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.

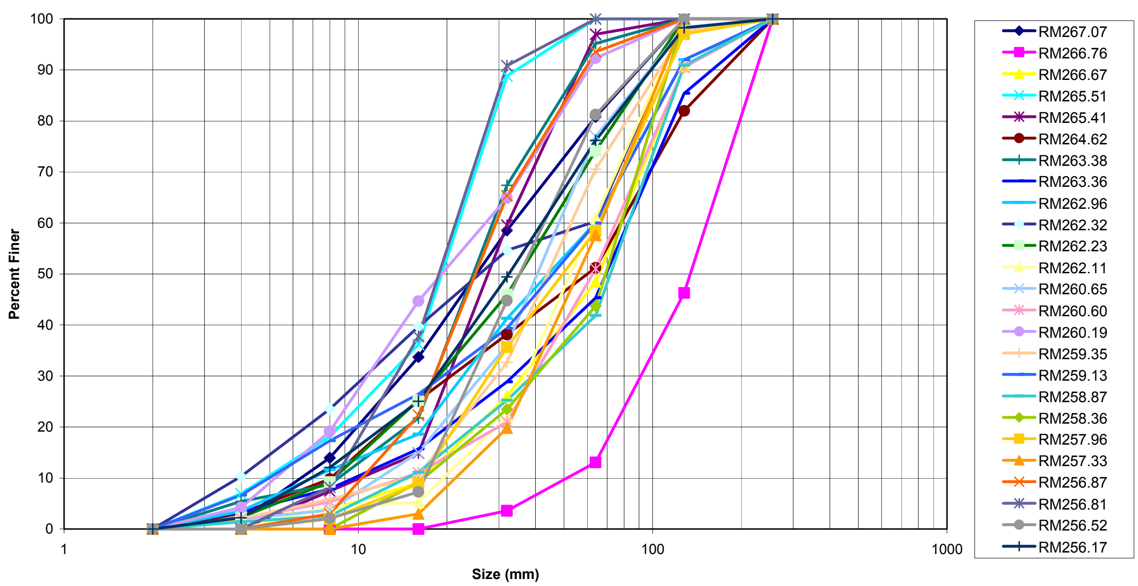

Figure 3.1-1. Surface grain size distribution for Reach 1A of the San Joaquin River. Stillwater Sciences conducted pebble counts to characterize the channel bed in Reach 1A. This figure shows the size distribution for each individual pebble count. Sediment particles finer than 2 mm were excluded from 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.

