CHAPTER 6. WATER QUALITY

6.1. INTRODUCTION

The San Joaquin Valley depends on water of good quality from the San Joaquin River to support agricultural production and provide domestic water supplies, and to support the fish and wildlife resources that inhabit the river. Historically, clean and abundant water supplies flowed from the Sierra Nevada, fed by the large volume of unimpaired snowmelt runoff from the pristine upper watershed.

Water quality has decreased markedly in recent decades, however, resulting primarily from major land use changes. The first significant land disturbance by European and East Coast immigrants was cattle and sheep ranching. By the 1870s, wheat farming began to eclipse ranching as the dominant land use. Throughout the 20th century, agriculture diversified, with wheat replaced by more water-intensive crops, such as truck crops, orchards, grain, and other products.

Prior to the last 50 years of rapid agricultural and urban expansion, water quality information was infrequently collected. In recent decades, however, water quality deterioration has been better documented, and has generally coincided with San Joaquin River flow reductions, population growth, and expanded agricultural production. For example, in 1988, 52.8 million pounds of restricted-use pesticides, of 350 different types, were used in the San Joaquin basin (Brown 1998). Nitrate concentrations in the San Joaquin River have increased over the last 40 years (Dubrovsky et al. 1998). Selenium, boron, and mercury concentrations are elevated in agricultural drain waters in the study area. Chapter 2 of this report documents changes in streamflow hydrology in the San Joaquin River, and Chapter 10 provides a complete description of the historical and contemporary land uses in the San Joaquin Valley.

Despite these dramatic changes to water quality in the San Joaquin basin, few studies have linked water quality to the health of aquatic resources (Dubrovsky et al. 1998). Intensified studies in recent years has advanced our knowledge of the sources and distribution of water quality and contaminants, and have identified a number of water quality parameters that may pose significant limits on the long-term restoration goals for the San Joaquin River. Our purpose in this chapter is to describe historical and existing water quality conditions from Friant Dam to the confluence with the Merced River and to analyze how these water quality conditions could affect restoration of riparian vegetation, fish resources, and other target species.

6.2. STUDY AREA

The study area considered in this chapter extends from Friant Dam below Millerton Lake at San Joaquin River Mile (RM 267), downstream to the confluence with the Merced River (RM 118) (Figure 6-1). Much of the available water quality information used in this analysis is derived from sampling at Newman and Vernalis, outside of the study area, and downstream of the influence of the Stanislaus, Tuolumne, and Merced rivers.

In addition to the study reaches in the mainstem San Joaquin River, this assessment also discusses several tributaries within the general study area because they are specific contaminant sources. South of the Merced River, many of the eastside tributaries now have dams and reservoirs, including Bear Creek (confluence within Reach 5), Chowchilla River, Fresno River, and Dry Creek (confluences within Reach 4). These tributaries are included in our assessments. Westside tributaries include Los Banos Creek, Mud Slough, and Salt Slough (confluences within Reach 5). The water quality monitoring station at Vernalis is the point of compliance of several water quality objectives, and the lower San Joaquin River is therefore included in our assessments. Water quality data from the remaining tributary streams to the San Joaquin River from the Merced River confluence (RM 118) northward to Chipps Island (RM 0), as well as other sources outside the study area, were excluded from this assessment. On the Westside, excluded sites are Orestimba, Del Puerto, Ingram and Hospital Creeks; on the eastside, these are the Merced River (and tributary Owens Creek), Tuolumne River (and tributary Dry Creek), Stanislaus River, Littlejohns Creek, Calaveras River, Mokelumne River, and Cosumnes River.

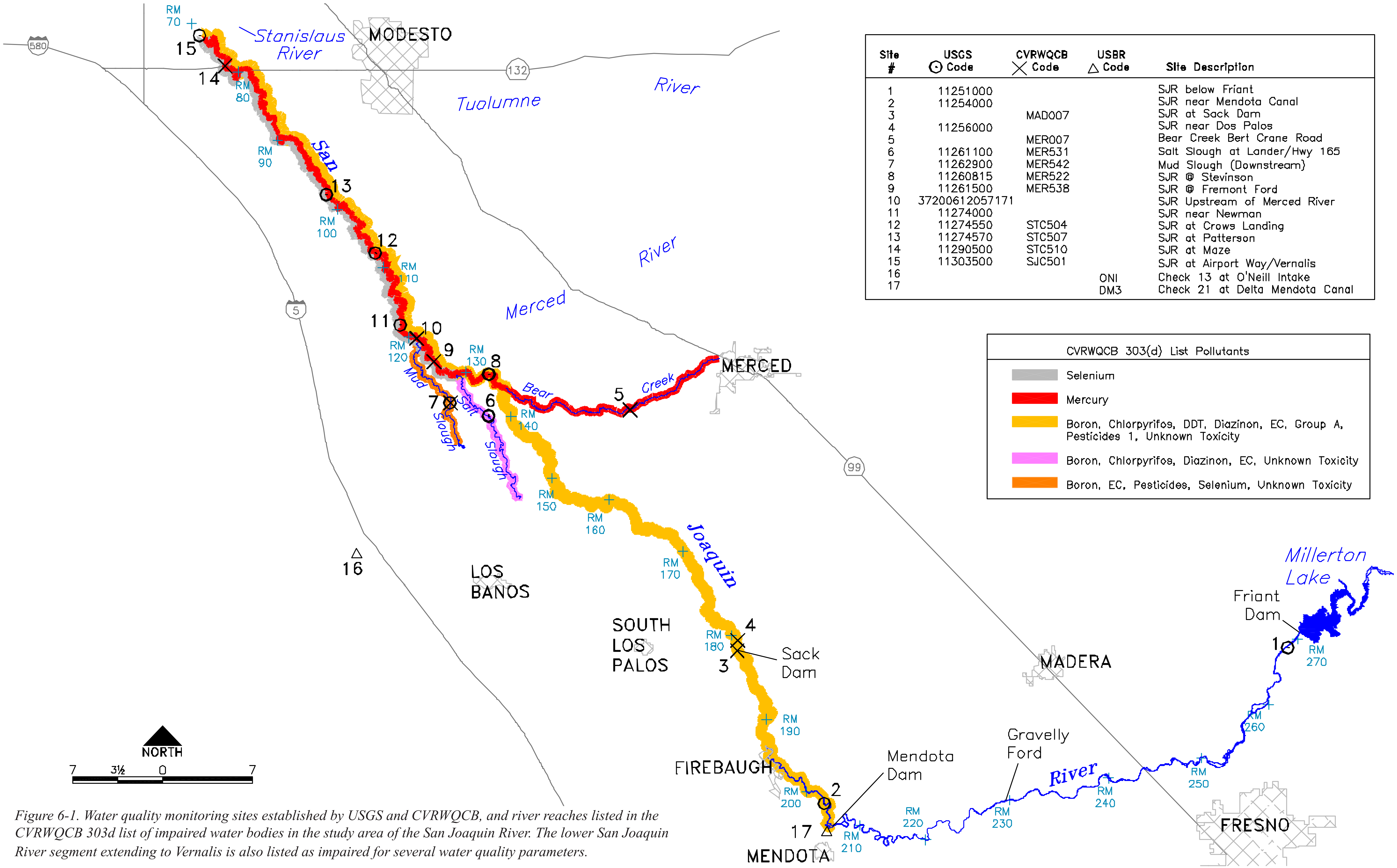
6.2.1. Surface and Groundwater Sources

The San Joaquin River basin is drained by its principal tributaries that flow from the Sierra Nevada range on the basin's east side, the Coast Range on the west side, and the Tulare Lake basin on the south side. Historically, tributaries that drain the basin's west and south edges were intermittent, due to low rainfall over the Coast Range and the Tehachapi Mountains. Maximum flow in the San Joaquin River and its eastside tributaries historically occurred in May and June, and was primarily snowmelt (Jackson 1972; USGS 1998). With the completion of Friant Dam in 1941 and the Friant-Kern canal in 1948, most of the San Joaquin River flow was diverted, leaving the river channel upstream of Mendota Pool dry, except during wetter water years when flood control releases were required. Currently, releases from Friant Dam provide 5 cubic feet per second (cfs) down to Gravelly Ford (RM 229). Farther to the south, the Kings, Kaweah, Tule, and Kern Rivers drained into Tulare Lake, which often spilled into the San Joaquin basin via Fresno Slough. Flood flows from the Kings River is still sent north to Fresno Slough and into the San Joaquin River.

Groundwater resources of the San Joaquin River Basin include all or part of 10 major groundwater basins: Kings, Madera, Chowchilla, Merced, Modesto, Eastern San Joaquin County, Tracy, Delta-Mendota, Westside, and Sacramento County basins. Poorer quality (higher salinity) water is imported from the south Delta via the CVP and SWP; this water is used for irrigation along the west side of the San Joaquin River. Irrigation water drains via Salt and Mud Sloughs, and Bear Creek. Reaches 2 and 4 are dry most years; Reaches 1 and 3 have perennial flows from Friant Dam and Mendota Dams, respectively. During the irrigation season (May through October), river flows between the Mendota Pool and Salt Slough largely originate from groundwater and tile drainage of Westside agricultural developments. Concentrations of Total Dissolved Solids (TDS), sodium, sulfate, boron, chloride, carbonate/ bicarbonate, and trace elements (e.g., selenium) all increase as CVP-delivered water is applied to westside soils, and as deep percolation returns to the San Joaquin River (Phillips et al. 1991). Besides these agricultural discharges to the river, impacts also result from the largest urban water users in the San Joaquin Valley, the cities of Fresno, Modesto, and Stockton. To the north of the Merced River, flows from the three major eastside tributaries (Merced, Tuolumne, and Stanislaus) substantially dilute negative effects on the water quality of the San Joaquin River. Chapter 2 discusses surface water hydrology, and Chapter 4 discusses groundwater resources in the study area.

6.3. DATA SOURCES

Several state and federal agencies have direct or indirect responsibility for assessing water quality in the San Joaquin basin, including the State Water Resources Control Board (SWRCB), Central Valley Regional Water Quality Control Board (CVRWQCB), the U.S. Geological Survey (USGS) National Water Quality Assessment Program (NAWQA), and the State Department of Water Resources (DWR). Within the study area of this chapter, monitoring stations' periods of record vary, as do the stations' types of water quality parameters (Table 6-1). In addition to the SWRCB and Regional Board data, we have compiled historical data found in DWR files, USGS data and reports (e.g., NAWQA and Water Supply Papers), the California Department of Fish and Game (CDFG) files, agency publications, and journal articles.



Site #	USGS ⊙ Code	CVRWQCB ✕ Code	USBR △ Code	Site Description
1	11251000			SJR below Friant
2	11254000			SJR near Mendota Canal
3		MAD007		SJR at Sack Dam
4	11256000			SJR near Dos Palos
5		MER007		Bear Creek Bert Crane Road
6	11261100	MER531		Salt Slough at Lander/Hwy 165
7	11262900	MER542		Mud Slough (Downstream)
8	11260815	MER522		SJR @ Stevinson
9	11261500	MER538		SJR @ Fremont Ford
10	37200612057171			SJR Upstream of Merced River
11	11274000			SJR near Newman
12	11274550	STC504		SJR at Crows Landing
13	11274570	STC507		SJR at Patterson
14	11290500	STC510		SJR at Maze
15	11303500	SJC501		SJR at Airport Way/Vernalis
16			ONI	Check 13 at O'Neill Intake
17			DM3	Check 21 at Delta Mendota Canal

Figure 6-1. Water quality monitoring sites established by USGS and CVRWQCB, and river reaches listed in the CVRWQCB 303d list of impaired water bodies in the study area of the San Joaquin River. The lower San Joaquin River segment extending to Vernalis is also listed as impaired for several water quality parameters.

Table 6-1. Water quality monitoring stations along the San Joaquin River.

New Site Number	Gage Name	CVRWQCB Code	USGS Code	Water Temperatures (Table 5)	General Water Quality (Table 7)	Inorganics (Table 8)	Pesticides and Herbicides (Tables 9 and 10)
1	SJR Below Friant		11251000	2000-2001	1951-1984	1951-1984	
2	SJR Near Mendota		11254000	2000-2001	1951-1984		
3	SJR @ Sack Dam	MAD007		2000-2001			
4	SJR Near Dos Palos		11256000		1951-1959	1951-1959	
5	Bear Creek Bert Crane Rd.	MER007					
6	Salt Slough @ Lander/Hwy 165	MER531	11261100	1985--2002	1985-1994	1984-2002	1993-1994
7	Mud Slough (Downstr)	MER542	11262900	1985--2002	1985-1999	1985-2002	1994-1999
8	SJR @ Stevinson	MER522	11260815	1985--2002	1985-2000	1985-2002	1994-2000
9	SJR @ Fremont Ford	MER538	11261500	1979--2002	1955-1994	1955-2002	
10	SJR Upstream of Merced R.		372006120571701	2000--2000	2000-2000	2000-2000	
11	SJR Near Newman		11274000	1984--1988	1958-1988	1958-1993	
12	SJR @ Crows Landing	STC504	11274550	2000--2000	1962-2000	1962-2000	
13	SJR @ Patterson	STC507	11274570	1985--2002	1962-2000	1962-2002	1994-2000
14	SJR @ Maze	STC510	11290500	1985--2002	1951-1994	1951-2002	
15	SJR @ Airport Way/Vernalis	SJC501	11303500	1961--2002	1950-2000	1950-2002	1972-2000

1 Not all parameters measured for entire periods of record shown.

6.4. OBJECTIVES

The primary objective of this chapter is to summarize water quality parameters, then 1) evaluate how these parameters impact aquatic resources, 2) link these water quality parameters with source contributions, and 3) assess how sensitive these parameters are to changes in increased instream flows and other potential restoration actions. This chapter assesses numerous water quality parameters, including temperature, salinity, dissolved oxygen (DO), and trace constituents such as metals, pesticides, and other contaminants. Historical water quality conditions are described where information is available, and then they are compared to existing water quality conditions.

6.5. EXISTING WATER QUALITY IMPAIRMENTS

The SWRCB and the CVRWQCB are responsible for ensuring implementation and compliance with the provisions of the federal 1972 Clean Water Act (CWA) and California's Porter-Cologne Water Quality Control Act. Water quality impairments arise from many sources, including instream flows, land use, and direct contaminant discharge. To better manage these responsibilities, the CVRWQB has grouped the study reaches in the San Joaquin River as follows (CVRWQCB 1998a):

1) Friant Dam to Mendota Pool (Reaches 1 and 2)
2) Mendota Dam to Sack Dam (Reach 3),
3) Sack Dam to the Merced River (Reaches 4 and 5).

Designated beneficial uses for the San Joaquin River and its tributaries include municipal and domestic drinking water supplies, and cold freshwater habitat use for Reaches 1–2; for Reaches 1–5, warm freshwater habitat is designated (Table 6-2). Other designated beneficial uses include agricultural supply, industrial process water, contact and non-contact recreation, migration of aquatic organisms, spawning habitat, and habitat for other wildlife (Table 6-2). In 2001, each of California's nine RWQCBs was asked to assist the SWRCB in preparing an update to the state's Clean Water Act Section 303(d) List of Water Quality Limited Segments (SWRCB 2001). Several reaches and tributaries within the study area currently do not meet the water quality criteria applicable to the designated beneficial uses and are therefore on the CVRWQCB's 303 (d) list (Table 6-3). These impaired segments include the San Joaquin River from Mendota Dam to the Merced River (and to Vernalis), Bear Creek, Salt Slough, and Mud Slough. No impairments were listed for Reaches 1 and 2.

