CHAPTER 7. FISH RESOURCES

7.1. INTRODUCTION

Fish communities in the San Joaquin River basin have changed markedly in the last 150 years. Before Euro-American settlement, the river supported a distinctive native fish fauna that had evolved in relative isolation over a period of several million years. These native fish assemblages were adapted to widely fluctuating riverine conditions, ranging from large winter and spring floods to warm low summer flows. These environmental conditions resulted in a broad diversity of fish species that included both cold-water anadromous salmonids as well as cold and warm-water resident fish species.

As the land and water resources of the San Joaquin Valley were developed, riverine habitat conditions for native fish species deteriorated. The loss of habitat, combined with the introduction of non-native fish species, precipitated a decline in both abundance and distribution of native species and unique assemblages of these species. Current habitat conditions bear little resemblance to those under which native fish communities evolved, reflecting the effects of two general periods of significant human disturbance:

- early agricultural conversion of floodplains and valley-bottoms, and smaller-scale streamflow regulation (e.g., Mendota Dam, Sack Dam).
- more recent and significant flow regulation and diversion associated with the Central Valley Project (e.g., Friant Dam and the Delta-Mendota Canal) and large-scale aggregate mining in Reach 1.

Fish assemblages currently found in the San Joaquin River are the result of substantial changes to their physical environment, combined with more than a century of non-native fish and exotic invertebrate introductions. Areas where unique and highly endemic fish assemblages once occurred are now inhabited by assemblages composed primarily of introduced species. The primary environmental conditions that currently influence native fish species abundance and distribution (and frequently favor non-native species) include:

- dewatered stream reaches,
- highly altered flow regimes and substantial reductions in flow,
- substantial reductions in the frequency, magnitude, and duration of floodplain inundation,
- isolation of floodplains from the river channel by channelization and levee construction,
- changes to sediment supply and transport,
- habitat fragmentation by physical barriers,
- creation of false migration pathways by flow diversions,
- poor water quality.

Despite these conditions, many native fish species still persist in the basin, underscoring the potential for enhancing native aquatic communities in the San Joaquin River.

7.2. OBJECTIVES

Fish populations in the San Joaquin River and its tributaries are a central focus of restoration efforts. The objective of this chapter is to provide background information useful for developing appropriate restoration strategies for the San Joaquin River downstream of Friant Dam. Because of the large amount of information available, we have focused on the most up-to-date and pertinent information on fish and fish habitats in the San Joaquin River, with a particular focus on anadromous salmonid species. Native fish populations and their habitats are dependent on many of the fluvial geomorphic processes that govern river ecosystems, as well as interactions with the riparian and terrestrial communities. This chapter attempts to describe the linkages with other chapters, particularly hydrology (Chapter 2), geomorphology (Chapter 3), and vegetation communities (Chapter 8). This chapter includes the following:

- A description of historical and current fish assemblages occurring in the San Joaquin River, including their general habitat requirements, changes in distribution and abundance, and the primary reasons for changes in fish assemblages that have occurred;
- Summaries of the life histories and habitat requirements of native anadromous salmonids and selected native non-salmonid fish species;
- A description of current and existing conditions, and major changes that have occurred to components of fish habitat, including instream flows, fluvial processes and channel morphology, water quality, etc;
- A description of the non-native fish species currently present in the system, along with summaries of selected non-native fish species believed to strongly interact with native species; and,
- An evaluation of how native fish populations have responded to anthropogenic changes in riverine habitats.

7.3. STUDY AREA

The study area focuses on the San Joaquin River from Friant Dam downstream to the Merced River; however, historical and current fish assemblage distributions transcended these boundaries, and included not only the broader San Joaquin and Tulare basins, but also the Sacramento River basin and the Bay-Delta ecosystem as well. This factor complicates the task of describing fish species distributions, but allows use of a much larger amount of information about individual species' life histories and habitat requirements.

7.4. CENTRAL VALLEY FISH ASSEMBLAGES

7.4.1. Historical Distribution and Species Composition

Moyle (2002) has recently updated an earlier work (Moyle 1976) that describes the fish fauna of California and their ecology. The following summary draws heavily from Moyle's extensive research on Central Valley ichthyofauna.

The Central Valley forms a subprovince of the Sacramento-San Joaquin ichthyological province (Moyle 2002). The endemic fish fauna of the Central Valley appear to have evolved from a relatively limited number of ancestral species of complex origins. It appears that only a small number of species were able to invade the system from the interior before the rise of the present Sierra Nevada range, or perhaps only a small number of forms were able to survive the harsh climatic conditions during or after the Pleistocene (Moyle 1976). Fossil evidence indicates that the Sacramento-San Joaquin fish fauna was considerably more diverse in the early Pleistocene when conditions were wetter (Casteel 1978, cited in Moyle et al. 1982). The Central Valley subprovince has been an important center of fish speciation in California because of its large size, diverse habitats, and long isolation from other systems (10–17 million years [Minckley et al. 1986, as cited in Moyle 2002]). Many species within the Sacramento-San Joaquin province are endemic to the Central Valley, as shown in Table 7-1. Appendix B consists of summaries of the life histories and habitat requirements of most native and non-native fish species known to occur in the San Joaquin River.

Moyle (1976, 2002) has described the following four fish assemblages for the Central Valley:

- Rainbow trout assemblage,
- California roach assemblage,
- Pikeminnow-hardhead-sucker assemblage, and
- Deep-bodied fish assemblage.