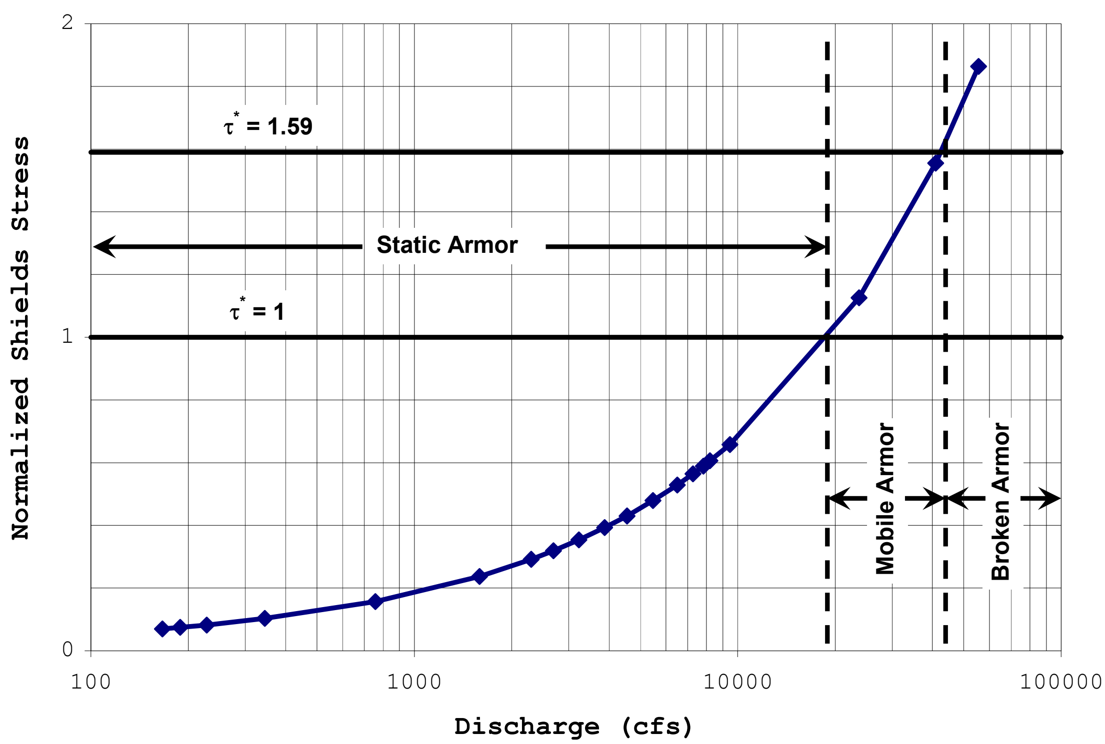

Figure 3.1-2. Periodicity of historical bed mobilization and scour for Reach 1. A Shields stress value of 1 indicates the threshold for the mobilization of individual bed surface particles, and a value of 1.59 represents the threshold for bed scour. (The regime of static armor, mobile armor and broken 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).

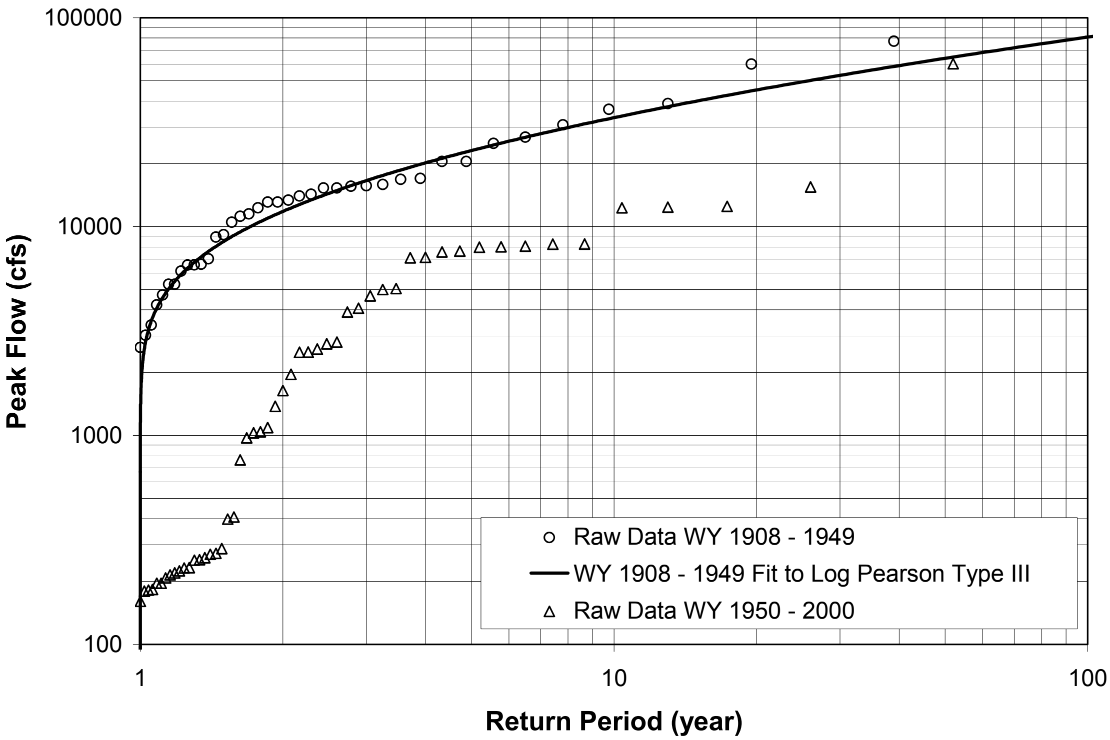

Figure 3.1-3. Peak flow recurrence in Reach 1 of the San Joaquin River. A pre-dam flow of 20,000 cfs corresponds with a return period of 4 years, and a discharge of 40,000 cfs represents a 15-year return period. This analysis represents flow conditions at the USGS Gauge at Friant Dam (no. 11251000).

