3 CONCEPTUAL MODELS FOR KEY ECOSYSTEM COMPONENTS

Articulating a general restoration vision helps define the restored conditions you are aiming for. This section includes visions for key components of the San Joaquin River ecosystem: salmonids, native resident fish, riparian and wetland vegetation, wildlife species. Also describes governing assumptions.

3.1 Fluvial Geomorphology

3.1.1 Geomorphic Context of the San Joaquin River

The San Joaquin River is a defining feature of the San Joaquin Valley, which forms the southern half of the Central Valley and stretches from near Bakersfield in the south to the confluence with the Sacramento River at the Sacramento-San Joaquin Delta in the north. The headwaters of the San Joaquin River are located at the Sierra Nevada crest near Mt. Davis. Starting at the headwaters, the river rushes over glacial polished granite, cuts through glacial deposits, and spills out onto the San Joaquin Valley where it meanders over 360 miles to the Sacramento-San Joaquin Delta. Downstream of the project area, the San Joaquin River is joined by its three dominant eastside tributaries: the Merced, Tuolumne, and Stanislaus rivers. Further downstream, the smaller Calaveras River empties into the mainstem San Joaquin near Stockton. Los Banos and Oristemba creeks are the major westside tributaries that drain the eastern slope of the Coast Range. The westside tributaries are precipitation-driven and have smaller drainage areas than the snow-fed tributaries of the east side of the San Joaquin Valley. Specific geomorphic features of the five reaches of the San Joaquin River in the project area are presented below.

Reach 1
At Friant Dam (RM 267.5), the San Joaquin River emerges from the bedrock foothills of the Sierra Nevada and cuts across the alluvial plain of the San Joaquin Valley and the channel is confined by terraces for 35 miles. The river is gravel-bedded and the river corridor is confined by bluffs. The reach-average gradient is low for its drainage area compared with similar streams that drain the Sierra Nevada such as the Tuolumne, Merced, and Stanislaus rivers. Early maps show that the river contained large islands in this reach.

Under the current regulated flow regime, historical alluvial floodplains along the channel function like terraces. Similar to its eastside tributaries, the San Joaquin River has been subjected to extensive gravel mining that has depleted some portions of Reach 1 of coarse sediment. Riverine habitats have been converted to lentic habitat in reaches where the river has captured adjacent floodplain gravel pits and where aggregate has been mined from the active channel. Under current conditions, many of the low-flow secondary channels that created historical islands in the river corridor are either used for riparian diversions or have been separated from the main channel and only function during flood conditions.

Reach 2
Downstream of Gravelly Ford (RM 204.8), the confining terraces dissipate and the alluvium spreads out as coalescing alluvial fans near the axis of the valley (Janda 1966). The valley is very wide in this reach. The channel bed transitions from gravel- to sand-bedded near Gravelly Ford and the channel is single-threaded and meandering. As the channel approaches the center of the

San Joaquin Valley and encounters the alluvial fans from the west side of the valley and backwater from Fresno Slough, the slope decreases.

Under current conditions, the river is single threaded and meanders within the floodway throughout this reach. The floodway is confined by levees on both sides of the channel. Peak flows are regulated by the Chowchilla Bypass Structure (RM 216.1), which diverts high flow to the Chowchilla Bypass Channel, and Mendota Dam (RM 204.8), which regulates upstream water surface elevations. Low flows can be absent downstream of Gravelly Ford during certain portions of the year.

Reach 3
At Mendota Dam (RM 204.8), the single-threaded channel turns north and flows along the axis of the valley toward the Sacramento-San Joaquin Delta. The protruding fans of the Coast Range basins on the west side of the valley exert the only control in this reach. The channel is sand-bedded and has a meandering pattern.

Under the current regulated conditions, the river is confined by levees along both banks.

Reach 4
Reach 4 begins at Sack Dam (RM 182.0), where the low gradient, sand-bedded channel enters the flood basin of the San Joaquin River. An extensive network of anabranching sloughs (channels that run parallel to the mainstem) conveys floodwaters and intercepts flow and sediment. Consequently, the sediment supply to the mainstem is limited.

Under current conditions, flow is regulated at Sand Slough Bypass Structure (RM 168.5), which diverts flow to Eastside Bypass Channel, and Mariposa Bypass Channel (RM 147.6), which returns water to the river from the Eastside Bypass Channel.

Reach 5
Reach 5 begins at the Bear Creek confluence (RM 135.8) and ends at the Merced River confluence (RM 118.0). This sand bedded reach is located in the San Joaquin River flood basin, and the alluvial fan of the Merced River acts as a base level control, helping to form the upstream detention basins in Reaches 4 and 5. Anabranching sand bedded sloughs in Reach 4 and 5 continue to intercept and return flow and sediment from the mainstem channel.

Under current conditions, levees confine the low-gradient, sand-bedded channel in Reach 5.

3.1.2 Fluvial Geomorphological Functions and Attributes of Alluvial Rivers

Several recent restoration plans have been developed for Central Valley rivers, most of which focus on the alluvial reaches downstream of major water supply and flood control dams. Many of these plans emphasize the restoration of ecological processes as the central approach for creating and maintaining aquatic and riparian habitats (CALFED 2000, McBain and Trush 1998, Stillwater Sciences 2002). This process-based approach to river restoration focuses attention on fluvial geomorphic processes—the fundamental forces that affect the shape and character of river channels and floodplains. Embodied in several of these restoration plans is a set of fluvial geomorphic functions and attributes that are emerging as targets for process-based river restoration. This set of attributes includes a frequently mobile bed, a balanced sediment budget and continuous bedload routing, a migrating channel, and frequently inundated floodplains.

Because the planning area for the San Joaquin River restoration strategies is broadly similar to that of these other restoration plans (e.g., an alluvial reach downstream of a major water supply dam), this set of fluvial geomorphic attributes provides a basis for analyzing the potential for restoring fluvial geomorphic processes in the San Joaquin River.

This section examines the rationale underlying the fluvial geomorphic functions and attributes that are being targeted widely in the restoration of Central Valley rivers. This evaluation provides a framework for understanding some of the limits imposed on restoring fluvial geomorphic processes in the San Joaquin River because of local characteristics and fundamental physical constraints.

3.1.2.1 Bed mobility and scour

Flows can mobilize the sediment that composes the bed of a river channel, transporting and depositing the sediment downstream. A number of factors help determine the magnitude of the flow required to mobilize bed sediments, including channel slope and width and the size of sediment that comprise the bed. Generally, steeper gradients, narrower channel widths, and smaller particle sizes reduce the magnitude of the discharge needed to initiate bed mobility. Conversely, lower gradients, wider channel widths, and larger particle sizes increase the magnitude of the discharge required to initiate bed mobility. In addition to mobilizing the surface of a channel bed, flows can also scour sediment by eroding and transporting subsurface sediment. The discharges required to induce bed scour are larger than the flows needed to initiate bed mobility.

The mobilization and scour of a channel bed supports several ecological functions, including:
- reducing vegetation encroachment of the active channel by scouring riparian vegetation that colonizes surfaces within the channel; and,
- scouring low-flow channels to support the movement of aquatic organisms during seasonal periods of low flow.

In gravel-bedded reaches, the mobilization and scour of the channel bed can also provide additional ecological benefits, including:
- improving spawning habitat quality for salmonid fish species by reducing the storage of fine sediments in framework spawning gravels, when balanced by efforts to reduce the supply of fine sediment delivered to the channel); and,
- stimulating aquatic invertebrate production by improving gravel quality and by creating disturbance associated with bed mobilization.

Many of the process-based restoration plans for Central Valley rivers link bed mobility with the concept of the “bankfull flow.” This concept suggests that the flow required to fill a river channel between its banks is a geomorphically significant discharge that provides sufficient energy to drive several fluvial geomorphic processes, including bed mobilization. For alluvial rivers in the western United States, the bankfull flow generally corresponds with 1.5- to 2-year flows. As a result, river restoration plans in the Central Valley often include guidelines for releasing flows on regulated streams that will mobilize the channel bed approximately every two years.

3.1.2.2 Sediment budget and continuity

When flows mobilize sediment from the channel bed and transport it downstream, the lost sediment must be replenished from upstream sources; otherwise, the channel will incise as flows erode its bed, or the bed will coarsen as the surface layer is eroded. When viewed at appropriate temporal and spatial scales, rivers generally have a balanced sediment budget, in which the sediment that is transported downstream is balanced by the supply of new sediment introduced to the channel from upstream sources. This balanced sediment budget results in long-term average aggradation and degradation, which is often termed as a “quasi-equilibrium” state. Rivers typically recruit sediment from upstream reaches and tributaries, as well as through bank erosion, but human activities can disrupt the delivery of sediment to the channel, causing an imbalance in the sediment budget. For example, dams can trap sediment from upstream sources, and the mining of floodplain gravel and the rip-rapping of banks can reduce the amount of sediment available for recruitment to the channel through bank erosion. A river’s sediment budget can also be thrown out of balance by the introduction of too much sediment to the channel, as can happen from both human activities (e.g., increased erosion from agricultural fields or forest cutting) and natural events (e.g., mass wasting events that deliver large pulses of sediment to the channel).

When the sediment budget of a river gets out of balance (i.e., when a river’s sediment transport capacity is not balanced with the supply of sediment to the channel), river channels can either aggrade (e.g., supply exceeds capacity) or degrade (e.g., capacity exceeds supply), with varying impacts upon aquatic and riparian habitats. A channel that incises can induce channel narrowing, which can reduce the amount and quality of aquatic habitat. An incising channel can also reduce groundwater levels underlying adjacent floodplains by establishing a lower baseflow elevation, which can, in turn, affect the recruitment and establishment of riparian vegetation. In contrast, an aggrading channel can reduce water depths and complicate fish passage.

Restoration plans for Central Valley rivers regulated by dams, or deprived of sediment by aggregate mining, generally recommend an initial, short-term infusion of sediment to compensate for years of lost sediment supply, followed by the periodic introduction of sediment in balance with the river’s sediment transport capacity (CALFED 2000, McBain and Trush 1998, Stillwater Sciences 2002). Such guidelines generally aim to prevent long-term degradation of the channel and to provide the river with a fundamental building block of aquatic and riparian habitat.

Even if a river has a balanced sediment budget, there can be local disruptions in the transport of sediment. For example, instream gravel mining pits disrupt sediment continuity by acting as sediment traps, capturing sediment transported from upstream reaches and depriving downstream reaches of sediment. Similarly, small dams can disrupt sediment continuity. For example, under normal operating conditions, Mendota Dam acts as a sediment trap by impounding sediment; however, sediment that accumulates behind the dam is periodically flushed from Mendota Pool, resulting in pulses of sediment being delivered periodically to downstream reaches. In this manner, Mendota Dam does not affect the overall sediment supply of the system, but it does disrupt the continuity of sediment routing. The continuity of bedload routing can also be disrupted by the coarsening of the channel bed, whereby regulated flows are incapable of mobilizing the coarser sediment that composes the bed.

Several restoration plans for Central Valley rivers strive to restore bedload routing, generally by reclaiming instream gravel pits to eliminate their trapping potential, and by the injection of smaller gravels that can be mobilized by regulated flows (CALFED 2000, McBain and Trush 1998, McBain and Trush et al. 2000, Stillwater Sciences 2002).

3.1.2.3 Channel migration

As described above, rivers can recruit sediment to the channel by eroding their banks. Periodically, high flows erode the bank on the outside of meander bends where water velocities are higher than average channel velocities, while depositing sediment on point bars on the inside of meander bends, where water velocities are usually lower. Through this process of eroding banks on the outside of a bend, and building point bars on the inside of bend, the channel migrates laterally. The sand-bedded reaches of a river usually experience higher rates of channel migration than the gravel-bedded reaches, because the smaller particle size of the sand composing the banks allows erosion to occur at lower flows than if the banks were comprised of gravel.

Channel migration can promote aquatic and riparian habitat complexity. For example, undercut banks can provide cover and rearing habitat for juvenile salmonids, and tall cutbanks can provide nesting sites for bank swallows. Channel migration also helps drives the riparian regeneration process, because the erosion of banks can recruit mature riparian vegetation to the channel, while the formation of point bars provides surfaces to support colonization by new riparian vegetation. Channel migration thus stimulates both structural and age diversity in riparian vegetation.

Unlike the use of the bankfull flow concept to estimate the discharge required to initiate bed mobility, there is no similar concept to estimate the flow magnitude to erode banks and drive channel migration, because bank erosion is influenced by bank composition and cohesiveness, and by vegetation that stabilizes banks. Though it is not always clear what flow is needed to drive channel migration, many restoration plans for Central Valley rivers promote the concept of a meander corridor, or a floodway within which a river is free to migrate (CALFED 2002, McBain and Trush 1998, SRAC 1998, Stillwater Sciences 2002,). These restoration plans also include recommendations for enhancing flows and the supply of sediment to help stimulate channel migration.

It is important to note that not all channels change their alignment through the relatively gradual process of bank erosion, which can require several periodic high flows to cause a discernible change in channel alignment. River channels can also leap from their current channel alignment and capture a new pathway in the course of a single high-flow event, often re-capturing a historical channel that had been abandoned by a previous channel avulsion. Many reaches of Central Valley rivers historically shifted their alignment through the process of channel avulsion, rather than migration. However, few restoration plans actively promote the restoration of channel avulsion, in large measure because of potential conflicts with surrounding land uses, and because the flows necessary to achieve channel avulsion would likely cause significant damage to human infrastructure.

3.1.2.4 Floodplain inundation

Floodplains on Central Valley rivers are typically wider than their associated active channels, with greater hydraulic roughness because of vegetation. When flood flows exceed a channel's conveyance capacity and inundate adjacent floodplains, water velocities are reduced, which induces sediment deposition on the floodplain. This deposition of fresh sediment can provide surfaces composed of bare mineral soils that support the colonization of riparian vegetation, which can contribute to the age and structural diversity of vegetation. Sediment deposition on a floodplain can be spatially variable, which can create topographical diversity of the floodplain, which can in turn stimulate vegetation diversity. Overbank flows can also create high-flow scour channels where flows concentrate and scour vegetation on the floodplain. Such scour channels support both topographical and vegetation diversity by creating openings in the existing vegetation canopy. Inundated floodplains also provide important spawning and rearing habitats for many native fish species (e.g., splittail, salmon).

Restoration plans for Central Valley rivers typically promote more frequent inundation of floodplains, often through a combination of setting back levees, releasing higher magnitude peak flows, and lowering existing floodplain surfaces or rebuilding new floodplain surfaces to better match a regulated flow regime (CALFED 2000, McBain and Trush 1998, McBain and Trush et al. 2000, Stillwater Sciences 2002). Sometimes, such actions must be accompanied by the removal, replacement, or re-location of key infrastructure (e.g., bridges, water treatment facilities) and developed areas (e.g., golf courses and housing developments that have encroached upon the floodway). Restoring the frequency of floodplain inundation, in conjunction with restoring sediment supply, can create and maintain topographical and vegetation diversity on the floodplains.

3.1.3 Fluvial Geomorphic Targets for the San Joaquin River

This section examines the applicability of the fluvial geomorphic functions and attributes described above to the mainstem San Joaquin River. In many cases, local conditions on the San Joaquin River, coupled with fundamental physical constraints imposed on flow magnitudes, make it infeasible to achieve many of the fluvial geomorphic functions and attributes that are guiding the restoration of other Central Valley rivers. As a result, there are no specific flow prescriptions defined for restoring fluvial geomorphic processes in the three restoration strategies. Nevertheless, flows defined for the restoration of other ecosystem components, such as riparian recruitment flows, have the potential to yield fluvial geomorphic benefits. Similarly, controlled flood management releases, and even larger uncontrolled flood flows, that are not contemplated in this report will likely yield fluvial geomorphic benefits.

3.1.3.1 Bed mobility and scour

The general goal of mobilizing and scouring the channel bed every two years, as is targeted on many Central Valley rivers, does not serve as a reasonable goal for the gravel-bedded reach of the San Joaquin River. Historically, bed mobilization and scour in Reach 1 was likely less frequent than this 2-year target because of the low channel gradient and sediment supply. In addition, the magnitude of the flows that historically mobilized and scoured the channel bed in Reach 1 were likely larger than the flows that can be released currently from Friant Dam. In contrast, frequent bed mobility and scour can be expected for the sand-bedded reaches of the San Joaquin River due to the small particle size of the sand bed.

Reach 1

The gravel-bedded reach of the San Joaquin River has a much lower slope than other Central Valley rivers, which increases the flow magnitude required to mobilize and scour the channel bed. Based on the simulated water surface profile developed with a HEC-2 model for a flow of 16,400 cfs, the average channel gradient of Reach 1 is 0.00056, which is among the lowest slopes one can find for a gravel-bedded river. In comparison, sample gravel-bedded reaches of the Tuolumne River and Merced River have average channel gradients of 0.0014 and 0.0023, respectively (Stillwater Sciences 2002). These channel slopes are 2.5 and 4 times steeper than that of the gravel-bedded reach of the San Joaquin River. To provide broader context, Table 3.1-1 compares the gradient of Reach 1 with the channel slopes of sample gravel-bedded reaches of other rivers in California and the Pacific Northwest.

Table 3.1-1. Average channel gradients in gravel bedded reaches of sample rivers in California and the Pacific Northwest. The gravel-bedded reach of the San Joaquin River has a channel gradient that is among the lowest one can find for a gravel-bedded river.

<table>
<tr><th colspan="3">Region</th><th>River Reach</th><th>Slope</th></tr>
<tr><td rowspan="11">Pacific Northwest</td><td rowspan="6">California</td><td rowspan="3">San Joaquin River Basin</td><td>San Joaquin River, Reach 1, CA</td><td>0.00056</td></tr>
<tr><td>Merced River Dredging Tailing Reach, CA</td><td>0.0023</td></tr>
<tr><td>Tuolumne River, CA</td><td>0.0014</td></tr>
<tr><td rowspan="8"></td><td>Clear Creek, CA</td><td>0.0024</td></tr>
<tr><td>Noyo River, CA</td><td>0.0015</td></tr>
<tr><td>Redwood Creek near Orick, CA</td><td>0.0035</td></tr>
<tr><td rowspan="5"></td><td>Sandy River near Marmot, OR</td><td>0.007</td></tr>
<tr><td>North Umpqua River near Copeland, OR</td><td>0.006</td></tr>
<tr><td>Oak Grove Fork of the Clackamas River, OR</td><td>0.0129, 0.0246</td></tr>
<tr><td>Lower Deschutes River, OR</td><td>0.00061–0.004</td></tr>
<tr><td>Lewis River, OR</td><td>0.0006</td></tr>
</table>

Table 3.1-1 indicates that few rivers have gravel-bedded reaches with slopes as low as Reach 1 of the San Joaquin River. Of the river reaches included in Table 3.1-1, only portions of the lower Deschutes River and Lewis River, both in Oregon, have channel slopes comparable to that of the gravel-bedded reach of the San Joaquin River, and the frequency of bed mobilization and scour on the lower Deschutes River is instructive. Grant et al. (1999) estimated that the channel bed of the lower Deschutes River has been mobilized 11 times over a 72-year period, or approximately once every 7 years—much less frequently than the two-year bed mobilization target being applied on Central Valley rivers. The low channel slope of Reach 1 of the San Joaquin River means that large magnitude, and therefore less frequent, flows are required to initiate bed mobility, as compared with other gravel-bedded rivers with higher channel gradients.

There is no data to indicate how often the channel bed in Reach 1 of the San Joaquin River was mobilized historically. Nevertheless, it is possible to estimate the periodicity of historical bed mobilization in Reach 1 by conducting a Shields stress analysis to calculate the flow that must be applied to mobilize and scour a given particle size in a particular reach. A Shields stress analysis requires making simplifying assumptions about the slope of the channel, the bankfull channel width, and the median grain size of particles that comprise the bed. We developed the following values for these parameters, using previously collected data and modeling:

- **a channel slope value of 0.0007.** This value represents the average bed slope of Reach 1A, as measured from a longitudinal profile of the channel bed developed for HEC-2 hydraulic modeling. It is important to note that this longitudinal profile is derived from a digital surface model rather than a ground survey, which can affect the accuracy of the channel slope measurement. It is also important to note that the channel gradient of Reach 1A is steeper than the average channel gradient of Reach 1 (0.00056), so this analysis may underestimate the discharge required to mobilize and scour the channel bed in Reach 1B.

- **a bankfull channel width of 300 feet.** There is no clear information on historical bankfull channel widths for Reach 1A; however, McBain and Trush (2002) estimated a historical average bankfull channel width of 875 feet in Reach 1B, as measured from the California Debris Commission maps that covered reaches downstream of Herndon (ACOE 1917). Cain (1997, as cited in McBain and Trush 2002) estimated 1939 bankfull channel widths between 630 feet and 1,400 feet in Reach 1A—the time period when Friant Dam was completed. Current bankfull channel widths in Reach 1A range from 300 feet to 1,000 feet, as measured from 1998 aerial photos. For this analysis, we selected the most narrow bankfull channel width (300 feet) to represent the best-case scenario of historical bed mobility and scour thresholds. Consequently, this analysis represents a conservative estimate of the flow required to initiate historical bed mobility and scour. Historical bankfull channel widths were likely wider, which means that our analysis likely underestimates the flow required historically to mobilize and scour the bed in Reach 1A.

- **a median grain size of 40 mm.** The median grain size value is based upon a series of 25 pebble counts conducted in Reach 1A by Stillwater Sciences (see Appendix A). Figure 3.1-1 shows the size distribution of each pebble count. A D_{50} of 40 mm is equal to the average of the median grain sizes for each individual pebble count. It is important to note that the median grain size derived from the pebble counts represents current bed texture, which may reflect bed coarsening associated with the sediment trapping effects of Friant Dam, as well as historical instream gravel mining. If current bed texture is coarser than historical bed texture, then our analysis overestimates the flows required to mobilize and scour the bed under historic conditions.

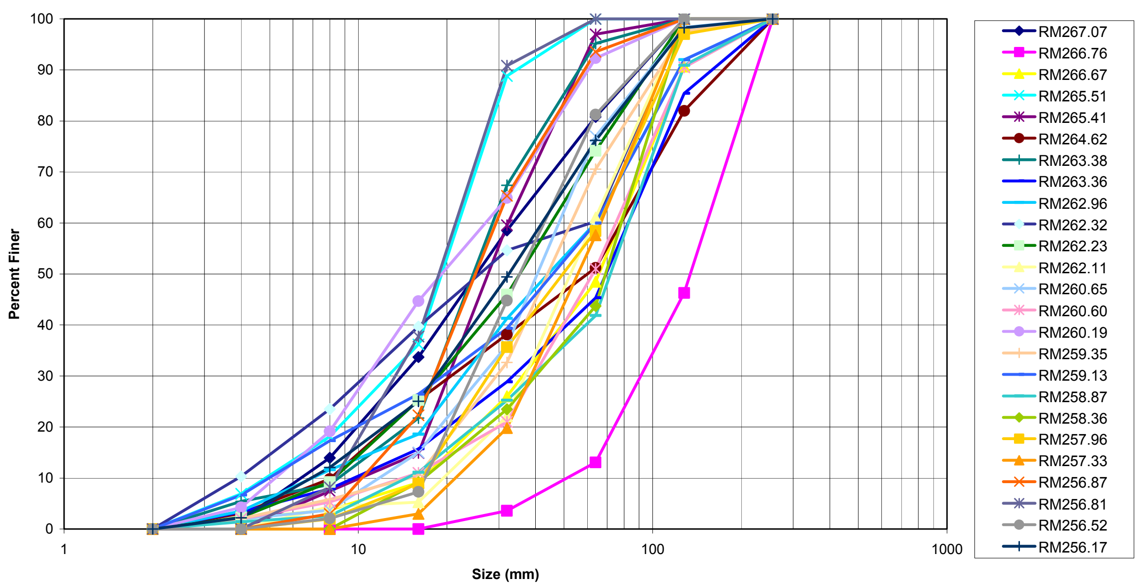

Figure 3.1-1. Surface grain size distribution for Reach 1A of the San Joaquin River. Stillwater Sciences conducted pebble counts to characterize the channel bed in Reach 1A. This figure shows the size distribution for each individual pebble count. Sediment particles finer than 2 mm were excluded from each plot to focus the analysis on the mobility of gravel. The sediment transport analysis used to estimate the periodicity of historical bed mobilization and scour assumes a D_{50} of 40 mm, which represents the average of the D_{50} values for each of the pebble counts.

Figure 3.1-2 presents the results of this Shields stress analysis for the hypothetical cross section of a channel with, a channel slope of 0.0007, a bankfull width of 300 feet, and a median grain size of

40 mm. According to Parker (1990a, b), individual particles that compose the surface of the bed have the potential to be mobilized if the normalized Shields stress (defined as the ratio of Shields stress to critical Shields stress) is between a value 1 and 1.59 (which Parker calls a mobile armor). Figure 3.1-2 shows that a flow of approximately 20,000 cfs corresponds with a Shields stress value of 1, indicating the point at which individual bed surface particles could begin to be mobilized.

The mobilization of individual bed surface particles does not achieve many of the ecological goals associated with bed mobilization. For example, to improve spawning habitat quality by mobilizing fine sediment from framework spawning gravels, subsurface particles must be exposed to scour, which requires flows capable of breaking the surface armor layer composed of coarser sediment particles. Parker (1990a, b) suggested that the surface armor layer has the potential to be broken if the normalized Shields stress is higher than 1.59. Figure 3.1-2 shows that the discharge of approximately 40,000 cfs corresponds with a Shields stress value of 1.59.

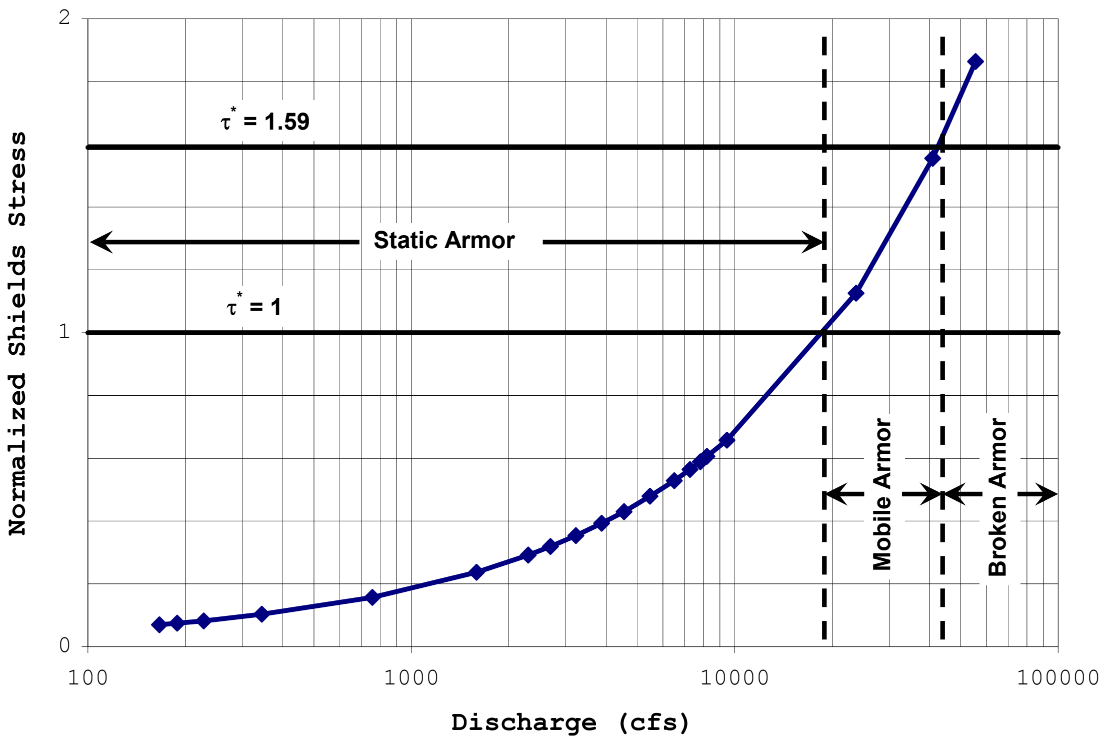

Figure 3.1-2. Periodicity of historical bed mobilization and scour for Reach 1. A Shields stress value of 1 indicates the threshold for the mobilization of individual bed surface particles, and a value of 1.59 represents the threshold for bed scour. (The regime of static armor, mobile armor and broken armor is based on the surface-based bedload equation of Parker [1990a, b], an assumed channel width of 300 feet, a median grain size of 40 mm, a channel slope of 0.0007, and a normalized critical Shields stress value of 0.0386.)

This analysis suggests that, historically, flows of 20,000 cfs were required to initiate general bed mobility in Reach 1A, while flows of 40,000 cfs were required to induce bed scour. As described above, this analysis probably underestimates the flow magnitudes that were required historically to initiate bed mobility and scour, because it uses a hypothetical bankfull channel width of 300 feet, which is considerably narrower than what was likely the historical bankfull channel width.

Also, Reach 1B has a lower slope than the 0.0007 slope value used for this analysis of Reach 1A; consequently, even higher flows were probably required historically to mobilize and scour the channel bed in Reach 1B.

Using historical flow data recorded at the USGS Friant gauge (no. 11251000), a pre-dam flow of 20,000 cfs corresponds to 4-year return period, and a discharge of 40,000 cfs represents a pre-dam 15-year return period (Figure 3.1-3). This analysis reinforces the concept that, historically, the gravel-bedded reach of the San Joaquin River was mobilized less frequently than the two-year, bankfull channel concept being applied in the restoration of other Central Valley rivers, in large measure because of the low gradient of the gravel-bedded reach. More importantly, this analysis suggests that it is not possible to achieve the goal of *general* bed mobilization and scour in Reach 1 on a 2-year recurrence interval, because Friant Dam has a managed release capacity of 16,400 cfs, which is less than the historical flows required to initiate bed mobility of the surface layer, much less to induce bed scour. However, these thresholds can be exceeded by *uncontrolled* spill events from Friant Dam (e.g., the 1997 flood).

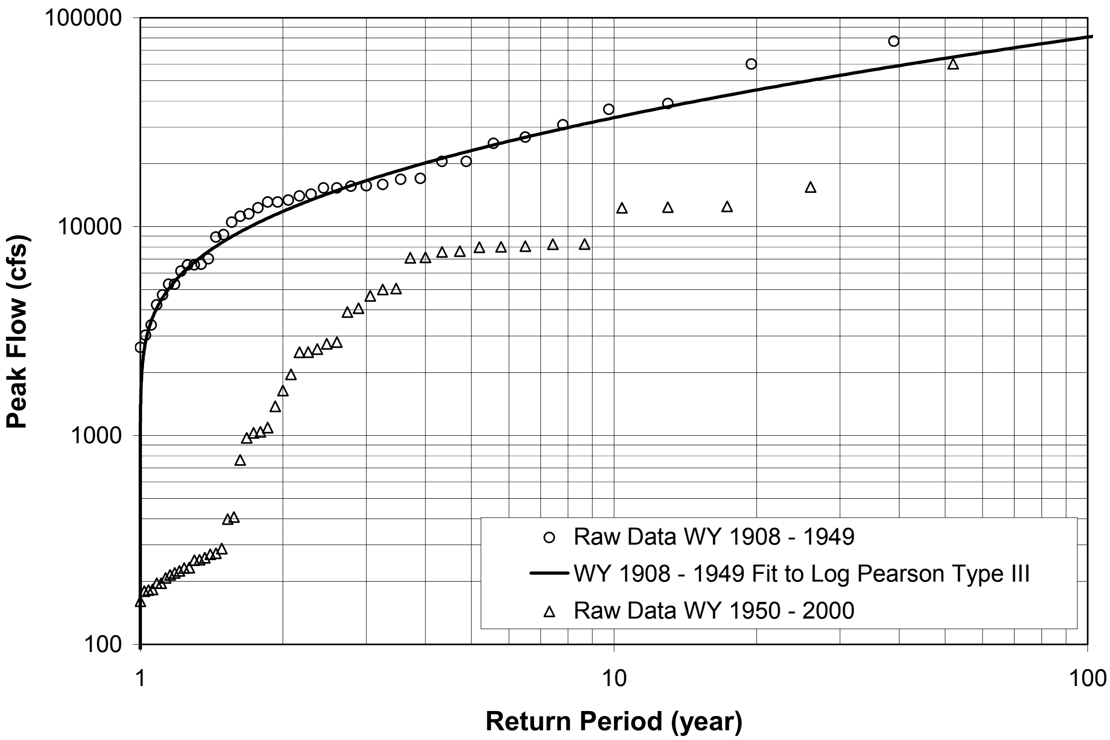

Figure 3.1-3. Peak flow recurrence in Reach 1 of the San Joaquin River. A pre-dam flow of 20,000 cfs corresponds with a return period of 4 years, and a discharge of 40,000 cfs represents a 15-year return period. This analysis represents flow conditions at the USGS Gauge at Friant Dam (no. 11251000).

The preceding Shields stress analysis uses reach-averaged values for channel slope and width; however, there are local variations in channel gradient and width within Reach 1. Even if general bed mobility and scour is not a reasonable target for Reach 1, several locations within the reach will likely experience bed mobilization and scour, including several riffles and sub-reaches associated with bedrock control or infrastructure (e.g., bridges and culverts). To identify locations in Reach 1 that may support bed mobility and scour for flows within the managed release capacity of Friant Dam, we examined shear stresses for individual cross sections. For this analysis, local channel widths and slope values were obtained from the cross sections contained in the HEC-2 model developed by MEI, with an assumed median grain size of 40 mm based upon the pebble counts conducted by Stillwater Sciences.

Figure 3.1-4 shows that there are several cross-sections within Reach 1A where Shields stress values may exceed 1.59 for flows of 8,000 cfs and 16,400 cfs, indicating locations with the potential to support bed mobility and scour within the managed release capacity of Friant Dam. Table 3.1-2 provides a description of locations with the potential for bed mobility and scour, assuming a flow of 8,000 cfs and a median grain size of 40 mm. Several of the identified locations are riffles that can be expected to support salmon spawning. It is important to note, however, that a cross section with a Shields stress value exceeding 1.0 or 1.59 does not necessarily indicate that the *current* bed in that location will be mobilized or scoured by a flow of 8,000 cfs or 16,400 cfs, because the current bed may be composed of coarser sediment particles than that assumed for this analysis (D_{50} = 40 mm). Nevertheless, this analysis indicates that many of the riffles in Reach 1A can be expected to mobilize and scour with a bed composed of spawning-sized gravels (either under existing conditions or with gravel augmentation).

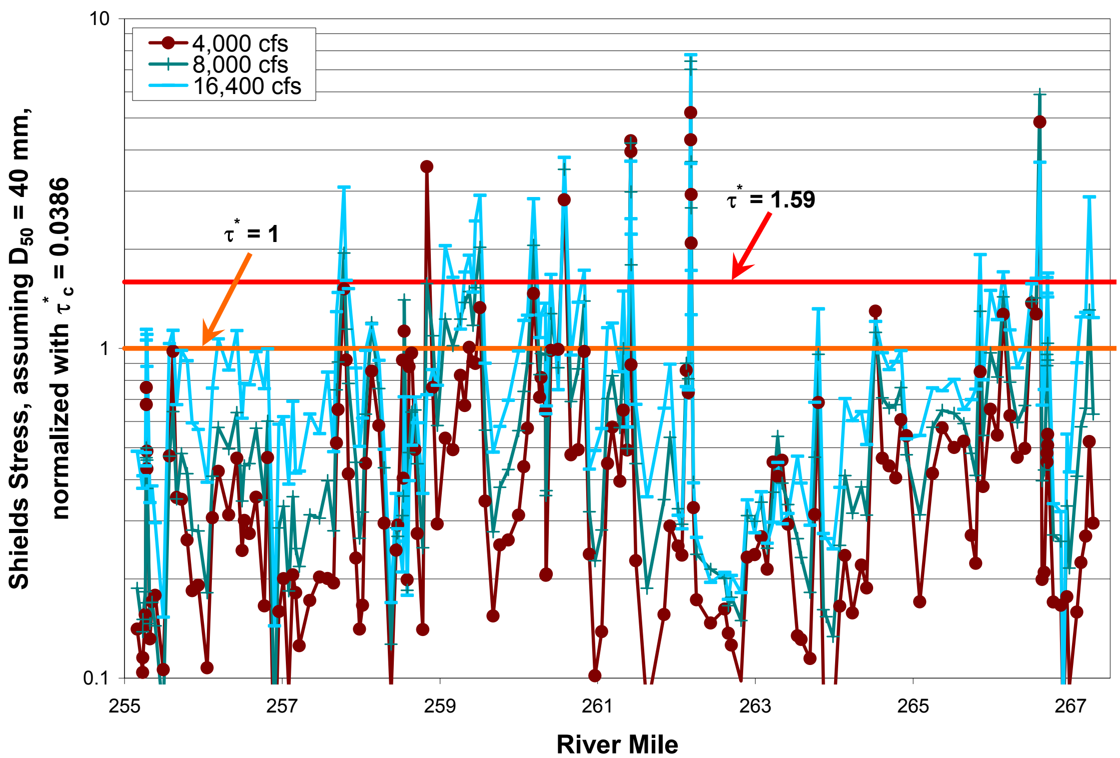

Figure 3.1-4. Pools within Reach 1 disrupt bedload routing (assuming a median grain size of 40 mm). These results are based on MEI HEC-2 results, a median grain size of 40 mm, and a critical Shields stress of 0.0386. Flows within the managed release capacity of Friant Dam will likely be sufficient to mobilize sediment from areas with locally high gradients. However, this sediment transported from these high gradient areas will deposit in pools within Reach 1A, and flow magnitudes greater than the release capacity of Friant Dam would be required to scour this coarse sediment from the pools.

Table 3.1-2. Descriptions of locations in Reach 1 with relatively high shear stresses. The values listed in the table are the normalized Shields stress at 8,000 cfs, assuming a median grain size of 40 mm, the local friction slope produced by the HEC-2 model, and a critical Shields stress of 0.0386 (Parker 1990a, b).

Cross Section ID	River Mile	Shields stress normalized with $\tau_c^* =$ 0.0386, D_{50} = 40 mm at 8,000 cfs	Site Description	Additional Site Description
461–461.5	**257.78–257.81**	1.14–1.95	Riffle	Site is bedrock controlled and confined by the bluff; the opposite side of the channel has deep gravel deposits
467	**258.13**	1.20	Run	Site has cobble bed material
474.5	**258.55**	1.40	Pool tail u/s of culvert	Site is on upstream side of culverted bridge
480	**258.83**	1.57	Riffle	Island/multiple channels
481	**258.91**	1.09	Run	The site is above riffle at RM 480; this is an active point bar that has been scoured of riparian vegetation
483–486	**259.07–259.32**	1.02–1.38	Pool	The site is upstream of the riffle at RM 480; one bank is armored with riprap
487	**259.37**	1.49	Riffle	Site is at tail of upstream riffle; one bank is armored with riprap
488	**259.42**	1.17	Head of riffle	Site is located at a bend armored with riprap
489–490	**259.45–259.51**	1.53–2.03	Tail of pool to riffle	Site is at former bridge crossing (gravel mining haul road); culverts are still present and constrict the channel
498	**260.19**	2.05	Riffle	Site is a shallow riffle; the channel is split by a large gravel/cobble bar; a secondary channel is used as a diversion by the golf course and a gravel diversion dam is maintained in the channel above the riffle
502	**260.41**	1.27	Run/riffle	Site is downstream of the Little Dry Creek confluence, above the gravel diversion structure
504	**260.58**	3.49	Riffle	Riffle is d/s of Ball Ranch and u/s of the Little Dry Creek confluence; the channel is split. Channel bed is gravelly cobble to cobbly gravel.
507	**260.83**	1.39	Run	Site is at head of pool, d/s of a run/riffle
514	**261.33**	1.00	Riffle tail	Site is at head of a shallow pool, d/s of gravel diversion structure; the channel has migrated in this area
515.8–516	**261.42**	1.79–4.19	Riffle head	Site is at top of the gravel diversion structure; the channel has migrated since the 1997 aerial photographs
525-528	**262.18–262.19**	2.67–7.03	Bridge scour hole	Undermined haul road bridge connecting to Ledger Island at d/s end of the island
557	**264.53**	1.12	Riffle head	Site is at top of split channel riffle below boat launch at Lost Lake Park

Cross Section ID	River Mile	Shields stress normalized with $\tau_c^* = 0.0386$, D_{50} = 40 mm at 8,000 cfs	Site Description	Additional Site Description
570	**265.85**	1.30	Riffle / boulder control	Boulders across the channel and bedrock control the drop at this location, which is d/s of the USGS gauge
574	**266.15**	1.44	Run	Bedrock constriction of the channel d/s of head the pool; u/s of the back channel confluence around the island, next to the fish hatchery
578	**266.50**	1.39	Riffle	Riffle adjacent to the fish hatchery; next to a large gravel/cobble bar with back channel
579	**266.56**	1.42	Riffle	Site is d/s of North Fork Bridge, at the confluence between the main channel and a secondary channel
580	**266.61**	5.89	Riffle	Main riffle d/s of the North Fork Bridge
585	**266.71**	1.04	Run/riffle head	Directly under North Fork Bridge
595	**267.24**	1.31	Bedrock pool	Deep bedrock bounded pool, d/s of confluence with Little Dry Creek

Notes:

1. There are 26 locations where the normalized Shields stress (assuming median grain size of 40 mm, which is based on the average grain size distribution of the Stillwater Sciences pebble counts, and critical Shields stress of 0.0386) exceeded unity. This indicates that the channel bed may experience some surface bed mobility if sediment grain size distribution at those locations is similar to the average of the Stillwater Sciences pebble counts. There are six locations (highlighted) with normalized Shields stress higher than 1.59, indicating that there may be bed scour if sediment grain size distribution at those locations is similar to the average of the Stillwater Sciences pebble counts.
2. Further examining the six sites with potential bed scour at 8,000 cfs indicate that three of the six sites are associated with bridge crossing and one is associated with a gravel diversion structure. The remaining two sites have channel compositions of gravel cobble, which is coarser than the average grain size distribution of the Stillwater Sciences pebble counts.

