# CHAPTER 5. WATER-RELATED INFRASTRUCTURE AND HUMAN CHANNEL MODIFICATION

## 5.1. INTRODUCTION AND BACKGROUND

Since the 19th century, significant levels of agricultural and economic growth have spurred the development of water related infrastructure and modifications along the San Joaquin River. In response to the increased irrigation demands from urban and agricultural needs, many large storage dams, small diversion dams, seasonal diversions and pumps, canals, bypasses, and other control structures have been constructed. Additionally, many of the historic sloughs and side channels were used for irrigation water conveyance in the later 1800s and early 1900s, and these channels continue to be used for agricultural conveyance, tailwater conveyance, and/or flood control bypasses. Some have been filled in and reclaimed for agricultural use. Today, the San Joaquin River is managed primarily with irrigation and flood control objectives, leaving the overall ecological health of the San Joaquin River ecosystem in a degraded condition.

During this development, the San Joaquin River has been transformed into a system of leveed channels with a highly managed flow regime. Floodways have been narrowed, sloughs and side channels have been modified or eliminated, sediment transport processes have been altered, certain reaches have been dewatered, and fish passage barriers have been constructed. These factors have imposed substantial constraints on future restoration efforts along the San Joaquin River corridor.

The development of the modern San Joaquin River began in the mid 1800's as the search for gold brought small-scale hydraulic and placer mining to the watershed. By 1879 an estimated 53 million cubic yards of material were being washed down the Sacramento and San Joaquin rivers by hydraulic mining operations (ACOE 1999a). The excessive amount of mining debris was transported downstream, where it settled, reduced channel capacities, and increased the amount of flooding of lower lying areas. Because the scale of hydraulic mining operations along the upper San Joaquin River mainstem were relatively small compared to mining activity along the San Joaquin River tributaries and the Sacramento River, direct impacts of gold mining was much less than the Central Valley rivers north of the San Joaquin River. Timber harvesting during the gold rush era may have also elevated sediment loads to the upper San Joaquin River, but there is no quantitative data to verify potential impacts.

Throughout the gold rush, agricultural development was also prominent near the banks of the San Joaquin River to feed the gold miners and new settlers. As agricultural uses began to expand, more of these newly developed areas were being damaged during winter flooding. Thus, landowners began to protect their developments by constructing their own levees. Water surface elevations continued to rise as channels became narrower from levee construction and shallower from the accumulation of mining debris. Throughout this period, landowners were regularly inundated with flood waters and mining debris. In 1884, the Sawyer Decision stopped virtually all mining activities throughout California. In 1893, the Federal Government modified the original court ruling and allowed hydraulic mining to continue under the supervision of the California Debris Commission (CDC).

By 1894, many miles of levees had been constructed and many flood control districts had been developed along the San Joaquin River to provide some level of flood protection. The high flow regime was still largely unregulated at this time, so these early efforts in flood protection were generally inadequate. The first comprehensive flood management plan for the Central Valley was sent to Congress in 1910. Under this plan, flood flows would be routed away from developed areas through a series of bypass channels and overflow basins. On the San Joaquin River, this plan included:

- Construction and repair of levees along the riverbanks in Reaches 2A, 4B, and 5;
- Construction of artificial channels or "bypasses" used to convey floods;
- Construction of hydraulic control structures to divert water from the main channel.

The next phase of development occured when the Central Valley Project (CVP) was authorized by Congress in 1933 to meet the increasing water demand in southern and central California. This plan included an extensive water conveyance and storage system that would provide irrigation water to the Central Valley and increase domestic water supply to southern California. As part of this plan, construction of Friant Dam was completed in 1941 to store and divert water from the San Joaquin River.

The San Joaquin River and Tributaries Project (SJRTP) was authorized in the Flood Control Act of 1944. Construction of the SJRTP was initiated in 1956. The SJRTP included the construction of levees along the San Joaquin River below the Merced River confluence, the Stanislaus River, Old River, Paradise Cut, and Camp Slough. The Chowchilla and Eastside Bypasses were constructed under the SJRTP by the State of California during the same time period.

The Flood Control Act of 1944 authorized other projects that would effect flooding in the San Joaquin River. After significant flooding events in 1955, construction of levees and bypasses along the upper San Joaquin River was authorized. Pine Flat Dam on the Kings River was completed in 1954, Buchanan Dam on the Chowchilla River was completed in 1975, and Hidden Dam on the Fresno River was completed in 1975. All of these reservoirs were constructed to provide domestic and agricultural water supplies, flood control, and in some cases, power generation (ACOE 1999a).

The last three decades have been devoted entirely to the repair of levee damage that has occurred as the result of many recent flooding events (1970, 1974, 1983, 1986, 1995, and 1997). Most of this work has been conducted on the Sutter Bypass and the Feather, Yuba, Sacramento Rivers. Little work has been done to repair and/or construct new levees along the San Joaquin River corridor. Most of these repair projects have been overseen by the U.S. Army Corps of Engineers (ACOE) and have been conducted in response to potential situations that pose immediate danger to life or developed property.

As a consequence of the past and ongoing infrastructure development along the San Joaquin River, there have been large-scale impacts on the geomorphological and ecological processes of the San Joaquin River. These impacts continue, and will have a significant influence on future efforts to rehabilitate the river. This chapter describes the basics of flood control and water supply infrastructure in the San Joaquin River, and provides a brief description of some of the broad geomorphic and ecological impacts of the infrastructure components. Discussion of opportunities and constraints is also provided.

## 5.2. STUDY AREA

The project study area includes the main channel of the San Joaquin River and the corresponding diversion channels and flood control bypasses from Friant Dam to the Merced River confluence. The adjacent flood control bypasses are also included because they may provide future fish passage opportunities and constraints to future restoration efforts. This area covers approximately 150 miles of river corridor through the Fresno, Merced, and San Joaquin Counties within the Central Valley of California. The study area begins at the base of Friant Dam at river mile (RM) 267.5, and ends near the Merced River confluence at RM 118 (Figure 5-1). A brief discussion of infrastructure, and restoration opportunities and constraints downstream of the Merced River confluence is presented in Chapter 12 rather than this chapter.

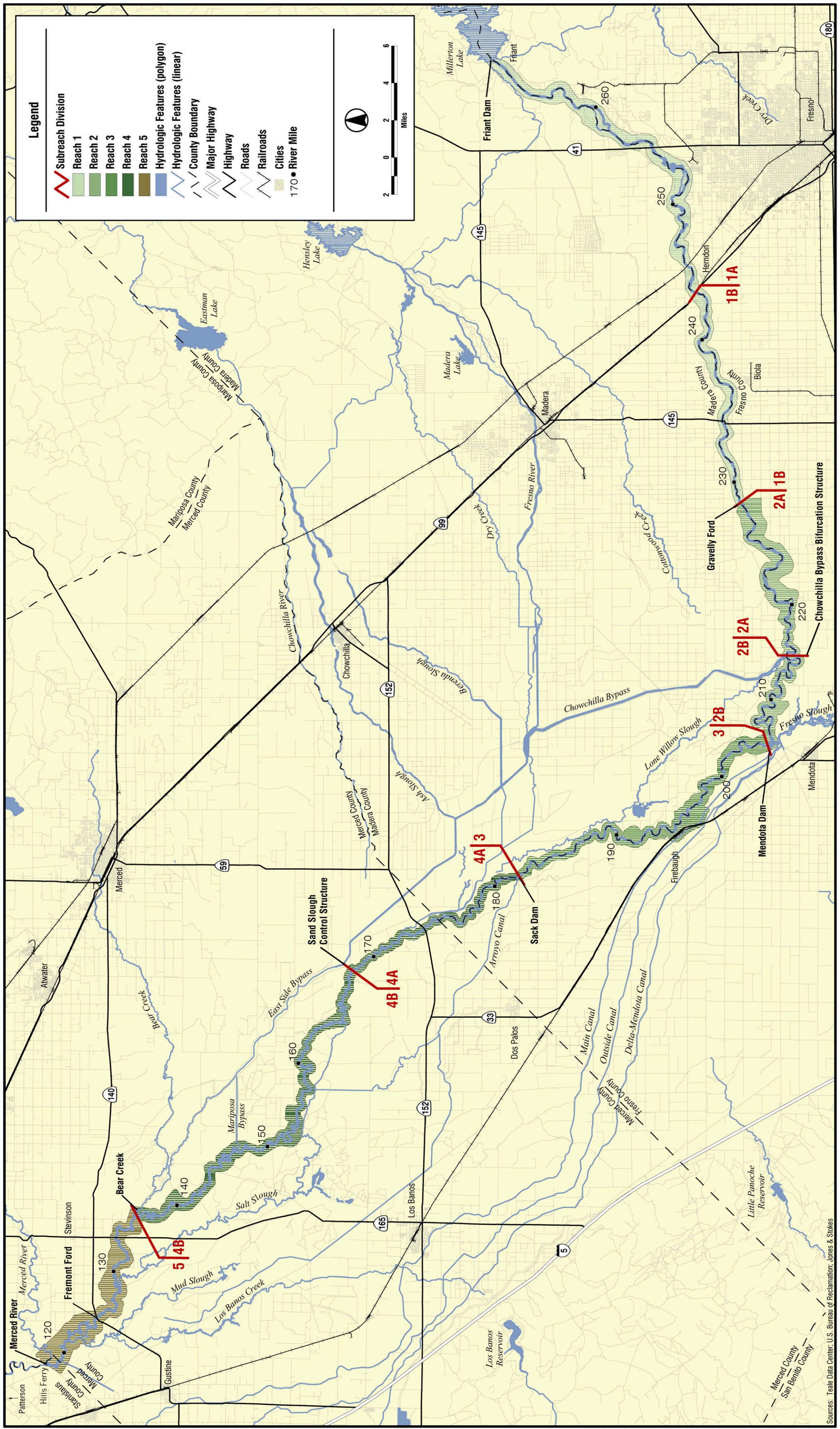
## 5.3. OBJECTIVES

The objectives of this chapter focus on describing opportunities and constraints of infrastructure along the San Joaquin River study reach. From the April 2000 scope of work, primary objectives of this chapter are:

- describe and evaluate flood control infrastructure of the San Joaquin River from Friant Dam to the Merced River confluence, including outlet works constraints for Friant Dam, operating criteria for structures, capacities of channels and bypasses, and future infrastructure and flood control changes;
- describe and evaluate water supply infrastructure of the San Joaquin River from Friant Dam to the Merced River confluence, including typical operations for Friant Dam, Mendota Dam, and Sack Dam;
- describe and evaluate other existing engineered infrastructure (e.g., bridges, mining pits) affecting the San Joaquin River from Friant Dam to the Merced River confluence;
- describe and map riparian water right holders and diversion infrastructure that may constrain restoration;
- describe, evaluate, and map lands along the river where seepage is or may be a potential problem;
- describe potential direct impacts of infrastructure components on the San Joaquin River, and discuss how these potential impacts may influence future restoration efforts along the San Joaquin River corridor; and
- identify potential opportunities and constraints of infrastructure components on restoration efforts from Friant Dam to the Merced River confluence.

## 5.4. DESCRIPTION OF WATER-RELATED INFRASTRUCTURE AND HUMAN CHANNEL MODIFICATIONS

Each component of water related infrastructure within the San Joaquin River corridor was constructed for the purpose of either flood control or water supply. Dams have been constructed to eliminate or reduce peak flood flows, store water, and divert water from the mainstem San Joaquin River. Canals and pipes are used to convey water to other regions. Canals and ditches are also used to drain agricultural lands, many of which return flows back to the San Joaquin River. Levees line the edge of the channel to protect low-lying agricultural lands from flooding, and bypasses have been constructed to direct floodwaters away from other agricultural lands and urban developments. These structures have impaired the natural ecological processes of the river by changing the flow regime and by making physical modifications to the floodway. The following sections provide an overview of existing information relating to the water supply and flood protection structures along the San Joaquin River.



Sources: Teale Data Center; U.S. Bureau of Reclamation; Jones & Stokes

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*Figure 5-1. Project area of the San Joaquin River Restoration Study showing Reach and Subreach boundaries.*

### 5.4.1. Overview of the San Joaquin Water Supply System

Runoff from the upper reaches of the San Joaquin watershed flow into Millerton Reservoir. Millerton Reservoir is created by Friant Dam and has a total storage of 520,500 acre-feet (DOI 1981), and average annual "full natural flow" computed by USBR from 1906-2002 at Friant Dam is approximately l,801,000 acre-feet (USBR 2002). Using a consistent time period of 1950-1989, the average annual output of water (diversions+downstream releases into the San Joaquin River) is 1,795,000 acre-ft, the full natural flow is 1,812,000 acre-ft, for a deviation of 17,000 acre-ft (Figure 5-2). Nearly all of the water stored in Millerton Reservoir is used for agriculture, municipal, and industrial purposes, and major water infrastructure components are listed in Table 5-1.

At Friant Dam, water is diverted into the Friant-Kern Canal and Madera Canal for delivery to water users in Tulare, Madera, Merced, Fresno, and Kern counties (Figure 5-2). The capacity of the Friant-Kern Canal and Friant-Madera Canal is 5,300 cfs and 1,200 cfs, respectively.

Friant Dam releases flows into Reach 1 to supply riparian water right holders. Under the terms of the water rights holding contracts, the Bureau of Reclamation is required to maintain at least 5 cfs past each riparian diverter. The downstream-most riparian diverter is located just upstream of Gravelly Ford (RM 228), so the Bureau of Reclamation uses the Gravelly Ford gaging station as a check to ensure that it is meeting its flow release obligations. This normally results in a 40 to 100 cfs release from Friant Dam in the winter and ranges from approximately 180 to 250 cfs in the summer. The larger summer release supplies riparian water right holders between Friant Dam and Gravelly Ford. During typical summer seasons, the river is dry between Gravelly Ford and Mendota Pool (Reach 2A and Reach 2B).

Mendota Pool receives flow from the Delta Mendota Canal and sometimes receives flow from Fresno Slough when the Kings River is flooding and from the San Joaquin River when operations at the Chowchilla Bifurcation Structure dictate. Mendota Dam releases up to 600 cfs during the irrigation

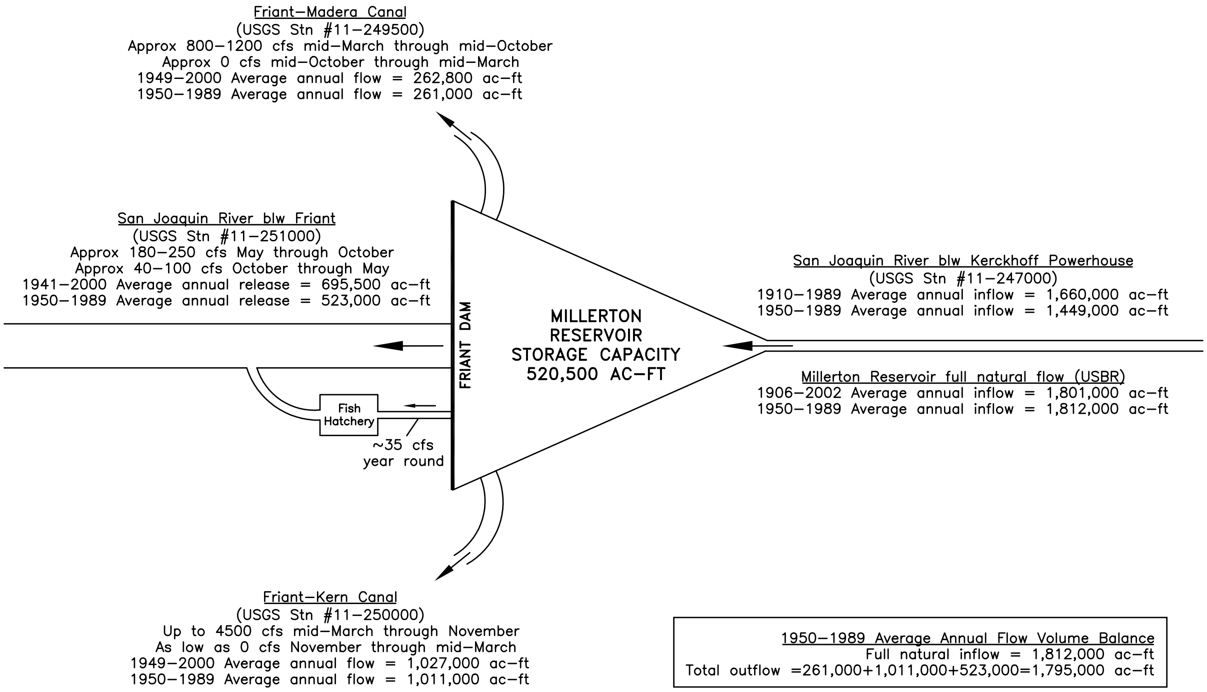

*Figure 5-2. Diagrammatic of typical river releases and diversions from Friant Dam during summer irrigation season and winter non-irrigation season.*

season, which is conveyed northward in the San Joaquin River through Reach 3 to Sack Dam (about 30 miles). At Sack Dam, all flow above 600 cfs is diverted into Arroyo Canal for delivery to various irrigation districts (exchange contractors), to refuges, and to wetlands in the western Grasslands area. Flows are intermittent in the reach immediately below Sack Dam (Reach 4A) and consist almost entirely of agricultural return water from the San Luis Unit. This water is again pumped from the channel and reused for local irrigation. Downstream of the Sand Slough Control Structure (Reach 4B), the river is again perennially dry.

*Table 5-1. Major water-supply infrastructure components from Friant Dam to the Merced River.*

| Element | Location (River Mile) | Description and Comments |
|---|---|---|
| **Reach 1A** | | |
| Friant Dam | 267.5 | Forms Millerton Lake. Total storage is 520,500 acre-feet (af) of which 170,000 acre-feet can be reserved for flood control. Most stored water is delivered via Friant-Kern Canal (capacity = 5,300 cfs) and Friant-Madera Canal (capacity = 1,200 cfs). Friant Dam has blocked fish access to upstream reaches since 1941. |
| Big Willow Unit Diversion | 261.3 | Cobble and rock weir structure diverts flow to the Department of Fish and Game DFG fish hatchery. |
| Rank Island Diversion | 260 | Cobble weir structure diverts about 5 cfs from the main channel. |
| Unnamed Diversion | 247.2 | Rock weir provides head for a pumping station upstream. |
| **Reach 1B** | | |
| Unnamed Diversion | 228.2 | Sand and gravel berm constructed to provide head for upstream pumping facility |
| **Reach 2B** | | |
| Columbia Canal | 206-183 | Right bank canal that borders the river, intake from Mendota Pool (typical irrigation season diversion = 200 cfs) |
| Helm Ditch | 204.6-197.5 | Left bank ditch, intake from Mendota Pool (typical irrigation season diversion = 5 to 10 cfs) |
| Mendota Dam | 204.6 | Headworks for regulating water that is conveyed into the system through the Delta-Mendota Canal. Has no flood storage capacity. Barrier to upstream fish passage with boards in dam. Has fish ladder that is non-functional. Mendota Dam is scheduled to be rebuilt soon. |
| Fresno Slough | 204.6 | Left bank slough, intake from Mendota Pool (typical irrigation season diversion= 300 cfs) |
| Delta-Mendota Canal | 204.6 | Delivers 800 to 2,800 cfs to left bank of Mendota Pool from Delta |
| FCWD Canal | 204.6 | Left bank canal, intake from Mendota Pool (typical irrigation season diversion = 300 cfs) |
| Main Canal | 194.5 | Left bank canal, intake from Mendota Pool (typical irrigation season diversion = 1,500 cfs). |
| Outside Canal | 198.0 | Left bank canal, intake from Mendota Pool (typical irrigation season diversion = 300 cfs). |
| **Reach 3** | | |
| Sack Dam | 182.0 | Low-head earth and concrete structure with wooden flap gates that diverts Delta-Mendota Canal flows into the Arroyo Canal. |
| Arroyo Canal | 182.0 | Left bank canal, intake from Sack Dam, diverts Delta-Mendota Canal (typical irrigation season diversion = 500 to 600 cfs, diverts all flows up to 600 cfs) |
| **Reach 4** | | |
| Reach 4B headgate | 168 | Earthfill plug of San Joaquin River with headgate culverts controlling flow into Reach 4B of the San Joaquin River. |

Friant Dam, Mendota Dam, Sack Dam, and several other small diversion dams located between Friant Dam and the Merced River confluence are discussed in the following sections.