Specific water quality objectives (WQOs) for the San Joaquin River and its tributaries are set forth in the Water Quality Control Plan for the Sacramento and San Joaquin River basin (Basin Plan) prepared by the CVRWQCB (1998a), currently in its fourth revision. WQOs are required under the Clean Water Act and are numerical or narrative limits for constituents or characteristics of water designed to protect beneficial uses of the water under the authority of the California Porter-Cologne Water Quality Control Act. Several water quality objectives have been established for the San Joaquin River by the CVRWQCB (Table 6-4). Although the WQOs define the least stringent standard that the Regional Water Board applies to protect regional waters for all beneficial uses, the WQOs may also be set for beneficial uses that require a more stringent standard than needed for fish restoration.

We assume that if the CVRWQCB does not list a river reach as impaired, then the existing water quality conditions are adequate for aquatic resources. This is the case for the WQO for salinity and molybdenum, because water quality criteria for drinking water and agriculture are more stringent than for aquatic resources.

Table 6-2. The designated beneficial uses of waters established by the Central Valley Regional Water Quality Control Board in the San Joaquin River study reaches. MUN=Municipal and Domestic Supply; AGR=Agricultural Supply; PRO=Industrial Process Supply; REC=Recreation ;WARM=Warm Freshwater Habitat ; COLD=Cold Freshwater Habitat ;MIGR=Migration of Aquatic Organisms ; SPWN=Spawning, Reproduction, and/or Early Development ; WILD=Wildlife Habitat.

Reach No.	Reach Name	River Miles	MUN	AGR	PRO	REC	WARM	COLD	MIGR
1	Friant Dam to Gravelly Ford	RM 267 to RM 229	X	X	X	X	X	X	X
2	Gravelly Ford to Mendota Dam	RM 229 to RM 205	X	X	X	X	X	X	X
3	Mendota Dam to Sack Dam	RM 205 to RM 182		X	X	X	X		X
4	Sack Dam to Bear Creek	RM 182 to RM 136		X	X	X	X		X
5	Bear Creek to the Merced River	RM 136 to RM 118		X	X	X	X		X

Table 6-3. San Joaquin River reaches within the study area designated as impaired and placed on the CVRWQCB Section 303(d) list.

Water Body	Pollutant	Segment (Reach #)
San Joaquin River	Selenium	Salt Slough to Merced River (Reach 5)
San Joaquin River	Mercury	Bear Creek to mouth of Merced River (Reach 5)
San Joaquin River	Boron, Chlorpyrifos, DDT, Diazinon, EC, Group A Pesticides[1], Unknown Toxicity	Mendota Dam to Merced River (Reaches 3, 4, and 5)
Bear Creek	Mercury	28 miles of Bear Creek (Reach 5)
Salt Slough [2]	Boron, Chlorpyrifos, Diazinon, EC, Unknown Toxicity	15 miles of Salt Slough (Reach 5)
Mud Slough	Boron, EC, Pesticides, Selenium, Unknown Toxicity	16 miles of Mud Slough (Reach 5)

[1] Group A pesticides = One or more of the Group A pesticides. The Group A pesticides include aldrin, dieldrin, chlordane, endrin, heptachlor, epoxide, hexachlorocyclohexane (including lindane), endosulfan and toxaphene.

[2] Selenium in Salt Slough was taken off the 303(d) list during the YR 2001 review due to implementation of the Salt Slough Total Maximum Daily Load (TMDL).

Table 6-4. The Water Quality Objectives established by the Central Valley Regional Water Quality Control Board in the San Joaquin River study reach.

Water Body	Pollutant	Water Quality Objective (WQO)1	Segment (Reach #)
Salt Slough, Mud Slough, and San Joaquin River	Molybdenum (heavy metal from eastside soils)	0.050 (mg/l) (maximum concentration) 0.019 (monthly mean)	Salt Slough, Mud Slough (north), and San Joaquin River from Sack Dam to the mouth of Merced River (Reaches 4 and 5)
San Joaquin River	EC (measure of salinity by electrical conductivity)	Shall not exceed 150 µS/cm from Friant Dam to Gravelly Ford (90th percentile)	San Joaquin River, Friant Dam to Mendota Pool (Reaches 1 and 2)

[1]Molybdenum objectives are total (unfiltered) concentrations.

6.6. WATER TEMPERATURE

Virtually all biological and ecological processes are affected by water temperature (Spence et al. 1996). Not only does temperature directly influence chemical equilibria, but invertebrate and fish communities are also extremely sensitive to temperature. Temperature has direct but often subtle effects on life history timing, habitat suitability, reduced growth rates, increased rates of infection, mortality from disease and toxic chemicals, and increased exposure to predators better adapted to warm water temperatures. The effects of temperature on specific species are discussed in Chapter 7 (Section 7.6.6). The historical and existing temperature conditions and their implications for the protection and restoration of aquatic resources of the San Joaquin River are described below.

6.6.1. Historical Conditions

Above the study area, the upper reaches the San Joaquin River were historically described as a cold water mountain stream (Blake 1857, from Yoshiyama et al. 1996 [Appendix C]). The river's valley portion was generally characterized by warm, meandering waterways with sluggish river channels, oxbow and floodplain lakes, and marshes and sloughs (Moore, 1990). The transition from cold to warm water conditions likely occurred where flows exited the foothills and drained to the valley bottom. This transition zone probably encompasses Reaches 1 and 2 of the study area, from Friant Dam downstream to Gravelly Ford. When runoff flowed unimpaired to the Delta, late summer and early fall water temperatures were recorded well above of 70°F (21°C) at Friant Dam, and were even higher on the lower river reaches (Clark, 1942). Within the study area, documentation indicating temperature refugia locations is scarce. Yoshiyama (et al. 1998), citing California Fish Commission reports from 1921, mentioned that the area near Friant Dam contained large pools "where the spring-run fish congregated after their upstream migration in May to early July, awaiting the fall." From the historical numbers of the spring-run escapements, we can assume that cold water holding habitat was available and adequate, and that spawning conditions sustained the spring-run Chinook population from year to year. Another hypothesis described in Chapter 4 of this report discusses the numerous artesian springs and groundwater seeps that were historically distributed throughout Reaches 2-5 of the study area (see Figure 4-6). These springs may have provided localized temperature refugia along the mainstem San Joaquin River. However, we found no historical documentation to support or refute this hypothesis.

6.6.1.1. Temperature Data Collected Prior to Friant Dam Construction

Other than these secondary and tertiary references, our ability to *quantitatively* describe the historical water temperature conditions of the San Joaquin River is limited by a lack of data. In our literature review, for the period prior to the construction of Friant Dam, only two sources of historical temperature data were found:

(1) Two reports of the Commissioners of Fisheries of the State of California (CFC) for 1874-75 and 1876-77 (Commissioners of Fisheries 1875, 1877)

(2) Four volumes (1880-1882) of the "State Engineers Dept.: River Records field books. SJR at C.P.R.R. bridge" authored by W.H. Hall.

The Fish Commissioners reports contain data from two San Joaquin River sites at railroad crossings; one is at the existing Atchison, Topeka, and Santa Fe Railroad Line just upstream of the State Highway 99 bridge, near Fresno at RM 244. The other is the Western Pacific Railroad crossing just south of the Hwy 120 Bridge near Tracy at RM 57. The data are maximum and minimum monthly mean water surface and water bottom temperatures, and corresponding mean air temperatures for August and September, during 1875, 1876, and 1877. Data collection methods, actual sampling dates, time of day, etc. were not recorded. The relevant information from the CFC Reports (Table 6-5) is summarized below:

- Little or no significant differences in water temperatures were apparent between upstream and downstream measurement sites; the upstream site frequently had slightly higher recorded temperatures and a wider temperature range. At the downstream site, temperature may have been moderated by streamflow from the Merced, Tuolumne, and Stanislaus Rivers, and/or inflow from groundwater sources.
- August maximum temperatures ranged from 76 to 84°F (24 to 29°C) at the upstream site, and from 78 to 82°F (26 to 28°C) at the downstream site. September maximum temperatures were slightly lower, ranging from 77 to 83°F (25 to 28°C), and from 75 to 78°F (24 to 26°C) in the upstream and downstream sites, respectively. Minimum daily temperatures generally fell to within the upper range considered suitable for salmonids. Maximum daily temperatures occasionally attained levels that are known to cause acute mortality to salmonids.
- At the downstream site, mean temperature dropped several degrees (°F) from August to September; at the upstream site, changes from August to September are less evident and mean temperatures actually increase in some instances.

6.6.1.2. Estimates of Water Temperatures under Unimpaired Flow Conditions

To qualitatively assess historical temperature conditions, unimpaired streamflows must be considered. Using data modeled from the Kings River, a hydrograph component analysis of unimpaired flows was completed for the USGS San Joaquin River at Friant Dam (presented in Chapter 2). The hydrograph analysis allowed a number of inferences. First, unimpaired spring snowmelt floods generally peaked during May and June, but the snowmelt recession would likely have extended through July and into August of wetter years. These sustained flows likely provided cooler water (about 60 to 70°F or 15 to 20°C) from Friant Dam toward the valley floor during wet (and perhaps normal) water year types. Median summer baseflows (occurring between July 15 and September 30) ranged from 200 to 600 cfs, depending on water year conditions, occasionally dropping to 100 cfs in dry years. Flows this low would likely have contributed to elevated water temperatures, probably approaching the maximum water temperatures presently observed in the lower reaches of the San Joaquin River, below Gravelly Ford (from 76 to 84°F or 24 to 29°C). Median fall baseflows (from October 1 to December 20) were

Table 6-5. Historical temperature data reported in the California Fish Commission Reports for years 1875-1877 for two sites in the San Joaquin River study area.

Lower Railroad Crossing, San Joaquin River, latitude 37° 50' N, longitude 121° 22' W [near Hwy-120 bridge, downstream of Reach 5 and the Stanislaus River, RM 57]

	AUGUST (Monthly value in °F)								SEPTEMBER (Monthly value in °F)								
	1875		1876			1877			1875			1876			1877		
	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom
Maximum	82	81	97	79	78	95	81	81	94	78	78	93	75	75	102	78	78
Minimum	72	71	75	75	74	78	71	71	73	72	72	73	70	69	70	71	71
Mean	79.7	78.6	86.2	76.9	76.1	89.6	77.9	77.9	85.6	74.1	74.4	83.4	72.5	72.1	87	73.8	73.8

Upper Railroad Crossing, San Joaquin River, latitude 36° 52' N, longitude 119° 54' W [upstream of Hwy-99 bridge in Reach 1, RM 244]

	AUGUST (Monthly value in °F)								SEPTEMBER (Monthly value in °F)								
	1875		1876			1877			1875			1876			1877		
	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom	Air Temp	Water Temp at Channel Surface	Water Temp at Channel Bottom
Maximum	84	83	111	77	76	112	77	76	104	82	83	108	78	77	105	78	77
Minimum	74	73	81	73	72	90	73	72	82	74	73	80	74	73	76	75	74
Mean	80.7	79.7	101	75	73.9	99.6	75.8	74.8	95.5	78.3	77.9	94	76.8	75.8	92.9	76.6	75.8

Conversion Equations: F = 9/5(C+32) or C = 5/9(F-32) lower than summer baseflows, and ranged from approximately 250 to 400 cfs. Minimum baseflows during this period were estimated to approach 100 cfs, with water temperatures in fall controlled by gradually decreasing air temperatures, and continually declining baseflows. Air temperature and declining baseflows allowed a broad range of seasonal variability. For example, unseasonably high ambient air temperatures and dry water year conditions may have pushed water temperatures near Friant Dam above 80°F (27°C) in September, while the opposite conditions (cooler air temperatures, wet water year) would have produced colder water temperatures. Streamflows during late fall through the spring snowmelt runoff were also generally higher than those of summer and fall, and water temperatures were likely relatively cold during winter and spring (<65°F or 18°C). Lastly, temperature stratification in pools and groundwater inflow may have also provided zones of colder water.

6.6.2. Existing conditions

Currently, water temperatures are lower in Reach 1 due to hypolimnial releases from Friant Dam. This temperature "benefit" is short-lived, however, because reductions in streamflow allow water temperatures to warm much faster.

6.6.2.1. Friant Hatchery Temperatures

Daily water temperatures were recorded at the Friant hatchery from 1993 to 2001 (Figure 6-2). Water used at the Friant hatchery is a mixture of Millerton Lake's deeper (cooler) water from the San Joaquin River outlet sluice gates (380 feet above MSL), and the higher (warmer) Kern Canal outlet (465 feet above MSL). Because the Friant hatchery staff control the water mixture (and therefore temperature) from these two elevations, potential reservoir release temperatures are difficult to predict from this record. However, minimum annual temperatures recorded at the hatchery in winter months range between 45°F and 50°F (6–10°C) from January through March. Hatchery water temperatures increase during the spring from about 50°F to 55°F (10–13°C) by the end of June. Summer hatchery temperature remains below 60°F, with the maximum daily temperatures often recorded at the end of September. Lastly, hatchery water temperatures decrease during the fall from about 60°F (16°C) to about 50°F (10°C) by the end of December. No other temperature data are available in the vicinity of Friant Dam, for either the pre- or post- Friant Dam era.

6.6.2.2. USGS and CVRWQCB Temperature Records

Daily temperatures were summarized for all months within the period of record for USGS and CVRWQCB data (Table 6-6). The longest period of record was collected at Vernalis (USGS 11303500), which began reporting maximum, minimum, and average water temperatures in 1961. Maximum temperatures recorded at Vernalis above 68°F (20°C) occurred between April 1 and November 1, with daily maxima occasionally approaching 85°F (30°C) (Figure 6-3). Although other long term records under the current (post Friant Dam) flow regime exist, most data reporting did not occur until 1985 (Table 6-5).

Under the current flow regime, mean monthly temperatures generally remain suitable for salmonids and other sensitive fish species (<65°F or 18°C) from November to April in most years. However, temperatures rise above 68°F (20°C) from May through October, which is generally above the range suitable for juvenile salmonids. Note that these mean monthly values do not reflect daily or monthly maxima at these sites, which can be much higher if cold water pools or other refugia are unavailable for cold water fish species. However, since 2001, the Vernalis Adaptive Management Plan (VAMP) has increased instream flows in the San Joaquin River below the Merced River during May of each year; the increased flows have decreased temperatures in May, compared with data at Vernalis prior to VAMP.