Based on the Table 3.1-2, it is likely that there is no significant bed scour even on riffles for a discharge of 8,000 cfs. The site at RM 261.42, where a gravel diversion structure is located and the local shear stress is high, indicates that appropriate gravel augmentation at some riffle locations will be able to induce gravel mobility and scour.

Figure 3.1-4 also indicates that sediment transported from local, high-gradient sections of the channel will not travel far downstream before shear stresses are insufficient to maintain transport. Sediment transport modeling predicts that gravel scoured from riffles in Reach 1 will deposit in downstream pools, where shear stresses are insufficient to maintain the transport of gravel through the pool at flows up to 16,400 cfs. The model also predicts that re-mobilization of this gravel will require extremely high flow events, greater than the 16,400 cfs managed release capacity of Friant Dam. Thus, pools in Reach 1 will likely function as gravel sinks. Figure 3.1-5 illustrates this point by identifying a cross-section at a riffle with the potential for bed mobility and scour (Shields stress value greater than 1.59), and a cross section from a downstream pool where shear stresses will be insufficient to maintain gravel transport (Shields stress value less than 1).

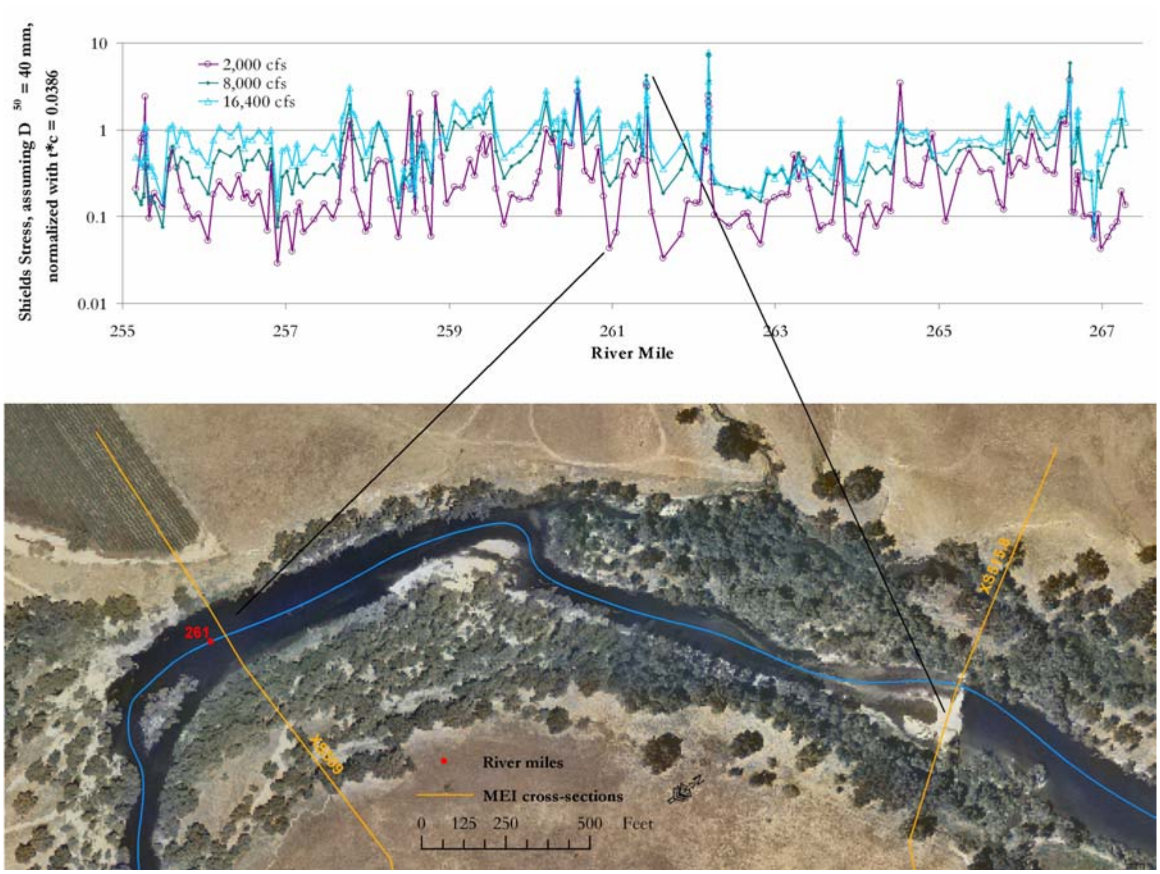

Figure 3.1-5. Pools in Reach 1 as gravel sinks. There are numerous riffles within Reach 1 where flows within the managed release capacity of Friant Dam will produce local shear stresses capable of mobilizing gravel. However, this gravel will likely deposit in pools, where shear stresses will not be sufficient to route the gravel to downstream reaches. Cross Section 5158 is located at a riffle, and the corresponding Shields stress value is greater than 1, suggesting the potential for bed mobility. Cross Section 509 is located in a pool, and the corresponding Shields stress value is less than 1, indicating that bed mobilization will not be achieved.

Within the constraints of Friant Dam release capacity, it will likely be impossible to restore bedload routing in the entire length of the gravel-bedded reach of the San Joaquin River. The gravel that is scoured from the few high-gradient locations within Reach 1 will likely deposit in intervening pools, and that gravel would not be available to replenish downstream spawning riffles. Gravel that is scoured from spawning riffles will need to be replaced periodically following high flows (> 8,000 cfs); otherwise, the habitat value of spawning riffles may degrade over time. It is important to note that periodic gravel augmentation of spawning riffles can achieve some of the desired effects of general bed mobilization and scour. For example, a key function of a bed scouring event is to reduce the amount of fine sediment in framework spawning gravels. Gravel augmentation can replicate this function with the augmentation of clean gravel.

It should be noted that it is *theoretically* possible to achieve bed mobility and scour in Reach 1A within the 16,400 cfs release capacity of Friant Dam, by reducing the channel width to increase the shear stress applied to a channel bed for a given flow. However, designing a narrower channel to achieve bed mobility and scour for a given flow is generally infeasible, because the narrower channel is unlikely to maintain its designed form. Estimates of historical and current bankfull channel widths in Reach 1A range from 300 feet (from 1998 aerial photos) to 1,400 feet (Cain 1997, as cited in McBain and Trush 2002), and the sediment transport analysis described above used the most narrow channel value of 300 feet. Any bankfull channel built with a width narrower than 300 feet is unlikely to be durable, because the channel will likely widen to resemble current bankfull channel widths found in Reach 1A, especially with the restoration of high flows. Designing a narrower bankfull channel that can support sediment transport in Reach 1 would require a channel with abnormally low width-depth ratios, considerably lower than the width-depth ratios of 35 to 50 that are typical for this type of gravel-bedded channel. Such a channel would be narrow and deep, which generally reduces the aquatic habitat value of the channel for salmonids and other organisms.

It is also possible to reduce bed mobilization and scour thresholds by injecting smaller sediment into the channel, thereby reducing the median grain size of channel bed sediment. However, this smaller sediment would be transported and deposited in the pools that are interspersed with riffles in Reach 1, and flows higher than the release capacity of Friant Dam will still be required to re-mobilize sediment from these pools. Figure 3.1-6 illustrates this point by showing the local shear stresses within Reach 1A assuming a D_{50} of 30 mm, representing a finer grained bed than that modeled for Figure 3.1-4, which assumed a median grain size of 40 mm.

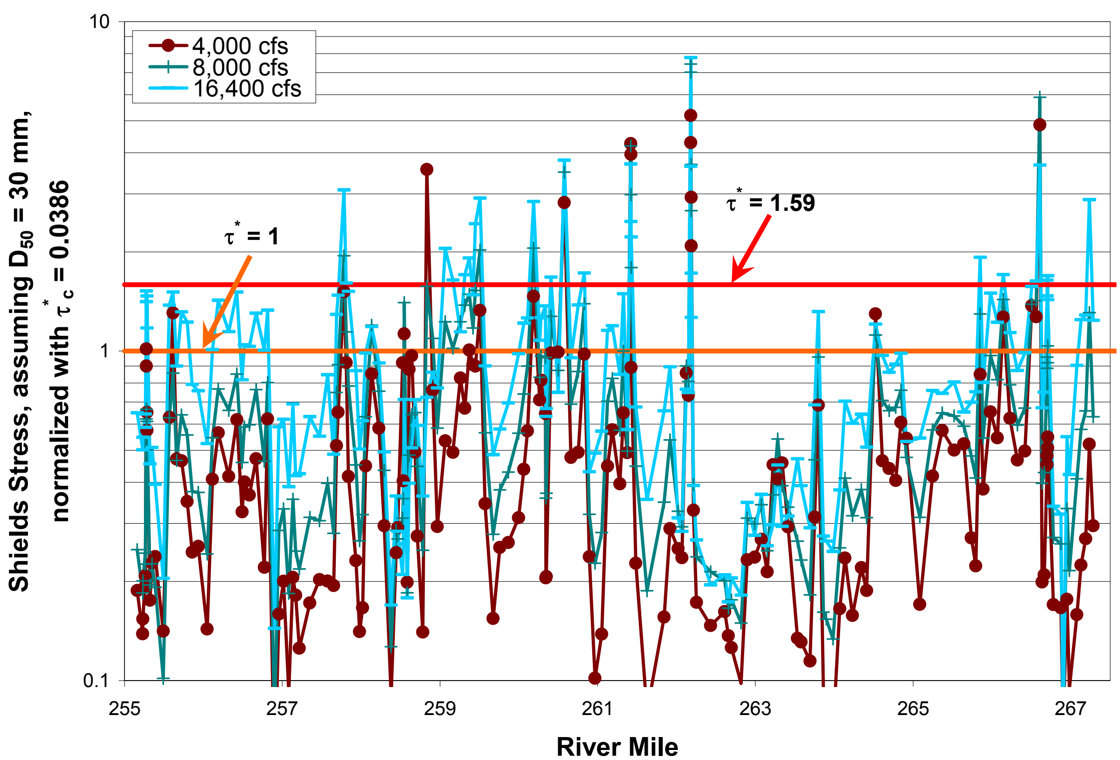

Figure 3.1-6. Sediment mobility and scour for a median grain size of 30 mm using local shear stresses. These results are based on MEI HEC-2 results, a median grain size of 30 mm, and a critical Shields stress of 0.0386. Introducing finer sediment to Reach 1A will not effectively restore general bedload routing, because flows higher than the managed release capacity of Friant Dam will still be required to scour coarse sediment from Reach 1 pools.

Reaches 2 and 3

To assess the potential for bed mobilization and scour in the sand-bedded reaches of the San Joaquin River, we analyzed the historical sediment transport characteristics of Reach 2, using Brownlie's bed material equation for sand-bedded channels (Brownlie 1982). This analysis requires historical flow data; however, there is little historical flow information for Reaches 2 and 3. To compensate for this lack of flow data, we have focused this sediment transport analysis on Reach 2, where historical flow conditions were likely similar enough to Reach 1 that the historical flow data from the USGS gauge at Friant (11251000) can be used reasonably.

Brownlie's equation requires input values for channel slope and width, as well as the grain size distribution of sediment composing the bed. Reaches 2 through 5 of the San Joaquin River are sand-bedded with channel slopes ranging between 0.0001 and 0.0003 (McBain and Trush 2002), so we selected a channel slope value of 0.0003, and a geometric mean grain size of 0.5 mm with a geometric standard deviation of 2.5. We used a bankfull channel width value of 744 feet, which is the average bankfull width of the historical channel in Reach 2 based on 1917 maps, as described in Chapter 3 of the Background Report (McBain and Trush 2002). Figure 3.1-7 shows the results of sediment transport calculations for Reach 2.

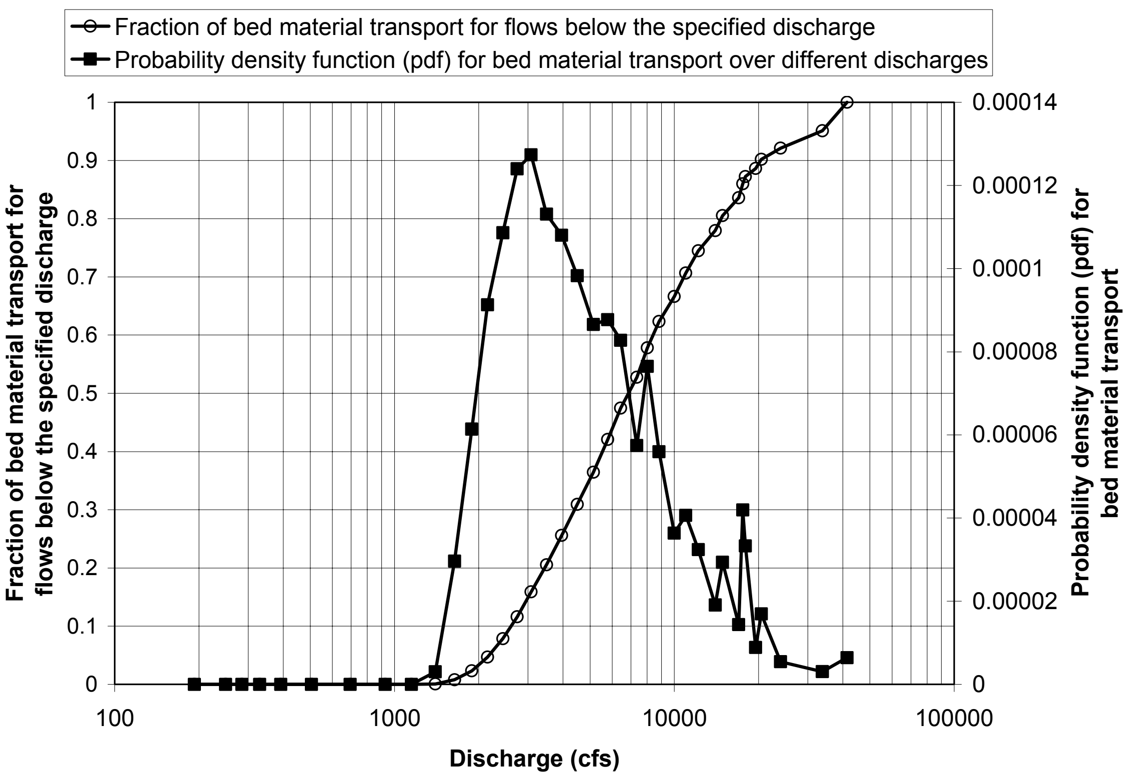

Figure 3.1-7. Estimated historical sediment transport regime in Reach 2, based on Brownlie's bed material equation (Brownlie 1982). Relatively low flows between 2,000 cfs and 3,000 cfs were sufficient to mobilize a significant portion of the bed material in Reach 2. (This estimate is based on flow data from the USGS gauge located below Friant Dam [no. 11251000] using a discharge record between 1909 and 1949; an assumed bankfull width of 744 ft; a channel gradient of 0.0003; and a geometric mean grain size of 0.5 mm and geometric standard deviation of 2.5.)

Figure 3.1-7 indicates that flows as low as 2,000 to 4,000 cfs are capable of mobilizing a significant fraction of sediment in Reach 2. For example, under historical conditions, an estimated 2 percent, 16 percent, and 27 percent of the sediment was transported with flow less than 2,000 cfs, 3,000 cfs, and 4,000 cfs, respectively. Under historical conditions, the dominant discharge (i.e., the flow at which most of the sediment is transported) was approximately 3,000 cfs, as demonstrated by the peak of the probability density function shown in Figure 3.1-7. Figure 3.1-3 indicates that a flow of 3,000 cfs corresponds with a pre-dam return period of less than 1 year and a post-dam return period of 2.5 years at Friant. The return period for a 3,000 cfs flow in Reaches 2 and 3 was, and is, likely higher because of natural attenuation of flow between Reaches 1 and 2. Nevertheless, this analysis suggests that frequent mobilization of the sand-bedded reaches is achievable within the regulated flow regime.

As described in Section 3.1.1, and more extensively in Chapter 3 of the Background Report (McBain and Trush 2002), Reach 3 of the San Joaquin River historically resembled the channel in Reach 2: sand-bedded, single-threaded, and meandering. Reach 3 is still similar to Reach 2, so the results of this sediment transport analysis are generally applicable to Reach 3, though a discharge of 3,000 cfs would likely have had a longer return period in Reach 3 because of natural flow attenuation between Reaches 2 and 3.

Reaches 4 and 5

Reaches 4 and 5 have slightly lower slopes than Reach 2, and historically, the anabranching channel morphology of Reaches 4 and 5 differed from the single-channel morphology of Reach 2. However, these differences have been erased over time as flow regulation and channel manipulation have transformed Reaches 4 and 5 into the single-channel morphology characteristic of Reach 2. Historically, Reaches 4 and 5 also had narrow riparian berms that hemmed the primary channel, which would have increased shear stress in the channel to facilitate bed mobilization. Also, the particle size of sediment composing the bed in Reaches 4 and 5 may have been smaller than that in Reach 2.

Despite these differences, it is reasonable to apply the results of the sediment transport analysis in Reach 2 to Reaches 4 and 5, such that relatively low magnitude flows can be expected to have mobilized the channel bed in these lower reaches. Flow data recorded at the Fremont Ford gauge (~RM 125) indicates that flows of 3,000 cfs are still common in Reaches 4 and 5.

3.1.3.2 Sediment supply and transport

Rather than restoring a balanced coarse sediment budget in Reach 1, as is often targeted in the restoration of other Central Valley rivers regulated by dams, the restoration strategies envision improving in-channel coarse sediment storage by strategically augmenting gravel on riffles. Historically, Reach 1 of the San Joaquin River had a low sediment yield which, coupled with a low channel gradient, produced low sediment transport. The sediment supply to Reach 1 has been reduced further by Friant Dam, which traps sediment from the upper watershed. Similarly, the sediment transport capacity of Reach 1 has been further reduced by the flow regulation associated with Friant Dam and its 16,400 cfs release capacity. Because of the lower transport capacity in Reach 1, gravel augmentation in the reach will need to be strategic, focusing on the recharge of riffles where gravel is scoured, in order to maintain aquatic habitat. Another key target for Reach 1 will be to reduce fine sediment supply, and increase fine sediment transport, to reduce the volume of sand currently stored in the channel.

Historical sediment supply and transport in Reaches 2 through 5 was also likely low as compared with similar rivers in the San Joaquin basin, not only because of the low sediment yield from the upper watershed, but also because the San Joaquin River has few tributaries to contribute sediment to the mainstem channel. Sediment supply was likely even lower in downstream reaches, because sediment deposited on upstream floodplains further reduced the supply to downstream reaches. Therefore, the general target in the sand-bedded reaches will be to restore sediment supply and continuity.

Reach 1

As discussed in Chapter 3 of the Background Report (McBain and Trush 2002), the historical sediment yield of the San Joaquin River basin was low. Janda (1966) estimated a total sediment yield of approximately 260,000 yd^3/year at the Friant Dam location. Cain (1997) has a higher estimate of the total sediment yield at the same location—486,000 yd^3/year. Both estimates indicate a low sediment supply from the upper watershed. For context, Browne and Thorp (1947) estimated a total sediment yield of approximately 521,000 yd^3/year for the Tuolumne River at La Grange, which is similar to that for the San Joaquin River at Friant, even though the San Joaquin River at Friant encompasses a larger drainage area (nearly 138 mi^2 larger). The yield of coarse sediment in Reach 1 was even lower historically, because coarse sediment constitutes only a small fraction of the total sediment yield. If we assume that coarse sediment constitutes 10 percent of the total sediment yield, then Janda's (1966) estimate of coarse sediment yield is approximately 26,000 yd^3/year, and Cain's (1997) estimate of coarse sediment is 48,600 yd^3/year. It is important to note that the estimate of coarse sediment as 10 percent of total sediment supply is probably the highest possible value, and the fraction of coarse sediment can be as low as 1 percent or less. Though it may be feasible to inject this volume of gravel into Reach 1 on an annual basis, the low sediment transport capacity of Reach 1 renders this objective moot, because constraints on the magnitude of flows that can be released will likely prevent the injected sediment from routing through the system. As described in Section 3.1.1.1, coarse sediment will likely be mobilized and scoured locally within Reach 1, but this sediment will deposit in Reach 1 pools, and the managed release capacity of Friant Dam will not permit the release of flows of sufficient magnitude to re-mobilize this coarse sediment from the pools. As a result, the injection of coarse sediment in Reach 1 will be more strategic, focusing on recharging riffles that experience scour so as to maintain the quality and extent of spawning habitat, rather than injecting sediment to be in balance with the sediment transport capacity.

Another goal for Reach 1 is to reduce sand storage in the reach. Though there has been no quantitative assessment of fine sediment sources and loadings in Reach 1, field reconnaissance suggests that a significant amount of sand is stored in the channel in the gravel-bedded reach, primarily in pools. Figure 3.1-8 shows that sand can be mobilized from these pools at relatively low flow events.

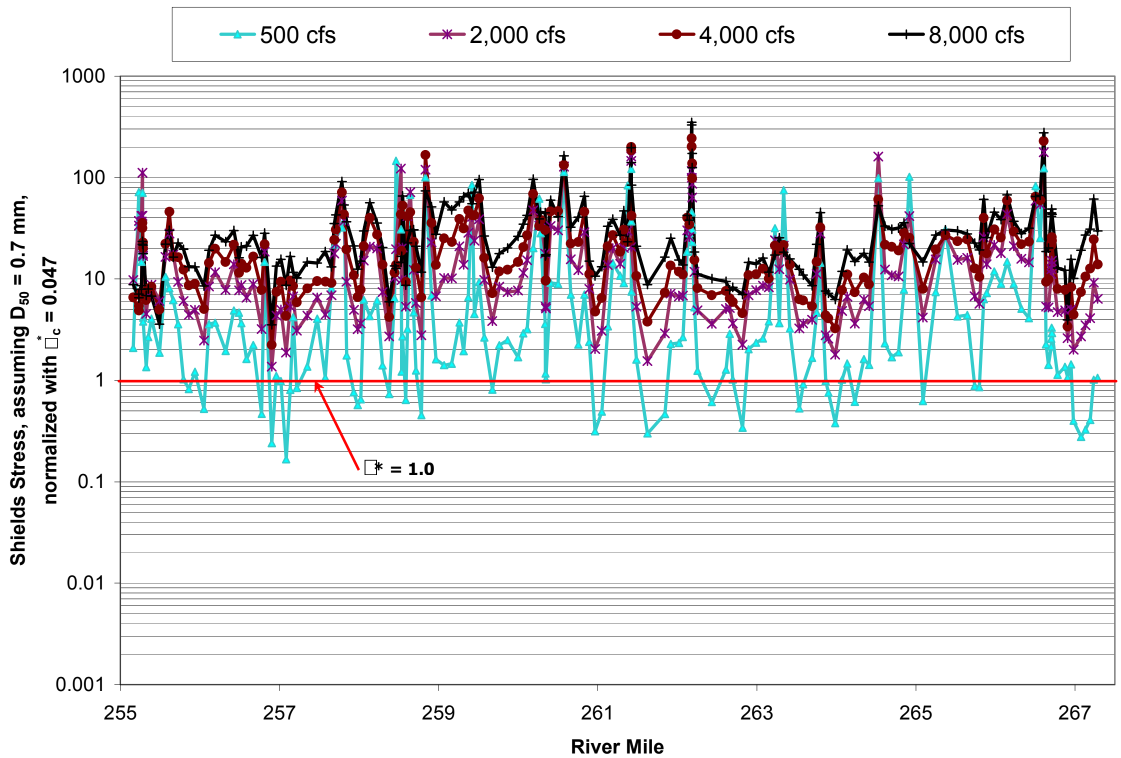

Figure 3.1-8. Mobility of sand for a range of flows. Shields stress is calculated based on an assumed median grain size of 0.7 mm and an assumed bankfull channel width of 300 ft. A normalized Shields stress value of 1.0 indicates the threshold of mobility. This plot shows that flows as low as 200 cfs will likely mobilize surface sand from riffles in Reach 1A, but will not be sufficient to transport sand through downstream pools. Pools will thus serve as sediment traps at these low flows. Sediment transport modeling suggests that flows on the order of 500 and 1,000 cfs will mobilize sand not only from riffles, but also from numerous pools. If the volume of fine sediment introduced to the channel is reduced through management intervention, sediment transport modeling suggests that moderate flows may be able to reduce the volume of sand stored in the channel in Reach 1A.

The mobilization of sand from pools and the continued supply of sand from upstream reaches will increase the potential for sand to infiltrate framework spawning gravels on riffles, thereby reducing intra-gravel permeability and the habitat value of spawning riffles. Though there are no flow releases prescribed specifically to transport sand in Reach 1, flows defined to achieve other ecological objectives (e.g., riparian recruitment flows, adult salmonid migration flows, juvenile salmonid outmigration flows) will nonetheless be of sufficient magnitude to mobilize sand from pools in Reach 1 and transport that sand downstream. As high flows are released to the San Joaquin River, sand will be transported downstream, eventually passing from Reach 1 into downstream reaches. The volume of sand stored in the gravel-bedded reach can be reduced, over time, if more fine sediment is transported downstream than is introduced to the channel. To facilitate an assessment of the need to control fine sediment inputs, and the feasibility of doing so, it will be important to conduct a fine sediment source analysis to quantify the contribution of sediment to the channel from different sources.

Reach 2

Both the historical and the current sediment supply in Reach 2 are unknown. However, Chapter 3 of the Background Report (McBain and Trush 2002) argues that Reach 2 likely had the highest sediment supply of any of the sand-bedded reaches of the San Joaquin River, as evidenced by extensive sand bars shown on the California Debris Commission maps (ACOE 1917), and as seen from 1937 aerial photos.

It is possible that mining operations in Reach 1 are providing a supply of fine sediment to Reach 2A, as mining overburden is captured and transported during high flows. The release of higher flows from Friant Dam will also likely increase the supply of sand to Reach 2A by scouring and transporting sand currently held in storage in the Reach 1 channel. Sediment routing in the lower portion of Reach 2A is affected by the Chowchilla Bifurcation structure, which creates a backwater effect that induces sediment deposition. The Chowchilla Bifurcation structure may need to be replaced or retrofitted to provide fish passage, which would allow designing a structure that has less impact upon sediment routing.

Currently, the sediment supply to Reach 2B is reduced because of flow operations at the Chowchilla Bifurcation structure. The mainstem channel in Reach 2B has a flood conveyance capacity of 2,500 cfs. In contrast, the Chowchilla Bypass channel has a capacity of 5,500 cfs. During periods of high flow, the volume of discharge directed into Chowchilla Bypass can be more than double the volume sent into Reach 2B because of this difference in conveyance capacity. Because these high flows transport sediment, a larger portion of the sediment is directed into the Chowchilla Bypass channel, reducing the volume of sand available to Reach 2B. Figure 3.1-9 illustrates the larger supply of sand delivered to the Chowchilla Bypass. Large sand deposits can be seen in Reach 2A above the Bifurcation structure, reflecting in part the sediment deposition induced by the backwater effect of the structure. Downstream of the bifurcation structure, large sand bars can be seen in Chowchilla Bypass, but there are relatively fewer and smaller sandbars in Reach 2B.

The current rules governing the operation of the bifurcation structure direct the first 2,500 cfs of flow into the mainstem channel in Reach 2B, although actual operation of the bifurcation structure often limits flows conveyed into Reach 2B below this 2,500 cfs threshold to avoid downstream seepage problems. Efforts to reduce downstream seepage problems will allow a greater proportion of flow to be directed into Reach 2B, up to the conveyance capacity, which will in turn help restore the supply of sediment to the reach and the routing of sediment. Each of the three restoration strategies involves expanding the conveyance capacity of Reach 2B so that it can convey a minimum of 4,500 cfs. Routing these higher flows through an expanded Reach 2B will further increase the sediment supply to, and enhance sediment routing in, Reach 2B and downstream reaches.

Reach 3

The historical and current sediment supply in Reach 3 is unknown. Chapter 3 of the Background Report (McBain and Trush 2002) argues that the sediment supply in Reach 3 was slightly less than that of Reach 2, because sediment deposited on upstream floodplains reduced the volume of material available for transport into Reach 3. However, Reach 3 apparently had a sufficient supply of sediment to build floodplains, and the depiction of exposed sand bars in the California Debris Commission maps (ACOE 1917) and 1937 aerial photos suggest that sediment was routing through the reach.

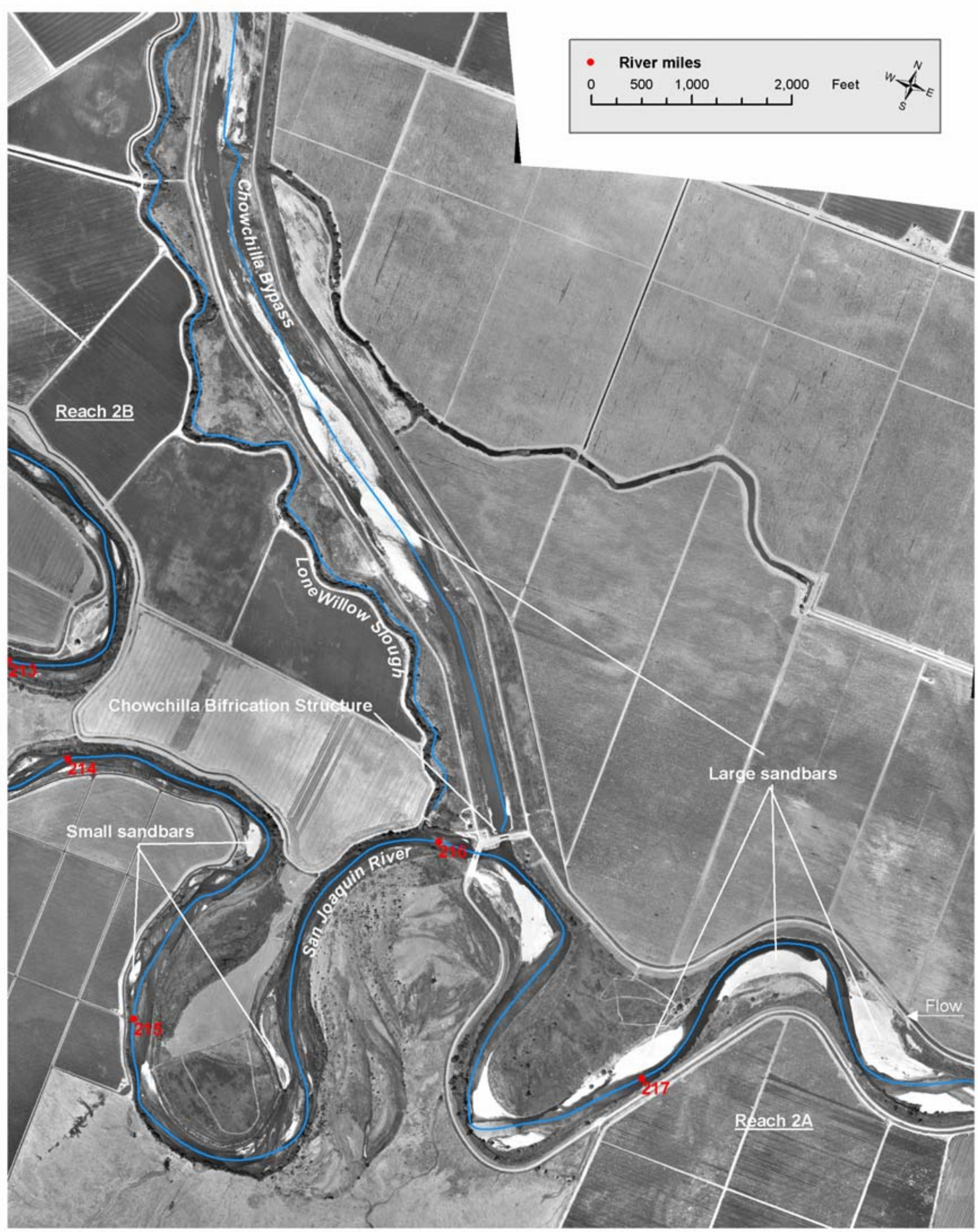

Figure 3.1-9. Restoring sediment supply and routing in Reach 2B. Current operation of the Chowchilla Bifurcation Structure directs a higher proportion of flow, and therefore sediment, into the Chowchilla Bypass during high flow events. As a result, the sediment supply to Reach 2B is reduced.

The current supply of sediment to Reach 3 has likely been reduced, because of the reduced flow and the upstream reduction of sand in Reach 2B as sediment is routed into the Chowchilla

Bypass. The Background Report (McBain and Trush 2002) also suggests that Mendota Dam temporarily disrupts sediment routing to Reach 3, because sediment is trapped in Mendota Pool during normal operations but pulsed downstream during periods of high flow when the boards on the dam are pulled.

By restoring sediment supply and routing to Reach 2B, sediment supply and routing will also be restored to Reach 3. Also, Mendota Dam is scheduled to be replaced in the near future, which provides an opportunity for designing and operating the new dam to improve sediment routing to Reach 3.

Reaches 4 and 5

As with Reaches 2 and 3, there is little information about the historical or current sediment supply in Reaches 4 and 5. The Background Report (McBain and Trush 2002) suggests that the historical supply of sediment to Reaches 4 and 5 was much lower than Reaches 2 and 3, as evidenced by the transition from floodplains to flood basins flanking the channel in Reaches 4 and 5, and by the transition from a single-channel morphology to an anabranching morphology. As sediment deposited on floodplains in upstream reaches, the supply to Reach 4 and 5 was reduced, and the flood basins surrounding the mainstem channel intercepted sediment from tributaries such as the Fresno River and the Chowchilla River. McBain and Trush (2002) note the presence of small exposed sand bars in Reaches 4 and 5, as depicted in the California Debris Commission maps (ACOE 1917), indicating that sediment did route through the primary channel in both reaches, as well as some of the anabranching channels and sloughs.

There are several pieces of water supply and flood management infrastructure in Reaches 4 and 5 that have the potential to disrupt sediment routing. McBain and Trush (2002) suggest that Sack Dam likely has a minimal effect upon sediment routing, owing to the relatively small size of the diversion. However, the Sand Slough control structure and the Mariposa Bifurcation structure have a more significant effect upon the routing of large flows that transport sediment, in both the mainstem channel and the Eastside Bypass. These structures may need to be replaced or retrofitted to provide fish passage, which would allow designing a structure that has less impact upon sediment routing.

With the restoration of sediment supply in upstream reaches (by routing sediment through the mainstem channel rather than Chowchilla Bypass), the sediment supply to Reach 4 will likely increase as high flows are restored to the reach, and the goal will be to route the sediment downstream. However, it is possible that the current sediment supply to Reach 4 and 5 is greater than historically, because irrigation return flows may transport sediment eroded from adjoining agricultural fields. As a result, sediment supply and routing should be monitored in Reaches 4 and 5 to help identify and prevent possible channel aggradation.

3.1.3.3 Channel migration and avulsion

Capitalizing on opportunities to create or preserve a floodway will provide space for the San Joaquin River to meander. However, channel migration will likely be limited in all reaches, because of the constraint on the managed release capacity of Friant Dam. Similarly, channel avulsion is not a target for the San Joaquin River because it would require large flows that are greater than the release capacity of Friant Dam.

Reach 1

Historical rates of channel migration were likely low in Reach 1 because of the low channel gradient, which meant that only large floods would provide the energy necessary to erode banks composed of coarse sediment. The low sediment yield in Reach 1 also reduced the rate of channel migration in Reach 1, because there was little sediment available to form point bars. Migration was also confined by the bluffs in Reach 1.

The potential for current channel migration in Reach 1 is low, because the 16,400 cfs release capacity of Friant Dam does not provide enough energy to scour gravel from instream pools, much less erode banks composed of coarse sediment. The target for Reach 1 will be to achieve many of the habitat benefits associated with channel migration (e.g., large woody debris recruitment, side channel habitat) through human intervention. For example, connection to side channel habitat can be enhanced by excavating side channels so that they receive flow more frequently, and large woody debris can be added to the channel to enhance aquatic habitat.

Reaches 2 and 3

McBain and Trush (2002) examined the California Debris Commission maps (ACOE 1917) and 1937 aerial photos to examine channel migration for sample sites in Reaches 2 and 3. Their review pointed to the lack of vegetation on large point bars as an indication that the low-flow channel was actively migrating within the bankfull channel in Reaches 2 and 3. Their review suggests historical migration rates of the bankfull channel were low in both reaches.

Channel migration has been reduced in Reaches 2 and 3 by flow regulation and levees, and channel migration rates in Reaches 2B and 3 have also been affected by the diversion of water and sediment into Chowchilla Bypass. Each of the restoration strategies includes expanding the flood conveyance capacity of Reach 2B, though the scale of the expansion differs by strategy. Similarly, each of the restoration strategies removes many of the low-lying agricultural berms in Reach 3.

The target for Reaches 2 and 3 is to define a broader floodway by setting back at least one levee in Reach 2B as part of the effort to expand flood conveyance capacity in the reach, and removing many of the low-lying agricultural berms in Reach 3. Creating this floodway will provide the channel with room to migrate. Another target for Reaches 2 and 3 is to release flows of sufficient magnitude from Friant Dam to drive channel migration. There is some question, however, about whether flows of sufficient magnitude can be released from Friant Dam to stimulate channel migration. The expanded conveyance capacity targeted for Reach 2B is 4,500 cfs for Strategy 1 and 8,000 cfs for Strategies 2 and 3, and it is uncertain if flows of this magnitude will provide sufficient energy to drive channel migration in the two reaches. Figure 3.1-3 indicates that a flow of 8,000 cfs represents an approximate 1.5-year event for pre-dam conditions at Friant, though the return period of an 8,000 cfs flow in Reaches 2 and 3 would likely be greater because of natural flow attenuation from Reach 1. Although it is unclear what flow events initiate channel migration, a 1.5-year return period raises concerns that the discharge will be insufficient to drive channel migration.

Reaches 4 and 5

McBain and Trush (2002) compared 1855 maps with 1917 maps and 1998 aerial photos to review changes in channel alignment for sample sites in Reaches 4 and 5. Their review suggests that historical channel migration rates in the two reaches were lower than those of Reaches 2 and 3, as evidenced by straight channels that did not change their alignment significantly over time. The low migration rates are probably attributable to low sediment supply, low stream energy, and riparian berms that bordered the channel. However, McBain and Trush (2002) suggest that the channel changed alignment primarily through avulsion during large, infrequent flood events, thereby creating the anabranching sloughs that characterize the two reaches.

It is possible that the current supply of sediment to Reaches 4 and 5 is larger than the historical supply, because of irrigation return flows carrying sediment eroded from agricultural fields. If current sediment supply is higher than historical supply, then the channel in Reaches 4 and 5 may experience migration rates higher than occurred historically. However, it is not clear if a migrating channel in Reaches 4 and 5 serves as a reasonable restoration target, because it is not certain that there has been an increase in the current sediment supply. The possibility of a migrating channel in Reaches 4 and 5 should be revisited following a better understanding of current sediment dynamics in both reaches.

Though channel migration may serve as a restoration target, channel avulsion is not a reasonable restoration target for Reaches 4 and 5, because water supply and flood management infrastructure prevent the release of flows of sufficient magnitude to initiate channel avulsion.

3.1.3.4 Floodplain formation and inundation

The historical floodplains in Reach 1 function more like terraces currently because of the significant reduction in peak flows caused by Friant Dam and upstream reservoirs. Expanding floodplain inundation in Reach 1 will require lowering existing surfaces so that they inundate more frequently in the regulated flow regime. Reaches 2 and 3 provide good opportunities for establishing functional floodplains, because existing floodplain elevations support frequent inundation and floodplain building through sediment deposition. Restoring sediment routing and overbank flows should facilitate sediment deposition on floodplains in these reaches. Historically, Reaches 4 and 5 did not have floodplains; rather, they had narrow riparian berms flanked by flood basins (McBain and Trush 2002). However, if current sediment supply is larger than historical supply, because of sediment contained in agricultural return flows, then it may be feasible to restore floodplain formation processes in these lower reaches.

Reach 1

Flow regulation associated with Friant Dam has reduced peak flows such that historical floodplains now function as terraces. Also, the floodplain has been mined for gravel in several locations throughout Reach 1, leaving pits that do not provide ecologically functional floodplain surfaces. Reductions in coarse sediment supply and transport capacity in Reach 1 also limit opportunities for sediment deposition on floodplains.

The target for Reach 1 will be to lower the elevation of existing surfaces so that they inundate more frequently—a practice being applied in the restoration of several Central Valley rivers regulated by dams. Surfaces will be lowered so that they provide floodplain rearing opportunities for young salmon, as well as recruitment surfaces for riparian vegetation. The lowering of floodplain surfaces provides a corollary benefit of generating excavated material that can be used locally as source material to fill gravel mining pits. Excavation of floodplain surfaces will also provide a source of spawning-sized gravel that can be used to augment existing spawning riffles (see Section 4.1.2), or possibly to construct new spawning riffles (see Section 4.1.3).

Reaches 2 and 3

In Reaches 2 and 3, levees currently separate the channel from its former floodplain. The target for Reaches 2 and 3 is to provide space for functional floodplains by pulling back levees in Reach 2B and removing some of the low-lying agricultural berms in Reach 3. Another target is to increase the sediment supply to Reaches 2 and 3 by releasing flows from Friant Dam that will mobilize and transport sand from Reach 1, and then inundate floodplains in Reaches 2 and 3 so that this sediment deposits on the floodplain, spurring the process of floodplain formation. These actions would be complemented by re-operation of the Chowchilla Bypass structure to improve sediment routing and restore the supply of sediment to Reaches 2B and 3.