These assemblages are naturally separated to some degree by elevation. The first three assemblages generally inhabit reaches flowing through high and mid-elevation mountains and foothills. The fourth assemblage previously occupied San Joaquin and Sacramento valley floor reaches, lakes, and floodplain habitats, but native fish species in this assemblage are now extinct (e.g., thicktail chub), extirpated (e.g., Sacramento perch), or are substantially reduced in abundance and distribution because of the drastic changes that have occurred in these ecosystems (Moyle 2002). The habitats once occupied by this assemblage are now inhabited primarily by non-native fish species. Table 7-1 lists the fish native to the San Joaquin River and the assemblages to which they belong. These assemblages are described in more detail below.

7.4.1.1. Rainbow Trout Assemblage

The higher gradient, upper reaches of the San Joaquin River (upstream of Reach 1) flow out of the Sierra Nevada Range and historically supported fish adapted to swift water velocities, high gradient habitats such as riffles, cold temperatures (<70°F), and high dissolved oxygen concentrations (Moyle 2002). The rainbow trout assemblage found in these reaches included rainbow trout, Sacramento sucker, speckled dace, riffle sculpin, and California roach. These species are adapted to living in coarse substrates with dense riparian vegetation that provides cover and shade, and habitats formed by instream large woody debris. Most of these species feed on aquatic and terrestrial invertebrates, although larger trout will prey opportunistically on other fish.

7.4.1.2. California Roach Assemblage

The California roach assemblage is adapted to the low dissolved oxygen concentrations and high temperatures (<86°F) that seasonally occur in intermittent lower-foothill (89 feet to 1,470 feet elevation) tributaries to the San Joaquin River (corresponding to tributary reaches in Reach 1). The California roach is the dominant species in this assemblage, although Sacramento suckers and some cyprinids occasionally spawn in intermittent streams during the winter and spring. It is also likely that Chinook salmon and steelhead occasionally spawned in the lower reaches of some intermittent streams (Maslin et al. 1997).

7.4.1.3. Pikeminnow-Hardhead-Sucker Assemblage

The pikeminnow-hardhead-sucker assemblage historically occupied the mainstem reaches of the San Joaquin River flowing through the lower foothills (corresponding to mainstem Reach 1). Habitats within these reaches range from deep, rocky pools to wide shallow riffles. Species within this assemblage were adapted to low flows and warm water temperatures in summer, infrequent large floods and cold water temperatures in winter, and high flows of long-duration during the spring snowmelt period. The primary species in this assemblage were Sacramento pikeminnow, Sacramento

Table 7-1. Fish species found in the San Joaquin River.

Common Name (Scientific Name)	Endemic (E)[1], Resident (R) or Migratory (M)	Status [2]	Current distribution [Reach No] (Historical distribution)[4]	Assemblage[3]	Source
NATIVE SPECIES					
Acipenseridae					
White sturgeon (*Acipenser transmontanus*)	M	Rare	[?] (1–5)	PHS, RT	Brown & Moyle 1993, Schaffter 1997, as cited in Moyle 2002.
Green sturgeon (*Acipenser medirostris*)	M	Rare	[?] (?)	PHS, RT	Moyle 2002
Catostomidae					
Sacramento sucker *(Catostomus occidentalis*)	R	Widespread w/ large numbers	[1,5] (1–5)	PHS, RT, CR	Saiki 1984, Brown & Moyle 1993, CDFG 2001, Moyle 2002
Centrarchidae					
Sacramento perch (*Archoplites interruptus*)	E, R	Extirpated	(1–5)	DB	Moyle et al. 1989
Cottidae					
Prickly sculpin (*Cottus asper*)	R	Widespread in moderate numbers	[1,3,5] (1-5)	PHS	Saiki 1984, Brown & Moyle 1993, Moyle 2002
Riffle sculpin (*Cottus gulosus*)	R	Uncommon	[1] (1-?)	PHS, RT	Brown & Moyle 1993
Cyprindae					
California roach *(Lavinia symmetricus.)*	E, R	Widespread w/ moderate numbers	[??] (1–5)	CR, RT, PHS	Moyle et al. 1989, Brown & Moyle 1993
Hardhead (*Mylopharodon conocephalus*)	E, R	Depleted and declining	[1] (1–5)	PHS	Brown & Moyle 1993, Saiki 1984, Moyle et al 1989, Mayden et al. 1991 as cited in Moyle 2002
Hitch (*Lavinia exilicauda exilicauda*)	E, R	Uncommon	[2,3,5] (1–5)	DB	Saiki 1984, Moyle 2002
Sacramento blackfish (*Orthodon microlepidotus*)	E, R	Widespread in moderate numbers	[3,5] (1–5)	DB	Brown & Moyle 1993, Saiki 1984

Table 7-1. cont.