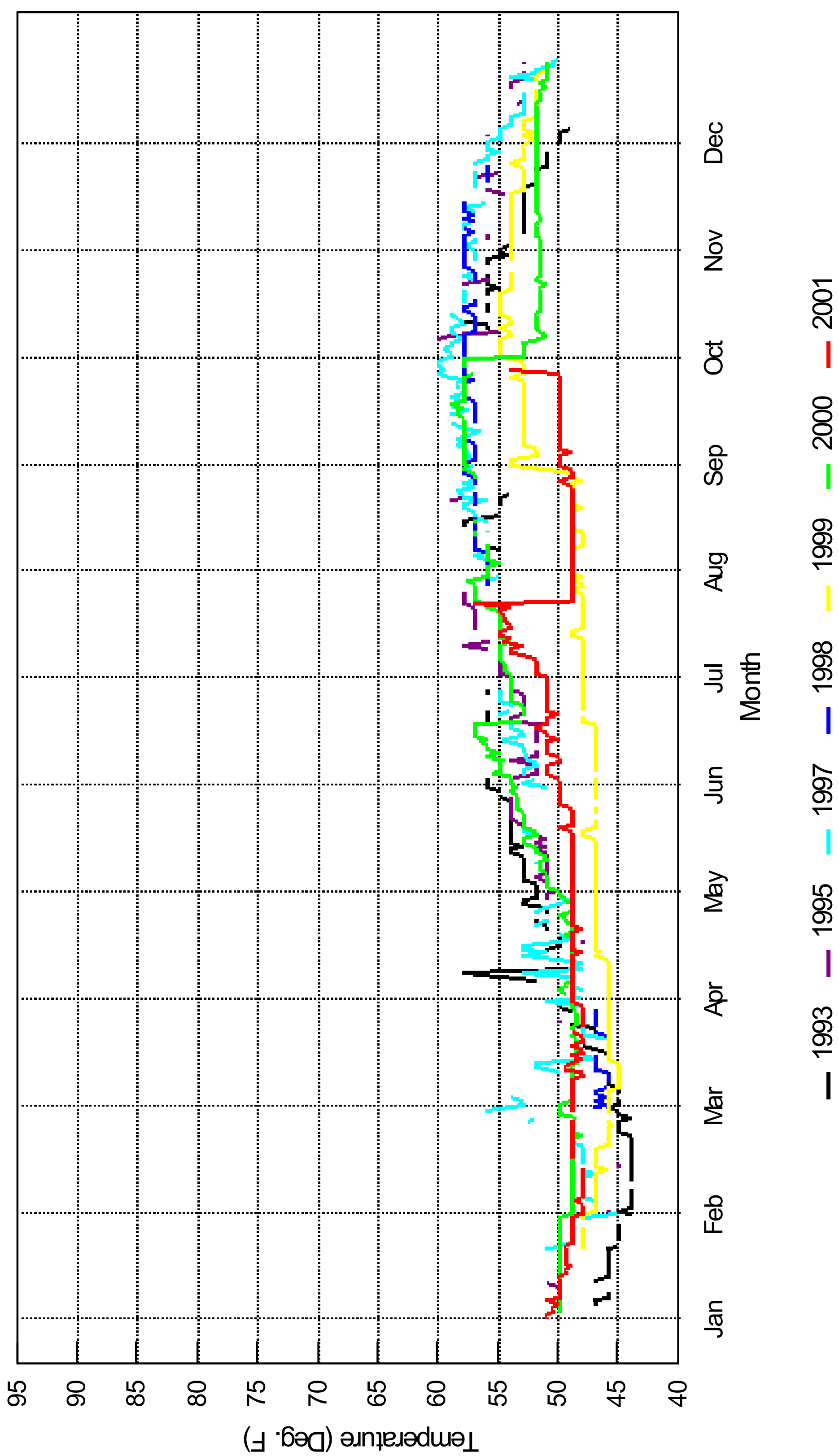


Figure 6-2. Mean daily water temperatures at the Friant Fish Hatchery from 1993 to 2001.

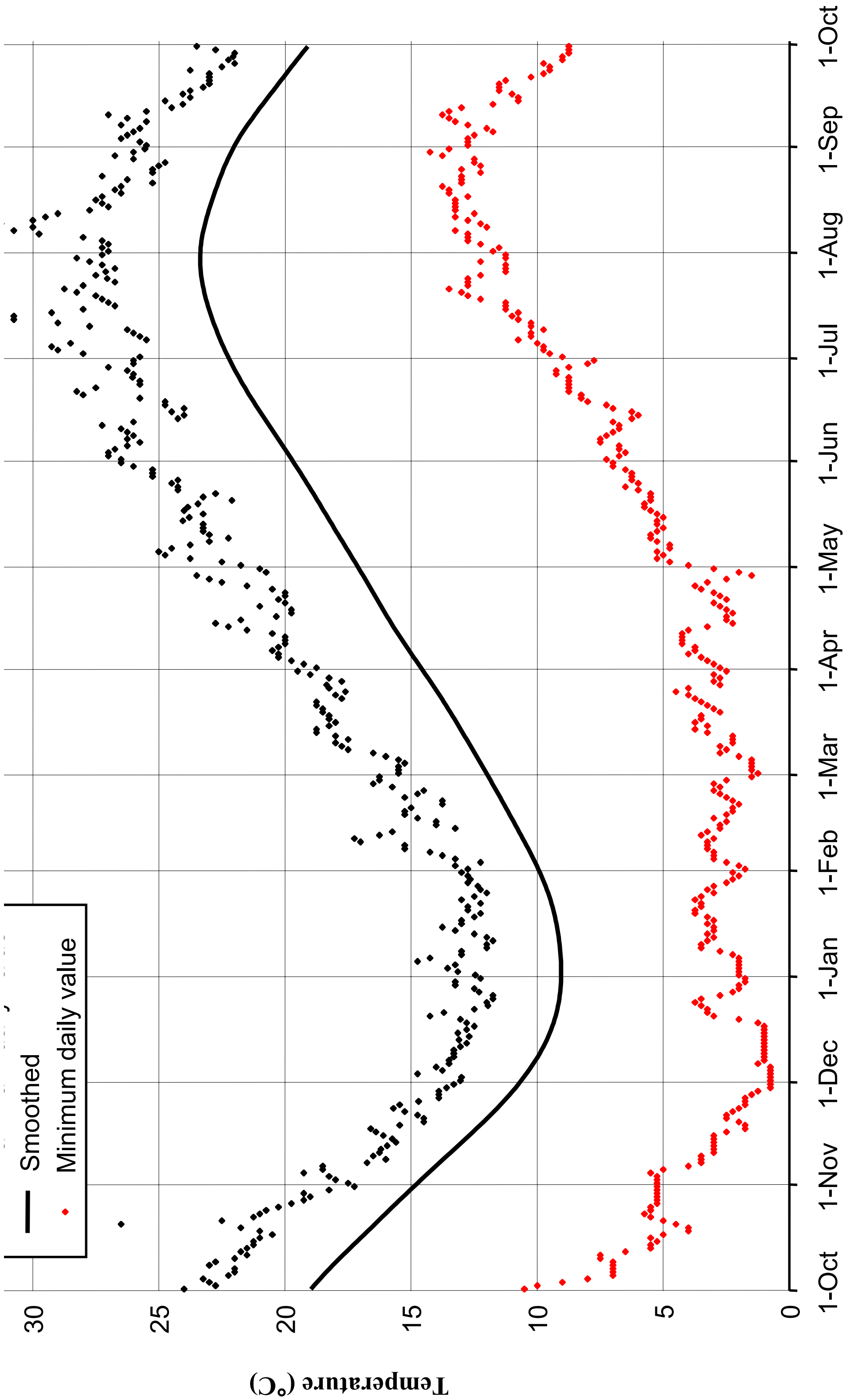


Figure 6-3. Summary of water temperature data from 1961 to 1997 for the San Joaquin River at Vernalis (USGS 11303500).

Table 6-6. Monthly water temperatures in the upper San Joaquin River for winter and summer conditions.

A. Winter Conditions

Site Number	Site Name	USGS Period of Record	CVRWQCB Period of Record	Nov Mean	Nov S.D.	Dec Mean	Dec S.D.	Jan Mean	Jan S.D.	Feb Mean	Feb S.D.	Mar Mean	Mar S.D.	Apr Mean	Apr S.D.	May Mean	May S.D.
1	SJR Below Friant[1]			11.0		10.9		9.8		9.2		9.2		9.4		10.6	
2	SJR Near Mendota[1]																
3	SJR @ Sack Dam[1]																
4	SJR Near Dos Palos[1]																
5	Bear Creek Bert Crane Rd.																
6	Salt Slough @ Lander/Hwy 165[2]	1985--1994	1996-2002	14.2	3.4	10.1	2.1	10.1	2.3	12.2	2.3	15.8	2.5	17.3	2.6	20.0	3.2
7	Mud Slough (Downstr)[2]	1985--1999	1996-2002	14.6	2.4	10.1	2.3	10.3	2.7	12.1	2.3	15.8	2.8	17.9	3.2	21.2	3.9
8	SJR @ Stevinson[2]	1985--1993	1996-2002	14.7	3.2	9.9	2.1	9.8	2.2	12.1	2.4	16.2	2.9	17.6	3.1	20.3	3.2
9	SJR @ Fremont Ford[2]	1979--1994	1996-2002	13.8	2.6	9.6	2.3	10.0	2.6	12.3	2.1	15.6	2.7	16.9	2.7	20.3	3.3
10	SJR Upstream of Merced R.	2000--2000															
11	SJR Near Newman	1984--1988		13.0	1.4	9.2	2.5	10.8	1.0	13.6	3.2	15.6	1.6	17.0	4.6	16.0	2.5
12	SJR @ Crows Landing	2000--2000															
13	SJR @ Patterson[2]	1985--1994	1996-2002	14.5	2.5	10.2	2.2	10.5	2.2	12.2	1.6	15.8	2.4	17.8	2.8	20.9	3.1
14	SJR @ Maze[2]	1985--1994	1996-2002	14.5	2.3	10.4	2.0	10.6	2.1	11.9	1.7	15.1	2.4	16.9	3.0	20.3	3.4
15	SJR @ Airport Way/Vernalis[2]	1961--2000	1996-2002	12.7	2.0	9.4	1.7	9.7	1.7	11.1	1.7	13.6	2.1	15.7	2.1	18.5	2.2

B. Summer Conditions

Site Number	Site Name	USGS Period of Record	CVRWQCB Period of Record	Jun Mean	Jun S.D.	Jul Mean	Jul S.D.	Aug Mean	Aug S.D.	Sep Mean	Sep S.D.	Oct Mean	Oct S.D.
1	SJR Below Friant[1]			10.4		10.6		10.6		Sep		10.6	
2	SJR Near Mendota[1]									22.9		22.9	
3	SJR @ Sack Dam[1]			24.5		26.0		25.7		23.5		23.3	
4	SJR Near Dos Palos[1]												
5	Bear Creek Bert Crane Rd.												
6	Salt Slough @ Lander/Hwy 165[2]	1985--1994	1996-2002	22.8	2.9	24.6	1.9	24.4	2.0	22.3	2.6	17.8	2.5
7	Mud Slough (Downstr)[2]	1985--1999	1996-2002	24.1	3.3	26.0	2.2	25.0	2.4	23.8	2.5	18.9	2.6
8	SJR @ Stevinson[2]	1985--1993	1996-2002	24.0	3.6	26.0	2.3	25.5	2.2	23.1	2.3	18.4	2.5
9	SJR @ Fremont Ford[2]	1979--1994	1996-2002	23.5	3.0	24.9	2.2	24.6	2.2	22.4	2.2	17.6	2.4
10	SJR Upstream of Merced R.	2000--2000				27.5	0.7	25.5	1.4	23.0	2.8		
11	SJR Near Newman	1984--1988		24.0	1.1	24.8	1.8	24.2	0.9	20.8	1.7	17.5	2.8
12	SJR @ Crows Landing	2000--2000				26.0	1.4	23.8	0.4	22.0	2.1		
13	SJR @ Patterson[2]	1985--1994	1996-2002	23.2	2.7	24.6	1.7	24.8	2.2	22.5	2.3	18.6	2.1
14	SJR @ Maze[2]	1985--1994	1996-2002	23.2	2.5	24.5	1.9	24.6	1.9	22.5	2.1	18.6	2.3
15	SJR @ Airport Way/Vernalis[2]	1961--2000	1996-2002	21.0	2.3	23.5	2.0	23.3	1.9	20.9	1.9	17.2	2.1

1 Year 2001 Temp Data from SJRTEMP Model calibration report (JSA 2001). Note, no standard deviation is reported for a single year of data.
2 Temperature means for these sites were compiled from USGS and CVRWQCB data
Conversion Equations: F = 9/5(C+32) or C = 5/9(F-32)

6.6.3. San Joaquin River Temperature Model

The JSATEMP model was developed as a tool for evaluating flow releases for the Restoration Plan, as a component of the SJRiver Model (JSA 2001). The temperature component simulates hourly water temperature to estimate daily minimum and maximum water temperatures in the upper reaches of the San Joaquin River, above the major eastside tributary inputs (Reaches 1–4). Hourly meteorological data measured at the Fresno California Irrigation Management Information System (CIMIS) were used for the hourly heat transfer calculations. The water temperature calculations use an hourly time step, and the minimum and maximum temperatures in each river segment are saved at the end of each day. Jones and Stokes (2001) described the model's assumptions, development, and calibration to the years 2000-2001. Temperature monitoring sites are listed in Table 6-7.

Table 6-7. Temperature probe locations placed in the study area in 2000-01 for JSATEMP temperature model calibration.

Location	San Joaquin River Mile	Year 2000	Year 2001
North Fork Bridge	266.8	X	X
Donaghy Ranch (Rank Island)	259.9		X
State Highway 41 Bridge	255.3	X	
CDFG Millburn Unit	248		X
Santa Fe Railroad Bridge	245.1	X	X
Dickenson Avenue	240.7		X
Skaggs Park	234.2	X	X
Emmert Ranch (Gravelly Ford)	228.2	X	X
Napa Avenue	222	X	X
River Mile 220	220	X	
Chowchilla Bifurcation Structure	216	X	X
San Mateo Avenue Bridge	212	X	X
Mendota Pool Release	204.8	X	X
Firebaugh Avenue 13 Bridge	195.2	X	X
Sack Dam	182	X	X
Turner Road Bridge	157	X	X

Note: Shaded boxes indicate no data collected for the indicated location and year.
Note: Temperature monitoring occurred during only selected time periods within each of the years.

October 2000 Water Temperature Monitoring. In the first data collection effort, hourly water temperatures were recorded from mid-September through October 2000 at 13 locations from Friant Dam to the Turner Road bridge, about 25 miles downstream of Sack Dam. Flows below Friant ranged from 150 cfs to 200 cfs, and at Gravelly Ford flows were around 100 cfs. Significant warming was evident by the time the water reaches the State Highway 41 Bridge (12 miles downstream of Friant Dam). In general, equilibrium temperature was reached by the time the river reached the Santa Fe Railroad Bridge (22 miles downstream of Friant), and temperatures were relatively constant at locations further downstream. Unfortunately, Friant Dam flow did not vary sufficiently during September 2000 to validate if flow affects Gravelly Ford water temperatures; Gravelly Ford flow was already near equilibrium temperature in September.

2001 Water Temperature Monitoring. In April 2001, thermographs were placed in the San Joaquin River, and left in place through early October 2001. Flows below Friant were maintained at an almost constant 200 cfs, except during a pulse flow from June 15 to 24, 2001. The pulse flow resulted in flows of 360 to 400 cfs, providing an excellent opportunity to calibrate the temperature model component. Contrary to anticipated results, these pulse flows had a relatively small effect on warming between Friant and State Route 41 (SR-41). Before the pulse flow release, at 200 cfs, water temperatures at SR-41 were warmed to 60–70% of the equilibrium temperatures. Water temperature warming dropped to about 40% of the equilibrium temperature during the pulse flow, and then rose to 70% of the equilibrium temperature within 3 days following the pulse flow.

JSATEMP Model Validation and Monitoring Results. Both historical and Year 2000–2001 data demonstrated that the JSATEMP model may be able to simulate both longitudinal and diurnal temperature fairly accurately (JSA 2001). Daily minimum and maximum temperatures for a limited range of Friant releases can also be simulated. The JSATEMP model results suggests that by mid-August a 250 cfs baseflow would provide approximately 14 miles of cool water (<68oF) habitat for over-summering salmonids from Friant dam to near the State Route 41 Bridge (RM 255). Given that the range of flows used for model calibration was very narrow, the temperatures predicted for higher flows may be less accurate. Additionally, the model currently assumes that Friant Dam release temperatures are relatively constant from month -to-month and year-to-year. The use of hatchery temperature data to represent temperatures at Friant Dam under either future or unimpaired flow conditions may be inaccurate, and an investigation of current operations and potential re-operation of Friant Dam will be required to better inform input temperatures to the model.

In summary, the JSATEMP model suggests that the dominant longitudinal temperature change in the upper San Joaquin River occurs from Friant Dam releases as they flow downstream toward Gravelly Ford. Below Gravelly Ford, the model shows that the instream temperatures are in equilibrium and diurnal temperature changes are controlled primarily by meteorology (ambient air temperatures, channel depth, and shading). This equilibrium zone will likely extend (un-modeled) downstream to the confluence with the major eastside tributaries (i.e., Merced, Tuolumne, and Stanislaus rivers) above Vernalis.

