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Environmental Flow Regime Recommendations for the Promotion of Salicaceae Seedling Recruitment in California's Central Valley

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This Master's Project

ENVIRONMENTAL FLOW REGIME RECOMMENDATIONS FOR THE PROMOTION OF *SALICACEAE* SEEDLING RECRUITMENT IN CALIFORNIA'S CENTRAL VALLEY

By

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Abbreviations

cfs	cubic feet per second
HCA	Hydrograph Component Analysis
IHA	Indicators of Hydrologic Alteration
NRDC	National Resources Defense Council
SJRRP	San Joaquin River Restoration Program
CDWR	California Department of Water Resources
DBH	Diameter at Breast Height
WY	water year
RM	river mile
AF	acre-feet
USBR	U. S. Bureau of Reclamation
SRMAP	Sacramento River Monitoring and Assessment Project
GIS	Geographic Information System
HFE	high-flow experiment

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Abstract

Rivers around the world are being degraded due to alteration of natural flow regimes caused by the creation of dams and diversions to serve human needs for water. Alteration to natural flow regime affects a river's flow magnitude, frequency, duration, timing, and rate of change of flow. These changes have major repercussions on the processes that drive riparian ecosystems. Repercussions to river processes are manifested in the degradation of riparian forest health. This is evident in the rivers of California's Central Valley, where altered flow regimes are present in all of its major rivers. As a result, Salicaceae spp. are not regenerating at historic rates and older trees are senescing. This dominant riparian tree family is dwindling due to these factors. Altered and historic flow regimes of Central Valley Rivers differ greatly. The most critical differences include an overall decrease in flow magnitude, an absence of winter flood peaks, and severe alteration to winter baseflow and snowmelt recession components of the hydrograph. The rate of flow decrease during the snowmelt recession is crucial to the recruitment of Salicaceae spp*. It is recommended that flow rate decrease at 1 to 3 cm* d^{-1}*. This range of flow rates allows for the root system of Salicaceae spp. to remain in contact with the receding instream and groundwater flows. Timing of these rates should correspond with Salicaceae seed release which range from mid-April to late May for Populus fremontii and from mid-May to late June for Salix spp. While much research has been conducted to prescribe environmental flows in the Central Valley, little has been done to ensure that these environmental flows regimes are effective. It is recommended that monitoring protocol be implemented that assesses the effectiveness of the Central Valley environmental flow regime. Recommendations have also been made to improve flow planning framework and implement an adaptive management approach to river restoration. These recommendations will promote the success of environmental flow prescriptions in the Central Valley and around the world.*

Introduction

Rivers and associated riparian ecosystems are the networks that distribute fresh water throughout earth. The riparian zone is the area of the stream channel between the low and high water marks and that portion of the terrestrial landscape from the high water mark toward the uplands where vegetation may be influenced by elevated water tables or flooding and by the ability of the soils to hold water (Naiman and Décamps, 1997). Throughout history rivers have provided mankind with many valuable services. These services include flood control, erosion/sediment control, carbon and nitrogen sequestration, food production, high biodiversity, temperature regulation, and water purification (Palmer et al. 2009, Arthington 2012). Currently, fresh water from rivers has been utilized as irrigation for agriculture, for human consumption, and for the creation of hydroelectricity. Rivers and the fresh water they carry are necessary for the society to exist.

Rivers around the world are threatened due to anthropogenic activities. Three factors threatening the structure and function of river systems include: ecosystem destruction, water chemistry alteration, and direct species additions or removals (Malmqvist and Rundle 2002). These three factors can all be linked to anthropogenic practices that modify a river's hydrologic regime. These practices include land use, river impoundments, and surface/groundwater abstraction (Arthington et al. 2010). Water is the foundational factor effecting riparian ecosystem dynamics but is also a highly significant resource for humanity.

River impoundments alter the hydrologic regime of rivers significantly through construction of dams that typically decrease peak flows and the variability of hydrologic regimes (Greet et al. 2011). An estimated $75 billion was spent by the World Bank in the second half of the twentieth century constructing large dams (dams > 15 m) in over 92 countries across the world. The reservoirs created by these large dams have a holding capacity of 7,000 to 10,000 km^3, equivalent to roughly five times the volume of the world's rivers (Arthington 2012). California is home to 1,404 dams used for the production of hydroelectricity, flood abatement, and water storage throughout the state

(KQED 2014). Management of these impoundments and the freshwater discharged for agricultural uses, human consumption, or hydroelectricity needs to be thoughtfully managed. The alteration of hydrologic regimes has changed composition, structure, and function of the riparian ecosystems associated with these waters (Nilsson and Berggren 2000). Flow on unregulated rivers in Mediterranean-type climates like California is highly variable on an intra-annual and inter-annual temporal scale. This variability is important to the functionality of healthy riparian ecosystems.

Management of allocated water from river impoundments is referred to as "environmental flows." Environmental flows describe the quantity, timing, and quality of water flows required to sustain freshwater and estuarine ecosystems and the humans that depend on these ecosystems (Arthington 2012). Environmental flows are prescribed hydrologic regimes developed and implemented by environmental managers. These prescribed flows must satisfy the ecological, agricultural, and societal demands for water. Other terms used to describe environmental flows include "instream flows," "ecological flows," "environmental water allocations," "recruitment flows" and "restoration flows" (Arthington et al. 2010).

Hydrology is considered the "master variable" (Power et al. 1995) because it greatly influences other abiotic as well as biotic factors of a riparian ecosystem. The critical components of hydrologic regimes include: magnitude, frequency, duration, timing, and rate of change of flow (Richter et al. 1996, Poff et al. 1997). Magnitude refers to the amount of discharge of water from a river at a given time and location. Magnitude is usually measured in cubic feet per second (cfs). Frequency refers to how often a discharge of a certain magnitude occurs. Duration is how long discharge of a certain magnitude occurs. Timing is the annual temporal scale at which predictable flow rates occur. The rate of change of flow, specifically the receding limb of the hydrographic flood peaks is important to vegetation with phenologic adaptations to flow rate.

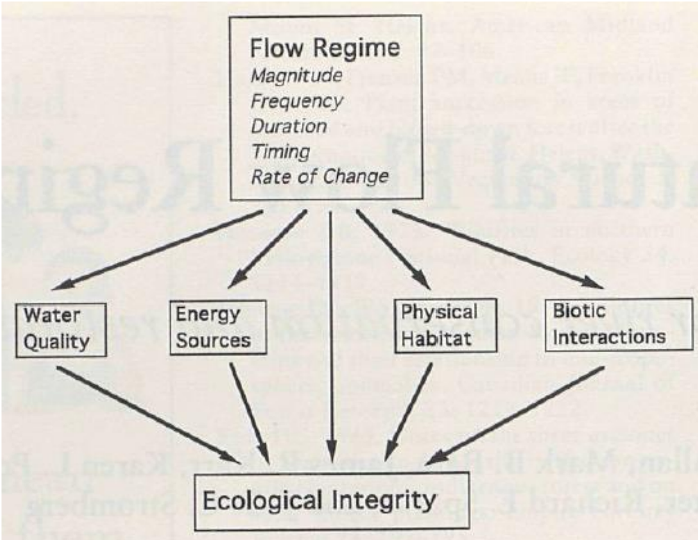

Figure 1: Five components of natural and altered flow regimes (Poff et al. 1997)

Each of these components must be carefully considered; together these components dictate the biodiversity and ecological integrity of the river and surrounding riparian ecosystem. Natural flow regimes, or flow regimes that mimic natural flow regimes, create the conditions necessary to promote high levels of biodiversity and ecosystem integrity within rivers and associated riparian zones (Naiman and Decamps 1997, Poff et al. 1997). When natural flow regimes are not utilized as templates for environmental flows or are abandoned all together, biodiversity and ecosystem integrity can decrease dramatically.

Riparian ecosystems should be thought of as legitimate users of water (Naiman et al. 2002). Alteration of natural flow regimes is likely to affect riparian vegetation. Although the effects of seasonal timing of flow on riparian vegetative communities are not well understood (Poff and Zimmerman 2010), it is thought that these alterations will negatively affect riparian vegetation (Nilsson and Berggren 2000, Catford et al. 2011). Alterations in flow regimes increase the susceptibility of riparian ecosystems to invasion by non-native species (Greet et al. 2013). It is hypothesized that altered flow regimes create physical conditions that benefit non-natives, reduce competition from native species as they are not well suited to altered flow regime conditions, and decrease frequency and peak flows that promote species adapted for drier conditions (Catford et al. 2011).

Alteration of seasonal timing of flow is a major threat to the health of riparian ecosystems. Native tree species populations have declined along rivers with flow regime alterations. Cottonwoods (*Populus* spp.) and willows (*Salix* spp.), belonging to the *Salicaceae* family, are experiencing population declines throughout western North America and in California (Mahoney and Rood 1998, Stella et al. 2006). These species possess specialized morphological and reproductive adaptations for life along rivers. Morphological adaptations of these riparian species to life in variable flows include adventitious roots and flexible stems. An important reproductive adaptation is the synchrony of receding peak flow and the release of seeds (Naiman and Decamps 1997). This process is known as “hydrochory” and is essential to the seedling recruitment of *Salicaceae* species.

Table 1: Cottonwood and willow species common to riparian ecosystems of California

Common Name	Scientific Name	Family
Fremont cottonwood	*Populus fremontii*	*Salicaceae*
Gooding’s black willow	*Salix goodingii*	*Salicaceae*
sandbar willow or narrow leaf willow	*Salix exigua* or *Salix exigua var. hindsiana*	*Salicaceae*

Currently riparian ecosystems of California’s Central Valley are threatened due to increase in demand for water and ongoing drought conditions. This last year (2013) was the driest year in California’s recorded history. On January 17 of this year (2014) Governor Jerry Brown declared California to be in a state of emergency and urged Californians to reduce water consumption (Chappell 2014). The Central Valley was naturally dominated by grassland ecosystems with patches of oak savanna, wetlands, and riparian woodlands. Currently the land between the Coastal Range and the Sierra Nevada Mountain Range is utilized mostly as farmland. The Central Valley is situated in the middle of the state’s largest watershed with the Sacramento and the San Joaquin

Rivers constituting the largest rivers in the watershed. These rivers meet at the San Francisco Bay Delta and flow into the San Francisco Bay before flowing in the Pacific Ocean.

Currently, the rivers in the Central Valley are stressed due to water withdrawal. This stress is compounded with the current and future drought conditions. Riparian ecosystems are becoming increasingly vulnerable to invasion of non-native species, decreased biodiversity, and decreased ecosystem integrity. Populations of *Salicaceae* species have declined in the rivers of the Central Valley due to the same conditions. In this research paper, I investigated environmental flow recommendations designed to promote the recruitment of *Salicaceae* species seedlings in California's Central Valley along two rivers, the San Joaquin and Sacramento Rivers.

Methodology

I conducted a literature search for this study to find general information on *Salicaceae* spp. common to California's Central Valley riparian ecosystems. The focus of this study is three species: *Populus fremontii, Salix exigua, and Salix goodingii.* Information was collected outlining their ecology, including: distribution, adaptations, life strategies, and function in the ecosystem. This information led to the establishment of general requirements needed to promote and sustain populations of these species. Environmental flow recommendations for *Salicaceae* recruitment are presented using the Recruitment Box Model. This model creates a box over an annual hydrograph. An annual hydrograph is the graph of flow magnitude of over time. The vertical sides of the box correspond with the timings of seed dispersal for *Salicaceae* spp. The horizontal sides of the box correspond with flow magnitude or river stage height and corresponding groundwater recession requirements needed to give seedling roots a constant supply of water. It is assumed that the river stage height is equivalent to the elevation of groundwater along the stream banks. The effects of altered flow regimes on *Salicaceae* spp. are briefly discussed.

California’s Central Valley is the area of interest for this study. This area is a vast drainage basin that flows into the San Francisco Bay Delta, and out of the Golden Gate into the Pacific Ocean. This region runs about 450 miles north and south and is about 40 to 60 miles wide. It is composed of two smaller valleys: the Sacramento Valley to the north and the San Joaquin to the south. For this study the data from each river will be synthesized to provide environmental flow recommendations for *Salicaceae* recruitment.

Throughout this study, flow data prior to flow alteration will be referred to as the historic flow regime instead of the natural flow regime. The term natural flow regime infers an absence of any flow alteration or impediment. Flow gauge data has not been collected on a long enough time scale, pre-alteration, to confidently state that it represents the natural flow regime. Historic flow regime data is the data set that represents the natural flow regime most closely. Historic flow regime data were compared to altered flow regime data for the two rivers. Historic and altered flow regime data is presented in the form of hydrographs. Hydrographs for both historic and altered flow regimes were visually analyzed for this report.

Hydrologic data for both rivers were analyzed using the Hydrograph Component Analysis (HCA) and Indicators of Hydrologic Alteration (IHA) analysis. These analyses were conducted in the two Cain reports, comparing historic and altered flow regimes for each river. HCA describes the components of the annual hydrograph in terms of the aspects of the natural flow regime, including*:* magnitude, timing, duration, frequency, and rate of change of flow. IHA analysis takes into account 33 ecological parameters to hypothesize ecological effects of altered flow (Richter et al. 1996).

Figure 2 shows the annual hydrograph for the San Joaquin River is broken down into seven main components of interest:

1. Fall baseflow – Baseflows necessary to sustain river height from October to December. These are typically the lowest flows of the year.

2. Fall storm pulses -- Peak flows corresponding with the Fall Baseflows. These are short relatively weak flood events.
3. Winter floods – Typically from mid-December to late-March. These stronger flood events are responsible for the scouring of stream banks and creation of lateral bars, point bars, and islands.
4. Winter baseflows – The low flows correspond with the winter floods. These events are the valleys in between the floods.
5. Snowmelt floods – Spring snowmelt floods are weaker flood events than Winter Floods.
6. Snowmelt recession – The ramping event that connects the increased winter flows with the Summer Baseflow.
7. Summer baseflows – The minimum flows that sustain the river through the dry summer months (Cain et al. 2003).

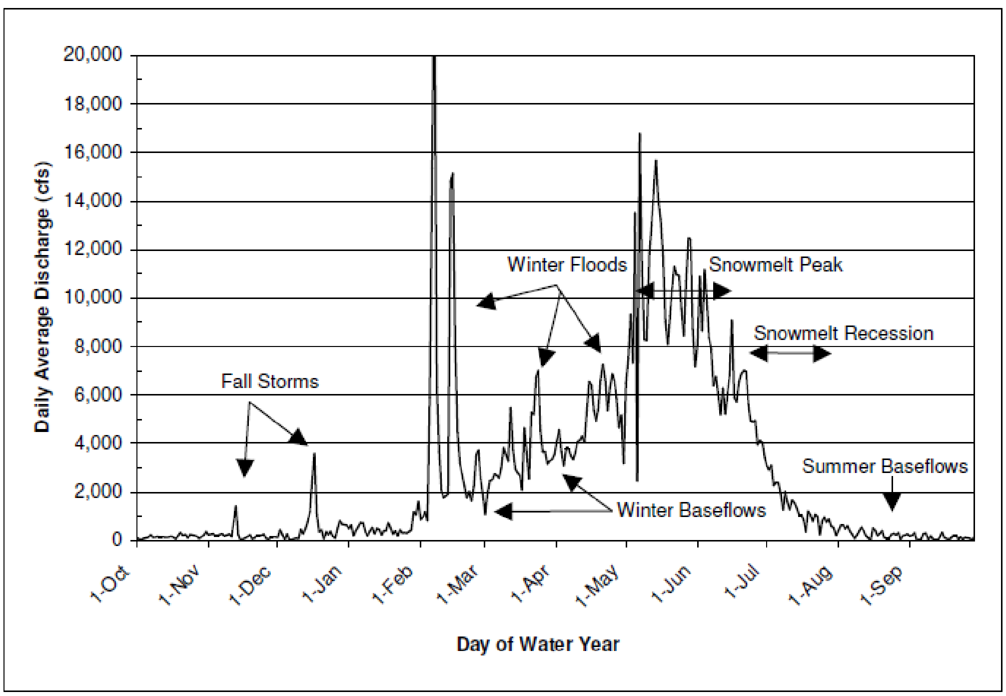

Figure 2: HCA components used for the flow regime analysis on the San Joaquin River (Cain et al. 2003).