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).

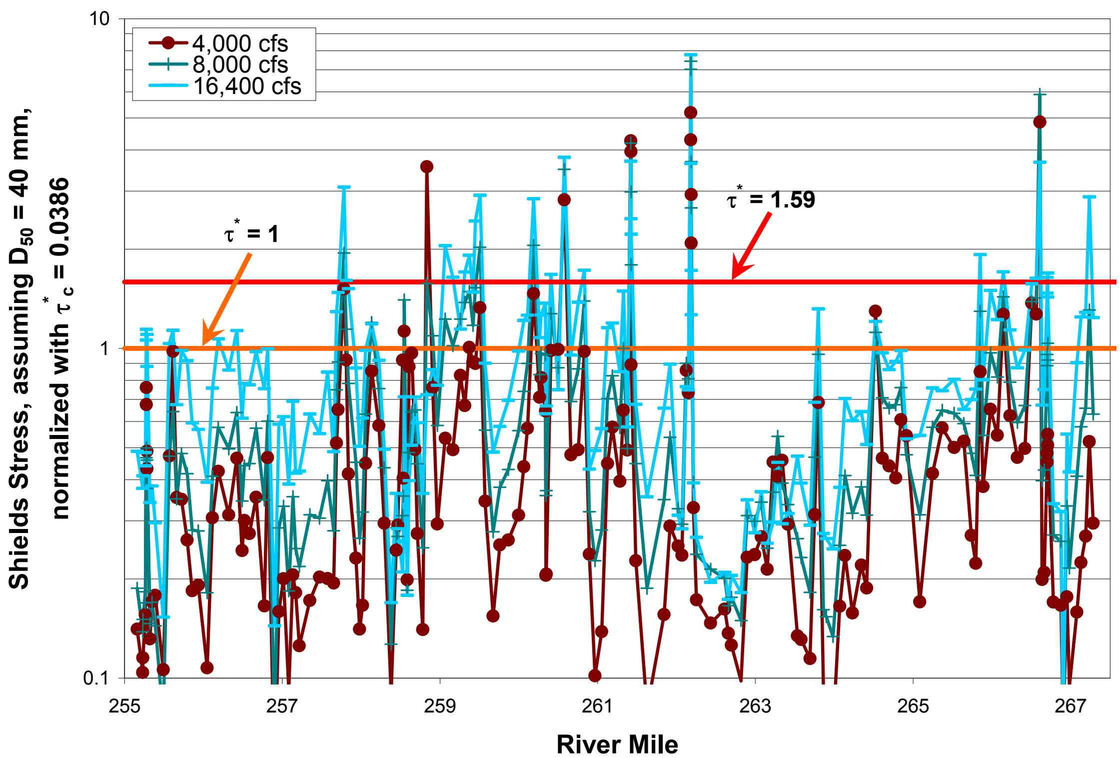

Figure 3.1-4. Pools within Reach 1 disrupt bedload routing (assuming a median grain size of 40 mm). These results are based on MEI HEC-2 results, a median grain size of 40 mm, and a critical Shields stress of 0.0386. Flows within the managed release capacity of Friant Dam will likely be sufficient to 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).