6.6.4. Implications for Aquatic Organisms

Temperature directly influences the habitat suitability for invertebrates and many fish species, with effects on life history timing, habitat suitability, growth rates, available DO, rates of infection and mortality from disease and toxic chemicals, and exposure to predators. As discussed in Chapter 7, temperatures have a dominant effect on the various life stages of many fish species. For salmonids, in addition to the need for cold water spawning habitat, warm temperatures can also have a significant effect on juvenile Chinook growth rates (Brett et al. 1982) and reduce the amount of suitable habitat for rearing (Lindsay et al. 1986). Beyond these well-known effects on salmonids, temperature also controls many other ecosystem components, such as invertebrate production and diversity (Rosenberg and Resh 1993).

The CVWRQCB Basin Plan (1998) contains narrative objectives that prohibit activities resulting in large (>9^{o}F or 5^{o}C) increases in water temperature for the protection of salmonids between April 1 through June 30 and September 1 through November 30 in all water year types. The current flow-regime of the river was established long before these objectives were codified and the distance of the Delta downstream of reservoirs is so large that the State Board considers reservoir releases to control water temperatures in the Delta an inefficient use (CVRWQCB 1998a). Nevertheless, water temperature is the physical factor with perhaps the greatest influence on anadromous salmonids, short of complete absence of water, and the model runs and temperature recorders show that the volume of water released from Friant Dam most directly influences water temperatures in Reach 1, with less to no effect downstream at moderate to low flows (<1,000 cfs).

In summary, historical measurements and reconstructed hydrographs of unimpaired flows for the River suggest longer periods of lower temperatures in the San Joaquin River above the Merced river confluence, possibly extending from early October into June under unimpaired flow conditions. Current temperature monitoring (post Friant Dam) and modeling for the San Joaquin River suggests the early summer and late fall temperature regime in the lower study reaches (Reaches 3–5) of the San Joaquin River frequently exceeds the temperature range recognized as suitable for salmonids, and poses a significant constraint for restoring anadromous salmonid populations.

6.7. SALINITY AND BORON

Along with temperature downstream of the Mendota Pool, salinity in the San Joaquin River basin is one of the largest water quality concerns, with the potential to influence the structure of biological communities, and to direct regional agricultural development. Salinity represents the accumulation of anions such as carbonates (CO_3), chlorides (Cl), and sulfates (SO_4), and cations such as potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na). Two general measures are used to assess salinity in water: electrical conductivity (EC) and total dissolved solids (TDS). EC measures the transmission of electricity between known electrode areas and path lengths (units µS/cm), and TDS is measured in mg/L by gravimetric analysis after drying (APHA 1998). TDS and EC are closely correlated; EC readings increase as salt levels increase. For the Lower San Joaquin River, from Landers Avenue to the Airport Way Bridge near Vernalis, TDS (in mg/L) to EC (in µS/cm) ratios range from 0.590 to 0.686 (SWRCB, 1987; 0.65 is typically used as the multiplier to convert from EC to TDS. The remainder of this section discusses salinity in terms of EC and TDS, with the exception of boron, which is discussed independently.

6.7.1. Historical Conditions

Inadequate drainage and salt accumulations were already concerns in the San Joaquin Valley at the turn of the century, and perhaps as far back as the 1880s (SJVDP 1990, as cited in CVRWQCB 2002b). Early irrigation practices intentionally over-irrigated fields to raise the local water table so that subsurface water would be available to crops during part of the dry summer season. However, water was usually applied well in excess of plant uptake and consequently some areas became waterlogged. Additionally, evapotranspiration of applied water resulted in salt build up in the soil and shallow groundwater table. By the late 1800s, salt accumulations and poor drainage had already adversely impacted agricultural productivity and some areas were removed from production (SWRCB, 1987).

Advances in pumping technology during the 1920s and 1930s led to increased groundwater pumping and accelerated agricultural production in the region. Groundwater withdrawals overdrafted the groundwater basin, lowering water table elevations; this overdraft temporarily alleviated the waterlogging problem and allowed salts to be leached below the crop root zone. In 1951, because of the continued groundwater overdraft and high regional demand for additional irrigation water supplies, the Delta Mendota Canal (DMC) began delivering surface water from northern California and the Delta to the northern San Joaquin River basin. Water delivered by the CVP essentially replaced and supplemented natural river flows that were diverted out of the San Joaquin River at Friant Dam, slowing groundwater overdraft, but exacerbating the basin's salt buildup problems by applying water with higher TDS (CVRWQCB 2002b).

The majority of salt and boron loading into the river originates from lands on the west side of the San Joaquin River watershed. Soils on the west side of the valley are derived from rocks of marine origin in the Coast Range that are high in salts and boron. Soils on the east side of the valley are primarily derived from the igneous parent material of the Sierra Nevada; consequently, east side soils contain relatively low levels of salts and trace elements. The floodplain deposits consist of a relatively thin and more recent deposits that are mainly located in the valley trough (Kratzer 1985 as cited in CVRWQCB 2002a). Due to the rain shadow of the Coast Range, runoff to the San Joaquin River is dominated by eastside tributaries, thus keeping salt loadings historically relatively low. Under current conditions, water quality from all three eastside tributaries is very good, with EC values ranging from 50 to 100 µS/cm. Other constituents such as boron, chromium, lead, nickel, and zinc, are all reported below their respective detection limits (Chilcott et al. 2000). In the mainstem San Joaquin River, historical salinity conditions are much closer to those of the eastside tributaries, except during drought conditions.

6.7.2. Existing Conditions

Water quality data collected by the Central Valley Regional Water Quality Control Board over the past 15 years (CVRWQCB 2002) indicates that water quality objectives for salinity have been routinely exceeded throughout the San Joaquin River from the Mendota Pool to Vernalis (Figure 6-1). In contrast, the upper river (Study Reach 1) has very low salinity than the 120 miles below Mendota Pool (Study Reaches 3, 4, and 5). Delta waters represent over half of the total annual anthropogenic salt load to the Grassland area and long-term irrigation practices have contributed high concentrations of salts to Mud and Salt sloughs, and to the San Joaquin River in Study Reach 5 (Figure 6-1).

Agricultural drainage water collection and disposal, including return flows discharged to the San Joaquin River through Mud Slough and Salt Slough, have been identified as a major source of salinity. The Grassland area surrounding Mud Slough has been the focus of numerous assessments for salt, boron, and selenium. Since the implementation of the Grassland Bypass project in 1996, the majority of irrigation return flows from the Grassland area is now collected in a portion of the San Luis Drain, where it flows back to the San Joaquin River via Mud Slough. This remedial action has resulted in improved water quality in Salt Slough in terms of salinity in addition to other parameters, but has essentially shifted the problems slightly further downstream to Mud Slough. Results of ongoing water quality monitoring of the Mud and Salt Slough area are available through the Grassland Bypass Project web site: http://www-esd.lbl.gov/quinn/Grassland_Bypass/ grasslnd.html

In addition, water delivered to the Grasslands area has salinity concentrations similar to those monitored by the State Water Project's automated water quality stations, located at Check 13 and Check 21 (Figure 6-1) (data can be viewed at: http://wwwomwq.water.ca.gov/). Ongoing CVRWQCB monitoring indicates that while the Grassland area contributes approximately 6% of the total flow to Reach 5, it also generates 37% of the river's total salt load and 50% of the river's total boron load (CVRWQCB 1998b, 2002b).

The degree to which the lower portions of the San Joaquin River (Reaches 3-5) can assimilate salts, in the absence of low salinity water, is largely unknown. Impairment of the lower study reaches (Reaches 3 through 5) has prompted a TMDL development for the San Joaquin River (CVRWQCB 2002b) to determine

2) the major sources of salt loading to the lower San Joaquin River
3) the maximum amount of salt loading that may occur while still meeting water quality objectives
4) how to equitably allocate the available "assimilative" capacity among the identified sources.

Reaches 1 and 2 of the San Joaquin River study area generally meet the water quality goal of 150 μS/cm (CVRWQCB 2002a), as do the conductivity values of the Merced, Tuolumne, and Stanislaus Rivers.

At Friant Dam, winter and summer salinities are low. At Dos Palos (RM 180) near Sack Dam, however, instream conductivity and TDS exceed the CVRWQCB objectives for the San Joaquin River. It is important to recognize that the transition from high water quality to impaired water quality designation below Mendota Dam is due to the inputs of agricultural runoff and from water imported from the Delta, and not from water released from Friant Dam. The CVRWQCB has recommended a Basin Plan amendment intended to address salinity impairment in the lower San Joaquin River from Mendota Pool to Vernalis (Reaches 3, 4, and 5). EC and TDS data from USGS and CVRWQCB data sources are available (Table 6-8). The longest records maintained by the USGS are located at Vernalis (USGS 11303500), Crows Landing (USGS 11274550), and Patterson (USGS 11274570), which began reporting daily values in the 1950s and 1960s, and continue to the present day. Other long-term records are available at Friant (USGS 1125100), Fremont Ford. (USGS 11261500), Newman (USGS 11274000), and Maze Road (USGS 1130500). Recent records include Salt and Mud Sloughs (USGS 11261100 and 11262900), Stevinson (USGS 1126815), and a number of CVRWQCB sites (Table 6-8).

Since the lower San Joaquin River is heavily influenced by the Delta Mendota Canal and agricultural drainage water, separate boron WQOs were applied to the lower San Joaquin River upstream and downstream of the Merced River inflow (CVRWQCB 2002b). In the San Joaquin River from the mouth of the Merced River upstream to Sack Dam (Reaches 4 and 5), the current WQO for boron is 5.8 mg/L maximum, and a 2.0 mg/L monthly mean from March 15 through September 15. This WQO is higher than concentrations that affect sensitive crops and aquatic organisms, and it also exceeds levels that are recommended for protection of drinking water supplies. Consequently, the boron WQO was not approved by the USEPA. The Regional Board is currently reviewing the existing boron objectives for the lower San Joaquin River upstream of Vernalis as part of the Basin Plan amendment. The revised objectives for salinity (including boron), once adopted, will be established to protect the most sensitive beneficial uses of water in the lower San Joaquin River, including agricultural and municipal supply. Although the existing water quality objectives are directed at the most affected areas (Reaches 3, 4, and 5) of the San Joaquin River study area, it is possible that more stringent requirements will be applied in the future and these may affect water quality objectives in Reaches 1 and 2 as well.

6.7.3. Potential Implications for Riparian and Aquatic Resources

That salinity impacts fish species is well-known; salinity is one of the strongest physical factors structuring biological communities (Loomis 1954). Leland and Fend (1998) found that the invertebrate fauna of the nontidal portion of the lower San Joaquin River displayed a large-scale (basin-wide) pattern in community response to salinity (sulfate-bicarbonate type) when a standardized, stable substratum was sampled. Community structure, taxa richness, and EPT (Ephemeropterans, Plecopterans, and Trichopterans) richness all varied with TDS (55 to 1,700 mg/L) and distributions of many taxa indicated an optimal salinity was preferred. This salinity range is within the range shown in Table 6-8; this suggests that increased freshwater flows and decreases in salinity may contribute to large changes in aquatic community assemblages in the San Joaquin River, particularly between the upper (Reaches 1, 2) and lower Reaches (Reaches 3, 4 and 5) and between the mainstem Mud and Salt sloughs.

As part of the CVRWQCB's TMDL for salinity, a literature review was conducted to provide a scientific basis for setting salinity objectives (Davis 2000a and Davis 2000b as cited in CVRWQCB 2002b). The San Joaquin Valley Drainage Program identified 29 inorganic compounds in addition

Table 6-8. General water quality parameters for the San Joaquin River study area during typical winter and summer periods.

A. Winter

Site Number	Site Name	Agency	Period of Record[1]	Winter (November-May)											
				EC (uS/cm at 25°C)		TDS (mg/l)		Alkalinity (mg/L)		TSS (mg/l)		pH		DO (mg/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS	1951-1984	52	14	38	6					7.12	0.30		
2	SJR Near Mendota	USGS	1951-1984	324	229					85	52				
3	SJR @ Sack Dam	CVRWQCB													
4	SJR Near Dos Palos	USGS	1951-1959			141	112					7.46	0.36		
5	Bear Creek Bert Crane Rd.	CVRWQCB													
6	Salt Slough @ Lander/Hwy 165	USGS	1984-1994[2]	2413	662	1776	413	213	25	109	66	7.78	0.19	8.46	1.43
7	Mud Slough (Downstr)	USGS	1985-1999[3]	2874	1302	2128	359	396	57	131	126	7.96	0.23	9.30	1.47
8	SJR @ Stevinson	USGS	1985-2000[4]	675	559	395	109	4		60	54	7.87	0.29	10.20	1.79
9	SJR @ Fremont Ford	USGS	1955-1994	1512	867	1293	374			102	76	7.63	0.42	9.54	1.50
10	SJR Upstream of Merced R.	USGS	2000-2000												
11	SJR Near Newman	USGS	1951-1993	1259	605	749	286			83	52	7.82	0.24	9.31	0.86
12	SJR @ Crows Landing	USGS	1962-2000[5]	1145	503	747	305					7.96	0.29		
13	SJR @ Patterson	USGS	1962-2000[6]	1152	509	719	273	122	33	93	116	7.79	0.28	8.68	1.09
14	SJR @ Maze	USGS	1951-1994	744	378	438	224			98	99	7.65	0.27	8.93	0.99
15	SJR @ Airport Way/Vernalis	USGS	1950-2000	600	314	351	175	101	39	79	58	7.59	0.35	9.45	1.26

B. Summer

Site Number	Site Name	Agency	Period of Record[1]	Summer (June-October)											
				EC (uS/cm at 25°C)		TDS (mg/l)		Alkalinity (mg/L)		TSS		pH		DO (mg/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS	1951-1984	45	12	32	6					7.11	0.29		
2	SJR Near Mendota	USGS	1951-1984	401	220					155	84				
3	SJR @ Sack Dam	CVRWQCB													
4	SJR Near Dos Palos	USGS	1951-1959			292	133					7.49	0.37		
5	Bear Creek Bert Crane Rd.	CVRWQCB													
6	Salt Slough @ Lander/Hwy 165	USGS	1984-1994[2]	1600	458	836	54	107	115	199	54	7.81	0.19	6.81	1.11
7	Mud Slough (Downstr)	USGS	1985-1999[3]	2368	887	1830		176	212	125	87	8.08	0.29	9.89	4.01
8	SJR @ Stevinson	USGS	1985-2000[4]	882	672	320	98			99	141	8.03	0.38	9.18	2.68
9	SJR @ Fremont Ford	USGS	1955-1994	1204	587	1180	641			156	38	7.69	0.37	8.12	1.51
10	SJR Upstream of Merced R.	USGS	2000-2000	1744	679					72		8.30	0.22	10.37	3.08
11	SJR Near Newman	USGS	1951-1993	1078	382	666	208			155	84	7.87	0.24	7.72	0.98
12	SJR @ Crows Landing	USGS	1962-2000[5]	872	297	483	4			63	11	8.06	0.30	8.25	1.46
13	SJR @ Patterson	USGS	1962-2000[6]	1051	374	454	144	81	68	107	41	7.86	0.25	7.94	1.80
14	SJR @ Maze	USGS	1951-1994	907	344	569	169			153	112	7.76	0.37	8.28	2.64
15	SJR @ Airport Way/Vernalis	USGS	1950-2000	706	323	401	156	102	29	112	56	7.76	0.48	9.50	2.75

1 Period of record for entire site; actual periods may differ for each parameter.
2 Period of record for TDS: 1985-1986, Alkalinity: 1994-1994
3 Period of record for TDS: 1985-1986
4 Period of record for TDS: 1985-1986, Alkalinity: 1985-1985
5 Period of record for TDS: 1962-1963, TSS: 2000-2000, DO: 2000-2000
6 Period of record for Alkalinity: 1994-1994

to selenium and dissolved solids that are a concern for public health and maintenance of fish and aquatic life (Brown 1996). The most salt-sensitive beneficial uses are drinking water, irrigated agriculture, and industrial uses. Other beneficial uses, such as fish and aquatic life, waterfowl, poultry, and livestock uses, while impacted by increasing salinity levels, are somewhat more tolerant of small increases in salinity. For example, the Environmental Health Law under California Code Regulations (CCR) Title 22, Article 16, recommends a secondary maximum contaminant level (MCL) of 500 mg/L TDS or 900 µS/cm EC, with an upper limit of 1,000 mg/L TDS or 1,600 µS/cm EC. These levels are approached at Fremont Ford above Mud and Salt Slough, and the MCL is routinely exceeded within these two water bodies, downstream to the mouth of the Merced River (Table 6-8).