#### 5.4.1.1. Friant Dam and Associated Diversions

The U.S. Bureau of Reclamation (USBR) constructed Friant Dam (RM 267) in 1941, creating Millerton Lake. This reservoir has a published storage capacity 520,500 acre-feet (DOI, 1981). During typical irrigation seasons, approximately 180 to 250 cfs is released to the San Joaquin River for downstream riparian water rights holders (Figure 5-2). Flows between 50 and 100 cfs typically released during the winter months to meet a lower diversion demand. In both cases, the releases must maintain at least 5 cfs past all riparian diversions. Because the downstream-most diversion is just upstream of Gravelly Ford, the Bureau of Reclamation tends to use the Gravelly Ford gaging station to ensure that they are meeting the 5 cfs requirement. Water is also distributed to the Friant-Madera and Friant-Kern canals during the irrigation season, with rated capacity of the Friant-Kern Canal of 5,300 cfs, and the rated capacity of the Friant-Madera Canal of 1,200 cfs. Typical irrigation diversions into the Madera Canal are 800 to 1,200 cfs, and typical irrigation diversions into the Friant-Kern Canal is up to 4,500 cfs (USGS gaging records from 1948-2000). Diversions into the canals during the winter months are often zero, but the canals are sometimes used to convey flows during flood control releases.

As mentioned above, typical flow releases from Friant Dam are typically less than 250 cfs. The exception is during periods of large inflows from the watershed that encroach into the flood control space in Millerton Lake. The outlet works capacity of Friant Dam varies with reservoir elevation, with maximum release capacity of 16,400 cfs at a reservoir elevation of 578 ft (Figure 5-3); therefore, most flood control releases are made through the outlet works. Larger floods, like the 60,000 cfs flood in 1997, exceed the capacity of the outlet works and enter the San Joaquin River via the spillway. The present operating rules during flood events for Friant Dam require that releases from the dam be restricted to levels that will not cause downstream flows to exceed, insofar as possible, either of the following criteria (ACOE 1980):

- a combined flow of 8,000 cfs to the San Joaquin River from Friant Dam, Cottonwood Creek, and Little Dry Creek, and
- a flow of 6,500 cfs at the gage near Mendota (below Mendota Dam).

The construction and operation of Friant Dam has impacted the San Joaquin River in three significant ways. First, reduced San Joaquin River releases from the Friant Dam, combined with downstream riparian diversions, have dewatered most of Reach 2 and Reach 4, preventing fish use and passage in most years. Second, even if fish could migrate up river, Friant Dam is a barrier for upstream fish migration, and thus the furthest upstream boundary for salmonid migration. Lastly, Friant Dam has reduced the high flow regime and eliminated sediment supply from the upper watershed. The recurrence interval of an 8,000 cfs flow at Friant has been increased from 1.3-year flood (pre-Friant Dam) to a 6-year flood by cumulative dams upstream of and including Friant Dam. Most of the coarse sediment supply is trapped in Millerton Reservoir and upstream reservoirs rather than routed downstream to provide salmonid spawning habitat. Therefore, coarse sediment available for other fluvial processes such as channel migration, riffle-pool formation, and sediment deposition must come from the coarse sediment stored in the channel itself. Hydrology, geomorphology, fishery, and riparian impacts of Friant Dam are discussed in more detail in Chapters 2, 3, 7, and 8, respectively.

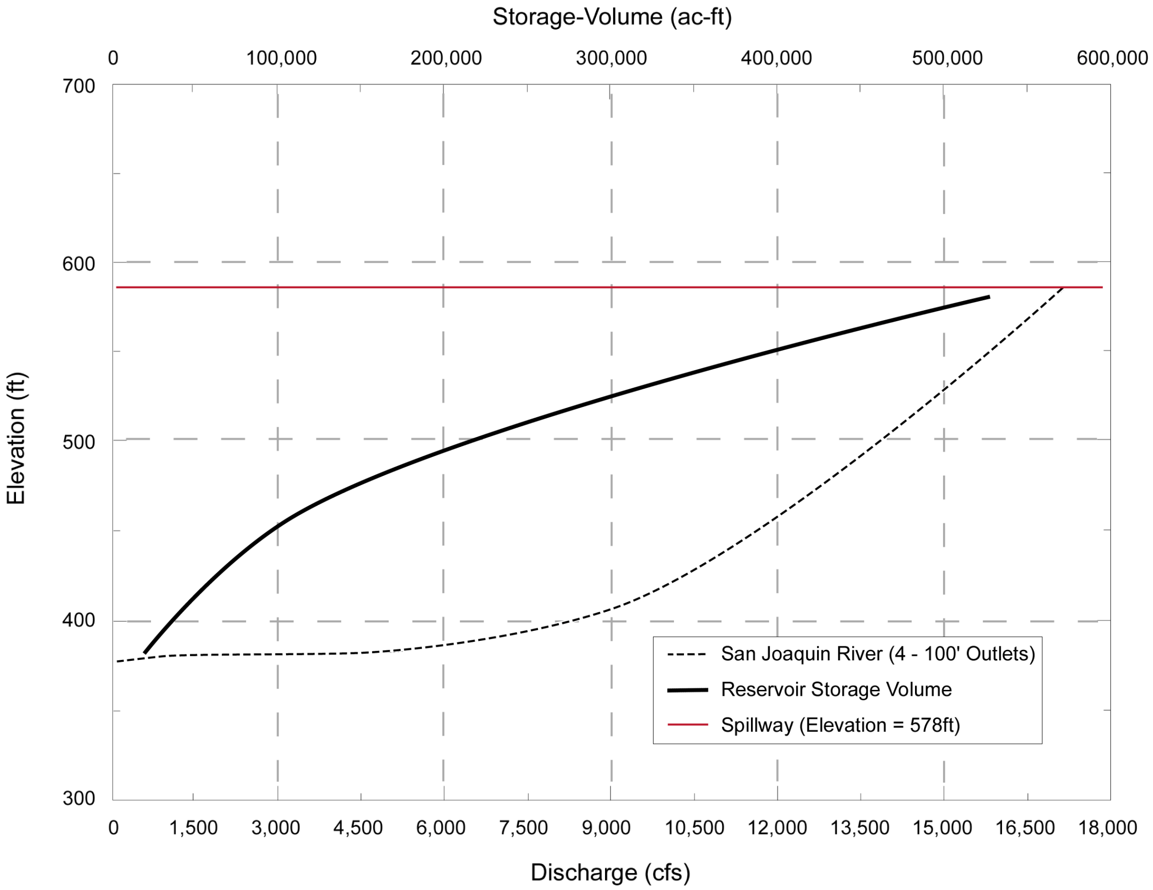

*Figure 5-3. Friant Dam storage curve and outlet works release rating as a function of Millerton Reservoir stage.*

### 5.4.1.2. Mendota Dam and Pool

Mendota Dam (RM 204.6) is located at the confluence of the San Joaquin River and Fresno Slough (Figure 5-1, Table 5-1). Fresno Slough connects the Kings River to the San Joaquin River, and delivers water to the south from Mendota Pool during the irrigation season, and delivers water to Mendota Pool and the San Joaquin River from the Kings River when the Kings River is flooding. Mendota Pool is the small reservoir created by Mendota Dam (3,000 acre-ft) and has a surface area of approximately 1,200 acres. The pool behind the dam redistributes water delivered by the Delta-Mendota Canal to canals that convey water for agricultural use. Mendota Pool does not provide any appreciable flood storage. The water surface elevation in the pool is maintained by a set of manual gates and flashboards that are manually opened/removed in advance of high flow conditions. This process lowers the water level in the pool to pass high flows to reduce seepage impacts to adjacent lands, but hinders distribution of flows into the canals.

Mendota Dam serves as a complex water distribution manifold to many diversions and riparian pumps, all of which are unscreened or do not meet National Marine Fisheries Service (NMFS) and California Department of Fish and Game (CDFG) screening criteria for salmonids. This complex area of water diversions will be a considerable constrain to salmonid restoration efforts due to the unscreened diversions and large volume of water exchanged in the Mendota Pool. Mendota Dam and Mendota Pool have been used for irrigation diversions since the late 1800s, and had historically depended on San Joaquin River and Fresno Slough flows to divert into irrigation canals originating from Mendota Pool. After completion of Friant Dam in 1948, flows to Mendota Pool from the San Joaquin River was greatly decreased. Completion of the Delta-Mendota Canal in 1951 delivered water pumped from the Bay-Delta to Mendota Pool. The DMC has a rated capacity of 4,600 cfs (DOI, 1981); however, typical water delivery by the DMC during the irrigation season is approximately 2,500 to 2,800 cfs (Figure 5-4), with no water delivered to Mendota Pool by the San Joaquin River or Fresno Slough during the irrigation season. Five diversion canals extract all but 500 to 600 cfs of water delivered to the Mendota Pool complex by the DMC. Mendota Dam releases this remaining flow into Reach 3 of the San Joaquin River. This release flows approximately 22 miles downstream to Sack Dam, where it is diverted into the Arroyo Canal.

Although Mendota Dam is much smaller than Friant Dam, it is substantial barrier to the upstream and downstream migration of salmonids. While there is a fish ladder on the dam, it has been inoperable since the late 1940’s, and erosion on the downstream side of the dam has perched the entrance to the ladder above the water surface. Therefore, adult salmonids (and other fish) cannot migrate upstream past the dam during typical flow conditions (it is potentially passable when all the boards are pulled, but water velocities may still be too great for passage) and the fish ladder would need to be reconstructed to be usable. In addition, downstream migrating juvenile fish would likely incur high entrainment losses through the unscreened diversions and canals.

The water delivered by the DMC contains much higher concentrations of Total Dissolved Solids and is more saline than San Joaquin River water released from Friant Dam. In addition to potential impacts on fishery restoration efforts by poorer water quality, there may be problems with juvenile salmonids imprinting on Delta-Mendota Canal water rather than San Joaquin River water.

Over time, Mendota Dam has partially filled with sediment during infrequent high flow releases from Friant Dam. During these higher flows when the flashboards have been pulled, some unknown portion of this sediment is able to flush and route downstream, such that Mendota Pool has retained much of its storage capacity. If the flashboards are not been pulled prior to a high flow from the San Joaquin River or Fresno Slough, the increased water surface elevations cause seepage problems on upstream and adjacent properties. Additionally, there have been recurring problems with water seeping under Mendota Dam, threatening the structural integrity of the dam. Mendota Pool is drained every other year to inspect the dam footings. These combined problems with Mendota Dam have led to preliminary designs of a new Mendota Dam approximately 300 ft downstream of the existing structure. Hoping to incorporate solutions to some of the fishery and sediment routing constraints imposed by the current Mendota Dam and diversions, the San Joaquin Restoration Oversight Team (ROST) has initiated technical discussions for solutions that could be integrated with the USBR effort to replace Mendota Dam. Future restoration hurdles include adult and juvenile fish passage, sediment routing, operations of pool during high flows in San Joaquin River and Fresno Slough, screening to prevent juvenile fish entrainment into the canals, and alleviating seepage problems occurring through nearby non-project levees during higher flows.

#### 5.4.1.3. Sack Dam

Sack Dam (RM 178) is a low-head structure used to control water released from the DMC as part of the diversion into Arroyo Canal. All flows conveyed through Reach 3 less than 600 cfs are typically diverted into Arroyo Canal. Larger flows continue downstream through Reach 4A and are diverted into the Eastside Bypass at the Sand Slough Control Structure (RM 168.5). Because of their similar operational objectives, many impacts associated with Sack Dam are similar to those of Mendota Dam (see Section 5.4.1.2). The major difference between the two structures is that Sack Dam is much smaller, and the fish ladder can be easily fixed to be fully functional. Therefore, adult fish passage is not a significant constraint. Juvenile fish entrainment into the Arroyo Canal, however, represents a

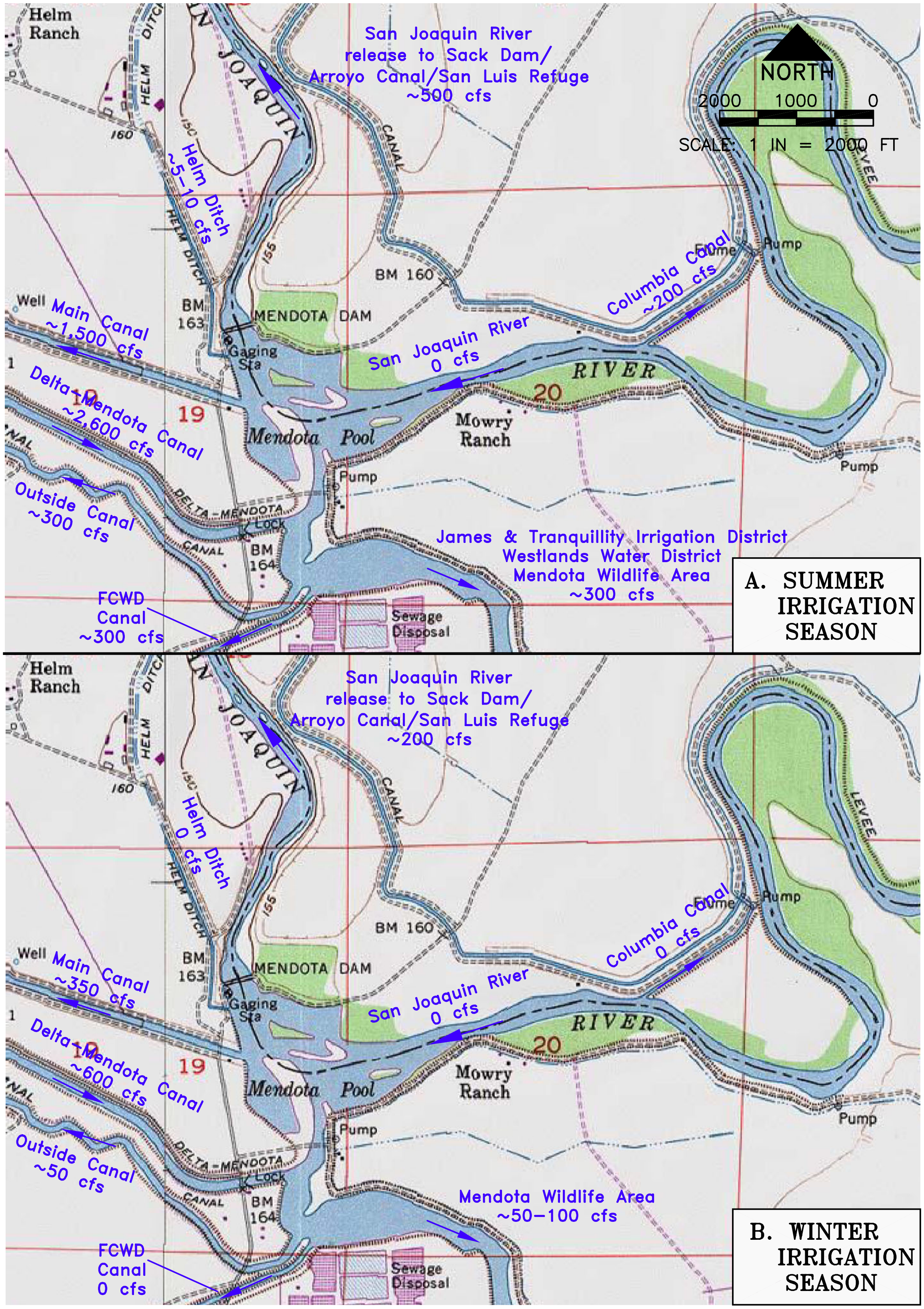

*Figure 5-4. Diagrammatic of typical river releases and diversions from Mendota Dam during summer irrigation season and winter season. Winter diversions and releases are largely for wildlife refuges.*

more significant hurdle. This diversion will either need to be screened, or potentially plumbed directly into the DMC, to alleviate anticipated juvenile entrainment into the canal.

#### 5.4.1.4. Riparian Diversions

A search of the State Water Resources Control Board's (SWRCB) Riparian Rights GIS database (State Water Resources Control Board, 2000) listed 54 riparian water rights holders within the San Joaquin River corridor between Friant Dam and Merced River. Only 13 of these riparian rights holders divert water directly from the San Joaquin River. The other 41 riparian water rights are located on several adjacent sloughs and bypasses that are supplied by the San Joaquin River. The SWRCB GIS database provided the locations of these Riparian Water Rights.

Mussetter Engineering also identified the location of three weir structures just downstream of Friant Dam and verified their locations. The Big Willow Unit Diversion (RM 261.3) is a cobble-type weir that diverts a small amount of water to the Fish Hatchery. The Rank Island Unit is a cobble weir located at RM 260. The Rank Island Unit diverts approximately 5 cfs to property on the north side of the river. The Milburn Unit Diversion is a small concrete-rubble weir located at RM 247.2. A small pump is located just upstream.

In 2001, CDFG inventoried riparian diversions along the project reach, and are summarized in Table 5-2. This represents the most complete inventory performed to date on the San Joaquin River. This inventory does not include potential alternative pathways that have been or are being considered for fish routing. Old sloughs and bypasses in Reaches 2 through 4 have been discussed for alternative pathways for fish routing (e.g., Pick Anderson Slough, Salt Slough, Lone Willow Slough); however, many of these sloughs function as agricultural return channels and the water is subsequently re-used by riparian pumps. Field observations of Pick Anderson Slough showed numerous pumps that would potentially constrain their use as alternative pathways for fish routing (e.g., they have similar number of riparian pumps as the main channel). Other alternative pathways being considered are the flood bypasses. CDFG did not include the sloughs or flood bypass system in their inventory; however, visual observation of the flood bypasses shows that there are far fewer riparian diversions in the bypasses than the sloughs and mainstem San Joaquin River, which may provide a restoration opportunity for juvenile fish routing.

In summary, impacts associated with riparian diversions include the following:

- Diversions cause cumulative reduction in flows, most notably during low baseflow periods.
- Hardpoints associated with extraction/diversion facilities often reduce the ability of the channel to migrate or adjust its dimensions.
- Many of the diversions along the San Joaquin River remain unscreened. During out-migration periods, juvenile fish may be entrained within the irrigation, water supply, or other conveyance systems attached to the main channel, causing functional mortality because the fish are distributed onto irrigated fields.
- On those diversions that may be screened, they may exceed entrance velocity criteria, impinging fish on the screen itself and causing mortality or stress.