Reaches 4 and 5

Historically, Reaches 4 and 5 did not have extensive floodplains because of a lack of sediment supply; rather, narrow riparian berms hugged the channel in these reaches (McBain and Trush 2002). However, the supply of sediment delivered to Reaches 4 and 5 may be larger now than the historical supply, because of sediment provided by agricultural return flows. Consequently, it may be possible to create functioning floodplains in Reaches 4 and 5, with overbank flows depositing sediment on the floodplain, contributing to floodplain building.

3.1.4 Summary of Fluvial Geomorphic Targets

The preceding sections describe many of the constraints to, and opportunities for, restoring key fluvial geomorphic functions and attributes on the San Joaquin River. This section distills the key geomorphic targets for each reach.

3.1.4.1 Reach 1

They key geomorphic targets in Reach include the strategic supplementation of gravel on riffles and reducing the volume of sand stored in the channel by increasing sand transport and reducing the supply of sand introduced to the channel. Adding clean, spawning-sized gravel to riffles will improve salmonid spawning habitat by providing adequate gravel depths to support redd construction and by providing a substrate that will enhance intragravel permeability, as compared with current gravel conditions in several parts of Reach 1. As discussed previously in this chapter, the release of higher flows from Friant Dam will likely induce local scour of gravel in areas with greater channel slopes, transporting the gravel downstream until it deposits in pools located between riffles in Reach 1. Riffles will be recharged with gravel periodically, following high flow events that scour gravel from the riffles. Over a longer time scale, the pools in Reach 1 will fill gradually with gravel scoured from upstream riffles. As the pools fill, the potential for re-mobilization of the gravel within the pools will increase, thereby creating the possibility of restoring bedload routing, at least for sub-reaches within Reach 1. Gravels that fill the pools will also reduce the storage space for sand, increasing the potential for sand to be transported downstream.

Another geomorphic target for Reach 1 involves reducing the in-channel storage of fine sediment, by reducing the amount of fine sediment introduced to the channel and by releasing flows from Friant Dam that will scour sand from pools in Reach 1 and transport it downstream into Reach 2. Reducing the sand stored in Reach 1 may prolong spawning habitat quality in Reach 1, especially in riffles augmented with clean spawning gravels, by reducing the infiltration of fine sediment within framework spawning gravels. Increasing the transport of sand from Reach 1 will also have beneficial effects downstream, because increasing downstream sediment supply may help stimulate channel migration and floodplain formation in Reaches 2 and 3.

Increased floodplain inundation is also a target in Reach 1, which will require lowering floodplain surfaces so that they inundate more frequently within the regulated flow regime. Appendix A includes an inventory of potential sites within Reach 1 where the floodplain can be lowered to create an ecologically functional floodplain surface that supports juvenile salmonid rearing and riparian vegetation establishment. Similarly, the excavation of back channels will facilitate reconnecting them to the main channel, thereby improving habitat complexity.

Another target for Reach 1 includes the dedication of a floodway, within which restoration actions are focused and existing habitat is preserved.

3.1.4.2 Reach 2

The geomorphic targets for Reach 2 include creating a floodway within which the channel is free to migrate, and increasing overbank flows that will inundate and shape floodplains. In each of the restoration strategies, flood conveyance capacity is increased in Reach 2B, which will require setting back at least one levee throughout the reach, thereby creating a wider floodway that will hopefully reduce seepage problems within the reach. With an increased sediment supply delivered from Reach 1, and with the release of higher flows from Friant Dam, Reach 2 will have the conditions to stimulate both floodplain formation, whereby overbank flows will build the floodplain through sediment deposition, and channel migration. The potential floodplains in Reach 2 offer the possibility for topographical diversity created by the spatial variability of sediment deposition on the floodplain, as well as the possible formation of high-flow scour channels.

Another target is to improve sediment routing in the reach. To preserve the benefits of the increased sediment supply transported from Reach 1, the re-operation of the Chowchilla Bifurcation structure, coupled with expanded flood conveyance capacity in Reach 2B, will allow a greater proportion of flow and sediment to route through the mainstem channel in Reach 2B, rather than shunting water and sediment into the Chowchilla Bypass. Routing more sediment and water into Reach 2B will enhance the potential for channel migration and floodplain formation within the reach, and it will also help preserve the conveyance capacity of Chowchilla Bypass, which must be dredged periodically because of channel aggradation. An associated target for Reach 2 will involve exploring approaches for reducing the aggradation in the lower end of Reach 2A associated with the backwater effect of the Chowchilla Bifurcation structure.

Another general target for Reach 2 includes the maintenance of a quasi-equilibrium channel, in which there may be short-term changes in bed forms, but in the longer term, channel aggradation and degradation are balanced. A related goal is the maintenance of a low-flow channel through the release of perennial flow, coupled with a balanced sediment supply and continuous bedload routing.

3.1.4.3 Reach 3

The geomorphic targets for Reach 3 include creating a floodway to provide space for channel migration and floodplain formation, which can be achieved by removing many of the low-lying agricultural berms within the reach. The sediment supply for Reach 3 will likely increase as more sediment is transported from Reach 1, and as sediment routing is improved in Reach 2B. The sediment supply in Reach 3 will likely be less than that of Reach 2, because sediment deposition on upstream floodplains will reduce material transported into Reach 3. With the release of higher flows from Friant Dam, the combination of overbank flows and an improved sediment supply will provide the conditions for floodplain building. Higher flows and sediment supply will also spur channel migration within the reach.

As for Reach 2, another target for Reach 3 is the maintenance of a quasi-equilibrium channel, in which channel aggradation and degradation are balanced over the long-term. A related goal is the maintenance of a low-flow channel through the release of perennial flow, coupled with a balanced sediment supply and continuous bedload routing. To help achieve these targets, it will be important to explore methods for evacuating sediment from Mendota Pool in a manner that does not release pulses of sediment into Reach 3.

3.1.4.4 Reach 4

The geomorphic targets for Reach 4 are dependent upon the selection of a restoration strategy, because the routing of flow, fish, and sediment in Reach 4B is a key distinguishing feature among the three restoration strategies.

One set of targets includes constructing wide functional floodplains within a floodway, and creating and maintaining a well-defined low-flow channel as part of a restored, multi-stage channel in Reach 4B to facilitate the movement of aquatic organisms.

Another set of geomorphic targets involves the creation and maintenance of a single-thread channel that is bordered by riparian berms, with swales on the back side of the berms to support seasonal and perennial wetlands.

And a third set of geomorphic targets includes creating and maintaining a low-flow channel in the Eastside Bypass to facilitate the movement of aquatic organisms.

As with the upstream sand-bedded reaches, one geomorphic target for Reach 4 is the maintenance of a quasi-equilibrium channel, in which channel aggradation and degradation are balanced over the long-term.

3.1.4.5 Reach 5

The geomorphic target for Reach 5 is to increasing floodplain inundation with the release of higher flows.

As with the upstream sand-bedded reaches, an important geomorphic target for Reach 5 is the maintenance of a quasi-equilibrium channel, in which channel aggradation and degradation are balanced over the long-term. A related goal is the maintenance of a low-flow channel through the release of perennial flow, coupled with a balanced sediment supply and continuous bedload routing.

3.2 Chinook Salmon Populations

3.2.1 Introduction

The restoration of chinook salmon populations in the mainstem San Joaquin River is the single-most important goal for each of the restoration strategies. To achieve the vision of a restored chinook population in the San Joaquin River, a number of objectives will need to be realized. Objectives for a restored population include:

- ***Self-sustaining populations***. Restored populations of chinook salmon will be self-sustaining, meaning that viable populations will be supported through natural spawning in the mainstem San Joaquin River and will not require artificial supplementation after they are successfully established. Natural habitats will be expected to provide for adult upstream migration, holding, spawning, egg incubation and alevin development, fry and juvenile rearing, and smolt outmigration.
- ***Minimum population size***. Escapement of restored populations will be large enough to maintain a self-sustaining population in the face of ongoing mortality factors operating outside of the planning area (e.g., entrainment or predation in the Delta, ocean harvest).
- ***Variable escapement***. Restored populations will exhibit variability in escapement, as is natural for wild chinook salmon populations. Escapement is expected to be high in years when ocean and freshwater habitat conditions are conducive to survival of the various life-history stages, and lower in years when environmental conditions–whether cyclical changes in ocean conditions, regional climatic effects, or other stochastic events–result in reduced survival of one or more salmon life-history stages.
- ***Genetic characteristics***. Restored populations will exhibit a genetic makeup as similar as possible to stocks that occurred in the San Joaquin River under historical conditions. Genetic variability and integrity will be maintained through minimizing the use of hatchery stocks and providing for natural selection within riverine habitats for each life stage.
- ***Life history characteristics***. Restored populations will exhibit life history characteristics within the range expected under historical conditions, but will not be expected to display the full range of life-history variability due to ongoing human uses of the San Joaquin River and basin.
- ***Support recreational fishing***. Restored populations may eventually be large enough to support a recreational fishery in the mainstem San Joaquin River.

The mainstem San Joaquin River once supported one of the largest runs of spring chinook salmon on the Pacific Coast until 1950, when the construction of Friant Dam (which blocked access to upstream spawning habitat) and the diversion of increasing amounts of water into canals initiated a population decline. Fall chinook salmon also occurred in the mainstem San Joaquin River, but in smaller numbers; the fall run was nearly eliminated by the 1920s due to reduced flows during the fall upstream migration. Although self-sustaining fall chinook salmon populations have successfully persisted in major San Joaquin River tributaries downstream of the project area, populations of spring chinook salmon have been extirpated from the San Joaquin basin. Because of this, it might be assumed that it would be more difficult to reestablish spring chinook salmon in the mainstem San Joaquin River than it would be to reestablish fall chinook salmon. Upon closer examination of the life history strategies employed by the two runs, however, it appears that it may actually be more realistic to reestablish spring chinook salmon populations in the mainstem San Joaquin River.

The restoration vision for chinook salmon includes both spring and fall runs, although we believe that restoring spring chinook has a greater likelihood of success. Spring chinook outmigrate at a larger size than fall chinook, and thus experience higher smolt and ocean survival. As a result, spring chinook could have lower escapement rates and nonetheless maintain a sustainable population.

The following sections address important assumptions and issues governing chinook salmon restoration in the mainstem San Joaquin River. These issues fall into three main categories: (1) the population dynamics of spring and fall chinook salmon, (2) the potential sources of parent stock for spring and fall run chinook salmon, and (3) the differences between the life histories of the two runs and the implications for restoring chinook salmon populations in the mainstem San Joaquin River.

3.2.2 Approach

Simulation population models were used to develop restoration strategies that attempted to meet the objectives for restoring chinook populations. The simulation models were used in an iterative process, using the following general procedures. Gaming was conducted with the population models to determine combinations of restoration measures (e.g., flow releases from Friant Dam) sufficient to meet basic sustainability targets. Next, the models were run with a long time-series of environmental inputs derived from historical data (appropriately modified to reflect basic restoration and likely operating scenarios), to determine the long-term average population levels that would be expected to result from these restoration measures. This process allowed us to evaluate the effect of various restoration strategies on the population abundance, or survival, at specific life stages. The population models were based on data from the Merced, Tuolumne, and Stanislaus rivers, and used life-stage parameter values based on the literature, as discussed in sections 3.2.3 to 3.2.6 below.

3.2.3 Sources of parent stock

Ideally, parent stock for restoring salmon populations originates from the river being restored. However, mainstem San Joaquin River chinook stocks have long since been extirpated. When selecting a stock from outside the basin, other considerations become crucial, including:

- life history timing (e.g., timing of adult migration, spawning, and smolt outmigration),
- habitat requirements (e.g., temperature tolerances),
- migration distance,
- genetic integrity of stock, and
- population size of stock.

Selection of a parent stock assumes that inherent genetic qualities of the parent stock will apply to the upper San Joaquin River stock after introduction. In truth, it is not known to what degree genetics versus environment dictate life history timing and habitat requirements of individual stocks. Determining the life history traits of introduced populations will be a key element of an adaptive management strategy, with potential consequences affecting all aspects of the life history and habitat requirements considerations discussed below.

3.2.3.1 Spring-run chinook salmon

The main concern in selecting a spring chinook stock is that the run timing be early, to avoid temperature increases in the lower river, and that the spawn timing be early, to avoid interbreeding with fall chinook. Since spring chinook hold during the summer, temperature tolerances have to be relatively high. Based on these considerations, Sacramento River tributaries are the primary candidates for stock (Table 3.2-1). In the Sacramento River, there are several tributaries that support relatively major spring chinook runs, including Deer, Mill and Butte creeks, and the Feather River. Based on the need for early upstream migration and spawning and relatively warm temperature tolerances, the best candidate for a parent stock is from Butte Creek. Butte Creek spring-run are genetically distinct from Feather River hatchery and Deer and Mill creek spring-run chinook (NMFS 1999) and their populations are relatively robust. Spring chinook return to Butte Creek early in the year (February and March), and are capable of withstanding relatively warm temperatures during adult holding (see Stillwater Sciences 2003). The Butte Creek stock migrates upstream earlier in the winter than other stocks, when water depths and temperatures in the San Joaquin River are likely to be more suitable than later in the season. In addition, the Butte Creek chinook typically spawn in September, early enough to avoid interbreeding with November-spawning fall chinook. Migration distances for Butte Creek spring chinook are about 200 mi (320 km), very similar to the 200-mi (320-km) distance expected for San Joaquin River, and therefore straying and stress related to migration distance are not likely to be a concern. Central Valley spring-run chinook are listed as threatened under the federal Endangered Species Act; therefore, developing an approach to jump-starting spring-run in the San Joaquin will require coordination with the regulatory agencies.

Table 3.2-1. Run Timing of Spring Chinook in Sacramento River Tributaries.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration													Sacramento River Ascend rivers in May and June (Rutter 1908). Which rivers, and source of data not stated. Upstream migration has been observed to be bi-modal in the Sacramento River (Fisher, pers. comm., as cited in Marcotte 1984) with a portion of the run migrating to or near spawning areas while the remaining fish hold downstream (where in the river was not stated) and move up in the summer.
Upstream Migration													Deer and Mill Creeks Migrate up Deer and Mill Creeks from March through June (Vogel 1987a and b, as cited in Moyle et al. 1995). Source of data not stated In 1941 adults were trapped at a weir in Deer Creek from April to July 6 (Parker and Hanson 1944). Migration peaks in late May in Mill Creek. Migration into rivers earlier in southern tributaries and later in northern tributaries (Colleen Harvey, CFG, pers. comm.. 2002). Data based on personal observations in Mill Creek.
Upstream Migration													Butte Creek Entered Butte Creek in February through April (Yoshiyma et al. 1996). Source of data not stated.
Upstream Migration													Feather River Enter Feather River in May or June (Yoshiyma et al. 1996). Hatchery influenced population. Source of data not stated.

	Span of Life History Activity
	Peak of Life History Activity

The adaptive management of spring chinook must focus in part on monitoring the life history traits of the population, with particular attention to determining if the run timing observed in Butte Creek is replicated in a restored San Joaquin River.

3.2.3.2 Fall-run chinook salmon

The main concern in selecting a fall chinook stock is the need for a run that migrates and spawns relatively early in the fall so that fry develop, emerge, and outmigrate before lethal temperatures set in during the spring. Also, spawning timing after October will minimize the risk of interbreeding with spring chinook. The spawning period needs to be compressed, since late spawners and late-emerging fry from fall chinook have a relatively low chance of survival. However, temperatures are high in the fall, so tolerance to high temperatures during migration is necessary. Tributaries to the San Joaquin River (Stanislaus, Tuolumne, and Merced rivers) were obvious candidates for fall chinook stocks, as they would likely provide phenotypes adapted to environments that resemble conditions in a restored San Joaquin River.

Of the fall chinook salmon stocks considered, Tuolumne River stocks appear to be best suited for use in restoring a fall run to the San Joaquin River. The Tuolumne River fall-run chinook migrate upstream in October and have compressed spawning period in November, which are ideally suited to temperature conditions in the San Joaquin River, and will minimize the risk of interbreeding with spring chinook. Tuolumne River fall-run chinook salmon are less influenced by hatchery introductions than stocks in other rivers, and are some of the most intensely studied salmon stocks in the Central Valley. The abundance of available data is a key advantage, as this information provides a detailed understanding of their specific life history and habitat requirements, and allows restoration planning efforts to incorporate these needs into restoration strategies. Fall-run chinook salmon stocks of the Stanislaus and Merced rivers are less well known; the lack of information on these stocks makes them less desirable.

The use of Tuolumne River fall-run chinook stock offers other advantages. Of the three tributaries considered, the Tuolumne River typically generates the largest escapements of naturally spawned fall-run chinook salmon (Figure 3.2-1), with relatively minor hatchery influence. This high level of production would minimize the impacts of an egg-harvesting operation on the Tuolumne River population, while allowing for a relatively high number of eggs to be collected for planting in the San Joaquin River. In addition, the genetic integrity (i.e., lack of hatchery influence) of the eggs planted would be relatively high.

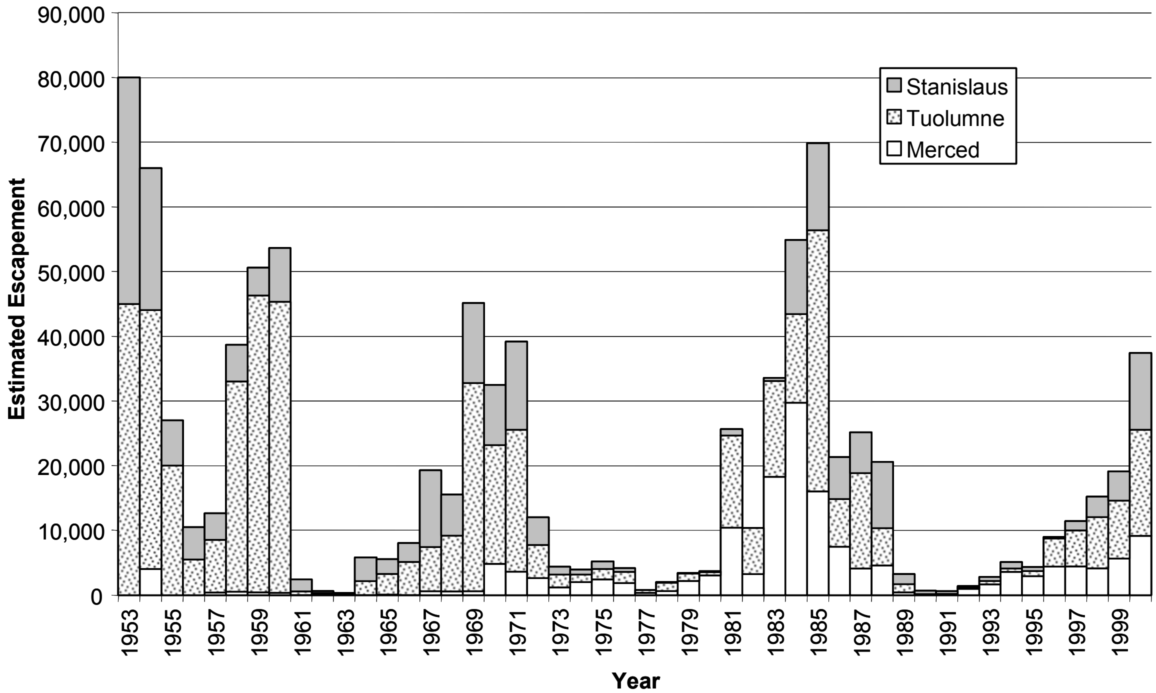

Figure 3.2-1. Cyclical escapement patterns of fall-run chinook salmon in San Joaquin tributaries. The cyclical nature of salmon populations is largely tied to environmental conditions, and is often a function of flow fluctuations. It is anticipated that restored San Joaquin River chinook populations that are based on Tuolumne River chinook parent stock will also exhibit cyclical population dynamics, however the restoration strategy will maximize population peaks to prevent population crashes.

The adaptive management of fall chinook will have to focus in part on monitoring the life history traits of the population, with particular attention paid to determining if the run timing observed in the Tuolumne River is replicated in a restored San Joaquin River. Because the migration distance for fall chinook in the San Joaquin River is much longer (200 mi [320 km]) than the migration distance in the Tuolumne River (about 80 mi [130 km]), there is a chance that the energy reserves, and thus health of the stock, could be a concern. Straying may also be a concern given the longer migration distance and the tributaries that may attract upstream migrants on their way upstream to spawning areas below Friant Dam.

3.2.3.3 Comparison of spring-run chinook salmon and fall-run chinook salmon

Selecting a parent stock for both runs focuses on the same principle factors, as described above. The Butte Creek spring chinook stock is well-suited for the San Joaquin River, although ideally the stock would come from within the basin. Even though a fall chinook stock from the Tuolumne River would migrate farther in the San Joaquin than in the Tuolumne River, this stock has the advantage of being from the same basin. There is more uncertainty associated with using the Butte Creek spring chinook stock than in using the Tuolumne River fall chinook stock. The Tuolumne stock originates from the San Joaquin River basin, and so does not present the uncertainties in transferring a stock to a new basin that the Butte Creek selection presents. In addition, a large amount of research has been conducted on the Tuolumne River, so the characteristics of the stock are relatively well known.

3.2.3.4 Introducing parent stock

Once parent stocks are selected, a program to "jump-start" populations is required. There are many different approaches that have had success in other rivers, including planting eggs, releasing hatchery-raised fry, releasing hatchery-raised smolts, releasing mature adults, and allowing adults to stray and recolonize the river. Fall-run chinook are likely to stray from existing tributaries, which could decrease the need to augment their populations in the San Joaquin River. Each of these methods has advantages and disadvantages. It is likely that a jump-start program will use several of these methods in attempts to establish populations. Major considerations in establishing the population include:

- imprinting smolts on the San Joaquin River,
- maximizing survival of early life stages,
- cost, and
- establishing populations in an experimental approach within an adaptive management program.

3.2.4 Chinook salmon life histories and habitat considerations

3.2.4.1 Upstream migration

Adult salmon migrating upstream to natal spawning grounds can be blocked or delayed in migration by physical barriers, lack of water depth, and inadequate water quality (e.g., temperature and dissolved oxygen). When conditions are poor, even fish that successfully migrate upstream may be too stressed to maximize their spawning effort, or may die from disease or other stress-related factors prior to spawning. Physical barriers to upstream migration of anadromous salmonids are discussed in Section 7.7.4 of the Background Report. Physical barriers mainly consist of flow control structures, such as the Bifurcation Structure, Sand Slough Control Structure, Sack Dam, and gates on Mariposa and Eastside bypasses. At these locations, structures may need to be removed and/or facilities added to achieve passage. Passage at some barriers, such as the Mendota Dam, is possible under certain flow conditions, but more modern facilities are warranted to allow passage under a wider range of flows.

Adequate water depths are necessary to facilitate safe passage to upstream holding and spawning areas. Instream flows of 100 cfs in the San Joaquin River upstream of the Merced River were observed to result in difficult passage routes that abraded the ventral areas of fall chinook salmon. Adult chinook salmon require depths of at least 0.8 ft (24 cm) for successful upstream migration (Thompson 1972, as cited in Bjornn and Reiser 1991). A minimum water depth of 1 ft (31 cm) needs to be maintained across at least 25% of the channel to provide for upstream migration. The restoration strategies will ensure that these minimum requirements are exceeded.

In addition to providing adequate water depth, increased flows are required to ensure suitable water quality for migration. Restoration strategies must provide sufficient volumes of cool water during upstream migration to ensure safe passage to cooler upstream holding and spawning areas, after which temperatures in downstream reaches can be allowed to warm without endangering the majority of the run. Providing sufficient flows to allow adequate passage past barriers is not expected to be a constraint, but providing sufficient flows to lower water temperatures in the lower river will be a challenge. Although the expectation is to increase discharges from Friant Dam to provide suitable water temperatures, initial analysis suggests that it is not certain that increased flows from Friant Dam will lower water temperatures in the lower reaches of the San Joaquin River. Other water quality conditions that may impede upstream migration of salmon include high salinity and low dissolved oxygen, as discussed in the Background Report.

Spring chinook salmon

The migration temperature target for spring chinook salmon is <65ºF (<18˚C), but spring chinook are commonly observed holding in water temperatures exceeding 70ºF (21°C) (Moyle 1976). Under historical conditions, spring chinook salmon in the mainstem San Joaquin River passed the Merced River between mid-April and mid-June; peak passage occurred in early May, and arrival at Mendota Pool in early June (Hallock and Van Woert 1959). Under current conditions, maintaining suitable water temperatures (<65ºF [18˚C]) during this time of year is a challenge. However, spring chinook salmon in Butte Creek (the proposed stock for a restored San Joaquin River population) migrate upstream from February through April, peaking in March (Yoshiyama et al. 1996). A restored spring run chinook population will need to migrate upstream during the period when temperatures remain suitable to reduce the need for substantial releases of water for this life stage. This will be accomplished by using early-run Butte Creek stock as parent stock and by ensuring that instream flows are sufficient to maintain suitable temperatures throughout the mainstem San Joaquin River. The later part of the run is likely to arrive in the mid-San Joaquin River in April or May, when flows are typically higher than in the winter. Although the flows are higher later in the spring, temperatures during this time are increasing from increased solar radiation, and thus later returning spring chinook will be at risk of exposure to elevated temperatures (Figure 3.2-2).

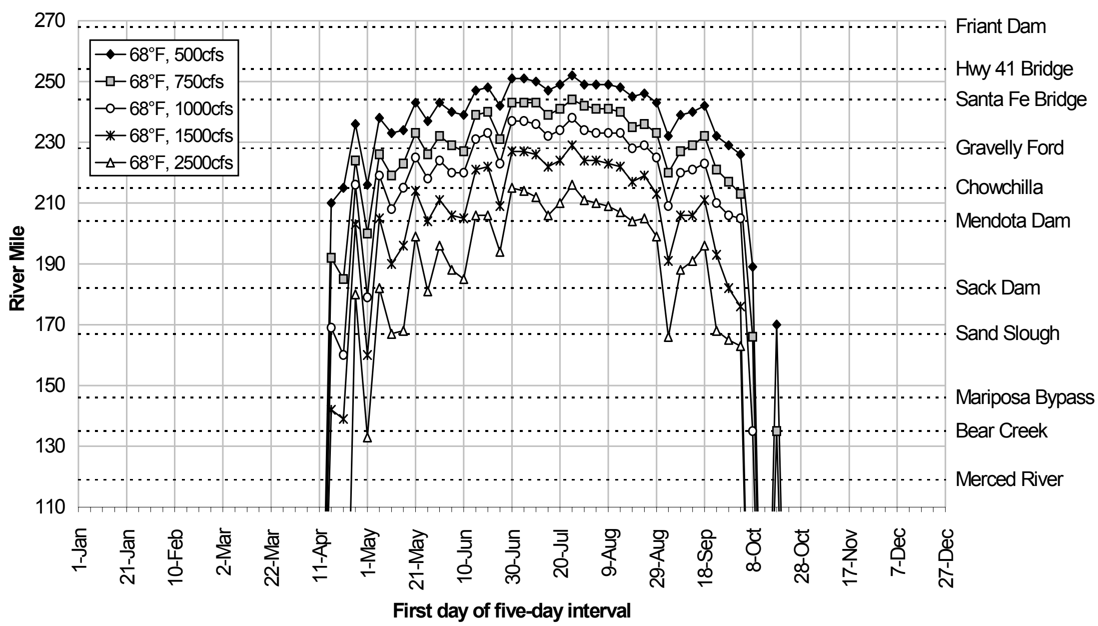

Figure 3.2-2. Last river mile for which 5-day average temperature is below threshold. San Joaquin River Temperature Model, average meteorology modeled temperatures from JSA, 26 April 2002.

Fall chinook salmon

Obtaining suitable water temperatures for fall chinook adult migration will be a challenge. Under current conditions, the lower San Joaquin River drastically exceeds the temperature objective of <65ºF (18˚C) for adult fall chinook migration. The San Joaquin River is inherently warm in its lower reaches, and even under historical conditions, fall chinook migrated upstream when average monthly temperatures often exceeded 70ºF (21°C) (Yoshiyama et al. 1996). If the

Tuolumne River stock is selected, adult upstream migration is likely to occur in October. It will likely be difficult to provide the high flows needed to obtain preferred migration water temperatures in the lower San Joaquin River, particularly in dry years. It will be possible to increase flows enough to provide adequate depths and velocities for migration, but migrants may encounter temperatures greater than 65ºF (18°C) for the initial part of the run. Temperatures will decrease in an upstream direction, from both decreasing solar radiation and increased cool-water flow releases at Friant Dam, so as migrants swim upstream their exposure to elevated temperatures will decrease. Although sublethal effects, such as susceptibility to disease, and decreased egg viability may result from exposure to high water temperatures in the lower river, most of the run could be expected to migrate successfully in most years. It is possible that the latter part of the fall chinook run may be stranded when flows drop, selecting for the early part of the run over time. The early part of the fall chinook run has a much higher chance of survival, since the young will emerge earlier and be able to outmigrate before water temperatures become unsuitable in the spring.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Historically, spring chinook likely encountered favorable conditions in their upstream migration. High spring snowmelt flows likely ensured relatively cool water, and reduced risk of encountering barriers. Fall chinook, however, migrated upstream during the low-flow period at the end of the summer. The susceptibility of fall chinook to poor water quality and potential low-flow barriers may have prevented them from historically having the run strength of fall chinook in other parts of the basin, or of spring chinook in the mainstem San Joaquin River.

Model parameterization

The population model uses a rate of upstream migration of 10 mi/day (16km/day) and has three statistical distributions representing the distribution of arrival dates of spawners of each age (age 2, age 3, and age 4). Temperature effects on upstream migration and other potential obstacles to migration are not included in the model, although these factors can be built into the model in the future.

3.2.4.2 Adult holding

Fall chinook do not require holding habitat during their upstream migration, whereas for spring chinook, holding habitat is a principle habitat requirement. Holding habitat for spring chinook must provide conditions that allow them to conserve energy and avoid predation while they mature, including cool temperatures of sufficient duration and deep water with slow velocities.

Spring chinook salmon

Spring chinook may hold for months after migration and prior to spawning. Spring chinook migrate upstream and hold in deep, cool pools over summer while they mature and then spawn in late summer/early fall. Historically, spring chinook probably held in pools above Friant Dam, and after Friant Dam was constructed, Clark (1942) observed an estimated 5,000 adult spring chinook holding in two large pools directly downstream of Friant Dam in July. The restoration vision for spring chinook adult holding is to provide holding habitat through the summer months in the same large bedrock pool below Friant Dam where Clark (1942) observed fish holding. This large pool is the best candidate for holding habitat because it is a bedrock pool that remains cool all summer and has complex structure, such as overhanging bedrock to provide cover.

Holding temperatures for spring chinook are reportedly optimal when <60.8ºF (<16.0°C), and lethal when >80.6ºF (<27.0°C). However, spring-run chinook in the Sacramento River basin typically hold in pools that have temperatures between 69.8 and 77ºF (21.0 and 25.0°C) (Moyle et al. 1995). In Butte Creek, average daily temperatures have been collected from 1996 to 2001 throughout a reach known to support spring chinook salmon holding and spawning (from Centerville Head Dam downstream to Parrott-Phelan Dam), which suggest that spring chinook salmon in this system can tolerate exposure to daily maximum temperatures in July of 59.7 to 74.7°F (15.4 to 21.2°C) and daily mean temperatures of 57.6 to 71.2°F (14.2 to 21.8°C) (Figure 3.2-3) (Williams et al. 2002). Release temperatures from Friant Dam range from 48 to 52°F (9 to 11°C), which would provide suitable holding temperatures in the existing pool below Friant Dam.

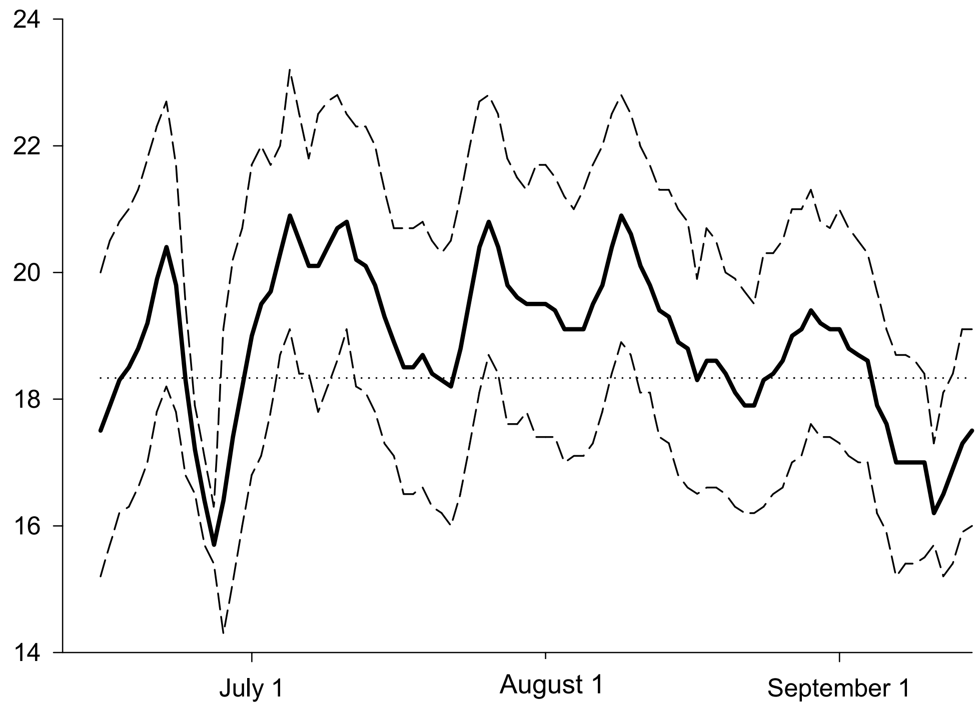

Figure 3.2-3. Daily maximum, average, and minimum water temperatures in a spring chinook holding pool in Butte Creek, summer 2001. Source: Williams et al. 2002.

The targeted pool for adult spring chinook holding has a maximum depth of 25 ft (8m) with an average depth of 11 ft (3m), with an approximate area of average depth of 93,000 ft^2 (8,600m^2) (Appendix B, Figure B-1). Chinook generally do not feed while they hold; therefore, they can hold at very high densities. Based on examination of photographs of spring chinook holding in Butte Creek, it was our professional judgment that spring chinook can hold at densities ranging from 0.5 fish/m^2 to 1.5 fish/m^2 (Appendix B, Figure B-2) Based on this assumption, the pool below Friant Dam can conservatively support 4,300 to 12,900 spring chinook. Other pools with residual depths of over 8 ft (2m) and a high potential to provide suitable habitat have been identified downstream of Friant Dam in Reach 1 (Appendix B, Figure B-3). There is potential to increase the overall holding habitat in Reach 1 by providing higher flows to maintain suitable holding temperatures in these downstream pools.

Poaching of holding salmon remains a concern, as fish are vulnerable for several months in a confined location at high densities. The banks of the pool below Friant Dam are fenced off, thus minimizing access for poachers. However, the North Fork Road bridge downstream of the dam has a boat launch that provides access to the river where poachers could gain access to the pool. To minimize poaching, a game warden or community organization may be required to police the holding pool during the summer. Adaptive management of spring chinook holding habitat should focus on assessing holding densities, egg viability, disease, and levels of poaching.

Fall chinook salmon

Fall chinook are not known to hold during their migration prior to spawning.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Conventional wisdom has held that a lack of adequate holding habitat limits the potential success of restoring spring chinook populations in the San Joaquin River. However, holding habitat is available for spring chinook in the San Joaquin below Friant Dam, and providing adequate conditions will not be as difficult as other challenges to restoration (e.g., providing suitable temperatures in lower reaches for upstream and downstream migration of fall chinook). It should be noted that Clark (1942) observed thousands of spring chinook holding in the mainstem San Joaquin River *after* the construction of Friant Dam, even after fall chinook had disappeared from the mainstem.

3.2.4.3 Spawning

Planning for spring and fall-run chinook spawning must take into account that these runs will likely share common spawning areas in the San Joaquin River below Friant Dam in Reach 1. Limitations on spawning gravels can result in redd superimposition, whereby later-arriving females build redds on top of existing redds, potentially destroying previously deposited eggs (McNeil 1964, Hayes 1987). Females do not distribute themselves equally, and may even select areas that have been previously dug, so even if spawning habitat is not limiting, superimposition is a potential concern (EA Engineering 1992). Spring chinook will be the primary run affected by superimposition, since they spawn earlier in the season than fall chinook.

Chinook are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). Depths most often recorded over chinook redds range from 3.9 to 78 in (9.9 to 198 cm) and velocities from 0.5 to 3.3 ft/s (0.15 to 1.0 m/s), although criteria may vary between races and stream basins. Fall chinook salmon, for instance, are able to spawn in deeper water with higher velocities, because of their larger size (Healey 1991); spring chinook tend to dig smaller redds and use finer gravels than fall chinook (Burner 1951). The vision for restoring both spring and fall runs of chinook salmon includes using their microhabitat requirements regarding temperature, depth, and velocity to create spatial, temporal, lateral, and longitudinal segregation of spawning areas, and by appropriate stock selection and flow management. Habitat segregation is desired to increase the amount of spawning habitat, decrease redd superimposition, and maintain the genetic integrity of the runs. After spring chinook spawn in the early fall, flows will be increased. As flows are increased, preferred water depths and velocities will shift from the center of the channel (where spring chinook spawn) to the lateral portions of the channel, creating lateral separation of the runs. Since temperatures will also be decreasing, and since fall chinook are larger than spring chinook, they will be able to spawn further downstream, creating longitudinal separation. The total area of spawning habitat will also be increased by augmenting current spawning areas with suitable gravel.

There is conflicting information on the location of historical spawning areas that were the most suitable and frequently used, but in general, Clark (1942) and Hatton (1940, as cited in

Yoshiyama et al. 1996) both report that highly suitable gravels occured in the 10-mi (16-km) reach from Lanes Bridge to the current site of the Friant Dam. Currently, potential spawning gravels for chinook exist throughout Reach 1A and upper Reach 1B (Appendix B, Figures B-4a through B-4c), but downstream of Reach 1B, the river becomes sand-bedded and unsuitable for spawning habitat.

Spring-run chinook salmon

In order to focus spawning of spring-run chinook in September to minimize risk of hybridization with the later-spawning fall-run chinook, Butte Creek spring chinook is proposed as the parent stock for restoring San Joaquin populations, since it appears that they spawn earlier than other spring-run chinook in the Central Valley (Table 3.2-2), and earlier than Tuolumne River fall chinook. Spring chinook in upper Reach 1A will disperse from holding areas to spawning areas in the center of the channel, where preferred flow velocities and depths will be provided by late summer base flows. It is expected that an increase in flows will mimic a fall freshet and provide a cue for spawning. A fall freshet may serve as a spawning cue, given the absence of a temperature cue in the San Joaquin River; however, the magnitude and duration of the flow cue is uncertain. The effectiveness of providing a cue for spawning will need to be assessed as part of the Adaptive Management Plan.

The water temperature target for suitable spawning conditions is <56ºF (<13°C). Suitable spawning temperatures will be maintained downstream of Friant Dam from fall flow releases, providing usable spawning habitat in Reach 1A. During spring chinook spawning, temperatures will likely approach or exceed 56ºF (13°C) in lower Reach 1A and in Reach 1B, while such temperatures may not prevent some spring chinook from spawning there, survival of eggs to emergence in lower Reach 1A will likely be low due to exposure to increased temperatures. It is possible to increase the acreage of spawning habitat by increasing flow; however, by concentrating spring chinook spawning in the upper portion of Reach 1A, there can be longitudinal segregation with fall-run chinook.

Table 3.2-2. Spawning Timing of Spring Chinook in Sacramento River Tributaries.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Spawning													Deer and Mill Creeks Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning													Sacramento River Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning													Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).

	Span of Life History Activity
	Peak of Life History Activity

Fall-run chinook salmon

In order to focus spawning of fall-run chinook in November to minimize risk of hybridization with earlier-spawning spring-run chinook and to facilitate earlier juvenile outmigration in the spring before water temperatures in the lower reaches become stressful or lethal, Tuolumne River fall chinook are proposed as the parent stock for restoring San Joaquin River populations. Fall chinook that spawn after November will produce juveniles that are not likely to survive their downstream migration, due to warming downstream temperatures. Water temperatures suitable for spawning will be maintained in November downstream of Friant Dam by increasing winter base flows. Increasing flows in November should shift preferred spawning habitat depth and velocity conditions out of the center of the channel to the channel margins, and farther downstream from Friant Dam (both by lowering temperature and increasing flow), thereby providing lateral and longitudinal segregation with spring-run spawning, and decreasing the risk of redd superimposition with established spring-run redds. Adult fall chinook are expected to migrate and immediately spawn, and should not require additional triggers to initiate spawning.

