Isolated and/or quite fragmented (high confidence)*

Stream channels in the Central Valley have been fragmented and heavily modified, especially in the southern regions (e.g., San Joaquin Valley). Surface and groundwater withdrawals can impact the extent of stream habitat, and this may be exacerbated by future drought conditions and increased water demand (Famiglietti et al. 2011).

Landscape permeability

Overall landscape permeability: *Low-moderate (high confidence)*
Impact of various factors on landscape permeability:
- ***Dams, levees, & water diversions:*** *High (high confidence)*
- ***Riprap:*** *High (high confidence)*
- ***Urban/suburban development:*** *High (high confidence)*
- ***Roads, highways, & trails:*** *Moderate (moderate confidence)*
- ***Agricultural & rangeland practices:*** *Moderate (moderate confidence)*
- ***Energy production & mining:*** *Moderate (moderate confidence)*

Dams, levees, and water diversions disconnect stream reaches and prevent some species from migrating, resulting in more homogeneous habitat and lower biodiversity (Graf 2006; Moyle &

Mount 2007; Wohl et al. 2015). Roads, highways, and trails also reduce stream connectivity, as culverts associated with stream crossings often impede flow, sediment transport, and the movement of wildlife (Trombulak & Frissell 2000). Agricultural and rangeland practices alter the ability of stream channels to migrate, while gravel mining directly impacts stream channels by removing the substrate[1].

Resistance and recovery

Overall ability to resist and recover from stresses: *Low-moderate (moderate confidence)*
Resistance to stresses/maladaptive human responses: *Low-moderate (moderate confidence)*
Ability to recover from stresses/maladaptive human response impacts: *Low-moderate (moderate confidence)*

Streams connected to deep aquifers may be more resistant to drought and extreme temperatures (Goforth 2009). However, direct channel modifications, as well as indirect factors that cause channel incision and/or widening, reduce the ability of stream channels to respond to changing conditions or extreme events by adjusting their shape or migrating (Hawley et al. 2012; Phillips & Jerolmack 2016). The San Joaquin River is less resistant to the impacts of climate change than the Sacramento River[1].

Habitat diversity

Overall habitat diversity: *Low-moderate (moderate confidence)*
Physical and topographical diversity of the habitat: *Low-moderate (moderate confidence)*
Diversity of component species within the habitat: *Low-moderate (moderate confidence)*
Diversity of functional groups within the habitat: *Low-moderate (moderate confidence)*

Component species or functional groups particularly sensitive to climate change:

- Salmonids (*Oncorhynchus* spp.)
- Pacific lamprey (*Entosphenus tridentatus*)
- Sturgeon (*Acipenser* spp.)

Keystone or foundational species within the habitat:

- Salmon
- Lamprey

Heterogeneous stream and riparian habitats are associated with high levels of biodiversity, especially invertebrate diversity and abundance, which serve as an important food source for other organisms (Perry et al. 2012). Altered patterns of sediment transport and organic matter buildup in stream channels can decrease substrate heterogeneity, and sometimes leads to vegetation encroachment (Perry et al. 2012). High flows increase the structural diversity of stream channels by removing accumulated sediment and flushing organic matter from the channel substrate (Yarnell et al. 2015). System dominated by non-native species may have reduced functional capacity, and maintaining diverse native species within stream habitats is important for stream channel processes[1].

Other Factors

Overall degree to which other factors affect habitat adaptive capacity: *High (high confidence)*

Flood operations
Politics and demographics
Agricultural markets

Flood operations

Flow regulation has reduced the natural spatial and temporal variability of floods, thereby impeding sediment movement, creating more homogenous habitat structure (Yarnell et al. 2015). By contrast, large dam releases to control flooding could result in extreme scouring and streambed degradation (Grams et al. 2007). Flood operations may also reduce flow variability, which drives many stream ecosystem processes (Naiman et al. 2008) and the interactions among habitat structure, physical processes, and ecological patterns (Fremier & Strickler 2010; Wohl 2012).

Agricultural markets

The impacts of climate change are likely to decrease the production of some agricultural products and contribute to reduced supply and increased demand for water, affecting the supply of water for irrigation (OEHHA 2013). Higher-revenue crops are grown on more productive soil, and changes in market prices, urbanization, and weather can cause economic losses (Jackson et al. 2012). Seasons when commodity prices are low may cause changes in the crops planted as farmers shift towards crops that are more economically viable (California Rice Commission 2013).

Management potential

Workshop participants scored the resource's management potential.

Management Potential Component	Score
Habitat value	Moderate-high
Societal support	Moderate
Agriculture & rangeland practices	Moderate-high
Extreme events	Moderate-high
Converting retired land	Low

Managing climate change impacts	Low-moderate
Overall Score	**Moderate**

Value to people

Value of habitat to people: *Moderate-high (moderate confidence)*
Description of value: *Fishing, primary water supply for urban use (although it is unclear whether the public fully understands this). The general public understands the value of this habitat, but does not understand the connections between human activities and habitat degradation.*

Support for conservation

Degree of societal support for managing and conserving habitat: *Moderate (moderate confidence)*
Description of support: *Highly regulated for water supply. There are increasing groundwater regulations and bonds. Although there are habitat management regulations, conserving habitat is not seen as equally important.*

Degree to which agriculture and/or rangelands can benefit/support/increase the resilience of this habitat: *Moderate-high (high confidence)*
Description of support: *Setback levees and other best management practices can help, but it is still difficult to deal with landowners.*

Degree to which extreme events (e.g., flooding, drought) influence societal support for taking action: *High (high confidence)*
Description of events: *Extreme events could have positive or negative impact on societal support.*

Likelihood of converting land to habitat

Likelihood of (or support for) converting retired agriculture land to habitat: *Low (high confidence)*
Description of likelihood: *May be possible for San Joaquin River, which is disconnected.*

Likelihood of managing or alleviating climate change impacts on habitat: *Low-moderate (moderate confidence)*
Description of likelihood: *May be possible if groundwater storage increases.*

Although substantial portions of both the Sacramento and San Joaquin Rivers are degraded, there is significant management potential for conserving habitat and restoring stream processes and functions (Huber et al. 2012). However, considerable effort and resources will be needed to achieve greater river functionality, especially within some of the highly modified sections. Management tactics that are targeted towards process-based restoration (i.e., restoring floods) will require connections between hydrologic and geomorphic dynamics (Beechie et al. 2010; Wohl et al. 2015). Physical habitat restoration, sediment transport, and flow regimes should be considered together in order to achieve greater floodplain benefits (Yarnell et al. 2015). Although expensive to implement over a large area, coarse sediment can be added to rivers to promote sediment transport and redistribution of bed material, increasing instream habitat diversity (e.g., Gaeuman 2014). Along reaches that might still receive high flows from unregulated tributaries, measures such as levee breaching could enhance floodplain connectivity (Florsheim & Mount 2002). Finally, efforts to de-armor bends and reconnect abandoned channels isolated by land conversion could increase opportunities for rivers to meander and create new surfaces for pioneer forest establishment (Perry et al. 2012).

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[1] Expert opinion, Central Valley Landscape Conservation Project Vulnerability Assessment