*Table 5-2. Summary of riparian diversions mapped by CDFG in 2001.*

| River Mile | Primary Use | Bank Location | Diversion Type | Intake Size (inches) | Estimated Maximum Diversion Capacity (cfs) |
|---|---|---|---|---|---|
| 266.76 | Agricultural | Right | Pump | 6 | 1 |
| 266.57 | Agricultural | Left | Pump | 8 | 2 |
| 265.73 | Recreation | Left | Pump | 12 | 4 |
| 265.20 | Recreation | Left | Pump | 7 | 1 |
| 265.19 | Agricultural | Right | Pump | 15 | 6 |
| 265.13 | Agricultural | Right | Pump | 12 | 4 |
| 265.13 | Agricultural | Right | Pump | 12 | 4 |
| 265.13 | Agricultural | Right | Pump | 12 | 4 |
| 264.75 | Recreation | Left | Pump | 7 | 1 |
| 263.45 | Agricultural | Right | Pump | 12 | 4 |
| 263.45 | Agricultural | Right | Pump | 12 | 4 |
| 263.08 | Agricultural | Left | Pump | 10 | Removed |
| 262.9[a] | Agricultural | Left | Pump | 12 | 4 |
| 262.72 | Agricultural | Right | Pump | 6 | 1 |
| 262.46 | Agricultural | Left | Pump | 6 | 1 |
| 262.46 | Agricultural | Left | Pump | 10 | 3 |
| 262.31 | Agricultural | Left | Pump | 10 | 3 |
| 262.16 | Agricultural | Right | Pump | 36 | 35 |
| 262.15 | Agricultural | Right | Pump | 8 | 2 |
| 262.14 | Agricultural | Left | Pump | 60 | Removed |
| 261.65 | Unknown | Left | Pump | unknown | |
| 261.65 | Unknown | Left | Pump | 8 | 2 |
| 261.65 | Unknown | Left | Pump | unknown | |
| 261.55 | Not in use | Left | Pump | 8 | 2 |
| 261.3 | Hatchery | Left | Weir | unknown | <5 |
| 261.25 | Agricultural | Left | Pump | 3 | <1 |
| 261.21 | Agricultural | Right | Pump | 12 | 4 |
| 261.05 | Agricultural | Right | Pump | 24 | 16 |
| 261.00 | Industrial | Left | Pump | 8 | 2 |
| 261.00 | Industrial | Left | Pump | 8 | 2 |
| 260.25 | Agricultural | Right | Pump | 7 | 1 |
| 260.25 | Agricultural | Right | Pump | 7 | 1 |
| 260.00 | Agricultural | Right | Weir | unknown | 5 |
| 259.95 | Agricultural | Left | Pump | 3 | <1 |
| 259.84 | Unknown | Right | Pump | 10 | 3 |
| 259.77 | Agricultural | Left | Pump | 9 | 2 |
| 259.67 | Agricultural | Left | Pump | 10 | 3 |
| 259.48 | Agricultural | Left | Pump | 6 | 1 |
| 259.48 | Agricultural | Left | Pump | 10 | 3 |
| 259.48 | Recreation | Right | Pump | 6 | 1 |
| 259.47 | Agricultural | Left | Pump | 10 | 3 |
| 259.47 | Not in use | Left | Pump | 6 | 1 |
| 259.20 | Recreation | Right | Pump | 4 | <1 |
| 259.00 | Agricultural | Left | Pump | 7 | 1 |
| 259.00 | Recreation | Right | Pump | 4 | <1 |
| 258.72 | Not in use | Left | Pump | 3 | Removed |
| 258.70 | Agricultural | Left | Pump | 12 | 4 |

*Table 5-2. cont.*

| River Mile | Primary Use | Bank Location | Diversion Type | Intake Size (inches) | Estimated Maximum Diversion Capacity (cfs) |
|---|---|---|---|---|---|
| 257.49 | Agricultural | Right | Pump | 30 | 25 |
| 256.77 | Agricultural | Left | Pump | 8 | 2 |
| 256.33 | Agricultural | Right | Pump | 7 | 1 |
| 256.32 | Agricultural | Right | Pump | 10 | 3 |
| 256.31 | Domestic | Left | Pump | 3 | <1 |
| 255.84 | Agricultural | Left | Pump | unknown | |
| 254.90 | Agricultural | Right | Pump | 7 | 1 |
| 254.90 | Agricultural | Right | Pump | 7 | 1 |
| 253.95 | Agricultural | Left | Pump | 13 | 5 |
| 253.40 | Agricultural | Left | Pump | 16 | 7 |
| 252.28 | Industrial | Right | Pump | 8 | 2 |
| 251.60 | Industrial | Right | Pump | 7 | 1 |
| 251.57 | Agricultural | Right | Pump | 15 | 6 |
| 251.37 | Agricultural | Right | Pump | 8 | 2 |
| 251.16 | Agricultural | Right | Pump | 7 | 1 |
| 249.66 | Agricultural | Right | Pump | 7 | 1 |
| 249.23 | Not in use | Left | Pump | 6 | Removed |
| 248.00 | Agricultural | Right | Pump | 36 | 35 |
| 247.20 | Agricultural | Unknown | Weir | unknown | <5 |
| 246.88 | Agricultural | Right | Pump | 48 | 63 |
| 246.29 | Not in use | Right | Pump | 12 | Removed |
| 245.73 | Agricultural | Right | Pump | 12 | Removed |
| 245.41 | Agricultural | Right | Pump | 36 | 35 |
| 242.57 | Not in use | Left | Pump | 7 | Removed |
| 242.16 | Not in use | Left | Pump | 8 | Removed |
| 241.62 | Not in use | Left | Pump | 6 | 1 |
| 240.56 | Agricultural | Left | Pump | 12 | 4 |
| 239.62 | Not in use | Left | Pump | 6 | Removed |
| 230.89 | Unknown | Left | Pipe | 5 | 1 |
| 230.13 | Agricultural | Right | Pump | 5 | 1 |
| 230.06 | Agricultural | Right | Pump | 10 | 3 |
| 230.06 | Agricultural | Right | Pipe | 10 | 3 |
| 229.85 | Not in use | Right | Pump | 10 | 3 |
| 229.56 | Agricultural | Right | Pump | 4 | <1 |
| 229.35 | Agricultural | Left | Pump | 8 | 2 |
| 229.35 | Agricultural | Left | Pump | 8 | 2 |
| 228.89 | Agricultural | Right | Pump | 12 | 4 |
| 228.78 | Agricultural | Right | Pump | 24 | 16 |
| 228.78 | Agricultural | Right | Pump | 24 | 16 |
| 227.72 | Agricultural | Right | Pump | 10 | 3 |
| 223.25 | Not in use | Left | Pump | 12 | Removed |
| 222.75 | Agricultural | Right | Pump | 12 | 4 |
| 215.50 | Agricultural | Right | Pump | unknown | |
| 210.89 | Agricultural | Left | Pipe | 19 | 10 |
| 210.89 | Agricultural | Left | Pipe | 19 | 10 |
| 210.70 | Agricultural | Left | Pipe | 11 | 3 |
| 210.43 | Agricultural | Left | Pipe | 10 | 3 |
| 209.61 | Agricultural | Left | Pipe | 20 | 11 |

*Table 5-2. cont.*

| River Mile | Primary Use | Bank Location | Diversion Type | Intake Size (inches) | Estimated Maximum Diversion Capacity (cfs) |
|---|---|---|---|---|---|
| 209.61 | Agricultural | Left | Pipe | 16 | 7 |
| 209.61 | Agricultural | Left | Pipe | 16 | 7 |
| 209.61 | Agricultural | Left | Pipe | 11 | 3 |
| 209.61 | Agricultural | Left | Pipe | 11 | 3 |
| 208.83 | Agricultural | Right | Pump | 24 | 16 |
| 208.83 | Not in use | Right | Pump | 36 | Removed |
| 207.73 | Agricultural | Right | Pump | 12 | 4 |
| 207.06 | Agricultural | Right | Pump | unknown | |
| 206.50 | Agricultural | Left | Pump | 12 | 4 |
| 206.50 | Agricultural | Left | Pump | 12 | 4 |
| 206.00 | Agricultural | Right | Pump | 10 | 3 |
| 205.95 | Agricultural | Right | Dam/Pump | Columbia Can. | 200 |
| 204.90 | Agricultural | Left | Dam | Fresno Slough | 300 |
| 204.90 | Agricultural | Left | Dam | FCWD Can. | 300 |
| 204.90 | Agricultural | Left | Dam | Outside Can. | 300 |
| 204.85 | Agricultural | Left | Dam | Main Can. | 1,500 |
| 204.80 | Agricultural | Left | Dam | Helm Ditch | 10 |
| 202.07 | Agricultural | Left | Pump | 3 | <1 |
| 202.00 | Domestic | Right | Pump | 3 | <1 |
| 195.38 | Municipal | Right | Pump | 8 | 2 |
| 194.70 | Agricultural | Left | Pump | 7 | Removed |
| 193.50 | Agricultural | Right | Pump | unknown | |
| 182.00 | Agricultural | Left | Dam | Arroyo Can. | 600 |
| 180.60 | Agricultural | Left | Pump | 17 | 8 |
| 173.79 | Agricultural | Right | Pump | 5 | 1 |
| 170.75 | Agricultural | Right | Pump | 10 | 3 |
| 169.95 | Agricultural | Left | Pump | 10 | Removed |
| 159.90 | Agricultural | Right | Pump | 10 | 3 |
| 159.60 | Agricultural | Right | Pump | 12 | 4 |
| 156.92 | Domestic | Right | Pump | 6 | 1 |
| 156.87 | Agricultural | Right | Flashboard riser | 18 | 9 |
| 156.67 | Unknown | Right | Flashboard riser | 18 | 9 |
| 155.30 | Agricultural | Left | Pump | 10 | 3 |
| 154.70 | Agricultural | Left | Pump | 9 | 2 |
| 154.70 | Agricultural | Left | Pump | 9 | 2 |
| 147.20 | Recreation | Right | Pump | 16 | 7 |
| 144.00 | Wildlife Refuge Enhance | Right | Pump | 36 | 35 |
| 131.00 | Not in use | Right | Pump | 8 | Removed |
| 130.30 | Agricultural | Right | Pump | 18 | 9 |
| 125.00 | Agricultural | Right | Pump | 16 | 7 |
| 118.80 | Not in use | Left | Pump | 5 | Removed |

[a] River mile location is approximate

#### 5.4.1.5. Agricultural Return Flows

The quantity and quality of San Joaquin River water is strongly influenced by the discharge of agricultural drainage. Agricultural return flows are minor in Reaches 1 and 2, with some small amounts of return flows from Fresno Irrigation District occurring near Biola (RM 236.1) and others. Most agricultural return flows occur downstream of Mendota Pool. During the irrigation season (March through September), water is imported from the Delta and delivered through the DMC to the Mendota Pool to supply the San Joaquin River Exchange Contractors along the San Joaquin River, and to the San Luis Reservoir and San Luis Canal to supply the majority of the San Luis Unit contractors. Friant Dam releases very good water quality, but during typical operations, these flows tend to terminate just downstream of Gravelly Ford and do not reach Mendota Pool. Mendota Dam then releases 500 to 600 cfs of DMC water, and accumulation of agricultural return flows with poorer quality DMC water causes water quality to decline downstream of Mendota Dam (see Chapter 6 for more detail).

Because of underlying geology, agricultural return flows, and urban runoff, the lower reaches of the San Joaquin River has some of the poorest quality water in the Central Valley. Downstream of Sack Dam, the primary sources of stream flows are irrigation returns and groundwater discharged either directly to the main channel or via Mud Slough and Salt Slough. Average annual discharges are 54,000 acre-feet for Mud Slough and 204,000 acre-feet for Salt Slough. Irrigation returns from Mud Slough and Salt Slough accounts for 44 percent of the flow in the San Joaquin River above its confluence with the Merced River during normal water years (e.g., 1979) (Moore et al. 1990). In a dry year (e.g., 1981), Mud Slough and Salt Slough account for 70 percent of the flow. The historic contribution of Mud Slough and Salt Slough (prior to construction of Friant Dam) to the San Joaquin River flows were below one percent of those total annual flows (SJVDP 1990).

Addition of agricultural drainage water to the lower reaches of the San Joaquin River results in reduced water quality due to accumulations of salinity, trace elements such as selenium, and nutrients. Many of these constituents impair natural nutrient cycles and biological processes. Selenium has been found to bioaccumulate in fish and birds. Resident fish collected from the Mud and Salt Slough during the mid 1980's showed elevated levels of selenium in their tissues. Aggregate geometric mean (dry weight) selenium concentrations in whole bluegill samples ranged from 4.4 parts-per-million (ppm) at Salt Slough to 10.4 ppm at Mud Slough (North). Selenium concentrations in freshwater fishes in the United States average 0.5 ppm. It has been estimated that selenium concentrations of 2.0 ppm could cause toxic effects in fish (Saiki 1986a). Based on data collected during 1986, Saiki (1986b) and Moore et al. (1990) noted that selenium concentrations in bluegill gonads from samples collected in the western Grasslands area were sufficiently elevated to impair the reproduction of this species. Refer to Chapter 6 for a more detailed discussion of water quality impacts.

### 5.4.2. Overview of Flood Control System

The flood control system along the San Joaquin River is composed of a series of dams, bifurcation structures, bypasses, levees, and the main river channel. Flood control efforts were initiated in the late 1800's to protect structures and agricultural lands from the regular inundation of winter and spring floods along the San Joaquin River corridor. By 1894, several flood control districts had been formed to construct the first several miles of levees with the hope to provide adjacent landowners some level of flood protection. Early efforts in flood protection were generally inadequate.

In 1933, the first phase of flood control development progressed when the Central Valley Project (CVP) was authorized by Congress. As part of this plan, construction of Friant Dam was completed in

1941 to store and divert water from the San Joaquin River. Congress authorized the Flood Control Act of 1944, which included the San Joaquin River and Tributaries Project (SJRTP).

The Lower San Joaquin River Flood Control Project was authorized by Congress in 1944 to protect irrigated agricultural lands and associated developments. The original plan prepared by the Chief of Engineers and reported to Congress recommended that an area of approximately 118,000 acres of grassland floodplain between Friant Dam and the Merced River be retained as flood detention basins, in lieu of flood protection works (Reclamation Board, 1966). The Corp of Engineers estimated the cost of this floodplain area at $800,000.

Several events following this original flood detention basin plan resulted in a revised flood control approach in the study area. Friant Dam was completed in 1948, and experienced difficulties in November and December of 1950 operating for flood control purposes. Following World War II, the completion of Friant Dam, Delta Mendota Canal, and associated water delivery systems, the demand and value of reclaimed lands along the San Joaquin River dramatically increased. In February 1952, the Reclamation Board held a public hearing to present the flood control plan proposed by the Corp of Engineers. There was local opposition to the ACOE plan authorized by Congress due to the large area of lands to be retained for flood detention, which would preclude its use for reclamation and agricultural utilization. Although supporting data is not provided, the Reclamation Board estimated that the land value of the 118,000 acres identified for flood detention use increased from $800,000 in 1944 to $18,300,000 in March 1953. This increase in value was due to land reclamation and development, changes in land use, and accelerated demand for irrigable land (Reclamation Board 1966).

In response to these increased land values and public opposition to the ACOE plan, the California Department of Water Resources prepared an alternative plan that reduced the land need for flood plains and bypasses to 22,000 acres, allowing 96,000 acres of the original 118,000 acres to be reclaimed. Additional public opposition to bypass alignments and capacities resulted in another modification to the flood control plan in 1957. Additional desires for flood control protection in Reach 2 and 3 resulted in the adoption of the Chowchilla Canal Bypass Plan in May 1961. Control structures, levees, and right-of-ways were firmly established in January 1964, and the project was dedicated on October 6, 1966. The project was intended to provide approximately 50-yr flood frequency protection, protecting approximately 96,000 acres of land previously subjected to annual flooding. The project claimed “prolonged periods of inundation and ponding following floods will now be eliminated and reduce the severity of crop damage, crop planting delays, and limitations of access” (Reclamation Board 1966). History has shown that many of these claimed benefits of the flood control project has been achieved; however, flood and seepage damage still occurs in many locations at a frequency greater than the original 50-year protection objective of the flood control project (see Section 5.4.2.2).

Dams were also constructed on tributaries to the San Joaquin River that contributed to the Flood Control Project, including Pine Flat Dam on the Kings River (completed in 1954), Buchanan Dam on the Chowchilla River (completed in 1975), and Hidden Dam on the Fresno River (completed in 1975). While these reservoirs are located on tributaries of the San Joaquin River, they provide flood control function to the San Joaquin River as well as the tributaries they are located on (ACOE 1999a). Pine Flat Dam provides baseflows to the Kings River downstream of the dam; however, Buchanan Dam and Hidden Dam dewater the Chowchilla River and Fresno River over much of the year.

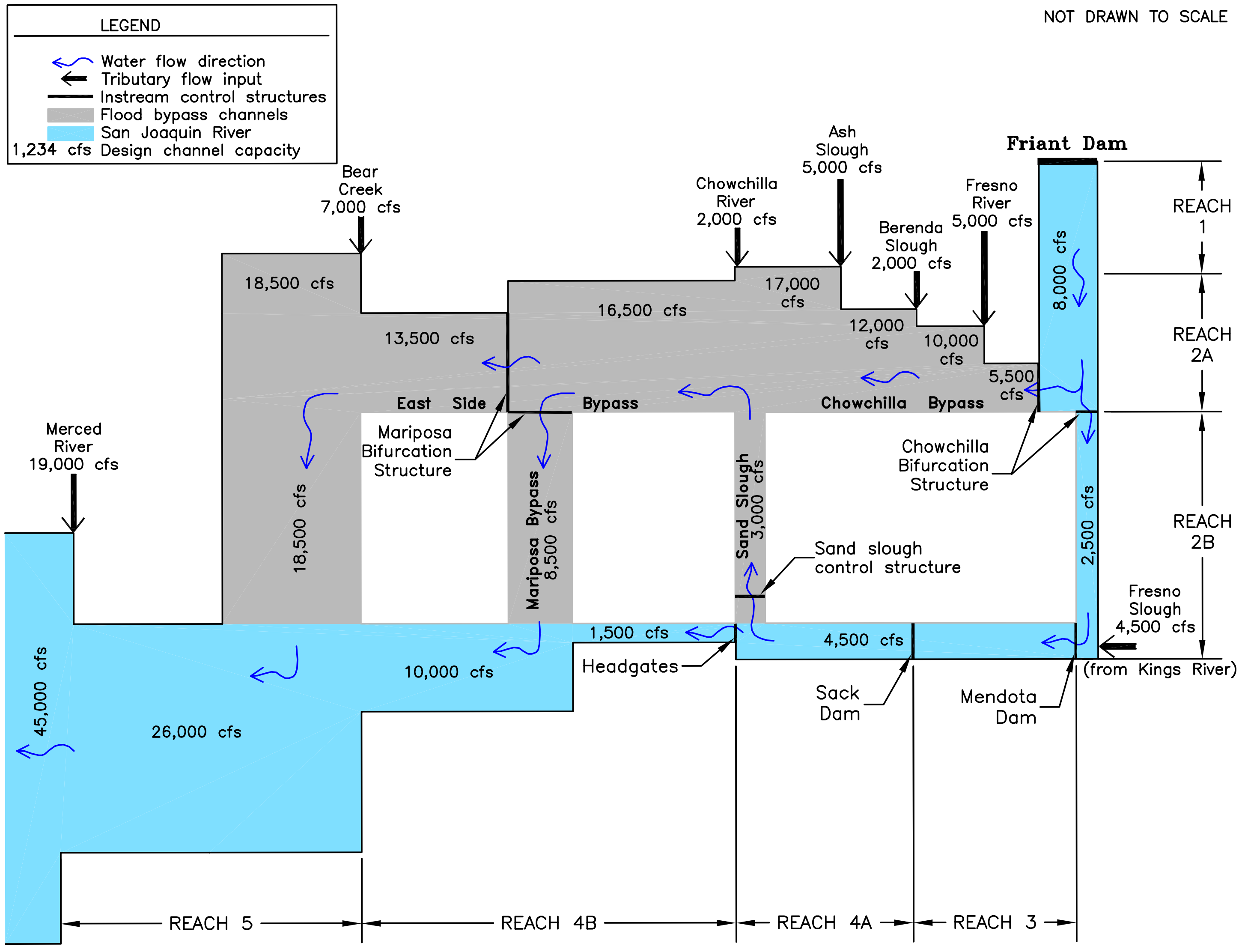

*Figure 5-5. Schematic map of structures and reach hydraulic capacity rating within the study reach of the San Joaquin River.*

Within the last three decades the ACOE has oversaw the repair of the existing levee system along the Sutter Bypass and the Feather, Yuba, and Sacramento rivers. Little work has been done to repair and/or construct new levees along the San Joaquin River corridor. Much of the work has been conducted in response to potential situations that pose immediate danger to life or developed property.