Figure 3 shows the annual hydrograph for the Sacramento River is broken down into four main components of interest:

1. Summer baseflows **–** The minimum flows needed to sustain the river through the dry summer months.
2. Winter floods **–** Peak flows on the hydrograph from the beginning of December through April.
3. Winter baseflows **–** The minimum flows in between the Winter Floods.
4. Snowmelt runoff **–** The recession limb of the hydrograph that connects the increased winter flows to the Summer Baseflows (Cain 2008).

Data were organized according to wet, above normal, below normal, dry and critical years for the Sacramento flow. Median flow was calculated for the historic and the altered flow regimes, and 25th percentile and 75th percentile flows were calculated for the historic flow regime only.

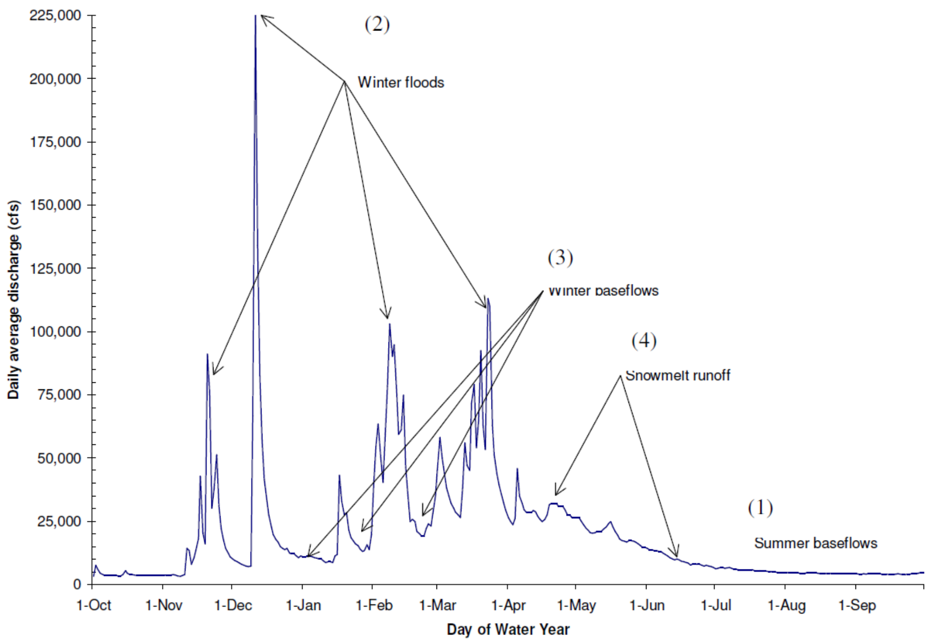

Figure 3: HCA components used for the flow regime analysis on the Sacramento River (Cain 2008).

Environmental flow regime recommendations for *Salicaceae* spp. were derived for the snowmelt runoff component of the annual hydrograph using the Recruitment Box Model format. The synthesis of this format requires:

- site hydrology be assessed

- seedling release and viability be documented
- Seedling response to water stress be investigated

The environmental flows associated with *Salicaceae* spp. recruitment and the snowmelt recession component of the hydrograph, are called recruitment flows and will be the focus of flow recommendations. Recruitment flows are named such because they promote recruitment of tree seedlings along the stream banks. Recruitment flows will be a focal component of the environmental flow regime for this study.

Current flows for each restoration project will be provided. Vegetation coverage will be compared before and after the implementation of an environmental flow prescription.

***Salicaceae* spp.**

The *Salicaceae* family is comprised of willows (*Salix* spp.) and cottonwoods (*Populus* spp.). The origin of the word *Salicaceae* means "near water" (Rood et al. 2007). This is a fitting name for these trees whose life strategies revolve around the seasonal variability of the water provided by rivers. Willows and cottonwood species recruitment occurs on bare soil after a flood disturbance has rid the stream banks of competing species. These pioneer species are important to riparian habitat structure because they secure substrate, fix carbon, and create vertical habitat layers (Stillwater Sciences 2006). These life strategies allow for these species to occupy similar habitats within similar geographic distributions. Riparian ecosystems of the western United States display banded patterns of *Salicaceae* spp. These vertical banded patterns are in a large part affected by instream flows and groundwater dynamics dictated by the hydrologic regime. This pattern is also affected by differences in substrates. These requirements allow for their seedling recruitment requirements to be similar.

***Populus* spp. - Ecology**

The cottonwood species of interest for this study the Fremont cottonwood (*Populus fremontii*). *Populus fremontii* ranges geographically throughout riparian ecosystems in California's Central Valley, the western Sierra, and near coastal Southern California.

Distribution is patchy, mainly in the riparian and wetland ecosystems. *Populus fremontii* can grow to a height of 40-60' tall with a crown diameter of 30'. It has a relatively short life span with an estimated longevity of 75-100 years (Hatch 2007).

Populus spp. have adaptations that make them ideal for growing along California streams. Morphological adaptations include:

- Flexible stems – Supple stems and branches that give during period of exposure to high flow events (Naiman and Decamps 1997).
- Adventitious roots – Roots that develop on the stem of a plant just above anaerobic conditions (Naiman and Decamps 1997, Mitsch and Gosselink 2007).

Populus spp. also possess the following physiological adaptations:

- Rapid root growth after germination – While some wetland and riparian species have rapid stem elongation, *Salix* have rapid root growth to reach the receding water table (Braatne et al. 1996).
- Asexual reproduction from broken branches or stems – When branches are broken off and carried away by instream flow, adventitious roots can form and form a genetically identical plant (Naiman and Decamps 1997).
- Timing of seed release – Hydrochory plays a large role in the dispersal of seeds along stream banks(Naiman and Decamps 1997, Naiman et al. 2005).

These adaptations provide a built-in resilience to the stresses of variability of instream flows. Instream flows are a major stress to the vegetative communities found in riparian ecosystems. Stress, caused by variability of flow, dictates the life strategies of native riparian plants.

Cottonwoods are a dominant species in many semi-arid regions such as are found in California. These fast-growing trees, along with select *Salix* species, provide much of the structure of the riparian forest. *Populus* spp. are utilized for stream restoration because they provide structure for riparian ecosystems, as stated earlier of all *Salicaceae* spp. They are vital to the sustainability of these ecosystems because often, if they are extirpated, no other tree species will replace them (Braatne et al. 1996). This keystone species and the abiotic factors that promote its recruitment and survivorship must be a priority in California.

Populus spp. - Seedling Recruitment Requirements

Disturbance plays a key role in the recruitment and establishment of *Populus* spp. The phenology of *Populus* spp. is determined by photoperiod (i.e., the amount of light present at a given time) and temperature. This makes the release of *Populus* seeds relatively predictable. *Populus* spp. have a range of seedling releases from March to July (Braatne et al. 1996), with variation throughout the various climate regions of the United States.

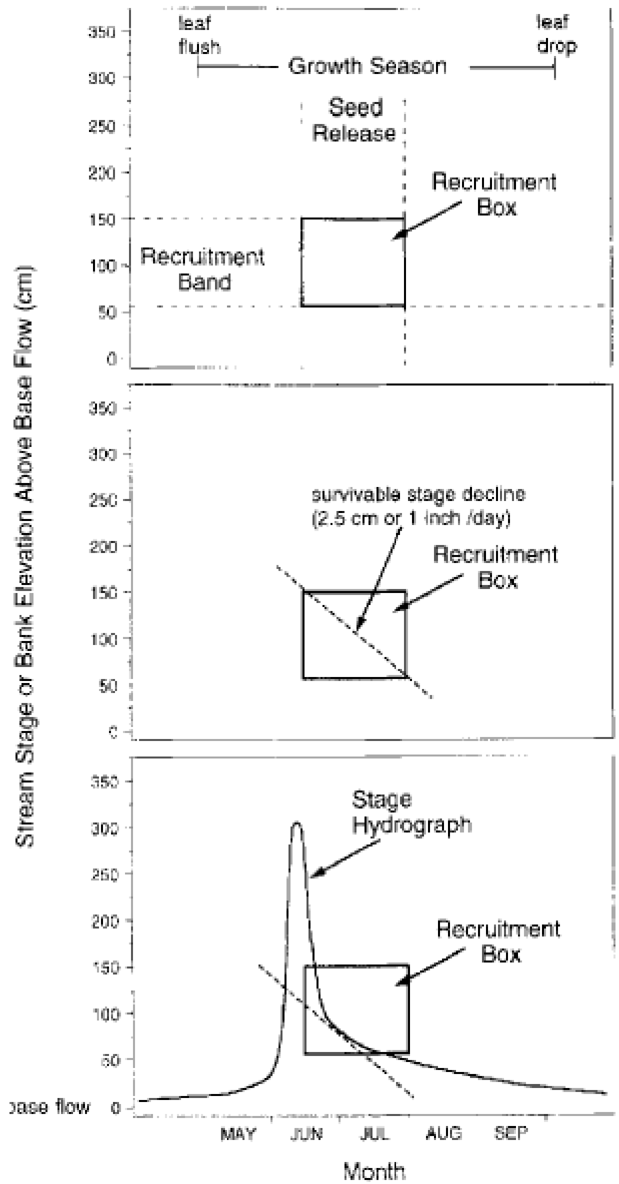

Figure 4: Recruitment Box Model for *Populus* spp. (Mahoney and Rood 1998).

Under conditions of natural flow regimes, the release of seeds follows the peak flows. These peak flows, or flood pulses, are essential to the maintenance of ecosystem function. The flood pulse is easily seen in Figure 4, the peak of hydrograph is the flood pulse. It is important because the high flow rate scours the banks of the river, leaving behind barren substrate. Barren substrate is ideal for the recruitment of *Populus* spp. as their seedlings compete poorly with other species. The pulse flow also carries sediment that is crucial for the creation of geomorphic features, such as point bars, lateral bars, and islands, which form crucial habitat for *Populus* seedlings (Rood et al. 2007).

The recession limb of this hydrograph is critical information. *Populus* spp. need a connection to the receding ground water in order to survive to the next season. Rapid root elongation is an important adaptation that promotes recruitment. In semi-arid areas of the United States, such as California's Central Valley, rivers are often losing streams. (i.e. those where water leaves the stream to recharge groundwater) (Ward and Trimble 2004). Semi-arid rivers usually exhibit groundwater levels that are equivalent to in stream flow levels. The recession limb is important because the stage height is a real time representation of the groundwater height. The capillary fringe serves as a buffer zone between substrate surfaces to the receding water table.

Populus spp. roots can grow an estimated 60 – 100 cm to the capillary fringe. The capillary fringe can extend 50 to 100 cm above the water table. Figure 5, shows the location of the capillary fringe in relation to the river and groundwater height for semi-arid rivers. A recruitment range above baseflow has been established. In coarse textured substrate the recruitment range is 60-150 cm above baseflow. In fine textured substrate the recruitment range is 60 – 200 cm above baseflow (Mahoney and Rood 1998).

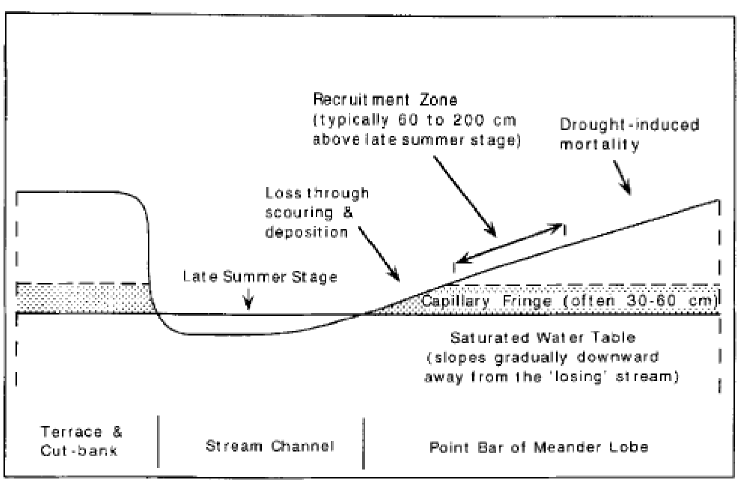

Figure 5: Diagram of the importance of water table heights and *Populus* spp. seedling recuitment (Mahoney and Rood 1998).

A recession limb slope of 2.5 cm/day is suggested for prescribed flow regimes with *Populus* spp*.* recruitment as a priority (Mahoney and Rood 1998).

Populus **spp. - Effects of Altered Flow Regimes**

Altering the disturbance regime of any ecosystem can make it prone to invasion by non-native species (Merritt and Poff 2010). The predominant disturbance of the Central Valley Rivers is flooding due to peak flows. When these flow peaks are diminished due to flow diversions much of the variability of the natural flow regime is muted. Variability in flow magnitude is what drives river health(Poff et al. 1997). The complexity of flow magnitude, duration, frequency, timing, and rate of change of flow needs to be understood at many different time scales. When this complex flow regime is altered the peaks and troughs of the natural flow regime are smoothed out. This is detrimental to species with phenologic adaptations. When these species are affected the ecosystem becomes vulnerable to invasion by generalist and ruderal species, many of which are non-native and invasive (Lytle and Poff 2004). *Populus* spp. are such a species with phenologic adaptations and are thus affected by the alteration of flow regimes.

Salix **spp. - Ecology**

Two willow species are of interest for this study: Narrowleaf willow (*Salix exigua)* and *Gooding's black willow (Salix goodingii)*. The *Salix* spp. can be found in wetlands and in riparian ecosystems. This is evidence of their need for wet, moist soils. The *Salix* spp. differ in geographic ranges only slightly *Salix exigua* ranges from Northern to Southern California along the coast and eastward into the Central Valley. *Salix goodingii* runs the length of California and east into the Central Valley. It is also shrubby in size and stature, with an estimated height of 10-30' tall. All of these *Salix* spp. have an estimated life span of 40-60 years (Hatch 2007).

Salix spp. are a close relative of the *Populus* spp. and have many overlapping life strategies for coping with life in the riparian ecosystems. *Salix* spp. morphological adaptations include:

- Flexible stems – Supple stems and branches give during period of exposure to high flow events (Naiman and Decamps 1997).
- Adventitious roots – Roots that develop on the stem of a plant just above anaerobic conditions (Naiman and Decamps 1997, Mitsch and Gosselink 2007).