Common Name (Scientific Name)	**Endemic (E)[1], Resident (R) or Migratory (M)**	**Status [2]**	**Current distribution [Reach No] (Historical distribution)[4]**	**Assemblage[3]**	**Source**
Sacramento pikeminnow (*Ptychocheilus grandis*)	E, R	Common	[1] (1–5)	PHS, CR	Saiki 1984, Brown & Moyle 1993
Speckled dace (*Rhinichthys osculus*)	R	Likely extirpated	[?] (1–5)	PHS, RT	Moyle 2002
Sacramento splittail (*Pogonichthys macrolepidotus*)	E,M	FT	[5] (1–5)	DB	Baxter 1998, Saiki 1984; Rutter 1908 as cited in Moyle 2002
Thicktail chub (*Gila crassicauda*)	E, R	Extinct	(1–5)	DB	Brown & Moyle 1993
Embiotocidae					
Tule perch (*Hysterocarpus traski traski*)	E, R	Declining	[1,3,5] (1–5)	PHS, DB	Brown & Moyle 1993, Saiki 1984, Moyle 2002
Gasterosteidae					
Threespine stickleback (*Gasterosteus aculeatus*)	R	Uncommon	[1] (1–5)	RT, PHS	Saiki 1984, Moyle 2002
Petromyzontidae					
Kern brook lamprey (*Lampetra hubbsi*)	R	Declining	[1?] (1–5)	RT, PHS	Brown and Moyle 1993
Pacific lamprey (*Lampetra tridentata*)	M	Widespread w/ moderate numbers	[?] (1–5)	PHS	Brown & Moyle 1993, Moyle 2002
River lamprey (*Lampetra ayresi*)	M	Possibly declining	[?] (?)	PHS	Moyle 2002
Western brook lamprey (*Lampetra richardsoni*)	R	Unknown	[?] (?)	PHS	Moyle 2002
Salmonidae					
Chinook salmon *(Oncorhynchus tshawytscha)*	M		[1] (1–5)	RT	California Department of Fish and Game 1991, Yoshyama et al. 1998, Moyle 2002
Fall run		Candidate FT			
Late fall run		CSC			
Spring		ST, FT			
Winter		SE, FE			
Rainbow trout *(Oncorhynchus mykiss)*	R	Common	[1] (1)	RT	Friant Water Users Authority 1992, Brown & Moyle 1993
Steelhead (*Oncorhynchus mykiss)*	M	Likely extirpated	(1–5)	RT, PHS	Brown & Moyle 1993, McEwan 2002

Table 7-1. cont.

Common Name (Scientific Name)	Endemic (E)[1], Resident (R) or Migratory (M)	Status [2]	Current distribution [Reach No] (Historical distribution)[4]	Assemblage[3]	Source
NON – NATIVE SPECIES					
Atherinidae					
Inland silverside (*Menidia beryllina*)	R		[3,4,5]	DB	Saiki 1984
Centrarchidae					
Black crappie (*Pomoxis nigromaculatus*)	R		[1,2,3,5]	DB	Saiki 1984
Bluegill sunfish (*Lepomis macrochirus*)	R		[1,2,3,5]	DB	Saiki 1984
Green sunfish (*Lepomis cyanellus*)	R		[1,2,3,5]	DB, CR	Saiki 1984
Largemouth bass (*Micropterus salmoides*)	R		[1,2,3,5]	DB	Saiki 1984
Pumpkinseed (*Lepomis gibbosus*)	R		[5]	DB	CDFG 2001, Moyle 2002
Redear sunfish (*Lepomis microlophus*)	R		[1,2,3,5]	DB	Saiki 1984
Smallmouth bass (*Micropterus dolomieu*)	R		[?]	DB, PHS	Saiki 1984, Moyle 2002
Spotted bass (*Micropterus punctulatus*)	R		[1–5?]	DB, PHS	Moyle 2002
Warmouth (*Lepomis gulosus*)	R		[1,2,3,5]	DB	Saiki 1984
White crappie (*Pomoxis annularis*)	R		[2,3,5]	DB	Saiki 1984
Clupeidae					
American shad (*Alosa sapidissima*)	M		[?]	DB	Moyle 2002
Threadfin shad (*Dorosoma petenense*)	R		[2,3,5]	DB	Saiki 1984
Cyprinidae					
Common carp (*Cyprinus carpio*)	R		[1,2,3,5]	DB, PHS	Saiki 1984
Fathead minnow (*Pimephales promelas*)	R		[2,3,5]	DB	Saiki 1984
Goldfish (*Carassius auratus*)	R		[1,2,3,5]	DB	Saiki 1984
Golden shiner (*Notemigonus crysoleucas*)	R		[1,2,3,5]	DB	Saiki 1984
Red shiner (*Cyprinella lutrensis*)	R		[3]	DB	Saiki 1984
Ictaluridae					

Table 7-1. cont.

Common Name (Scientific Name)	Endemic (E)[1], Resident (R) or Migratory (M)	Status [2]	Current distribution [Reach No] (Historical distribution)[4]	Assemblage[3]	Source
Black bullhead (*Ameiurus melas*)	R		[1,2,3,5]	DB	Saiki 1984
Brown bullhead (*Ameiurus nebulosus*)	R		[1,2,3,5]	DB	Saiki 1984
Channel catfish (*Ictalurus punctatus*)			[2,3,5]	DB	Saiki 1984
White catfish (*Ameiurus catus*)	R		[2,3,5]	DB	Saiki 1984
Percichthyidae					
Striped bass (*Morone saxatilis*)	M		[2,3,5]	DB	Saiki 1984
Percidae					
Bigscale logperch (*Percina macrolepida*)	R		[1,2,3,5]	DB	Saiki 1984
Poeciliidae					
Mosquitofish (*Gambusia affinis*)	R		[1,2,3,5]	DB	Saiki 1984

[1] E = Endemic to the Sacramento-San Joaquin Providence

[2] SE = Endangered under California State Law
ST = Threatened under California State Law
CSC = California Species of Special Concern
FE = Endangered under Federal Law
FT = Threatened under Federal Law

[3] based on Moyle 2002
RT = Rainbow Trout
CR = California Roach
PHS = Pikeminnow, Hardhead, Sucker
DB = Deep bodied fish

[4] Historical distribution is considered to be the late 1800's prior to introductions of non-native species
? indicates unknown

sucker, and hardhead. Tule perch, speckled dace, California roach, riffle sculpin, and rainbow trout were also occasionally found in this assemblage. Anadromous Chinook salmon, steelhead, and Pacific lamprey spawned in this zone, and rearing juvenile spring-run Chinook salmon, steelhead, and lamprey were part of the assemblage.