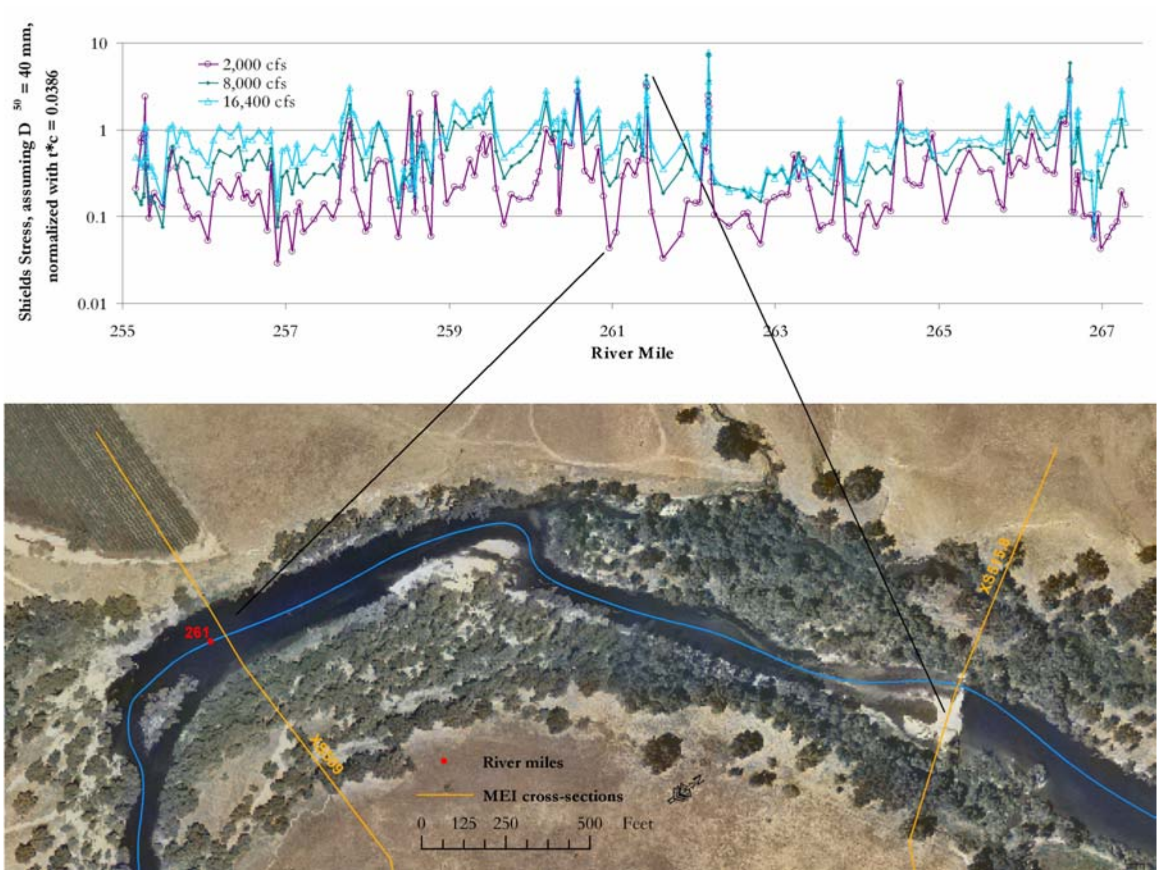

Figure 3.1-5. Pools in Reach 1 as gravel sinks. There are numerous riffles within Reach 1 where flows within the managed release capacity of Friant Dam will produce local shear stresses capable of mobilizing gravel. However, this gravel will likely deposit in pools, where shear stresses will not be sufficient 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.