Salix spp. also possesses the following physiological adaptations:

- Extensive fibrous roots system – Fibrous roots, located in the upper 40-45 cm of the soil profile, grow from May through October (Kuzovkina and Quigley 2005).
- Tolerance of periodic saturated soil conditions – Tolerance of higher concentrations of Carbon Dioxide and Methane (Kuzovkina and Quigley 2005).
- Rapid root growth after germination – While some wetland and riparian species have rapid stem elongation.
- Asexual reproduction from broken branches or stems – When branches are broken off and carried away by Instream flow, adventitious roots can form and form a genetically identical plant (Naiman and Decamps 1997).
- Timing of seed release – Hydrochory plays large role in seed dispersal (Naiman and Decamps 1997, Naiman et al. 2005).

Willow presence is beneficial to the riparian ecosystems of California. Willows are pioneers species that can act as act as an anchor for pioneer communities and accelerate the ecosystem development of the degraded site. *Salix* spp. can facilitate the establishment of large woody tree species (Kuzovkina and Quigley 2005). *Salix* spp., specifically *Salix exigua* and *Salix goodingii*, is a key contributor to the stabilization of stream banks, creation of habitat, flood abatement, and water quality improvements (County of Ventura Planning Division 2006).

***Salix* spp. – Seedling Recruitment Requirements**

Salix spp. like the *Populus* spp. is dependent on a disturbance regime. The flood pulse provides *Salix* spp. with a pulse of nutrients, sediments, organic material, and energy. It is the energy that is utilized in the process of hydrochory. *Salix* spp. seed release differs slightly with differences in species, geographic location, and annual variation in weather patterns. A longitudinal study of seed releases of *Populus fremontii, Salix exigua,* and *Salix goodingii was conducted* at three remnant riparian ecosystems in the San Joaquin Basin in California. The study calculated the day of the calendar year that the seed release began and ended. *Salix exigua* had a mean day of seed release initiation for all three sites on all three years of 150; this is equivalent to April 30. *Salix goodingii* also had a mean day of seed release initiation for all three sites on all three years of 150; this is equivalent to April 30 (Stella et al. 2006). These initial release dates represent the three San Joaquin Basin sites during the 2002, 2003, and 2004 calendar year. *Salix exigua* begins seeding in mid-May and continues through mid-July (U. S. Forest Service 2014).

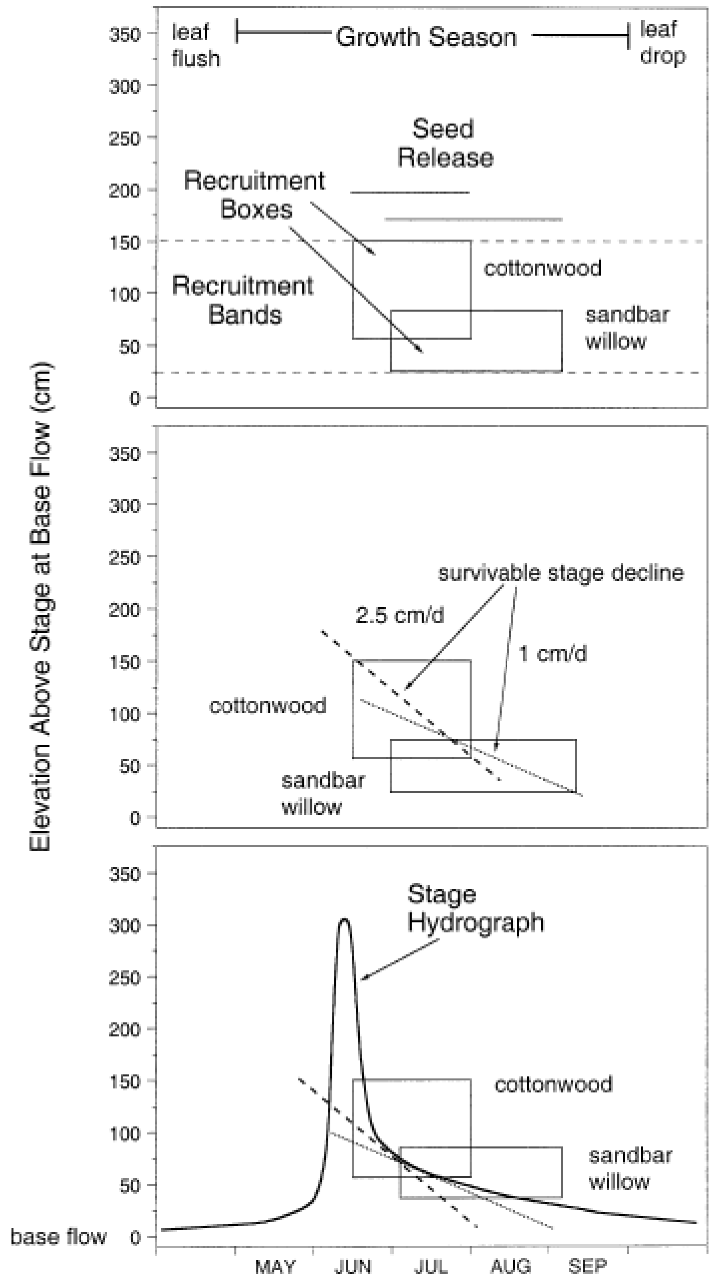

Figure 6: Comparison of *Populus* spp. and *Salix* spp. in the Recruitment Box Model (Amlin and Rood 2002).

A similar study was conducted comparing the groundwater requirements of *Salix* spp. and *Populus* spp. *Salix* spp*.* require peak flows before the release of their seeds to scour the river banks, creating habitat and reducing competition with other seedlings found in sandy substrate near the river channel. *Salix* spp*.* generally seed after the *Populus* spp. but the *Populus* spp. seedling recruitment occurs at a higher stream stage and thus occurs at a higher elevation along the stream banks leading to the banded pattern mentioned earlier. As the flood pulse subsides the rate of decrease of the receding limb of the hydrograph, also subsides. *Salix* spp*.* require a stream stage height decrease of 1cm day^{-1} (Amlin and Rood 2002). This is the general estimation for *Salix* spp. and differs from across species and geographic distributions.

***Salix* spp. - Effects of Altered Flow Regimes**

Alteration of the natural flow regime results in an increase in erosion, and in a decrease of *Salix* spp*.* abundance due to lack of suitable habitat. Figure 7 shows the percentage of transects with *Salix exigua,* taken along the Hell's Canyon corridor along the Snake River. The free flowing Salmon River has the highest percentage of *Salix exigua*, thus correlating the natural flow regime with the promotion and survivorship of native species. The downstream reaches exhibit the lowest percentage due to the alteration of the natural flow regime(Rood et al. 2011).

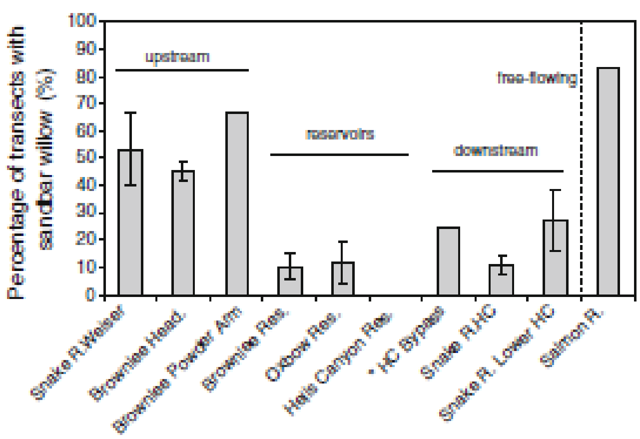

Figure 7: Percentage of transects along Hell's Canyon with *Salix exigua* (Rood et al. 2011).

When *Salix* spp. are extirpated from a site there are effects on other aspects of the ecosystem. Erosion increases in the downstream reaches where the *Salix* spp. have been extirpated due to the low sediment loads of these waters. These low sediment loads are trapped in the upstream reaches of dammed rivers. This water flows through the downstream reaches and erodes instead of deposits. Erosion also negatively affects *Salix* spp*.* recruitment and survivorship Due to the destruction of point bars, lateral bars, and islands created by the deposition of sediment in rivers. These geomorphic features are the habitat of the *Salix* spp*.* Such destruction of habitat causes the vertical movement of these species vertically to higher location along the stream bank.

Central Valley Hydrology

California's Central Valley is the largest watershed in California with a surface area of 75,000 mi^2. It is confined by the Coastal Ranges on the west, the Sierra Nevada on the east, the Tehachapi Mountains on the south, and the Cascade Mountains on the north. This large watershed is home to the Sacramento and San Joaquin Rivers, the two largest rivers in California. These two rivers provide 25 million Californians with drinking water and irrigate 7,000 mi^2 of farm land (U. S. Environmental Protection Agency 2014).

The hydrology of Central Valley Rivers is driven by California's topography and Mediterranean climate. California's climate is characterized by large rain events typically from November to March, and these winter storms are typically the only source of precipitation throughout the year. Summers in California are characterized by drought conditions. Stark contrast in seasons drives the hydrology of California Rivers. The large winter rain events cause the winter flood peaks in the hydrograph. Consecutive winter rain events add to the increase of the winter baseflow until the rains subside. Dry summer and early fall conditions slow the flow magnitude to a minimum.

The majority of winter precipitation that falls in the upper elevations of the Central Valley falls as snow. While these winter storms bring rain to the lower elevations of the Central

Valley, snow simultaneously falls in the upper elevation. These snows cause a lag in flow events along Central Valley Rivers. It is not until spring snowmelts occur that the snow adds to the flow of the river. This is component of the hydrograph is generally known as the receding limb or spring snowmelts component. Spring snowmelt events are extremely important to the recruitment of *Salicaceae* spp. (Mount 1995).

San Joaquin River Background

The San Joaquin River is the second largest river in California flowing 350 miles from the Sierra Nevada Mountains to the San Francisco Bay Delta. This large river once supported the southernmost Chinook salmon runs on the west coast of the United States. After the completion of the Friant Dam in 1942, nearly 95% of the instream flow from the San Joaquin was diverted for agricultural uses. The San Joaquin Restoration Project encompasses the river reach between the Friant Dam and the river's confluence with the Merced River (Natural Resources Defense Council 2013). The alteration of the historic flow regime is due in a large part to the presence of the Friant Dam and many other water diversions for agricultural use.

In 1988 the National Resources Defense Council (NRDC) led a law suit with several other conservation organizations against the U. S. Bureau of Reclamation, the U. S. Department of Commerce, National Marine Fisheries Service, U. S. Fish and Wildlife Service, and numerous water districts associated with Friant Dam operations. This lawsuit was filed on the basis that Friant Dam operations were the cause of decreased flow magnitude in the river, and the reason that a 60 mile reach runs dry annually during the summer months. Decreases in flow magnitude have negatively affected *Salmonid* spp. within the river due to the 60 mile gap in the river flow. On September 13, 2006, *NRDC et al v. Kirk Rodgers et* al. was settled in favor of the NRDC and other conservation groups. This environmental lawsuit settlement calls for the implementation of an environmental flow regime that would guarantee continuous flow, except in critical low water years (WY), from the Friant Dam to confluence with the Merced River. Improving the health of riparian ecosystems is a central issue in the reintroduction and conservation of *Salmonid* spp. in the San Joaquin River. *Salicaceae* spp. are focal species in the riparian ecosystem because they are dominant species that affect water temperature, the detrital food web, and provide habitat structure. The restoration project will run a 150 mile stretch of the river from the Friant Dam to the confluence of the Merced River. Implementation of this project will be conducted under the guidance of two main objectives:

1. To restore flows necessary to promote, sustain, and reintroduce *Salmonid* spp. in the San Joaquin River.
2. To avoid decreases in water diversions to the water contractors along the river as a result of the Interim or Restoration Flows.

On January 31, 2014, the San Joaquin River Restoration Project (SJRRP) announced that the 2014 WY was classified as a critical low year. Restoration flows were halted on February 1, one month earlier than scheduled. This decision was supported by the restoration administrator. On February 1, 2014, flow from the Friant Dam decreased at 50 cfs/day until flow reaches 200 cfs. At that time flow will be incrementally decreased until the only flow from the Friant Dam will be flow necessary to satisfy needs of prior water rights holders in the upper San Joaquin River. It was suggested that decreasing flows one month earlier would allow for an increase in environmental flow credits to be utilized in the future and for current flow to be utilized for human needs (Johnson 2014).

San Joaquin River Reach Descriptions

Vegetation types were established using Holland's vegetation type classification (Holland 1986). Between July and October 2000, the California Department of Water Resources (CDWR) conducted a vegetation survey along the five river reaches. The three vegetation types of interest in this study are the cottonwood riparian forest, willow riparian forest, and willow scrub.

Cottonwood riparian forest and willow riparian forests types are based on Holland's Great Valley Cottonwood Riparian Forest (#61410). *Populus fremontii* and *Salix* *goodingii* dominate the cottonwood riparian forest. Other present tree species include red willow (*Salix laevigata*), arroyo willow (*Salix lasiolepis*), box elder (*Acer negundo*), and ash (*Fraxinus Latifolia*). Older stands can have trees ranging in height from 40 to 60 ft tall. Low density cottonwood riparian forests have the same species makeup but display less than 50% coverage of these species. Tree heights usually range from 10 to 50 ft tall. These lower density stands are susceptible to invasion by non-native species.

Willow riparian forest is almost exclusively dominated by *Salix goodingii*. Other present tree species include *Populus fremontii*, *Salix laevigata*, *Salix lasiolepis*, *Acer negundo*, *Fraxinus Latifolia*. Low density willow riparian forests have the same species makeup but display less than 50% coverage of these species. Tree heights usually range from 10 to 50 ft tall.

Willow scrub is based on Holland's Great Valley Willow Scrub (#63410). Stands occur in disturbed sand and gravel substrate, along open channel. These physical characteristics support shrubby willow stands less than 15 ft tall. The dominant species are *Salix goodingii* and *Salix exigua*. Low density willow scrub have the same species makeup but display less than 50% coverage of these species (Moise and Hendrickson 2002).

The SJRRP has broken the river into five river reaches. Some river reaches are broken into sub-reaches which are noted by the presence of a letter. Each of the river reaches is marked by characteristic vegetation types and by distinct landmarks such as the confluence of the San Joaquin and larger tributaries. The CDWR survey established 125 transects perpendicular to the river, along the five river reaches. The locations of the transects were chosen to represent a range of vegetation types. At each transect herbaceous plant cover, tree and shrub cover, and diameter at breast height (DBH) was recorded. The vegetation types of each of the river reaches was established from the information that was collected at each transect. The following descriptions were those taken by the California Department of Water in 2000 (McBain and Trush 2002).

River Reach 1 extends from Friant Dam, river mile (RM) 267 to Gravelly Ford, RM 229. This reach is broken into Sub Reaches 1A and 1B. Reach 1A extends from the Friant Dam to RM 243 at Highway 99 Bridge in Herndon. Reach 1A is the most urban reach of the entire river and is confined by steep bluffs on each side of the river. The two main vegetation types in this reach are riparian oak forest and mixed riparian forest. River Reach 1A contains 290 acres of willow scrub and 223 acres of willow riparian forest. Reach 1B is very narrowly confined by levees and is about one half herbaceous and exotic plants. Vegetation types include 193 acres of cottonwood riparian forests, 155 acres of willow scrub, and 120 acres of willow riparian forest.