7.4.1.4. Deep-Bodied Fish Assemblage

The deep-bodied fish assemblage generally occupied the lower gradient, valley bottom reaches of the San Joaquin River where flows were generally slower and water temperatures were higher than upstream habitats. Some of the native species in this group, such as Sacramento perch, thicktail chub, and tule perch, were adapted to warm, shallow, low-velocity backwaters with thick aquatic vegetation, while others, such as hitch, blackfish, and splittail, were adapted to large, open, sluggish mainstem river channels. Large pikeminnows and suckers were also abundant in this zone, migrating into tributaries to spawn (Moyle 2002). Adult Chinook salmon and steelhead migrated through this zone to spawn further upstream, and their juveniles passed through this zone while migrating downstream to the ocean. Extended rearing by salmonids on large floodplains likely occurred when flows in late winter or spring were high enough to inundate the floodplain for several weeks. Species in this assemblage were particularly well-adapted to the once-abundant floodplain habitat found in the valley floor. Floodplains provided refuge from high flows, productive foraging habitat, and protection from larger predaceous fish that inhabited adjacent deep-water habitats (Moyle 2002, Sommer et al. 2001). Splittail, Sacramento blackfish, and possibly thicktail chub spawned in the inundated floodplains (Moyle 2002). Moyle suggests that the huge, shallow lakes in the San Joaquin Valley (e.g., Tulare, Buena Vista, Kern Lakes) that historically drained the Kern, Tulare, Kaweah, and Kings rivers were perhaps the most productive year-round habitat for this assemblage (Moyle 2002). These lakes supported large populations of Sacramento perch, thicktail chub, Sacramento blackfish, Sacramento pikeminnow, and Sacramento suckers. Indigenous tribes and early Euro-American settlers were sustained year-round by harvesting these abundant fish (Moyle 2002).

7.4.1.5. Historical Distribution and Abundance of Anadromous Salmonids

Salmon were an important part of the cultures of many indigenous tribes living in the Central Valley; tribes in this region attained some of the highest pre-European-settlement population densities in North America (Yoshiyama 1999). In the mid-1800s, particularly during the California Gold Rush, salmon gained the attention of early European settlers, and commercial harvest of salmon in the Sacramento and San Joaquin rivers soon became one of California's major industries (Yoshiyama 1999). Excerpts from Yoshiyama et al. (1996) is provided in Appendix C, which details accounts of the historical distribution of Chinook salmon in the San Joaquin River watershed.

In the San Joaquin River, spring-run Chinook salmon historically spawned as far upstream as the present site of Mammoth Pool Reservoir (RM 322), where their upstream migration was historically blocked by a natural velocity barrier (P. Bartholomew, pers. comm., as cited in Yoshiyama et al. 1996). Fall-run Chinook salmon generally spawned lower in the watershed than spring-run Chinook salmon (CDFG 1957). The San Joaquin River historically supported large runs of spring-run Chinook salmon; CDFG (1990, as cited in Yoshiyama et al. 1996) suggested that this run was one of the largest Chinook salmon runs on any river on the Pacific Coast, with an annual escapement averaging 200,000 to 500,000 adult spawners (CDFG 1990, as cited Yoshiyama et al. 1996). Construction of Friant Dam began in 1939 and was completed in 1942, which blocked access to upstream habitat. Nevertheless, runs of 30,000 to 56,000 spring-run Chinook salmon were reported in the years after Friant Dam was constructed, with salmon holding in the pools and spawning in riffles downstream of the dam. Friant Dam began filling in 1944, and in the late 1940s began to divert increasing amounts of water into canals to support agriculture. Flows into the mainstem San Joaquin River were reduced to a point that river ran dry in the vicinity of Gravelly Ford. By 1950, the entire run of spring-run Chinook salmon was extirpated from the San Joaquin River (Fry 1961).

Although the San Joaquin River also supported a fall-run Chinook salmon run, they historically composed a smaller portion of the river's salmon runs (Moyle 2002). By the 1920s, reduced autumn flows in the mainstem San Joaquin River nearly eliminated the fall-run, although a small run did persist.

Steelhead are believed to have been historically abundant in the San Joaquin River, although little detailed information on their distribution and abundance is available (McEwan 2001). In large river systems where steelhead still occur, they are almost always distributed higher in a watershed than Chinook salmon (Voight and Gale 1998, as cited in McEwan 2001, Yoshiyama et al. 1996). Therefore, steelhead would likely have spawned at least as far upstream as the natural barrier located at the present-day site of Mammoth Pool (RM 322), and in the upper reaches of San Joaquin River tributaries.

7.4.2. Current Distribution and Species Composition

Anthropogenic activities have substantially changed aquatic habitats in the San Joaquin River (Table 7-2), and these habitat changes have altered the distribution and species composition of the native fish assemblages compared to historical conditions. Several factors have contributed to these changes, including flow regulation, levees, and colonization by non-native fish species. Of the 19 native fish species historically present in the San Joaquin River, 14 are now uncommon, rare, or extinct (Table 7-1), and an entire fish assemblage—the deep-bodied fish assemblage—has been largely replaced by warmwater fish assemblages composed of non-native fish species (Moyle 2002). Warmwater fish assemblages, composed of many non-native species such as black bass (*Micropterus* spp.) and sunfish (*Lepomis* spp.), appear better adapted to current, disturbed habitat conditions than native assemblages. However, habitat conditions in Reach 1 (slightly higher gradient, cooler water temperatures, and higher water velocities), seems to have restricted many introduced species from colonizing the upstream reach.