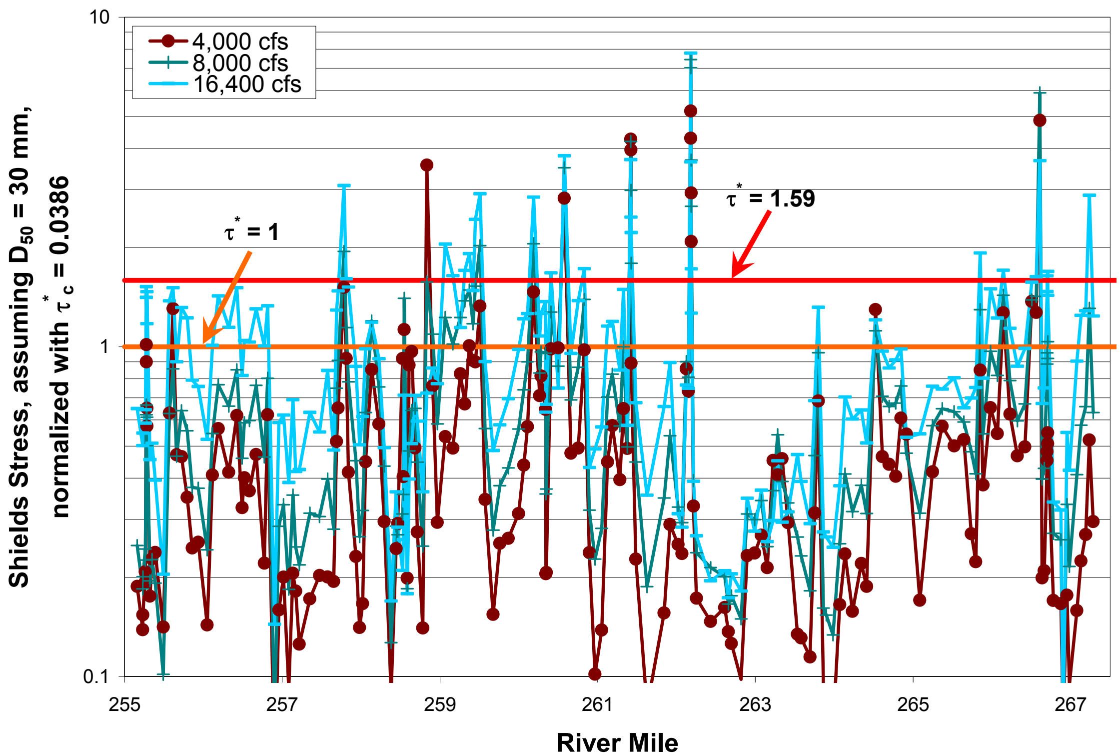

Figure 3.1-6. Sediment mobility and scour for a median grain size of 30 mm using local shear stresses. These results are based on MEI HEC-2 results, a median grain size of 30 mm, and a critical Shields stress of 0.0386. Introducing finer sediment to Reach 1A will not effectively restore general bedload 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.