River Reach 2 extends from Gravelly Ford, RM 229 to Mendota Pool RM 205. This reach has coarse substrate and drains very quickly. Given the characteristics of the substrate, riparian forest cannot be sustained in large quantities in this reach. Herbaceous vegetation makes up about 71% of this reach. Vegetation types in this reach include 254.2 acres of willow scrub, 165.4 acres of willow riparian forest, and 125.4 acres of cottonwood riparian forest. Reach 2 boasts 79.0 acre/mi native vegetation per mile ratio.

River Reach 3 extends from RM 230 to 135; this is from Mendota Pool to Sack Dam. This reach has a confined channel that flows continuously but flows are seasonally low. This reach has the lowest percentage of herbaceous cover (25.2) and the highest% of riparian forest (53.7). Vegetation types include 460.8 acres of cottonwood riparian forests, 230.5 acres of willow scrub, and 124.8 acres of willow riparian forest.

River Reach 4 extends from the Sack Dam to the Bear Creek confluence (RM 136 – 182). River Reach 4 is broken into River Reach 4A and 4B, with River Reach 4A extending from the Sack Dam to the boundary of the San Luis National Refuge (RM 148 – 182). This reach has the lowest ratio of native vegetation per RM. By vegetation type Reach 4A is 66.7% herbaceous, 22.4% forest, and 5% scrub. Of the forest vegetation 89.1 acres were willow riparian and 19.3 were cottonwood riparian forest. River Reach 4B (RM 136 – RM 148) is unique because of elevated water table levels compared to the other reaches of the San Joaquin. This reach also runs through public lands in which native vegetation is protected. Reach 4B records high native vegetation per RM ratio of 512.8 acres/mile. Reach 4B by vegetation type was 74.3% herbaceous, 12.1% forest, and 13.6% scrub. Of the forest vegetation 701.2 acres were willow riparian forest, 132.1% acres were willow scrub, and 36.9% were cottonwood riparian forest.

River Reach 5 extends from the confluence of Bear Creek (RM 136) to the confluence of the Merced River (RM 118). This reach has similar characteristics to River Reach 4B. Reach 5 borders about eight miles of agricultural land and runs through relatively undisturbed lands of duck clubs and state and federal protected parks and refuges. Reach 4B and Reach 5 are home to more than twice the wetland acreage of the remaining reaches combined. By vegetation type Reach 5 was 86% herbaceous, 12.2% forest, and 1.7% willow scrub. Of the forest 972.6 acres were willow riparian forest, 86 acres were willow scrub, and 36.25% were cottonwood riparian forest (McBain and Trush 2002, Moise and Hendrickson 2002).

According to the 2000 CDWR data collection, the largest cottonwood riparian forest stands were located in River Reach 3 (441 acres), River Reach 1A (167 acres), and River Reach 1B (79 acres). The largest cottonwood riparian forests in low density, were located in River Reach 1B (114 acres), River Reach 2A (41 acres), and River Reach 1A (27 acres). The largest stands of willow riparian forests were River Reach 5 (590 acres), River Reach 4B (508 acres), and River Reach 1A (205 acres). The largest stands of willow riparian forest in low density, were located in River Reach 5 (308 acres), River Reach 4B (118 acres), and River Reach 1A (28 acres). The largest stands of willow scrub were River Reach 1A (216 acres), River Reach 3 (190 acres), and River Reach 1B (113 acres). The largest stands of willow scrub in low density, were located in River Reach 2A (124 acres), River Reach 1A (74 acres), and River Reach 3 (41 acres) (McBain and Trush 2002, Moise and Hendrickson 2002, Stillwater Sciences 2003a).

River Reach 1A was in the top three of each of the six vegetation types. Even though this was the most urban of all of the reaches this area promotes *Salicaceae* spp. recruitment and survivorship. While River Reach 3 contains the largest amount of mixed riparian forest by acre, a single dominant *Salicaceae* spp. type is not present. Willow scrub is in the top three vegetation types in Reach 3. Reach 5 contains the largest amount of willow riparian forest. Because the San Joaquin is a dynamic river system that contains a mosaic of vegetation patches, it is important to observe patch dynamics at the river reach scale and at the river scale to understand the vegetative coverage pre-restoration.

San Joaquin River Hydrology

Hydrology was assessed for the San Joaquin River downstream of the Friant Dam to the town of Newman, near the confluence of the Merced River. All data was collected from two USGS stream gauges. Gauge # 11-251000, just below the Friant Dam, is located at river mile 268 and has been in existence since 1907. Gauge #11-254000, near the town of Mendota, is located at river mile 207 and has data ranging from 1939 – 1954 and from 2000 –present (United States Geological Survey 2014).

Table 2: Reoccurrence intervals for historic and altered flow regimes along the San Joaquin River (Cain et al. 2003)

	Middle San Joaquin (cfs)[2]	
	Pre-Dam (1908-1940)	*Post-Dam (1948-1997)*
$Q_{1.5}$	8,651	636
Q_{2}	11,652	1,059
Q_{5}	25,070	3,355
Q_{10}	40,607	7,062
Q_{25}		
Q_{100}	194,205	77,682
Q_{MAF}	18,644	4,378

Significant alterations to the timing, magnitude, duration, frequency, and rate of change are evident in the altered flow regime compared to the natural flow regime for the San Joaquin River. Table 2 shows, flow magnitude decrease observed in reoccurrence intervals for annual peak flows. The 1.5-year to 2-year flood events are thought to be instrumental in reshaping the geomorphology of a river system by mobilizing bed loads and defining channel geometry. Table 2 shows peak flows for the San Joaquin River have drastically decreased from 8,651 cfs to 636 cfs. This decrease in flow will decrease the geomorphic dynamics of the river and in turn affect habitat for native species, including *Salicaceae* spp. The 5-year to 10-year flood events are a more relevant flow range for *Salicaceae* spp*.* because it is in this range that scouring of riverbanks occurs and bar morphology is changed within the river. At these flow rates, the difference between the historic and altered flow rates differs by more than 30,000 cfs. With these significant decreases in flow rates at specific reoccurrence intervals, river processes are being reduced tremendously.

The IHA analysis found that the most significant changes in flow include the following:

- Average monthly flows have decreased by 82-97% along the middle San Joaquin River.
- The timing of the annual low flows are delayed a month from November to December and the annual high flows delayed a month from May to June.
- Figure 8 show low pulse flows, those in the 25th percentile or less, have increased 900%. This is an increase of 5 to 54 days a year that the middle San Joaquin River experiences flows in the 25th percentile or less (Cain et al. 2003).

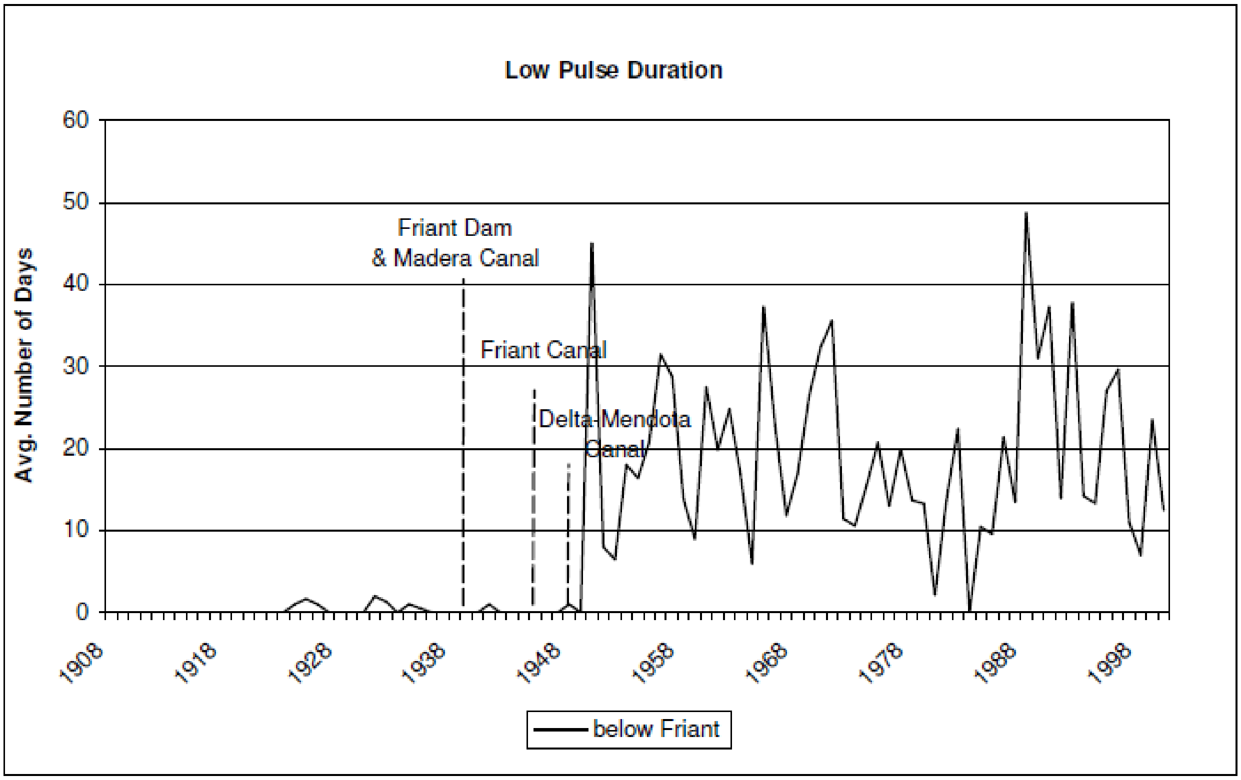

Figure 8: Low pulse flows increase after implementation of Friant Dam (Cain et al. 2003).

The HCA found that the most significant changes in flow include the following:

- Water yields have decreased from 1,813,000 AF to 528,000 AF, a 71% reduction in yield.
- Summer and fall baseflows naturally ranged from 200 to 1000 cfs, now are rarely greater than 100 cfs.
- The spring snowmelt runoff component of the hydrograph (recession limb) is critically reduced. Historic flows ranged from 6000 cfs during dry water years to 18,000 during extremely wet water years, with peaks up to 30,000 cfs. Altered flows range from 150 to 200 cfs during dry water years(Cain et al. 2003).

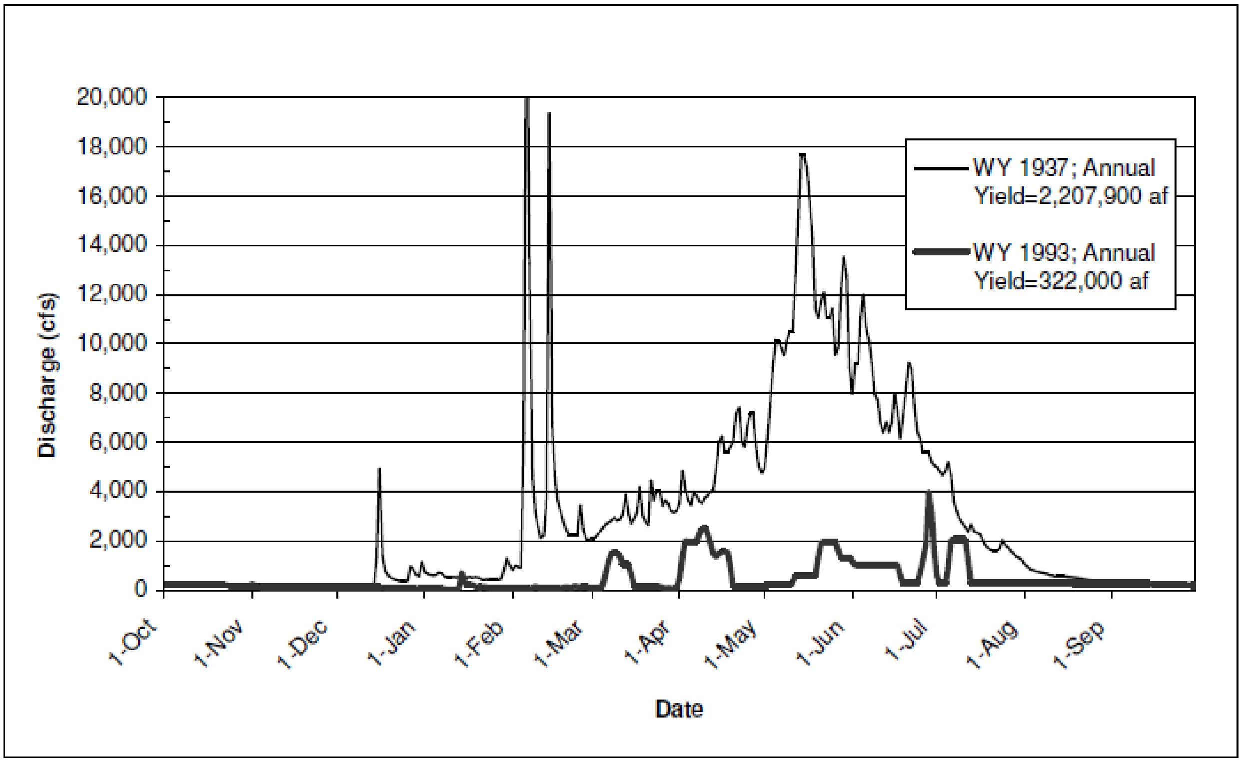

Figure 9: Wet historic and altered water years, along the San Joaquin (Cain et al. 2003).

Hydrographic comparisons display the drastic alterations in flow regimes. An overall reduction in flow magnitude is apparent in the vertical height of the hydrographs. Historic flow regime hydrograph maintains a higher cfs for the majority of the water year. This alteration will lead to greater *Salicaceae* spp. seedling mortality. Lower flows lead to lower seedling establishment along the river. This lower establishment makes seedling much more susceptible to scour during wetter water years. Summer and fall baseflows are comparable for three months of the water year. Flow magnitude affects the river dynamics needed to shape river morphology. Scour, deposition, mobilization of bed load, and the creation of river sands bars occur at a diverse range of flows. Environmental flows without any resemblance to natural flow regimes will lead to more static river systems that lack health and ability for regeneration.

Frequency of flow events are diminished in the altered flow regime. Each spike in the hydrograph is representational of a rain or snowmelt event. While the historic hydrograph has many peaks and valleys the altered flow regime is a whittled down version of the natural. Little resemblance remains between the two.

Duration and timing of flood events is also critically altered. While the historic hydrograph increases from fall baseflow in December the altered hydrograph does not increase until mid-January. The natural hydrograph spikes in February, representing late winter rain events, and then recedes to an elevated winter baseflow. A ramping disturbance flow represents increasing cfs due to rain and snowmelt runoff (Naiman et al. 2005). The winter snowmelt peaks in June before gradually receding to summer baseflow. The altered hydrograph has much lower winter flows and does not display a ramping disturbance flow or increasing winter baseflows. After increased discharge events on the altered hydrograph occur, flow returns to an annual minimum flow. Timing is also delayed about a month for each component of the hydrograph.

Rate of change of flow is greatly impacted; the historic hydrograph shows the presence of a ramping disturbance flow while the altered hydrograph does not. The peaks of the altered hydrograph increase and decrease at high rates of change, unlike the more gradual rates of change present in the historic hydrograph. Each peak in the altered hydrograph returns to an annual minimum flow greatly affecting the disturbance ecology of the river system.