Comparison of spring-run chinook salmon and fall-run chinook salmon

The restoration vision provides for spawning in September for spring-run chinook salmon, with spawning redds located in the center of the channel and high upstream in Reach 1A. There is a risk of redd superimposition with fall-run chinook if lateral segregation is not as extensive as anticipated. Superimposition is mostly a risk for spring chinook redds, since they spawn prior to fall chinook. In addition, when fall-run spawn, flows will be higher and temperatures lower, so they will have a broader area of habitat to utilize for spawning. Monitoring and adaptive management will be necessary to address the effectiveness of using flows to provide habitat segregation. The genetic integrity of selected stock is also important to maintain temporal segregation between runs. Early spawning by spring-run chinook should also minimize the potential for redd scour, as high flows that could cause scour are not likely to occur until the spring, which is after emergence of fry. High fall migration flows designed to ensure safe passage for fall chinook are not expected to scour spring chinook redds (Section 3.1), although this uncertainty should be addressed through adaptive management. Spawning is expected to be concentrated in Reach 1A (see above), and thus gravel augmentation may be warranted in this reach as a component of an adaptive management approach to increase suitable habitat there. It is expected that gravel augmentations will increase permeability by increasing the amount of clean, suitable substrate

Model parameterization

The population model spatially distributes spawners over the reaches where temperature is suitable for spawning. It uses temperature data provided by outputs of a temperature model that predicts water temperature for varying flows and river miles. A scheduler is used to assign actual spawning dates and times, and to keep track of delayed or foregone spawning due to limitations in undefended spawning habitat and losses of embryos due to superimposition. The model assumes that spring and fall chinook have the same fecundity at a given age, the same ratio of females at a given age, and the same spawning age structure. 50% of the spawning run are considered to be 3-year-old fish, the remainder split between 2-year-old and 4-year-old spawners. The percentage of females (based on Merced River Hatchery data) was 20% of 2- year-old fish, 50% of 3-year-old fish, and 55% of 4-year-olds. Fecundity increases with age of spawning female: 2-year-old females spawn 2,217 eggs, 3-year-old females spawn 4,458 eggs, and 4-year-old females spawn 5,552 eggs/female (TID/MID 1992).

3.2.4.4 Incubation

Chinook eggs require cool temperatures (daily maximum <58ºF [14°C]) and high intragravel flow for successful incubation. Incubation temperatures influence the rate of embryo development, with warmer temperatures decreasing time to emergence. Water released from Friant Dam during egg incubation will meet temperature objectives for both fall and spring chinook egg incubation.

Intragravel flow delivers dissolved oxygen to incubating eggs and removes metabolic waste. Survival to emergence is a function of permeability, which in turn is influenced by substrate size, intragravel fines, and hydraulic head. Increases in permeability directly increase survival to emergence, which can have population-level effects. Permeability measurements indicate that intragravel flow conditions in Reach 1A are adequate (Appendix B, Figure B-5), though in many riffles spawning substrates compose only a thin (<12 in [<30 cm]) layer over bedrock. Permeability in lower Reach 1A and 1B is higher, though it begins to decline as the component of sand in the substrate increases in mid- to lower Reach 1B (Appendix B, Figure B-6). Spawning is expected to be concentrated in Reach 1A (see above), and thus gravel augmentation may be warranted in this reach as a component of an adaptive management approach to increase suitable habitat there. It is expected that gravel augmentations will increase permeability by increasing the amount of clean, suitable substrate.

Spring-run chinook salmon

Target incubation temperatures for spring chinook salmon are daily maximums of less than 58ºF (14°C). Water released from the Friant Dam when spring chinook are spawning (late September) will be lower than this target, and will decrease during their spawning period due to decreased solar radiation.

Fall-run chinook salmon

When fall chinook initiate spawning in November, daily maximum water temperatures released from Friant Dam will be less than 58ºF (14°C). The farther fall chinook spawn downstream from the dam, the warmer the water is likely to be. Fall chinook emergence and rate of development may be an important factor if juveniles outmigrate too late in the spring when lower river temperatures are likely to be stressful or lethal. A shorter time to emergence and faster growth can improve the likelihood that outmigration occurs before temperatures become too warm in the lower river. As water from Friant Dam warms downstream, it may increase the rate of embryo development and result in earlier emergence in redds located in lower Reach 1A or 1B.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Spring chinook eggs will develop faster than fall Chinook because spawning occurs when the water is warmer. However, fall chinook that utilize the higher flows and cooler temperatures during November may spawn farther downstream in Reach 1, and thus be exposed to warmer water temperatures, and shorter development times. The fall chinook redds in proximity of spring Chinook redds (in upper reach 1A) are expected to develop more slowly than spring chinook, since the water temperatures will be cooler in November when fall chinook spawn, than in September. If flows are dropped after spring chinook spawning, or after fall chinook spawning, redd desiccation could result. Redd stranding should be evaluated as part of the adaptive management strategy.

Model parameterization

The survival-to-emergence parameter in the population model is based on existing information on gravel permeability from the San Joaquin River above Lane's Bridge. Permeability was measured before and after disturbance that was applied to mimic the movement of gravels that occurs when chinook dig redds. The permeability rate was then used to estimate survival to emergence based on McCuddin (1977). Permeability was highest in disturbed riffles at RM 267 (just below Friant Dam) and dropped immediately downstream. Survival to emergence was estimate at 40% for the gravels with highest permeability, and 20% for spawning gravels in lower Reach 1.

3.2.4.5 Freshwater rearing

The target size for rearing chinook is 3.2 in (80mm), which is the average size of Tuolumne River smolts (Hume et al. 2001). Opportunities to provide rearing habitat for juvenile chinook salmon depend on providing suitable habitat conditions to promote growth and survival. Reach 1 provides the best habitat conditions for rearing in the San Joaquin River; however, juveniles may disperse downstream into less suitable reaches and as they outmigrate, they will need to move through the lower reaches. Below Reach 1, channel conditions, temperatures, and food production may be less suitable for rearing. Screening diversions and creating or rebuilding new channels will also likely be required. If new channels are created, they can be designed to provide surfaces targeted specifically for floodplain rearing habitat.

Predators (large mouth bass in particular) have been found as far upstream as Reach 1A in temperatures as low as 60ºF (16°C), at which temperatures become conducive for feeding and growth (Mohler 1966, as cited in Stuber et al. 1982; Hathaway 1927, as cited by Heidinger 1976). The restoration strategy will avoid creating conditions favorable for large mouth bass predation on rearing fry by maintaining temperatures below 60ºF (16°C) and providing floodplain habitat with shallow inundation depths, particularly in Reach 1.

The ability of juvenile chinook to grow during the rearing period will be crucial to ensure that smolts outmigrate at a size that will increase their chances of surviving in the delta and ocean. Juvenile chinook salmon often seek refuge in low-velocity habitats where they can rest and drifting invertebrates will tend to be deposited. Because of the energetic demands of both retaining position within the water column and obtaining prey items, as well as the metabolic demands on ectotherms as water temperatures increase, fish feeding and growth in lotic system depend on a number of factors working in concert. Energy required to maintain position within the water column is generally a function of body size (Chapman and Bjornn 1969, Everest and Chapman 1972). For example, small fish and newly emerged fry typically inhabit slower-water habitats, often found at the margins of mainstem channels, backwaters, or side channels. Larger fish typically move into more faster-flowing habitats, where larger prey are usually available (Lister and Genoe 1970). This shift is also energetically more economical, since larger fish would require more prey items, and capturing one prey item is energetically more efficient than capturing many.

Food availability and water temperature directly influence fish growth. On maximum daily rations, growth rate increases as temperature increases up to a certain optimal temperature and then declines with further increases in temperature. Rations reduced from maximum levels reduce growth rates, and so declines in juvenile salmonid growth are a function of both temperature and food availability. Brett et al. (1982) found the highest growth rates under maximum daily ration to occur at 64.4–71.8°F (18.0–22.0°C), with declines in growth rates at higher temperatures and much reduced growth at 75.6°F (24.8°C). Rich (1987) showed only slightly reduced growth rates at 66 and 70°F (19 and 21°C) for American River juvenile chinook salmon under constant exposure for 45 days, with the highest growth rates occurring at 56–60°F (13–15°C).

Estimated growth rates of juvenile chinook were modeled to assess flow strategies for the San Joaquin River for various water year types by determining if fish could attain a minimum size for outmigration before lower Reach temperatures warmed to stressful or lethal levels. Based on growth rates calibrated using Tuolumne River Chinook, ration was estimated at 70%. Ration is likely similar or higher in the gravel-bedded Reach 1 of the San Joaquin River based on a comparison of macroinvertebrates with the Tuolumne River, although there is greater uncertainty about ration levels in the sand-bedded reaches and the floodplains of the San Joaquin River.

Because of the many factors associated with fish growth, it is difficult to predict the time required for juvenile fish in the San Joaquin River to grow to an adequate size before outmigrating. Since success of juvenile salmonids outmigrating through the Delta and to the ocean likely depends on fish size, and since the water cost of maintaining suitable temperatures in downstream reaches into late spring months is high, our governing assumption for juvenile rearing is to provide conditions that encourage growth and potentially shift peak outmigration to earlier in the season. Invertebrate production is typically higher in gravel-bedded reaches than in sand-bedded reaches, so as juveniles move downstream, food availability will likely decrease and temperatures will increase. Rearing habitat for both spring and fall chinook will be provided primarily in Reach 1, and on seasonally inundated flood plains. Inundated floodplain habitat is expected to provide an abundance of low-velocity habitat, increased food availability, and slightly higher water temperatures, all which are expected to increase growth rates.

The river temperatures that were modeled to determine an appropriate flow strategy to maximize growth have inherent uncertainties that affect growth rate predictions. For example, the model estimates thalweg temperatures, whereas chinook are expected to rear on channel margins (Everest and Chapman 1972), or on inundated floodplains (Sommer et al. 2001). River temperatures vary across the width across the channel (Bartholow 1989), due to varying water velocities and water depths. Actual temperatures encountered by rearing chinook are likely to be higher than those modeled for the thalweg of the main channel. Swales et al. (1986, 1988) found that water temperatures in British Columbia rivers are often 1.8 to 4.5°F (1.0 to 2.5ºC) higher in side-channel or off-channel habitat than in main channel habitat. Sommer et al. (2001) found that water temperatures were up to 41°F (5ºC) higher in the flooded Yolo bypass than in the main channel of the Sacramento River. Remote thermal imagery has shown that during the summer, water temperatures vary with microhabitats, and that fish respond to these variations, apparently to maximize habitat suitability. Actual growth rates that will be achieved by rearing chinook remain a critical uncertainty, and should be addressed as a component of the Adaptive Management Strategy.

Spring-run chinook salmon

Butte Creek spring-run chinook salmon are a prime candidate for parent stock for restoring spring-run chinook salmon to the San Joaquin River. In Butte Creek, the majority of the spring chinook migrate as subyearlings during high flows in November, but some fish rear during the winter and outmigrate during the spring, and another group rears for up to a year and outmigrates the following October (Hill and Webber 1999). Nicholas and Hankin (1989a) suggested that the duration of freshwater rearing in the Pacific Northwest is tied to water temperatures, with juveniles remaining longer in rivers with cool temperatures.

In other Sacramento tributaries, the yearling life history strategy is more common. In both Deer and Mill creeks, spring-run chinook tend to migrate as yearlings in the fall and winter (State Water Resources Control Board 1998). There is uncertainty about which life history strategy will be exhibited by spring-run in the San Joaquin River, but this uncertainty should be addressed through monitoring and adaptive management.

Rearing habitat for fry and older stages of spring-run chinook should be available in Reach 1, where habitat includes gravel-bedded pools that provide suitable velocities, temperatures, and food production (Appendix B, Figure B-7). However, only seasonal rearing habitat will be available downstream of Reach 1 due to increases in air and water temperatures in late spring and summer. Reach 1 contains gravel-bedded pool habitats that are likely to be ideal for rearing juveniles and that provide ample invertebrate production. The strategy for determining appropriate temperatures incorporates the interaction between temperature and ration on juvenile growth and the effects of temperature at release from Friant Dam as it warms downstream. The main constraint for juvenile rearing is to attain a size (3.2 in [80 mm] fork length) at which juveniles can outmigrate through the lower reaches prior to temperatures reaching levels that are stressful or lethal (the chronic upper lethal limit for juvenile Central Valley chinook salmon has been estimated at approximately 77°F [25°C][Myrick and Cech 2001]).

Release temperatures from Friant Dam currently range from 48 to 52ºF (9 to 11°C), and temperatures increase with distance downstream. Based on existing release temperatures, if spring-run spawn by October 1, juveniles can attain 3.2 in (80 mm) on 60% ration before the end of April just below Friant Dam (Figure 3.2-4). Juveniles that rear 5 mi (8 km) downstream reach 3.2 in (80 mm) even earlier, due to the warming that accelerates growth. Flows will be provided to inundate floodplain habitats. Temperatures in off-channel and flood plain habitats are likely to be a few degrees higher than in the main channel. Increased temperature and increased food availability on floodplains (Sommer et al. 2001) are expected to provide conditions that allow most juvenile spring chinook to reach 3.2 in (80 mm) prior to outmigrating. Spring-run chinook salmon that move downstream in late fall or winter as fry are not likely to encounter temperatures exceeding 68°F (20°C) through Reach 5 until early to mid-April.

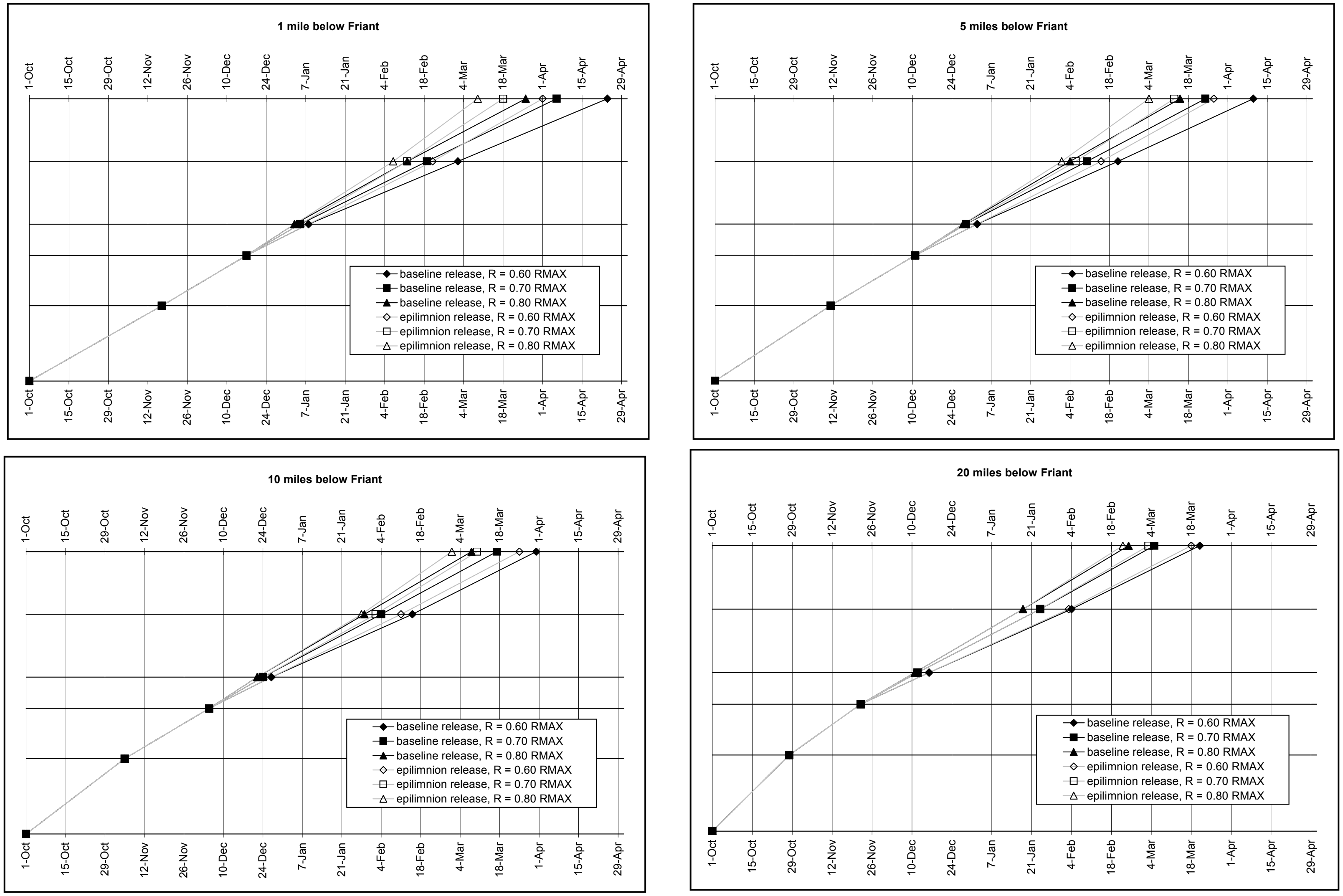

Figure 3.2-4. Emigration calendars for spring-run chinook salmon. Fry growth is dependent upon a function of water temperature and food availability. Based on degree-day modeling, we expect that epilimnetic releases would result in faster growth since the water would be warmer than baseline releases. As a result of faster fry growth, the salmon would exit the system by up to one month earlier, with important implications for managed flow release schedules. This enhanced growth effect can be expected to gradually diminish downstream from Friant Dam, as the epilimnetic release would thermally diffuse into the cooler water. The benefits of an epilimnetic release would thus be more concentrated in the upstream area close to Friant Dam. Spring-run chinook have a natural competitive advantage over fall-run chinook because they exit the system earlier in the season. These calendars assume a 60% maximum food availability ration, which best estimates optimal food availability conditions in a stream. A 100% maximum ration is only found in controlled laboratory conditions, and is therefore not appropriate for use in this model.

Fall-run chinook salmon

Fall-run chinook salmon do not have a life history with extended rearing—they tend to rear only for a few months before emigrating. The restoration vision for fall-run chinook is to provide flows to inundate floodplains for 45 to 60 days. Floodplain inundation has been demonstrated to provide particularly high survival and growth opportunities for juvenile fall chinook (Sommer et al. 2001). Based on the population model and existing release temperatures, if fall chinook spawn by November and juveniles experience 70% ration, they would attain emigration size (3.2 in [80 mm]) by mid-May. Juvenile fall-run chinook, more so than spring-run chinook, risk exposure to stressful or lethal temperatures in downstream reaches as they emigrate, in part due to their later time of spawning, and typically smaller outmigrant size.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Spring chinook and fall chinook require very similar rearing conditions. However, a least a proportion of spring chinook will likely rear for a few months longer than fall chinook due to their earlier emergence timing, and will thus outmigrate at a larger size than fall chinook. Another group of spring chinook are expected to rear for up to a year before outmigrating, and thus would require suitable habitat conditions during the summer, in addition to winter and spring.

Model parameterization

Juvenile rearing is a complex life stage to model. The population model addresses movement among reaches and accounts for the different conditions for growth in different segments of the river. For example, growth conditions are modeled differently for fry rearing in the gravel-bedded reaches near the spawning areas, and for those dispersing downstream into the sand-bedded reaches of the lower river. Currently the model simply assigns fixed fractions of the fry to various reaches of the river; a model of fry development (Stauffer 1973) is used to determine growth rates (using temperature output from the temperature model and reach-specific feeding rations); and survival is a reach-specific constant.

To address daily growth as a function of temperature and ration, the model assesses the distribution of fish relative to temperatures at different river miles under different flow scenarios. The river was divided into 8 areas for rearing: Reaches 1, 2A, 2B, 3A, 4A, 4b, and 5. Temperatures were estimated using the temperature model at the middle of each reach. The model assumes that 10% of the emergent fry migrate to the Delta immediately after emergence, and die. Of the remaining 90% of the emergent fry, 80% would remain in the gravel-bedded Reach 1, and 20% would be distributed in equal densities in the sand-bedded Reaches 2 to 5.

Ration was calibrated using data from the San Joaquin and Tuolumne rivers. The model was calibrated for growth rate and estimated ration based on Tuolumne River data (Vick et al. 2000). The estimated ration in the Tuolumne River to achieve the observed growth rates was 70%; temperatures in the Tuolumne and upper San Joaquin are similar. Macroinvertebrate production in the upper San Joaquin River in Reach 1 is higher than production in the Tuolumne, providing increased confidence in using a ration of 70%. Macroinvertebrate production in the sand-bedded reaches is unknown but was set at 20% of maximum rations.

3.2.4.6 Smoltification and outmigration

The onset of smoltification and outmigration depends on several factors, such as the attainment of appropriate minimum size (Bradford et al. 2001, Folmar and Dickhoff 1980). Larger juvenile chinook also have a greater tendency to move downstream earlier in the season than smaller juveniles (Nicholas and Hankin 1989). The minimum size must be reached before temperatures in downstream reaches warm to stressful or lethal levels. For smoltification and outmigration, juveniles need to encounter appropriate conditions that allow them to prepare physiologically, morphologically, and behaviorally to emigrate from freshwater habitats to the estuary and eventually to the ocean. The restoration goal for smoltification and outmigration is to provide suitable average daily temperatures in the lower reaches (<68ºF [20ºC]) with increased spring flows, which will also provide a stimulus for outmigration. In addition to providing adequate water depth, increased flows are required to ensure suitable water quality for outmigration. Providing sufficient flows to allow adequate passage past barriers is not expected to be a constraint, but providing sufficient flows to lower water temperatures in the lower river will be a challenge. Although the expected strategy for providing suitable water temperatures is to increase flows, initial analysis suggests that it is not certain that increased flows from Friant Dam will lower water temperatures in the lower reaches of the San Joaquin River, as discussed in section 2.5.x.

Spring-run chinook salmon

In Butte Creek, spring chinook outmigrate as subyearlings during high flows in November, during spring flows in March and April, and as yearlings in the following October (Hill and Webber 1999). The majority of fish outmigrate as subyearlings in the fall at sizes typically less than 1.6 in (40 mm). Subyearlings outmigrating in the spring reaches sizes of 3.2 in (80 mm) or more, and yearlings that remain in Butte Creek over the summer outmigrate at sizes up 5.9 in (150 mm), and emigrate in the fall after rains have fallen and flows increase (Hill and Webber 1999). It is anticipated that if spring-run chinook spawn in upper Reach 1 in September, juveniles will attain the target minimum size (3.2 in [80 mm]) for outmigration by at least the end of April (Figure 3.2-3). It is not known whether yearlings contribute more to escapement than young-of-the-year, though outmigration and marine survival tends to increase with smolt size. Appropriate temperatures (<68ºF [20°C]) will be ensured though summer spring flows for outmigration in February through April, and May in wet years. Suitable outmigration temperatures will be provide in the fall as well, in part to ensure successful fall chinook upstream migration. The pulse of outmigration of subyearlings in the fall may have decreased survival due to their relatively small size (<1.6 in [<40 mm]). An adaptive management strategy will need to address the timing and size of outmigrants in the San Joaquin River, and their relative survival to the Delta.

Fall-run chinook salmon

Juvenile fall-run chinook salmon will not likely attain the minimum target size (3.2 in [80mm]) for outmigration until later than juvenile spring-run without some manipulation of temperatures to accelerate growth during rearing. Based on the population models, juvenile chinook can optimistically (at 60% ration) attain 3.2 in [80 mm] by the end of May. This assumes that growth conditions in the San Joaquin River will be similar to those in the Tuolumne, which is a critical uncertainty.

Along the migration route within the planning area, temperatures at RM 150 begin to exceed 68ºF (20°C) in mid-May at 4,500 cfs and at the end of April at 2,500 cfs. A driving factor for restoring fall-run chinook salmon will be providing conditions to rear juveniles as fast as possible to attain the minimum migration size before flow releases from Friant Dam are unable to maintain downstream temperatures below stressful or lethal levels. The strategy will depend on appropriate selection of early spawning fall-run chinook stocks, and increasing water temperatures by floodplain inundation to accelerate growth during rearing.

Comparison of spring-run chinook salmon and fall-run chinook salmon

Spring pulse flow will provide suitable water temperatures and outmigration stimulus for both spring and fall chinook. It is anticipated that spring chinook will outmigrate earlier than fall chinook, since they spawn and emerge earlier. Suitable flows will be available from February through April, and thus more than one peak in outmigration will be supported in most years.

Model parameterization

Water temperatures in the lower San Joaquin River reach stressful and even lethal levels during the spring. Fall chinook salmon in particular face the risk of exposure to excessive water temperatures during outmigration. The model assumes 100% mortality of juveniles that do not reach smolt size (3.2 in [80 mm]) by August 1; there is no mechanism in the model for starvation, so if they don't grow, they die. The model assumes 17% survival (83% mortality) of outmigrating smolts, based on Tuolumne River coded wire tag studies (Hume et al. 2001).

3.2.5 Population dynamics

One of the main objectives in restoring chinook populations to the San Joaquin River is the establishment of viable populations. A viable salmon population is an independent population with a negligible risk of extinction due to threats from demographic variation, local environmental variation, and changes in genetic diversity over a 100-year time frame (McElhany et al. 2000). To achieve viable populations, population dynamic parameters need to be considered, including:

- salmon abundance,
- population growth rate, and
- genetic diversity.

Chinook salmon abundance (or the total number of individuals at any life stage) is important because small populations typically face a greater risk of extinction than larger ones. Population-level effects operate differently in small populations than in large ones, primarily because density-dependent effects, environmental variation, genetic processes, ecological feedback, and catastrophes all have impacts that are progressively greater as the number of individuals in a population declines (McElhany et al. 2000). San Joaquin River chinook populations will need to be large enough to withstand stochastic events such as floods and droughts, as well as varying estuarine and ocean conditions. A restoration strategy and adaptive management plan that identify factors limiting production and enhance or augment limiting habitats, will likely succeed in restoring a viable salmon population, in the San Joaquin River. For example, if spawning habitat is limiting production, increasing spawning gravel quality and area for fall and spring chinook with flow and gravel augmentations will allow a larger number of fish to reproduce successfully.

Fall and spring chinook have different life history strategies that can affect the potential to restore viable populations. For example, some proportion of spring chinook will outmigrate as yearlings, which are larger than subyearlings and therefore more likely to survive subsequent life-stages than subyearling outmigrants. The overall viability of spring chinook populations may depend more on the number of yearling outmigrants, and less on the number of spawners, whereas because fall chinook outmigrate solely as subyearlings, their population viability relies on the number of spawners.

Population growth, or the productivity of chinook over their entire life cycle, is a measure of their performance. The goal for the San Joaquin River is to establish a viable population that is capable of replacing itself, and adapting to unstable environmental conditions. In any given cohort, life-stage-specific survival rates vary, and survival through any one life stage may or may not have a population-level effect. For example, survival to emergence, growth rates, and size at outmigration each can potentially affect population viability by altering population abundance and the ability to survive the subsequent life stage. Chinook salmon population growth will be achieved in the San Joaquin River in part by increasing life-stage-specific survival or productivity.

Genetic diversity has important effects on population viability (McElhany et al. 2000). Diversity allows a species to use a wide variety of environments, and protects it against short- and long-term environmental change. Human-caused selection (e.g., hatchery influence) typically reduces the characteristics of a stock that it has adapted to allow it to survive in its environment. As described in below, selection of a parent stock for the San Joaquin River focused on a stock from an environment with similar conditions as San Joaquin River, and on reducing the influence of human-caused selection through hatchery influence.

3.3 Steelhead Populations

3.3.1 Introduction

Land management, water development, and flow management have all contributed to the decline of salmon and steelhead in the Central Valley. However, the mechanisms by which these impacts have occurred have not been the same for all species and races. Whereas chinook spawning habitat is largely still available in the mainstem San Joaquin River, dams have blocked access to historical steelhead spawning and rearing habitat, forcing steelhead to spawn and rear in lower-elevation reaches where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001). Loss of spawning and rearing habitat is believed to have had the single-greatest impact on steelhead populations in the Central Valley (McEwan 2001).

The historical distribution of steelhead in the San Joaquin River is not well known. However, in other drainage basins they are usually more widely distributed than chinook salmon, and likely spawned and reared in tributaries above Friant Dam (Yoshiyama et al. 1996, Voight and Gale 1998, as cited in McEwan 2001). One reason for the wider distribution than chinook is that steelhead typically spawn in tributaries where chinook salmon tend to spawn in mainstem channels. Based on the historical distribution of chinook salmon in the San Joaquin River, steelhead likely also occurred at least as far upstream as Mammoth Pool (RM 322) in the San Joaquin River, and probably occurred in many of the small tributaries as well (Yoshiyama et al. 1996). Very little habitat suitable for steelhead spawning and rearing is currently accessible in the San Joaquin River basin. The mainstem San Joaquin River, similar to other large streams, is characterized by substrates that are probably too coarse for steelhead spawning; steelhead would also have to compete with chinook salmon in these reaches. Therefore an appropriate restoration strategy to reintroduce and enhance steelhead populations is fundamentally different than the strategies to enhance chinook salmon.

The vision for restoring steelhead focuses on enhancing steelhead habitat in tributaries downstream of Friant Dam. The construction of Friant Dam blocked access to many of the upper San Joaquin River tributaries with potential steelhead habitat. Because access to upper reaches is blocked, and steelhead habitat is extremely limited in the remaining San Joaquin basin, augmenting flows in suitable tributaries may be the best method for reintroducing a steelhead population. Stillwater Sciences surveyed the tributaries downstream of Friant Dam for their potential as steelhead reintroduction sites. These tributaries are typically dry during the summer and fall months, and so would not have supported year-round rearing of steelhead under historical conditions. The initial selection for enhancement sites focused on tributaries that have a potential supply of cool water. Cottonwood Creek and Dry Creek were selected for more detailed analysis because they have potential for obtaining flows from nearby irrigation canals. They are intermittent so there is no potential for stocked steelhead to affect native resident fish, and fry or juveniles that outmigrate would have suitable rearing habitat in the mainstem (Appendix B, Figures B-8 and B-9). Reconnaissance field surveys were conducted in the two tributaries to assess the potential for steelhead enhancement. Following the initial field assessment, Cottonwood Creek was surveyed to obtain a more detailed assessment of potential production and opportunities for enhancement. Stillwater Sciences and a steelhead expert (Dr. Bill Trush, McBain & Trush, Arcata, California) surveyed Cottonwood Creek in September 2002 to evaluate its potential as a steelhead reintroduction site. The survey was restricted to the lower 6,000 ft (1830 m) of stream where flows could be augmented using water from Madera Canal. The goals of the habitat survey were to (1) estimate the amount of potential steelhead spawning and rearing habitat in the reach in order to calculate the number of smolts that could be produced, and (2) estimate the instream flows that might be required to achieve this level of smolt production based on physical habitat requirements.

If flow were provided from the Madera Canal to Cottonwood Creek, approximately 6,000 ft (1830 m) of channel could be augmented with flow year-round. It appears from the analysis that with an augmented flow of 20 cfs, a spawning population could be sustained in Cottonwood Creek, with an annual production of about 1,000 smolts; however, if a restoration strategy involving Cottonwood Creek is pursued, more analysis will be required. Habitat conditions in Little Dry Creek also appear promising for steelhead restoration, although constraints in Little Dry Creek present far more of a challenge than in Cottonwood Creek.

It is very likely that flow management of the mainstem San Joaquin River that is designed to restore chinook populations will be adequate to support the upstream and downstream migration of steelhead, and may improve mainstem rearing habitat for steelhead as well. However, because steelhead restoration will require further efforts in tributaries, and because juvenile steelhead are known predators on juvenile chinook, it is not prudent to initiate their restoration at this time. Rather, after the reintroduction efforts for chinook, it is anticipated that habitat conditions will be suitable for steelhead in the mainstem. There appears to be less known about steelhead in the Central Valley than salmon, and the delay in efforts to restore steelhead will provide time for advancements in steelhead biology to inform a potential restoration strategy. A general vision of the restoration strategy for steelhead is provided below. During the adaptive management experiments that will be needed to reestablish chinook, a more detailed steelhead strategy can be developed.

Restoring a self-sustaining population of steelhead to the San Joaquin River should be pursued after self-sustaining chinook salmon populations have become well-established and can tolerate the additional predation pressure in upstream reaches that steelhead may represent. Steelhead rear for up to two years in fresh water before outmigrating to the ocean, during which time they attain sizes capable of preying on fry and smaller juvenile salmon. Because juvenile steelhead would be present year-round in the same cold-water reaches as fry and juvenile chinook salmon, they may pose a larger threat than non-native species in warmer reaches that would only be expected to prey on juvenile salmon during outmigration.

3.3.2 Potential sources of parent stock

There are potentially several parent stocks for restoration of steelhead to the San Joaquin River. CDFG recommended that a parent stock be selected based on an analysis of steelhead genetics being conducted by Jennifer Nielson that is expected to be completed in summer 2003 (Katie Perry, CDFG, pers. comm.). This analysis is addressing the genetic relationships between and within populations of Central Valley steelhead and rainbow trout, and specifically examines San Joaquin basin steelhead from the Kings River, Calaveras River, upper and lower Tuolumne River, and upper and lower Stanislaus River. Steelhead also occur in the Mokelumne River and are propagated by Nimbus Hatchery, but genetic analysis confirms that these fish originated in the Eel River and are therefore not suitable for use as a parent stock (Katie Perry, CDFG, pers. comm.). Once a parent stock is selected, life history timing and habitat requirements can be defined and lend focus to other components of the restoration strategy.

3.3.3 Steelhead life histories and habitat considerations

3.3.3.1 Upstream migration

In the Central Valley, adult winter steelhead migrate upstream during most months of the year, beginning in July, peaking in September, and continuing through February or March (Hallock et al. 1961, Bailey 1954, both as cited in McEwan and Jackson 1996). Because their migration timing overlaps with fall chinook, flow enhancement designed for fall chinook migration in the mainstem San Joaquin will likely benefit steelhead as well.

Steelhead are among the strongest swimmers of freshwater fishes, and are known to be faster and able to leap much larger obstacles than chinook (Bjornn and Reiser 1991). Therefore, flows designed for fall chinook migration can be expected to be suitable in velocity for steelhead, and passage facilities at migration barriers designed to accommodate chinook will also be suitable for steelhead.

For adult steelhead migration, temperatures ranging from 46 to 52^{o}F (8 to 11^{o}C) are considered to be preferred (McEwan and Jackson 1996), while temperatures exceeding 70^{o}F (21^{o}C) are stressful (Lantz 1971, as cited in Beschta et al. 1987). Chinook have far more restrictive migration habitat requirements in terms of flow depth, water velocity, and temperature, and it is very likely that migration conditions favoring their restoration will benefit adult steelhead migration in the San Joaquin River mainstem.

A steelhead restoration strategy for Cottonwood Creek would likely require providing increased flows in the spring and fall for upstream and downstream migration cues, in addition to minimum base-flows. At an estimated flow of 20 cfs, water depth or velocity is unlikely to inhibit adult steelhead migration. Because water velocity varies across a channel, it is very likely that suitable water velocities for spawning would be available in Cottonwood Creek at 20 cfs, especially in pool tailouts, where modeled water velocities at 20 cfs ranged from 1.0 to 8.0 ft/s (0.31 to 2.44 m/s).

3.3.3.2 Adult holding

During their upstream migration, adult steelhead require pools for resting and holding (Puckett 1975, Roelofs 1983, both as cited in Moyle et al. 1989). Such pools should be available in the San Joaquin River during fall and winter as a result of implementing the chinook restoration strategy.

3.3.3.3 Spawning

Adult steelhead prefer to spawn in streams with water depths from about 7.0 to 53.4 in (18 to 137 cm) and velocities from 1.97 to 3.77 ft/s (0.60 to 1.15 m/s) (Moyle et al. 1989, Barnhart 1991). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). Gravels ranging in size from 0.25 to 5.1 in (0.64 to 12.9 cm) in diameter are suitable for redd construction (Barnhart 1991). These conditions most often occur in small, high gradient streams, which are the preferred spawning locations for steelhead. Steelhead may even spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). Bell (1986) indicates that preferred temperatures for steelhead spawning range from 39.0º to 48.9ºF (3.9º to 9.4ºC). As described above, most of the tributaries that historically provided spawning habitat are currently blocked by the Friant Dam.

Most spawning habitat identified in the mainstem San Joaquin River is too coarse for steelhead, although it is likely that substantial spawning could occur in isolated patches in upper Reach 1. Cottonwood Creek was examined as a potential spawning tributary as it probably approximates historical steelhead habitat. Nine patches of suitable steelhead spawning gravel were found in the 3,400-ft (1037-m) surveyed reach of Cottonwood Creek, totaling 200 ft^2 (18 m^2). Based on the professional judgment of the surveyors, all patches identified could be used by at least one adult pair. There appeared to be opportunities for gravel augmentation, which could double or triple the amount of suitable spawning habitat. A HEC-RAS model was used to simulate depths and velocities that would result from various discharges. Model inputs included thalweg elevations measured over a 260-ft (79.3-m) surveyed reach, and three cross sections. The results of the simulations indicated that with 20 cfs of augmented flow, depths and velocities would be suitable for spawning in the observed patches in Cottonwood Creek. Temperatures during the winter, when steelhead are spawning and eggs are incubating, appear to typically be cool, and are not likely to be a concern in Cottonwood Creek. This reach is likely to produce less than 1,000 smolts based on our estimates of available spawning habitat and our assumptions about the productive potential for steelhead. Spawning habitat appears to be limiting steelhead production and if spawning habitat is augmented, the number of smolts could be increased dramatically.

3.3.3.4 Freshwater rearing

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

Older juvenile steelhead (age 1+ and older) occupy a wide range of hydraulic conditions. They prefer deeper water during the summer and have been observed to use deep pools near the thalweg with ample cover, as well as higher-velocity rapid and cascade habitats (Bisson et al. 1982, Bisson et al. 1988). Age 1+ fish typically feed in pools, especially scour and plunge pools, resting and finding escape cover in the interstices of boulders and boulder-log clusters (Fontaine 1988, Bisson et al. 1988). The minimum size at which juvenile steelhead become piscivorous is typically assumed to be about 11 in (25 cm), based on studies on brown trout (Bachman 1991). It is likely that some age 2+ or older steelhead could grow to a piscivorous size prior to outmigrating, and may pose a predation risk for emergent chinook fry. Enhancing habitat in tributaries to the San Joaquin River will encourage habitat segregation between steelhead and chinook, and decrease potential predation. In addition, steelhead restoration efforts will be delayed until chinook populations are established.

It is likely that suitable rearing habitat will exist for steelhead in the mainstem San Joaquin River, particularly in upper Reach 1. A stocked rainbow trout fishery in upper Reach 1 is currently successful, indicating that water temperatures and habitat complexity in this part of the mainstem are adequate to support rearing steelhead. However, younger age classes would benefit from shallow, complex habitat more typically found in tributaries. Surveys were conducted in Cottonwood Creek to enumerate the amount of suitable rearing habitat for juvenile steelhead. Approximately 55,415 ft^2 (5,148m^2) of optimal juvenile steelhead rearing habitat was delineated in the 3,400-ft (1040-m) reach surveyed. Rearing habitat is unlikely to limit steelhead production based on the estimated numbers of steelhead that can be produced from the limited available spawning habitat.

An augmented flow of 20 cfs from the Madera Canal would provide suitable steelhead rearing habitat based on examination of HAC-RAS modeling for Cottonwood Creek. At a discharge of 20 cfs, pool depths would range from 2 to 4 ft (0.6 to 1.2 m), and riffle depths would range from

0.49 to 2 ft (0.15 to 0.3 m) Average water velocities would range from 0.3 to 1.5 ft/s (0.09 to 0.46 m/s) in the pools, and up to 8 ft/s (2.4 m/s) in riffles. The stage height at 20 cfs would partially inundate a lower bench, above the existing silt line, and below bankfull depth. Based on field observations, a majority of the habitat in the channel would be suitable for juvenile steelhead rearing at this flow, and would be well within their preferred depth and velocity requirements (Appendix B, Figure B-10).

Water temperature has a strong influence on almost every life history stage of steelhead (Berman 1998), though the specific thermal requirements of steelhead are not well understood (McEwan 2001). In summer, Central Valley steelhead are well adapted to higher temperature ranges, with preferred rearing temperatures ranging from 63 to 68°F (17 to 20°C) and a maximum temperature tolerated (lethal critical thermal maximum) of 80°F (27°C) (Myrick 1998). However, other environmental conditions also indirectly influence habitat suitability at higher temperatures. For example, if food availability is high, fish have a much higher tolerance for high temperature.

Water temperatures in an enhanced Cottonwood Creek would principally be determined by the temperatures in the Madera Canal. Millerton Lake is thermally stratified, thus lake elevation influences the temperatures in the Madera Canal (446.0 FMSL). In all but drought conditions, lake levels are high enough that this discharge height lies below the seasonally warm epilimnion of Millerton Lake. Unfortunately, no temperature data are available for the Madera Canal, and the only representative available data are for the Friant Kern Canal (464.0 FMSL), which were collected by the USGS during monthly water quality tests between 1975 and 1981. The utility of the Friant Kern data is limited here, since the seasonal thermocline structure of Millerton Lake was not measured. Temperatures during the summer (July to October) do exceed preferred temperatures (<68ºF [<20ºC]). However, the maximum tolerated temperature (lethal critical thermal maximum) of 80°F (27°C) is rarely exceeded. Improving these estimates would require extensive modeling and/or the accumulation of thermal profile data at the dam face. Although the Friant Kern temperature data may overstate the temperature risk to steelhead, it does not appear that summer rearing temperatures are high enough to preclude a steelhead population. However, there is some risk of extended periods of high summer water temperatures >68º (>20ºC), and this could potentially limit production. It is likely that sublethal temperature effects, including and susceptibly to disease, may be an issue. A multiple-year record of continuous temperature data from the Madera Canal should be collected and analyzed before any enhancement is implemented in Cottonwood Creek. It is likely that the amount of flow released into Cottonwood Creek will also influence water temperature. Modeling to determine the relationship between flow and water temperature may be a primary factor affecting selection of flows for augmentation.

3.3.3.5 Smoltification and outmigration

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 5.9 to 7.8 in (15 to 20 cm) (Meehan and Bjornn 1991). A length of 5.5 in (14 cm) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). In the Sacramento River, steelhead generally emigrate as 2-year-olds during spring and early summer months, although outmigration can occur during any month of the year (McEwan 2001), and appears to be more closely associated with size than age.