7.4.2.1. Rainbow Trout Assemblage

Distribution of the rainbow trout assemblage has increased in the Central Valley as a result of extensive introduction of hatchery trout in small mountain streams and lakes throughout the area. CDFG supplements rainbow trout populations in the San Joaquin River through its hatchery located near Lost Lake Park (RM 266). Interbreeding between native and hatchery rainbow trout stocks has likely reduced the genetic integrity of some native rainbow trout populations. Species composition within the assemblage has also changed as a result of brook and brown trout introductions. Interspecific competition with non-native brook and brown trout may have also reduced the abundance and distribution of native rainbow trout, sculpin, and dace (Moyle 2002). The cold, high-water-velocity conditions found in the reaches immediately below Friant Dam provides suitable habitat for the rainbow trout assemblage.

7.4.2.2. California Roach Assemblage

The California roach assemblage continues to be found in small, intermittent streams in the San Joaquin River, though its distribution is not well known. Green sunfish and mosquitofish appear to have largely replaced California roach in many tributaries (Moyle 2002), particularly in the upper San Joaquin River (corresponding to Reaches 1 and 2) where streams have been diverted and water temperatures have been altered.

Table 7-2. Major human activities affecting the San Joaquin River above the confluence with the Merced River prior to 1941

Year	Human Activity
1849	Gold Rush began
1860s	Agricultural colonies established
1870	Railroad constructed to Modesto
1870–1900	Nonnative fish introduced to California waters: smallmouth and largemouth bass, white catfish, brown bullhead, black bullhead channel catfish, carp, bluegill, green sunfish, white crappie, black crappie, striped bass, American shad
1871	Mendota Dam constructed
1872	Miller-Lux Canal constructed
1872	Railroad to Bakersfield
1880s	Artesian wells used for agriculture in San Joaquin Valley
1890s	Electric and natural gas pumps installed in the San Joaquin Valley
1892	Railroad constructed to Fresno
?	Sack Dam
After 1900	Nonnative fish introduced to California waters: readear sunfish, pumpkinseed, spotted bass, inland silversides, mosquitofish, golden shiner, spotted bass.
1910	5,000 electric or gas pumps on wells
1910	Bass Lake Reservoir
1915–1930	Local levee and flood control projects began
1916	Mendota Dam upgraded
1916–1920	Construction of James Bypass (Fresno Slough)
1917	Hunnington Lake Reservoir
1920	Kerckhoff Reservoir
1920-1930	Drains installed in more than 5,000 farms
1926	Florence Lake Reservoir
1930	23,500 electric or gas pumps on wells in the San Joaquin Valley
1941	Friant Dam and Millerton Lake Reservoir
1948	Friant-Kern Canal completed
1949	Temporary fish barrier erected above confluence with Merced River
1951	Delta-Mendota Canal completed
1989	Fish barrier re-erected above confluence with Merced River

7.4.2.3. Pikeminnow-Hardhead-Sucker Assemblage

The pikeminnow-hardhead-sucker assemblage is still present in the mainstem San Joaquin River downstream of Friant Dam; however, Chinook salmon and steelhead no longer spawn and rear in these reaches because flows downstream of Friant Dam are currently inadequate to support these species. Anthropogenic changes such as flow regulation, in-channel aggregate mining, channelization, agricultural land conversion, and levee construction have increased water temperatures and reduced water quality and habitat complexity, altering the distribution and species composition of the assemblage (Brown and Moyle 1992). The distribution of this assemblage has shifted upstream as a result of reduced instream flows and increased water temperatures, and tends to fluctuate based on flow and water temperature. Brown (2000) suggested that the downstream distribution of the pikeminnow-hardhead-sucker assemblage will continue to fluctuate with flow regime, extending further downstream during periods of high flows when the influence of cold water extends further downstream.

The native fishes of this assemblage are adapted to seasonal high flows and an extended period of cool water temperatures (Moyle 2002). Non-native fish species generally become abundant in the lower foothills (e.g., Reach 1) only where flow regimes have been stabilized and these seasonal fluctuations are largely reduced, such as downstream of Friant Dam. In general, smallmouth bass and green sunfish may be particularly abundant in zones occupied by the pikeminnow-hardhead-sucker assemblage; however, they rarely establish populations of any size where gradients are moderate to high and semi-undisturbed habitats remain (Moyle et al. 1982). The large pools, created by commercial aggregate mining in Reach 1, may provide the low-velocity, warmwater habitat that support the establishment of sizeable populations of non-native fish species in an area that would normally support the native fish of the pikemnnow-hardhead-sucker assemblage.

7.4.2.4. Deep-Bodied Fish Assemblage

The deep-bodied fish assemblage that once occupied aquatic habitats in the San Joaquin valley has been largely eliminated by (1) isolation of the channel from its floodplain by levee construction, (2) flow reductions and stabilization of flow regimes, (3) changes in channel morphology, including extensive channelization, and (4) poor water quality (Moyle 2002). The vast floodplains, huge shallow lakes, and wetlands that once covered the San Joaquin valley floor are greatly diminished, with most water now flowing through substantially modified channels and canals. The native fishes of this assemblage are extinct (thicktail chub), have been extirpated (e.g., Sacramento perch), or reduced to a few small populations. The current fish assemblage occupying valley-floor habitats is dominated by non-native species, including largemouth bass, white and black crappie, bluegill, redear sunfish, warmouth, threadfin shad, striped bass, bigscale logperch, red shiner, inland silverside, channel and white catfish, black and brown bullhead, common carp, and goldfish. These non-native fish often feed on non-native invertebrates such as *Corbicula* clams and crayfish, and use non-native aquatic vegetation as cover (Moyle 2002). As environmental conditions in the lower San Joaquin River continue to change, the species composition of this low-elevation fish assemblage will likely continue to change as well (Moyle 2002).