The following paragraphs discuss the overall flood control system within the San Joaquin River study area and the associated impacts on restoration efforts. A summary of flood control system components is provided in Table 5-3 and Figure 5-5.

*Table 5-3. Summary of flood control components along the San Joaquin River*

| Element | Location (River Mile) | Description and Comments |
|---|---|---|
| **Dams** | | |
| Mammoth Pool, Shaver Lake, Florence Lake, and others | Upstream of Friant Dam | Total storage of 560,000 acre-ft, and provides some incidental flood control functions. Some of the 170,000 acre-ft of flood control space in Millerton Reservoir can be transferred to Mammoth Pool. |
| Friant Dam | 267.5 | Forms Millerton Reservoir. Total storage is 520,500 acre-feet of which 170,000 acre-feet can be reserved for flood control. Significant barrier to upstream fish passage. |
| Pine Flat Dam | | Dam on Kings River that provides flood control purpose to Tulare Lake basin, and portion of flood control release is conveyed to the San Joaquin River via James Bypass and Fresno Slough. Total storage 1,001,000 acre-feet, flood control storage 475,000 acre-ft. |
| Buchanan Dam | | Dam on Chowchilla River that provides flood control purpose. Flood control releases into the Fresno River are delivered to the Chowchilla Bypass. Total storage 150,600 acre-feet, flood control storage 45,000 acre-ft. |
| Hidden Dam | | Dam on Fresno River that provides flood control purpose. Flood control releases into the Fresno River are delivered to the Chowchilla Bypass. Total storage 90,600 acre-feet, flood control storage 65,000 acre-ft. |
| **Diversion Structures** | | |
| Chowchilla Bypass Bifurcation Structure | 216.1 | Diverts flood flows from the mainstem of the San Joaquin to Chowchilla Bypass Canal |
| Mariposa Bypass Bifurcation Structure | 147 | Diverts flood flows from the East Side Bypass / Mariposa Bypass confluence back to the San Joaquin River |
| **Other Hydraulic Control Structures** | | |
| Sand Slough Control Structure | East Side Bypass | Low head control structure in Sand Slough between San Joaquin River and East Side Bypass. |
| Eastside Bypass Control Structures | East Side Bypass | Low head grade control structures within the East Side Bypass |
| Mariposa Bypass Control Structures | Mariposa Bypass | Low head grade control structures within the Mariposa Bypass |
| Reach 4B Headgates | 168 | Low-head control structure within the mainstem San Joaquin River that controls flows into Reach 4B. |
| **Bypasses** | | |
| James Bypass/Fresno Slough | 204.6 (outlet) | Conveys flood flows from the Kings River North to Mendota Pool |
| Chowchilla Bypass | 216.1 (inlet) | Currently functions solely as a flood conveyance system conveying flood flows from the Chowchilla Bifurcation Structure (RM 216.1) to the East Side Bypass canal. |
| Mariposa Bypass | 147.2 (outlet) | Conveys water from the Mariposa Bypass Bifurcation Structure back to the San Joaquin River. |

*Table 5-3. cont.*

| Element | Location (River Mile) | Description and Comments |
|---|---|---|
| East Side Bypass | 136 (outlet) | Conveys water from the Chowchilla Bypass to the Mariposa Bypass Bifurcation structure and back to the San Joaquin River. |
| **Levees** | | |
| Project Levees | 225 - 118 | Project levees line the Chowchilla Bypass and East Side Bypass, as well as the San Joaquin River from 4 miles downstream of Gravelly Ford to the Chowchilla Bifurcation Structure, then again from Mariposa Bypass confluence downstream to the Merced River confluence. |
| Non-Project Levees | 216.1 - 147.2 | Non-project levees have been constructed on both sides of the river by local landowners from the Chowchilla Bifurcation Structure to the confluence of the Mariposa Bypass. |

#### 5.4.2.1. Flood Control Dams

There are many dams contributing to flood control on the San Joaquin River. Friant Dam is the keystone of this system, but flood control is also provided by dams on the upper San Joaquin River, and dams on the Kings River, Fresno River, and Chowchilla River (Table 5-3). The space allocated to flood control in Millerton Lake increases from 0 acre-feet on October 1 to 170,000 acre-feet during the rain flood season (November 1– February 1), and decreases again to 0 acre-feet on April 1 (Figure 5-6). A portion of the 170,000 acre-ft flood control space reserve for Millerton Reservoir can be transferred to Mammoth Pool (i.e., storage space available in Mammoth Pool can be used to allow Millerton Reservoir to “encroach” or fill into the reserved flood control space). For example, rain flood space of up to 85,000 acre-feet can be transferred to Mammoth Pool, allowing Millerton Reservoir to store more water through the rain flood season. In addition, up to 390,000 acre-ft of conditional flood control space is reserved for the snowmelt runoff period (Figure 5-6). The mandated releases from Friant Dam when the reservoir storage encroaches into flood control space depends on tributary flows downstream of Friant Dam, irrigation demand, runoff forecasts, future precipitation forecasts, and discussions with the ACOE.

Flood flows from the Kings River basin are sometimes delivered to the San Joaquin River via James Bypass and Fresno Slough. Flows in the Kings River North are controlled by the operation of Pine Flat Dam. Although early studies indicated that the capacity of the James Bypass and Fresno Slough was about 4,500 cfs, flows up to 6,000 cfs have passed through this reach (ACOE, 1993). This contribution from the Kings River, combined with tributary accretion from Cottonwood Creek (RM 267) and Little Dry Creek (RM 261), sometimes creates complicated flood control operations from Friant Dam. ACOE criteria require flood releases from Friant Dam limited so that: (1) the combined maximum flow to the San Joaquin River from Friant Dam, Cottonwood Creek, and Little Dry Creek does not exceed 8,000 cfs, and (2) the flow at the San Joaquin River near Mendota gage below Mendota Dam (USGS #11-254000) does not exceed 6,500 cfs (ACOE, 1980). Theoretically, if the Fresno Slough and downstream tributaries are contributing high flows, flow releases from Friant Dam could be constrained to the capacity of the Chowchilla Bypass (5,500 cfs) because flow conveyance for Fresno Slough and tributary contributions takes precedence over Friant Dam releases.

During wet years, large inflows into Millerton Lake sometimes encroach into flood control storage space. Flood operating criteria during these periods result in a release hydrograph with flows of near 8,000 cfs for an extended time (see San Joaquin River hydrographs in Appendix A). Since completion of Friant Dam and the Friant-Madera and Friant-Kern canals in the late 1940s, gage records show releases of 8,000 cfs or greater occurred in 10 of the 52 post-Friant Dam years during the spring snowmelt period between March and July (1952, 1958, 1967, 1969, 1978, 1982, 1983, 1986, 1988,

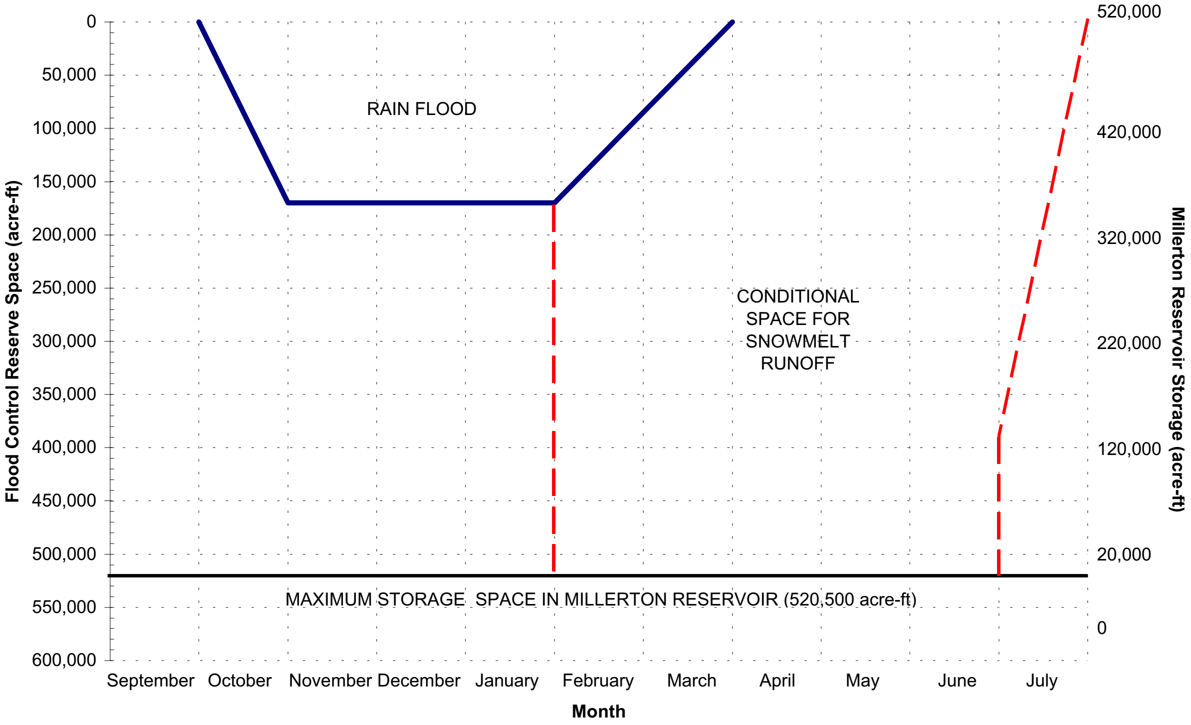

*Figure 5-6. Flood control reserve space in Millerton Reservoir as required by the Army Corps of Engineers. The volume of water released during encroachment into either flood control space varies depending on tributary inflows downstream of Friant Dam, irrigation demand, forecasted runoff, and discussions with the Corps of Engineers.*

1995, and 1998). In three other years (1980, 1996, and 1997), flows reached or exceeded the 8,000 cfs during the winter rather than the snowmelt runoff period. Flows were greater than 8,000 cfs in water year 1969 (peak flow=12,400 cfs), 1983 (peak flow=12,300 cfs), 1986 (peak flow=15,500 cfs), 1995 (peak flow=12,500 cfs), and 1997 (peak flow=60,300 cfs). Consistent with the peak flood frequency analysis, these results indicate that discharges in the 8,000 cfs range are reached or exceeded during the winter flood season and spring snowmelt season approximately 13 of 49 years. Using the flood frequency analysis in Chapter 2, the recurrence interval of an 8,000 cfs flow at Friant has been increased from 1.3-year flood (pre-Friant Dam) to a 6-year flood by cumulative dams upstream of and including Friant Dam.

### 5.4.2.2. San Joaquin River Levees and Dikes

There are two classes of levees and dikes along the San Joaquin River study area: (1) those associated with the San Joaquin River Flood Control Project, and (2) those constructed by individual landowners to protect site specific properties, and thus are not associated with the San Joaquin River Flood Control Project. The San Joaquin River Flood Control Project consists of a parallel conveyance system: (1) leveed bypass system on the east side of the San Joaquin Valley, and (2) leveed flow conveyance system in the San Joaquin River. This section describes levees and dikes that have been constructed along the San Joaquin River, and does not describe the bypass system of the San Joaquin River Flood Control Project.

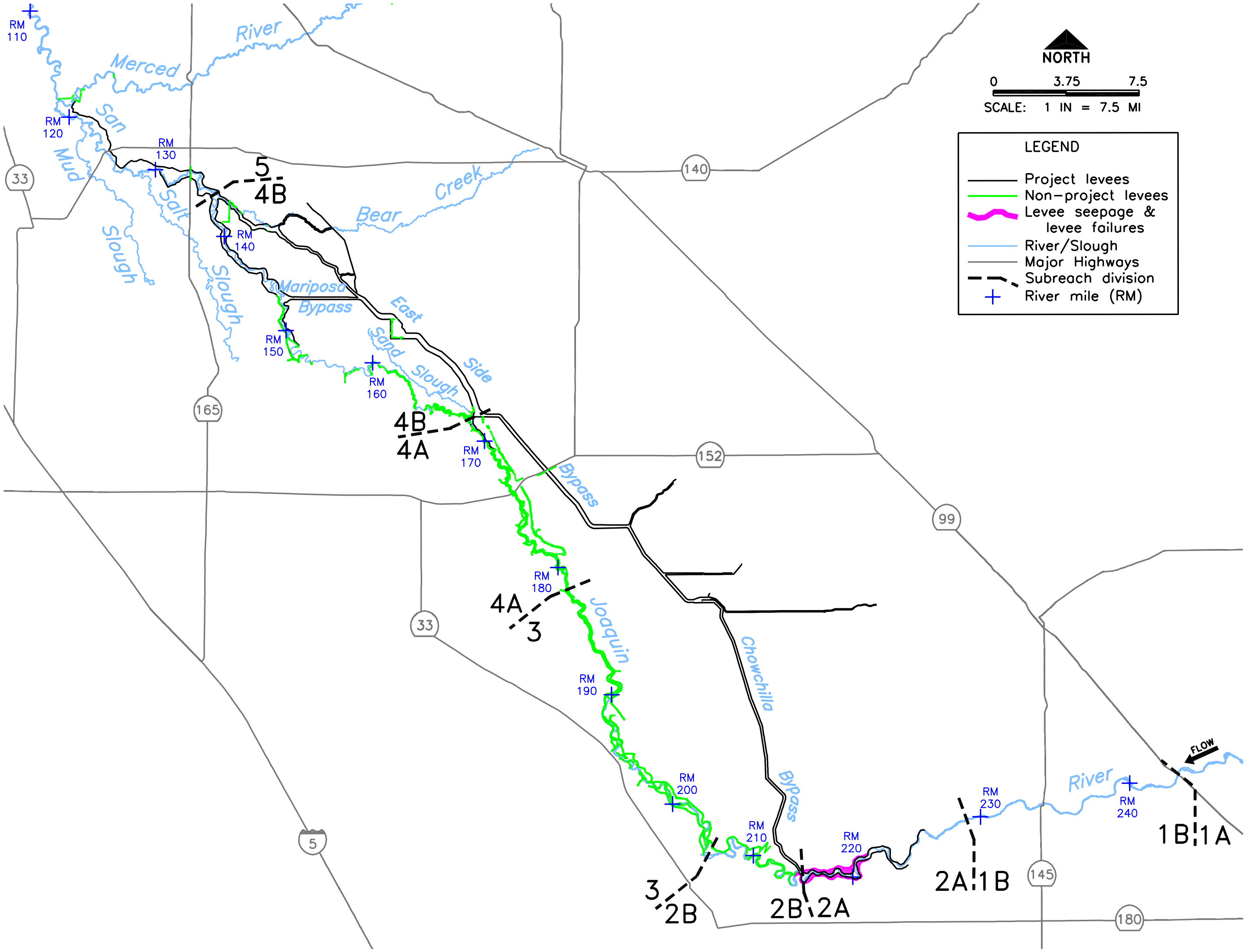

*Figure 5-7. Map of study reach showing locations of Project and Non-project levees, locations of levee breaches during the 1997 flood (from ACOE 1999), and areas of seepage problems.*

The mainstem San Joaquin River levee system within the study area is composed of approximately 192 miles of project levees and various non-project levees located upstream of the Merced River confluence (ACOE 1999b) (Figure 5-7). Project levees are levees constructed as part of the San Joaquin River and Tributaries Flood Control Project by the ACOE, and occur in Reach 2A downstream of Gravelly Ford from RM 225 on the south bank and RM 227 on the north bank, and extend downstream to the Chowchilla Bifurcation Structure (RM 216.1), then begin again in Reach 4B and 5 at the Mariposa Bypass confluence (RM 148) downstream to the Merced River confluence (RM 118.5) (Table 5-4). All project levees in the study area are contained within the Lower San Joaquin River Levee District. Non-project levees are typically associated with levees and dikes constructed by early flood control districts and adjacent landowners between the Chowchilla Bifurcation Structure (RM 216.1) and the Mariposa Bypass confluence (RM 148).

Canal embankments bordering both sides of the San Joaquin River between Sand Slough Control Structure (RM 168.5) and the Mendota Dam (RM 204.6) effectively form a set of non-project levees that have significantly reduced the width of the floodplain, primarily on the east side of the river. An alluvial terrace, 6 feet higher than the floodplain of the river, confines the right side of the river. Local landowners have constructed other low-elevation berms within the corridor that tend to confine contain flows up to 4,500 cfs. Flows exceeding 4,500 cfs spill onto agricultural lands up to the canal embankments.

The ACOE has established flood control objective flows for the San Joaquin River tributaries, bypasses, and flood control operations of reservoirs within the system. “Objective” flows are generally considered to be safe carrying capacities, but some damages to adjacent land developments do occur when passing objective flows. “Design capacity” is defined by the ACOE as the amount of water that can pass through reaches of the San Joaquin River with a levee freeboard of 3 feet. Design capacity was intended to provide protection against the 50-year storm (Reclamation Board 1966), and these intended design capacities are illustrated in Table 5-4 and Figure 5-5. Table 5-4 also summarizes ACOE design flow capacities and modeled objective flow capacities for various reaches throughout the San Joaquin flood control system.