In contrast to chlorides and sulfates found in most salts, the most sensitive beneficial uses (agriculture, aquatic life, and municipal supplies) may be impacted by boron concentrations as low as 0.5 to 2.0 mg/L. With effects ranging from human cancer to leaf deformities in some irrigated crops, a concentration of 0.75 to 1.0 mg/L is one boron limit in aquatic systems (Davis 2000b as cited in CVRWQCB 2000b). For aquatic organisms, this level is based partly on laboratory and field studies on rainbow trout (Black, et al., 1993), which is a particularly boron-sensitive species. These levels are routinely exceeded in Salt and Mud sloughs, with periodic violations at downstream San Joaquin River sites too (Table 6-9).

Boron and salinity levels in soils and shallow groundwater could potentially limit the recruitment of riparian vegetation for much of the San Joaquin River study reaches (JSA 1998; Maas 1984 as cited in CVRWQCB 2000b). Boron and salinity may be limiting factors that are magnified by groundwater overdraft east of the river and the near absence of overbank flow over most of the historic floodplain. Although the salt tolerance for most riparian plant species (e.g., valley oak, Fremont cottonwood, narrow-leaf and black willow, etc.) is very low (Maas 1996, USDA-NRCS 2001), limited testing of representative soils within the former floodplain of the Upper San Joaquin River would better inform the potential success of riparian plant restoration in Reaches 3 through 5.

In summary, salinity in the San Joaquin River basin is a large influence on species diversity, and it represents a major limiting factor for restoration of aquatic resources in the lower study reaches (Reaches 3 through 5), with effects on invertebrates, fish, and riparian plant establishment (e.g., boron). Winter and summer salinity at Friant Dam is low, but in-stream conductivity and TDS rises above the CVRWQCB WQO for the San Joaquin River at Dos Palos (RM 180) near Sack Dam. It is likely that higher releases of low-salinity water from Friant Dam may produce changes in the aquatic and terrestrial communities along the river corridor. However, long term storage of groundwater laden with salt and boron has resulted in salt accumulation in the unconfined and semi-confined aquifers that underlie most of the west side of the San Joaquin Valley, and lands on the east side of the San Joaquin Valley directly adjacent to the river (CVRWQCB 2000b). At this time, the degree to which groundwater exchanges during irrigation season (May-October) will affect present and future salinity levels in the river is unknown.

6.8. DISSOLVED OXYGEN

Dissolved oxygen (DO) is a very important indicator of a water body's ability to support aquatic invertebrates and fish. Oxygen enters surface waters through direct absorption from the atmosphere, with typical natural water concentrations between 7 to 12 mg/L (Horne and Goldman 1994). Small amounts of DO may be produced by aquatic plant and algal photosynthesis, but much of this oxygen is removed during "dark" respiration and bacterial decomposition of organic matter. The sources of dissolved oxygen from the atmosphere and from photosynthetic inputs are counterbalanced by consumptive metabolism (Wetzel 1975). Dissolved oxygen concentrations in water depend on several

Table 6-9. Selected Inorganic Water Quality Parameters in the San Joaquin River study area.

Site Number	Site Name	Period of Record[1]	Nitrate (mg/l as N and NO_3)		Ammonia (mg/l as N and NH_4)		Phosphorus (mg/l)		Boron (ug/l)		Selenium (ug/l)		Mercury (ug/g)[2]	
			Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	1951-1984					0.00	0.00	38	53	1.0	0.0		
2	SJR Near Mendota	1951-1984												
3	SJR @ Sack Dam													
4	SJR Near Dos Palos	1951-1959							143	112				
5	Bear Creek Bert Crane Rd.													
6	Salt Slough @ Lander/Hwy 165[3,4,5]	1984-1994	5.9	4.0	0.2	0.7	0.11	0.04	1118	1011	4.7	6.9	0.15	
7	Mud Slough (Downstr)[4,5]	1985-1999	2.2	1.7	0.1	0.2	0.15	0.11	3466	1676	182.3	681.9	0.17	0.04
8	SJR @ Stevinson[3,4]	1985-2000	0.6	0.2	0.1	0.2	0.17	0.12	173	111	0.4	0.5	0.05	
9	SJR @ Fremont Ford[4]	1955-1994	3.2	2.9	0.1	0.1	0.13	0.06	593	447	2.1	3.6		
10	SJR Upstream of Merced R.	2000-2000			0.0	0.0	0.08	0.05						
11	SJR Near Newman	1951-1993	2.7	1.4	0.2	0.2	0.15	0.08	721	477	4.0	2.6		
12	SJR @ Crows Landing[4,6]	1962-2000	3.1	1.4	0.1	0.1	0.10	0.02	661	385				
13	SJR @ Patterson[3,4]	1962-2000	3.2	1.8	0.4	0.5	0.23	0.12	637	330	2.7	1.7	0.11	
14	SJR @ Maze[4]	1951-1994	2.9	1.8	0.3	0.3	0.19	0.10	345	199	1.5	1.0		
15	SJR @ Airport Way/Vernalis[4]	1950-2000	2.5	1.7	0.1	0.2	0.13	0.07	256	152	1.3	0.9	0.12	0.02

1 Period of record for entire site; actual periods may differ for each parameter.
2 Sediment mercury content from bottom samples, <63U, wet sieve.
3 Period of record for Mercury: 1992-1992.
4 Boron and selenium means for these sites were compiled from USGS and CVRWQCB data.
5 Period of record for Nitrate: 1985-1986.
6 Period of record for CVRWQCB Boron data: 1996-1997

factors, including temperature (i.e., colder water absorbs more oxygen), and the volume and velocity of water flowing in the water body (re-aeration), salinity, and the number of organisms using oxygen for respiration. This last factor (respiratory consumption) is, in turn, strongly influenced by the availability of limiting nutrients (nitrogen and phosphorus), generally derived from anthropogenic sources such as fertilizer.

6.8.1. Historical Conditions

Although DO concentrations in the San Joaquin River were not measured prior to the construction of Friant Dam, the San Joaquin River's historical equilibrium DO within the 10 to 25°C temperature range is estimated to be on the order of 8–12 mg/L, with higher oxygen solubility at lower temperatures (APHA 1998). However, as agricultural development increased, the impact of large-scale applications of industrial fertilizers on primary productivity is unknown.

With the exception of the oxygen demand exerted by the accumulated peat soils found in the lower San Joaquin River and Delta, historical DO in the lower study reaches was likely close to the saturation conditions described above. With the exception of a higher gradient reach near the Merced River Confluence (Reach 5), historical reports of sluggish summertime flows and high temperatures were a result of low gradients (USGS 1899) and this may have inhibited re-aeration and resulted in historical DO lows similar to those found today. In contrast, the low organic and nutrient inputs to the Upper San Joaquin River were likely associated with historical DO levels on the order of 7 to 10 mg/L, which is suitable for most aquatic species.

6.8.2. Existing Conditions

In the last half century, large-scale changes in agricultural production, urbanization, and streamflow regulation have generally decreased DO concentrations in the San Joaquin River. The USGS gage at Vernalis (USGS 11303500) began measuring DO approximately monthly in 1966, with other stations collecting data for shorter periods. Most records span from 1985 to 1994. DO levels were also measured in grab samples in several locations along the San Joaquin River (Table 6-8). For the entire period of record at Vernalis, none of the monthly mean DO levels fall below CVRWQCB criteria for their beneficial uses. The gage at Vernalis appears to be stable from summer to winter (Table 6-8), and the generally good DO conditions in the lower San Joaquin River (at Vernalis) may be attributed to the large volume of tributary inputs from eastside rivers, relative to the San Joaquin River flows. However, minimum DO at Mud and Salt Sloughs (USGS 11261100 and 11262900) and in the San Joaquin River at Stevinson (USGS 11260815) are on the order of 4 to 5 mg/L, near or below the 5.0 mg/L criteria for warm water habitat, set by the CVRWQCB (1998). All sites shown in Table 6-8 below Mud and Salt sloughs exhibit a larger variability in DO during summer (June-October) than in winter (November-May), indicating excessive photosynthetic production from nutrient-stimulated algal and plant growth (Vollenweider 1974).

Although most DO data are generally not indicative of water quality impairment, low DO concentration has impaired the upstream end of the Stockton Deep Water Ship Channel since the 1970s, and a stakeholder-led effort has been developing a DO TMDL for the lower San Joaquin River within the Delta. In general, upstream nutrient sources and excessive algal productivity have been cited as the primary causes (Lehman and Ralston 2000). Numerous sources of this apparent eutrophication have been studied during TMDL development, indicating major contributions of subsurface drainage from Mud and Salt Sloughs, wastewater effluents, and urban runoff (Lee and Jones-Lee 2000; Stringfellow and Quinn 2002). DWR has in recent years installed a temporary rock barrier at the Head of Old River for the purpose of improving instream flows and dissolved oxygen concentrations within the lower San Joaquin River for the benefit of migrating fall-run adult Chinook salmon and other aquatic resources.

6.8.3. Potential Implications for Riparian and Aquatic Resources

Even small reductions in DO concentrations can have adverse effects on invertebrates and aquatic resources, particularly on rearing and migratory life stages of salmonids. While the greatest concern of the current TMDL process is within the lower river (Stockton Ship Channel), summer and autumn depressions in DO near the confluence of the San Joaquin River with Mud and Salt Sloughs (Reach 5) may continue to occur even with increases in instream flows in the San Joaquin River. Organics can be carried in sediment transported from the upper San Joaquin River under high flow regimes; whether these organics will exacerbate the current low DO conditions in the lower river, or be offset by flushing and nutrient reductions in the Delta and its backwater sloughs, remains unknown.

Low DO levels (< 5 mg/L) can cause physiological stress to Chinook salmon and impair development of other aquatic species; DO minimums in Reach 5 and further downstream (i.e., Vernalis, Stockton) can inhibit adult upstream migration (Hayes and Lee 1998; Hallock et al. 1970). In documenting passage delays and seasonal migration blockage of fall-run Chinook salmon in the lower San Joaquin River, Hallock et al. (1970) found that few adult fish migrated through water containing less than 5.0 mg/L DO, and the bulk of the salmon did not migrate until the DO concentration exceeded 5.0 mg/L. Hallock also noted that water temperatures in the lower river may have contributed to inhibiting adult salmon migration. Because seasonal highs in solar irradiance, algal growth, and water temperatures all occur at the same time as DO minimums, it is likely a combination of physical conditions – temperature and DO – are responsible for inhibiting upstream migration.

Daily fluctuations in DO are known to be associated with excessive pH fluctuations from algal productivity (Odum 1956; Vollenweider 1974). Even in portions of the San Joaquin River with suitable water column DO, the organic load may cause local DO depressions near the channel bottom and sediment-water interface. In addition to sediment, temperature, and other contaminants, many individual species of invertebrates (e.g., EPT) are sensitive to changes in DO (Rosenberg and Resh 1993), and low DO concentrations may alter the abundance and diversity of invertebrate and fish assemblages.

In summary, low DO in Reach 5 may approach levels that inhibit restoration of salmonids and other native fish resources, but the area of greatest concern is in the Stockton Deep Water Ship Channel. Changes in flows and sediment loads to the San Joaquin River may have effects on invertebrate and fish community assemblages in the near term. Increased instream flows may dilute nutrient inputs, lower respiratory metabolism of dissolved oxygen, and thus increase instream DO concentrations throughout the San Joaquin River. However, higher seasonal peak flows under consideration in the restoration plan may transport upstream organic sediments. This sediment would also likely carry additional nutrients from upstream to the DWSC and the lower San Joaquin River, and lead to further deterioration in DO at Stockton. This scenario would need to be evaluated within the context of the overall restoration plan. A limited amount of near-bottom DO measurements and site-specific sediment quality data (i.e., carbon and nitrogen content, sediment oxygen demand incubations) may have to be collected to characterize the potential changes in oxygen demand to the lower San Joaquin River (Reaches 3-5) that may occur under future flow regimes.

6.9. NUTRIENTS

High nutrient loads in past decades are associated with eutrophication of the lower San Joaquin River and Delta (Kratzer and Shelton 1998 as cited in Dubrovsky et al. 1998). Although water clarity in the Delta has improved in the past decade, it is coincident with improvements in wastewater treatment and the accidental introduction of many non-native filter-feeding shellfish (Jassby et. al. 2002). Nutrient enrichment of the lower study reaches has significantly affected aquatic resources. Diurnal fluctuations in pH and DO concentrations can occur in waters with enhanced plant growth caused by eutrophication. Problems occur in the early morning when algal and plant respiration causes low oxygen levels in the water column, causing mortality of invertebrates and fish, or causing long-term shifts in community structure. This section discusses ammonia, nitrate, and phosphates, because they are the primary nutrients required for aquatic life.

Ammonia. The EPA has established criteria for maximum ammonia concentrations in surface water, based on the potential threat to the health of aquatic organisms. These criteria vary with acidity and water temperature, which affect both the toxicity of ammonia and the form in which it occurs. In most natural surface waters, total ammonia concentrations greater than about 2 mg/L exceed the chronic exposure criteria for fish, with primary effects related to impaired gill function (Horne and Goldman 1994). In alkaline water at high temperature, the criteria can be exceeded by total ammonia concentrations less than 0.1 mg/L.

Nitrate. In natural waters, elevated concentrations of nitrate causes eutrophication, algal and plant growth, and subsequent water quality problems such as DO depletion (Horne and Goldman 1994). Nitrate contamination of groundwater and surface water is a major concern, especially in regions where large doses of agricultural fertilizers are applied. Other than its biostimulatory effects on plant life, nitrate by itself is generally not a health problem; when ingested by humans it is converted into nitrite by enteric bacteria. In humans lacking a key enzyme, however, nitrite can lead to “blue baby syndrome” (methemoglobinemia).

Phosphorus. Similar to nitrate, phosphorus is often a limiting nutrient in natural waters and contributes to eutrophication (Horne and Goldman 1994). Phosphorus as phosphates may be found in low levels in natural waters and in wastewaters. The principally bioavailable form includes several classes of phosphates: orthophosphates, condensed phosphates, and organically bound phosphates. These compounds are found in solution (by natural weathering or fertilizer application), in detritus, and in tissues of aquatic organisms (organic phosphates).