San Joaquin River - *Salicaceae* spp. Seed Release Timing

Seed release timing data for *Salicaceae* spp. is necessary for generating environmental flow recommendations along the Sa Joaquin.   Since, seed release timing varies annually and from location to location, it is important establish a temporal range. Seed release timing was studied along the San Joaquin by John Stella and his colleagues at Stillwater Sciences. Between 2002 and 2004 seed fecundity index was calculated (i.e. the average number of open catkins per tree in a given location.

At all locations, *Populus fremontii* and *Salix goodingii* have similar open catkins timings and fecundity indexes. *Salix exigua* open catkins timings displayed a later peak release than *Populus fremontii* and *Salix goodingii* and more irregular catkin opening timings. This irregularity is hypothesized to be due to *Salix exigua*'s ability to clonally reproduce when a branch is broken off and swept downstream. This difference in life strategies could explain the difference in seed fecundity. *Populus fremontii* release their seeds from mid-April through late May, *Salix goodingii* release their seeds from mid-May through late June, and *Salix exigua* release their seeds immediately following *Salix goodingii*.

Hydrochory is a phenomenon that is crucial to the establishment of Salicaceae spp. seedlings. Figure 10 shows the sequential occurrence of peak flows caused by snowmelt runoff and peak seed releases of *Salicaceae* spp. *Populus fremontii* seed release peaks two to three weeks before the *Salix* spp. This occurred consistently in the years these species were studied(Stella et al. 2006).

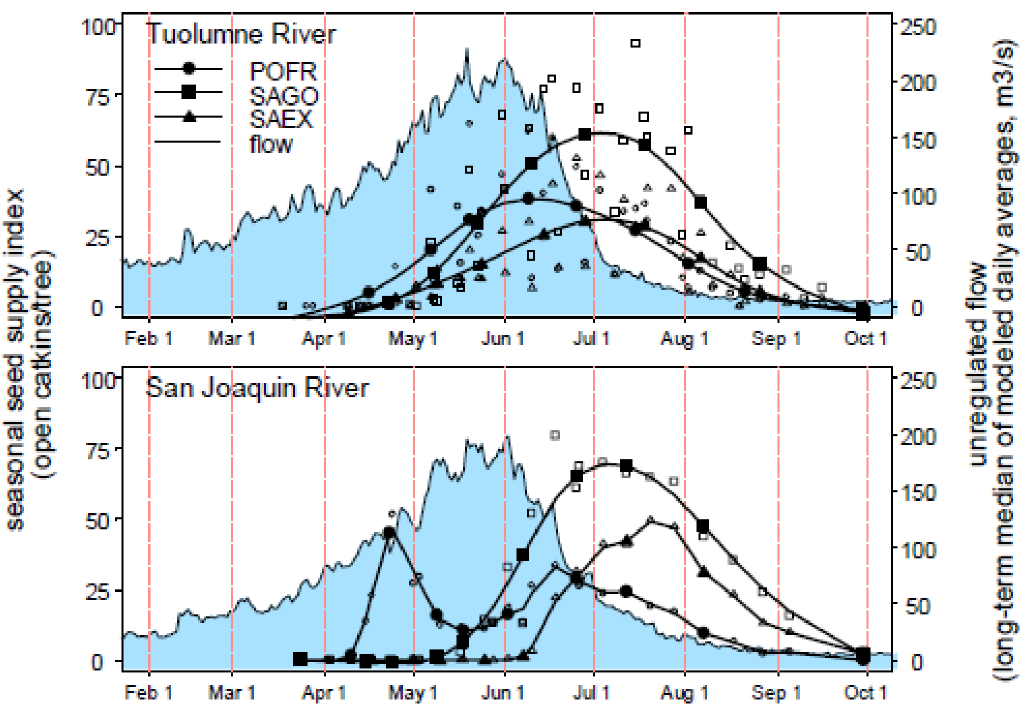

Figure 10: Annual hydrograph v. fecundity index (Stillwater Sciences 2006)

San Joaquin River - *Salicaceae* spp*.* Response to Receding Groundwater

Groundwater is essential for the recruitment of Salicaceae spp. seedling recruitment after germination. Along rivers of the Central Valley the river stage is equivalent to the height of groundwater. *Salicaceae* spp. require constant contact with a groundwater source or they will not survive. Therefore, the rate of decrease of river height from snowmelt peak to summer baseflow is crucial to the survival of Salicaceae seedlings.

Experiments conducted showed that for *Populus fremontii* the crucial threshold was a rate of decrease of 1cm d^{-1}, for *Salix exigua* the crucial threshold was a rate of decrease of 1.5 cm d^{-1}, and for *Salix goodingii the* crucial threshold was a rate of decrease of 3 cm d^{-1}. At this rate *Populus fremontii* displayed a survival rate of 0.68, *Salix goodingii* displayed a survival rate of 0.84, and *Salix exigua* displayed a survival rate of 0.64. When the rate of decrease increased to 3 cm d^{-1}, survival rates plummeted. *Populus fremontii* survival rate decreased by 0.56 to 0.12, *Salix goodingii* decreased by 0.46 to 0.38, and *Salix exigua* decreased by 0.38 to 0.26. Seedling survival was highest from 0 – 1 cm d^{-1}. Increased survivorship was positively correlated with increased root growth rates. Overall *Salix goodingii* displayed the highest root growth rates and highest survivorship under the largest range of receding groundwater rates (Stillwater Sciences 2006).

San Joaquin River Environmental Flow Recommendations

The natural flow regime‘s natural variability is beneficial to the overall health of a river system(Poff et al. 1997). It is important that this variability be apparent in the environmental flow regime prescription for any river. Environmental flows for Central Valley Rivers should focus on the winter snowmelt component of the hydrograph. Winter snowmelt is crucial to the establishment of Salicaceae spp. and other riparian tree species.

Magnitude

Due to water diversions and the presence of dams along the San Joaquin River, an overall decrease in flow magnitude is currently being experienced (McBain and Trush 2002, Cain et al. 2003). Key recommendations for flow magnitude along the San Joaquin River provided by hydrographic components:

- Summer baseflow – Flow should range from 200 to 400 cfs during the dry summer months associated with California's Mediterranean climate.
- Winter floods – These peak winter flows are associated with large winter rain storms. Natural winter floods are underrepresented in the current default restoration flow schedule created by the SJRRP.
- Winter baseflow - Depending on the restoration type-year winter baseflow will increase as a ramping disturbance flow (i.e. a stair step shaped hydrographic component). This ramping disturbance flow would mimic the natural winter baseflow. Wet and normal-wet restoration type-years will experience a 4,000 cfs flushing flow, as seen in figure 11. These flows occur from April 16-30 and have geomorphological importance. Associated with the flushing flow, is a short lived 8,000 cfs flow. During wet restoration type-years recruitment flows may be implemented. These are flows > 8,000 cfs that promote the recruitment and survivorship of *Salicaceae* spp*.* along the stream bank and associated riparian ecosystem (San Joaquin River Restoration Program 2010, 2013a).
- Snowmelt recession– This component is most critical to the recruitment of *Salicaceae* spp*.* California's Central Valley. Snowmelt recession must mimic the natural flow closely in order for seedling recruitment to occur. A major spike in flow must occur to scour stream banks of vegetation, mobilize and deposit fine sediments, and recharge the water table and soil moisture levels. The following timeline outlines the general flow rates for recession limb of the winter snowmelt.

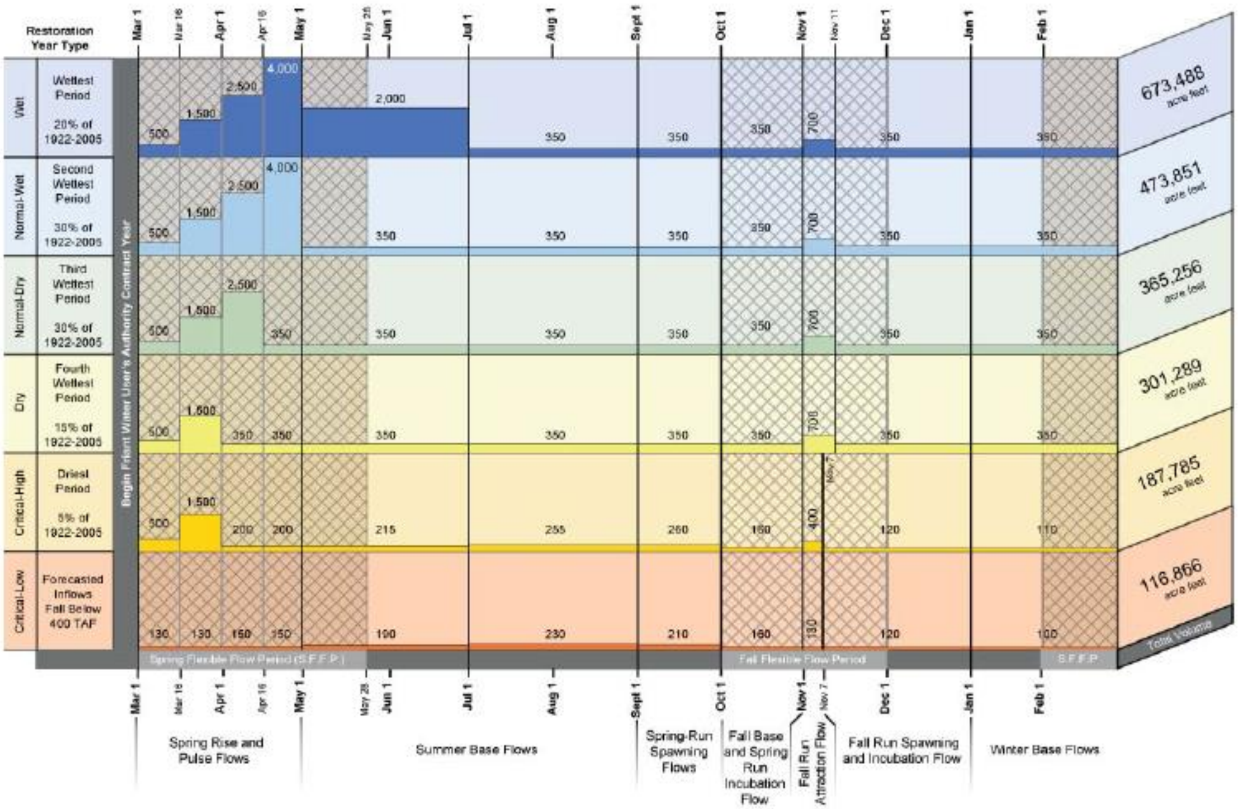

Figure 11: SRRJP restoration flow default schedule (San Joaquin River Restoration Program 2013a)

- March 15 – Starting at 1,500 cfs increase 300 cfs/day
- April 19 – Peak at 13,500 cfs, begin rapid decline of 500 cfs/day
- April 24 – Flow of 10,000 cfs ramp down is rapid and at 9,000 cfs ramp down maintains 100 cfs/day ramp down to facilitate recruitment of *Populus fremontii.*
- May 12 – At 7,500 cfs ramp down increases to 200 cfs/day
- June 1 – Second peak occurs at 7,000 cfs, this corresponds with *Salix goodingii* recruitment timing.
- June 8 – Ramp down at 100 cfs/day to facilitate recruitment (Stillwater Sciences 2003b)

Frequency

Due to this inter-annual variability in flow, the SJRRP has implemented a restoration year-type classification system. It is useful for scheduling annual flow requirements in the San Joaquin River, and ensuring inter-annual variability in the environmental flow regime. This restoration year-type classification calculated the unimpaired inflow into Millerton Lake, this is the Lake formed by the Friant Dam along the San Joaquin River. Wet years are those when unimpaired flow > 2,500,000 acre feet (AF) per year. Normal-wet years are those when unimpaired flow < 2,500,000 AF per year but > 1,450,000 AF per year. Normal-dry years are those when unimpaired flow < 1,450,000 AF per year but > 930,000 AF per year. Dry years are those when unimpaired flow < 930,000 AF per year but > 670,000 AF per year. Critical-high years are those when unimpaired flow < 670,000 AF per year but > 400,000 AF per year. Critical-low years are those when unimpaired flow < 400,000 AF per year (San Joaquin River Restoration Program 2010, 2013a).

Each of these restoration year-types will determine a water allocation that may be released from Friant and other dams along the San Joaquin. For the purpose of this study the water allocations for the Friant Dam will be the only ones considered. Figure 11, shows the restoration year-type in the left hand column, the default restoration flow schedule in the middle, and the water allocation in the right column. Water allocations decrease as river conditions move from wet to dry years. Higher water allocations at the Friant Dam allow for greater variation between winter peak flows and summer baseflow.

Flushing flows are flows at 4,000 cfs that are only present during the wet restoration type-years. These flows are designed to flush fine sediment and leave behind the larger particles. Flushing flows are also associated with a short-lived (several hours) 8,000 cfs flow. This is another flow designed to facilitate geomorphic dynamics within the river and associated riparian ecosystems. During wet years, the restoration administrator has 90 days from the beginning of the flushing flows to schedule recruitment flows. Recruitment flows are the larger magnitude flow events that facilitate the recruitment of *Salicaceae* spp. along the stream banks and associated riparian ecosystems (San Joaquin River Restoration Program 2013a). Recruitment flow will not be scheduled every year however this is characteristic of the natural flow regime.

Duration

Restoration flows begin on March 1, because the restoration year begins in March. From March 1 to May 28 the spring rise and pulse flows occur along the San Joaquin. The spring rise pulse flow would be equivalent to the winter baseflow described in Cain 2008. Spring rise and pulse flows is considered a flexible flow period. This means that the timing of release can be modified by the restoration administrator. Since this component of the hydrograph is dependent on the timing of *Salicaceae* spp. seed release its timing must be modified slightly from year to year. Summer baseflow occurs from May 29 to August 31, it is equivalent to the hydrograph component of the same name from Cain 2008. Spring and fall run spawning and incubation flows occur between September 1 and December 31. This restoration hydrograph component is designed to promote the recruitment and survivorship of *Salmonid* spp. and is the other flexible flow period. This restoration hydrographic component is equivalent to the tail end of summer baseflows and winter floods from Cain 2008. A small peak is scheduled during this time and is aimed at facilitating *Salmonid* spp. survival. The winter flood component from Cain 2008 is underrepresented here. Winter baseflows occur between January 1 and February 28/29 and are equivalent to the beginning of the hydrograph component of the same name from Cain 2008 (San Joaquin River Restoration Program 2010, 2013a).

Timing

Timing is variable. Flexible flow periods were created to adhere to the most critical aspect of the natural flow regime, variability (Richter et al. 1996, Poff et al. 1997). The timing of seed release from *Salicaceae* spp. is also variable due to temperature and other factors (Mahoney and Rood 1998, Stella et al. 2006). The snowmelt recession of the hydrograph corresponds with *Salicaceae* seedling recruitment. *Populus fremontii* generally releases its seeds between mid-April and late May. *Salix* spp. generally release their seeds between mid-May and late June.