*Table 5-4. Comparison of objective flow capacity from Mussetter (2000a and 2000b) with design channel capacities for the San Joaquin River Flood Control Project (ACOE, 1993)*

| Reach Along San Joaquin River | River Mile | Reach | ACOE design capacity with 3 ft freeboard | Estimated hydraulic capacity with no freeboard (top of levee) |
|---|---|---|---|---|
| Friant Dam Gravelly Ford | 267.5 – 229 | 1 | 8,000 cfs | 16,000 cfs |
| Gravelly Ford to the Chowchilla Bifurcation Structure | 229 – 216.1 | 2A | 8,000 cfs | Approximately 16,000 cfs |
| Chowchilla Bifurcation Structure to Mendota Dam | 216.1 – 204.6 | 2B | 2,500 cfs | Approximately 4,500 cfs |
| Mendota Dam to Sand Slough and Chowchilla Bypass | 204.6 – 168.5 | 3, 4A | 4,500 cfs | 6,000 cfs to 8,000 cfs |
| Sand Slough to Mariposa Bypass Confluence | 168.5 – 148 | Upper 4B | 1,500 cfs | 400 cfs to 1,500 cfs |
| Mariposa Bypass confluence to East Side Bypass confluence | 148 – 136 | Lower 4B | 10,000 cfs | Exceeds 10,000 cfs |
| East Side Bypass confluence to Merced River confluence | 136 – 118.5 | 5 | 26,000 cfs | Exceeds 26,000 cfs |
| Downstream of Merced River | 118.5 – 84 | n/a | 45,000 cfs | Not modeled |

Objective flow capacities of the leveed reaches were estimated with 1-D hydraulic models (HEC-2) (Mussetter Engineering 2000a, 2000b). Modeling was conducted in all reaches in the study area, and

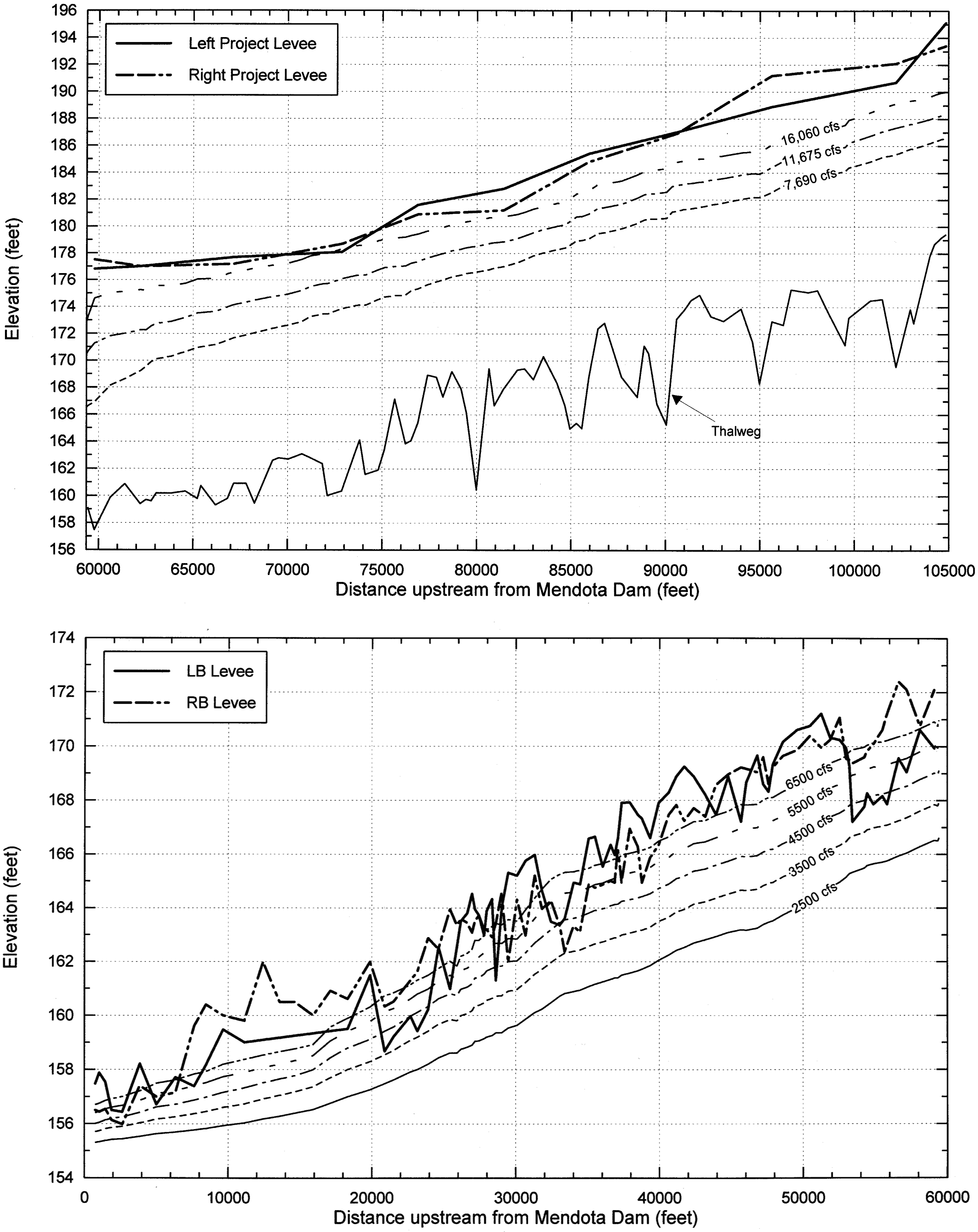

*Figure 5-8. Reach 2 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is the downstream portion of Reach 2A (design capacity 8,000 cfs), lower graph (B) is Reach 2B from the Chowchilla Bifurcation Structure to Mendota Dam (design capacity 2,500 cfs).*

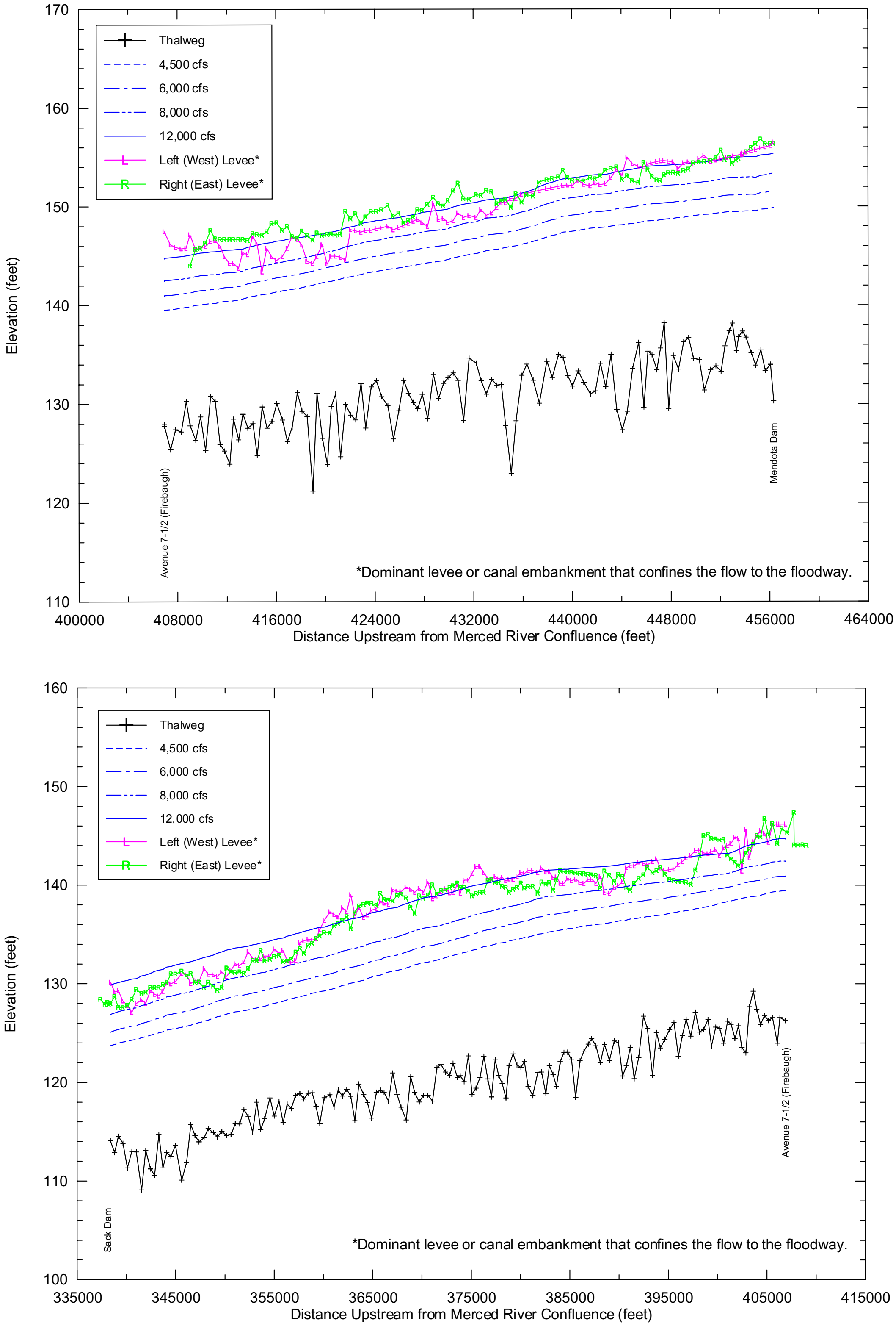

*Figure 5-9. Reach 3 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Mendota Dam to Firebaugh (design capacity 4,500 cfs), lower graph (B) is from Firebaugh to Sack Dam (design capacity 4,500 cfs).*

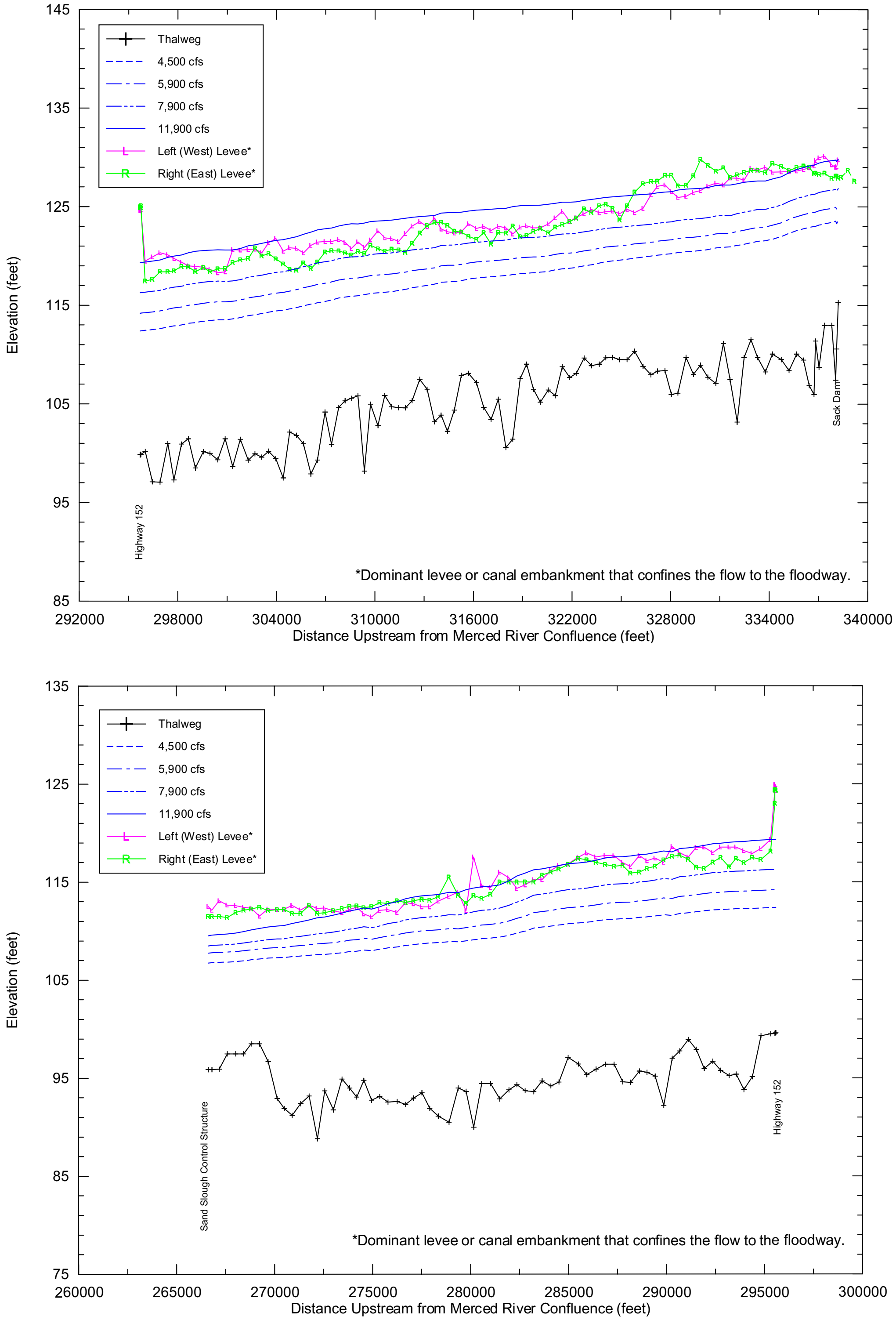

*Figure 5-10. Reach 4A plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Sack Dam to the SR 152 Bridge (design capacity 4,500 cfs), lower graph (B) is from the SR 152 Bridge to the Sand Slough Control Structure (design capacity 4,500 cfs).*

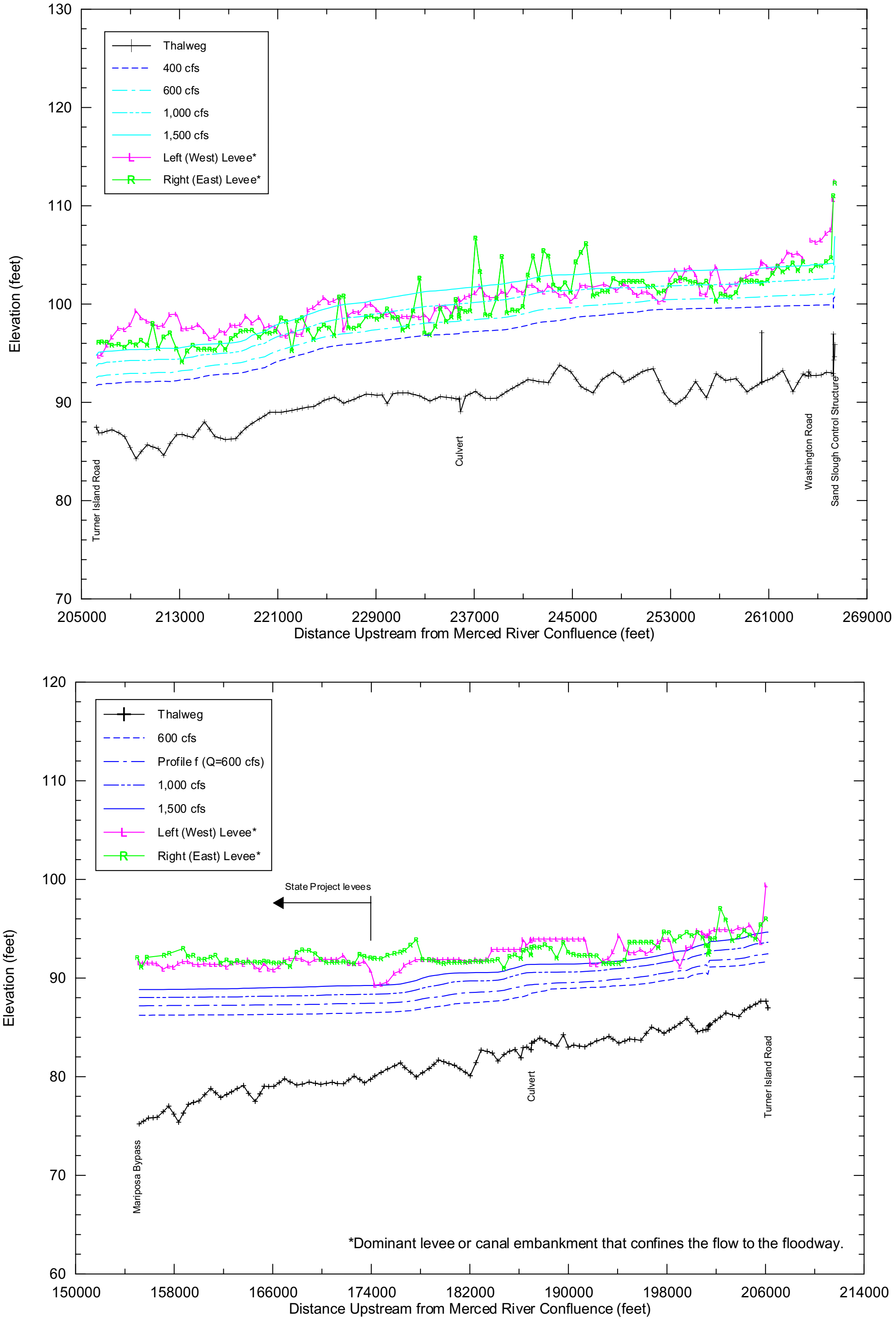

*Figure 5-11. Upper portion of the Reach 4B plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Sand Slough Control Structure to the Turner Island Bridge (design capacity 1,500 cfs), lower graph (B) is from the Turner Island Bridge to the Mariposa Bypass confluence (design capacity 1,500 cfs).*

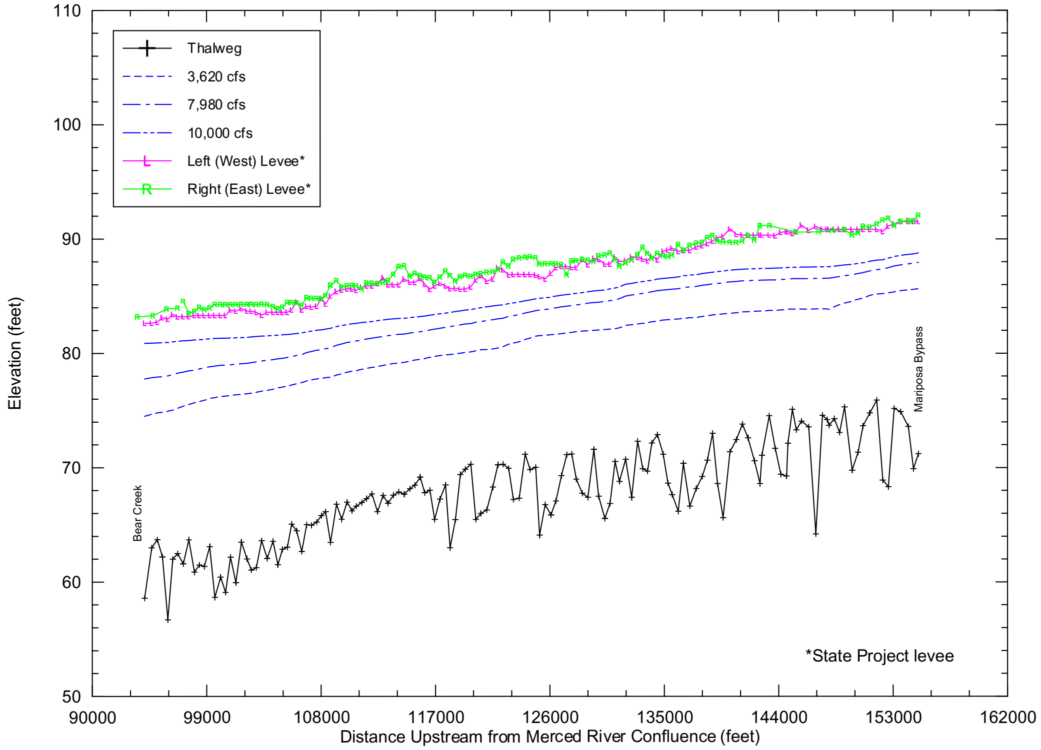

*Figure 5-12. Lower portion of the Reach 4B plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Graph is from the Mariposa Bypass confluence to the Bear Creek and Eastside Bypass confluence (design capacity 10,000 cfs).*