Estuarine rearing may be more important to steelhead populations in California than farther north due to greater variability in ocean conditions and paucity of high quality near-shore habitats in this portion of their range (NMFS 1996a). However, estuaries may be less important to populations spawning in the Central Valley than in smaller coastal tributaries, due to the more limited availability of rearing habitat in the headwaters of smaller stream systems (McEwan and

Jackson 1996). Most marine mortality of steelhead occurs soon after they enter the ocean, primarily due to predation (Pearcy 1992, as cited in McEwan and Jackson 1996). Because predation risk and fish size are likely to be inversely related (Pearcy 1992, as cited in McEwan and Jackson 1996), the growth that takes place in estuaries may be very important for increasing the odds of marine survival (Pearcy 1992, as cited in McEwan and Jackson 1996; Simenstad et al. 1982, as cited in NMFS 1996a; Shapovalov and Taft 1954). The importance of estuaries is a critical uncertainty in the San Joaquin system, and further research may be required to develop an appropriate restoration strategy for steelhead.

The preferred outmigration temperature is generally <57^{o}F (<13^{o}C) (McEwan and Jackson 1996). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments used steelhead that were reared at the Mokelumne River State Fish Hatchery from eggs that were collected at the Nimbus Fish Hatchery (American River). These experiments indicate that Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures ranging from 63 to 68^{o}F (17 to 20^{o}C) and a maximum temperature tolerated (lethal critical thermal maximum) of 80^{o}F (27^{o}C). Water temperatures in Reach 5 and farther downstream are warmer than 68ºF (20ºC) for much of the year, which may cause steelhead to delay outmigration until temperatures are lower during pulse flows provided for chinook migration. The chinook restoration strategy includes a pulse flow in February and March of approximately 1500 cfs. Modeled water temperatures at this flow indicate that temperatures will be less than 60ºF (15.6ºC) from Reach 1 downstream to the confluence with the Merced River, where temperatures drop due to the cool receiving waters from the Merced. Although steelhead can outmigrate in any month of the year, it is likely that migration will peak during this period of higher flows and lower water temperatures.

It is unlikely that the number of outmigrating steelhead will be large enough to saturate predators, as may be achieved with chinook. However, steelhead typically outmigrate at about 6 in (15 cm), which is large enough to avoid predation.

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3.4 Resident Fish Populations

3.4.1 Introduction

Under current conditions, resident fish communities of the mainstem San Joaquin River consist of both native and non-native species. Most of the resident native fish species that historically existed in the mainstem San Joaquin River are still present, although the abundance and distribution of many species has substantially declined, especially on the valley floor. Even the most ambitious restoration program will not completely eradicate populations of non-native resident fish species. One of the primary reasons is that their life histories and habitat requirements overlap with those of many native resident fish, most notably those belonging to the deep-bodied fish assemblage. Efforts to reduce suitable spawning, rearing, and adult habitat for non-native species would thus reduce habitat for certain native species as well. Similarities in life histories and habitat use are one reason why many of the native species have declined. A prime example is Sacramento perch, which have life histories and habitat requirements that overlap with introduced centrarchid species. The Sacramento perch has been extirpated from its native range in the San Joaquin River, but the species persists in other areas and reintroduction therefore remains a possibility.

This section describes an overall vision for restoration of resident fish communities in the mainstem San Joaquin River and explores the habitat requirements of a set of species chosen to represent the needs of the larger native fish community as a whole. These habitat requirements were then evaluated in relation to habitat changes likely to result from measures to restore chinook salmon, because the highest priority for restoration in the project area has been assigned to restoring chinook salmon populations. Where native resident fish needs did not appear adequately addressed by measures designed for restoring chinook salmon and their habitat, we evaluated potential ways of addressing these needs with additional restoration components. These restoration components (i.e., the actions necessary to achieve the vision described in this section) for resident native fish are discussed in Section 3.4.6.

Although this section focuses on resident fish communities, it includes discussion of Pacific lamprey and river lamprey, which are anadromous species, because they have habitat requirements that may not be met by strategies for anadromous salmonids.

3.4.2 Overall vision and objectives for resident fish communities

The overall vision for the resident fish community in the project area is to maintain, enhance, or restore naturally reproducing populations of all native resident fish and lamprey species, including the currently extirpated Sacramento perch, even if some species may occur primarily in isolated habitats. Ideally, all native species that historically occurred in the project area would be restored to healthy populations that inhabit their original distribution; however, this objective may be unrealistic due to current demands for water and surrounding land uses. Non-native fish species will continue to co-exist with native resident and anadromous fish in most reaches, but restoration measures will reduce competition with and predation on native species through reducing habitat quality and quantity for non-natives.

To attain the vision and objectives, strategies for resident fish were developed with the following priorities:

- Maintain all extant populations of native fish species, and provide conditions necessary to

maintain viable, well-distributed populations of these species wherever possible.
- Increase the abundance and distribution of species that have declined by restoring or enhancing the types of aquatic habitats, habitat characteristics, or hydrologic characteristics that were available under historical conditions in the project area, even if not in the same quantity or distribution as they historically occurred.

Specific measures included in one or more strategies to achieve these objectives include:
- Inundating floodplain habitats in spring for Sacramento splittail and other native floodplain spawners.
- Enhancing spring flows to improve spawning habitat for native riffle-spawning species.
- Providing opportunities for reintroducing Sacramento perch into the San Joaquin basin by designing some perennial wetlands for this purpose.
- Establishing a native fish community in Mendota Pool for public education purposes and to provide a source of native fish stock for seeding other habitats as they are restored or enhanced.
- Enhancing habitat connectivity for native fish where currently impaired.

3.4.3 Assumptions governing development of strategies for resident fish communities

Analysis of potential effects of restoration strategies on resident fish populations will be largely qualitative due to lack of quantitative information on the abundance and distribution of many of these species and general gaps in the understanding of these species' biology and habitat requirements. Many of the restoration strategy hydrographs are designed to provide suitable temperatures for chinook salmon to successfully complete their life cycle. Because these species evolved in the same river systems as those used by chinook salmon, many of their flow-related habitat needs may be met by the same hydrographs, with some minor adjustments. Most of the information used to determine appropriate measures for native resident fish was drawn from what is known about their temperature and habitat preferences.

Some native resident species will likely benefit from restoration measures designed for chinook salmon, while others may require additional measures to address their habitat and instream flow needs. The needs of some native fish species, or at least certain of their life stages, will likely be met through implementing restoration measures for chinook salmon and riparian vegetation, especially riffle-spawning species, riffle sculpins, and Sacramento splittail. Fish in the deep-bodied fish assemblage that are adapted to low-elevation, valley-floor habitats, such as hitch, Sacramento blackfish, and Sacramento perch, are less likely to benefit from measures to improve habitat for chinook salmon. These species, however, may benefit from measures designed to reduce predation on outmigrating smolts by reducing the abundance of non-native fish species. Some species may be negatively affected by strategies focusing on chinook salmon needs. For example, the larval stages of Pacific lamprey live burrowed in mud and fine sediment in low-velocity habitats such as channel margins and backwaters from four to six years before metamorphosing to the young adult stage. Seasonal flow fluctuations focused solely on fulfilling the needs of anadromous salmonids may dewater or drown shallow backwater habitats used by larval lamprey, mobilize gravels in nests, or dewater nests.

Non-native species will continue to persist in the basin, but restoration measures may be able to reduce negative interactions between certain native and non-native fish populations by reducing the distribution and abundance of non-native species through managing flows to more closely resemble natural hydrologic regimes.

Restoration measures to enhance native resident fish populations, native anadromous fish populations, and riparian vegetation include components that aim to reduce the abundance and distribution of non-native fish species. These measures do not include direct control measures and are not expected to result in short- or long-term extirpation of any non-native species in the project area. The continuing presence of non-native species and the likelihood that there will be future unwanted introductions do not necessarily spell doom for native fish species; however, human land use and competing demands for water limit the potential for restoring natural hydrologic regimes and habitats in the basin.

Native fish species in the San Joaquin basin are adapted to widely fluctuating but relatively predictable seasonal changes in stream flows, multi-year periods of extreme drought, and occasional large floods. Many species are relatively long-lived and can persist through several years of poor recruitment if spawning and rearing conditions are not suitable. Stable flows appear to favor non-native species, many of which may be able to spawn repeatedly throughout the spring and summer if temperatures remain suitable (Baltz and Moyle 1993; Moyle and Light 1996a, 1996b; Brown and Ford 2002). Brown and Ford (2002) found that the model that best predicted the proportion of non-native species in the Tuolumne River included both river kilometer and mean daily April/May discharge in the previous year, supporting the hypothesis that differential spawning success of native and non-native species during the previous spring was important in determining fish community structure in that stream. They noted that elevated spring flows occurred in unimpaired hydrographs even in years of low outflow, and suggested that this component of the seasonal flow regime may be partially responsible for the continuing dominance of native species in some of the less altered streams in California such as Deer Creek. High flows in the spring that maintain cooler temperatures later into the spring may facilitate early spawning by native fish that can then grow large enough by late spring to prey on non-native fish larvae and fry. If temperatures warm up early in the spring spawning season, both native and non-native fish may spawn at approximately the same time and predation on native fish by non-natives is likely to be higher (P. B. Moyle, pers. comm., 2002). Inundating floodplain habitat in late winter and early spring and drawing water off the floodplain in late spring may increase spawning habitat for native fish such as Sacramento splittail while reducing the period of time that floodplains are suitable for spawning by non-native centrarchids.

Under current conditions, flows in the mainstem San Joaquin River are extremely reduced from historical conditions, which has drastically altered fish communities in the area and has likely improved habitat for non-native species while reducing habitat for native species. The non-native fish species that are currently most common in the mainstem San Joaquin River include several with the ability to tolerate very poor water quality, including common carp, red shiner, fathead minnow, inland silverside, and threadfin shad. Red shiners and inland silversides can be extremely abundant in shallow habitats and may be important predators on Sacramento splittail eggs and larvae and compete for food with juveniles of native fish species. Increasing flows and improving water quality in the mainstem San Joaquin River may actually improve habitat for non-native centrarchids that are currently more abundant in the lower reaches of the San Joaquin's major tributaries.

Many non-native fish are habitat generalists or have habitat requirements that closely overlap those of native fish in the deep-bodied fish assemblage. Reducing the availability of certain habitat types used by non-native species may also reduce habitat for the native resident fish species that have most declined in abundance and distribution. Measures that focus on flows that give a competitive edge to native fish or that reduce the distribution of non-native fish by reducing spring and summer water temperatures may be more successful at reducing negative impacts of non-native fish while maintaining native fish populations.

Populations of certain native fish species may be more difficult to enhance than others because they appear particularly vulnerable to negative interactions with non-native fish species. Certain species, such as Sacramento perch, appear to have declined primarily because of competition with or predation by non-native species. These species may require habitats that are spatially or temporally more isolated from non-native fish in order to thrive. Measures designed to increase habitat segregation between these species and non-native species may increase the abundance and distribution of native species.

Habitat availability and the effects of non-native species may not be the most important factors controlling populations of some native species. Factors such as poor water quality, pumping mortality, and entrainment into unscreened diversions may also reduce the abundance and distribution of fish species. For example, selenium may be affecting reproductive success of Sacramento splittail, which feed on *Potamocorbula* clams that bioaccumulate toxins (P. B. Moyle, pers. comm., 2002). Little is known regarding the effects of non-native aquatic plants and other organisms on native fish species.

Conditions favorable for producing strong year-classes of native fish species should occur at least once every 3 to 5 years for each to ensure long-term persistence of their populations in the study area. Most of the native resident fish that have been declining are long-lived species that can persist through years of unfavorable conditions, as long as years with favorable spawning and rearing conditions occur with enough regularity for them to persist. The strategies were evaluated in terms of their expected potential to provide each species with occasional years of high recruitment.

3.4.4 Approach used to develop restoration strategies to benefit native fish

For evaluating how strategies might affect native resident fish populations, we chose to select a set of "analysis species" to represent the habitat needs of the full complement of native species, instead of attempting to evaluate effects on each and every species. Restoration strategy measures designed for enhancing native resident fish populations focus on fulfilling the habitat requirements of native analysis species and reducing the abundance and distribution of non-native analysis species. By providing key habitat components for a set of carefully selected analysis species, the restoration strategies should be providing conditions that promote the persistence of all of the native fish species.

The life histories and habitat requirements of all native resident fish species were summarized in Appendix B of the Background Report (McBain and Trush 2002) and subsequently evaluated for similarities and differences between species. A set of criteria was used to determine which native fish species may be the most sensitive to changes in habitat from historical conditions. Analysis species selected met at least three of these criteria (Table 3.4-1). For each species, information was compiled on (1) key habitats and habitat requirements for important life stages, (2) timing of important life history events, (3) temperature requirements for spawning and other potentially important life stages, and (4) key interactions with non-native species that may limit native species populations. Some native fish species in the San Joaquin River basin appear to be relatively resilient to the habitat changes that have occurred and to the presence of non-native species. Species that fall into this category include Sacramento sucker and Sacramento blackfish. These fish were not included as analysis species because they are expected to benefit from any restoration measures that are implemented in the basin. Resident rainbow trout were excluded due to uncertainty about the origins of the population downstream of Friant Dam. White sturgeon were considered, but excluded because it is unlikely that they occurred in large numbers in the project area under historical conditions and because it would be very difficult to restore populations in the mainstem San Joaquin River (P. B. Moyle, pers. comm., 2002). The following species were selected as native analysis species: Pacific lamprey, Kern brook lamprey, Sacramento pikeminnow, hardhead, Sacramento splittail, hitch, tule perch, and Sacramento perch.

Table 3.4-1. Criteria used in selection of analysis species and results for selected analysis species.

CRITERIA	NATIVE FISH ANALYSIS SPECIES (X = species meets criteria; ? = likely that species meets criteria)						
	Pacific Lamprey	Sacramento Pikeminnow	Hardhead	Sacramento Splittail	Hitch	Tule Perch	Sacramento Perch
Species that have been extirpated in the San Joaquin River							X
Species with special status under the federal or state Endangered Species Act				?			
Species suspected to have substantially declined from their former distribution and abundance in the project area	?	?	X	X	X	X	X
Species that currently occur as disjunct populations or that may be vulnerable to habitat fragmentation and isolation					X	X	X
Species that may be particularly affected by physical or chemical barriers to freshwater movements and migrations (e.g., between mainstem and tributaries or between mainstem habitats used by different life history stages)	X	X	X		X		
Species suspected of being negatively affected by loss of floodplain and lake habitats				X	X	X	X
Species suspected of being negatively affected by loss of riparian and wetland habitats		X				X	
Species that may be particularly sensitive to changes in water temperatures and seasonal temperature regimes	X					X	
Species that may be relatively intolerant of contaminants or that tend to be found in areas where concentrations of contaminants are high	X			X			
Species likely to be adversely affected by interactions with introduced species	X	X	X	X	X		X
Species that may be negatively affected by changes in flow regimes, particularly the loss of high spring flows							
Species that may be particularly susceptible to entrainment at agricultural diversions and pumps	X	?		X			

By addressing the needs of a set of species that encompass a wide variety of life history strategies and habitat requirements, we hoped to address the needs of the remaining species, acknowledging that the use of "umbrella" species may overlook the needs of some, especially those for which there is little available information. Such a strategy has certain limitations. For example, it is not likely that each strategy will provide equal benefits for native resident fish; however, it will allow us to assess which restoration measures might come closest to providing for the needs of most native fish species and to design further measures to address those that appear to fall through the cracks.

Other potential methods of addressing the needs of species in a freshwater fish community that were considered include the use of habitat-use guilds or key habitats. Because several native fish in the San Joaquin basin are anadromous, and others use different habitats at different life stages, habitat connectivity is crucial for maintaining native fish populations. Another consideration that may not be adequately addressed by a key habitat approach is that spatial and temporal differences in water temperatures may have substantial effects on habitat quality for native and non-native species.

The habitat requirements of key life history stages of the native fish analysis species were compared to determine non-overlapping habitat needs that might not be addressed by strategies designed to benefit the other species. For fish species that appeared to have habitat requirements that would require instream flows or restoration of habitat components over and above those being proposed for anadromous salmonid or riparian restoration, we tried to develop measures to fulfill the needs of these species. Many uncertainties remain due to our lack of knowledge about native resident fish species in the San Joaquin River. Our analysis focused on what we knew regarding habitat and temperature preferences during critical life history stages such as spawning and early rearing.

To develop restoration strategy measures that enhance native fish populations, we have included measures aimed at reducing negative interactions between non-native and native species by reducing the abundance and distribution of non-native species that appear to be strong interactors in the fish communities of the San Joaquin River. Some non-native fish species, especially omnivores and detritivores, may have relatively little effect on native aquatic species. Certain non-native species may be providing benefits to native fish and aquatic communities in ways that are not immediately evident. Some non-native fish species may feed on introduced plants or invertebrates (e.g., non-native bivalves and crayfish) that may themselves alter aquatic habitats and food webs. Others, such as smaller introduced cyprinids, may provide non-native black bass and other piscivorous fish with alternative prey and thereby buffer predation on native species. Invasions of piscivorous fish may have the greatest effects on native fish communities (Moyle and Light 1996).

3.4.5 Restoration strategy considerations for analysis species

The following sections describe habitat requirements for analysis species that likely need to be addressed to achieve the vision of maintaining and restoring populations of native fish species in the project area. These habitat requirements were considered when developing specific restoration strategy components to benefit native fish populations. More detailed information on habitat requirements for all species likely to be found in the project area are found in Appendix B of the Background Report.

3.4.5.1 Habitat requirements held in common by several analysis species

The following summarizes habitat requirements held in common by several analysis species. The lack of certain habitats, habitat characteristics, or habitat connectivity between important habitats used by different life stages in the project area may severely limit the abundance and distribution of several native species.

Deep, low-velocity habitats for adults

Adults of many native resident fish require deep, slow habitats such as sluggish mainstem runs, deep main-channel pools, backwaters, oxbow lakes, and sloughs. Several species appear to require summer water temperatures between 68° and 82.4°F (20° and 28°C) in order to thrive. These species include Sacramento pikeminnow, hardhead, and hitch. Sacramento perch may also use deeper warmwater habitats if cover from vegetation, large woody debris, or turbidity is available.

Habitat connectivity for instream movements and migrations
Several species make upstream spawning migrations to riffle spawning habitats in tributaries or upper mainstem reaches when flows increase with spring runoff, primarily from February through April. Others, such as Sacramento splittail, move upstream from Delta habitats to spawn in inundated floodplains. Analysis species that may require habitat connectivity in the spring to successfully complete their life cycles include Pacific lamprey, Sacramento pikeminnow, hardhead, Sacramento splittail, and hitch. Hardhead exhibit relatively poor swimming performance at low temperatures, and water velocity may act as a barrier to their upstream movements (Myrick 1996, as cited in Moyle 2002).

Gravel riffles for spawning
Pacific lamprey and other native lamprey species (Kern brook lamprey, river lamprey, and western brook lamprey) build nests in gravel or gravel-sand riffles. Several other native resident species broadcast spawn over riffle habitats, including Sacramento pikeminnow, hardhead, Sacramento sucker, and hitch. All of these species spawn in the spring from February through May at temperatures of about 53.6−64.4°F (12−18°C). Some species may spawn into the summer months where temperatures remain suitable.

Shallow areas with cover for rearing
Many native resident fish species require shallow areas with dense emergent or aquatic vegetation for larval and early juvenile rearing, including Sacramento pikeminnow, hardhead, hitch, Sacramento splittail, and Sacramento perch. Shallow areas with dense vegetation provide hiding cover from both avian and larger fish predators. Most species spawn in the spring; therefore, early rearing habitat would likely be provided by inundation of channel margins and floodplain habitat during snowmelt runoff under unimpaired conditions. Extreme flow fluctuations or rapid downramping of flows during the spring or summer may result in stranding mortality of fish rearing in these shallow habitats.

3.4.5.2 Pacific lamprey and Kern brook lamprey

Three lamprey species known to occur in the mainstem San Joaquin River downstream of Friant Dam have recently been petitioned for listing under the federal Endangered Species Act due to substantial declines in their abundance—Pacific lamprey (anadromous), river lamprey (anadromous), and Kern brook lamprey (resident) (Klamath Siskiyou Wildlands Center et al. 2003). It is not known whether western brook lamprey currently exist in the San Joaquin River. For the sake of developing restoration strategies for native resident fish, it was assumed that providing for the habitat needs of Pacific lamprey and Kern brook lamprey will be sufficient for protecting populations of all lamprey species that may occur in the project area.

Pacific lamprey are an anadromous species that rear for 4 to 7 years before outmigrating to the ocean as subadults. Pacific lamprey appear to prefer rearing temperatures below 68°F (20°C) (BioAnalysts 2000), and temperatures >82.4°F (28°C) result in mortality of ammocoetes (van de Wetering and Ewing 1999). When abundant, outmigrating Pacific lamprey may act to buffer predation on juvenile and smolt salmon because they are easier to capture than salmonids (Close et al. 2002).

The Kern brook lamprey is a resident lamprey species whose populations are believed to be thinly scattered throughout the San Joaquin River basin and appear to be isolated from one another (Moyle 2002). All known populations except for one are located below dams where flow regulation may dewater rearing habitat and result in mortality of rearing ammocoetes. Moyle (2002) notes that ammocoetes may also be transported to habitat "sinks" such as the Friant-Kern siphons. The Kern brook lamprey is believed to be at risk of being locally extirpated where these isolated populations occur.

All lamprey ammocoetes rear burrowed in fine sediments in low-velocity habitats for several years before metamorphosing to the subadult stage. Low-velocity areas along the margins of runs may provide some habitat for ammocoetes where backwaters, pool eddies, or other shallow areas are not available or are not inundated year-round (P. B. Moyle, pers. comm., 2002). The long freshwater rearing period required by lamprey before metamorphosis makes them more vulnerable to episodic mortality factors than salmonids or other native fish. Such factors include dewatering of areas used as rearing habitat by rapid flow fluctuations or downramping, contaminants, dredging, and streambed scouring by high flows. River channelization increases stream velocity and reduces the amount of rearing habitat available for ammocoetes (Close et al. 2002). Lamprey ammocoetes may pass through screens designed to prevent juvenile salmon from passage. Transport into irrigation ditches is likely to result in mortality when ditches are drained and there is no passage back to a natural waterway.

Adult Pacific lamprey returning from the ocean to spawn require suitable migration corridors. Adult upstream migration of Pacific lamprey into spawning streams in California may occur as early as January and February, but primarily occurs from early March to late June during high flows (Moyle 2002). Nests are constructed by Pacific lamprey in the spring in gravel or gravel-sand riffles at temperatures of 53.6−64.4°F (12−18°C) (Moyle 2002). Eggs hatch in two to three weeks; larval ammocoetes spend another two to three weeks in the gravels before emerging and rising into the current to drift downstream and settle into slow backwater areas (Pletcher 1963). During the ammocoete stage, larvae may periodically move and relocate in response to changing water levels, channel adjustments, or substrate movements (ULEP 1998). This generally results in a gradual downstream movement that may lead to higher densities in downstream reaches (Richards 1980). Downstream migration of young adults on their way to the sea may occur from winter through spring during high flows.

The following are important habitat management considerations for Pacific lamprey and Kern brook lamprey:
- managing spring flows to provide suitable upstream migration corridors and spawning habitat,
- managing flows to reduce dewatering of lamprey nests before ammocoete emergence, and
- maintaining suitable ammocoete rearing habitat year-round in upstream reaches.

An important factor potentially limiting lamprey populations that may not be addressed by restoration strategies is their use of low-gradient stream reaches at lower elevations, where human disturbance and habitat degradation is often highest. Ammocoetes may be vulnerable to bioaccumulation of pollutants as a result of spending several years as filter feeders in stream sediments. Moyle (2002) noted that Pacific lamprey are usually absent from highly altered or polluted streams.

3.4.5.3 Sacramento pikeminnow

Adult Sacramento pikeminnow inhabit deep pools and slow runs with cover where water temperatures are about 68.0−82.4°F (20−28°C) in the summer months. Upstream movements to suitable spawning habitat occurs from March through May. Broadcast spawning takes place over gravel riffles and may begin in late February through May, with peak spawning in March and

April. Spawning may continue into June and July in some areas. Young-of-the-year rear in shallow channel margin habitats and move into riffles and runs as they grow.

The following are important habitat management considerations for Sacramento pikeminnow:
- managing spring flows to provide suitable upstream migration and spawning habitat,
- inundating shallow rearing habitat in late spring and early summer, and
- regulating downramping in late spring to minimize stranding of young-of-the-year in shallow rearing habitat.

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3.4.5.4 Hardhead

The general habitat requirements of hardhead are similar to those of Sacramento pikeminnow in several ways. Hardhead spawn in April and May and possibly into the summer in some areas. Although spawning has not been observed, they are believed to broadcast spawn over gravel in riffles, similarly to pikeminnow. They are also similar in that adult hardhead use deeper pool and open-water habitats, while young-of-the-year prefer shallower habitats where they are likely less vulnerable to fish predation. Hardhead also make upstream migrations to suitable spawning areas and therefore require habitat connectivity between adult and spawning habitat in the spring. The species is most often found where summer water temperatures are at least 68°F (20°C) for extended periods of time. For the purposes of this analysis, the above habitat requirements will be assumed to be the same as for Sacramento pikeminnow.

Hardhead appear to have much more restricted microhabitat preferences than Sacramento pikeminnow, being found “only in the sections of large, warm streams that contain deep, rock-bottomed pools” (Moyle et al. 1982). Hardhead distribution may also be limited by low dissolved oxygen concentrations at higher temperatures (Cech et al. 1990, as cited in Moyle 2002). High water velocities may act as a barrier to upstream movements of hardhead at low temperatures, when their swimming abilities are relatively poor (Myrick 1996, as cited in Moyle 2002).

The following are important habitat management considerations for hardhead:
- managing spring flows to provide suitable upstream migration and spawning habitat, and
- maintaining or enhancing deep rocky pool habitat for juveniles and adults.

3.4.5.5 Sacramento splittail

The loss of large lake and floodplain spawning habitat is believed to have been a major contributor to decline of this species in the San Joaquin River basin. Adult Sacramento splittail make upstream spawning migrations from January through April. Adult splittail may require a period of time to congregate and feed on the floodplain prior to spawning. Spawning occurs from February through May, with peak spawning generally occurring in March and April. Spawning is triggered when temperatures reach 57.2−66.2°F (14−19°C), but spawning appears to occur primarily where water temperatures are less than 59° (15°C) (Bailey et al. 1999, Moyle et al. 2001). At least a month of rearing on the inundated floodplain appears necessary for development of a strong year-class (Sommer et al. 1997). Following spawning, splittail are expected to move downstream out of the project area into brackish habitats.

The following are important habitat management considerations for Sacramento splittail:
- managing spring flows to inundate floodplain surfaces from February through at least the end of April for spawning, and
- managing flows or modifying floodplain surfaces to reduce stranding of young-of-the-year

splittail on floodplains.

3.4.5.6 Hitch

Populations of hitch in the San Joaquin River basin appear to be declining and increasingly isolated from one another (Moyle 2002). Hitch appear to have been extirpated from some areas of the San Joaquin River within the past decade (Moyle 2002). They generally make upstream migrations to spawn in mainstem or tributary riffles from March to June when flows increase in the spring, at temperatures from 57.2 to 64.4°F (14 to 18°C) (Moyle 2002). Factors potentially contributing to their decline include loss of spring spawning flows, loss of summer rearing and holding habitat, increased pollution, and predation by non-native species (Moyle 2002). Hitch tolerate the highest temperatures of any Central Valley native fish, preferring temperatures between 80.6° and 82.4°F (27° and 28°C).

The following are important habitat management considerations for hitch:

- managing spring flows to provide suitable upstream migration and spawning habitat, and
- creating additional spawning habitat on floodplains, where feasible.

3.4.5.7 Tule perch

Tule perch inhabit slow-moving reaches that have shoreline areas with cover provided by dense aquatic or emergent vegetation, overhanging riparian vegetation, or other complex structure. They bear live young and appear to be less vulnerable to predation by non-native species than other native resident fish. They prefer cooler water temperatures than the other analysis species, being rarely found in streams where temperatures exceed 77°F (25°C) for extended periods and generally preferring temperatures <71.6°F (22°C). Poor water quality, low dissolved oxygen, and contaminants may limit their distribution.

The following are important habitat management considerations for tule perch:

- maintaining and restoring riparian habitat and shoreline areas with complex cover, and
- maintaining suitable temperatures in areas with dense riparian vegetation.

3.4.5.8 Sacramento perch

Sacramento perch tolerate high water temperature (preferring temperatures of 77 to 82.4°F [25 to 28°C]), high turbidity, high salinity, and high alkalinity. They may be best able to persist in habitats where non-native centrarchids are excluded by high alkalinity, due to high overlap in habitat preferences and competition for food. The species appears to compete for food and space most strongly with bluegill and black crappie (Moyle 2002). Adults defend nests and larvae, but eggs and larvae are nonetheless vulnerable to predation. For spawning, Sacramento perch require shallow areas (8−20 in [20−50 cm] in depth) with dense aquatic vegetation that are inundated in the spring at temperatures from 64.4 to 84.2°F (18 to 29°C) (P. Crain, University of California, unpubl. data, 1998, as cited in Moyle 2002). Spawning occurs from late March through early August, generally peaking in late May and early June. Adults prefer slow-moving reaches with aquatic vegetation, but highly turbid reaches without cover may also be suitable (Moyle 2002). Little is known regarding their early life history stages and whether physical or chemical factors may limit their survival (Moyle et al. 2002); however, efforts to answer these questions may be helpful for developing strategies for their reintroduction to the San Joaquin River system.

The following are important habitat management considerations for Sacramento perch:

- creating opportunities for reintroducing Sacramento perch into habitats where they can reproduce in relative isolation from non-native fish species and act as source populations for seeding mainstem habitats, and
- managing flows to reduce the abundance and distribution of non-native centrarchids.

Table 3.4-2 summarizes the habitat requirements of native fish analysis species.

Table 3.4-2. Habitat requirements of native fish analysis species.

HABITAT REQUIREMENTS SHARED BY MORE THAN ONE SPECIES		
HABITAT REQUIREMENT	**SUITABLE TEMPERATURE RANGE**	**REQUIREMENTS FOR RELEVANT ANALYSIS SPECIES**
deep (>3 ft [1 m]) habitats (e.g., deep runs, pools, sloughs) with warm summer temperatures for adults	68.0° to 82.4°F (20° to 28°C)	C **Sacramento pikeminnow** are most abundant where summer temperatures are >68°F (20°C) for extended periods of time C **hardhead** most often occur in streams with summer temperatures >68°F (20°C) C **hitch** tolerate extremely high temperatures and actively select temperatures >77°F (25°C)
longitudinal habitat connectivity for seasonal spawning migrations in late winter and spring, especially March and April	53.6° to 64.4°F (12° to 18°C)	C **Pacific lamprey** upstream migration occurs during high flows and may begin in ***January and February***, but primarily occurs from ***early March to late June***; downstream migration most likely occurs in winter and spring during high flow events C **Sacramento pikeminnow** move upstream to spawn from ***March through May*** C **hardhead** move upstream to spawn in ***April and May*** C **Sacramento splittail** move upstream to spawn from ***January through April*** C **hitch** move upstream to spawn with spring high flows in ***March and April***
gravel riffles suitable for spawning in spring	53.6° to 64.4°F (12° to 18°C)	C **Pacific lamprey** spawn in gravel or gravel and sand substrates (generally smaller than those preferred by chinook salmon) in spring at temperatures of 53.6−64.4°F (12−18°C) C **Sacramento pikeminnow** spawn from late February through May, with peak spawning in March and April C **hardhead** spawn in April and May and possibly into the summer months C **hitch** spawn in clean, fine to medium size gravel during high spring flows from March to June at temperatures from 57.2−64.4°F (14−18°C)
shallow (0-20 in [0-50 cm]) rearing habitat, with cover provided by aquatic, emergent, or annual vegetation or turbidity, and warm summer temperatures [late spring through summer]	68.0° to 82.4°F (20° to 28°C)	The following species share this habitat requirement: C **Sacramento pikeminnow** C **hardhead** C **hitch** C **Sacramento splittail** C **Sacramento perch**
SPECIES-SPECIFIC NON-OVERLAPPING HABITAT REQUIREMENTS		
Pacific lamprey	year-round temperatures <77°F (25°C), but preferably <68°F (20°C)	shallow, low-velocity, flowing-water habitats (e.g., backwaters, sloughs, channel margins) with mud or other fine substrate that remain inundated year-round
Hardhead	summer temperatures >68°F (20°C), but more preferably >24°C (75.2°F)	deep (>2.5 ft [0.75 m]) rock-bottomed pools with and relatively high dissolved oxygen concentrations
Sacramento splittail	temperatures ≥57.2−66.2°F (14-19°C); but preferably <59°F (15°) for spawning	floodplains inundated at depths from 1.6 to 6 ft (0.5 to 2 m) for a minimum of 60 days within the period from February through May
Tule perch	summer temperatures <71.6°F (22°C)	deeper low-velocity habitats with shoreline areas having dense cover from aquatic vegetation, overhanging riparian vegetation, or complex large woody debris
Sacramento perch	summer temperatures from 64.4° to 82.4°F (18° to 28°C)	low-velocity habitats with cover provided by aquatic or emergent vegetation or turbidity, and shallow areas (8-20 in [20-50 cm]) with dense aquatic vegetation for spawning inundated for at least 30 days during the period from April through July (peak spawning generally occurs in late May and early June)

3.4.6 Restoration strategy measures anticipated to benefit native resident fish

3.4.6.1 Inundating floodplains in the spring

One of the primary restoration measures intended to support the reintroduction of chinook salmon to the San Joaquin River is the restoration of spring high flows and floodplain inundation to the riverine ecosystem. The strategy includes inundating already existing floodplains, as well as designing and creating new floodplains in Reach 4B and the Mendota Bypass reach. These measures are likely to improve conditions for native resident fish while reducing habitat quantity and quality for non-native fish species. Sacramento splittail, Sacramento blackfish, and Sacramento perch are all adapted to spawning on floodplains in the spring. Inundating floodplains during the natural spring run-off period should promote spawning by native resident fish and provide larvae and early life history stages with high-quality rearing habitat. Drawing water off of the floodplains by late spring or summer may reduce the amount of time that non-native centrarchids such as bass and sunfish can successfully spawn on the floodplains. Engineered floodplains can also be designed to reduce the potential for stranding during the period when downramping occurs.

Most mortality of both native and non-native resident fish occurs during the critical egg and young-of-the-year stages, when vulnerability to predation is extremely high. Providing suitable spawning and rearing habitat early in the spring for native resident fish may increase survival during the critical first few months when predation mortality may be highest. Shallow areas with dense vegetation would provide warm temperatures for fast growth, cover from predation, and may discourage larger piscivorous fish from moving onto the floodplains from the main channel. Because many of the non-native resident species spawn later in the spring or at warmer temperatures than native species, promoting early spring spawning on floodplains by native species may actually increase predation by juvenile native fish on the larvae and fry of later-spawning centrarchids. Common carp are likely to use floodplains for spawning; however, their presence may not substantially reduce habitat quality for native fish species. Other non-native resident fish species that may use floodplains include largemouth bass, sunfish (*Lepomis* spp.), crappies (*Pomoxis* spp.), inland silverside, red shiner, and threadfin shad. Largemouth bass generally spawn at depths from 12 to 40 in (30 to 100 cm), but prefer to spawn at depths >18 in (45 cm); it may be possible to discourage some spawning by bass by manipulating the availability of their preferred depths when temperatures are suitable for spawning (largemouth bass most often spawn at temperatures between 61° and 72°F [16° and 22°C]). However, the spawning habitat preferences of largemouth bass overlap to a large degree with those of Sacramento perch, which could also benefit from floodplain habitat enhancement if they become reestablished in the basin.

Floodplains in Reach 4B and the Mendota Bypass reach could be used to provide high-quality Sacramento splittail spawning and rearing habitat in some water-years. These floodplains could be designed to test how various characteristics affect splittail use and year-class strength as part of an adaptive management program. Parameters that could be tested include: (1) inundation depth, (2) inundation duration, (3) inundation timing, (4) water velocities on the floodplain surface, (5) temperature, (6) stranding effects, and (7) substrate and vegetative cover characteristics. The results of such investigations could be used to modify areas to further improve habitat for splittail or to guide restoration of floodplains in other areas. Such floodplains are expected to benefit both splittail and rearing chinook salmon. Juvenile chinook move onto the flooded Yolo Bypass in January and February and move off in March when temperatures are increasing. Splittail move onto floodplains in February as temperatures increase to 57.2−66.2°F

(14−19°C) and generally spawn where temperatures are generally less than 59°F (15°C) (Moyle et al. 2001). Splittail tend to depart the Yolo Bypass for cooler habitats when temperatures approach 68°F (20°C). Juvenile chinook salmon may be able to remain on the floodplains at these temperatures as long as nighttime temperatures are below about 64°F (18°C) (P. B. Moyle, pers. comm., 2002). Sacramento blackfish would be expected to spawn later in the season than splittail; in Clear Lake they are observed to spawn from April to July at temperatures from 54° to 75°F (12° to 23°C) (Moyle 2002).

3.4.6.2 Creating perennial wetlands on floodplains

Reconstructing perennial wetlands within natural and engineered floodplains would restore naturally occurring habitats that may be used by certain native fish species such as Sacramento blackfish and hitch. Both of these species are capable of surviving in small ponds less than a half-acre in size (P. B. Moyle, pers. comm., 2002). Pools that are hydrologically connected with the main channel appear to support non-native fish species better than those that are completely disconnected when flows recede (P. B. Moyle, pers. comm., 2002). Sacramento blackfish are found in areas where summer water temperatures exceed 86°F (30°C) and dissolved oxygen concentrations are low (Moyle 2002); upper lethal temperatures for blackfish may be as high as 98.6°F (37°C) (Knight 1985, as cited in Moyle 2002). In lakes and ponds, blackfish, which are filter-feeding herbivores, may feed on plankton suspended in the water column as well as on soft bottom material that is rich in organic matter and small invertebrates (Moyle 2002). Hitch are also planktivores that feed on filamentous algae and aquatic and terrestrial insects (M. Dege, University of California, Davis, unpubl. data, 1996, as cited in Moyle 2002). Hitch tolerate the highest temperatures of any Central Valley native fish, selecting temperatures between 80.6°F and 82.4°F (27°C and 28°C) and withstanding temperatures up to 100.4°F (38°C) for short periods of time (Knight 1985, as cited in Moyle 2002). They have also been found in water with salinities as high as 9 ppt (J. J. Smith, California State University, San Jose, pers. comm., as cited in Moyle 2002). Ponds and wetlands on floodplains may also be colonized by non-native fish species that tolerate high water temperatures and low dissolved oxygen, such as largemouth bass and carp. Factors that may influence colonization by non-native fish may include when and how often the habitats are hydrologically connected to the San Joaquin River. Monitoring and adaptive management of floodplain wetlands may be useful for attempting to resolve such uncertainties and maintaining these wetlands and ponds as pockets of habitat for native fish.

3.4.6.3 Creating opportunities for Sacramento perch reintroduction

Perennial wetlands and small floodplain ponds and lakes could be restored with the intention of creating opportunities for reintroducing Sacramento perch to the San Joaquin basin. Some perennial wetlands on floodplains could be designed to provide high-quality habitat for Sacramento perch where interactions with certain non-native fish species could be controlled through isolation, periodic dewatering and removal of non-natives, or other means. Ponds for experimental perch reintroduction should first be constructed where they can be easily maintained. If they are flooded only when flows are high and temperatures cool enough, and if water is drained off before temperatures warm too much, colonization by non-native fish species may not pose a big problem. Floodplain ponds that are hydrologically connected to the mainstem channel at high flows can also provide a mechanism for seeding mainstem habitats with Sacramento perch. Floodplain ponds and depressions would also be expected to provide high-quality feeding habitat for Sacramento splittail, which have been found to congregate in pools in the Yolo Bypass when zooplankton blooms occur in them (P. B. Moyle, pers. comm., 2002). Existing aquaculture ponds upstream of Mendota Pool along RM 246 may be able to be redesigned to provide opportunities for experimental Sacramento perch reintroductions to the San Joaquin basin.

Floodplain ponds designed for Sacramento perch would need to consider their specific habitat requirements and tolerances. Sacramento perch prefer temperatures from 77° to 82.4°F (25° to 28°C) and can tolerate high salinity, alkalinity, and turbidity (Moyle 2002). Their ability to tolerate high alkalinities may make it possible for them to persist in some areas because of reduced interactions with non-native species that do not share this tolerance. They can successfully survive and reproduce in ponds as small as 200 ft^2 (P. B. Moyle, pers. comm., 2002). Floodplain ponds created for Sacramento perch and other native fish should be at least 6 ft (2 m) deep to provide cover from avian predation and refuge from temperature extremes (P. B. Moyle, pers. comm., 2002). Aquatic and emergent vegetation would be important as cover from predation, especially for larvae and young-of-the-year fish, although turbid water may afford similar cover (Moyle 2002). Tule marsh can provide suitable habitat for perch if open water is available. In small lakes and ponds, chironomids appear to remain important in the diet of even large adult Sacramento perch, with small crustaceans and fish of secondary importance (Moyle 2002). Occasional removal of excess aquatic and emergent vegetation may be required to maintain open water if habitats become choked with vegetation.