7.4.2.5. Changes in the Abundance and Distribution of Anadromous Salmonids

The historical abundance and distribution of anadromous salmonids is discussed in 7.4.1.5, and historical abundance of Chinook salmon is summarized in Appendix C. Anadromous salmonids have been extirpated from the mainstem San Joaquin River due principally to dewatering of stream channels. Construction of Mendota Dam in 1898, and a seasonal dam near Dos Palos (Sack Dam) in the early 1900s, created almost complete barriers to the upstream migration of fall-run Chinook salmon in the San Joaquin River (Warner 1991). By the early 1920s, flows in the mainstem San Joaquin River were reduced significantly by diversions at Mendota Dam (RM 205) and Sack Dam (RM 182). In general, fall-run Chinook salmon were greatly reduced in the mainstem San Joaquin River by the late 1920s due to commercial harvest and reduced fall flows from water diversions (Clark 1929, as cited in Yoshiyama et al. 1996). Runs of fall-run Chinook salmon are still present in the major tributaries to the lower San Joaquin River (Merced, Tuolumne, and Stanislaus rivers), supported in part by hatchery stock in the Merced River. The total average annual escapement (1950-2000) was an estimated 18,000 adult spawners. Since 1950, the fall-run in the San Joaquin basin has fluctuated widely, (see Figure 7-1), with a distinct periodicity that generally corresponds to periods of drought and wet conditions. During the last decade (1990-2000), escapements have ranged from 590 (1991) to 37,500 (2000). This periodicity was to some degree natural under unimpaired conditions, but has been exacerbated by the severity of streamflow regulation in the San Joaquin River and its tributaries during prolonged droughts (EA Engineering 1991). For example, following the drought of 1987-92, the total combined Chinook salmon run in the San Joaquin basin tributaries fell to 660, 590, and 1,370 in 1990–92, respectively. These population crashes aremay represent a major impediment to future restoration. Efforts are underway (e.g., VAMP) to coordinate water management among the downstream tributaries to the San Joaquin River to avoid the population crashes and encourage a more stable and robust population.

Spring-run Chinook salmon migrated upstream during higher flows fed by spring snowmelt runoff, so that Mendota and Sack Dams posed less of a barrier to migration. Consequently spring-run Chinook salmon remained relatively abundant in the mainstem San Joaquin River into the 1940s, when the construction and operation of Friant Dam began to take a toll on the spring run population by blocking access to upstream habitats and reducing flows downstream of the dam. These two effects were likely the largest factors contributing to the decline of Chinook salmon in the upper San Joaquin River (Brown and Moyle 1992). After closure of Friant Dam in November 1941, spring-run Chinook salmon and a few fall-run Chinook salmon continued to spawn below the Dam, including a run of 56,000 spring-run Chinook salmon observed in 1948 (Fry 1961). However, irrigation diversions increased in 1948 following completion of the Delta-Mendota Canal, and the juvenile salmonids resulting from the run in 1948 were stranded in the reach between Sack Dam and the mouth of the Merced River during their outmigration, as flow continuity was disrupted. By 1950, diversions at Friant Dam consistently eliminated surface water flow over a span of about 60 miles of river downstream of Sack Dam. The last real run of spring-run Chinook salmon in the upper San Joaquin River, consisting of only 36 individuals, was observed in 1950 (Warner 1991). Since the 1950's, the remaining Chinook salmon in the San Joaquin Basin consists only of fall-run Chinook salmon populations in the three tributaries to the lower San Joaquin River. Escapement data for these fall-run salmon populations is provided in Figure 7-1.

The Department of Fish and Game currently operates an artificial fish barrier on the San Joaquin River to direct fish into the Merced River, so as to prevent adult stranding in the upper San Joaquin River. Despite the barrier, fall-run Chinook salmon occasionally stray up the San Joaquin River, especially during wet years. Although data is limited, California Fish and Game (1991, as cited in Brown 1996) reported that 2,300 fall-run Chinook salmon of Merced River origin strayed up the San Joaquin River during 1988, 322 in 1989, and 280 in 1990. Each of these years was relatively dry; it is likely that more adult fall-run Chinook salmon would attempt to stray upstream during wet years. More detailed information on Chinook salmon distribution changes and population trends is provided in the species accounts contained in Appendix B.

Steelhead abundance and distribution in the San Joaquin River basin have been substantially reduced, and the native run is considered extinct by some researchers (Reynolds et al. 1990, as cited in