6.9.1. Historical Conditions

Prior to the construction of Friant Dam and other tributary impoundments along the San Joaquin River, nutrient conditions were not monitored, so information on these conditions is unavailable. Due to the lack of nutrient data from before the era of large-scale use of fertilizers and extensive agricultural development of the San Joaquin Valley, national and global background levels were reviewed. Fuhrer et al. (1999) suggest 2 mg/L nitrates as a typical background level for both groundwater and surface water, and ammonia and phosphate concentrations less than 0.1 mg/L. While higher nitrate levels are sometimes found, Horne and Goldman (1994) suggest typical surface water nitrate concentrations would be below 1 mg/L. Although particulate phosphate is associated with weathering of mineral deposits, dissolved orthophosphate is also typically low in the nation’s waters (Fuhrer et al. 1999). Granitic soils characteristic of the upper San Joaquin River basin generally yield low phosphate levels. As discussed below, changes in limiting nutrient status from nitrogen to phosphorus and back again are likely as sediment inputs, mineral geology and fertilizer inputs all change along the river corridor.

6.9.2. Existing Conditions

The major sources of nutrients in the San Joaquin River basin are dissolution of natural minerals from soil or geologic formations (e.g., phosphates, iron); fertilizer application (e.g., ammonia and organic nitrogen); effluent from sewage-treatment plants (e.g. nitrate and organic nitrogen); and atmospheric precipitation of nitrogen oxides. Organic nitrogen, ammonia, and organic phosphorus are all present in treated and untreated agricultural wastes and municipal effluents.

Prior to industrial production of ammonia, agricultural inputs of organic nitrogen sources were likely low. Following WWII, industrially produced ammonia largely replaced the use of manure and although experimental agricultural fertilization probably occurred in the early 20th century, between the 1950s and the 1980s, nitrogen fertilizer application rates increased from 114 to 745 million pounds per year nationwide (Mueller and Helsel 1996). Concentrations of nitrate in groundwater also increased, from less than 2 mg/L in the 1950s to about 5 mg/L in the 1980s. This increase, coupled with the construction of extensive tile drainage systems, has resulted in an overall increase in nitrates in the lower San Joaquin River.

Dissolved phosphates (PO_4^{2-}), ammonia (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) concentrations are presented for the period of record at the San Joaquin River water quality monitoring stations (Table 6-9). Phosphate and nitrate levels are greater than 2.5 mg/L at all monitoring stations downstream of Fremont Ford, which is much higher than typical background levels (Fuhrer et al. 1999). Ammonia concentrations are generally in excess of 0.1 mg/L in Reach 5, which may exert chronic stress on some aquatic organisms but does not exceed toxic acute thresholds. However, ammonia concentrations in agricultural drainages may approach acute levels (1-2 mg/L NH_4-N) along Mud and Salt Sloughs (Stringfellow and Quinn 2002). Kratzer and Shelton (1998) found that flow-adjusted ammonia concentrations have decreased during the 1980s at several sites, which is probably related to improved regulation of domestic and dairy wastes.

Nitrate levels are consistent with the widespread nitrate contamination of the region's shallow groundwater, but do not exceed the 10 mg/L drinking water maximum contaminant level (MCL) criteria (Table 6-9). Kratzer and Shelton (1998) found that flow-adjusted nitrate concentrations in the lower San Joaquin River have increased steadily since 1950. Since 1970, this nitrate increase has been due primarily to increases in subsurface agricultural drainage. Although many groundwater wells exhibit nitrate concentrations that exceed the 10 mg/L drinking water MCL for nitrate in drinking water (Mueller and Helsel 1996), no concentrations approaching this level were found in the monitoring sites on the mainstem San Joaquin River (Table 6-9). Salt Slough, however, may approach or exceed these concentrations.

In earlier investigations of existing conditions, Dubrovsky et al. (1998) assessed nutrients and suspended sediment in surface water of the San Joaquin-Tulare basins using data from the U.S. Geological Survey's National Water Information System and the U.S. Environmental Protection Agency's STOrage and RETrieval database, over the period from 1972 to 1990. Comparisons of nutrient and suspended sediment concentrations were made in three environmental settings: the San Joaquin Valley-westside, the San Joaquin Valley-eastside, and the Sierra Nevada. Nitrate concentrations in the lower San Joaquin River are determined primarily by relatively concentrated inputs from west-side agricultural drainage, east-side wastewater treatment plants, and dairy runoff, with relatively dilute inputs from large east-side tributaries. Within the San Joaquin River watershed, there are large areas of riparian seasonal wetlands, some of which discharge high concentrations of nitrate to the San Joaquin River tributaries (Kratzer and Shelton 1998). Within Reach 5, Mud and Salt sloughs receive flow from subsurface drains underlying approximately 60,000 acres of agricultural land. Although the sloughs account for only about 10% of the streamflow in the San Joaquin River near Vernalis, the subsurface drainage is highly concentrated with nitrate (about 25 mg/L as N), and the sloughs contribute nearly one-half the total nitrate (Kratzer and Shelton 1998, as cited in Dubrovsky et al. 1998).

6.9.3. Potential Implications for Riparian and Aquatic Resources

Eutrophication of surface waters is the primary effect of excessive nutrient input. Moderate levels of ammonia (0.1 to 0.2 mg/L) in the lower study reaches (Reaches 3 through 5) may cause chronic stress to fish (Alabaster and Lloyd 1982). Phosphates are generally less of a concern for eutrophication, since phosphates generally do not migrate within groundwater far from the point of fertilizer application (Fuhrer et al. 1999). Algae and plant growth under eutrophic (high nutrient) conditions, along with their subsequent decomposition in the water column, lead to increased oxygen consumption and decreased DO concentrations, reduced light penetration, and reduced visibility. Reduced light penetration in water limits plant photosynthesis in deeper waters, and may, in combination with increased oxygen consumption (due to decomposition), lead to oxygen depletion at deeper levels. As discussed in Section 6.8, reduced DO levels from algal blooms and low visibility may render these areas unsuitable for some fish species (e.g., trout) and favor others (e.g., blackfish, sucker, carp, shad). Although daily DO fluctuations from excess nutrients are associated with excessive pH fluctuations (Odum 1956), whether the eutrophic conditions of the San Joaquin River vary pH enough to affect abundance or diversity of fish and invertebrate, is unknown. Acidity (pH) must vary significantly to cause additional nutrient releases (for example, a pH of 9.4 is required for the release of free ammonia).

In addition to the potential impairment of fish habitat from DO depletion and ammonia toxicity, increased turbidity and light absorption by algae may reduce water clarity substantially, and based upon turbidity increases, may interfere with fish foraging, which could lead to decreased growth rates (Section 6.12). Total suspended solids (TSS) (Table 6-8) are generally higher in summer than in winter for all stations reporting, suggesting a large TSS contribution by algae, which may consequently effect organic loading and sediment anoxia. Nutrient reductions are likely to substantially improve the water clarity of the San Joaquin River, along with sediment load reduction. Under current conditions, existing sediment loads and turbidity may be controlling algal blooms; improved light penetration from load reductions may allow increased algal and plant growth as light (rather than low DO levels), becomes the limiting factor in primary productivity in the San Joaquin River.

Riparian establishment may be limited by relationships established between soils and crop plants. Soils along the San Joaquin Valley floor have had historically low nutrient concentrations and have likely supported plants adapted to low nutrient conditions (i.e., oligotrophic plants). With the changes in agricultural practices in the past decades, riparian areas were both physically and chemically impacted by exposure to fertilizers, which can cause plant community shifts towards species adapted to higher nutrient levels (State of Washington 1992 as cited in Williamson et al. 1998). For this reason, nutrient requirements of desired plant species and continuing nutrient-laden water from agriculture may limit riparian re-establishment.

In summary, with the possible exception of higher groundwater exchange rates, nutrient loads in the San Joaquin River basin will not likely be improved without a reduction in the source of the nutrients. Given the economic incentives of fertilized and irrigated agriculture in the San Joaquin Valley, excessive nutrient conditions along the river will continue to be a significant water quality issue, potentially affecting restoration of fisheries and riparian resources along the lower reaches of the river.

6.10. TRACE ELEMENTS

Trace metals are generally multivalent cationic elements (heavy metals) that in minute quantities play an important role in cellular functions of living organisms. The primary elements of environmental concern are copper (Cu), zinc (Zn), silver (Ag), nickel (Ni), cadmium (Cd), chromium (Cr), lead (Pb), selenium (Se), mercury (Hg), and tin (Sn). Although some of these metals are biologically necessary in small quantities, at high concentrations nearly all of them cause serious harm, including mortality, birth defects, and behavioral and carcinogenic consequences. Of the trace elements discussed by Brown (1996), this section discusses only two: selenium and mercury. Boron is the subject of an ongoing TMDL development in the basin (CVRWQCB 2000b) and is discussed in Section 6.5. The particular focus on Se and Hg results from their interaction with the aquatic environment because Se and Hg can both be converted into methylated compounds by bacteria. In this methylated form, Se and Hg can "biomagnify" within the food chain; in other words, even very low ambient concentrations can become functionally larger due to fat solubility and can then produce large biological effects.

Mercury. Unlike selenium, no mercury levels are beneficial as a nutrient and even small amounts of mercury can cause neurological and reproductive harm. A few geologic sources of mercury ore (Cinnabar) exist in the region. But organic mercury enters the water as metallic mercury from past mining (primarily gold), from the burning of fuels or garbage, and from municipal and industrial discharges. Like selenium, mercury can be converted into methylated forms, which allows biomagnification up the food chain.

Selenium. Selenium, generally considered to be a micronutrient, is common to the soils of the western San Joaquin valley and has a toxic threshold very close to levels required for nutrition. Much of the selenium in soils is combined with sulfide minerals or with silver, copper, lead, and nickel minerals. During soil weathering, selenium combines with oxygen to form several substances, the most common of which are sodium selenite and sodium selenate. Plants easily take up selenate compounds from water and change them to organic selenium compounds such as selenomethionine. Some plants can build up selenium levels that are harmful to livestock that feed on these plants, potentially causing deformities and nervous system impairment.

6.10.1. Historical Conditions

Historical mercury conditions in this region were likely low because mercury-bearing ore deposits are generally not found in this region. Gold mining practices in many Sierra watersheds left a legacy of mercury contamination in the remaining tailings piles (Churchill 1999, Hunerlach et al. 1999) and in hydraulic mining alluvium; present-day mercury concentrations in the San Joaquin River study area (e.g., Bear Creek) are likely a result of these sources because historical concentrations were likely low.

Historical concentrations of trace elements in the San Joaquin River study area were likely similar to present conditions of water originating from the Sierra Nevada. The important exception was selenium runoff and groundwater flow from soils along the west side of the San Joaquin Valley that contain natural sources of selenium and boron. At a Regional Water Quality Control Board Staff Workshop on the San Joaquin River Selenium TMDL development (May 16, 2001), the following estimates of background concentrations of selenium were provided:

- Merced River = 0.2 µg/l
- San Joaquin River above Salt and Mud Sloughs = 0.5 µg/l
- Grassland wetlands = 1.0 µg/l

6.10.2. Existing Conditions

Mercury TMDL. The lower San Joaquin River (Reach 5) was added to the 303(d) list during the 2001 review period due to the mercury impairment. Evidence used to justify adding mercury to the 303(d) list was presented in Appendix B of the CVRWQCB's Draft Staff Report on Recommended Changes to California's Clean Water Act, Section 303(d) List, 27 September 2001. Mercury problems are evident region-wide, but only occur in Reach 5 of the study area because of historical mining in the Bear Creek watershed. This CVRWQCB report stated that trophic level 4 fish had an average mercury concentration of 0.45 ppm, exceeding the EPA criterion of 0.3 ppm. This concentration was an average for fish sampled in three locations in the San Joaquin River, including Landers Ave/Hwy165 downstream of the mouth of Bear Creek, a site between Crow's Landing and Las Palmas Roads, and a site near Vernalis.

Selenium TMDL. Selenium problems have a long history in the San Joaquin Valley. Due to the high salt, boron, and selenium concentrations in west side agricultural drainage identified in the early 1960s, an interim solution for salt and selenium accumulations was developed. The San Luis Drain project construction began in 1968 and halted in 1975. Funding limitations and environmental concerns ranging from disclosure of selenium-related bird mortalities in the Kesterson Reservoir, and concern for public health, prompted the Department of the Interior to develop an agreement with the Westlands Water District in 1985, calling for cessation of drainage flows to Kesterson Reservoir.

The CVRWQCB responded to the environmental problems at the Kesterson Wildlife Refuge with an amendment to the Basin Plan (CVRWQCB 1998) in which they established numerical water quality objectives for Selenium. The amendment was intended to protect sensitive beneficial uses from elevated levels of selenium in three identified areas within the San Joaquin River study area, including Salt and Mud sloughs and the San Joaquin River from Salt Slough to Vernalis. All three sites were added to the CVRWQCB 303 (d) list (Figure 6-1). The current Basin Plan (CVRWQCB 1998a) includes a water quality objective for selenium of 5 µg/l, based on a 4-day average of total recoverable selenium, and was instituted for Mud Slough and the San Joaquin River from Sack Dam to Vernalis. A 2 µg/l selenium water quality objective based on a monthly average of total recoverable selenium was instituted for Salt Slough and the Grassland channels. As stated in the TMDL for the lower San Joaquin River (CVRWQCB 2001b), water quality objectives were made more stringent than the selenium objective for other water bodies to offer added protection to the waterfowl using the wetlands. The compliance date for the San Joaquin River and Mud Slough is set for October 1, 2010 with earlier performance goals for the San Joaquin River of October 1, 2002 and 2005.

Selenium concentrations at selected sites along the San Joaquin River range between 1 to 5 µg/l (Table 6-9), which approach or exceed Basin Plan objectives set for Mud and Salt Sloughs. Mean selenium concentrations range widely for Mud and Salt Sloughs, however. Selenium is much higher for the Mud Slough monitoring site adjacent to the Grasslands Project Area (discussed below).

The limited amounts of data suggest that CVRWQCB water quality objectives for selenium are currently being exceeded for Mud Slough (Table 6-9) and downstream mainstem reaches to Vernalis (including Reach 5). The San Joaquin River at Stevinson station may be indicative of conditions upstream of Reach 5, in which selenium concentrations are one to two orders of magnitude lower than the San Joaquin River below Mud Slough. This difference in selenium concentrations will be useful when evaluating measures to reduce selenium input from Mud Slough.

Grasslands Project

The Grassland Bypass Project, initiated in 1995, utilizes a 28-mile segment of the San Luis Drain (SLD) to convey agricultural drainage water. This segment, known as the Grassland Bypass, conveys agricultural drainage waters from the Grasslands Subarea to the San Joaquin River via Mud Slough. This drainage had previously been contributing high concentrations of selenium to Salt Slough. Since September 1996, the implementation of the Grassland Bypass Project and the selenium TMDLs for Grassland Marshes and Salt Slough has dramatically improved selenium concentrations in Salt Slough. Water quality objectives are now being met for selenium and Salt Slough was removed from the 303(d) list for selenium during the 2001 review. Although Mud Slough and the San Joaquin River remain impaired due to selenium, long-term solutions to meet the selenium WQO by October 1, 2010 have been recommended by the CVRWQCB in their implementation section of the Basin Plan. Water quality monitoring results that document Salt Slough's water quality improvements since the implementation of the Grassland Bypass Project in 1996 are available http://www.esd.lbl.gov/quinn/Grassland_Bypass/grasslnd.html.

6.10.3. Potential Implications for Riparian and Aquatic Resources

The San Joaquin Valley Drainage Program identified selenium as one of 29 inorganic compounds that are a concern for public health and maintenance of fish and aquatic life (Brown 1996). Agricultural tile drainage has been shown to cause episodic toxicity to juvenile salmonids and striped bass (Saiki 1992), and high selenium concentrations from drain water have been linked to mortality and developmental abnormalities in fishes (Moyle and Cech 1988). Selenium dilution in the river may be expected with increased freshwater inputs from Friant Dam, but the major selenium accumulation in groundwater and increases in groundwater table elevation are legacies of past irrigation practices that increased surface flows may not be able to completely ameliorate. A long-term solution to the subsurface drainage problem has not been found for sustained agricultural crop production in western Fresno County. Nor is dilution of selenium by increased streamflows necessarily endorsed as the best approach to resolving impaired water quality. Furthermore, since only trace amounts of selenium cause reproductive harm in fish and birds, continued impairment of the lower portions of the San Joaquin River study area is likely to continue, posing a major limiting factor in any restoration plans.