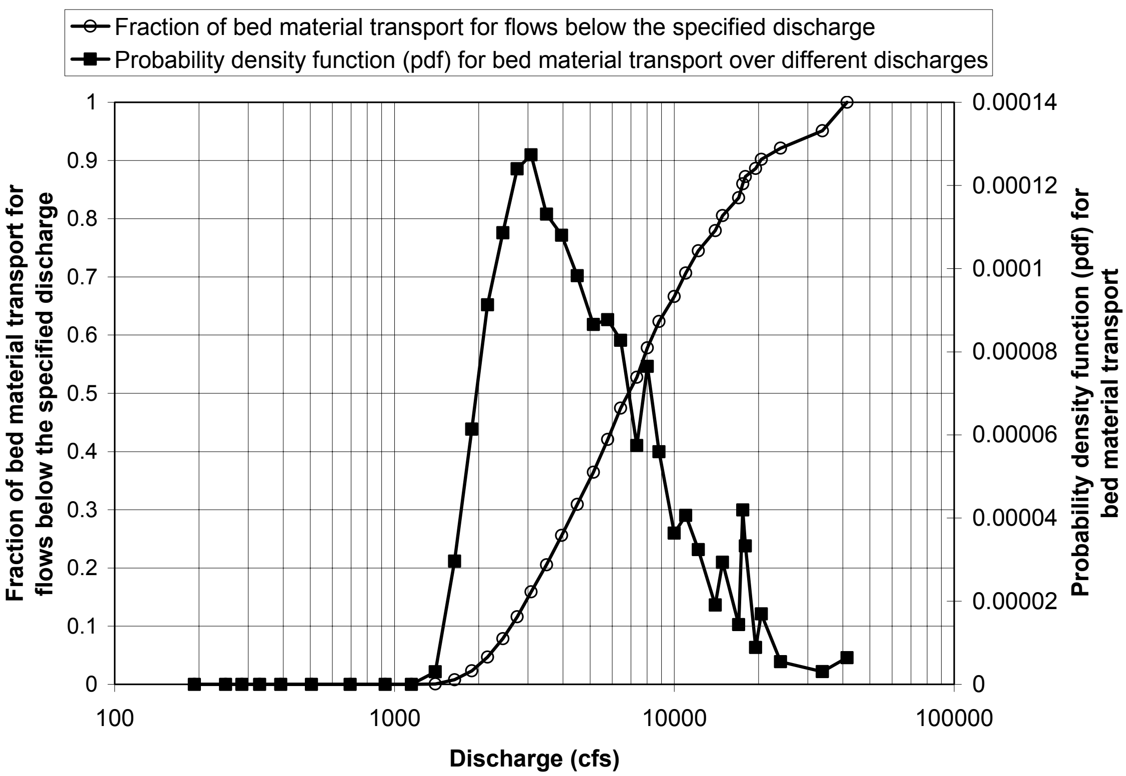

Figure 3.1-7. Estimated historical sediment transport regime in Reach 2, based on Brownlie's bed material equation (Brownlie 1982). Relatively low flows between 2,000 cfs and 3,000 cfs were sufficient to mobilize a significant portion of the bed material in Reach 2. (This estimate is based on flow data 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.

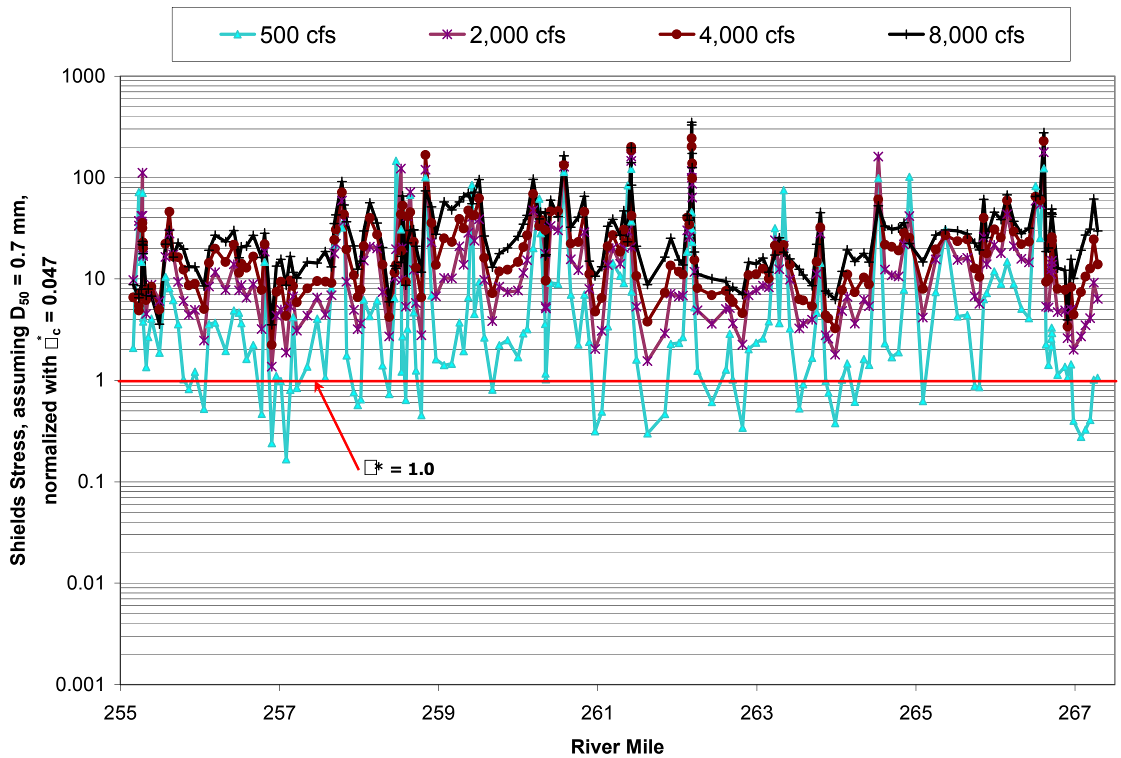

Figure 3.1-8. Mobility of sand for a range of flows. Shields stress is calculated based on an assumed median grain size of 0.7 mm and an assumed bankfull channel width of 300 ft. A normalized Shields stress value of 1.0 indicates the threshold of mobility. This plot shows that flows as low as 200 cfs 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.