Monitoring and adaptive management of floodplain habitats designed for Sacramento perch would improve the likelihood that isolated populations could be successfully established and that such populations might someday act as source populations for recruiting individuals to mainstem San Joaquin River habitats in the future. Several variables could be manipulated to evaluate how they affect Sacramento perch survival and reproduction in floodplain habitats and their ability to withstand potential periodic invasion by non-native fish. Some of the variables that could be experimented with include depth, area/size of open-water habitat, percent cover by submergent and emergent vegetation, and degree of hydrologic connectivity with main channel.

3.4.6.4 Flow management to reduce abundance and distribution of non-native fishes

Although non-native species may be here to stay, it may be possible to reduce their negative impacts on native fish communities so that most, if not all, of the native species can continue to maintain viable populations. Managing flows in the San Joaquin River to more closely resemble the naturally variable hydrograph may give native fish species a competitive edge over non-native species. Certain flow-related measures may only be feasible to implement in wetter water years due to conflicting needs for water in the basin. However, the long life span of many native fish species and the fact that they have evolved to withstand periods of prolonged drought, floods, large seasonal and interannual variations in instream flows, and other disturbances increases the likelihood that such measures would be successful.

High spring flows will reduce temperatures in the main channel, which will improve rearing habitat quality for juvenile salmonids. These same flows should provide suitable riffle spawning habitat for native fish species in Reach 1 during the spring when these species spawn. Flows that inundate shallow, vegetated channel margin habitat will also create valuable early rearing habitat for these species. Native species that may benefit from these habitat improvements include Pacific lamprey, Sacramento pikeminnow, hardhead, and Sacramento sucker. High spring flows that reduce temperatures in the main channel should reduce the area suitable for the spawning and rearing of centrarchids, as well as the duration of the season that spawning of these species can successfully occur. Managing flows to reflect different water-year types should also promote native resident fish over non-native resident fish. Within the group of native resident species, between-year fluctuations in environmental conditions may be critical for maintaining the diversity of species that are present in the system. Since many species are long-lived, they can persist during periods when conditions may be more suitable for other members of the community.

Flow fluctuations or high flows timed during late spring or early summer may delay or disrupt spawning by some non-native species such as largemouth bass and thus reduce the duration of their spawning season. Repeated flow pulses in wet years may reduce spawning success and larval survival of non-native centrarchids for a large portion of the season. Even if such measures are only implemented in wet years, they may benefit native fish species through reducing populations of resident centrarchids. There are many uncertainties regarding the potential for such measures to succeed; a monitoring and adaptive management program would be valuable for evaluating flow-management techniques for reducing spawning success of non-native species.

3.4.6.5 Establishing a native fish community in Mendota Pool

It may be possible to establish a native fish community in Mendota Pool and to use this as a source of fish for seeding floodplain ponds and other newly restored habitats. Because Mendota Pool is periodically drained, it would be possible to physically remove many non-native fish and restock the reservoir with native fish. Restoring wetland and riparian habitats on the banks of Mendota Pool could increase its habitat value for native fish. Native resident fish that could be introduced include Sacramento perch, hitch, Sacramento blackfish, prickly sculpin, and tule perch (if temperature and water quality are suitable). Larvae of non-native fish species would continue to be recruited into Mendota Pool, but predation by established populations of native fishes might prevent successful establishment of non-native populations (P. B. Moyle, pers. comm., 2002). However, periodic draining of the water body may be necessary to ensure that non-native fish do not become established. Mendota Pool could also provide an opportunity to educate the public about native fishes and their ecology. Public education is very important for protecting native fishes and their habitats and may increase support for enhancement measures.

3.4.6.6 Improving habitat connectivity

Under current conditions, physical barriers, water velocities, insufficient flows, high water temperatures, contaminants, and low dissolved oxygen may prevent or impede upstream movements of native resident, as well as anadromous, fish species. In addition, entrainment of eggs, larval fish, and juvenile fish into screened and unscreened agricultural diversions, and Delta pumps, may affect habitat connectivity for juvenile fish dispersing to appropriate rearing habitats.

3.5 Riparian and Wetland Vegetation and Wildlife Habitat

3.5.1 Overview of riparian and wetland vegetation and wildlife habitat restoration goals

The following is a draft list of over-arching goals for vegetation and wildlife habitat in a restored river corridor. This list builds on basic principles of conservation biology, restoration ecology, and ecosystem management (Noss and Cooperrider 1994, NRC 1995, Fiedler and Kareiva 1998, Pickett et al. 1997); ideas developed by the ROST Riparian Vegetation Subcommittee (2001); information contained in the Background Report (McBain and Trush 2002); and riparian and wetland ecological requirements and functions presented in the Restoration Objectives Report (Stillwater Sciences 2003):

- Maintain/restore a diverse assemblage of native species and habitats in a dynamic, self-sustaining system.
- Maintain/restore a mosaic of habitat types, and seral and structural stages, with relative abundance of the various types (e.g., riverwash, riparian forest and scrub, valley oak woodland, grassland, freshwater emergent marsh, seasonal wetlands, alkali scrub and other alkali habitats, and elderberry savanna) similar to the historical condition, within the constraints posed by current and/or likely future land uses, land ownership and critical infrastructure needs.
- Create opportunities and encourage actions to restore a relatively broad riparian and flood basin corridor similar to, but narrower than, that which was historically present along the San Joaquin River throughout the project area.
- Restore river-floodplain connectivity and longitudinal connectivity of riparian vegetation near the channel (without major breaks in the distribution of woody vegetation except where natural conditions prevent establishment of native trees or shrubs) that can provide cover and habitat for a variety of wildlife species.
- Re-introduce elements of the natural disturbance regime to prevent or minimize vegetation encroachment onto active sand and gravel bars, and to “reset” a portion of the riparian vegetation frequently enough to maintain a mosaic of all desired seral and structural stages. The geomorphic analysis (Section 3.1.) indicates that this goal may not be achievable in gravel-bedded areas (i.e., Reach 1), implying that periodic human intervention might be necessary in some cases.
- Promote development of large patches of riparian forest of various types to provide habitat for obligate riparian wildlife species that depend on interior forest conditions (e.g., yellow-billed cuckoo).
- Create or maintain juxtaposition of habitats required by selected wildlife species, such as species that depend on juxtaposition of aquatic, wetland or riparian, and upland habitats to meet various life history stage requirements (e.g., western pond turtle, Swainson’s hawk).
- Provide riparian or wetland habitat, where appropriate, that contributes to the maintenance of viable populations of threatened, endangered, sensitive, or other focal species of plants and animals.
- Enhance landscape connectivity between the river corridor and adjacent areas of ecological significance (e.g., wildlife refuges and other protected lands, biodiversity hotspots, adjacent sloughs or tributary channels with existing riparian habitat, wildlife movement corridors).

- Restore and maintain a system that is dominated by native species and is more resistant than the existing system to invasion by and spread of non-native species.
- Restore natural riparian and wetland vegetation types and processes that help improve water quality, promote groundwater recharge, improve nutrient cycling and soil health, support food webs for aquatic and terrestrial wildlife, and are compatible with improved flood protection when combined with levee setbacks in some areas.
- Protect, restore or enhance rare vegetation types.

3.5.2 Assumptions governing development of strategies for riparian and wetland vegetation and wildlife habitat

The goals listed above and their related objectives are based on a number of assumptions about limitations and opportunities throughout the river corridor (Chapter 3 in the Restoration Objectives Report [Stillwater Sciences 2003], Chapter 8 of the Background Report [McBain and Trush 2002], and ROST Riparian Vegetation Subcommittee 2001). Some of the key governing assumptions are:

- If suitable habitat is provided, habitat and many or most of the targeted species will eventually come, although active reintroduction may be desired to speed up the recovery process in general or may be necessary to re-establish populations of certain desirable dispersal-limited species.
- Restoration will take time, but certain actions may be undertaken that are likely to facilitate or speed up the recovery process.
- Immutable natural limitations exist. Some of these include soils, climate, geomorphology, and geologic structure, which will limit the spatial distribution and type of riparian vegetation.
- Vegetation potential varies by reach and subreach.
- Vegetation restoration is spatially limited by alluvial groundwater availability and controlled by thresholds of water and geomorphic surfaces.
- Establishment and succession of riparian vegetation were historically controlled by fluvial geomorphic processes that are associated with the timing, magnitude, frequency, and duration of flows. Riparian hydrograph requirements should be incorporated as foundations for both process-based (natural recruitment) and active (horticultural restoration) riparian restoration strategies.
- The flood control system currently limits vegetation restoration opportunities. Conversely, expansion of the floodway system should provide additional opportunities.
- The hydrological and geomorphic processes that maintain riparian vegetation also benefit a variety of other species.
- There is a physical limit imposed by floodplain, terrace, and bluff topography that will ultimately control the area and width of the riparian corridor.
- The restoration strategies will be designed to establish, enhance, and maintain vegetation on appropriate surfaces for riparian vegetation within the topography of the channel and floodplain (although the practical limits in many reaches are generally constrained by existing levees or constraints on the amount of levee setback that is realistic).
- Adaptive management will be required to meet restoration goals.

3.5.3 Riparian hydrograph components

Riparian tree species along the San Joaquin River have evolved life history strategies that depend on the river's historical hydrology, including the annual cycles of winter floods and spring snow-melt, as well as more infrequent large spring floods. Conceptual models linking riparian tree life history attributes with specific hydrograph components are detailed in the Background Report (see Section 8.7 in McBain & Trush 2002). In order to reestablish woody riparian vegetation along the San Joaquin River, restoration flows will need to mimic natural hydrographs in several key ways.

- High flow peaks, which would mimic to some degree the characteristics of peak flows associated with winter high-volume rain events in the unimpaired hydrograph, will need to be included in the proposed restoration strategies to control vegetation encroachment and prepare seedbeds prior to seedling recruitment flows in wet years (*encroachment prevention flows* and *seedbed preparation flows*).
- High spring peak flows with relatively gradual recession rates during the seed release period for cottonwoods and willows (generally mid-April through June) will be needed during wet years to moisten the seedbeds and induce seed germination at elevations suitable for long-term establishment (*recruitment flows* for seedling initiation).
- Summer and fall base flows are needed to ensure that new seedling cohorts and older cohorts of saplings and mature trees have adequate soil moisture to survive the annual dry season (*maintenance flows*).

These components are described below in terms of the key life history stages that they benefit and the overall effects that they have on vegetation distribution and structure.

To date, much of the riparian research and process-based restoration efforts on have focused on pioneer species such as willow and cottonwood. These species, which release their seeds in spring coincident with the historical snowmelt pulse, are most dependent on riverine hydrology for reproduction and survival and suffer the largest changes in distribution and age structure under severely regulated conditions. For these reasons, the San Joaquin River Riparian Recruitment Model and the riparian restoration hydrograph components focus on these species. Nevertheless, other riparian tree species of interest that occur in the historical riparian zone such as box elder, Oregon ash, white alder, valley oak, and western sycamore disperse their seeds in fall and winter, and rely to varying degrees on river hydrology for initiation and survival (see Section 8.7.3 of the Background Report). Where the restoration hydrograph components will likely affect these species' ecologies, they are discussed below.

Although we generally focus on seedling recruitment, vegetative reproduction also occurs in a variety of riparian species, including willows and cottonwoods. High flows occurring anytime during the year may help to disperse branches or other vegetative fragments to new sites. If these propagules are washed ashore in sites that provide some protection from subsequent high flows, and if suitable soil moisture and receding groundwater levels occur during the root growth period, successful vegetative reproduction may occur. Horticultural restoration techniques for cottonwood and willows that rely on cuttings take advantage of this trait. Although they may occur at other times, the conditions for vegetative propagule dispersal and successful establishment would most likely occur during wet years, in association with managed riparian recruitment flows that would allow the roots of newly deposited cuttings to stay in contact with the slowly declining water table. Some non-native invasive species, such as giant reed, readily colonize new sites through vegetative reproduction. Control of potential sources of such non-native invasive species prior to high flow releases for riparian vegetation seedbed preparation and recruitment may be warranted to reduce the risk of such species colonizing new areas along the river corridor.

3.5.3.1 Indexing Flow Planning to Water Year Type

The volume of water available for a recruitment flow (and therefore the range of potential magnitude, duration, and flow recession) will be largely determined by contemporary hydrologic conditions. Recognizing the stochastic nature of historical floods as well as the extremes of interannual water availability within California's climate, we need to take advantage of years when surface water is abundant to optimize recruitment. The ideal condition is to release a large flow in a wet water year when the reservoir is fairly full (from previous wet or above-normal years). Under these conditions the flow pulse can be sustained to allow moist conditions to persist high on floodplains until seedlings can grow extensive root systems and reach the perennial water table. Under less ideal conditions, lower magnitude flows can be used to encourage recruitment on lower floodplain and bank surfaces. Modulating the magnitude in conjunction with the timing of recruitment flows may be used to achieve a desired landscape distribution of certain species on particular geomorphic surfaces.

Because of these considerations, we recommend a dual approach to flow management for riparian vegetation issues (Table 3.5-1): (1) for wet years, a focus on seedling recruitment and survival (Figure 3.5-1); and (2) in all other years, a focus on preventing vegetation encroachment (Figure 3.5-2).

Table 3.5-1: Primary riparian flow management objectives, by water year type.

<table>
<tr><th>Water Year Type</th><th>Average Recurrence Interval (years)</th><th>Management Objectives</th></tr>
<tr><td>Wet</td><td>5</td><td>Spring recruitment flows to establish seedlings on lower floodplains, with summer flow conditions sufficient to maintain seedlings on desired surfaces. No fall encroachment prevention flows.</td></tr>
<tr><td>Normal-wet</td><td>3.33</td><td rowspan="3">No planned recruitment. Recruitment in active channel likely in some years; encroachment prevention flows likely needed in fall to scour near-baseflow elevations. Need to maintain summer water table for young cohorts</td></tr>
<tr><td>Normal-Dry</td><td>3.33</td></tr>
<tr><td>Dry</td><td>5</td></tr>
</table>

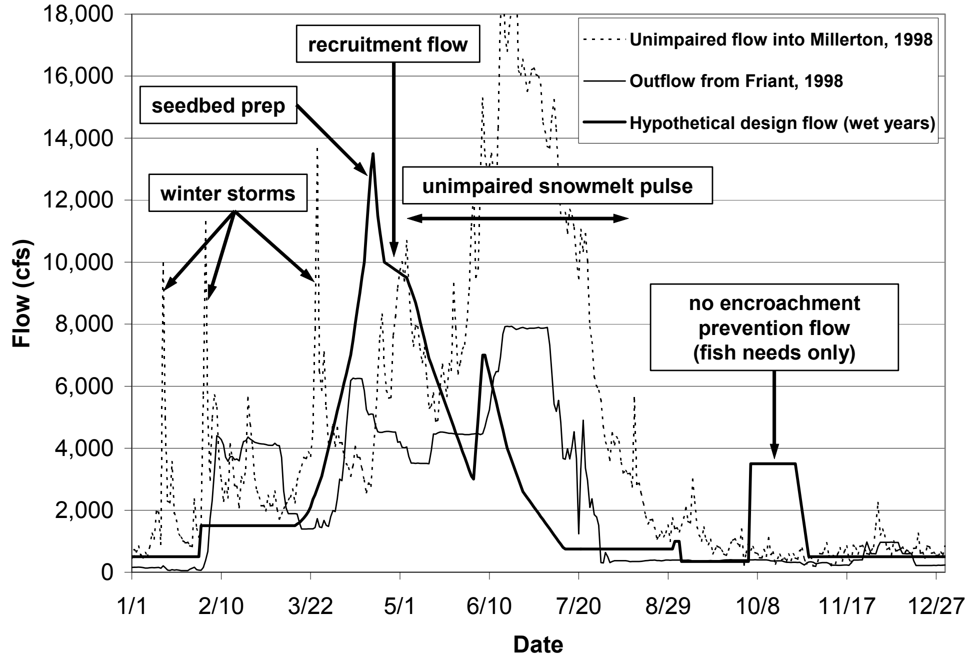

Figure 3.5-1. Hypothetical wet year design hydrograph and example Millerton inflows and Friant outflows from 1998. Riparian recruitment will be encouraged by mimicking unimpaired winter storm pulses (to prepare seedbeds) and spring snowmelt ramp-down rates (to encourage seedling germination and survival).

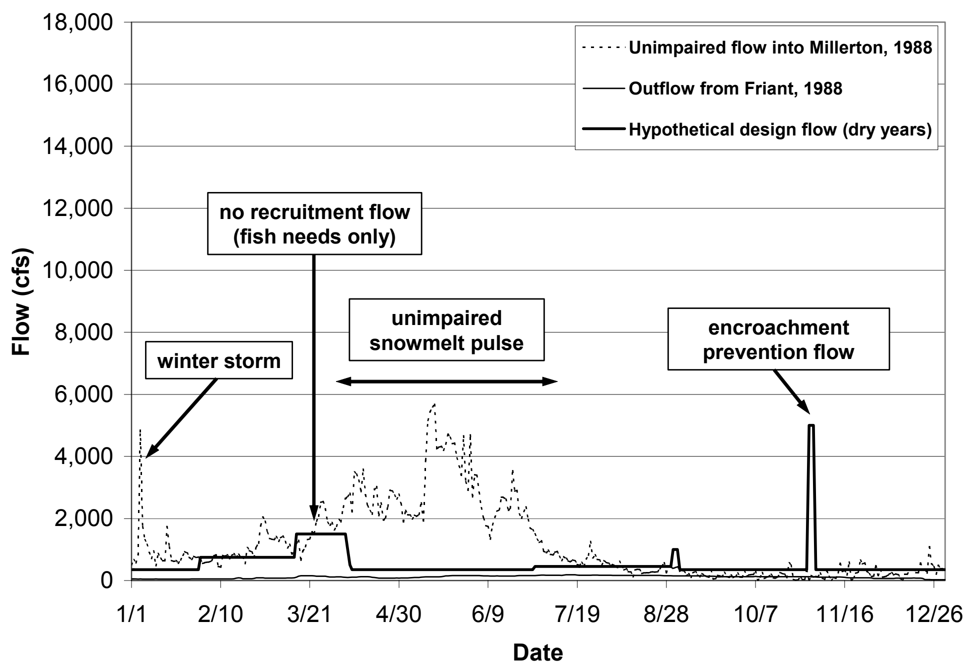

Figure 3.5-2. Hypothetical dry year design hydrograph and example Millerton inflows and Friant outflows from 1988. Seedling recruitment will be not be encouraged in dry, normal-dry, and normal-wet year. The vegetation management priority in these years will be to prevent encroachment at the active channel margin.

Under all scenarios discussed in later chapters of this report, recruitment flows would be planned for wet years only. In early spring, a seedbed preparation flow consisting of a sharp pulse in flow rate would be released, followed by a recruitment flow, which is characterized by a more gradual recession rate. Figure 3.5-1 illustrates a proposed recruitment flow superimposed on an example of an unimpaired wet year hydrograph (Water Year 1986). The seedbed preparation flow would function similarly to the unimpaired winter storm peaks by mobilizing sediments and scouring existing vegetation from potential seedbeds. The recruitment flow would operate analogously to the spring snowmelt pulse, achieving a gradual stage decline rate to allow seedlings to survive at higher bank elevations. The timing, duration, and exact shape of the recruitment flow hydrograph could be adjusted to meet flood control requirements in any particular wet year. The key factor is ensuring that the general rate of stage decline during the recession limb subsequent to the peak flood control releases is gradual enough to support riparian seedling establishment. Another important issue is the timing of the recession limb – if it occurs too late to support recruitment of desired species, a faster rate of decline may be justified (although other ecological objectives, such as groundwater recharge and wetland inundation, should also be considered).

Recruitment flows would not normally be targeted for dry, normal–dry, or normal-wet water years, since reservoir volumes would not likely be sufficient to meet recruitment flow needs and should be conserved to provide baseflows to help recharge water tables in late summer when existing trees would be most vulnerable to drought mortality. In these years vegetation growth near the low-flow channel margin is likely and encroachment prevention flows will likely be needed to clear new growth. These flows correspond to winter storm peaks that are short in duration but high enough in magnitude to mobilize sediments and scour vegetation. In the strategies outlined later in this report, encroachment prevention flows are specified for non-wet water year types, in most cases in coordination with fall flows targeted toward fish objectives. Figure 3.5-2 illustrates a dry year prescribed flow (including the encroachment prevention flow in fall) superimposed on an example dry year unimpaired hydrograph. Note that unimpaired winter storm peaks are still high, but that the spring snowmelt pulse is meager compared to wet years.

No encroachment prevention flows will be prescribed in wet years in order to protect the seedling cohorts that germinated in the spring. In this case, protecting the ecological and economic investment in a recruitment flow takes highest priority.

3.5.3.2 Interannual flow planning

Environmental conditions during the several years after a recruitment event are critical for survival of young cohorts. Seedlings and saplings face a host of potential mortality agents including desiccation (Sacchi and Price 1992; Rood et al. 1998) scour (McBride and Strahan 1984), prolonged inundation (Kozlowski 1997), water table decline (Stromberg et al. 1996), herbivory (Griggs 2003), and disease. As discussed above, the frequency of planned recruitment flows should be initially high to mitigate for possible high mortality events due to these factors. Under an adaptive management framework, intervals between recruitment flows may be increased as more information about mortality agents becomes known.

Variability in the timing and magnitude of recruitment flows is likely to lead to a more diverse and heterogeneous mix of plant species, vegetation types, and habitat structure. We have assumed that such heterogeneity is closer to natural conditions and more likely to promote a variety of ecological objectives than the simpler riparian communities that would likely develop if recruitment flows always occurred at the same time, peak flow magnitude, and recession rate. Adaptive management could be used to find an appropriate approach to designing and implementing spatially and temporally variable recruitment flows. In addition, during the first few years of restoration implementation, a lower magnitude recruitment flow during a normal-wet year might be warranted to test our assumptions about process-based riparian restoration via natural recruitment. In addition, this type of preliminary recruitment test is likely to establish new patches of cottonwood and willows that, when mature, would improve the chances of success of subsequent larger magnitude recruitment flows by increasing the potential supply of seeds throughout the river corridor.

Flow planning in the years after a recruitment flow will likely be critical to cohort survival. High flows with the potential to scour young of the year seedlings should be avoided if possible in the winter after a recruitment event. Subsequent summer spring and summer flows should be adequate to maintain soil moisture during the growing season, but not so elevated as to concentrate root growth near the soil surface and increase vulnerability to desiccation during rapid declines later.

3.5.3.3 Seedbed preparation flows

The seeds of pioneer riparian trees require high light and moisture levels to germinate, and do best on fine-grained mineral soil with little accumulated litter. Under historical conditions, winter floods provided these conditions by scouring banks of vegetation, depositing fine sediments on floodplains, and recharging water tables and soil moisture levels. Restoration efforts will need to include flow peaks adequate to clear herbaceous vegetation and mobilize fine sediment prior to the spring seed-release period to create suitable seed beds. To conserve water and make best use of potentially limited fine sediment, seedbed preparation flows should be implemented only in years when subsequent recruitment flows are planned. Seedbed preparation flows that precede recruitment flows by only a few days or weeks are likely to be more successful, since the timing would reduce the risk of non-native annuals becoming established in time to outcompete willow and cottonwood seedlings. Larger substrate size in Reach 1 (and consequent higher critical shear stresses) may prevent adequate seedbed formation in almost all years. Species such as valley oak, box elder, and sycamore have larger seeds with more stored resources to allow growth under low seedbed light levels, and may not require mineral soil and extensive scour to the degree that willows and cottonwoods do. Winter or early spring seedbed preparation flows may benefit fall and winter dispersing species through increased dispersal of propagules onto floodplains.

If managed seedbed preparation flows are insufficient to create appropriate seedbed conditions through scour or sediment deposition in appropriate locations, human intervention may be required periodically to set the stage for natural recruitment processes. The Adaptive Management Report (Stillwater Sciences 2003) will discuss this issue in more detail.

3.5.3.4 Recruitment flows

For the purposes of this project, recruitment flows refer to controlled releases that occur during the spring seed release and dispersal period for pioneer riparian trees (particularly Fremont cottonwood and Gooding's black willow). These flows are designed to mimic in some respects the historical snowmelt pulse. Biologically important aspects of recruitment flows include flow frequency, timing, magnitude, duration, and rate of stage decline. The importance of these hydrograph attributes for pioneer riparian tree seedlings is described below. For lower floodplain species such as white alder and box elder that disperse seeds in fall and winter, flow timing is less important because their seeds survive longer, but all other issues apply. High floodplain species such as valley oak and western sycamore may be more dependent on rainfall events and other climatic or stochastic events for establishment (see Section 8.7.3 of the Background Report [McBain and Trush 2002]) than on spring snowmelt pulses.

Frequency
For any biological population to be self-sustaining, viable offspring must be produced in adequate numbers during the adults' reproductive lives to offset deaths due to multiple causes. Riparian trees live in a dynamic physical environment where catastrophic disturbance from floods (and in some cases fire) can severely limit the abundance and distribution of fecund adults. Willows and cottonwoods also tend to have short life spans, typically a century or less. For these species' populations to be sustainable, new cohorts of these trees need to be created at short enough intervals to replace adults killed by disturbance or senescence. Research on riparian forest stands in western North America indicates that successful recruitment events typically occur after flows representing a 5- to 10-year recurrence interval (Bradley and Smith 1986, Cordes 1991, Reid 1991, Howe and Knopf 1991, Stromberg et al. 1991, Stromberg et al. 1993, Rood et al. 1997, Scott et al. 1997, Cordes et al. 1997, Rood et al. 1998). Though some cite intervals as short as 3 years (Baker 1990, Howe and Knopf 1991) and some as long as 30 to 50 years along some non-meandering rivers (Hughes 1994, as cited in Chapter 8 of McBain and Trush 2002). Recruitment flows on the San Joaquin River should be timed initially on the lower end of that range to ensure viable seedling cohorts soon and to account for potential large-scale mortality events. However, the potential for a recruitment flow in any particular year will be constrained to a large degree by factors such as the magnitude and timing of winter rainfall, prior year hydrology, and reservoir operational issues.

Timing
For willows and cottonwoods, whose seeds are viable only for several weeks, seed release must coincide with wet conditions and seedbed availability to produce a successful cohort. Appropriate flow timing is therefore the first condition necessary for a successful recruitment flow, and constraining flood timing will conceivably benefit some species over others. The annual chronological order of spring seed-releasing species is as follows: arroyo willow, Fremont cottonwood, black willow, and narrow leaf willow. Generalized seed dispersal periods are graphed in Figures 8-36 through 8-39 of the Background Report (McBain and Trush 2002). Recruitment flows should be targeted from mid-April to late-May to improve cottonwood recruitment, and mid-May to late June to benefit black willow. Flows prior to mid-April will likely miss the seed release window for these species (but may benefit arroyo willow, currently a less dominant species within the San Joaquin River riparian corridor but one that is common along portions of the Merced and Tuolumne rivers), and later flows will likely benefit narrow leaf willow, which releases seeds throughout the summer. This latter species also benefits from elevated summer baseflows in the absence of spring peaks because of its vigorous sprouting ability.

Magnitude
The magnitude of a spring flow pulse determines how high on the banks and floodplain the river stage reaches, and therefore, how high and broad the areas of potential recruitment occur. As discussed above, willow and cottonwood seedbeds need to have moist, fine-grained mineral substrates for germination to be successful. If winter flow releases have adequate capacity to scour vegetation and deposit sediment, spring recruitment flows need not have the same magnitude and can function similarly to a flood irrigation treatment. However, the relative timing of the seedbed preparation and recruitment flows must be considered, since many non-native grass species germinate and proliferate in late winter and early spring, and may invade prepared seedbeds before riparian tree seedlings can establish. In these cases, altering the timing of the winter releases or mechanical removal may be necessary prior to recruitment flows.

Duration

Recruitment flow peaks should be of sufficient duration to fully saturate the seedbed substrate (down to the perennial water table) and allow for floating seeds to raft up onto floodplain surfaces. Most willow and cottonwood seeds germinate within 24–48 hours after wetting (Pelzman 1973; Guilloy-Froget et al. 2002; Stillwater Sciences, unpublished data), so flows likely need to be maintained several days to a week (maximum) at peak levels to induce germination. Since brief flow peaks will limit the quantity of seeds rafted onto floodplains from upstream areas, peak flows should occur during peak seed release, when waterborne seed density is highest, to most efficiently collect rafted seeds. The restoration hydrograph should be designed to maintain peak flow for several days followed by a gradual initial ramp down in order to concentrate and deposit these seeds at appropriate higher elevation surfaces. With shorter peak flow duration and more rapid ramp down rates, seed deposition will occur at lower elevations as long as viable seed is available (Rood et al. 1998).

Rate of stage decline

Because willows and cottonwoods are phreatophytic (i.e., their roots must maintain contact with a perennial water source), decline rates recruitment flows must be gradual enough to prevent desiccation of newly germinated seedlings. A given flow ramping rate will produce different stage recession pattern depending on cross-sectional geometry, but most river corridors, including the San Joaquin River's, exhibit dominant channel geometries along large reaches, so some simplifying assumptions may be possible. Spatially-explicit restoration approaches such as the San Joaquin River Riparian Recruitment Model are most valuable, because stage-discharge relationships can be modeled independently at each cross section.

Research on a variety of cottonwood and willow species over the last fifteen years have produced a consensus of 1 to 1.5 inches/day as the survivable rate of water table decline (McBride et al. 1989; Segelquist et al. 1993; Mahoney and Rood 1992, 1998; Amlin and Rood 2002). However, it is important to point out several issues that may qualify these values. Most of these studies grew seedlings in controlled tank environments at higher latitudes than the San Joaquin Basin, so field vapor pressure deficits (and therefore drought stresses) may be underestimated for the study reach. Furthermore, most of these studies grew seedlings from willow and cottonwood cuttings, which are more resilient than newly germinated seedlings. Lastly, several of these studies held the water table constant for several days to several weeks before the drawdown treatments began, also moderating the stresses that would be expected under field conditions. A recent manipulation experiment of Fremont cottonwood, black willow, and narrow leaf willow seedlings found that water table declines of one inch or more resulted in 80% mortality within 60 days, even when the water table was maintained near the soil surface for several weeks before drawdown (Stillwater Sciences, unpublished data). It therefore seems prudent to assume that the published rates are best-case scenarios; actual management actions may want to use more conservative rates.

A series of modeling runs using the San Joaquin River Riparian Recruitment Model indicated that flow recession rates of 100 to 300 cfs/day generally yielded predicted recruitment areas close to the maximum possible, while recession rates greater than 300 cfs generally showed more substantial decreases in recruitable area (see Section 3.7 in the Restoration Objectives Report). Though an extensive sensitivity analysis of various stage decline rates was not attempted, model results indicate that at most cross sections, rates in the range of 100 to 300 cfs/day were sufficient to prevent desiccation under the assumed 0.1 foot/day maximum root growth rate. Additional sensitivity analysis indicated that the model is relatively insensitive to root growth rate, at least under the conditions assumed for modeling purposes (see Restoration Objectives Report, Section 3.7, for more details on the model [Stillwater Sciences 2003]).

3.5.3.5 Seedling maintenance flows

During the summer following a large recruitment event, drought is a major factor potentially limiting seedling survival. If the water table and its capillary fringe recede below the rooting zone of newly established seedlings, widespread desiccation may kill the entire cohort. Field and experimental studies report that successful seedling establishment is often limited to sites where the water table reaches a depth of no more than 2–8 feet at the end of the growing season; however, the specific elevation range may vary with river size and various local or regional factors (McBride and Strahan 1984; Mahoney and Rood 1992, 1998; Segelquist et al. 1993; Stromberg and Patten 1996; Scott et al. 2000). Though data are not available on later dispersing species, desiccation is a threat and the same rooting depth range appears reasonable. Data from the Merced River on the relative elevation of established riparian trees suggests that most native species recruit successfully somewhere in the range of 2–8 ft above summer baseflow water surface elevation (which is assumed to represent local groundwater levels near the channel where the surveys were conducted) (see Table 3-14 and Section 3.3.4 in the Restoration Objectives Report).

Modeling results from the San Joaquin River Riparian Recruitment Model (see Appendix E-1 and E-2 for modeling results for each strategy; see Section 3.3.8 in the Restoration Objectives Report for further description of the model) indicate that recruitment flows of 5,000 to 8,000 cfs can potentially lead to successful seedling recruitment on geomorphic surfaces within this 2–8-ft relative elevation zone (although the specific elevational range of the recruitable zone will vary somewhat by reach and individual cross section due to local variations in topography and stage-discharge relationships). Based on the literature, Merced River data, and the San Joaquin River Riparian Recruitment Model, we assume that successful recruitment of native riparian species is most likely to occur in the range of 2–8 feet above summer baseflow water surface elevation. Under Strategies 2 and 3, higher magnitude managed releases would be possible, providing the possibility of recruiting native riparian species on somewhat higher surfaces (approximately 8–10 feet above summer baseflow). Under all three strategies, it is likely that many native riparian tree and shrub species can be established on many higher elevation surfaces outside of the flow recruitment zone (generally ranging from 8 to 15 or 20 feet above summer baseflow water surface elevation) if soils conditions are suitable and horticultural techniques are used to plant and maintain individual trees and shrubs until their roots can tap into the local shallow groundwater table (e.g., Griggs and Golet 2002).

On the San Joaquin River, flows during the summer following a flow recruitment event will need to maintain the riparian water table at a level sufficient to prevent desiccation. Summer flow levels need to be planned in coordination with recruitment peak flows using modeled stage-discharge relationships (to ensure that the difference between maximum and minimum stage at most cross sections does not exceed 2–8 feet), as well as in coordination with fish and geomorphic restoration objectives.

Maintenance flows may also be needed in losing reaches to ensure that the roots of older saplings and established trees of phreatophytic riparian species maintain contact with ground water during the summer and fall dry season, particularly if summer and fall ground water levels are greater than 10-20 feet below the ground surface (Griggs and Golet 2002, JSA 2002).

3.5.3.6 Encroachment prevention flows

Vegetation encroachment occurs on regulated rivers when stable flow conditions encourage the establishment of vegetation in the formerly active channel and annual flow peaks are not sufficiently forceful to remove plants from bars and banks. This phenomenon has been documented widely throughout western North America (Johnson 1994, 1998, Ligon et al. 1995), as well as for the San Joaquin River and its tributaries (McBain and Trush 2002; Stillwater Sciences 2002). Flow releases designed to scour existing vegetation need to be incorporated into a long-term management plan for the San Joaquin River, especially following a series of dry years when encroachment can be expected to be most severe. Scouring flows can be implemented as part of a seedbed preparation flow, since the timing and magnitude necessary for both purposes would be the same. A scouring flow should be avoided in the fall immediately following a recruitment event, however, to prevent potential destruction of the new seedling cohort. Hence, encroachment flows are not included in wet year hydrographs, but they are included in the hydrographs for every other water year type.

Encroachment prevention flows may achieve their purpose by causing mortality of seedlings on lower surfaces on channel bars due to scour, inundation or sediment deposition. Managed flow release constraints of Friant Dam would likely limit the effectiveness of encroachment flows in the gravel substrates of Reach 1. In the sand-bedded region (Reaches 2 – 5), we assume that encroachment prevention flows of 5,000 cfs are likely to achieve the desired objectives. Observations along the sand-bedded reach of the lower Tuolumne River in 2002 suggest that 3,500 cfs peak flows were sufficient to kill seedlings within 2 ft vertical elevation of summer baseflow water surface through scour, sediment deposition (up 0.5 ft of sand deposited in some sites), or prolonged inundation) (Stillwater Sciences, unpublished data). Based on the Tuolumne River observations, and an added "margin of safety," we have assumed that 5,000 cfs flows should be capable of preventing or greatly reducing encroachment by woody vegetation. This assumption needs to be confirmed through monitoring and adaptive management.

3.5.4 Approach used to develop strategies for riparian and wetland vegetation and wildlife habitat

In order to develop reach-specific strategies for improving conditions for riparian and wetland vegetation and wildlife habitat, areas were identified that, through various restoration activities, would promote the "target" developed for each vegetation type described below in Section 3.5.5. Our governing assumptions in developing strategies can be generalized as follows:

1. Preserve and enhance the diversity of natural plant types along the river corridor.
2. Expand the existing riparian corridor to improve conditions for fish (e.g., through stream shading), wildlife (e.g., promote a wildlife movement corridor), and water quality (e.g., widen riparian buffer zones to reduce anthropogenic sources of nutrient inputs to the river).
3. Provide larger habitat patches at strategic locations along the river corridor that would benefit wildlife and provide a seed/propagule source for natural recruitment of native riparian species.
4. Provide habitat connectivity to adjacent natural areas, such as sloughs, vegetated bypasses, tributaries, and refuges, in order to improve landscape-level linkages to the mainstem San Joaquin River.

The methods employed for determining the extent of strategy-specific actions (discussed in Chapters 4 through 7) included a combination of San Joaquin River Riparian Recruitment Model predictions and a more traditional opportunities and constraints analysis. The San Joaquin River Riparian Recruitment Model results were used to quantify potential naturally recruitable areas within each reach under each of the three Strategies (see Appendix E-1 and E-2 for modeling results for each strategy; see Chapter 3 of the Restoration Objectives Report [Stillwater Sciences

2003] for a detailed description of the model). In reaches where the existing riparian vegetation within the potential recruitable area is currently sparse, horticultural restoration of small parcels is proposed to "jump start" the natural recruitment process by providing seed/propagule sources throughout the corridor. Additionally, actions proposed for certain reaches include horticultural restoration of wetland and mesic riparian plant species within the potential recruitable area, to improve invertebrate habitat, increase vegetative cover for juvenile fish rearing, and minimize woody riparian species from encroaching into the active channel.

A preliminary opportunities and constraints analysis was used to delineate parcels outside of the potential recruitable area by examining existing conditions of the project area using aerial photographs and GIS maps of inundation, topography, soil salinity/texture, vegetation, and current land use. This analysis allowed us to identify parcels at a coarse scale that are potentially suitable for horticultural restoration (i.e., site conditions could support restored vegetation with a minimum of maintenance), in order to develop appropriate restoration strategies for each reach. Appendix D provides example maps illustrating some of the basic mapped information used in the preliminary, coarse-scale opportunities and constraints analysis. It should be emphasized that more site-specific information (e.g., data on groundwater/surface water interactions, local soil conditions) and communication with invested landowners will ultimately be necessary before a detailed, site-specific restoration plan can be developed to implement the strategies discussed in Chapters 4 through 7.

The majority of selected parcels fell within existing or proposed levees/canals. Parcels outside existing levees were identified primarily to promote landscape-level habitat connectivity or improve diversity of vegetation by restoring higher elevation vegetation types such as oak woodland/savanna. Parcels were included or excluded from a particular strategy depending on the focus and primary considerations for that strategy (the focus of each strategy is discussed in Chapters 4–7).

Each of the strategies discussed in Chapters 4 through 7 include reach-specific activities for improving conditions of identified parcels for riparian vegetation and wildlife. These activities can be generalized into six categories: (1) preservation of existing high quality or rare habitats, (2) appropriate flow regime to promote natural recruitment, (3) floodplain re-grading to promote natural revegetation, (4) horticultural restoration, (5) improving landscape-level linkages along and to the river corridor, and (6) management of non-native invasive species. The sections below describe the benefits and typical implementation methods for each of these six activities. This information will be referenced throughout Chapters 4 through 7. The project proponents will need to work closely with the communities within and adjacent to the planning area to develop effective, locally supported restoration projects that balance the needs of the community and landowners with ecosystem restoration goals.

3.5.4.1 Preservation of existing habitat

Preservation of existing ecologically intact lands can be a more cost-effective means of meeting restoration goals for vegetation and wildlife than restoring degraded land. Whereas horticultural restoration requires time and significant maintenance and monitoring effort to restore the natural processes and ecosystem functions of the area, preservation assures that existing high-quality habitat (e.g., a mature stand of oak woodland) is, at a minimum, protected from further degradation and/or destruction. It also supports a core area of intact habitat upon which to build further restoration efforts, providing seed/propagule sources for horticultural restoration, and a source population of wildlife that can colonize the adjoining restoration areas as they develop over time.

Conservation easements, fee-title purchases, partnerships between government agencies and nonprofits, and incentive programs provide a mechanism for preserving ecologically or agriculturally significant resources on private property while also supporting economic productivity. Through easements and incentives, private property owners maintain title to the properties and their riparian water rights, while forfeiting some potential uses of that property in return for compensation. This ensures that ecologically valuable functions remain intact.

Conservation easements can be funded through a variety of public and private sources and can be administered by both government agencies, such as the Wildlife Conservation Board, and non-governmental agencies, such as land trusts and land conservancies. In addition to the compensation provided to the landowner for purchase of the easement, conservation easements can reduce property tax burden by reducing the assessed property value. Additionally, easements can be flexible enough to accommodate the needs of all parties. For example, the duration of a conservation easement can be determined on a case-by-case basis, depending on the interests of the funding source and the landowner. Typical sources will provide funds for easements lasting from 10 years to perpetual easements.

Preservation efforts should attempt, whenever possible, to build on existing easements/public lands in order to maximize the benefits of habitat connectivity. The Trust for Public Land (TPL), in a joint venture with the nonprofit San Joaquin River Parkway and Conservation Trust (Parkway Trust), has been working since 1992 to help create the 22-mile San Joaquin River Parkway north of Fresno. TPL and the Parkway Trust work in cooperation with the private sector and public agencies, including the San Joaquin River Conservancy, Wildlife Conservation Board, Bureau of Reclamation, Department of Fish and Game, and Cal Trout, to preserve river lands for natural reserves, parks, and open space. The parkway eventually will comprise some 6,000 acres or more of protected land, trails, and river access points along the San Joaquin River below Friant Dam in the Fresno–Madera region (San Joaquin River Conservancy 2000, as cited in TPL 2001). To date, TPL and the Parkway Trust have acquired and conveyed Rank Island to CDFG, as well as the Wildwood Property and the Jensen River Ranch to the San Joaquin River Conservancy. Rank Island, with its approximately 270 acres of wetlands and riparian forest, is an urban nature preserve that provides habitat for deer and bald eagles, and also serves as a large heron and egret rookery. The 22-acre Wildwood Property, directly adjacent to Highway 41, provides critical public access to the river in Madera County. Finally, the 156-acre Jensen Ranch ties Woodward Park to the San Joaquin River in the heart of the San Joaquin River Parkway. These efforts have secured key riparian properties for habitat restoration (TPL 2001).