In addition to the regional selenium contamination, mercury contamination of the lower watershed may represent another limiting factor in the restoration of the San Joaquin River. Methyl mercury bio-magnification in fish can cause death, reduced reproductive success, impaired growth and development, and behavioral abnormalities (Slotton 2000). Because methyl mercury is also a human neurotoxin, transfer to humans through consumption of fish from the Bay-Delta is a major health concern. Unintentional re-suspension of past mercury deposits in the channel bed, leading to increased uptake into the food chain, is a possible risk to anticipate in any restoration actions.

6.11. PESTICIDES AND HERBICIDES

Pesticides vary in their potential to affect water quality and aquatic resources. According to Brown (1998), many of the recently developed pesticides, such as the organophosphate compounds, are highly soluble in water and are relatively short-lived in the environment. In contrast, the previous generation of pesticides included organochlorine compounds such as DDT and toxaphene, which are non-polar and poorly soluble in water, and may persist in the environment for long periods. Non-polar compounds also allow bio-accumulation in animal tissues over time, posing a direct threat to aquatic resources and human health. Many of these chemicals were banned several decades ago, but the legacy of their use is still detected at levels considered a threat to water quality (Brown 1998).

A large number of pesticides have been detected by water quality sampling programs in the San Joaquin basin, including Aldrin, Carbaryl, Chlorpyrifos, Diazinon, Dieldrin, Diuron, Heptachlor, Lindane, Malathion, Metribuzin, and Trifluralin (Domagalski et al. 2000). Most problems occur in the lower study reaches (Reaches 3-5) where water quality is influenced by water imported from the Delta and by agricultural drainage. Reaches 1 and 2 have generally good water quality (Brown 1997). Domagalski's study (et al. 2000) and other multi-year studies (Brown 1997, Panshin et al. 1998) assessed a wide array of contaminants. The large and growing number of chemical pesticides found in the San Joaquin Valley is too large to encompass in this review. Furthermore, accurately quantifying risks that pesticides pose to aquatic resources is not easily validated; most studies rely on comparing contaminant levels (from biota or the environment) to literature values, regional or national statistics, or suitable reference sites. Because of the importance of DDT as a marker of past pesticide-use practices, this section discusses DDT along with two other pesticides (Diazinon and Chlorpyrifos) and two herbicides (Simazine and Metalachlor). These compounds were some of the most frequently detected compounds in the National Water Quality Assessment program studies (Dubrovsky et al. 1998).

Dichlorodiphenyltrichloroethane (DDT). DDT was the first chlorinated organic insecticide discovered (1873), but it was not until 1939 that the effectiveness of DDT as an insecticide was discovered. DDT earned wide publicity in the early 1970s environmental movement as a primary cause of declining avian populations. The chemical stability of DDT and its fat solubility contributed to its acute effects on wildlife (including egg shell thinning and deformities in birds) and its chronic, low-level toxicity in fish. DDT was eventually banned in the United States in 1973. Since 1998, DDT has also been regulated in Dicofol (now required to be less than 0.1 percent DDT).

Diazinon and Chlorpyrifos Pesticides. In winter, dormant-spray pesticides including diazinon and chlorpyrifos are applied to fruit orchards and alfalfa fields in the San Joaquin Basin and Delta islands (Kuilvila 1995, 2000). These pesticides are delivered to local water courses and the Delta by overland runoff. Diazinon is the common name of an organophosphorus (OP) insecticide used to control pest insects in soil, on ornamental plants, and on fruit and vegetable field crops. Chlorpyrifos is also an OP insecticide and is used to kill insect pests by disrupting their nervous system. OP pesticides were originally developed for their water solubility and ease of application. After they have been applied, they may be present in the soil, surface waters, and on the surface of the plants that are sprayed, and may be washed into surface waters by rain.

Simazine and Metalochlor Herbicides. In the late 1950s, Simazine was originally introduced and used as an aquatic herbicide to disrupt photosynthesis and control algae and submerged aquatic vegetation in lakes and ponds. Studies during the 1960s showed that this chemical was effective in controlling algae and certain species of aquatic plants with no apparent harm to fish (Mauck 1974). Metolachlor is a selective pre-emergence herbicide used on a number of crops. It can be lost from the soil through bio-degradation, photo-degradation, and volatilization. It is fairly mobile and under certain conditions, it can contaminate groundwater but it is mostly found in surface water.

6.11.1. Historical Conditions

Because the pesticides and herbicides discussed in this report have no natural origin, historically the San Joaquin River was free of these organic contaminants. Agricultural applications over the past 50 years have resulted in existing water quality conditions.

6.11.2. Existing Conditions

Although extraordinarily large amounts of data have been collected within the San Joaquin basin (Brown 1997, Dubrovsky et al. 1998, Gronberg and Burow *in press*, Panshin et al. 1998), only a limited amount of data available at the USGS website were analyzed in this report (Tables 6-10 and 6-11). The occurrence of pesticides and other toxic agents have been associated with land use activities that contribute to agricultural drainage and runoff in the lower reaches of the San Joaquin River study area (Reaches 3, 4, and 5). Although mean contaminant levels are low (Tables 6-10 and 6-11), it is likely these samples did not capture episodic contaminant exceedances during peak pesticide use and peak surface flow runoff into the San Joaquin River (Kuilvila 1995, 2000).

6.11.2.1. USGS NAWQA Toxicity Monitoring

The San Joaquin-Tulare study unit was among the first basins chosen for the USGS National Water Quality Assessment Program (NAWQA), and has recently focused considerable attention on pesticide

Table 6-10. Pesticides in water samples in the San Joaquin River study area.

Site Number	Site Name	Agency	Period of Record[1]	Winter (November-May)				Summer (June-Oct)			
				Diazinon (ug/l)		Chlorpyrifos (ug/l)		Diazinon (ug/l)		Chlorpyrifos (ug/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS									
2	SJR Near Mendota	USGS									
3	SJR @ Sack Dam	CVRWQCB									
4	SJR Near Dos Palos	USGS									
5	Bear Creek Bert Crane Rd.	CVRWQCB									
6	Salt Slough @ Lander/Hwy 165	USGS	1993-1994	0.052	0.043	0.018	0.014	0.067	0.096	0.007	0.005
7	Mud Slough (Downstr)	USGS	1994-1999					0.013	0.001	0.010	0.008
8	SJR @ Stevinson	USGS	1994-2000	0.033	0.023	0.011	0.016	0.002	n.a.	0.004	n.a.
9	SJR @ Fremont Ford	USGS									
10	SJR Upstream of Merced R.	USGS									
11	SJR Near Newman	USGS									
12	SJR @ Crows Landing	USGS									
13	SJR @ Patterson	USGS	1994-2000	0.022	n.a.	0.007	n.a.	0.009	0.001	0.015	0.010
14	SJR @ Maze	USGS									
15	SJR @ Airport Way/Vernalis	USGS	1972-2000[2]	0.094	0.180	0.010	0.010	0.009	0.014	0.008	0.004

1 Period of record for monitoring of selected herbicides.
2 Period of record for monitoring Chlopyrifos: 1992-2000.

Table 6-11. Herbicides in water samples in the San Joaquin River study area.

Site Number	Site Name	Agency	Period of Record[1]	Winter (November-May)				Summer (June-Oct)			
				Simazine (ug/l)		Metolachlor (ug/l)		Simazine (ug/l)		Metolachlor (ug/l)	
				Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	SJR Below Friant	USGS									
2	SJR Near Mendota	USGS									
3	SJR @ Sack Dam	CVRWQCB									
4	SJR Near Dos Palos	USGS									
5	Bear Creek Bert Crane Rd.	CVRWQCB									
6	Salt Slough @ Lander/Hwy 165	USGS	1993-1994	0.048	0.025	0.010	0.009	0.028	0.022	0.016	0.015
7	Mud Slough (Downstr)	USGS	1994-1999					0.036	0.035	0.006	0.006
8	SJR @ Stevinson	USGS	1994-2000	0.119	0.083	0.006	0.005	0.043	n.a.	0.110	n.a.
9	SJR @ Fremont Ford	USGS									
10	SJR Upstream of Merced R.	USGS									
11	SJR Near Newman	USGS									
12	SJR @ Crows Landing	USGS									
13	SJR @ Patterson	USGS	1994-2000	0.163	n.a.	0.008	n.a.	0.038	0.004	0.109	0.051
14	SJR @ Maze	USGS									
15	SJR @ Airport Way/Vernalis	USGS	1992-2000	0.246	0.325	0.018	0.060	0.023	0.016	0.066	0.053

1 Period of record for monitoring of selected herbicides.

contamination in the San Joaquin basin (Dubrovsky et al. 1998; Panshin et al. 1998; Kratzer and Shelton 1998; Brown and May 2000). Generally, toxicity within the San Joaquin River has been attributed to pesticides from agricultural nonpoint sources, substantiated by the lack of detection of pesticide compounds in reference sites on the upper Kings River and Tuolumne River, situated above agricultural influences (Dubrovsky et al. 1998). In the NAWQA studies, available drinking water standards were not exceeded at San Joaquin River monitoring sites, but the concentrations of several pesticides exceeded the criteria for the protection of aquatic life. As mentioned previously, regional or national contamination levels are used to interpret San Joaquin River study results. Gilliom and Clifton (1990, from Brown 1998) reported that the San Joaquin River had some of the highest concentrations of organochlorine residues in bed sediments among the major rivers of the United States. Concentrations of organophosphate insecticides (i.e., Diazinon and Chlorpyrifos) in runoff are high, and highly variable during winter storms (Kratzer and Shelton1998). Long-banned organochlorine (e.g., DDT) concentrations detected in biota of the San Joaquin Valley streams appear to have declined from levels measured in the 1970s and 1980s (Dubrovsky et al. 1998), but still continue to be transported to streams by soil erosion of contaminated agricultural fields, resulting in contamination of suspended sediment, bed sediment, and aquatic organisms.

Reaches 1 and 2 of the San Joaquin River have not been identified as problem areas by the NAWQA studies, but pesticides have been detected in groundwater samples from domestic water supply wells. However, concentrations in groundwater supplies generally have not increased in the last decade (Dubrovsky et al. 1998). The extremely low levels of pesticides and herbicides, and ephemeral nature of their presence in surface waters, prompted the creation of the California Department of Pesticide Regulation within CalEPA, which tracks pesticide use. Data are available at the following web site: http://www.cdpr.ca.gov/dprdatabase.htm

6.11.2.2. Basin Plan Objectives and CVRWQCB Monitoring

For most pesticides, numerical water quality objectives for pesticides have not been adopted, but a number of narrative water quality objectives (e.g., no adverse effects) for pesticides and toxicity are listed in the Basin Plan (CVRWQCB 1998a). The EPA criteria and other guidelines are also extremely limited, since numerical targets based on the anti-degradation policy would not allow pesticide concentrations to exceed natural "background" levels (i.e., nondetectable levels or "zero"). For the San Joaquin River system, including the five reaches of this study area, the California SWRCB has set a goal of "zero toxicity" in surface water. This goal is intended to protect the beneficial uses of Recreation, Warm Freshwater Habitat, Cold Freshwater Habitat, and Municipal and Domestic Supply from potential pesticide impacts.

The most recent 303(d) list of impaired waterbodies presented by the CVRWQCB identifies Reaches 3, 4, and 5 of the San Joaquin River study area, Mud Slough, and Salt Slough as impaired due to pesticides and "unknown toxicity" (Figure 6-1). In addition to the CVRWQCB, the USGS and the State Department of Pesticide Regulation (DPR) are conducting cooperative synoptic and/or in-season sampling for pesticides, herbicides, and insecticides. The following stations are part of the ongoing studies: San Joaquin River at Vernalis (USGS 11303500), Maze (USGS 11290500), Patterson (USGS 11274570), Crows Landing (USGS 11274550), and Stevinson (USGS 11260815), Bear Creek at Bert Crane Rd. (CVRWQCB MER007), Salt Slough at Lander/Hwy 165 (USGS 11261100), Mud Slough (USGS11262900), and Los Banos Creek at Hwy 140 (CVRWQCB MER554). Results of these sampling efforts will help characterize the distribution of pesticides and other toxins within these impaired waterbodies. Annual reports discussing the results for the DPR-funded studies can be found at: http://www.cdpr.ca.gov/docs/empm/pubs/memos.htm.

Ongoing efforts to reduce and minimize the effects due to pesticides within the larger San Joaquin River area are coordinated through a recent draft workplan to develop a Diazinon and Chlorpyrifos TMDL for the Lower Sacramento River, Lower Feather River, Lower San Joaquin River (includes the San Joaquin River downstream of Mendota Dam to the Airport Way Bridge near Vernalis), and the main channels of the Sacramento–San Joaquin River Delta.

6.11.3. Potential Implications for Riparian and Aquatic Resources

Although modern pesticides are formulated for water solubility and low application levels, and although pesticides are detected ephemerally (Kuilvila 2000), a large number of older pesticides continue to be detected in the San Joaquin River (Panshin et al. 1998). The effects of pesticides on the restoration of riparian and aquatic resources include episodic toxicity and low level contamination of the San Joaquin River.

Pesticides and herbicides do not appear to alter invertebrate and fish species diversity in the NAWQA study areas (Brown 1998), but their synergistic effects with other environmental variables is largely unknown. For salmonids, chemical interference with olfactory functions (and therefore homing), and other chronic toxic effects, are potential problems due to pesticides and herbicides, and may limit restoration activities in Reaches 3-5 of the study area. Moore and Waring (1996) showed that the organophosphate pesticide diazinon had sublethal effects on the olfactory system of mature male Atlantic salmon. Reductions in the ability of mature salmon to detect and respond to reproductive odorants and pheromones may have long term implications for populations (Moore and Waring 1996). Pesticides at even low concentrations interfere with the production and activity of sex hormones in salmon, causing decreases in sperm production. (Moore and Waring 1996).

In summary, continued pesticide use may be a long term limiting factor for aquatic resources in the San Joaquin River. In terms of planned restoration activities, the combination of coarse-grained deposits and the relatively shallow depth to groundwater of the Valley's eastern side, increase the risk of transport of pesticides from irrigated areas (Domagalski and Dubrovsky, 1991, 1992). Continued toxicity episodes may occur. The greatest uncertainty with legacy deposits of DDT in sediments is the potential for sediment re-suspension and transport. DDT metabolites have been detected in bottom sediment samples in Reach 5 of the San Joaquin River (Dubrovsky et al. 1998), and could be remobilized at higher flows.

6.12. SUSPENDED SEDIMENT AND TURBIDITY

Very fine (colloidal) suspended matter such as clay, silt, organic matter, plankton and other microscopic organisms cause turbidity in water. Turbidity is an optical property (light scattering), which itself is not a major health concern, but high turbidity can interfere with temperature, DO, feeding habits, photosynthesis, and is associated with total metals loadings and sorption of contaminants from the water column (e.g., polar organics and cationic metal forms). Turbidity is closely related to total suspended solids (TSS). TSS and turbidity sources to the San Joaquin River include suspended sediment from tributary inflows, agricultural return flows, bank erosion, resuspension of local sediments from tidal mixing, high flows, wind-generated wave fetch, and summer algae production. Suspended sediment is discussed in Section 7.7.5.2 in relation to effects on fish species. This section emphasizes turbidity as a water quality parameter. For the purposes of this chapter, turbidity and suspended solids were estimated to have a 1:1 equivalence to turbidity (Montgomery 1985), where 1 mg/L TSS is approximately one nephelometric turbidity unit (1 NTU).