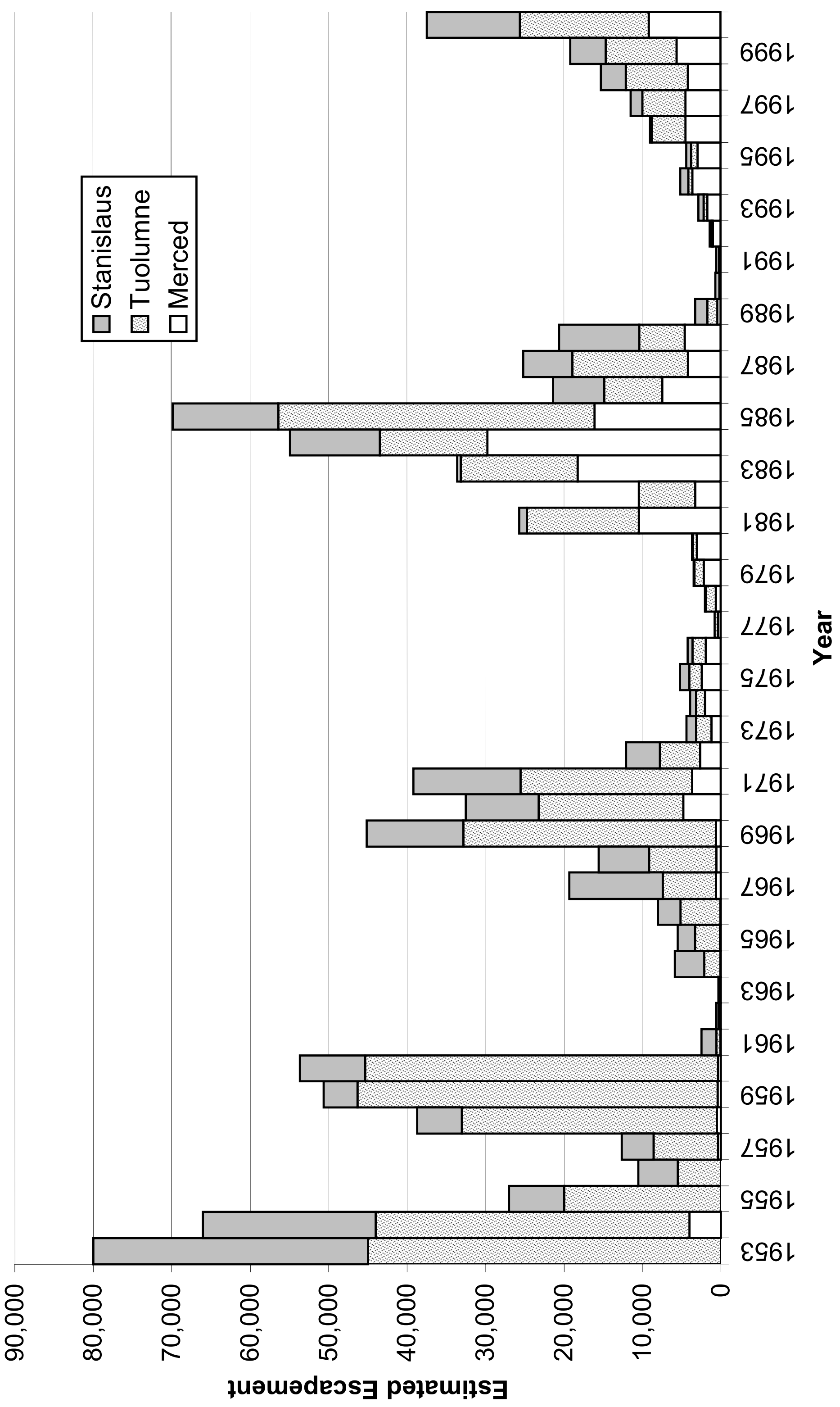


Figure 7-1. Fall-run Chinook salmon escapement into San Joaquin basin tributaries 1953 to 2000.

McEwan 2001). There is evidence of steelhead smolts in some lower San Joaquin River tributaries such as the Stanislaus River (McEwan 2001). Based on their review of factors contributing to steelhead declines in the Central Valley, McEwan and Jackson (1996) concluded that population declines were related to water development and flow management that resulted in habitat loss. Dams have blocked access to historical spawning and rearing habitat in upstream reaches, forcing steelhead to spawn and rear in lower river reaches where water temperatures are often lethal (Yoshiyama et al. 1996, McEwan 2001). More detailed information on steelhead distribution changes and population trends is provided in the species accounts contained in Appendix B.

7.5. SALMONID LIFE HISTORIES AND HABITAT REQUIREMENTS

7.5.1. Overview

Chinook salmon and steelhead are anadromous species that utilize freshwater rivers and tributaries for adult spawning, egg incubation, and early juvenile rearing. Juveniles migrate downstream after variable periods of rearing. Salmon and steelhead spend from 1 to 6 years in the ocean foraging in coastal and offshore habitats in the Pacific Ocean. Chinook salmon are semelparous (spawn once and die), and steelhead are iteroparous (capable of multiple spawning).

Chinook salmon and steelhead have genetically distinct runs differentiated by the timing of spawning migration, stage of sexual maturity when entering fresh water, timing of juvenile or smolt outmigration, and other characteristics (Moyle et al. 1989). Spring-run Chinook salmon adults migrate upstream in the spring during spring snowmelt floods, when the more sustained higher flows enable them to access upper reaches of a basin (Figure 7-2). During the summer, they reduce metabolic demands and become sexually mature while holding in deep pools, and then they spawn in the early fall. According to Healy (1991) juvenile spring-run Chinook salmon generally spend one or more years rearing in freshwater before migrating to the sea. Studies in the Sacramento River system have observed downstream movement of fry and subyearling smolts in addition to age 1+ smolts (Hill and Weber 1999). For the ocean phase of their life, spring-run Chinook salmon perform extensive offshore migrations, eventually returning to their natal river to spawn as two, three, four, and occasionally five year olds, (spring-run Chinook salmon are also referred to as “stream-type” Chinook salmon).

Fall (or “ocean-type”) Chinook salmon adults in the San Joaquin migrate upstream during the fall to return to their natal river a few days or weeks before spawning, which typically peaks in mid-November (Figure 7-3). Juveniles outmigrate to sea during their first year of life, typically within three months after their emergence from redds. Adult fall-run Chinook salmon in California streams spend most of their ocean life in coastal waters, before returning to their natal streams to spawn as two, three, four and five year olds.