The 26,609-acre San Luis National Wildlife Refuge complex is a mixture of managed seasonal and permanent wetlands, riparian habitat associated with 3 major watercourses, and native grasslands, alkali sinks, and vernal pools. The refuge is primarily managed to provide habitats for migratory and wintering birds. The largest concentration of mallards, pintails, and green-winged teal in the San Joaquin Valley are found here. One of only 22 herds of the indigenous tule elk lives here, as are a variety of endangered, threatened and sensitive species. This refuge is a major sanctuary for mallards, green-winged teal, ring-necked ducks, and northern pintails, an also supports a large diversity of raptors. The Refuge is a remnant of San Joaquin riparian bottomland and floodbasin habitat. Existing marsh basins and riparian channels retain a natural topography, but must be artificially flooded and maintained via labor-intensive manipulations to create desired habitat conditions. The diverse mixture of habitats—riparian, wetland, native grassland, vernal pools, alkali scrub, etc.— attract a wide diversity of species, including a number with threatened and endangered status (USFWS 2003).

Farther downstream, the James J. Stevinson Corporation is in the process of placing conservation easements on nearly 9,000 acres of its landholdings along the eastern side of the downstream portion of Reach 5, at the confluence of the Merced and San Joaquin rivers in Merced and Stanislaus counties. The easement lands are adjacent to and will serve to expand the San Luis National Wildlife Refuge and the North Grasslands State Wildlife Area. By placing the land under easement, the Stevinson Corporation will retain riparian water rights, create opportunities for habitat enhancement, and be eligible for tax benefits (Riviere 2000).

3.5.4.2 Promoting natural recruitment

Central Valley riparian forest initiation begins with the colonization of bare, moist alluvial surfaces by seedlings (typically Fremont cottonwoods, willows and other fast-growing species) following large flow events that meet the life history requirements of these species (see Section 3.5.2). These pioneer species are physiologically adapted to the highly variable hydrologic and geomorphic regimes of alluvial river floodplain systems. Providing flow conditions necessary for the natural recruitment of riparian vegetation will provide the physical forces, such as flooding, scour, and sediment deposition, that strongly influence riparian plant species composition, distribution, and physical structure and serve as major drivers of riparian community succession (see Section 8.7 of the Background Report [McBain and Trush 2002] and Section 3.3.7 of the Restoration Objectives Report [Stillwater Sciences 2003] for a more thorough discussion of riparian plant recruitment and succession). This, in turn, enhances the quality of the established habitat, maintains a functional riparian corridor width, and dramatically reduces the need for horticultural restoration and associated maintenance, which can be a costly and labor-intensive undertaking.

To enhance the ability of vegetation to recruit naturally, release of recruitment flows is included as a major component of each of the three strategies discussed in Chapters 4 through 7. The rationale for and more detailed discussion of these flow releases are described in Section 3.5.3. Typically, these flows should be scheduled every five to ten years to provide a regular cycle of disturbance and recruitment. Variation in the timing, magnitude, and duration of peak flows will help to promote diversity, complexity, and extent of the recruited vegetation type. It is important to note that many non-hydrologic factors, including shade tolerance and other competetive abilities, proximity to seed source, intensity of herbivory, and presence of disease, contribute to the success of plant establishment and species distributions within riparian zones.

Flow release schedules should be prioritized based on the desired outcome for the distribution and diversity of species on various floodplain surfaces. For example, flow releases during late April to mid-May would support recruitment of Fremont cottonwood, while later flow releases would benefit black willow and narrow leaf willow, based on our understanding of their peak seed release both in the San Joaquin River mainstem and its major tributaries. Flows with higher magnitude and duration would increase the area in which potential recruitment occurs. The San Joaquin Riparian Recruitment Model was used as a planning tool to help design restoration hydrographs and to predict the potential amount of recruitable area that might be provided under each of the three strategies (see Sections 5.3, 6.3, and 7.3 for a summary of the modeling results, and Appendix E-1 and E-2 for more detailed results). The model is described in more detail in Section 3.3.8 of the Restoration Objectives Report.

3.5.4.3 Riparian and wetland considerations during floodplain reconstruction

As much as possible, the goal is to re-create self-sustaining riparian processes within the managed flow regimes, in order to minimize the need for more costly and labor-intensive methods such as horticultural restoration. Potential actions to restore riparian processes include re-scaling the channel cross-section under managed flow regimes to create physical conditions conducive to natural recolonization by native vegetation (natural recruitment is discussed above in Section 3.5.3.2). Floodplain reconstruction can be designed to provide topographic variation with zones that experience different inundation durations and flood recurrence intervals. This would create topographic and hydrologic complexity necessary for natural establishment of a diversity of plant communities. For example, creating shallow depression areas that mimic to some degree the abandoned channel features found in alluvial river systems would provide recruitment areas for cottonwood and other riparian species. This technique has been successfully implemented on the Truckee River (S. Rood, pers. comm., 2002) and on Clear Creek (McBain and Trush et al. 2000). Higher elevation surfaces that would support valley oak woodland could be created if appropriate fill material were available (e.g., non-saline soils with low clay content).

Creation of seasonal wetlands could be implemented opportunistically, depending on where heavy equipment is being used for channel reconstruction. Surfaces could be further graded where groundwater levels would support complexes of perennial open water and wetlands. These re-constructed open water and wetland areas would mimic oxbow lake conditions that naturally occurred along the San Joaquin River (see Chapter 8 of McBain and Trush 2002).

Management of non-native invasive plant species must be considered when planning floodplain re-grading activities, including removal of these species from regraded areas, and monitoring for new invasion into areas disturbed by re-grading activity. See Section 3.5.4.6 for further discussion of management of non-native invasive plant species.

3.5.4.4 Horticultural restoration

Horticultural restoration can enhance the benefits of the naturally recruited riparian corridor by increasing the width of the corridor, providing an important initial seed and propagule source to stimulate natural regeneration, and hastening the establishment of riparian habitat patches along the river corridor, which increases the diversity and complexity of available habitat for wildlife. This restoration activity is primarily recommended in areas where there will be significant floodplain reconstruction and/or levee setbacks under all strategies (this includes Reaches 1, 2 and 4), and in strategic areas throughout the project area where horticultural restoration is both likely to be sustained (given site conditions identified during the opportunities/constraints analysis) and likely to provide plant-community-specific benefits. These benefits are summarized below.

Areas graded to levels appropriate for floodplain rearing will likely experience some natural recruitment based on the proposed flow regime, but should be horticulturally restored with wetland and mesic riparian plant species to promote suitable habitat conditions for terrestrial and aquatic invertebrates (an important food source for fish when vegetated floodplains are inundated), minimize the risk of woody riparian species encroaching into the active channel, and reduce the threat of invasion by non-native plant species (further recommendations for eradicating and controlling non-native invasive plant species are included in Section 3.5.4.6). Horticultural restoration of communities whose historical extent has been greatly diminished in the project area through human disturbance (e.g., habitat loss and fragmentation, and land use change), such as freshwater wetlands and valley oak woodlands, increases the diversity of available habitat important for many wildlife species. The habitat value of these community types is discussed in more detail in Section 3.5.5. The benefits of horticultural restoration to hasten development of landscape-level linkages between the San Joaquin River mainstem and adjacent natural areas (e.g., sloughs, vegetated bypasses, and refuges) is discussed in more detail under Section 3.5.4.1.

The main plant communities that are the focus of horticultural restoration efforts recommended for the San Joaquin project area under the various strategies include seasonal perennial wetlands, riparian forest and scrub (including willow, cottonwood, and mixed riparian vegetation types), valley oak woodland/savanna, and to a limited extent, elderberry savanna. Appropriate plant species for horticultural restoration will vary with desired target habitat conditions and local site factors. Freshwater marsh and seasonal wetland restoration may include tules and bulrushes, sedges, cattails, pondweed, and rushes as dominant species. Riparian forest and scrub restoration may include a variety of mature tree and shrub species, such as Fremont cottonwood, Gooding's black willow, Oregon ash, button bush, alder, red willow, arroyo willow, box elder, valley oak, and western sycamore. Plants of understory species such as mugwort, wild grape, native blackberry, wild rose, and Mexican elderberry may also be desired to promote floristic and vegetation structural diversity and to provide key habitat elements for certain wildlife species (e.g., mugwort appears to be important for nesting success of several riparian bird species in Sacramento River riparian forests [Golet et al. 2003, Small 2000, Griggs and Golet 2002]) (see Section 3.5.5 for more detail on composition and distribution of these community types).

Horticultural restoration can be implemented in a variety of ways, including direct seeding (direct planting of seeds such as acorns, or dispersal of seed over the surface via hydromulching, etc.), use of donor seed banks, or direct planting of propagated nursery plants and vegetative fragments (cuttings). The planting of propagated nursery plants or vegetative fragments (cuttings) is a common practice at restoration sites (Middleton 1999). The revegetation of some lands following their restoration can occur spontaneously, but others may require massive intervention to eradicate non-native invasive plants and irrigation to promote establishment of restored plants. Horticultural restoration can be combined with land preservation and conservation easements, or may be conducted on already protected public and private lands.

Revegetation should be compatible with restored hydrologic and fluvial processes to promote long-term success. Riparian plant species should be planted to correspond with specific geomorphic surfaces that are inundated by specific flood recurrence intervals (McBain and Trush 2000). Natural conditions of species diversity and structural diversity are generally the desired restoration target, which may require planting a mix of woody overstory species and shrubby and herbaceous understory species, to achieve the desired target. Horticultural restoration should be done with locally collected seeds and seedlings to preserve the genetic integrity of the local population (CNPS 1989, as cited in CALPIF 2002).

Potential horticulture restoration sites may be prioritized according to the likely success of regeneration and viability of transplanted individuals (i.e., where site soil, elevation, and inundation conditions are most likely to support the restored vegetation with minimal maintenance), and by their potential to connect to patches of existing riparian habitat (CalPIF 2002, RHJV 2000).

The following are additional considerations for developing horticultural restoration projects.

- Plan restoration efforts by selecting patch size, configuration, and connectivity of riparian habitats to adequately support the desired populations of riparian-dependent species (RHJV 2000).
- Balance efforts directed at planting and maintaining woody overstory species with those focusing on restoring a native herbaceous understory, in order to maximize benefits to multiple species (Griggs and Golet 2002). For example, songbird distribution in restored riparian areas was largely dependent on the understory component (Small 2000, as cited in Griggs and Golet 2002). Managing riparian and adjacent habitats to maintain a diverse

and vigorous understory and herbaceous layer can be particularly important to birds during the breeding season (RHJV 2000).
- Maintain a diverse age structure in riparian vegetation. This diversity can be promoted through protecting seedling and sapling trees; retaining decaying or dead trees, limbs, snags, and mistletoe (to provide habitat for cavity-nesting birds and other wildlife, and retaining large trees whenever possible (for habitat and food production) (CalPIF 2002). Retaining at least some existing trees on restoration sites and planting around them can provide habitat for birds that require mature trees (RHJV 2000).
- Conduct vegetation restoration with an eye towards benefiting healthy bird populations, by restoring understory components, restoring upland habitats in conjunction with adjacent riparian habitats, and restoring a mosaic configuration of a diversity of vegetative types (CalPIF 2002). Other methods of vegetative restoration to enhance avian populations include: avoiding the construction or use of facilities and pastures that attract and provide foraging habitat for European starlings and brown-headed cowbirds (a parasitic bird species); limiting restoration activities and disturbance events such as grazing, prescribed fires, firewood harvesting, disking, and herbicide application to the non-breeding season; and managing restoration activities at the landscape level (CalPIF 2002, RHJV 2000).
- Revegetate in patches rather than in rigid grid spacing (McBain and Trush 2000), to mimic the natural patchiness of historical riparian forests and create interior habitat for wildlife.

Recommendations for restoration activities directed at improving the condition of riparian vegetation and wildlife habitat by strategy were developed for each reach by: (1) identifying the potentially recruitable area under the strategy-specific flow regime, (2) identifying parcels that are located within the existing levees but likely to be outside the naturally recruited area under the recommended flow regime, (3) conducting an analysis of opportunities and constraints (based on aerial photographs and GIS maps of inundation, topography, soil salinity/texture, existing vegetation, and current land use) to determine the suitability of these parcels for other restoration activities (e.g., preservation, horticultural restoration); and (4) designating all, or a portion of, the identified parcels according to the objectives of and conditions of each strategy.

Parcels were included or excluded from a strategy depending on the focus and considerations for each strategy (discussed in Chapters 4–7). The riparian vegetation and wildlife focus of Strategy 1 was to compensate for the restrictions of existing flow capacity (and thus the lower area that could potentially be naturally recruited) by emphasizing horticultural restoration within the floodway. In addition, because Strategy 1 emphasizes anadromous salmonid rearing in Reach 1, the recommendations for riparian/wildlife strategies are focused on maximizing the number of appropriate sites for floodplain rearing (i.e., a larger number of appropriate sites were identified for floodplain rearing habitat than for other vegetation types). Under Strategy 1, parcels were included for horticultural restoration if they would provide larger habitat patches at strategic locations, such as at meander bends, connected by enhanced riparian buffers.

Because of the larger flow capacity and resultant increase in potential natural recruitment, the focus of Strategy 2 was to improve the riparian corridor for anadromous salmonids by enhancing SRA cover and increasing rearing habitat throughout the project area (i.e., not just focused in Reach 1). Under Strategy 2, parcels were included for horticultural restoration if they enhanced the riparian buffer width outside of the area predicted for natural recruitment, but typically still within the existing or proposed levee configuration.

Again, the larger flow capacity under Strategy 3 and the emphasis on riparian and wildlife needs focused the strategy toward improving the diversity of vegetation types throughout the project area and promoting increased wildlife benefits from larger habitat patches, wider riparian buffers, and increased habitat connectivity between the mainstem and adjacent natural areas (e.g., sloughs, tributaries, refuges). Although horticultural restoration of lands to improve habitat connectivity acreage was included under all strategies, it was expanded under Strategy 3.

3.5.4.5 Landscape-level linkages and riparian habitat connectivity

A primary component of the restoration target for the San Joaquin River corridor is the restoration of relatively wide riparian buffers. Riparian buffers are corridors of riparian vegetation that separate the river channel from adjacent managed lands. Typically, riparian buffers are discussed in the context of minimizing the effects of human land use activities on river-riparian ecosystems. Depending on their width, floristic composition, vegetative structure, and location within the larger landscape, riparian buffers can perform many important functions in the river system (Gregory et al. 1991, Mitsch and Gosselink 1993, Malanson 1993, Naiman and Decamps 1997, NRCS 1991), including:

- trapping and uptake of sediment from run-off and flood flows;
- stabilizing streambanks and reducing erosion;
- trapping and removing contaminants;
- providing shade and cover in near-bank aquatic habitats, to benefit a variety of native aquatic species;
- contributing large wood to the channel (when trees or branches fall into the river), which provide cover and habitat complexity for fish, amphibians, and turtles;
- contributing to riverine and terrestrial foodwebs;
- providing dispersal corridors for aquatic invertebrates and a variety of terrestrial plants and animals;
- providing nesting, rearing, foraging, and breeding habitat for native terrestrial species, particularly Neotropical migrant birds and bats;
- providing wildlife movement corridors, and
- creating scenic landscapes (aesthetic value).

In some sections of the study area, riparian vegetation may be naturally restricted to very narrow buffer zones. Management and restoration strategies need to consider the historical condition and the potential of a site to support appropriate riparian vegetation in the future. In some cases, existing infrastructure, land uses, or habitat characteristics (soils, topography, etc.) may limit the riparian buffer width. In these cases, even limited native riparian and floodplain vegetation should be encouraged to provide some cover for species living in or moving through the corridor. Wherever possible, however, buffer widths should be increased to at least 300 ft (100 m). Riparian buffers of these widths, or greater when possible, provide landscape-level habitat corridors, conserve riparian ecosystems and food webs, improve flood storage, and provide habitat for riparian forest-obligate wildlife species, such as yellow-billed cuckoo (Gaines 1974, Laymon et al. 1997).

One of the main goals of creating riparian buffers is to increase and maintain landscape-scale connectivity among patches of woody riparian vegetation along the San Joaquin River corridor. This includes enhancing both longitudinal connectivity along the river channel as well as lateral connectivity between the riparian corridor and upland habitat patches. This habitat connectivity can provide linkages among ecologically important areas for the various life-history stages of wildlife species found within the study area, and can create opportunities for genetic exchange between populations of organisms. Below we describe existing patches and complexes of protected habitat along the San Joaquin River corridor that could be used as starting points for enhancing existing areas and building larger networks of wildlife habitat. The habitat patches, presented from upstream to downstream (beginning at Friant Dam) within the project area, represent opportunities for habitat enhancement, restoration, and preservation, using a variety of implementation methods described in previous sections (e.g., easements, horticultural restoration).

The confluence of Little Dry Creek with the San Joaquin River (RM 260.5) and Rank Island (RM 260) is currently under public ownership and may provide a core area around which to focus initial conservation and restoration efforts in Reach 1. Great blue heron and egret rookeries occur on Rank Island (J. Cain, pers. comm., 2002), and numerous waterfowl and riparian bird species are found in the existing network of channels and standing water and marshy habitat at the mouth of Little Dry Creek (JSA 2001). Sycamore alluvial woodland habitat, a declining and relatively rare native vegetation type in California, is found about 5 miles upstream along Little Dry Creek, and provides particularly valuable habitat for larger hawks, such as Swainson’s hawks. Expanding the quality and/or quantity of wildlife habitat in this area would provide a protected node of diverse habitat types in Reach 1.

Kerman Ecological Reserve occurs just south of the San Joaquin River (the northern border of the Preserve is approximately 1.25 miles south of the river corridor) in Reach 2 (RM 223) (see Figure 2-1). It is managed by CDFG and is home to many sensitive species, including Lost Hills crownscale, lesser saltscale, and, at least historically, the Fresno kangaroo rat. The Alkali Sink Reserve and Mendota State Wildlife Refuge are located approximately 4 miles to the south of the San Joaquin River at RM 210 (Reach 2B). The Alkali Sink Ecological Reserve is home to many sensitive species, including blunt-nosed leopard lizard, Fresno kangaroo rat, palmate-bracted bird's beak, and Hoover’s woolly star. The Mendota State Wildlife Refuge includes the Fresno Slough area, and is home to numerous waterfowl and wading birds. Acquiring lands, or placing some of those lands under conservation easement, between the San Joaquin River and these three reserves would connect the main river corridor with these important core areas of wildlife habitat, which are otherwise tending to function primarily as “islands” within the larger landscape.

The area around the Bifurcation Structure (RM 216.1) and the Chowchilla Bypass (27 miles paralleling the San Joaquin River from RM 216.1 to 168), located in Reach 2, also represent opportunities for providing habitat linkages for wildlife species. The area around the Bifurcation Structure is the confluence of two major waterways, and should be considered as a node for establishing wildlife movement corridors. The Bifurcation area historically supported Fresno kangaroo rats and is home to other small mammal species. Increasing vegetation in this area would enhance habitat for birds and other wildlife, and would provide a corridor for animals traveling between the San Joaquin River, the Chowchilla Bypass, Mendota State Wildlife Refuge, and the Alkali Sink Ecological Reserve.

The Chowchilla Bypass remains dry for much of the year. However, when it is wet, only a thin margin of vegetation is present along the sides of the canal. A larger band of vegetation could provide additional cover for animals. The Chowchilla Bypass corridor is home to Fresno kangaroo rats and is used as a movement corridor for San Joaquin kit fox (Kucera et al. 2001). The Recovery Plan for Upland Species of the San Joaquin Valley identifies the Chowchilla Canal as one of its top priority restoration areas in the basin, particularly for San Joaquin kit fox and blunt-nosed leopard lizard. In addition to supporting mammals such as kit fox and kangaroo rat, a wider band of vegetation would provide habitat for birds, and provide a corridor for species traveling from the smaller rivers and creeks (Chowchilla River, Ash Slough) that drain into the Bypass before intersecting with the San Joaquin. Operation of the Bypass for flood control purposes, however, may severely constrain opportunities for establishing large amounts of woody riparian vegetation within the Bypass floodway.

Another opportunity to restore and enhance habitat for wildlife species is around Mendota Pool (border of Reaches 2B and 3). Mendota Pool currently provides lacustrine, marsh, and riparian habitat for a number of wildlife species. Focal species that historically occurred in this area include western pond turtle, yellow-billed cuckoo, and San Joaquin pocket mouse (CNDDB 2002). By actively managing Mendota Pool, enhancing the riparian buffer around its perimeter, and possible developing wetland complexes adjacent to the pool, we could further enhance the suitability of habitat for wildlife and native resident fish species.

The Merced River enters the San Joaquin River from the east at RM 118. Remnant riparian forests occur in this area and provide some of the largest and most contiguous patches of riparian habitat in the vicinity. The riparian corridor in this zone ranges from one-half to one mile wide and is bordered by protected state and private lands, row crops, dairies, and grazing lands. The area supports cottonwood forest, mixed riparian forest, mixed willow, valley oak forest, and herbaceous cover. This area is largely protected and includes George Hatfield State Park (along the Merced River), the China Island Unit of the North Grasslands Wildlife Area (managed by CDFG), and 335 acres protected by Stevinson Corporation conservation easements. Preservation of additional areas would provide connectivity with existing refuges and managed properties, enhancing the habitat value of this region. Much of Kesterson National Wildlife Refuge is a mosaic of wetland marsh complexes, and these habitats could be extended to include areas near the confluence of the Merced River. Given the large extent of intact riparian habitat, this area is likely to support a wide variety of wildlife species that would benefit from habitat preservation and active restoration projects. Many threatened, endangered, or sensitive species have been recorded in the vicinity of the Merced/San Joaquin confluence, including Delta button-celery, California tiger salamander, western spadefoot toad, giant garter snake, great blue heron, great egret, Swainson’s hawk, tricolored blackbird, and San Joaquin kit fox (CDFG 2001).

3.5.4.6 Management of non-native invasive plant species

The San Joaquin riparian corridor, like most California landscapes, is host to many non-native invasive plant species. In 2000, the California Department of Water Resources (CDWR) mapped vegetation along the San Joaquin River from Friant Dam to the confluence with the Merced River (CDWR 2002). Their mapping identified 127 non-native plant species, or 50 percent of all plant species identified. The primary non-native invasive species identified in the CDWR mapping include: tree-of-heaven, giant reed, pampas grass, eucalyptus, edible fig, white mulberry, Lombardy poplar, castor bean, Himalayan blackberry, scarlet wisteria, and tamarisk (CDWR 2002). The CDWR effort also recorded parrot’s feather, a highly invasive aquatic plant. Non-native invasive plant species cover 99 acres along the river corridor in nearly monospecific stands and occur as a component of most, if not all, native vegetation types (Chapter 8 in McBain and Trush 2002). These plant species are particularly abundant in Reach 1, where high levels of disturbance may have aided their spread, as suggested by their distribution in and around aggregate mining pits (McBain and Trush 2002).

Through funding by the San Joaquin River Riparian Habitat Restoration Program and based on the 2000 CDWR vegetation maps, the San Joaquin River Parkway and Conservation Trust prioritized non-native species for control as part of their current non-native invasive plant species management efforts for Reaches 1 through 5. Based on each plant’s listing with California Exotic Pest Plant Council (CalEPPC), proximity to the active channel, potential for floodway impedance, relative ease of control, and relative cost of removal, the Parkway Trust identified the following species for high-priority control: scarlet wisteria, tree-of-heaven, giant reed, pampas grass, tamarisk, edible fig, and Himalayan blackberry. These species, as well as non-native annual grasses, parrot's feather, and water hyacinth, are discussed in detail in Appendix G-1, because they are documented as aggressive invaders that displace native plants and disrupt natural habitats (CalEPPC 1999). The location and extent of thee species within the planning area is summarized in Table 3.5-2.

Table 3.5-2. Location and extent of non-native invasive plant species within the planning area.

Species	Reach in which species were observed*
scarlet wisteria	Primarily Reach 1A, but found down to RM 242 in Reach 1B.
tree-of-heaven	3 acres in Reach 1A and 0.5 acres each in Reach 1B and Reach 2.
giant reed	Most abundant (~41 acres) in Reaches 1 and 2; ¼ acre or less in Reaches 3 and 5.
pampas grass	Not yet widespread, but documented in Reach 1.
tamarisk	Not yet widespread, although widespread in many tributaries to the San Joaquin.
edible fig	Documented in Reach 1.
Himalayan blackberry	Documented in Reach 1A, and likely to be established throughout the planning area, particularly in riparian scrub habitats that line the banks of the channelized river.
annual Mediterranean grasses	Not mapped by CDWR, but pervasive throughout the planning area.
parrot's feather	Documented in Reach 3; also observed near Lanes Bridge (RM 255.2) by Stillwater Sciences staff.
water hyacinth	Not mapped by CDWR, but observed by Stillwater Sciences staff in the lower reaches of the river. May have been more widespread prior to 1997 floods (S. Weaver, pers. comm., 2003).

*based on mapping conducted by CDWR (2002). See Appendix G-1 for more information.

Exotic plant species can alter the structure and dynamics of natural ecosystems. Non-native plant species can impact native wildlife by displacing native vegetation that is used for nesting or as a food source. Once established, non-native plant species can alter nutrient cycling, energy fixing, food web interactions, and fire and other disturbance regimes, to the extent that the native landscape is changed. Habitat fragmentation contributes to the spread of non-native species by increasing edge habitat, which provides greater opportunities for invasion by exotic species (Cox 1999). Ecosystem alterations resulting from non-native plant species invasions can be exacerbated by activities such as grazing and vegetation clearing that create favorable conditions for further non-native plant establishment (Cox 1999, Randall and Hoshovsky 2000). Alteration of historical flooding regimes by flow regulation further promotes invasions by non-native species by eliminating processes necessary for recruiting and maintaining native plant species (Cox 1999).

Typical eradication and control methods for non-native invasive plant species include mechanical removal (including by hand, or with tools, heavy machinery, etc.), chemical removal (herbicides), and in a few cases biological control. Other issues to consider in managing non-native invasive plants include:

- *Eradication of isolated occurrences of invasive non-native plants*. Eradicating non-native plant species is difficult and usually unattainable. Complete eradication is, however, a potentially feasible goal where non-native species occur as small, isolated patches. In the San Joaquin River corridor, pampas grass and tamarisk are two such species that, because of their isolated distribution and limited extent, could potentially be eradicated. Eradicating these types of species would likely require an integrated pest management approach (e.g., a combination of physical removal and limited herbicide application) to remove the existing stands, monitoring of sites to identify any resprouting of treated stands, maintenance to treat any resprouting, and river-wide monitoring to identify any other occurrences or recent introductions of the species (see below).
- *Minimizing the introduction of non-native plant species when implementing restoration actions*. Because many non-native species can out-compete native species in colonizing disturbed areas, non-native species can interfere with the success of restoration actions, particularly when restoration actions (such as dispersal flows, floodplain grading, or channel modifications) create opportunities for the dispersal and establishment of the invasive species. The biology of potential invasive species and the techniques available to control their spread should therefore be considered when developing restoration strategies and actions.
- *Promoting processes and conditions that encourage native plant species recruitment over non-native species*. Habitat fragmentation, alteration of historical disturbance regimes (such as flooding and fire), and increased nutrient delivery by adjacent land uses are just a few of the ways humans have altered riparian areas such that non-native plant species have a competitive advantage over natives. Conserving and expanding existing native habitat patches will not only reduce edge habitat (which is more easily colonized by non-native species), but will also provide necessary sources for native seed dispersal. Restoring natural fluvial processes to the extent possible will provide the conditions necessary to recruit native riparian species (such as bare, moist seedbeds and thinning of the understory), while scouring and inhibiting non-native species. Actions to improve water quality, such as the ongiong TMDL process, will also help improve conditions for natives that are sensitive to elevated levels of nutrients and other pollutants.
- *Re-establishing native plants in areas where non-native species are removed or treated*. Removal of invasive species is not guaranteed to remove the invasive impacts. Locally extirpated native species may require re-introduction to the site.
- *Establishing a river-wide monitoring program*. Frequent monitoring of the river corridor will be needed to identify recent introductions and infestations. Once a species has become widespread and abundant, mechanical and/or chemical removal can be prohibitively expensive, and even after an invasive species is removed, it frequently re-invades, requiring ongoing treatment. Regular monitoring of the river corridor for new introductions or resprouting of treated stands will help identify small, isolated patches of invasive non-native plants that can be more feasibly eradicated before they become widespread.

3.5.5 Restoration targets for specific vegetation and habitat types

Section 3.5.4.5 identified geographical areas that may provide site-specific opportunities for increasing riparian buffers and habitat connectivity within the project area. Riparian buffers and core areas of wildlife habitat can be composed of a diversity of specific vegetation and habitat types. This section describes restoration targets for these vegetation types or natural communities, and discusses associated wildlife benefits that would result from restoration of the following:

- riparian forest and scrub,
- valley oak woodland,
- freshwater marsh and wetlands,
- alkali scrub and wetlands,
- elderberry savanna,
- Central California sycamore alluvial woodland, and
- vernal pools.

For each natural community type, we discuss (1) the common or dominant vegetation and distribution of the community, (2) the habitat value provided by the native vegetation in the community, and (3) the restoration target for the community. These targets should be used as preliminary guidelines to be considered in developing the SJR restoration plan. The targets are intended to feed into a stakeholder-based process to develop a shared restoration vision for the 150-mile corridor.

A broad diversity of wildlife species along the San Joaquin River corridor, representing numerous ecological niches and habitat requirements, depend on these natural plant communities. In order to develop riparian objectives (see Restoration Objectives Report) and to evaluate the benefits of potential restoration actions, we selected a group of species (analysis species) that currently occur or historically occurred within the San Joaquin corridor. These species were selected based on their status under state and federal Endangered Species Acts, the prevalence of preferred habitat within the project area, and the ecological niche they represent. These analysis species cover a range of habitat and vegetation requirements and represent various taxonomic groups and guilds within the river-riparian ecosystem. Technical information on each analysis species (presented in the Restoration Objectives Report) was used to help develop vegetation objectives and to identify the potential restoration targets and opportunities described below for each natural community.

3.5.5.1 Riparian forest and scrub

Description and distribution

Riparian forest is a multi-layered native vegetation type that was once widespread throughout the Central Valley. Riparian forest and scrub is generally found on the low active floodplain of the San Joaquin River and adjacent low or intermediate terraces.

Under pre-dam conditions, riparian forest included cottonwood riparian forest, mixed riparian forest, and valley oak riparian forest vegetation types, with mixed riparian forest intergrading with valley oak riparian forest at sites higher on the floodplain, and with cottonwood riparian forest and willow scrub on sites closer to the active channel. Flood flow attenuation following the construction of Friant Dam has, however, altered the toposequence of riparian forest types and mixed riparian forest now often occurs at elevations where cottonwood riparian forest historically occurred (McBain and Trush 2002). Species dominance in riparian forest depends on site conditions, such as elevation, availability of groundwater, and frequency of flooding. Dominant tree species in the riparian forest vegetation type generally include Fremont cottonwood, Gooding’s black willow, box elder, Oregon ash, and western Sycamore. White alder occurs immediately along the water’s edge in the upper portion of the study area. Common shrub species are red willow, arroyo willow, buttonbush, California wild grape, and California wild rose. The ground layer varies from sparse to lush with a mixture of native and non-native grasses and forbs.

Riparian scrub is a dense assemblage of willow and other shrubs often found within the active floodplain of the river (McBain and Trush 2002). Sites with riparian scrub are subject to more frequent scouring flows than are sites supporting riparian forests. Riparian scrub often occupies stable sand and gravel point bars immediately above the active channel. Often, riparian scrub is successional to riparian forest and persists only in the presence of frequent disturbance. Dominant shrubs include narrowleaf willow, arroyo willow, and red willow. Occasional emergent Fremont cottonwood may also be present in willow riparian scrub. Several invasive exotics (giant reed, Himalayan blackberry, and scarlet wisteria) are more abundant in riparian scrub than in other vegetation types (McBain and Trush 2002).

Riparian forest and scrub are found in all reaches of the river, with the majority occurring in Reaches 1 and 5 (CDWR 2002). Historically, Reach 1 and potentially portions of Reach 2 consisted of bands of riparian forest and scrub along the floodway of the river corridor, typically in discontinuous patches along high flow scour channels and side channels closer to the groundwater table (McBain and Trush 2002). Reaches 2 through 5 consisted of bands (typically less than 2,000 feet wide) of woody riparian vegetation (in places perhaps exclusively black willow) along the margins of the river channels and sloughs, with extensive tule marshes in the flood basins beyond the relatively narrow riparian bands. In these reaches, riparian forest and scrub probably also grew on higher ground along the margins of sloughs, oxbow lakes, and minor natural levees along abandoned channels (McBain and Trush 2002).

In comparison with historical conditions, existing bands of riparian forest and scrub are very narrow, in some instances only one-tree wide, and patches are small and isolated by adjacent land uses. A lack of scouring flows and bed mobility resulting from flow regulation has allowed riparian vegetation to become established on formerly active gravel bars in several reaches. This encroachment of pioneer riparian species (primarily narrowleaf willow) into the active channel, particularly in Reach 1, has reduced the active channel width, simplified the channel cross section, and reduced aquatic habitat. Riparian forest and scrub distribution, composition, and health have been impacted by clearing of floodplain areas for agriculture and reduced natural recruitment as a result of changes in flow and sediment supply from flow regulation. In addition, numerous non-native, invasive plant species have become established within the riparian corridor and can compromise the quality of riparian forest and scrub habitats.

Habitat value

Lush riparian forests and scrub that border the river channel and perform the functions listed are often referred to as shaded riverine aquatic (SRA) habitat. Increasing and enhancing SRA habitat to improve shade, cover, and food for chinook salmon and steelhead is listed as a programmatic restoration action for both the west and east San Joaquin Basin Ecological Management Zones by the CALFED Bay-Delta Program (CALFED 2000).

In California, over 225 species of birds, mammals, reptiles, and amphibians depend on riparian habitats, and riparian ecosystems harbor the most diverse bird communities in the arid and semi-arid regions of the western United States (Knopf et al. 1988, Dobkin 1994, Saab et al. 1995). In addition to high species richness, riparian areas can harbor individuals during the bird breeding season (May–June) at densities up to ten times greater than the surrounding terrestrial habitats (RHJV 2000). The discussion below summarizes the value of riparian forest and scrub for western pond turtle, yellow-billed cuckoo, riparian brush rabbit, and bats. The habitat requirements of these species help define minimum patch size and acreage goals for the preservation and restoration of riparian forest and scrub within the project area.

Deciduous riparian forest habitats adjacent to backchannels, side channels, ponds, and rivers are important habitat types for western pond turtle (Nussbaum et al. 1983, Zeiner et al. 1988). Western pond turtles use riparian forest habitat for burrowing and nesting, and also for basking, particularly along backwater channels. Juxtaposition of suitable aquatic foraging and basking sites with riparian or upland burrowing and nesting sites is a key determinant of habitat quality for this analysis species. Because habitat use can vary greatly among turtle populations, and because turtles often return to the same wintering and nesting sites each year, Reese (1996) suggests that management priorities should be site- and population-specific. Reese's recommendations include establishing a buffer zone on each side of the watercourse of at least 1,650 ft (500 m) for key sites.

Yellow-billed cuckoo is an example of a riparian-obligate species and is found only in larger patches of willow-cottonwood riparian forest vegetation types. Cuckoos inhabit densely foliated, deciduous trees and shrubs, particularly willows, with a dense understory formed by blackberry, nettles, and/or wild grapes adjacent to slow-moving watercourses, backwaters, or seeps (CDFG 1983). Field studies and habitat suitability modeling have concluded that vegetation type (e.g., cottonwood-willow), patch size, patch width, and distance to water are critical factors determining the suitability of habitat for yellow-billed cuckoo breeding (Laymon and Halterman 1989, Greco 1999). Patch size was the most important variable determining presence of cuckoos on the Sacramento River from 1987 to 1990 (Halterman 1991, as cited in Laymon 1998), with a trend toward increasing occupancy with increased patch size. Willow-cottonwood habitat patches greater than 600 m in width were found to be optimal, while typically anything less than 100 m was unsuitable (Laymon and Halterman 1989). Halterman (1991, as cited in Greco 1999) and Laymon et al. (1997, as cited in Greco 1999) also observed nesting more frequently in areas where the distance to water was less than 100 m. Dense vegetation less than 20 m in height is especially important for nesting, while lower and higher vegetation with greater overall foliage density is used for foraging (Laymon et al. 1997, as cited in Greco 1999). Young, rapidly growing stands of riparian vegetation provide preferred nest sites and high productivity of invertebrate prey, with a lower prevalence of predators compared with older stands (Laymon 1998; Halterman 1991, as cited in Laymon 1998). Greco (1999) defined this to be less than 45–60 years since vegetation became established on newly formed substrate, stressing the importance of meandering riparian systems with intact erosional and depositional processes that create new areas for riparian vegetation to establish. Halterman (1991, as cited by Laymon 1998) found that habitat fragmentation, as determined by the extent of habitat per 8-km river reach, was the second most important variable (after patch size) in determining the presence of cuckoos, followed by the presence of low woody vegetation. Conservation and restoration efforts need to keep in mind that large areas need to be conserved to allow for the natural formation and loss of yellow-billed cuckoo habitat. Management strategies involving "minimum dynamic areas" (Pickett and Thompson 1978, as cited in Greco 1999), such as those discussed in the Sacramento River Conservation Area Handbook (California Resources Agency 1998, as cited in Greco 1999), are preferred over conservation of minimum patch size areas (Greco 1999). Restoration should be geared toward maintenance of channel hydrodynamic processes that result in formation of complex riparian habitat (Greco 1999). The Restoration Objectives Report describes yellow-billed cuckoo life history, distribution, habitat requirements, and restoration goals in detail.

Riparian brush rabbits are most often found in clearings within dense riparian forests within the natural floodplain, feeding on understory vegetation (Williams 1986). The riparian brush rabbit has been heavily impacted by construction of large dams in the Central Valley and the conversion of large tracts of land to agriculture, which has fragmented riparian habitat. It is considered one of the most sensitive mammals in California because of its susceptibility to floods, fire, disease, predation, disturbance, and flood control activities (CALFED 1997). This species is not known to disperse far and has a relatively small home range. Riparian brush rabbits will not cross large open areas, so habitat connectivity is important for this species. Because of their small home range, smaller patches of suitable habitat may be sufficient for individual rabbits or pairs, but a complex of adjoining patches is needed to maintain populations of this species by connecting tracts of suitable habitat and upland areas in order to provide cover from annual floods (CALFED 1997).

Bats account for a substantial fraction of the native mammal diversity within the Central Valley. All species found in California are insectivorous and foraging by many bat species is concentrated near rivers, streams, and riparian vegetation. Foraging strategies and nightly movement distances differ among species, but range from a fraction of a kilometer to several tens of kilometers per night. During the day, bats roost in foliage or in crevices and cavities, presumably in larger trees, or snags in mature riparian forest remnants. Persistence (or restoration) of local bat diversity is intimately tied to riparian forest dynamics. Existing evidence indicates that cottonwood and sycamore riparian forests provide high-quality roosting habitat for several bat species, such as western red bat and California myotis (Barbour and Davis 1969, Pierson et al. 1999), as well as potentially critical foraging habitat for big brown bat, western red bat, and hoary bat (E. Pierson, pers. comm., 2002). A recent study suggests that riparian restoration projects that reinstate naturalistic flood regimes and foster regeneration of cottonwood and sycamore would benefit the western red bat (E. Pierson, pers. comm., 2002).

Habitat restoration target

Restoration goals for improving the quality and quantity of riparian forest and scrub in the San Joaquin River corridor were developed by: (1) identifying current patches of the vegetation type suitable for conservation and enhancement; (2) identifying areas along the river that have physical, chemical, and inundation characteristics suitable for supporting riparian forest and scrub; (3) extracting conservation recommendations from the scientific literature regarding habitat requirements for wildlife analysis species; and (4) following the recommendations given in the Riparian Habitat Joint Venture's Riparian Bird Conservation Plan (RHJV 2000). A wide variety of research and literature strongly supports the value of healthy riparian forest and scrub in maintaining many of the functions of the river-riparian ecosystem and providing habitat value for fish and wildlife. Goals for restoration of riparian forest and scrub include:

- Increasing the acreage of the riparian forest and scrub throughout the river corridor. Riparian habitat patches should be of sufficient size to support riparian-dependent species. The quantitative data available on patch size requirements of yellow-billed cuckoo provide a starting point for establishing minimum habitat patch sizes for protection or restoration. Riparian forest habitat patches between 100 and 600 m (or greater) in width have been documented to support yellow-billed cuckoo (Laymon and Halterman 1989), and will support a wide variety of other riparian-dependent species. As more quantitative data become available, minimum and ideal patch sizes can be refined for the management of other riparian wildlife populations. At a minimum, a riparian corridor width sufficient to support chemical, physical, and habitat functions important to the river system should be restored. A range of corridor widths can be prescribed to achieve specific restoration goals or support particular wildlife species. For example, a buffer zone of at least 1,650 ft (500 m) has been recommended to support western pond turtle populations (Reese 1996). Section 3.3.7 in the Restoration Objectives Report (Stillwater Sciences 2003) summarizes other buffer widths that have been proposed in the literature to protect various ecosystem functions in different regions.
- Restore and maintain riparian forest and scrub, in large contiguous patches (where possible) that include a mosaic of different successional or structural stages of woody riparian vegetation and other native vegetation types. Connectivity between habitat patches is particularly important to riparian brush rabbit, which will not cross open areas, and yellow-billed cuckoo, which require large tracts of intact riparian habitat. Expanding and linking

isolated patches of habitat provides dispersal corridors for plant and animal populations and movement corridors for access to various habitat types along the river corridor.
- Utilize natural fluvial geomorphic processes as much as possible to maintain a self-sustaining system of riparian forest and scrub. A governing assumption of all three restoration strategies is that managing flows to promote natural revegetation processes is the most effective and efficient means of restoring riparian forest and scrub throughout the 150-mile San Joaquin River corridor. Restoring flows that provide periodic scour, inundation, or sediment deposition will also help reduce the threat of riparian encroachment into the river channel.