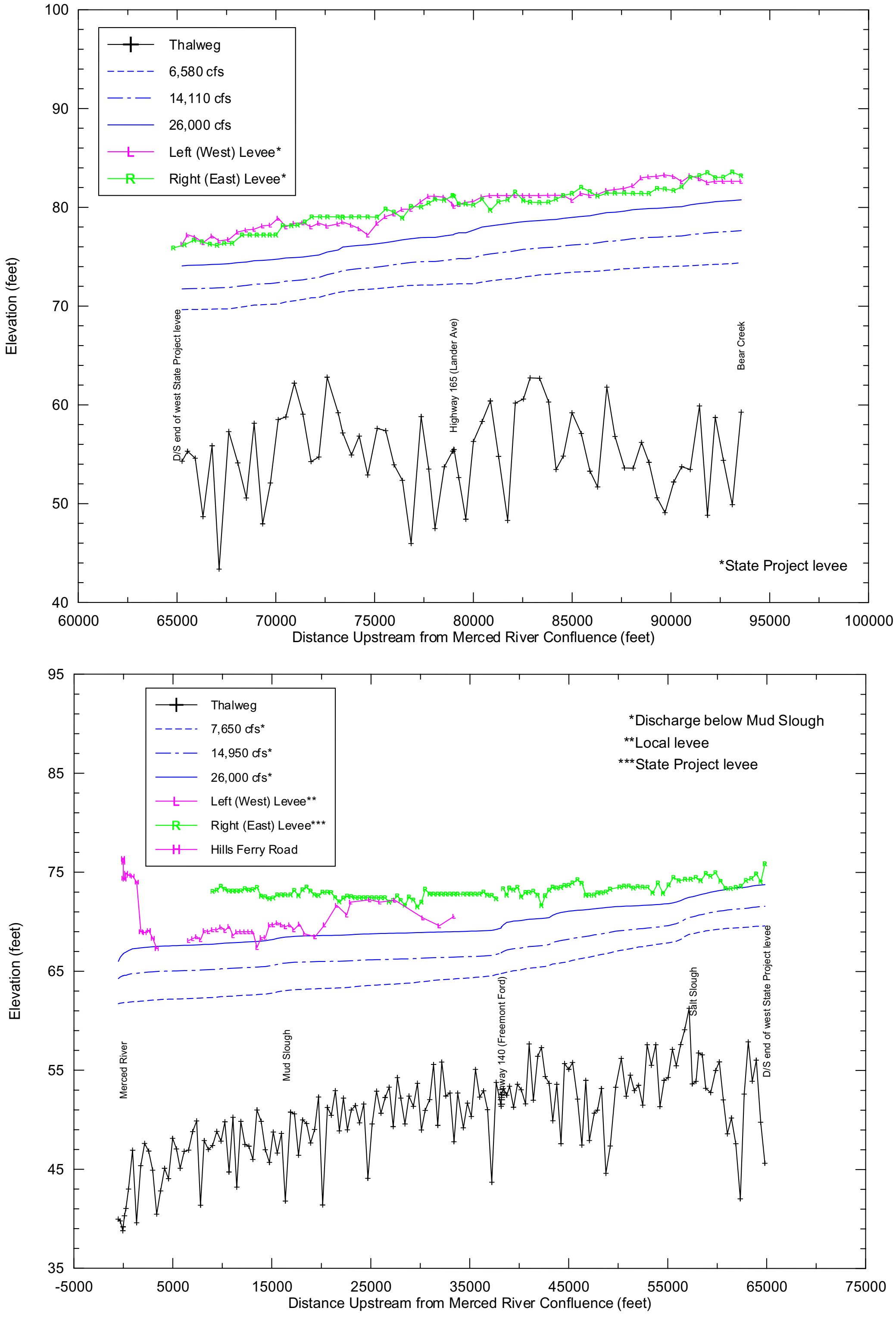

*Figure 5-13. Reach 5 plot of water surface profiles computed from HEC-2 hydraulic model with adjacent dike and levee elevations to compare computed reach capacities with advertised reach capacities. Upper graph (A) is from Bear Creek and Eastside Bypass confluence to the end of the project levee on the left (west) bank of the river (design capacity 26,000 cfs), lower graph (B) is from the end of the project levee on the left (west) bank of the river to the Merced River confluence (design capacity 26,000 cfs).*

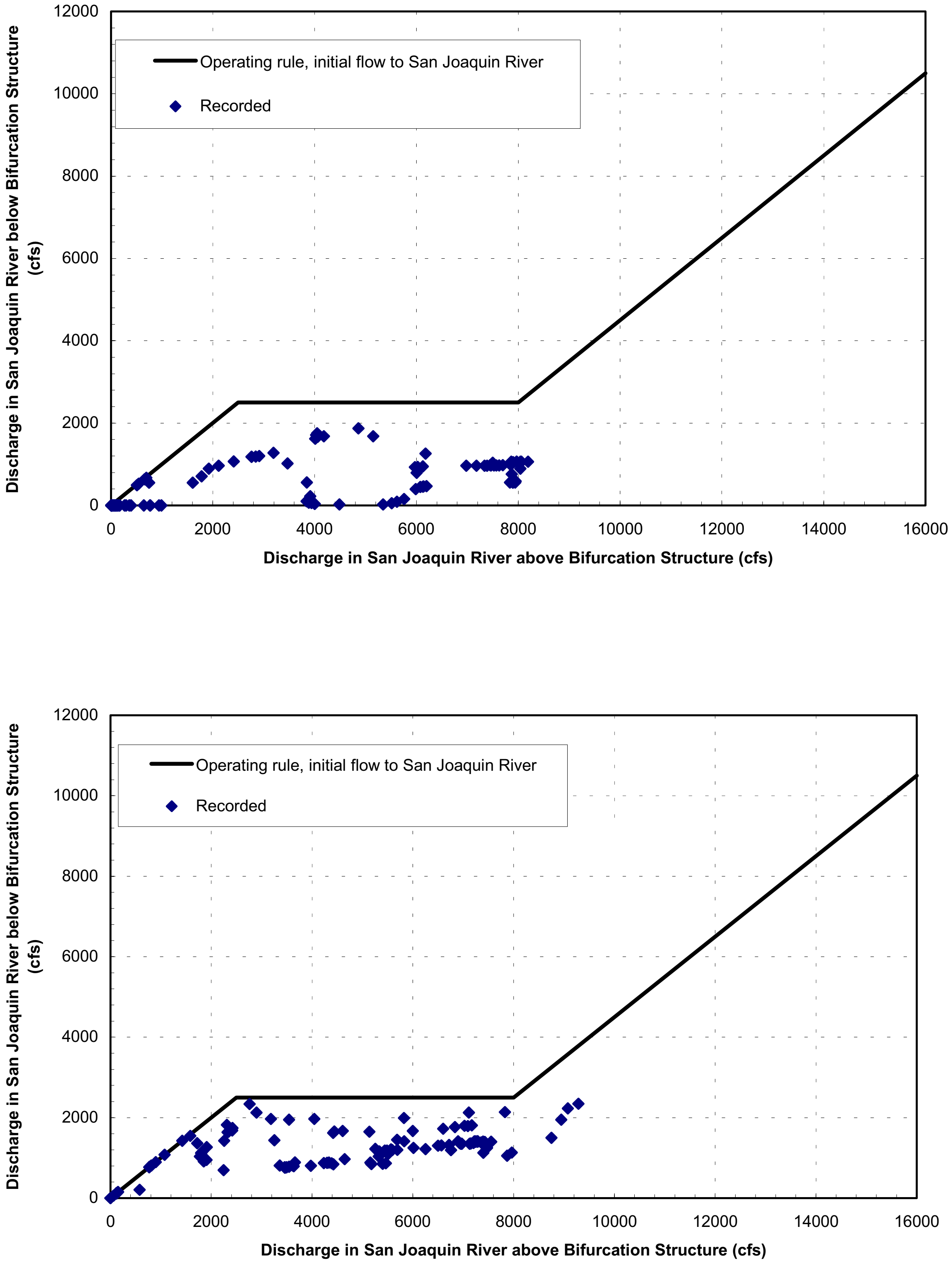

*Figure 5-14. Operating rules for the Chowchilla Bifurcation Structure based on San Joaquin River flows upstream of the structure, and actual operations for the Chowchilla Bifurcation Structure during (A) the 1986 high flow event and (B) the 1995 high flow event.*

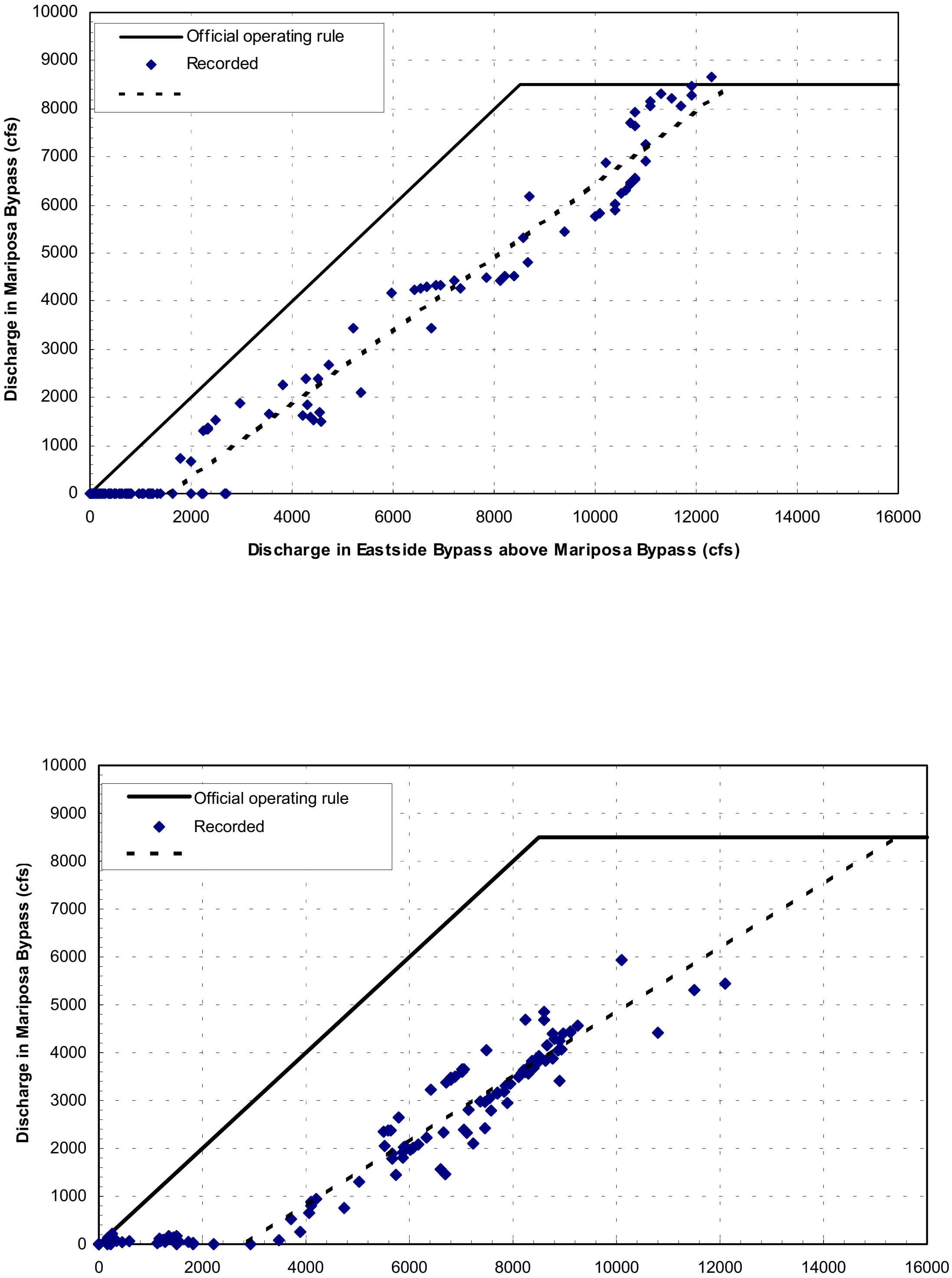

*Figure 5-15. Operating rules for the Mariposa Bifurcation Structure based on Eastside Bypass flows upstream of the structure, and actual operations for the Mariposa Bifurcation Structure during (A) the 1986 high flow event and (B) the 1995 high flow event.*

Reaches 2 through 5 have levees and dikes. Reach 1 has dikes attempting to isolate gravel pits from the river, but does not have any significant levees or dikes protecting agricultural lands. Hydraulic modeling in Reach 1 indicates that some flooding of a sewage disposal pond at RM 245.5 (16,300 cfs), and at a trailer park just upstream of Highway 41 at RM 255.5 (8,000 to 12,000 cfs) (Mussetter Engineering 2000a). Upstream of the Chowchilla Bifurcation Structure (RM 216.1), the project levees extend as far as RM 225 on the left (south) bank and RM 227 on the right (north) bank. The maximum levee capacity predicted from hydraulic models without any freeboard was about 16,000 cfs in this reach (Figure 5-8), exceeding the ACOE design capacity of 8,000 cfs. However, levee district staff has observed piping and seepage problems in this reach well before the design flow of 8,000 cfs. Eleven levee breaks occurred in this reach during the 1997 flood as a result of piping failure (Figure 5-7). Because of aggradation in the channel as a result of the backwater generated by the Chowchilla Bifurcation Structure, the bed of the channel in the lower portion of Reach 2A is elevated at or above some of the adjacent orchard lands. Periods of sustained high flows in the river have been reported to cause seepage damage in certain orchards (Hill pers. comm.).

Downstream reaches were also modeled by Mussetter Engineering (2000a, 2000b), and objective flow capacities evaluated by plotting various water surface profiles against levee/dike profiles in Reach 2 through 5 (Figures 5-8 through 5-13, Table 5-4). Between the Chowchilla Bifurcation Structure (RM 216.1) and Mendota Pool (RM 206), the San Joaquin River is bounded by non-project local levees. Current operating rules for the flood control system limit flows in the river to 2,500 cfs when the discharge in the river upstream of the Bifurcation Structure is 8,000 cfs. The water-surface profiles shown on Figure 5-7 indicate that approximately 4,500 cfs could be released into the river without significant overtopping of the local levees. However, even if the levees were not overtopped, the levees would likely fail as a result of piping and seepage. During the irrigation season when Mendota Pool is full, the elevated water surface and backwater may cause seepage problems when San Joaquin River discharges into Mendota Pool are as low as 1,300 cfs (White pers. comm).

Between Mendota Dam (RM 204.6) and the Sand Slough Control Structure (RM 168.5), the San Joaquin River is bordered by canal embankments that act as non-project levees. The hydraulic capacity of the channel between these levees was estimated without any freeboard considerations or taking into account the stability of the levees themselves (Mussetter Engineering 2000b). Between Mendota Dam and Avenue 7½ Bridge at Firebaugh (RM 195.2), the predicted hydraulic channel capacity is approximately 8,000 cfs, except for a short reach where the capacity is approximately 6,000 cfs (Figure 5-9). The design discharge for the reach is 4,500 cfs, which was set to minimize flooding of agricultural lands between the canals (Hill pers. comm.). Between Avenue 7½ Bridge and Sack Dam (RM 182.1), the predicted hydraulic channel capacity is approximately 8,000 cfs (Figure 5-9). Between Sack Dam and SR 152 (RM 173.9), the predicted hydraulic channel capacity is also approximately 8,000 cfs (Figure 5-10), and between SR 152 and the Sand Slough Control structure (RM 168.5), the predicted hydraulic channel capacity is also approximately 8,000 cfs (Figure 5-10).

Between the Sand Slough Control Structure and Turner Island Road (RM 157.2), the channel is bounded by local levees, and the predicted hydraulic capacity is approximately 400 to 1,000 cfs (Figure 5-11). Design discharge for this reach of the river is 1,500 cfs, but because of agricultural encroachments, the effective capacity is much less. In practice, flows are no longer accessible to the San Joaquin River because the headgates controlling flow into this reach have not been opened for many years. All flows exiting Reach 4A are discharged into the East Side Bypass at the Sand Slough Control Structure. Between Turner Island Road and the start of the project levees upstream of the Mariposa Bypass (RM 151), the predicted hydraulic capacity is approximately 1,000 to 1,500 cfs. Within the project levees, the capacity exceeds 1,500 cfs (Figure 5-11). From the Mariposa Bypass (RM 147.2) to the Bear Creek confluence where the remaining Eastside Bypass flows are returned to the San Joaquin River (RM 136), the predicted in-levee hydraulic capacity is in excess of the 10,000-cfs design flow (Figure 5-12). Between Bear Creek and the downstream end of the project levee on the left bank of the river, the predicted hydraulic capacity exceeds the 26,000-cfs design flow level (Figure 5-13). In the floodway section from the downstream end of the project levee to the Merced River confluence, the predicted hydraulic capacity is approximately 26,000 cfs (Figure 5-13).

The estimates of hydraulic conveyance capacity compare modeled water surface elevations with the tops of adjacent dikes and levees, rather than the 3 feet freeboard required by the ACOE. Therefore, the hydraulic capacity estimates for many of the above reaches underestimates the actual conveyance capacity if the ACOE freeboard requirement were to be satisfied. Additionally, the levees in Reach 2 are constructed primarily of sandy soils that begin to seep into adjacent agricultural lands once flows access the toe of the levee. Therefore, based on hydraulic modeling and field observations during high flows, Reach 4B, Reach 2A, and Reach 2B are the primary constraints to meeting the existing design capacity of the San Joaquin River Flood Control Project. Current investigations by the ACOE for the Sacramento and San Joaquin Comprehensive Plan should update estimates of the channel capacities.

#### 5.4.2.3. Bypass System

The State of California constructed the Eastside Bypass project from the Merced River upstream to the head of the Chowchilla Bypass between 1959 and 1966. The bypass system and its associated levees isolate about 240,000 acres of floodplain from the river (ACOE, 1985). The bypass is composed primarily of man-made channels and converted sloughs: the Chowchilla Bypass Channel, Eastside Bypass Channel, and the Mariposa Bypass Channel (Figure 5-5). Several structures are located along the bypass system to control the flow within of the system. Structures within the bypass system include the Chowchilla Bypass Bifurcation Structure, Sand Slough Control Structure, Mariposa Bypass Bifurcation Structure, and several associated drop structures (Table 5-3 and Figure 5-5).

The bypass system was constructed with the objective to divert and carry floodflows from the San Joaquin River at the Chowchilla Bifurcation Structure, along with flows from the eastside tributaries, downstream to the mainstem San Joaquin River upstream of the Merced River confluence (Figure 5-5). The system was designed to provide a 50-year level of protection (Reclamation Board 1966), and the flood capacities for each portion of the bypass system is illustrated in Figure 5-5. The rain generated flood frequency curve shows that the 50-year flood is approximately 24,000 cfs (ACOE 1999a), and comparing this 50-year flood magnitude with the design capacity of the current flood control system suggests that the 50-year flood protection design capacity is insufficient in Reach 1, Reach 2, Reach 3, the Chowchilla Bypass and the Eastside Bypass down to the Mariposa Bifurcation Structure (Figure 5-5). This probable lack of capacity assumes that all river reaches and bypasses functioned according to design capacity, no other flood flow contributions from tributaries occurs, and no flood peak attenuation occurs along the reaches. The ACOE Comprehensive Study was intending on further evaluating flood conveyance limitations, and developing remediation options, but it is unclear whether the ACOE will assume a larger role in flood protection, or will delegate responsibility for developing remediation options to local agencies.