6.12.1. Historical Conditions

Although no historical measurements of suspended sediment and turbidity were found for this assessment, the San Joaquin River (and tributaries) probably historically carried relatively low suspended sediment loads due to the predominantly granitic geology of the upper basin. These conditions likely changed above Friant, as the parent geology shifted to decomposed granite and clays, producing relatively higher natural background suspended sediment and turbidity in the valley floor portion of the river below Friant (USGS, 1899). Perhaps the best description of the historical turbidity levels in the upper river are from Blake (1857 from Yoshiyama et al. 1996) who described the San Joaquin River in the vicinity of Millerton, in July, as "remarkably pure and clear, and very cold." Suspended sediment concentrations were likely historically higher in west side tributaries to the San Joaquin River because of the finer-grained alluvial deposits of the Coast Ranges (Kratzer and Shelton 1998). However, other historical accounts suggest that the flood basins in Reaches 3-5 caused suspended sediments to deposit in the upper portion of the flood basin, longitudinally reducing turbidity in the downstream direction. This trend ended at the Merced River confluence.

6.12.2. Existing Conditions

The USGS currently collects suspended sediment data at Vernalis (USGS 11303500), which began reporting daily values in 1965. In addition, weekly and bi-weekly data were collected between 1985 and 1988 at Patterson (USGS 11274570), Fremont Ford (USGS 11261500), Stevinson (USGS 11260815), and near Mendota (USGS 11254000). Table 6-8 shows suspended sediment concentrations range between 60–100 mg/L in the winter and from 100–150 mg/L in the summer. Assuming a 1:1 correspondence between turbidity and TSS (Montgomery 1985), the range of TSS shown in Table 6-8 would vary from 60–100 NTU in winter and 100–150 in summer. Although the water transparency (Secchi depth) corresponding to these levels is low, we cannot accurately estimate transparency (light transmission) since its relationship between turbidity (light scattering) is non-linear. These grab sample data may suggest lower wintertime suspended sediment levels, perhaps reflecting decreases with increased rainfall and lower turbidity from eastside tributary inputs, but more likely reflect algal productivity in the river (Section 6.8). According to USGS Professional Paper 1587, nutrient and suspended sediment loads increased during wetter water year types, by increasing non-point source loading (Kratzer and Shelton 1998 as cited in Dubrovsky et al 1998) making these effects difficult to separate without targeted synoptic studies (e.g., nutrients, TSS, Chl-a). Also, TSS and turbidity levels are known to increase during storm events, perhaps as much as two to three orders of magnitude over an individual storm event. Mean suspended sediment concentrations are therefore misleading if data are not collected during storm events. Section 7.7 presents additional information regarding suspended sediment and turbidity.

6.12.3. Potential Implications for Riparian and Aquatic Resources

Suspended sediment and turbidity may be critical variables in restoration efforts in the San Joaquin River. In addition to its direct effects on primary production and fish, turbidity can cause decreases in the abundance of plants, zooplankton, and insect biomass, and reductions in herbivore, omnivore, and, consequently, predator classes of fish (Berkman and Rabeni, 1987 as cited in Henley et al. 2000).

At the base of the food web, high turbidity and TSS can limit algal productivity due to photo-inhibition, with indirect effects that propagate upwards (i.e., suppressed secondary production and reduced food availability for native fish assemblages). Lloyd et al. (1987) found that an increase in turbidity of only 5 NTU decreased primary production by 3–13 percent, and increases of 25 NTU decreased primary production up to 50 percent (Henley et al. 2000). High turbidity and fine sediment can cause dramatic shifts in invertebrate assemblages in rivers (Henley et al. 2000), and can impair the quality of spawning gravels used by salmonids (Tappel and Bjornn 1983).

In terms of its direct impacts on fish, excessive turbidity can reduce DO in the water column, and in extreme cases may cause a thickening of the gill epithelium and reduced respiratory function (Horkel and Pearson, 1976; Goldes et al., 1988; Waters, 1995; all as cited in Henley et al. 2000). Turbidity is also believed to reduce the visual efficiency of piscivorous and planktivorous fish in finding and capturing their prey (Henley et al. 2000). Turbidity works to reduce the reaction distance of a predator to its prey, greatly reducing the volume a fish can search in a given time: a 50 percent reduction in reaction distance reduces the volume searched by a factor of four (Confer and Blades 1975 as cited in Vinyard and O'Brien 1976). Higher turbidity may occasionally favor the survival of young fish by protecting them from predators (Bruton 1985, Van Oosten 1945) at the expense of reduced growth rates for sight feeding fish (Newcombe and MacDonald 1991, Newcombe and Jensen 1996).

In addition to the direct effects on fishes, indirect effects of high suspended sediment is related to contaminant transport. Regional gradients of total metal distributions in sediments and dissolved metals in the water column are generally reflective of parent geology and follow depositional trends and the transport of TSS (Brown, pers. comm. 2002). DO depressions are generally due to transport and settling of organic matter that sorbs on the sediment. Lastly, there may be a number of synergistic effects on aquatic resources impacted by pesticides and other toxins entering the river or stream sorbed onto the eroded material (Henley et al. 2000).

In summary, the current levels of turbidity in the San Joaquin River may inhibit feeding efficiency and may impair the quality of juvenile fish rearing habitat in the study reaches below Mendota Dam (Reaches 3-5). Algal productivity may contribute significant amounts of turbidity to the San Joaquin River, which will continue to inhibit food availability to higher focal fish species, overall measures of environmental quality, and habitat availability, regardless of the anticipated restoration measures. Because of these potential effects, even small decreases in sediment transport and turbidity from increased fresh water flows may lead to shifts in species density, biomass, and diversity throughout all trophic levels.

6.13. SUMMARY

Invertebrate and fish communities are responsive to water quality conditions and the effects are most critically related to physical parameters such as DO, temperature and salinity. A number of studies have demonstrated that fish and invertebrate assemblages structure themselves along water quality gradients (Brown 2000; Hughes and Gammon 1987; Saiki 1984), with subtler effects of pesticide gradients at low levels such as disruption of olfactory cues and hormonal effects on salmonids (Moore and Waring 1996). Despite intensified study and advances in our knowledge of the sources and distribution of water quality and contaminants, a number of parameters identified in this assessment may limit the ability to achieve long term restoration goals for the San Joaquin River.

Temperature. Water temperature modeling suggests that cold water habitat in the first few miles below Friant Dam can be improved by increased flow releases from Friant Dam. However, this effect only extends a short distance downstream during late spring and summer months. Historical measurements and reconstructed hydrographs of daily average flow suggest longer periods of lower temperatures in Reaches 1 and 2 of the San Joaquin River were historically available for salmonids and other native fish species. Additionally, the extensive artesian springs and shallow groundwater contributions may have provided local thermal refugia in Reaches 2-5. The early summer and late fall temperature regime in the lower study reaches (Reaches 3–5) of the San Joaquin River will remain a significant management issue for restoring anadromous salmonids, because the high ambient air temperatures, long river length, and loss of the spring snowmelt hydrograph make it difficult to provide suitable cold water temperatures in the downstream reaches (Table 6-12).

Salinity and Boron. Salinity has an enormous influences on aquatic community structure and species diversity and is potentially a major limiting factor for restoration of aquatic resources in the lower study reaches (Reaches 3–5), with effects on invertebrates, fish, and riparian plant establishment (Tables 6-8 and 6-9). Reaches 1 and 2 have relatively good water quality, but salinity increases in Reaches 3-5, and both conductivity and TDS increase above the CVRWQCB water quality objectives for the San Joaquin River at Dos Palos (RM 180) near Sack Dam. Increases in inputs of low salinity water from Friant Dam and decreases in the importation and irrigation of Delta water would reduce salinity in Reaches 3-5. However, modeling of "losing" and "gaining" reaches within the upper reaches of the river may be necessary to determine how much time would be required to reverse contributions from salinity accumulated and delivered in groundwater.

Dissolved oxygen. DO does not appear to be a critical water quality issue in the study area and it is likely that historical DO levels of the Upper San Joaquin River were on the order of 7-10 mg/L, similar to what is now typically measured in Reach 5 (Table 6-8). The primary exception to this generality is low DO problems in Mud Slough and Salt Slough. Farther downstream in Stockton, low DO levels from algal growth and nutrient contamination from the Delta Mendota Canal, Mud and Salt sloughs (Reach 5), and municipal effluent from Stockton may potentially delay fall-run salmon migration. Because of localized effects on benthic macro-invertebrates and its effects on migrating salmon, the nutrient causes of this DO condition represent a potentially important limiting factor for Reach 5.

Nutrients. High nutrient loads in the past decades continue to be associated with eutrophication of the lower San Joaquin River and Delta, with consequent effects on DO and the possibility of localized ammonia toxicity. Although phosphate and nitrate levels are higher than typical background concentrations (Table 6-9), it is unclear whether increased flows of low nutrient water would substantially reduce nutrient concentrations in the lower reaches. Nutrient dilution in the lower study reaches from future flow releases would be related to the magnitude and timing of the proposed reservoir releases, and adjacent groundwater exchanges. Modeling of "losing" and "gaining" reaches within Reaches 3-5 will have to be conducted to determine how much time would be required to reverse the groundwater buildup of nutrients in the basin.

Trace Elements. Mercury and selenium contamination are well-known problems in the lower San Joaquin River reaches (Table 6-9). Mercury is found primarily in the Bear Creek tributary of Reach 5 and is the most important trace element contaminant from a human health standpoint. Risks of sediment re-mobilization of historical mining deposits in the San Joaquin River need to be considered in restoration planning. The primary sources of selenium are from the Grasslands area and represent a major risk to larval fish species and birds. Although selenium is being addressed by a number of ongoing studies, changes in the groundwater relations of the river under future (higher) flow scenarios could be expected to reduce selenium concentrations in the river by dilution. As with other parameters (nutrients, salt, and boron), selenium impacts will be determined by reach-specific hydrology and concentrations identified in ongoing studies.

Pesticides and Herbicides. The most recent 303(d) list of impaired waterbodies presented by the CVRWQCB identifies Reaches 3, 4, and 5 of the San Joaquin River study area and Mud and Salt Slough as impaired due to pesticides and "unknown toxicity." Pesticides and other toxicity have been associated with land use activities in these areas, and organophosphate insecticide concentrations (i.e., Diazinon, and Chlorpyrifos) in runoff to Reach 5 are elevated, and highly variable during winter storms. Reaches 1 and 2 or the San Joaquin River study have not been identified as problem areas by the NAWQA studies, but pesticides have been detected in groundwater samples from domestic water

Table 6-12. Summary of beneficial uses controlling water quality objectives, water quality impairments, and potential effects on aquatic resources and restoration planning for the San Joaquin River study area.

Reach	Study Reach	Beneficial Use Controlling Water Quality	303(D) Pollutant Limitation or Other WQO	Water Quality Parameters Likely Affecting Restoration of Aquatic Resources
1	Friant Dam to Gravelly Ford (RM 267-229)	Municipal water supply, cold water fish habitat.	EC<150 µmhos/cm	Late spring and early fall water temperature.
2	Gravelly Ford to Mendota Dam (RM 229-225)	Municipal water supply, cold water fish habitat.	EC<150 µmhos/cm	Late spring and early fall water temperature.
3	Mendota Dam to Sack Dam (RM 205-182)	Agriculture, warm water migratory game fish spawning habitat.	Boron , EC, Pesticides (Table 6-3)	Salinity and boron affecting riparian vegetation. Salinity and pesticides affecting invertebrate and fish species diversity. Possible effects of elevated turbidity.
4	Sack Dam To Bear Creek (RM 182-136)	Agriculture, warm water migratory game fish spawning habitat.	Boron, EC, Pesticides (Table 6-3)	Salinity and boron affecting riparian vegetation. Salinity and pesticides affecting invertebrate and fish species diversity. Possible effects of elevated turbidity.
5	Bear Creek To Merced River (RM 136-118)	Agriculture, warm water migratory game fish spawning habitat	Boron , EC, Pesticides (Table 6-3) Mercury, Selenium	Early fall water temperatures; salinity and boron affecting riparian vegetation, species diversity; TSS and DO extremes affecting invertebrates and fish; selenium affecting fish and avian species. Mercury, pesticides, and herbicides affecting invertebrate and fish species, avian species and human health.

supply wells. Long-banned organochlorine insecticides (e.g., DDT) continue to be transported to streams by soil erosion of contaminated agricultural fields, resulting in contamination of suspended sediment, bed sediment, and aquatic organisms (Table 6-10). Like mercury, risks of sediment re-mobilization of long buried sediment deposits containing DDT in Reaches 3-5 of the San Joaquin River need to be considered in restoration planning.

Suspended Sediments and Turbidity. Current levels of turbidity in the San Joaquin River may inhibit feeding efficiency and represent a major limiting factor for juvenile fish rearing in the study reaches below Mendota Dam (Reaches 3-5). In addition, the potential for direct impacts to the focal fish species (e.g., gill irritation), there are a number of subtler effects of suspended sediments related to contaminant transport and DO conditions.

6.13.1. Potential Water Quality Impacts under Restored Environmental Conditions

Water quality in the San Joaquin River is currently impaired by several parameters that will continue to impact fish and other aquatic and terrestrial resources for the foreseeable future. Recent intensified study and advances in our knowledge of the sources and distribution of water quality and contaminants have identified a number of parameters that may limit the ability to achieve long-term restoration goals for the San Joaquin River. A number of contaminants threaten fishes of the Central Valley (Saiki 1995). Reaches 1 and 2 generally have good water quality. The primary constraints to restoration are agricultural return flows in Reaches 3-5, Mud Slough, and Salt Slough, and the legacy of contaminants available for re-recruitment from surface flows and groundwater contributions. Despite these problems, significant progress has been made to ameliorate water quality contamination in the past decade and represents an enormous opportunity for restoration to contribute to improved water quality in the lower reaches of the San Joaquin River.

Several water quality parameters would likely be improved in Reaches 3-5 by higher streamflow releases from Friant Dam. However, dilution is not the best long-term solution to impaired water quality in the lower reaches. Instead, point-source and non-point source reduction are more viable long-term solutions. Identifying contaminant sources is the first step in the process of pollution control. The San Joaquin River was among the first watersheds selected for study under the USGS NAWQA program in the 1990s, and the second phases of this assessment are currently underway. The CVRWQCB has just initiated a Rotational Basin Monitoring Program to provide an expanded assessment of water quality conditions in five sub-watersheds. In addition to the WQOs set forth in the Basin Plan (CVRWQCB 1998a), ongoing and planned TMDL efforts are seeking to reduce and minimize the effects of nutrients (Stockton), salt and boron (Grasslands area-Reach 5), Mercury (Reach 5), selenium (Reaches 4 and 5) and pesticides (Reaches 3–5).

Although water quality conditions on the San Joaquin River relating to conservative ions, (e.g., salt and boron), and some nutrients are likely to improve under increased flow conditions, it is unclear how these and other potential restoration actions will impact many of the current TMDL programs and existing contaminant load estimates. This is most true of constituents with complex oxidation-reduction chemistry, and sediment/water/biota compartmentalization (e.g., pesticides, trace metals). A number of investigations could be planned to address uncertainties in DO, Hg contamination, salt accumulation in floodplain deposits, and improved temperature monitoring along the San Joaquin River. Perhaps the greatest risks to potential restoration actions within the San Joaquin River study reaches relate to uncertainties regarding remobilization of past deposits of organochlorine pesticides, i.e., DDT and mercury. The effects and implications of the water quality parameters on aquatic resources should be re-visited after a suite of recommended restoration actions is developed.

6.14. LITERATURE CITED

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