According to the vegetation mapping conducted by CDWR (2002), the GIS analysis conducted by Stillwater Sciences, and the results of the Stillwater Riparian Recruitment Model, there are approximately 6,000 acres of existing riparian forest and scrub that are suitable for conservation or enhancement and potentially another 6,000 acres along the river corridor that have the soil, elevation, and potential for inundation required to support the restoration of riparian forest and scrub. Reaches 1A, 4B2, and 5 have the greatest potential area (approximately 1,000 to 2,000 acres each) suitable for the restoration and conservation of riparian forest and scrub, although the other reaches have substantial potential as well.

Riparian forest and scrub should be maintained, enhanced, or restored through a combination of preservation of existing patches, flow management to promote natural recruitment and disturbance processes, and active restoration (such as horticultural revegetation techniques or floodplain reconstruction to increase floodplain connectivity, and facilitate natural regeneration processes). Natural fluvial geomorphic processes should be utilized as much as possible to maintain a self-sustaining system of riparian forest and scrub, but management intervention should be considered to speed up development of the desired condition or to maintain it in locations where a process-based approach would not be effective. In Reaches 4 and 5, the potential area for riparian recruitment is substantially greater than the extent of existing riparian vegetation. In these areas, the objective of flow management should be to maintain or enhance existing stands and to restore additional acreage of riparian forest and scrub. Uncertainty exists, however, as to whether prolonged inundation or levels of boron and selenium in soil and water in Reaches 4 and 5 will limit potential restoration of woody riparian vegetation to substantially less acreage than that predicted by the San Joaquin River Riparian Recruitment Model.

3.5.5.2 Valley oak woodland

Description and distribution

Valley oak woodland is a native vegetation type in California's Central Valley. It is a vegetation type of special concern because of its declining distribution throughout the state, severe reduction in extent compared with historical times, and the disruption/suppression of its regeneration processes (IHRMP 1996). Valley oak woodland typically consists of an overstory canopy dominated by valley oak and an understory dominated by grasses and annual forbs. Associated tree species include western sycamore, California black walnut, box elder, Oregon ash, interior live oak, California buckeye, and blue oak. This vegetation type typically occurs on the highest parts of the floodplain and on terraces, where it is less subject to physical disturbance but still receives annual subsurface irrigation and periodic inputs of silty alluvium during larger flood events. The valley oak forest canopy averages 50–65 ft in height, and mature dominant trees can reach 120 ft tall (IHRMP 1996). Canopy closure in valley oak forest type varies from open (representing a savanna or woodland phase) to dense (true forest, typically occurring in riparian zones). Dense-canopy valley oak riparian forest, which occurs in lower, wetter areas in the riparian zone, is included in the riparian forest and scrub discussion above.

Historical records suggest that valley oak woodland did not occur in Reaches 2 through 5 of the project area and was limited to terraces in Reach 1 by confining bluffs although there is still much uncertainty over the actual historical distribution of this vegetation type (McBain and Trush 2002). Clearing for agriculture and livestock grazing has dramatically reduced the extent of this habitat type. In addition, valley oak regeneration is not sufficient to replace mature trees lost to natural and human causes. Likely causes of reduced regeneration include competition for surface water with non-native grasses and forbs, acorn and seedling predation by livestock, deer, and small mammals, and alteration of the natural flooding regime. In upland areas, fire suppression has limited valley oak recruitment by encouraging competition from drought-tolerant understory plants (IHRMP 1996, Pavlick et al. 1991). Currently, there are about 265 acres of valley oak woodland in Reach 1A and smaller patches in Reach 4B1 (16 acres), Reach 4B2 (7 acres), and Reach 5 (46 acres) (McBain and Trush 2002, Stillwater Sciences 2003).

Habitat value

Valley oaks and other trees, shrubs, and grasses associated with oak woodlands provide habitat structure and foraging opportunities for a diverse assemblage of native wildlife, including many that are associated with the river corridor. In turn, the species that depend on oak woodlands for foraging, breeding, and cover influence the structure and composition of the oak woodlands through herbivory, seed dispersal, nest building, and other activities. Oak acorns, leaves, twigs, sap, roots, and pollen are all important wildlife food sources. Martin et al. (1951) list 19 species of bird and 11 game, small, or hoofed mammal species occurring in the Pacific region (California, Oregon, and Washington) that rely on acorns or oak twigs and foliage for an appreciable portion of their diet. Nine of these species consume acorns for 25–50 percent of their diet (Martin et al. 1951). The cavities, perches, and cover found in valley oak woodlands provide habitat for a variety of wildlife species. More than 300 vertebrate species have been documented to use oak-dominated woodlands for breeding, foraging, or cover (Block et al. 1990, Pavlick et al. 1991). The discussion below summarizes the value of valley oak woodlands for Swainson’s hawk and acorn woodpecker. These bird species use valley oak woodlands for part or all of their life history and their habitat requirements help define minimum patch size and acreage goals for the preservation and restoration of valley oak woodland.

Although the availability of nesting substrate is closely tied to riparian areas, Swainson’s hawk is not an obligate-riparian species (Bloom 1980, Estep 1989). Swainson’s hawks are known to nest in isolated oak woodland bordering narrow bands of riparian vegetation (England et al. 1997). The proximity of a nest site to foraging areas (e.g., where suitable prey are open to aerial attack, such as agricultural fields under moderate levels of cultivation) is an important factor determining habitat suitability. A trend toward planting crops unsuitable for Swainson's hawk foraging and urban expansion into agricultural and grassland areas represent the major threats to this species' breeding grounds (CDFG 1992). Restoration recommendations for Swainson’s hawk emphasize the continued need for available, suitable nesting and foraging habitat through preservation of riparian systems, woodlands, and lone groves or mature trees in agricultural fields (CDFG 1992). Tree planting is a preferred management technique where nest sites (large, old trees) are limiting (England et al. 1997). Bloom (1980) believed that the Central Valley Swainson’s hawk population, because of its size and distribution, could function as a center for the dispersal of populations for the colonization of historically occupied sites. CDFG (1994) recommends an average of 15,000 acres of potential foraging area per nesting pair should be preserved in order to avoid jeopardizing the existing population. The area preserved should also be sufficient to accommodate additional hawks to successfully breed and utilize foraging habitat during good production years (CDFG 1994).

Acorn woodpeckers prefer pine-oak woodlands where oaks are plentiful. They are commonly found in oak woodland habitats growing adjacent to riparian sycamore groves (Small 1994). They prefer stands with snags and sparse canopies (Zeiner et al. 1990). Although acorn woodpeckers typically feed on insects, sap, oak catkins, fruit, and flower nectar, acorns constitute over 50 percent of the acorn woodpecker diet (Pavlick et al. 1991). Acorns are stored in individually-drilled holes in dead limbs or thick bark of a granary tree. Acorn woodpeckers typically forage in or near the canopy of oak woodland habitats, and require water daily (Zeiner et al. 1990). Curtis (1981, as cited in Zeiner et al. 1990) described optimal habitat as an open oak forest patch of at least 15 ac (6 ha), containing at least 4 species of oak, and less than 0.4 km (0.25 mi) from water. Acorn woodpeckers typically live in communal groups of 2 to 16 individuals, defending a territory of 1–7 trees 11.5 acres (4.7 ha) (Swearingen 1977, as cited in Zeiner et al. 1990). Continued elimination of oaks in California due to development and disease is a threat to this species (Verner and Boss 1980, as cited in Zeiner et al. 1990).

Habitat restoration target

The following restoration goals for valley oak woodland in the San Joaquin River corridor were developed and prioritized by: (1) identifying current patches of the vegetation type suitable for conservation and enhancement; (2) identifying areas along the river that have physical and chemical characteristics suitable for supporting oak valley woodland (using a GIS analysis of the DEM assessment area); (3) using information on habitat requirements for the analysis species described above; and adapting published guidelines for oak woodland restoration and conservation (CalPIF 2002).

- Expand existing patch of oak woodland in Reach 1A. Review of existing soil and topographic characteristics of the existing patches of valley oak woodland indicates that there are up to 500 acres in Reach 1A potentially suitable to support oak woodland restoration. Expanding existing patches of valley oak woodland would provide an important center for the dispersal of valley oak, associated plant species, and wildlife populations. Increasing the extent of existing patches would provide valuable breeding, and cover habitat for wildlife such as Swainson’s hawk, and could potentially provide a link between isolated patches of habitat in the area, improving conditions for the movement of wildlife throughout the river corridor.
- Create patches of valley oak woodland in Reach 3. Review of soil and topographic characteristics of this reach indicate that there are potentially many acres in Reach 3 suitable to support valley oak woodland (e.g., elevation of 8–16 feet above the water table; unstratified non-saline soils with coarse or medium texture; and current non-native vegetation land cover in the disturbed, herbaceous, or agricultural categories). Creating relatively large patches (e.g., 20–40 acres or larger) should be explored in this reach, in order to increase the wildlife habitat value of restored sites, although restoration sites may be smaller (e.g., 10 acres) and still retain much habitat value if they are adjacent to intact riparian forest stands.
- Link and expand the small, isolated patches of valley oak woodland in Reaches 4B1, 4B2, and 5. Reach 5 at the confluence of the Merced River is currently the focus of several extensive conservation efforts by the Stevinson Corporation to protect the existing stands of high-quality riparian and oak forest in this area. Linking and expanding the isolated patches in these lower reaches would enhance the on-going conservation efforts at the confluence of the Merced River and extend the area and wildlife habitat value of neighboring easements and wildlife refuges.

According to the vegetation mapping conducting by CDWR (2002), the GIS analysis conducted by Stillwater Sciences, and the results of the Stillwater Riparian Recruitment Model, there are approximately 300 acres of valley oak woodland that are suitable for conservation or enhancement and potentially 3,000 acres along the river corridor that may have the soil and relative elevation characteristics (as a proxy for depth to groundwater) required to support horticultural restoration of valley oak woodland. Griggs and Golet (2002) document successful horticultural restoration of valley oaks along the Sacramento River when suitable soils and elevation to groundwater conditions were present.

The restoration of valley oak woodland along the San Joaquin River will likely require a combination of preserving existing patches as a source of acorn dispersal for natural regeneration and recolonization, and horticultural restoration to expedite recolonization of oaks, as natural recruitment of valley oaks, especially in open woodlands and savannas, is low or nonexistent in much of California (Pavlick et al. 1991). At some sites, such as the lower reaches where levee setbacks may be proposed, flow management and floodplain reconstruction may be used to create conditions that will support oak valley woodland.

3.5.5.3 Freshwater marsh and wetlands

Description and distribution

Freshwater marsh and wetlands encompass a diverse spectrum of habitats ranging from seasonally saturated or inundated to persistently inundated, with the type of vegetation reflecting the duration of saturation or inundation (NRC 1995, Middleton 1999, McBain and Trush 2002). Characteristic marsh species include bulrushes and cattails. The most abundant wetland herbaceous species in the project area are western goldenrod and pale smartweed (McBain and Trush 2002). Freshwater marshes can form in backwater channel areas, oxbow lakes and sloughs, and on floodplain terraces.

Vast areas of freshwater marsh complexes dominated by tules (hardstem bulrush), cattails, and other emergent wetland plants once dominated the flood basins bordering the San Joaquin River from Reach 3 through Reach 5 (see Chapter 8 of the Background Report). Of the 4 million acres of wetlands that existed in the Central Valley in the 1850s, a mere 14 percent (560,500 acres) remained in 1939 (Beedy and Hamilton 1997). Remnants of these freshwater wetland complexes are still found in the San Luis National Wildlife Refuge complex (see Appendix G-2) and at selected other locations along the river. At present, approximately 1,000 acres of wetlands occur in the project area, two-thirds of which occur in Reach 4 and 5 (see Restoration Objectives Report Table 3-2). Most of the remaining wetlands in the study area are associated with aggregate mining pits in Reach 1A.

Habitat value

Wetlands provide many ecological functions and values, including high productivity, nutrient cycling, and filtration (Middleton 1999, Mitsch and Gosselink 1986, NRC 1995). Large complexes of wetlands with habitats ranging along a toposequence from deep water (>6 feet deep), to submersed and floating aquatic macrophytes, to emergent tules and cattails, and then to seasonal wetlands along the margins provide valuable breeding, foraging, and cover habitat for a wide variety of avian species, reptiles, and amphibians. Waterfowl species such as mallards, green-winged teal, ring-necked ducks, and northern pintails are found on the San Luis National Wildlife Refuge complex (http://sanluis.fws.gov/sanluis_info.htm), and many species of resident and migratory shorebirds, wading birds, rails, and songbirds depend upon the seasonal and permanent wetland areas of the San Joaquin Valley. The discussion below summarizes the value of freshwater marsh and wetland for: waterfowl, giant garter snake, tricolored blackbird, and white-faced ibis, which depend on freshwater marsh for all or a significant portion of their life cycle. The habitat requirements of these species help define minimum patch size and acre goals for the preservation and restoration of freshwater marsh and wetland. They are summarized briefly below and discussed in more detail in the Restoration Objectives Report.

Waterfowl species depend on marsh habitats for foraging and cover. A number of waterfowl species, including northern pintail and mallard, commonly breed and overwinter in the San Joaquin Valley. They prefer open shallow-water feeding areas bordered by emergent vegetation where preferred cover types include bulrush, cattail, and tule (Weller 1994). Waterfowl species that breed in the San Joaquin Valley, such as the mallard, prefer to nest near foraging sites and usually nest within 100 m of water (Small 1994). Breeding waterfowl prefer to conceal nests in dense emergent stands of vegetation (Weller 1994).

Giant garter snakes depend on marsh habitats, particularly with mud and silt bottoms for foraging and cover. They require permanent marshes with emergent vegetation (such as tules and cattails) adjacent to low-growing bankside vegetation (such as blackberry or grape). Median home ranges have been estimated anywhere from 9 hectares (23 acres) to 53 hectares (131 acres) for this species. Foraging sites are typically within 50 m of water, while overwintering burrows (typically abandoned mammal burrows) can be as far as 250 m from water (Wylie et al. 1997). According to USFWS (1999), the San Joaquin Valley subpopulations have shown severe declines over the last 2 decades. The major cause for decline is attributed to loss of habitat from conversion of aquatic, wetland, riparian, and adjacent upland habitats to other land uses, and degradation of habitat from land-use practices (CALFED 1997).

Tricolored blackbirds require the following habitat characteristics for successful breeding: (1) open, accessible water at or near the breeding site, (2) protected nesting substrate, usually flooded by at least one foot (Hamilton, pers. comm.) and/or with spiny or thorny vegetation to protect nests from predators, and (3) suitable foraging grounds within a few (< 5) miles of the nesting colony (Beedy and Hamilton 1997). Tricolored blackbirds typically nest in tules and cattails but are also found nesting in silage and grain fields, Himalaya berries, *Arundo*, and tamarisk. A majority of colonies currently depend on privately owned agricultural fields for nesting (Miller and Hornaday 1999). Nesting colonies range in size from a minimum of 50 breeding pairs (Grinnell and Miller 1944, as cited in Zeiner et al. 1990a; T. Beedy, pers. comm.), to tens of thousands of birds (e.g., 30,000 birds reported in a colony on the Merced NWR; S. Milar, pers. comm. 2002). Hamilton (pers. comm.) suggests a restoration goal of 1,800 to 3,000 birds as a sustainable nesting colony. Minimum patch size required for breeding was estimated to be between 3 and 5 acres of suitable nesting substrate to account for habitat heterogeneity (Hamilton, pers. comm.; Beedy, pers. comm.). According to Beedy (pers. comm.), a colony would be unlikely to establish in an area less than one acre, unless nesting conditions were optimal (e.g., abundant available prey and protected nesting substrate like Himalaya blackberry).

Like tricolored blackbirds, white-faced ibis nest in tules and cattails. Some shallow water habitat is required for fledgling rearing. White-faced ibis forage in irrigated fields, pastures, open marshes, mudflats, canal edges, ponds, and ditches, typically in habitat patches of at least 30 hectares (74 acres), within 6 km of a colony site (Bray and Klebenow 1988). Earnst et al. (1998) suggest that ibis "would benefit from a landscape mosaic of well-distributed peripheral wetlands and persistent colony sites. The nomadic nature of the white-faced ibis and the dynamic nature of their breeding habitat necessitates that wetland management decisions and population monitoring be conducted in a regional context."

Wetland habitat values for native resident fish are discussed in Section 3.4.6.2.

Habitat restoration target

The following restoration goals for improving the quality and quantity of freshwater marsh and wetlands in the San Joaquin River corridor were developed and prioritized by: (1) identifying current patches of the vegetation type suitable for conservation and enhancement; (2) identifying areas along the river that have physical and chemical characteristics suitable for potentially supporting freshwater marsh and wetlands; (3) considering the historical vastness of this community type in the study area; and (4) following guidelines for freshwater marsh and wetland restoration and conservation focused on specific wildlife species described above.

- Maintain or enhance the existing patches of this ecologically valuable native vegetation type in the river corridor. In particular, identify opportunities to create larger marsh and wetland complexes in Reaches 2B–5, where remnant patches are concentrated. Such opportunities would be especially valuable if the additional restoration builds on existing wetlands, such as the managed wetlands on the San Luis NWR, to create freshwater marsh/wetland complexes greater than 100–200 acres in size. See Appendix G-2 for more specific information on wetlands management on the San Luis NWR complex.
- Incorporate freshwater marsh when opportunities for recontouring flood basin topography behind low riparian berms along the main channel arise. The proposed levee setbacks in Reach 2B and 4B1 to increase flood conveyance capacity should provide good opportunities for restoration of new wetland areas.
- Create mosaics of upland, seasonal wetlands and permanent, open water and emergent wetlands, including conservation of existing oxbow lakes and sloughs, to support a diversity of waterfowl, other avian species, reptiles, and amphibians. For example, management of wetlands should also consider needs of species like the giant garter snake, whose hydroperiod requirements are often opposite that of migratory waterfowl (see Restoration Objectives Report). A mosaic of freshwater marsh and wetlands on gradients of topography and in various successional stages will facilitate foraging, cover, and nesting habitat requirements for wildlife species discussed above.
- Consider prioritizing restoration efforts in areas identified in Recovery Plans as critical for special-status wildlife species that depend on freshwater marsh habitat. For example, the Draft Recovery Plan for the giant garter snake (USFWS 1999) highlights the following areas that are in or near the project area:
    1. North and South Grasslands area (Reaches 4 and 5): Parts of this area are privately owned and recommendations are to "develop and implement a management plan benefiting the giant garter snake, restore wetland habitat, create additional nesting habitat for the tri-colored blackbird, protect existing tri-colored blackbird breeding colonies, maintain compatible agricultural practices, and protect and maintain wintering habitat for the white-faced ibis."
    2. Mendota Area (Reach 2B/3): This area is private and recommendations are to "develop and implement management plan benefiting the giant garter snake," and "to restore wetland habitat."
- Consider the susceptibility of these areas to predators. Predation by black-crowned night herons (a native wetland species) on tricolored blackbirds is considered one of the primary threats to this species.

Large freshwater marsh complexes were once a dominant habitat type in the flood basins of Reaches 3 through 5, but have been reduced to remnant patches, including those within the project area (approximately 1,000 acres) and the adjacent San Luis NWR. Because the intent is to restore freshwater marsh (rather than brackish or saline wetlands), determining potentially suitable sites for restoration using the GIS (see Restoration Objectives Report Section 3.3) focused on finding sites with low salinity soils and shallow depth to groundwater (or presumed groundwater based on predicted elevation of base flows) (elevations <2 feet above predicted base flow elevation). Depending on surface water-groundwater dynamics that become established with the implementation of the flow management regime developed in the final restoration plan, some of the potentially suitable area may not support full development of the desired range of wetland conditions without some type of floodplain excavation. Thus, it is difficult to identify potential areas for wetland creation at this scale, and the initial priority should focus on reaches currently containing freshwater marsh.

Restoration of perennial wetlands in areas that may result in higher salinity or alkalinity habitats may provide locations for Sacramento perch reintroduction (see Section 3.4.6.3).

In general, wetland restoration strategies should focus on reconnection of landscape-level linkages for hydrology and dispersal, and restoration of the natural hydrologic regime (Middleton 1999). Horticultural restoration of various dominant and associated plant species may be necessary, but could be used in conjunction with a donor seed bank. According to Weller (1990), "contouring with earth-moving equipment is commonplace in wetland restoration, and should be used to create water depths associated with the desired plant community. Where such work is done on areas with a rich seed bank, soil should be moved off-site and returned as topsoil both for the merits of its organic content and as a seed bank. This will reduce invasions by exotics where they are an issue and the necessity of seeding with cultivated varieties that result in low natural diversity." Project evaluation is essential both during and after wetland construction to determine compliance with project goals and permit mid-course corrections (Erwin 1990).

3.5.5.4 Alkali scrub and associated habitats

Description and distribution
Alkali scrub and associated alkali habitats occur in areas with saline, sometimes alkaline soils with fine to medium texture. These areas are typically dominated by halophytic shrub plant communities (i.e., plants tolerant of alkaline/saline soils) such as saltbush species and saltgrass. Alkali scrub often intergrades with other alkali vegetation types (alkali meadows, alkali wetlands, alkali grasslands such as alkali sacaton and saltgrass series), depending largely on local variations in soil salinity, texture, and the timing, duration, and magnitude of inundation or surface soil saturation (Holland 1986, Sawyer and Keeler-Wolf 1995, Holland and Keil 1996, Edminster 1998). Alkali claypan vernal pools, and associated plant and invertebrate species, may also occur in the vicinity of alkali scrub.

Alkali scrub is a once-common native vegetation type that is now greatly restricted in abundance in the Central Valley. Historical accounts (as summarized in Chapter 8 of McBain and Trush 2002) indicate that alkali scrub, saltbush scrub, and other alkali vegetation types were once common along the outer margins of the flood basins on either side of the San Joaquin River from Reach 3 through Reach 5. Remnants of this vegetation type currently occur in the project area in the National Wildlife Refuge lands east of Reach 5 (approximately 5 acres was mapped by CDWR as occurring south of the San Joaquin River from RM 125–129, near the confluence of Salt Slough in Reach 5) and in the Alkali Sink Ecological Reserve a few miles south of Reach 2B.

Habitat value
Alkali scrub provides habitat for a number of species that have adapted to these special conditions. It contributes to the diversity of native ecological communities and species occurring in the Central Valley and along the San Joaquin River corridor.

Alkali scrub communities support several species of special-status plants in the San Joaquin Valley, including palmate-bracted bird's beak, lesser saltscale, Bakersfield smallscale, Lost Hills saltbush, Munz's tidy-tips, and Jared's peppergrass (Williams et al. 1998). In addition, alkali scrub provides cover and forage (mostly seeds, but to a limited extent stems and leaves) for several small mammals, a few waterfowl species, and reptiles (Martin et al. 1951), including special-status wildlife species such as the blunt-nosed leopard lizard, San Joaquin kit fox, San Joaquin antelope squirrel, Fresno kangaroo rat, and short-nosed kangaroo rat (Williams et al. 1998). More specific habitat requirements for two of these species are discussed below.

Blunt-nosed leopard lizards are often found in poorly drained, saline or alkaline soils. They inhabit areas with sandy soils and scattered vegetation and are usually absent from thickly vegetated habitats (CDFG 1992). Chesemore (1980, as cited in Williams et al. 1998) found that moderate ground cover (15 to 30 percent) was optimal for the leopard lizard, but that greater than 50 percent was unsuitable. The blunt-nosed leopard lizard Recovery Plan recommends that habitat units of 500 to 1,000 acres should be protected for this species (USFWS 1980).

The Fresno kangaroo rat also occurs in alkali scrub habitat, and seasonally flooded or arid alkali plains. The Fresno kangaroo rat has narrow habitat requirements, only occupying alkali desert scrub communities between 200 and 300 feet elevation (CDFG 1992) within the alkali desert scrub habitat type. Seasonally flooded or arid alkaline plains with alkaline, clay-based soil and sparse growths of grassland or low brush are used (CDFG 2000). Vegetation such as saltbush, iodine bush, saltgrass, and alkali blite provide food and cover for this subspecies (Culbertson 1946). Fresno kangaroo rats shelter in ground burrows located in slightly elevated areas above the level reached by seasonal floodwaters (Brylski and Roest 1994). Availability of suitable burrowing sites in areas free from winter flooding is probably a major limiting factor (Williams et al. 1998). Goldingay et al. (1997) recommended that a minimum of 5,000 hectares is required to support a viable population.

Habitat restoration target

The following reach-specific restoration goals for improving the quality and quantity of alkali scrub and wetlands in the San Joaquin River corridor were developed and prioritized by: (1) identifying current patches of the vegetation type suitable for conservation and enhancement; (2) identifying areas along the river that have physical and chemical characteristics suitable for supporting alkali scrub and wetlands (using a GIS analysis of the DEM assessment area); and (3) using information on habitat requirements for the analysis species described above and published guidelines for alkali scrub and wetland restoration and conservation.

- Maintain or enhance the existing patches of this rare native vegetation and restore additional vegetation where suitable soils and hydrology exist in Reaches 4 and 5.
- As opportunities arise over the longer term, consider additional restoration in lower priority areas in Reach 5 and Reach 4B2.
- Maintain or enhance a diversity of topographic complexity to promote the development of a mosaic of alkali scrub vegetation (e.g., alkali sink, alkali marsh, alkali meadow).
- Consider prioritizing restoration efforts in areas identified in Recovery Plans as critical for special-status wildlife species that depend on alkali scrub habitats. More specifically:
    1. The Recovery Plan for the Fresno kangaroo rat (Williams et al. 1998) promotes the protection of the large block of natural land north of and between the Alkali Sink Ecological Reserve and the San Joaquin River (in Reach 2B).
    2. The Recovery Plan for the San Joaquin kit fox (Williams et al. 1998) suggests areas for priority conservation including (1) expanding Mendota area, Fresno County, and (2) maintaining and enhancing movement between the Mendota area, natural lands in western Madera County, and natural lands along Sandy Mush Road and in the wildlife refuges and easement lands of Merced County. Specifically, maintain and enhance the Chowchilla or Eastside Bypass and natural lands along this corridor through acquisition, easement, or safe harbor initiatives.
    3. The blunt-nosed leopard lizard Recovery Plan suggests preserving and protecting habitat units 500 to 1,000 acres in size (USFWS 1980), for a total of 30,000 acres for the species.

> Three of the 20 areas identified within the Recovery Plan as "Essential Habitat Areas" are within the project area: (a) Firebaugh Area (16,000 acres in private ownership in Reach 3), (b) Madera Area (11,000 acres in private ownership), and (c) Whitesbridge Area (9,000 acres in private ownership)

The GIS was used to identify potential restoration sites that have similar characteristics to existing patches of alkali scrub habitat (high salinity and the presence of clay in the soils that are approximately 6–10 feet above potential base flow levels) (Table 3-23 of Restoration Objectives Report).

Restoration strategies may involve alteration of hydroperiod conditions through flow management or floodplain reconstruction, and horticultural restoration of various dominant and associated plant species found in alkali sink scrub vegetation. If feasible, selection of sites with topographic diversity in addition to suitable soils and hydrology may be desirable for restoration to promote development of a more complex alkali vegetation mosaic (i.e., that includes alkali wetland types as well as just alkali sink scrub). Because of the uncertainties associated with restoration of alkali habitats, flow management may provide the most appropriate large-scale restoration approach. However, smaller-scale pilot efforts to test active, horticultural restoration techniques may also be warranted.

3.5.5.5 Elderberry savanna

Description and distribution
Elderberry savanna is a rare native vegetation type that occurs in silty, sandy soils on well-drained floodplains and terraces throughout the state. This vegetation type is an open, winter-deciduous shrub savanna dominated by blue or Mexican elderberry, with an understory of introduced annual grasses and forbs (Holland 1986). Common associated plant species include bromegrass, yellow starthistle, and horehound (Holland 1986). Without a regular disturbance regime such as grazing, flooding, or fire, elderberry savanna may succeed quickly to mixed riparian forest, where it is generally dominated by California wild grape (Holland 1986). Although we know little about its historical distribution and abundance in the project area, this community currently has very restricted distribution in the San Joaquin River corridor. There are about 63 acres of elderberry savanna on the south side of the channel near the Chowchilla Bifurcation Structure at the junction of Reaches 2A and 2B and small isolated patches in Reach 1A (2 acres) and 2A (3 acres) (McBain and Trush 2002). Elderberry is also found in Reach 1 as a component of the mixed riparian forest and valley oak woodland vegetation types.

Habitat value
The elderberry plant is the host plant for the entire life history of the valley elderberry longhorn beetle, which is listed as threatened under the federal Endangered Species Act. The valley elderberry longhorn beetle historically occurred throughout the Central Valley from Redding (Shasta County) to Bakersfield (Kern County), but population levels are declining (Arnold et al. 1994). Occurrences or signs of the beetle have been reported at several locations within the project area (see Restoration Objectives Report). Guidelines for conserving and improving valley elderberry longhorn beetle populations include: restoring ecosystem processes that benefit riparian vegetation establishment (CALFED 1997); linking isolated areas of habitat that currently support the beetle (CALFED 1997); and planting a mix of native plants associated with the elderberry plants, as studies have found that the beetle is more abundant in dense native plant communities with a mature overstory and a mixed understory (USFWS 1999). In a recent study, Collinge et al. (2001) found that valley elderberry longhorn beetle occurs in drainages that appear to function as distinct, relatively isolated metapopulations, and that signs of the beetle

consistently occur in clumps of elderberry bushes (rather than in isolated bushes) and in branches 5–10 cm in diameter and <1 m off the ground. These results provide additional guidelines for valley elderberry longhorn beetle conservation, as they suggest that conserving or planting groups of elderberry bushes of suitable sizes on a watershed-scale is necessary for successful conservation.

In addition to their value as habitat for valley elderberry longhorn beetle, mature elderberry plants produce edible berries that are an important summer food for many bird and small mammal species. Martin et al. (1951) identified 14 species of songbirds that use elderberries for 2 to 50 percent of their diet, and three mammal species that use elderberries or the twigs and foliage of the plant for 2 to 5 percent of their diet.

Habitat restoration target

The following reach-specific restoration goals for improving the quality and quantity of elderberry savanna in the San Joaquin River corridor were developed by: (1) identifying current patches of the vegetation type suitable for conservation and enhancement; (2) identifying areas along the river that have physical and chemical characteristics suitable for supporting elderberry savanna; and (3) following the guidelines for valley elderberry longhorn beetle conservation discussed above.

- Expand existing patches or add new patches to the complex of patches found in Reach 2B just downstream of the Chowchilla Bifurcation Structure. Review of existing soil and topographic characteristics of the existing patches of elderberry savanna indicate that there are approximately 520 acres in Reach 2B that may be suitable to support elderberry savanna. Population dynamic studies of valley elderberry longhorn beetle suggest that linking the patches of elderberry savanna in this reach would provide an important center for the dispersal of elderberry and beetle populations (Collinge et al. 2001).
- Expand or add new patches adjacent to the existing patches in Reach 1A and 2A. Expansion of these patches would also serve to promote the dispersal of elderberry and valley elderberry longhorn beetle populations. Larger, contiguous patches of elderberry savanna would serve as foraging habitat and provide cover along the river corridor for wildlife species.
- Extend the distribution upstream or downstream of existing patches to reduce the distance between patches of elderberry savanna by adding new patches in Reaches 1 and 2. As described above, linking these patches would provide opportunities for the dispersal of elderberry plant species, associated elderberry savanna, and valley elderberry longhorn beetle populations, and would provide foraging and cover habitat for wildlife.

According to the vegetation mapping conducting by CDWR (2002), the GIS analysis conducted by Stillwater Sciences, and the results of the Stillwater Riparian Recruitment Model, there are approximately 60 acres of existing elderberry savanna that are suitable for conservation or enhancement and potentially 3,000 acres along the river corridor that appear to have the soil and elevation characteristics required to support the restoration of elderberry savanna. Reaches 1A and 2 have the greatest potential for the restoration or creation of elderberry savanna.

The restoration of elderberry savanna along the San Joaquin River will likely require a combination of preserving existing patches as a source of elderberry and valley elderberry longhorn beetle population dispersal, and horticultural restoration to expedite recolonization of elderberry and associated plant species. Horticultural restoration techniques are well developed for elderberry in the California and the Central Valley (Oldham and Valentine 1989, Stanley et al. 1989, Alpert et al. 1999), presumably because horticultural restoration of elderberry for valley elderberry longhorn beetle habitat is often required as mitigation for various development projects. While horticultural restoration techniques for the species are well established, little is known about natural seed dispersal and establishment processes for elderberry. This limits our ability to predict the trade-offs between using horticultural restoration entirely vs. using horticultural techniques in a more limited fashion to establish some additional patches initially, but then relying on natural dispersal and establishment of new plants to expand existing patches or establish new patches of elderberry savanna.

3.5.5.6 Central california sycamore alluvial woodland

Description and distribution

Sycamore alluvial woodland is a winter-deciduous broad leafed riparian woodland community type, dominated by California sycamore with open to moderately-closed canopy (Holland 1986). Valley oak, as well as Fremont cottonwood, red willow, and Gooding's black willow can also occur (CDFG 1997). Other woody tree species found within this community type are California buckeye and blue (Mexican) elderberry. The understory is often made up of mule-fat, coffeeberry, buttonwillow, and introduced grasses (Holland 1986). Sycamore alluvial woodlands typically occur along braided, depositional channels of intermittent streams, on cobble or boulder substrates.

In low-gradient rivers, such as the San Joaquin, sycamore alluvial woodlands occur in broad valleys where pronounced stream terraces (usually over 500 ft wide) were formed from fine-grained alluvium (CDFG 1997). The only known sycamore alluvial woodland habitat within the study area is located along Little Dry Creek (Reach 1A; the confluence with the San Joaquin River occurs near RM 260.5), and is approximately 29 acres in size in a narrow band 1-mile long along the creek (CDFG 1997). Because Little Dry Creek retains moisture year-round, wetland plants such as cattail and tule have established within the stand (CDFG 1997). This location is one of only 17 known stands greater than 10 acres of Central California sycamore alluvial woodland, and one of only 11 stands known of the rare "interior alluvial" phase of this vegetation type (CDFG 1997). The largest patch of Central California sycamore alluvial woodland in the state occurs on Los Banos Creek, Merced County (426 acres), in the general vicinity of the study area.

Habitat value

Sycamore alluvial woodland habitat provides cover for many riparian bird species, including Cooper's hawk, Least Bell's vireo, and Swainson's hawk, as well as foliage-roosting bats. Because these habitats often occur at the confluence of tributary streams with larger river channels, sycamore alluvial woodlands also provide important habitat connectivity from upper drainage areas to the valley floor.

Most Swainson's hawk nests occur within 1 mile of the riparian zone (Bloom 1980), usually in the upper canopy or lateral branches of tall trees such as sycamores or cottonwoods. Swainson's hawks were observed at the sycamore alluvial woodland habitat on Little Dry Creek (JSA 2001). Population increases in Owens Valley suggest that Swainson's hawks can respond to improved habitat conditions (Woodbridge 1998). Other species that occupy the same mature tree and gallery forests of riparian systems and may benefit from improved nesting conditions for Swainson's hawks include yellow-billed cuckoos, yellow-billed magpie, long-eared owl, great horned owl, red-tailed hawk, white-tailed kite, Cooper's hawk, great blue heron, and black-crowned night heron (Woodbridge 1998).

Breeding western red bat females are often found in association with cottonwood/sycamore riparian habitat along large river drainages in the Central Valley (Pierson et al. 1999 and 2000). It is believed that this non-colonial species roosts almost exclusively in foliage under overhanging leaves. Preliminary investigations of the western red bat suggest that it is highly associated with cottonwood and sycamore riparian forest, and is more abundant in more mature stands (Pierson et al. 2000).

Habitat restoration target
The following restoration goals for improving the quality and quantity of sycamore alluvial woodland in the San Joaquin River corridor were developed by: (1) identifying current patches of the vegetation type suitable for conservation and enhancement; and (2) identifying areas along the river that have physical and chemical characteristics suitable for supporting sycamore alluvial woodland.

- Preserve the existing sycamore woodland community found in Reach 1A, and promote natural geomorphic conditions within the downstream end of that reach to encourage expansion or establishment of new stands.

The specific physical conditions that support sycamore alluvial woodlands make it a rare vegetation type, even historically (Farquhar 1966, as cited in CDFG 1997). In addition to requiring an alluvial, intermittent stream-bench location, sycamore alluvial woodland stands require periodic flooding, high moisture conditions for seedling establishment, and low grazing pressure (CDFG 1997). Although anthropogenic impacts have undoubtedly exacerbated the situation and decreased the suitable area for recruitment, creating these conditions artificially is difficult given our current understanding of the community.

3.5.5.7 Vernal pools

Description and distribution
Vernal pools are seasonal wetlands that form in shallow, poorly drained depressions outside of the river channel (typically in grasslands), and alternate on an annual basis between drought conditions and periods of standing water (Keeley and Zedler 1998). They are predominantly rain-fed and tend to form perched water tables above duripan or claypan soils (Chetham 1976, as cited in Smith and Verrill 1998). The temporary nature of vernal pools favors organisms that complete an annual life cycle and can withstand both wet and dry periods, resulting in a large number of vernal pool specialists and California endemic flora and, to a lesser extent, in endemic invertebrate fauna (Keeley and Zedler 1998).

Though greatly reduced from their historical distribution (McBain and Trush 2002), remnant vernal pool complexes are found throughout the Central Valley, and are those in teh vicinity of the San Joaquin River typically of the northern claypan type. Many of these pools border extensive alkaline wetlands, particularly near the San Luis National Wildlife Refuge Complex (bordering Reaches 4 and 5). In addition to the claypan vernal pools mentioned above, northern hardpan vernal pools also occur in the vicinity of, but outside of, the immediate project area to the north and south of Reach 1A.

Habitat value
Many of the rare and/or special-status plant, invertebrate, and amphibian species within the project area are associated with vernal pools (McBain and Trush 2002). Thirteen vernal pool plant species, including species of saltbush, navarretia and Orcutt grass, and six vernal pool wildlife species are known to occur in the project area (McBain and Trush 2002). Longhorn fairy shrimp is one of approximately four shrimp species that depends on vernal pools in the San Joaquin basin. Their entire life cycle occurs within seasonal pools, and they are able to withstand years of desiccation before returning to an active state when pools form again. Amphibians,

including the California tiger salamander and western spadefoot toad, rely on these ephemeral wetland areas for the reproductive portion of their life cycle.

Additionally, vernal pools provide feeding and roosting habitat for both resident and migratory birds, including many species of waterfowl and shorebirds. Although they are limited both in spatial and temporal extent, vernal pools provide short but very productive periods of invertebrate prey abundance during the springtime, which is critical to waterfowl survival and recruitment (Silveira 1998). As pools begin to dry, they are used for a variety of other purposes. Cliff swallows glean mud from vernal pools for nest material, tricolored blackbirds forage in dry pool beds, and lesser nighthawks nest in dry pool beds (Silveira 1998).

Habitat restoration target

The following restoration goals for vernal pools in the San Joaquin River corridor were developed by reviewing the scientific literature regarding this rare ecosystem and the species that are specially adapted to it.

- Avoid impacts on, and protect and enhance where possible, existing vernal pools within the restoration planning area. Where active restoration efforts are to occur, it is critical to survey for vernal pools prior to construction, to avoid both direct construction impacts and localized hydrologic impacts that may affect vernal pool formation. If the pools cannot be avoided, then creation of vernal pool complexes as mitigation must be considered, recognizing the potential difficulties and uncertainties associated with active creation of this rare habitat.
- Consider appropriate grazing regimes when developing management plans for vernal pools. All special-status fairy shrimp species are open water, planktonic forms (D.C. Rogers, pers. comm. 2003). If grazing is completely eliminated from the restored areas, vernal pools tend to fill with vegetation, especially invasive grasses, and this promotes habitat for mosquitoes (D.C. Rogers, pers. comm. 2003). If the sites are overgrazed, manure in the runoff often causes nutrient enrichment and produces a similar effect (D.C. Rogers, pers. comm. 2003).

Vernal pool complexes have been greatly reduced from their historical extent. Fragmented and isolated patches still occur throughout the Central Valley. Within the project area, these areas are typically found near the San Luis National Wildlife Refuge Complex bordering Reaches 4 and 5. Although they are typically associated with claypan soils, the microtopography responsible for their formation is difficult to identify via the coarse-scale GIS analysis used to map other vegetation types in the project area (see Restoration Objectives Report). Site-specific field observations should be employed when restoration planning has proceeded to a more refined scale (e.g., when sites for active re-construction have been identified).