#### 5.4.2.4. Chowchilla Bypass Bifurcation Structure

The Chowchilla Bypass Bifurcation Structure is a gated structure that controls the proportion of flood flows into the Chowchilla Bypass and Reach 2B of the San Joaquin River. The bifurcation structure has a drop (plunge pool) on the downstream side of the San Joaquin River, and has no fish passage facilities. The Chowchilla Bypass Bifurcation Structure is operated to attempt to keep flows in Reach

2B less than 2,500 cfs due to operational problems at Mendota Dam (see Section 5.4.1.2). Therefore, the operating rules for the Chowchilla Bypass Bifurcation Structure are based on the initial flow to the San Joaquin River and the initial flow to the Chowchilla Bypass (Reclamation Board 1969). The operational flow split rules, as well as example actual operations for 1986 and 1995 high flow events are shown in Figure 5-14. The present operations limit flows to 2,500 cfs in the San Joaquin River downstream from the bypass when upstream river flows are less than 8,000 cfs, with flows increasing to 6,500 cfs when the discharge in the upstream river is 12,000 cfs. The bypass operation is ultimately based on the current overall flood control needs in the project area, thus may deviate from the operating rules shown in Figure 5-14 (Reclamation Board, 1969).

#### 5.4.2.5. Sand Slough Control Structure and Reach 4B Headgate

The Sand Slough Control Structure, located in the short connection between the San Joaquin River at RM 168.5 and the East Side Bypass, helps control the flow split between the mainstem San Joaquin River and the Eastside Bypass. The control structure conveys all flows from the San Joaquin River to the East Side Bypass. The Sand Slough Control Structure does not appear to be a significant constraint to fish passage based on our field observations.

There is also a headgate at the entrance to Reach 4B of the San Joaquin River. There are no documented operating rules for the structure during low flows, but downstream flows in the mainstem San Joaquin River are theoretically limited to the design discharge of 1,500 cfs (Figure 5-5). However, the headgates have not been opened for many years, including during the 1997 flood. Even if it were open, the structure would pose a significant barrier to fish migration. The present capacity of the downstream channel is severely limited (300 to 600 cfs) due to extensive vegetation (Figure 5-11). Flows into Reach 4B are augmented by agricultural tailwater and seepage from canals, but are pumped and reused for irrigation.

#### 5.4.2.6. Mariposa Bypass Bifurcation Structure

The Mariposa Bypass Bifurcation Structure is a gated structure that controls the proportion of flood flows continuing down the East Side Bypass and through the Mariposa Bypass back into Reach 4B of the San Joaquin River. The bifurcation structure has a drop (plunge pool) on the downstream side into the Mariposa Bypass, and has no fish passage facilities. The Mariposa Bypass delivers flow back into the river from the Eastside Bypass near RM 148. The operating rule for the Mariposa Bypass is for all flow to be diverted back into the San Joaquin River at discharges in the Eastside Bypass up to 8,500 cfs, with any higher flows remaining in the Eastside Bypass and eventually discharging back into the San Joaquin River at the Bear Creek Confluence at the end of Reach 4B (Figure 5-15). However, actual operations seem to deviate from this rule, with all flows up to 2,000 cfs to 3,000 cfs staying in the East Side Bypass, after which approximately one-quarter to one-third of the flow is allowed to flow into the Mariposa Bypass (Figure 5-15). Flood flows that are not diverted back to the San Joaquin River via the Mariposa Bypass continue down the East Side Bypass and are returned to the San Joaquin River via Bravel Slough and Bear Creek. Bravel Slough reenters the San Joaquin at RM 136 and is the ending point of the bypass system.

There are also a series of drop structures to dissipate energy during high flows in the Mariposa Bypass, which are presently fish barriers. The channel elevation of the Mariposa Bypass is also at the shallow groundwater table in this reach, which allows for more frequent baseflows and has resulted in a somewhat more defined channel than exists in the East Side bypass. Although most of the bypass channel appears to allow fish passage, the drop structures are barriers and would have to be modified before fish passage would be attainable.

#### 5.4.2.7. Summary of Fish Passage Impacts by the Flood Control System

The bypass system provides a variety of fish passage complications. These complications are both flow and structurally related. Since portions of the main San Joaquin River are dry, flows are generally released into the bypass system before Reach 2B and 4B. This could lead fish into channels that have several control structures and that are operated to be quickly dewatered once the flood control event is over. With the possible exception of the Sand Slough Control Structure, the control structures do not presently facilitate fish passage during low to moderate flows. The current configuration of structures in the river and in the bypass system will require substantial work to remove barriers or construct fish ladders to provide fish passage to the upper reaches of the San Joaquin River.

Despite the constraints imposed by the bypass system for fish routing, the bypass system could show promise for use as a fish passage corridor for portions of the San Joaquin River between the Merced River confluence and the Chowchilla Bypass Bifurcation Structure. Although considerable modification of structures would be needed to allow fish passage, there are few to no diversions that may entrain migrating salmonids (adult and/or juvenile) compared to numerous large diversions at Mendota Pool, Sack Dam, and small riparian pumps. Furthermore, juvenile salmonids (as well as resident warm water species) may realize significant growth and survival benefits by being able to access the bypasses in the winter and early spring (See Chapter 7 for more detail). Routing or raising fish in the bypass system could lead to conflicts with the primary use of the bypass system (flood routing and hydraulic conveyance). For example, the bypasses are largely devoid of habitat due to hydraulic conveyance maintenance efforts, and may not be able to support the food base for fish as well as the Yolo Bypass on the Sacramento River. Additional drawbacks may include releasing additional water to reduce stranding and allow enough time for juveniles to migrate downstream back to the San Joaquin River, and flow losses may be greater in the bypasses than if flows were routed through the San Joaquin River channel. These options should be further considered in the Restoration Study.

### 5.4.3. Bridges and Culverts

There are many bridges and culverts in the study reach, the primary seventeen of which are listed in Table 5-5. Many of these culverts and smaller bridges are undersized to the flood flow regime downstream of Friant Dam. Culverts and smaller bridge crossings often wash out during high flows, and those that do not wash out may cause backwater effects at both high and low flows. Chapter 3 discusses the geomorphic constraints imposed by the extremely low channel gradient in Reach 1. The elevation drop provided by this low slope is critical for creating spawning and rearing areas for salmonids. One of the most significant impacts of undersized bridges and culverts is the effect they have on sediment transport and deposition, and the resulting impacts they have on stream gradient distribution along the river. The unconstricted river channel is connected to its floodplain, such that as flows increase, water spills onto floodplain surfaces and moderates stream energy over the reach (Figure 5-16). However, once a constricting bridge or culvert is installed, two processes tend to occur. First, a backwater forms upstream that causes sediment to deposit at the upstream end of the backwater. Second, the constriction locally disconnects the river from its floodplain, which increases local water velocities and sediment transport. At a constricted bridge (e.g., North Fork Bridge immediately downstream of Friant Dam), sediment is scoured underneath the bridge at the constriction, and is then immediately deposited downstream, causing local aggradation at that location (Figure 5-16). Over numerous high flow events, this tends to concentrate much of the elevation drop over a given reach over a very short distance, with long flat pools connecting these locations. In extreme cases, the aggrading sediment creates a steep riffle that is much less suitable for salmonid spawning than the unimpaired condition where gentle riffles were better distributed over the reach (McBain and Trush 2000).

*Table 5-5. Bridge and Culvert Crossings of the San Joaquin River between Friant Dam and the Merced River.*

| Transportation Element | Location (River Mile) | Comments |
|---|---|---|
| **Reach 1** | | |
| North Fork Road Bridge | 266.7 | Very Narrow opening due to confining abutments |
| Ledger Island Bridge | 262.2 | |
| Culvert | 258.5 | Probably washes out at high flows, causes backwater at lower flows |
| SR 41 Bridge (Lane's Bridge) | 255.3 | Recently replaced with bridge with greater conveyance capacity. 5.4 feet of channel degradation between 1940 and 1997 (Cain 1997). |
| Culvert | 252.8 | Probably washed out at high flows, causes backwater at lower flows |
| AT & SF Railroad Bridge | 245.1 | |
| SR 99 | 243.2 | 5.6 feet of channel degradation between 1970 and 1997 (Cain 1997) |
| SR 145 (Skaggs Bridge) | 234.1 | Causes some backwater at higher flows |
| **Reach 2A** | | |
| Bifurcation Structure | 216.1 | Causes backwater at higher flows |
| Concrete Dip Crossing at San Mateo Road | 211.8 | Barrier to fish passage at low flows |
| **Reach 3** | | |
| Avenue 7½ Bridge, Firebaugh | 195.2 | Two bridge openings. 2.2 feet of channel degradation between 1970 and 1997 |
| **Reach 4A** | | |
| SR 152 Bridge (Santa Rita Bridge) | 173.9 | 3.3 feet of channel aggradation between 1972 and 1997 |
| **Reach 4B** | | |
| Headgates | 168 | Culvert / Control Structure, probable fish barrier even when opened |
| Culvert | 163.1 | Probably washed out at high flows |
| Turner Island Road Bridge | 157.2 | |
| Culvert | 153.4 | Probably washed out at high flows, causes backwater at lower flows |
| **Reach 5** | | |
| SR 165 Bridge (Lander Avenue) | 132.9 | Causes some backwater at higher flows |
| SR 140 Bridge (Fremont Ford) | 125.1 | Causes some backwater at higher flows; 1.6 feet of channel degradation between 1972 and 1997 |

Improperly installed culverts may also significantly impact upstream fish migration. Current National Marine Fisheries Service fish passage criteria requires culverts to have less than a 1 ft drop (with accompanying jump pool depth greater than 2 ft), average velocity less than 6 ft/sec for adult passage, average velocity less than 2 ft/sec for juvenile passage, greater than a 1 ft depth for adult passage, and greater than a 6-inch depth for juvenile passage (NMFS 2001). Many culverts do not meet these criteria and will have to be replaced once the Restoration Study commences.

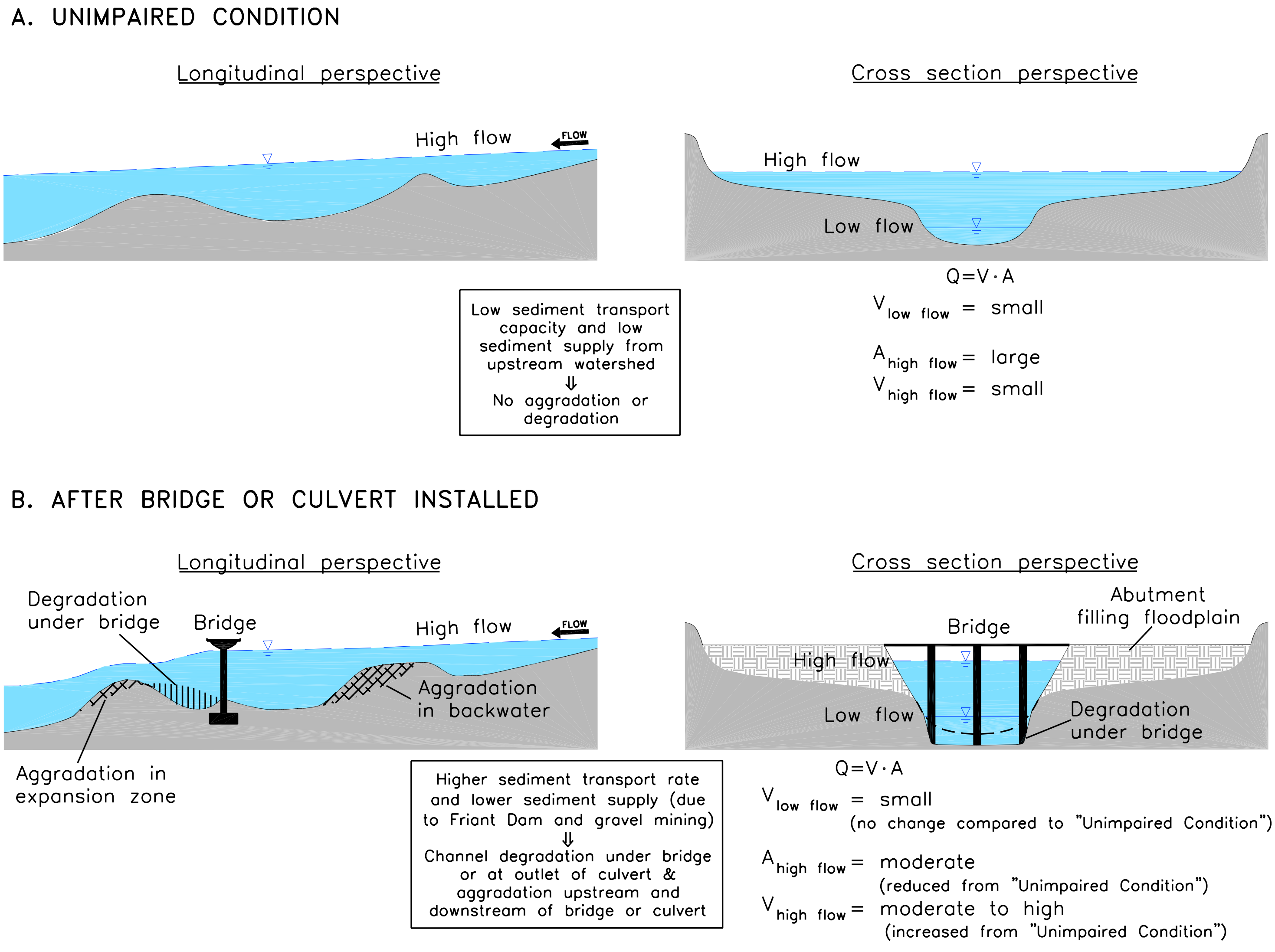

*Figure 5-16. Conceptual impacts of local floodway constrictions (bridges and culverts) to hydraulics, local bed scour/degradation, and local bed deposition/aggradation.*

### 5.4.4. Sand and Gravel Mining

Sand and gravel mining occurs from Friant Dam downstream to the Chowchilla Bifurcation Structure. Reach 1 is predominately gravel and sand mining, while Reach 2 is exclusively sand mining. Both are discussed briefly below.

#### 5.4.4.1. Reach 1

Between Friant Dam (RM 267) and Skaggs Bridge (RM 234.1), there has been considerable in-channel and floodplain mining for sand and gravel. Cain (1997) estimated that mining resulted in a sediment deficit on the order of 163,000,000 cubic yards between 1939 and 1996. Based on comparative cross sections, it is apparent that the channel has significantly degraded in several locations since 1939, and that the combined effects of the gravel mining and elimination of the upstream sediment supply by Friant Dam may have been greater had it not been for the presence of local bedrock outcrop and controls in the bed of the river channel (Cain, 1997). Overall, the bed of the channel has degraded to varying degrees based on local bedrock control, and in many locations, the former floodplain is now a terrace about 5 to 10 feet above the bed of the channel. Table 5-6 summarizes the total mined area along the river, including the breached "off channel" pits through which the river currently flows. Table 5-7 identifies the specific locations where the river has captured the pits. Based on the available data, it appears that about 3.3 miles of channel (17,424 feet) has been altered due to gravel mining activities.

*Table 5-6. Mined Areas along the San Joaquin River between Friant Dam and Skaggs Bridge*

| Reach | Total Mined Area (acres) | Mined Area Captured by River (acres) | Percentage of Captured Pits |
|---|---|---|---|
| Friant Dam (RM 267)—SR 41 (RM 255.2) | 494.5 | 7.5 | 1.5 |
| SR 41 (RM 255.2)—SR 99 (243.2) | 784.4 | 155.4 | 19.8 |
| SR 99 (RM 243.2)—Skaggs Bridge (232.8) | 76.2 | 26.8 | 35.1 |
| Total | 1,355.1 | 189.7 | 14.0 |

*Table 5-7. Locations of Pit Capture along the San Joaquin River between Friant Dam and Skaggs Bridge*

| Location (RM–RM) | Pit/Channel Length (feet) | Pit Area (acres) |
|---|---|---|
| 258.5–258.8 | 1,584 | 7.7 |
| 253.4–254.2 | 4,224 | 67.3 |
| 252.8–253.4 | 3,168 | 23.7 |
| 252.3–252.8 | 2,640 | 42.5 |
| 246.3–246.5 | 1,056 | 9.2 |
| 243.9–244.1 | 1,056 | 2.8 |
| 243.8–243.9 | 528 | 9.9 |
| 240.9–241.3 | 2,112 | 11.3 |
| 233.2–233.4 | 1,056 | 15.5 |
| Total | 17,424 | 189.7 |

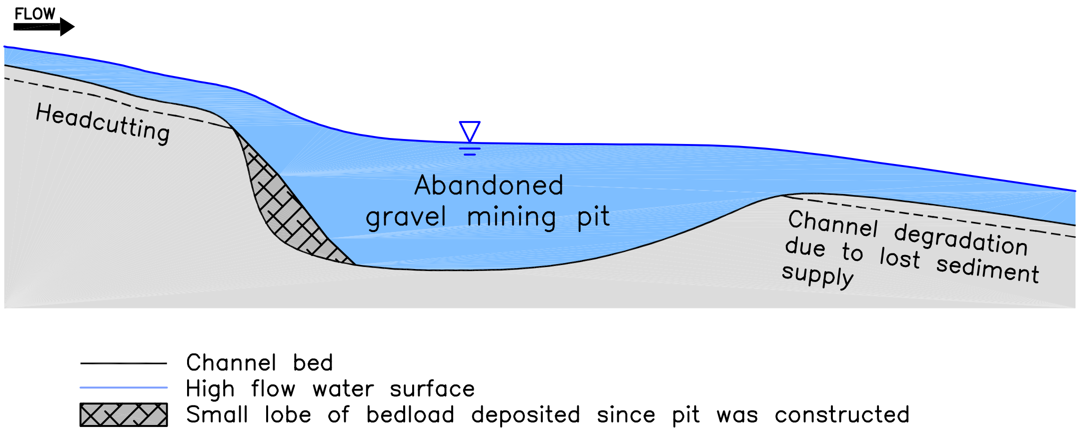

*Figure 5-17. Conceptual impact of instream gravel pit or captured "off-channel" gravel pit on bedload routing through Reach 1 of the San Joaquin River. Upstream sediment supply and transport is so small that it would take centuries for the river to naturally fill these large pits.*

The fluvial geomorphic impacts of gravel mining are fairly well documented (e.g., Collins and Dunne 1990, Kondolf 1994); however, the biological impacts are often indirect and not as well documented. Direct biological impacts include loss of aquatic habitat, or transformation of aquatic habitat from a riverine condition to a ponded condition. Direct geomorphic impacts include loss of instream gravel storage, loss of gravel bars and riffles, and bedload transport impedance reaches (gravel pits). Gravel mining pits cause indirect impacts, including trapping gravel transported from upstream reaches (Figure 5-17), and bed coarsening and channel degradation downstream of the pits due to loss of gravel supply. Gravel mining has transformed much of Reach 1 from a single-thread, moderate-sinuosity, meandering channel to a conveyance system composed of short single-thread channel segments connecting mining pits (see Reach 1 aerial photograph in Chapter 3). In addition to these biological and geomorphic impacts, gravel mining in Reach 1 may also:

- Increase evaporative water losses due to increased surface area of the river;
- Increase habitat for invasive fish species that prey on juvenile salmonids;
- Allow small lateral movement of the river to capture "off-channel" mining pits;
- Increase water temperatures; and
- Physically remove floodplains and riparian vegetation, thereby preventing future possible riparian vegetation in those areas.