Rate of Change of Flow

Rate of change of flow should resemble those characteristics of the natural flow regime. Central Valley Rivers are flashy and display peak flows that recede quickly. These flood peaks are those caused by large rain events. The only component that is different is the snowmelt recession. Snowmelt recession displays winter baseflows that ramp up to the snowmelt peak and ramp down to summer baseflow. Snowmelt recession should recede at slower rates to mimic the natural flow regime and the facilitate *Salicaceae* spp. recruitment. Due to the uniqueness of the snowmelt recession and its importance to recruitment of *Salicaceae* seeds, specific recommendations will be provided for this component only. The most important aspect of this component is that flow should recede at a rate that the river stage decreases no more than 1 cm d^{-1} to maintain 50% survivorship for *Populus fremontii*, 1.5 cm d^{-1} to maintain 50% survivorship for *Salix exigua,* and 3 cm d^{-1} to maintain 50% survivorship for *Salix goodingii* (Stillwater Sciences 2006). Figure 12 displays a hypothetical hydrograph depicting these conditions. See the snowmelt recession section for a more detailed suggestion of what this component should resemble.

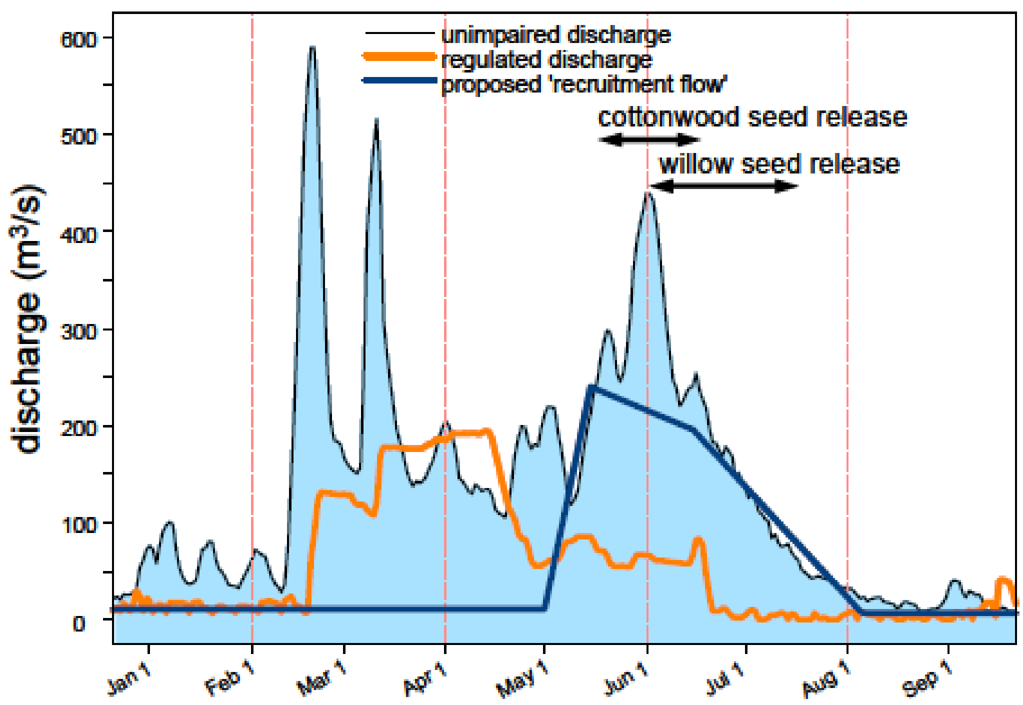

Figure 12: Hypothetical hydrograph outlining flow recommendations for the San Joaquin River (Stillwater Sciences 2006).

San Joaquin Vegetation Monitoring

Interim flows, are the experimental flows released from the Friant Dam beginning October 1, 2009 extending no longer than January 1, 2014. Restoration flows, are the full environmental flows that will be implemented in the future after adaptation due to interim flow monitoring and assessment (Natural Resources Defense Council et al. 2006). Flow data provided is interim flows for the San Joaquin for the 2011 and 2012 WY's. The 2011 WY was classified as a wet year and the 2012 WY was classified as a normal-dry year. These flows are considered interim flows, and do not reflect default restoration flow scheduling but show some resemblance.

The 2011 WY is characterized by higher flow magnitude than the 2012 WY. The April 2011 peak was 7,800 cfs. This peak was considered a flood control release. With the exception of an extra flow peak in early July this component is similar to the snowmelt recession component of the hydrograph described in Cain 2008. The 2012 WY is similar to a normal-wet WY. There is a peak just over 700 cfs in October that corresponds with the fall run attraction flow designed facilitate *Salmonid* spp. migration seen in figure 11. The hydrograph also displays a ramping winter baseflow beginning March 1, 2012. Figure 12, also displays a hydrograph component similar to a ramping flow that peaks just over 1,000 cfs.

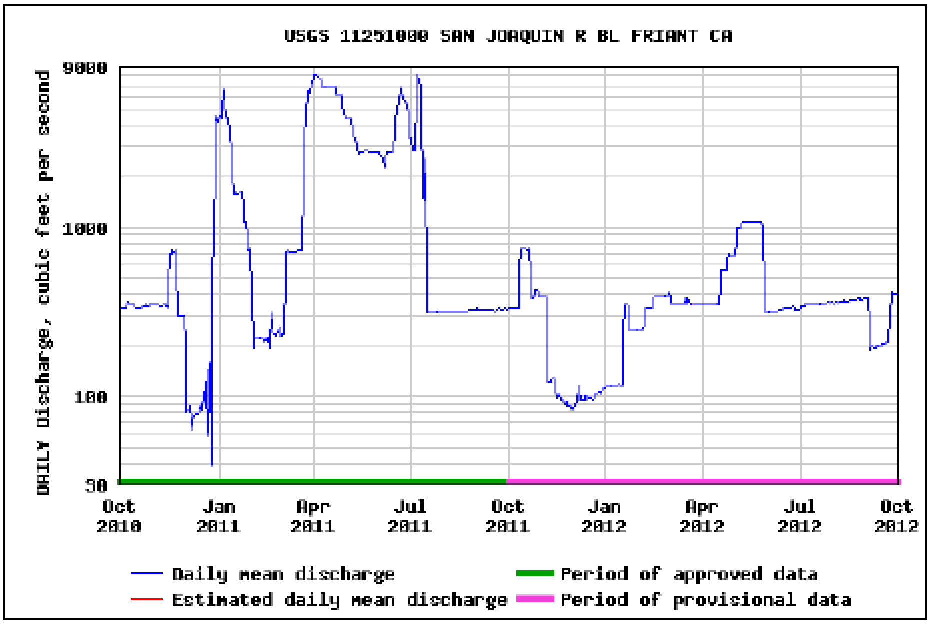

Figure 13: Interim Flow Data, 10-2010 through 10-2012, recorded from USGS gauge 11251000 just downstream of Friant Dam (United States Department of the Interior 2013).

Twenty transects were established by the United States Bureau of Reclamation (USBR) in 2011. These transects were revisited in 2012. At each transect percent overstory coverage was calculated. This was done by noting the point along the transect where the species overstory began and ended. The height of the largest specimen within the stand was then calculated (United States Department of the Interior 2012, 2013).

Results from table 3 showed that *Populus fremontii* decreased in percent overstory coverage in River Reach 1B from 2011 to 2012 (4.1 to 2.7) but average height increased from 2.0 m to 3.7m. Percent overstory coverage also decreased from 2011 to 2012 (16.7 to 14.4) but tree height remained the same (15.0 m). The smaller tree heights at River Reach 1B indicate that the trees were young. It is hypothesized that these young trees were lost due to the high flood control release that took place in April

2011. The increase in tree height could be contributed to the loss of smaller trees located closer to the river that were swept away in the larger flow events of 2011. River Reach 3 had the highest percentage of riparian forest cover. The average heights of these trees were higher indicating they were older. Even though the percent overstory coverage decreased the average height remained the same.

Table 3 shows *Salix exigua* increased in percent overstory coverage and average tree height in River Reaches 1A and 1B. *Salix goodingii* increased in overstory percent coverage with the exception of River Reaches 2A, 4B, and ESB. Average tree height generally increased as well, with the exception of river reach 1B and 3. Due to very different condition from the 2011 WY to the 2012 WY, it is doubtful that vegetation changes were due to interim flows.

Table 3: Average total percent overstory cover in San Joaquin river reaches for 2011 and 2012 (United States Department of the Interior 2013).

Average Total Percent Overstory Cover - Upstream Reaches																				
	1A				1B				2A				2B				3			
	2011		2012		2011		2012		2011		2012		2011		2012		2011		2012	
Species	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)
White alder	0.6	4.3	0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
Button bush	7.1	2.2	9.0	3.4	7.6	2.4	7.8	2.7	0.0		0.0		0.0		0.0		0.0		0.0	
Oregon ash	8.9	10.3	17.6	15.0	0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
Fremont cottonwood	0.0		0.0		4.1	2.0	2.7	3.7	0.0		0.0		0.0		0.0		16.7	15.0	14.4	15.0
Valley oak	21.1	12.1	20.0	21.3	0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
Sandbar willow	5.7	2.2	9.4	2.4	22.1	2.8	28.3	2.8	0.0		0.0		0.0		0.0		0.0		0.0	
Gooding's willow	0.0	0.0	1.8	2.7	11.8	3.5	12.7	3.5	1.1	3.9	0.9	4.1	4.4	5.9	12.5	6	0.8	3.0	2.8	3.0
Arroyo willow	4.7	4.9	3.8	6.0	0.0		0.0		0.0		0.0		0.0		0.0		0.0		0.0	
Black elderberry	0.0		0.0		0.0		0.0		0.0		0.0		2.8	4.2	6.9	4.8	0.0		0.0	
Total native	48.0		61.6		45.5		51.5		1.1		0.9		7.2		19.4		17.4		17.2	
Giant reed	0.0		0.0		9.8	4.4	9.5	5.2	0.0		0.0		0.0		0.0		0.0		0.0	
Scarlet wisteria	0.0		0.0		0.3	1.3	1.6	1.7	0.0		0.0		0.0		0.0		0.0		0.0	
Total introduced	0.0		0.0		10.1		11.1		0.0		0.0		0.0		0.0		0.0		0.0	
Total canopy*	45.2		46.7		54.9		58.9		1.1		0.9		7.2		19.4		17.4		16.1	

Average Total Percent Overstory Cover – Downstream Reaches										
	ESB				4B2				5	
	2011		2012		2011		2012		2012	
Species	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)	Tot % cov	Avg. Ht. (m)
Gooding's willow	0.2	na	0.0		9.3	8.6	8.5	10.5	62.8	4.4
Total native	0.2		0.0		9.3		8.5		62.8	
Total canopy*	0.2		0.0		9.3		8.5		62.8	

Sacramento River Background

The Sacramento Valley, home of the largest river in California, is a 27,500 mi^2 watershed in the northern portion of the Central Valley. The Sacramento River flows

447 miles from its headwaters in the Cascade Mountains to the San Francisco Bay-Delta, making it the longest river in California. Tributaries of the Sacramento River include the Feather River, the American River, and Butte Creek. Anthropogenic degradation has been affecting the river since the mid-19th-century California gold rush. 20th-century farming practices have continued to degrade the river and associated riparian ecosystems(U. S. Environmental Protection Agency 2014).

In 1986 the California Legislature passed Senate Bill 1086, which required the protection and restoration of the Sacramento River and associated riparian ecosystems. The reach of the river from Red Bluff to Colusa, known as the middle river, is the main focus of ecological restoration along the river (Brown et al. 2011). The Upper Sacramento River Fisheries and Riparian Habitat Plan, written in 1989, outlines the objectives and implementation plan for the restoration of the Sacramento River. Objectives for the restoration project include:

1. To protect and restore the health of the wild strains of Salmon and Steelhead species in the river.
2. To protect and preserve current patches of riparian ecosystem. Then reestablish continuous riparian ecosystem from the reach of river between Redding and Chico, and reestablish riparian ecosystem from the reach of river between Chico and Verona(The Resources Agency of the State of California 1989).

Sacrament River Reach Descriptions

Vegetative and land use descriptions for the river reaches of the Sacramento River were based on aerial imagery. Aerial imagery surveys were carried in 1999 out by the Geographic Information Center at Chico State University. For restoration purposes the Sacramento River is broken down into four main river reaches. The following are vegetative and land use descriptions of each reach.

River Reach 1 extends from Keswick Dam to the Red Bluff Diversion Dam (302 – 243 RM). Major land use by percentage incudes agriculture 35%, upland habitat 34%, and riparian habitat 12%, and urban 12%. Of the vegetation in the conservation area 42% was riparian forest and 30% was riparian scrub. This reach is unique for its 128 acres of valley oak woodland vegetation type that occurs outside the river's 100-year flood plain.

River Reach 2 extends from Red Bluff Diversion Dam to Chico Landing (243 – 194L RM). Major land use by percentage incudes agriculture 53%, riparian habitat 20% and upland habitat 15%. Of the vegetation in the conservation area 15% was riparian forest and 12% was riparian scrub.

River Reach 3 extends from Chico Landing to Colusa Bridge (194L – 143 RM). Major land use by percentage incudes riparian habitat 48%, agriculture 16% and upland habitat 11%. Of the vegetation in the conservation area 42% was riparian forest and 30% was riparian scrub. This reach boasts the largest acreage of freshwater marsh and mature riparian forest.

River Reach 4 extends from Colusa Bridge to Verona (143 – 80 RM). Major land use by Percentage incudes agriculture 53%, riparian habitat 20% and upland habitat 15%. Of the vegetation in the conservation area 15% was riparian forest and 12% was riparian scrub (Sacramento River Advisory Council 2003).

Sacramento River Hydrology

Hydrology was assessed for the Sacramento River downstream of the Shasta Dam to the Verona. All data was collected from two USGS stream gauges. Gauge # 11-377100, just below the Shasta Dam, is located near the Red Bluff California and has been in existence since 1880. Gauge # 11-425500, near the town of Verona, and has been in existence since 1929 (United States Geological Survey 2014).

A comparison of the natural and altered flow regimes shows the extent of alteration to the flow regime of the Sacramento River. Reoccurrence Interval data in table 4 shows how the alteration of the natural flow regime. This is evident in the flow decrease of corresponding flow events. The 2-year flood event, instrumental in mobilizing bed loads and affecting channel morphology, has decreased from 105,000 cfs to 78,000 cfs, a decrease of 27,000 cfs. The 10-year flood event has decreased from 225,000 cfs to 153,000 cfs, a decrease of 72,000 cfs. The 5 to 10-year flood events are thought to effectively scour the stream banks and create bar geomorphology along river and riparian ecosystems. This is important because it creates the habitat needed for seedling recruitment.

Table 4: Reoccurrence interval data for the Sacramento River (Cain 2008).

Recurrence Interval (years)	Post 1939 (cfs)	Pre 1939 (cfs)
1.5	65,000	87,000
2	78,000	105,000
2.5	87,000	120,000
5	120,000	160,000
10	153,000	225,000
20	160,000	285,000
50	190,000	350,000
100	210,000	400,000

The hydrographs below represents historic and altered flow regimes for the Sacramento River. The blue line represents the historic flow regime, the red line represents the altered flow regime, the upper black line represents the 75th percentile flows of the historic flow regime, and the lower black line represents the 25th percentile of the historic flow regime. Key findings include:

- An elevated summer baseflow for each water year type. 3,000 to 4,000 cfs was average in the historic flow regime; the altered flow regime displays flows of over 10,000 cfs. This is attributed to heightened agricultural demand for water during the summer months.
- Snowmelt recession is nonexistent in the dry and critical years. During the wet WY's it is shortened considerably.