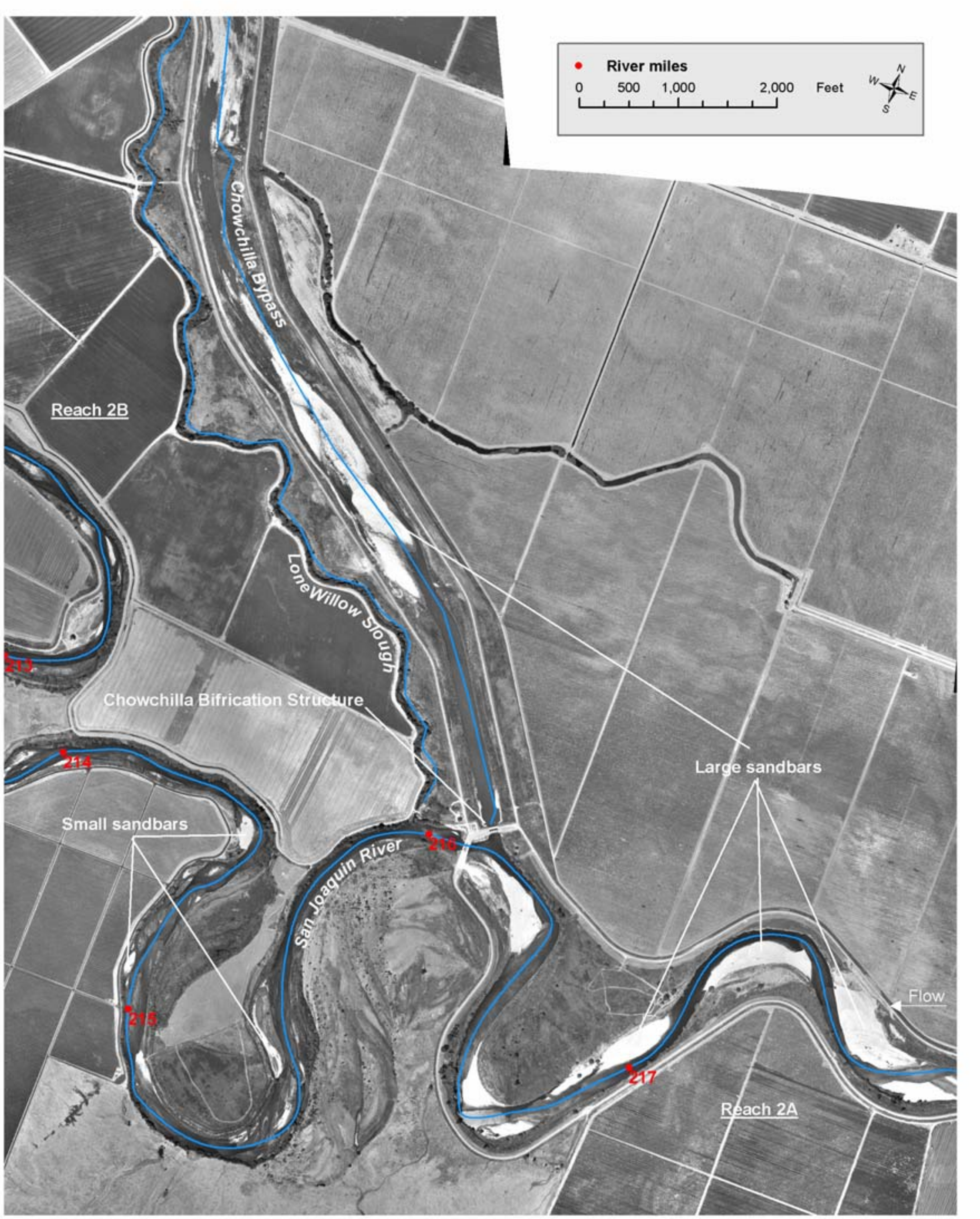

Figure 3.1-9. Restoring sediment supply and routing in Reach 2B. Current operation of the Chowchilla Bifurcation Structure directs a higher proportion of flow, and therefore sediment, into the Chowchilla Bypass during high flow events. As a result, the sediment supply to Reach 2B is reduced.

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.