### 5.4.4.2. Reach 2A

Sand mining activities have primarily been performed in Reach 2A by local landowners. Sand is excavated by skimming sand bars within the Project levees, with excavation sometimes as deep as 10 to 15 feet. For the most part, excavation does not appear to extend below the thalweg elevation of the river, and these excavated areas can fill quickly during a single high flow event. Sand tends to accumulate in the backwater upstream of the Chowchilla Bypass Bifurcation Structure, as well as in the Chowchilla Bypass itself. A 200,000 cubic yard sediment detention basin is located in the upstream section of the Chowchilla Bypass, and is commonly excavated following high flow events. Sand deposition is also removed from the Eastside Bypass immediately downstream of Sand Slough Control Structure because of deposition of materials scoured from the upstream portion of the East Side bypass. This aggradation has caused impacts on the conveyance capacity of the bypass (ACOE 1993).

### 5.4.5. Subsidence

Groundwater withdrawal for agricultural uses and hydrocompaction of the soils by agricultural activity has led to accelerated subsidence since the 1920s (Poland et al. 1975, Bull 1964, Basagaoglu et al. 1999). Maximum subsidence of nearly 30 feet has occurred in the Los Banos–Kettleman City area, with 1 to 6 feet of subsidence occurring along portions of the San Joaquin River between Mendota and about Los Banos (Ouchi 1983) (see Figure 4-16 in Chapter 4). As the valley floor has subsided, project and non-project levees have also subsided. Levee subsidence coupled with sediment accumulation has reduced the capacity of the lower 1.5 to 2 miles of the Eastside Bypass to about 6,000 to 7,000 cfs from the design capacity of about 16,500 cfs (ACOE 1993). To correct the problem, the Lower San Joaquin Levee District (LSJLD) has raised the levee height by three feet.

Comparison of thalweg elevations at cross sections that were originally surveyed by the California Debris Commission (CDC) in 1913/1914 with 1998 ACOE survey data indicate that there has been general bed lowering in reaches 4A and 3. The changes in elevation range from 1.5 to 10.8 feet with the higher numbers being recorded closer to Mendota, where the recorded subsidence has been on the order of 6 feet. Some of the potential bed lowering within Reaches 3 and 4A may also be due to subsidence. However, it is not known whether the apparent degradation is a result of subsidence or is incision due to human-induced changes to the sediment supply and hydrology of the San Joaquin River. One of the problems in distinguishing subsidence driven channel lowering from other sources (e.g. dams) has been associated with the level of survey accuracy, differing datum used for historical surveys, and lowering of local vertical control points.

As part of the Sacramento and San Joaquin River Basins Comprehensive Study, the ACOE is running first order cross valley survey traverses to determine the degree and extent of subsidence in the valley. Until these traverses are completed it will not be possible to resolve many of the apparent datum problems in the valley, to determine whether the San Joaquin River has degraded downstream of Mendota Dam, and to determine the causes of degradation.

Primary impacts of subsidence to potential restoration efforts on the San Joaquin River are primarily related to hydraulic and geomorphic impacts of differential subsidence. For example, if Reach 3 subsides at a greater rate then Reach 4, the river gradient will decrease, which will reduce flow conveyance capacity and sediment transport capacity. This compounds the problems presented by natural deposition and scour processes that may be a result of hydrologic changes and changes in the sediment regime from land use or diversion dams. Additionally, potential future physical manipulation of the river channel and floodway may have to contend with future reach-scale changes in valley gradient. Lastly, groundwater extraction will continue into the foreseeable future, and the degree of over-extraction will dictate the amount of additional subsidence. Assuming a similar rate of over-extraction, subsidence will continue in all historical subsidence areas, but at lower rates because much of the overall subsidence potential in the soil (voids previously filled with water) has already occurred (Swanson 1998). Increasing flows in the river may reduce the depletion of (or even begin to replenish) the shallow groundwater table depending on the amount of flows released and the future rate of groundwater pumping.

### 5.4.6. Levee Seepage

Seepage occurs when the hydrostatic pressures within the river channel become large enough to push water through the strata underlying adjacent levees. Historically, the strata beneath the levees consisted of several layers of sands and silts. Over time, the silts have been removed by seepage processes and have been deposited in the various interceptor ditches lining the backside of each levee. During annual maintenance, the silts are removed from the system. Thus, in many areas, levee foundations are now composed of well-washed layers of sands. These sands convey water under the levee structures once the water surface in the San Joaquin River reaches a sufficient height to cause a differential in hydrostatic pressure.

Levee seepage generally occurs along a 6-mile corridor of the San Joaquin River from Mendota Pool to the Chowchilla Bifurcation Structure (Figure 5-7). Seepage is a direct effect of diversion operations occurring at the Mendota Pool (Harvey, 2000), the diversion at the Chowchilla Bifurcation Structure, and the flow release regime at Friant Dam.

Operations at Mendota Pool effect seepage by raising the water surface level in the pool. This produces a backwater effect and increases the water surface elevations upstream. During irrigation seasons when the Mendota Pool is in operation, 1,300 cfs may pass through the south diversion of the Chowchilla Bifurcation Structure without significant seepage into adjacent lands. However, larger flows begin to cause seepage problems. During the non-irrigation season when the boards can be pulled from Mendota Dam, 2,500 cfs may pass through the Reach 2B portion of the Chowchilla Bifurcation Structure with minor amounts of seepage problems.

The Chowchilla Bifurcation Structure also contributes to the upstream backwater affect and increases the potential for seepage in Reach 2A. At the design discharge of 8,000 cfs through the Chowchilla Bifurcation Structure, seepage has been observed to occur up to 3 to 4 miles upstream. In an effort to reduce backwater-induced seepage problems, the trash racks in the Chowchilla Bypass structure have been removed. This was conducted in hopes of reducing the water surface elevation by decreasing the roughness factor of the Bifurcation Structure.

Overall, discharges and the associated seepage are dictated by the releases at Friant Dam. Large storm events that require large releases of water have a significant effect. For instance, during the storm of 1986, significant amounts of seepage conveyed underneath and through levees flooded six miles of adjacent lands for a period of two weeks. Eleven levee failures were recorded during over the area of seepage (Figure 5-7). The estimated peak discharge from Friant Dam was approximately 14,000 cfs.

As a result of seepage problems, interceptor ditches and tile drains have been constructed on the back side of the levees in Reach 2A. Many of the interceptor ditches along the backside of the levees have been modified for irrigation purposes, such that seepage through the levees is pumped out periodically to reduce root inundation and irrigate crops elsewhere. According to Batty (2000), landowners often collect water in these interceptor sumps (apparently from the shallow groundwater recharge from surface flows in the river) even during the summer months.

## 5.5. OPPORTUNITIES AND CONSTRAINTS

Summary of water supply and flood control infrastructure on important restoration components of the San Joaquin River are listed in Table 5-8.

*Table 5-8. Summary of water supply and flood control infrastructure on important restoration components of the San Joaquin River.*

| **INFRASTRUCTURE TYPE** | **IMPACT TO RIVER AND/OR RESTORATION EFFORTS** |
|---|---|
| Large Storage Dams<br>(Friant Dam) | ○ Prevents adult passage, impairs sediment routing, causes local aggradation and degradation (See Chapter 2, 3, and 7).<br>○ Promotes riparian encroachment (See Chapter 8).<br>○ Reduces floodplain inundation, baseflows, and the overall flood flow regime (see Chapter 2).<br>○ Limits opportunities to increase or improve salmonid habitat to areas below Friant Dam.<br>○ Smaller flow regime is a constraint to achieving fluvial geomorphic objectives that create and maintain aquatic and terrestrial habitat.<br>○ Upstream watershed is permanently blocked.<br>○ Due to pre-existing water supply and flood protection objectives, dam operations are very difficult to modify for restoration efforts.<br>○ Minimum flow, ramping, and temperature requirements must be able to adapt to existing coldwater pool and water supplies. |
| Small Diversion Dams<br>(Mendota Dam, Sack Dam) | ○ Impedes or prevents adult passage.<br>○ Impairs sediment routing.<br>○ Creates salmonid predator habitat, thus may increase invasive/predatory populations.<br>○ Increases water temperatures.<br>○ Reduces base flows.<br>○ Fish passage structures are typically not cost effective when multiple barriers exist over short reaches.<br>○ Fish screens designed for juveniles are very expensive.<br>○ Alternate fish passage routes are difficult to implement. |
| Pumping Facilities<br>(Numerous pumps along the entire study reach) | ○ Entrains and impinges juvenile salmonids.<br>○ Reduces base flows during low-flow conditions.<br>○ May create habitat that harbors invasive/predatory species.<br>○ Hardpoints may have been added to stabilize riverbanks near pumping facilities.<br>○ Channel restoration efforts must accommodate pumping operations and water supply.<br>○ May require another means of diversion to properly restore function of channel section. |

*Table 5-8. cont.*

| INFRASTRUCTURE TYPE | IMPACT TO RIVER AND/OR RESTORATION EFFORTS |
|---|---|
| Flood Control Project Levees (Reach 2A, lower Reach 4B, and Reach 5) | ○ Prevents sediment and nutrient transfer between the river and its floodplain.<br>○ Limits flow access to large floodplain areas that are highly valuable for spawning, rearing, and feeding for fish.<br>○ Changes natural flood hydrograph and routing, which increases flood depths, reduces flood peak attenuation, reduces flood routing time, reduces residence time on floodplain.<br>○ Impairs life history of certain fish species that depend on inundated floodplains.<br>○ Physically removes riparian vegetation during construction, maintenance continually removes new vegetation within levees.<br>○ Inhibits the recruitment of large woody debris.<br>○ Concentrates shear stress between levees, promoting channel incision and reducing aquatic habitat diversity.<br>○ Bank protection measures simplify channel and habitat diversity.<br>○ Confinement limits ability of future channel migration or avulsion.<br>○ Levee removal or setback removes land from agricultural production and/or may require property or conservation easement purchases.<br>○ Adjacent developments may significantly constrain opportunities to reconfigure levees.<br>○ Levee removal or setback may be costly due to earthworks and property/conservation easement purchase.<br>○ Vegetation removal for flood conveyance hampers riparian regeneration efforts. |
| Non-Project Levees and Dikes (Reach 1, Reach 2B, Reach 3, Reach 4A, and upper Reach 4B) | ○ Prevents sediment and nutrient transfer between the river and its floodplain.<br>○ Limits flow access to floodplain area that is highly valuable for spawning, rearing, and feeding for fish.<br>○ Impairs life history of certain fish species that depend on inundated floodplains.<br>○ Physically removes riparian vegetation during construction, maintenance continually removes new vegetation.<br>○ Confines lateral migration of river if maintained.<br>○ Frequent failure of non-project levees and dikes during moderate to high flows.<br>○ Levee removal or setback removes land from agricultural production and/or may result in property or conservation easement purchase.<br>○ Adjacent developments may significantly constrain opportunities to reconfigure levees and dikes.<br>○ Bank protection measures simplify channel and habitat diversity.<br>○ Levee removal or setback may be costly due to earthworks and property/conservation easement purchase. |
| Agricultural Return Drains (Primarily in Reach 3, Reach 4, and Reach 5) | ○ Degrades water quality by discharging excess nutrients, pesticides, herbicides, and heat into river.<br>○ Unscreened channel discharge points may provide false pathways for fish passage.<br>○ Non-point source pollution problems are generally difficult to remediate.<br>○ Eliminating false pathways may require additional in-stream structures (screens or weirs). |

### 5.5.1. Summary of Opportunities

The myriad of infrastructure components on the San Joaquin River study reach makes restoration opportunities few and constraints many. Restoration opportunities do exist, and are listed below:

- One of the most significant challenges facing salmonid restoration to the upper San Joaquin River is restoring continuous streamflow to all reaches in order to provide adequate adult and juvenile salmonid passage. Releases already made from Friant Dam (Reach 1) and Mendota Dam (Reach 3) already provide year-round baseflows. Additionally, agricultural returns provide continual baseflows in Reach 5 and the lower portion of Reach 4B, although the quality of this water is poor.
- Friant Dam outlet works have controlled release capacity of up to 16,400 cfs, which could be used to improve geomorphic processes in downstream reaches in the event that the numerous constraints and impacts are alleviated.
- The size of Millerton Lake is sufficient to provide cold hypolimnial releases in most water years, with the possible exception of driest years due to reservoir drawdown (being evaluated as part of the Restoration Study). These cold water releases can be provided throughout the summer months to provide adequate summer rearing temperatures in Reach 1, as well as potentially influencing water temperatures in the early spring and late fall for juvenile outmigration and adult immigration, respectively.
- Mendota Dam and diversions from Mendota Pool would require extensive modifications to protect downstream migrating salmon from being entrained in the diversions, as well as providing adult migration past the dam. The Bureau of Reclamation is considering alternative designs for rebuilding Mendota Dam, and opportunities to improve adult and juvenile salmonid routing through or around Mendota Dam and Mendota Pool could be integrated into the Bureau of Reclamation effort. Diversion screens are a viable (but expensive) option as they have been constructed and operated successfully throughout the Central Valley. Additionally, as part of the Mendota Dam reconstruction, there may be opportunities to directly connect the Arroyo Canal to the DMC, thus eliminating a large diversion from the mainstem San Joaquin River. However, this would also eliminate the source of Reach 3 perennial flows of approximately 200 cfs during the non-irrigation season, and up to 600 cfs during the irrigation season.
- Adult salmonid passage could easily be restored at Sack Dam by simply placing boards back into the fish ladder. No significant retrofitting or construction would appear warranted.
- Efforts are underway to improve water quality in the lower San Joaquin River (Reaches 3 through 5, as well as reaches downstream of the Merced River confluence). Actions include reductions in effluents from treatment plants and dairies/feedlots. Wetland restoration along the river floodplain such as that being undertaken by the San Joaquin National Wildlife Refuge (with support from the CALFED program), as well as other programs, may help to reduce these loadings.
- The Chowchilla Bypass, East Side Bypass, and Mariposa Bypass may provide some favorable opportunities for juvenile salmonid rearing during winter and early spring months when ambient air temperatures are low and there is flow in the bypasses. Recent research conducted on the Yolo Bypass has shown that fish growth is greater in the bypass than in the mainstem Sacramento River. While the San Joaquin River bypasses are much different than the Yolo Bypass, there may still be benefits to considering a strategy that uses the bypasses

for juvenile rearing and outmigration. Additionally, the number of riparian diversions and pumps is substantially less than that on the mainstem San Joaquin River, which may reduce diversion and pump entrainment losses to juvenile and adult salmonids.

- The San Joaquin River channel and bypass system presently lacks the capacity to convey the design 50-year flood release from Friant Dam, thus will surely incur local failures again someday as occurred in 1997 and other years. Furthermore, portions of the levee system do not provide reliable flood protection because of structural instability, poor foundation conditions, and excessive seepage. Future efforts to alleviate these flood control problems could provide restoration opportunities if these efforts integrate levee setbacks and floodplain conveyance as part of the flood control solution.
- The ACOE Comprehensive Study provides the opportunity to coordinate improvements in the flood management system in the study area with restoration efforts, since ecosystem restoration is one of the many goals of the Comprehensive Study. The ACOE effort may also be a mechanism to apply Federal funds to develop projects that benefit both flood conveyance and restoration efforts on the San Joaquin River.
- Buchanan Dam, Hidden Dam, and/or Madera Canal could provide flows to the San Joaquin River at certain times of the year that would benefit salmonids (e.g., smolt outmigration period); however, there are ecological and geomorphic constraints that would need to be considered (among others). If flows from these sources occurred during the smolt outmigration period, juvenile imprinting on non-San Joaquin River water could lead to some unknown amount of straying of returning adults. If flows occurred during the adult migration time, adults could be attracted into non-San Joaquin River channels rather than their intended destination in Reach 1. Additionally, the lower portions of the Chowchilla and Fresno rivers are not adequately connected to the San Joaquin River, and defined channels would need to be created in the lower portions of these two rivers.

### 5.5.2. Summary of Constraints

Constraints imposed by the water related infrastructure within the study reach of the San Joaquin River are numerous, and include:

- Lack of continual streamflows in Reach 2 and Reach 4, and lack of continuous streamflow connectivity amongst all reaches, due to diversions from Friant Dam, Mendota Dam, Sack Dam, and numerous riparian pumps. Streamflow is the initial limiting factor to restoring salmon and steelhead in the San Joaquin River study reach. Infrequent flood control releases that provide full flow routing (and enable fish migration) are insufficient to achieve salmonid restoration goals.
- Lower streamflows due to flow regulation will also cause a constraint to restoring salmonid populations in the San Joaquin study reach. Even if adequate water for fish passage is released from Friant Dam, water temperatures over the late spring, summer, and early fall months would too high to permit adult and juvenile salmonid migration.
- Juvenile and adult salmonid entrainment in water diversions will be a constraint for restoration efforts given that, at present, all non-flood water released from Friant Dam and Mendota Dam is captured by riparian diversions, leaving much of Reach 2 and 4 dewatered. Diversions at Mendota Pool, Sack Dam, and many small diversion dams and pumps would divert a significant portion of downstream migrating juvenile salmon into canals and agricultural fields. Remediating potential future entrainment losses will be a significant task.

- Water quality studies have shown that concentrations of dissolved solids and selenium, along with low dissolve oxygen in agricultural drainwater impair growth and survival of salmonids and other native fishes (See Chapter 6). Furthermore, non-native fish species are often better suited to survive these degraded water quality conditions, thus out-compete the native fishes.
- The transformation of the San Joaquin River from a natural riparian and tule marsh floodway to a leveed water supply and flood control channel has completely altered the hydrology, geomorphology, and channel morphology of the river. Reversing this cumulative impact will be a major constraint. Portions of the stream channel upstream of the mouth of the Merced River have been dewatered, and the lower reaches have been maintained more as an agricultural drain than a river. Wetlands and riparian habitats have been lost, which along with changes in flow, have greatly altered the character and structure of the stream channel and floodplain terraces. Gravel mining in Reach 1 has reduced sediment supply, created enormous bedload traps, and increased channel degradation. Reversing the impacts of gravel mining, even for a scaled-down floodway, will be a lengthy and expensive effort.
- The Mariposa Bypass, Chowchilla Bypass, and Eastside Bypass all have bifurcation structures or drop structures that may constrain upstream adult salmonid migration and downstream juvenile salmonid migration (as well as other native fish species). Adult salmonids may be attracted to bypass outfalls and then become stranded in the bypass when flows recede too quickly. If adult salmonids are intended to be routed through the bypasses, all drop structures and bifurcation structures in the bypass will need fish passage modifications.
- Larger irrigation returns (e.g., Mud Slough, Salt Slough) may attract adult and juvenile salmonids. Adults are known to move far upstream in irrigation systems only to eventually become trapped or forced to retrace their path. Weirs at the downstream ends of these return channels are reasonably inexpensive fixes, but still may cause harmful delays to upstream adult migration.
- Given the limited water supply in the San Joaquin River, and structures potentially concentrating fish, poaching may become problematic at these locations.
- The travel time of flood releases from Friant Dam is several days longer than releases from the tributaries (Tuolumne River, Merced River, Stanislaus River), further confounding flood control operations and increasing the risk of flood damage in the lower San Joaquin River.

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