- Winter floods are not represented in the altered flow regime. Floods in both regimes begin around the same time, but in the altered regime the flood recede quickly (Cain 2008).

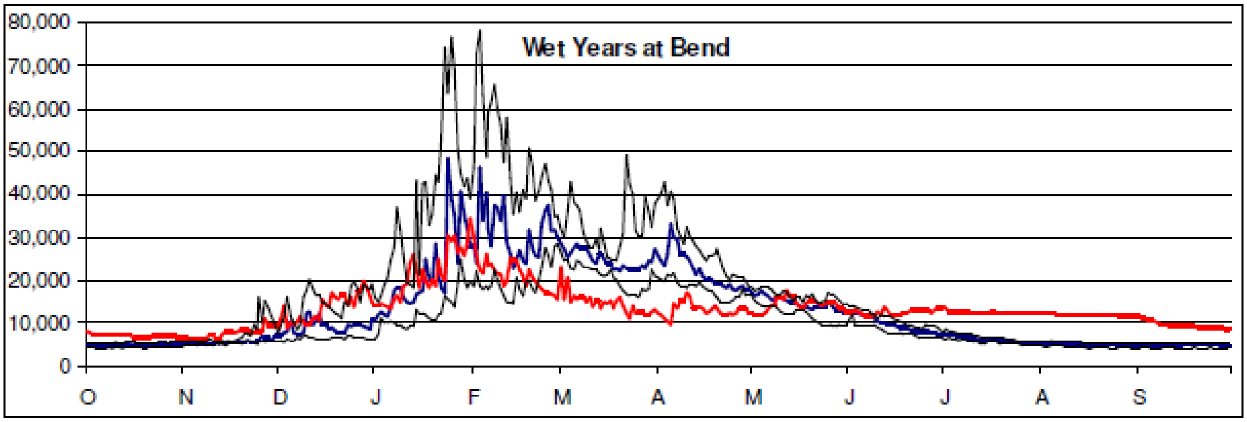

Figure 14: Wet water year for the Sacramento River (Cain 2008)

Figure 14 displays a historic wet WY's for the Sacramento River display a series of ramping flow peaks from later November to the beginning of February. This ramping disturbance flow is caused by late fall and early winter rain events. The altered flow regime hydrograph falls in between the 25th and 7th percentile during these months and resembles the historic flow regime. From February through September a disparity in flow regimes is apparent. From the beginning of February through the beginning of April, the altered flow regime recedes to summer baseflow very quickly. From April through the beginning of June flow is variable until stabilizing in the beginning of June. Summer baseflow in the altered flow regime is almost double the flow magnitude of the historic flow regime.

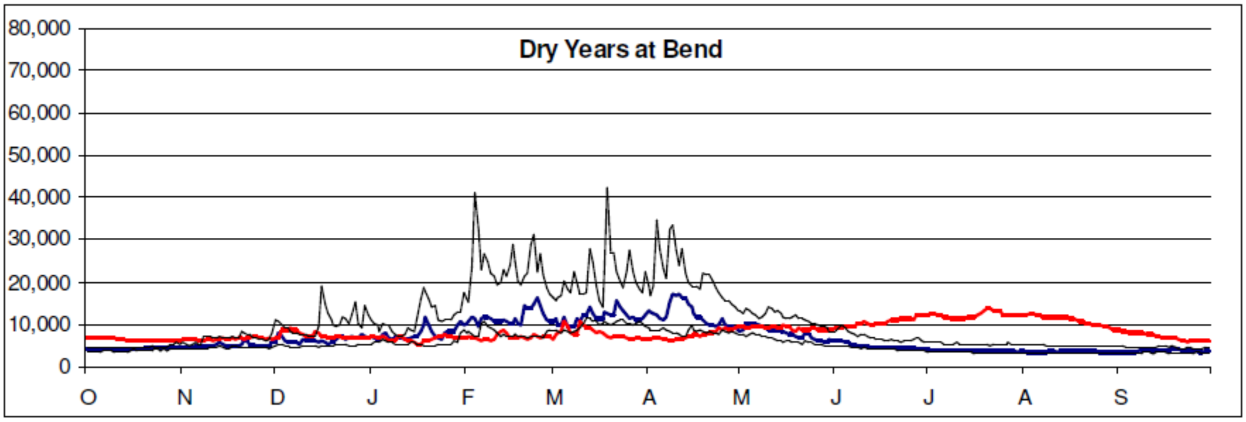

Figure 15: Dry water year for the Sacramento River (Cain 2008).

Historic and altered dry years sow an increased disparity in the flow regimes. The altered flow regime shows limited variability making it difficult to differentiate the unique components of a Central Valley River hydrograph. Increased summer baseflow displays the highest flow magnitude of the altered flow regime during a dry year. Winter floods, winter baseflow, and snowmelt recession are not represented in altered flow regime.

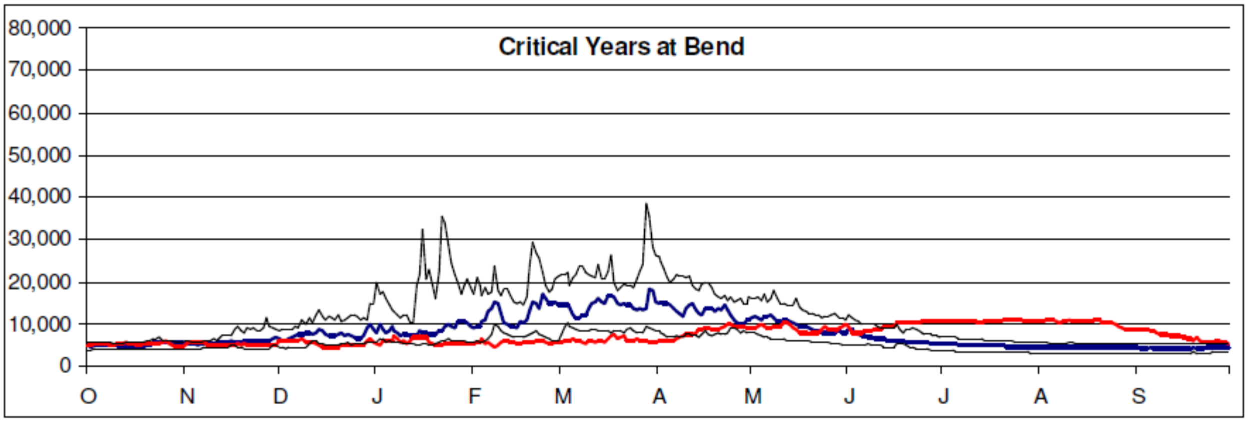

Figure 16: Critical water year for the Sacramento River (Cain 2008).

Critical water years are similar to the dry water years on the Sacramento River. Variability in the altered flow regime is minimal, the summer baseflow peaks around 10,000 cfs during the months of July and August. Winter floods, winter baseflow, and snowmelt recession components are nonexistent.

Sacramento River - *Salicaceae* spp. Seedling Release Timing

Salicaceae spp. seedling release varies between locations, species, and annually. Data presented in this section represents average seedling release timings. Data collected along the Sacramento is also cross referenced with the studies conducted along the San Joaquin by Stillwater Sciences and J. Stella between 2002 and 2006.

Populus fremontii seedling release along the Sacramento River was calculated from April 15 through July, with a peak from the last week of April through the beginning of June. *Salix goodingii* was calculated from May 15 through August, with a peak from June 1 through July 15. *Salix exigua* seedling release was calculated from June through August, with a peak between June 1 through July 15 (Stillwater Sciences 2007). Note the lack of specificity in the date ranges: it is suggested that the degree-day model be utilized to calculate seedling releases (Stillwater Sciences 2006, 2007).

Sacramento River - *Salicaceae* spp. Response to Receding Groundwater

Salicaceae spp. are considered phreatophytic, meaning that their roots must remain in contact with a perennial water source (Stillwater Sciences 2007). This perennial water sources is groundwater. Assuming that groundwater and river stage height are equivalent, stage height above summer baseflow is a critical factor in the seedling recruitment.

Data on seedling root growth and subsequent response to the receding groundwater was conducted by Roberts in 2002 and was cross-referenced with Stillwater Sciences' study conducted by Stella in 2006. Roberts found that on average seven week old seedling roots grew 40 cm in length. Average root growth over the seven week period 8 mm d^{-1} (Roberts et al. 2002). Another study conducted by Morgan in 2005 recorded average root growth of *Populus fremontii* seedlings at 5 mm d^{-1} (Stillwater Sciences 2007).

With slightly higher root growth rate along the Sacramento River, receding groundwater rates are suggested to recede at < 2 cm d^{-1}. Decreasing rates of 2-4 cm d^{-1} result in moderate percentages of seedling recruitment. Decreasing rates less than 4 cm d^{-1} is highly stressful for seedling recruitment and can result in 100% seedling mortality (Roberts et al. 2002, Stillwater Sciences 2006).

Receding groundwater rates of 2 - 4 cm d^{-1} will result in higher percentages of *Salix* spp. seedling recruitment. At a receding groundwater rate of 3 cm d^{-1} *Salix goodingii* displays 35% survivorship, *Salix exigua* displays 26% survivorship, and *Populus fremontii* displays 12% survivorship (Stillwater Sciences 2006). Some receding groundwater rates are more beneficial to *Salix* spp. then *Populus* spp. *Populus fremontii* requires a slower rate of decline for higher percentage of seedling recruitment than *Salix goodingii* and *Salix exigua*.

Sacramento Environmental Flow Recommendations

The Sacramento River natural flow regime displays higher flow magnitude relative to the San Joaquin. During dry years this magnitude is greatly reduced and the natural variability of the river is non-existent. Summer baseflows are abnormally high in the altered flow regime. These issues and those surrounding recruitment flows will be addressed in the this section.

Magnitude

Due to water diversions and the presence of dams along the Sacramento River, an overall decrease in flow magnitude is currently being experienced (McBain and Trush 2002, Cain 2008). Key recommendations for flow magnitude along the Sacramento River include:

- Summer baseflow, under the altered hydrologic regime, is high. This excess flow should be utilized at other times of year when flow is more crucial to *Salmonid* spp. or riparian tree recruitment. Lower summer baseflows would also be beneficial in controlling the spread of non-native vegetation. Flow should decrease as water nears the San Francisco Bay Delta. Suggested Summer Baseflows are 8,000 cfs below Keswick Dam, 6,000 cfs below Red Bluff

Diversion Dam, 4,500 below Glenn Colusa Irrigation District Diversion (GCID) Dam, and 4,000 cfs below Colusa. Fall baseflow is the lowest flow of the year and should have a similar flow allocation 5,500 cfs below Keswick Dam, 5,250 cfs below Red Bluff Diversion, 5,000 cfs below GCID Diversion Dam, and 4,750 cfs below Colusa (Cain 2008).

- Winter floods should initiate the geomorphic processes of bed mobilization, scour, and channel migration. Data on bed mobilization is most abundant than the other two processes. Suggested flow rates from Keswick Dam to Bend Bridge (near Red Bluff) is 105,000 cfs in wet years, 85,000 cfs for normal-wet years, 65,000 cfs normal-dry years, and 35,000 cfs for dry years. Ideal time for these flow peaks is early March (Cain 2008).
- Winter baseflow will increase with the ramping disturbance flow. The duration and magnitude of this ramping flow will depend on the WY. This ramping disturbance flow would mimic the natural winter baseflow. Suggested flows from Keswick Dam are 8,000 cfs in wet years, 7,000 cfs in normal-wet years, 6,500 cfs in normal-dry years, 6,000 cfs in dry years, and 4,500 cfs in critical years (Cain 2008).
- Snowmelt recession is the most critical hydrographic component to the recruitment of *Salicaceae* spp. Snowmelt recession must mimic the natural flow closely in order for seedling recruitment to occur. A major spike in flow must occur to scour stream banks of vegetation, mobilize and deposit fine sediments, recharge the water table and soil moisture levels. Suggested snowmelt peaks from Keswick Dam in wet years is 37,000 cfs and in normal-wet years is 23,000(Cain 2008). These peaks should be maintained for four to seven days and should begin a 50 day ramp down period to suggested summer baseflow. These recruitment flows should occur from late April to early June to facilitate *Populus fremontii* seedling recruitment, from late May to early July to facilitate *Salix goodingii* seedling recruitment. Recruitment flows prior to late April might benefit Arroyo Willow (*Salix lasiolepis*) and those after the windows suggested might benefit *Salix goodingii* and *Salix exigua* (Stillwater Sciences 2007).

Frequency

Due to this inter-annual variability in flow, a restoration year-type classification system has been utilized. This is a similar classification used by the SJRRP. The Sacramento River classification was developed by the CDWR which was developed by the State water Resources Control Board. Wet and normal-wet years occur 40% of the time. For the Sacramento River recruitment flows occur only during these two WY classifications (Stillwater Sciences 2007). Normal-wet, dry and critically dry years occur 60% of the time and do not facilitate recruitment flows.

Duration

A general hydrographic schedule is outlined. Fall baseflow would last from September 16 to November 30. Winter baseflow would last from December 1 through March 1. March 1 through the beginning of July would encompass the snowmelt recession component of the hydrograph. Summer baseflow would last from June 15 through September 15 (Cain 2008). These durations can vary from year to year depending on temperature and precipitation amounts.

Timing

Timing is variable but general guidelines are outlined in Cain 2008 for the timing of hydrologic events. See the Duration section for a timeline of events.

Rate of Change

The most important rate of change rate is the decrease of snowmelt recession component of the hydrograph. Over the 50 day ramp down period, critical rates of decrease include the following: a decrease in flow magnitude < 2 cm d^{-1} will facilitate the recruitment of *Populus fremontii* and a decrease in flow magnitude of 2-4 cm d^{-1} will facilitate the recruitment of *Salix* spp. seedlings. A disparity in required decrease in flow rates exists between the two *Salix* spp. but they are grouped together because of *Salix exigua*'s ability to reproduce asexually. Ability to reproduce clonally through branch pieces reduces *Salix* exigua's dependence on high success rates for seedling recruitment (Stillwater Sciences 2007).

Sacramento Vegetation Monitoring

In 2011 the Sacramento River Monitoring and Assessment Project (SRMAP) released a final administrative report. This report outlined results found from a 2007 vegetative mapping project, changes between vegetative mapping conducted in 1999 and in 2007, and improvements to methodology. The mapping was conducted using Geographic Information Systems (GIS) technology. Fourteen vegetation types and two habitat types were delineated for the study. The two habitat types were gravel bars and open water.

SRMAP found that of the 32,811 acres that make up the Sacramento Conservation Area 7,892.5 acres consisted of *Populus fremontii* coverage, 92.2 acres consisted of *Salix goodingii* coverage, 1,849.5 acres consisted of mixed willow (*Salix* spp.) coverage, and 1,717.4 acres consisted of gravel bar habitat. The gravel bar habitat type was included because of its importance to the germination of *Salicaceae* spp. along the stream banks of rivers (Brown et al. 2011). SRMAP was reluctant to make large scale comparisons between the 1999 vegetative maps and data produced by the Geographic Information Center at Chico State. This was due to differences in methodologies. Due to inconsistencies in methodology, data cannot accurately link flow releases with successional trends in vegetation.

Recommendations

The following recommendations are made to ensure the effectiveness of restoration activities and environmental flow regime prescriptions. Recommendations for restoration and environmental flow regime are based on related literature.

Restoration Objectives

I recommend that the Sacramento River restoration and the SJRRP develop specific ecosystems process based objectives. Both restoration projects have been driven by conservation objectives designed to protect and restore primarily *Salmonid* fish species and to promote the general health of the river. Even though the Endangered Species Act dictates that these fish species should be protected, a restoration objective should be added to address ecosystem processes that drive the health of these fish and the overall health of the watershed as a whole (Palmer et al. 2009). Although the restoration project on the San Joaquin River is being implemented as the result of the law suit settlement for *Salmonid* spp., I believe incorporating an ecosystem objective would enhance success of the overall project.

While restoration on both rivers investigates a wide variety of factors affecting *Salmonid* spp., such as riparian ecosystem and river health, ecosystem processes should be listed specifically in their objectives. Large river restoration projects have budgets in the millions of dollars, SJRRP has an estimated $892,056,000 through 2025 (estimate does not include the San Joaquin River Fund) (San Joaquin River Restoration Program 2013b). With this much money on the line, adequate development of objectives that promote the health and sustainability of the whole watershed is a necessity. Ecosystem based objectives should drive these large projects and restoration methods and monitoring protocol. The implementation of environmental flows can easily be linked to environmental processes, such as physical and biochemical processes that increase water purification (Palmer 2008). Both restoration projects take multi-disciplinary approaches to their focal species approach with a variety of restoration activities that address a myriad of underlying ecosystem processes. Process based objectives should be clearly stated in the objectives so that the many government agencies, consulting firms, and universities involved do not lose sight of the underlying restoration goals.

Process based objectives can also be easily translated into ecosystem services that are beneficial to stakeholders. This is key in the paradigm shift needed to take place if river restoration and environmental flow implementation is to gain support (Naiman et al. 2002). While biodiversity is a crucial ecosystem service, the ecosystem service is not enough to convince funders or the voting public that money should be allocated to restore a river system. Process based objectives, while sometimes difficult to assess, address root issues and limiting factors that have caused degradation of the ecosystem or landscape.

Restoration Implementation

Implementation of several guidelines is recommended for each of these restoration projects:

- Promotion of stream migration (Stillwater Sciences 2006)
- Eradication of weedy species (Stillwater Sciences 2006)
- Incorporation a default flow schedule for the Sacramento River
- Inclusion of a winter flood pulse for both rivers

Any channelization of both rivers should be minimized to promote the creation of suitable habitat for *Salicaceae* spp. As a river meanders it erodes outside of the s-shaped curve and deposits sediment on the inside of the s-shaped curve. This deposition creates point bars along the stream bank which are ideal habitat sites for *Salicaceae* spp. seedlings to germinate (Mahoney and Rood 1998, Stillwater Sciences 2006, Rood et al. 2007).

The eradication of invasives species should be undertaken by each of the river restoration projects. Along the stream banks, scour caused by peaks in flow magnitude will control the encroachment of invasive species. At higher elevations along the flood plain, manual eradication should be considered for those species that provide the largest threat to native riparian species present. Priority invasive species include: giant reed (*Arundo donax)*, tree of heaven *(Ailanthus altissima),* perennial pepperweed (*Lepidium latifolium*) and *Tamarix* spp.

SJRRP has a default restoration flow schedule that outlines the magnitude, frequency, duration, timing, and rate of change of the restoration flow regime. Creating this schedule would be a valuable tool for the Sacramento River. Within these schedules both river projects should reevaluate the incorporation of the winter flood pulse. The winter flood pulse is representative of large winter rain events that produce high flow events (HFE’s) within the river channel. In the SJRRP default restoration flow schedule these events are underrepresented.

Restoration Monitoring

Monitoring data is crucial for an adaptive management approach. SJRRP does a great job of outlining its monitoring plan. It is recommended that these procedures should be adopted and implemented along the Sacramento River. Key monitoring data needed for the assessment of *Salicaceae* spp. recruitment are as follows (San Joaquin River Restoration Program 2014):

- Flow data, magnitude and stage height data
- Percent overstory coverage
- Tree DBH
- Stem density
- Riparian habitat evaluation
- Groundwater levels
- Aerial imagery

Flow data will provide information that can be used to make connections between changes in flow regime and *Salicaceae* spp. recruitment. Percent overstory coverage, tree DBH, and stem density is also used to establish the relationship between flow regime and *Salicaceae* spp. recruitment. These data will help to develop an understanding of locations that possess physical characteristics that promote the recruitment and survivorship of *Salicaceae* spp. Groundwater is an important physical characteristic needed for riparian tree establishment (United States Department of the Interior 2013, San Joaquin River Restoration Program 2014).

Long term data are needed to drive Central Valley River restoration. This requires that current monitoring plans be implemented over the life of these projects. It is recommended that both river restoration projects utilize aerial imagery to analyze long term vegetative community dynamics. A consistent protocol should be adopted in the Central Valley watershed. Constituent mapping techniques would allow for successes to be investigated and compared throughout the Central Valley and between restoration projects. I recommend that both restoration projects adopt the mapping guidelines, field forms, and protocol outlined in the Vegetation Program developed by the California Native Plant Society (CNPS). This program is clearly described and easily accessible on the CNPS website. It also utilizes A Manual of California Vegetation (2009) a more current manual than Holland's 1986 manual.

Adaptive Management

An adaptive management approach is clearly displayed in SJRRP documents. The interim flow project is an example of how this approach can drive restoration monitoring and assessment. As stated in the previous section monitoring data should be collected and documented in a way that it can be utilized for future use.

The adaptive management plans for the Central Valley should include high flow experiments (HFE). Due to incomplete historic flow data experiments should be conducted in wet WY's, when reservoirs are at or near capacity. These HFE's should be designed to represent large flow events such as the 75-year flood event. A great example of such an adaptive management approach is the Glenn Canyon Dam along the Colorado River. HFE's along the Colorado were conducted in 1996, 2004, and 2008. In 1996 a seven day peak of 45,000 cfs provided much data on sediment dynamics, sandbar deposition, and the effects of HFE's on rainbow trout (*Oncorhynchus mykiss*) habitat (United States Department of the Interior and United States Geological Survey 2011, Konrad et al. 2011).

Winter flood peaks are underrepresented along the two main Central Valley Rivers. Flood peaks provide many unknown services that drive physical and biological processes. With limited water resources and increased water needs winter floods do not occur every WY but they do serve a purpose in river flow regimes. Ample experiments should be undertaken during such even including documentation of pre and post sandbar conditions, vegetative coverage along stream banks, and water quality (i.e. temperature).

Timing of HFE should be planned in ordered to not adversely affect fish species, riparian vegetation communities, and river processes. It is recommended that HFE's occur from the beginning of January through the end of March. This will mimic the natural flow regime of Central Valley Rivers.

Environmental Flow Planning Recommendations

Water needs will increase as human population levels increase, along with demands for energy, irrigation for agricultural needs, industrial uses of water, and uncertainties associated with climate change (Palmer et al. 2009). As rivers continue to be harnessed and altered for human benefit, the less the river reflects the dynamic natural flow regime. The less the river reflects the natural flow regime the more degraded the health of the river becomes. It is recommended that environmental flow planning strive to balance the river's need for the natural flow regime and the human need for water. Due to increased needs for water planning protocol associated with river conservation and restoration becomes vital. Effective planning will maximize cost-effectiveness, promote decisions based on scientific research, promote decisions that incorporate stakeholder input, and ultimately contribute to fields of hydro-ecology and environmental flow management.

It is recommended that the ecological limits of hydrologic alteration (ELOHA) framework be utilized to further develop environmental flow requirements for California's Central Valley Rivers. ELOHA is a framework that utilizes historic flow data, modeled flow data, and current flow data to classify rivers by type and establish environmental flow requirements (Poff et al. 2010). Current frameworks resemble those outlined in (Richter and Thomas 2007) which is a for-runner of the ELOHA framework.

The ELOHA planning network begins by collecting baseline hydrographs and developed hydrographs in step one, as seen in figure 17. Baseline hydrographs represent rivers with minimal alterations, while the developed hydrograph represents the altered flow regime associated with flow alteration and other anthropogenic alteration such as land use and urban encroachment. These hydrographs will be generated using models and historic flow data. Step two analyzes flow regime and geomorphic characteristics to classify rivers by type. This allows for commonalities to be found between rivers of the same type. The third step is analyzing the degree flow alteration; this is done through the use of computer software. The degree of alteration is calculated by comparing the difference between the baseline hydrograph and the developed hydrograph. Step four is the development of a hypothesis to relate quantified ecological metrics to a degree of alteration of the hydrograph. General concepts are well established in the hydro-ecology community. One such example is Poff's paradigm of the natural flow regime which states that the natural variability of a river is crucial to the ecological health of the river and associated riparian ecosystems. Step four will drive the promotion of data that links specific ecological metrics with the degree of deviation between the baseline and developed hydrographs. This step is crucial in collecting data necessary to develop hydro-ecology and the science of prescribing environmental flow regimes. Poff et al 2010 admits shortcomings in developing a societal process for incorporating input from stakeholders and resource managers. Societal input has been incorporated into this model in Pahl-Wostl et al 2013 (Pahl-Wostl et al. 2013). After environmental flow regimes are prescribed and implemented an adaptive management is approach is utilized to ensure the calibration of the environmental flow regime. The pivotal segment of the ELOHA framework is ecological data, because this data drives understanding of the effects of the degree of deviation between the baseline hydrograph and the developed hydrograph(Poff et al. 2010).

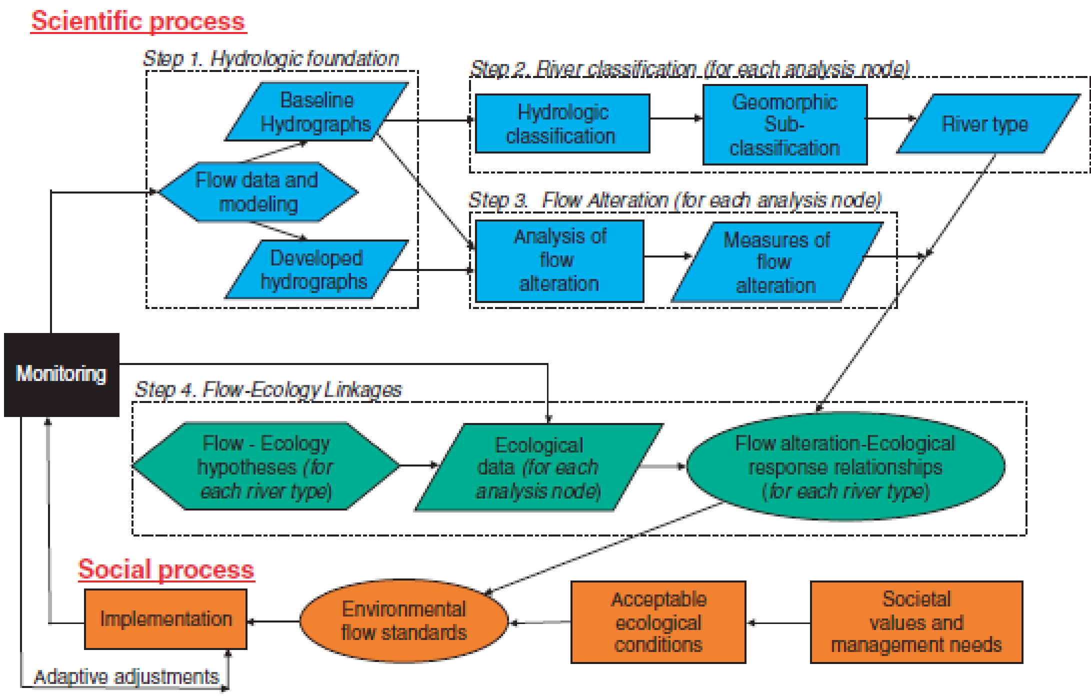

Figure 17: ELOHA framework for developing appropriate environmental flow regimes (Poff et al. 2010).

The ELOHA framework is recommended for future river restoration and conservation for three main reasons. Reason one; ELOHA drives the development of hydro-ecology and the science of prescribing environmental flow regimes. This is crucial as water needs increase. Reason two, ELOHA is beneficial in situations where historic flow regime data is lacking. In most cases flow gauge data has not been collected on a long enough time line to provide a full picture of the characteristics of the natural flow regime. For example, a flow gauge that has collected flow data for fifty years might or might not reflect 100-year, 75-year, or even 50-year flood events. These flood events are critical in delineating flood plains, establishing flood event magnitude, and developing a clear picture of the natural flow regime. Through modelling, baseline hydrographs can enhance or take the place of historic flow data. Reason three; adaptive management is incorporated into the framework. Adaptive management promotes the re-calibration of environmental through ongoing monitoring and assessment.

The ELOHA framework is the fusion of many environmental flow planning and analysis frameworks. The science of environmental flow prescription is in its infancy the ELOHA framework needs further evaluation and modification. The main modification is the need for analysis of water quality data in conjunctions with the analysis of flow data. Implementation of the ELOHA framework in the Upper Tennessee River Basin resulted in mixed results. The results were attributed to the need for further investigation in the relationship between water temperature variation and fish survivorship (McManamay et al. 2013). Water quality is included in the definition of environmental flow provided by the 2007 Brisbane Declaration. Water quality includes water temperature, sediment loads, salinity, and the presence of pollutants. Water quality data needs to be incorporated into the prescription of environmental flows.

Conclusion

The flow regimes of the two main Central Valley Rivers have been greatly altered. So much water has been diverted from the San Joaquin stream channel that a 60 mile reach annually runs dry. The extirpation of Chinook salmon can be linked to this break in river flow. *Salicaceae* spp. and other *Salmonid* spp. are among the numbers organisms that are affected by this annual occurrence. Similar conditions exist on the Sacramento River. Lowered winter floods have affected *Populus fremontii* recruitment along its stream banks. It is important that a default environmental flow schedule be implemented for the Sacramento to address issues of altered flow regime and decreasing *Salicaceae* seedling recruitment.

Many of the articles and reports cited in this study have systematically gathered the data required to prescribe an environmental flow regime needed to promote *Salicaceae* seedling recruitment. Seedling release timings and effects of receding groundwater on seedlings is well understood. Data proving the effectiveness of these flow regimes within the Central Valley are lacking. Adaptive management strategies not only improve the effectiveness of restoration techniques but they also drive the science behind restoration ecology and environmental flow regimes. Both restoration projects can promote environmental flow science by gathering and synthesizing this data for use in other rivers in California and around the world.

Monitoring and assessment of the effectiveness of the environmental flow regime in the Central Valley can be very effective. It will require the monitoring of the five components of natural flow regimes and vegetation dynamics in the riparian ecosystems. These data will need to be assessed properly so that scientists and river managers can adequately understand the effects of these restoration implementations. Groundwork has been laid, especially in the SJRRP, to collect and synthesize large quantities of flow and vegetative data. These projects have the capacity to restore these degraded river systems and refine restoration ecology. In time it will be understood to what extent these projects are deemed successful.

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