Steelhead exhibit highly variable life history patterns throughout their range, but they are broadly categorized into winter- and summer-runs based on timing of upstream migration. Currently, only winter steelhead stocks are present in Central Valley streams (McEwan and Jackson 1996). They enter spawning streams in fall or winter, and they spawn soon after in winter or spring (Meehan and Bjornn 1991, Behnke 1992) (Figure 7-4). Adults may return to the ocean after spawning and return to freshwater to spawn in subsequent years. Juveniles remain in freshwater for 1 to 3 years before outmigrating to the ocean from April through June (Hopelain 1998, as cited in Moyle 2002).

The following section provides a general summary of salmonid life histories, with specific information on San Joaquin River populations where possible. Detailed habitat requirements and timing of specific life history events for Chinook salmon and steelhead, with a focus on San Joaquin River data, are provided in Appendix B.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Adults enter the rivers			▒	▒	▒								Geographic area: California rivers Enter estuaries March through May (Marcotte 1984). Source of data not stated.
Upstream Migration				▒	█▒	▒							Geographic area: San Joaquin River In San Joaquin River fish passed the Merced between mid-April and mid-June, and usually peaked there in the first half of May, and peaked at Mendota pool in early June (Hallock and Van Woert 1959). Source of data not stated
Upstream Migration					▒	▒	▒						Geographic area: San Joaquin River Fish ascend river during May, June, and the first part of July (CFGC 1921). Source of data is personal observation.
Upstream Migration			▒	▒	▒								Geographic area: San Joaquin River March to May in the San Joaquin River (Hatton and Clark 1942). Based on data from the Mendota weir.
Upstream Migration					▒	▒							Geographic area: Sacramento River Ascend rivers in May and June (Rutter 1908). Which rivers, and source of data not stated. Upstream migration has been observed to be bi-modal in the Sacramento River (Fisher, pers. comm., as cited in Marcotte 1984) with a portion of the run migrating to or near spawning areas while the remaining fish hold downstream (where in the river was not stated) and move up in the summer.
Upstream Migration			▒	▒	▒█	▒							Geographic area: Sacramento River basin, Deer and Mill Creeks Migrate up Deer and Mill Creeks from March through June (Vogel 1987a and b, as cited in Moyle et al. 1995). Source of data not stated In 1941 adults were trapped at a weir in Deer Creek from April to July 6 (Parker and Hanson 1944). Migration peaks in late May in Mill Creek. Migration into rivers earlier in southern tributaries and later in northern tributaries (Colleen Harvey, CFG, pers. comm.. 2002). Data based on personal observations in Mill Creek.
Upstream Migration		▒	▒	▒									Geographic area: Sacramento River basin, Butte Creek Entered Butte Creek in February through April (Yoshiyma et al. 1996). Source of data not stated.
Upstream Migration					▒	▒							Geographic area: Sacramento River basin, Feather River Enter Feather River in May or June (Yoshiyma et al. 1996). Hatchery influenced population. Source of data not stated.

Figure 7-2. Spring-run Chinook salmon life history.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration			▒	▒	▓	▓	▒						Geographic area: Sacramento River basin March through July, peaking in May–June (Fisher 1994). Source of data not stated.
Upstream Migration			▒	▒	▒	▒	▒	▒	▒				Jones and Stokes, Foundation Runs Report Geographic area: not stated Migrate to natal streams March through September (USFWS 1995). Source of data not stated.
Adult Holding				▒	▒	▒	◧						Geographic area: San Joaquin River River Congregate in large pools near Friant from May through mid-July (CFGC 1921), and then spawn in gorge upstream. Source of data is personal observation. Fish observed holding on May 23, 1942 in the pool directly below the Friant Dam (Clark 1942). No visits were made prior to this date. Fish were continued to be observed in subsequent visits in August and September in pools downstream of the dam, and directly below the dam. It appeared that fish moved as much as 10 miles downstream from holding pools to spawn.
Adult Holding				▒	▒	▒	▒						Geographic area: Sacramento River basin, Mill Creek Holding as early as late April and early May in Mill Creek. However, no observations conducted before late April, so fish could be holding earlier. Most fish holding by July. (Colleen Harvey, CFG, pers.comm. 2002). Based on walking and dive surveys. General comment: Many spring chinook migrate from holding pools to spawning areas further upstream in the watershed, while the rest remain to spawn in the tails of the holding pools (Moyle et al. 1995). No source or location of data stated.
Adult Holding					▒	▒	◧						Jones and Stokes Foundations Runs Report Geographic area: San Joaquin River Congregate in pools after upstream migration during May to early July (Yoshiyama et al. 1998).

Figure 7-2. cont.

LIFE STAGE	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	NOTES
	MONTH												
Spawning								□░	▓▓	▓▓			Geographic area: San Joaquin River The San Joaquin River below Friant dam was surveyed for one day in late August, late September, early October, and early November of 1942. The first spawning was observed on September 21, and large numbers of fish were spawning on all the riffles observed between Friant Dam and Lanes Bridge on November 4 (Clark 1942). Clark also reports that in detailed surveys prior to dam construction 417,000 ft^2 of spawning gravel were observed between Lanes Bridge and the Kerchoff Powerhouse. He reports that 36% of this area was eliminated by construction of the Friant Dam.
Spawning									░░	░□			Geographic area: San Joaquin River Spawning took place in September and early October near Friant (Hallock and Van Woert 1959). Source of data not stated.
Spawning								□░	░░	░□			Geographic area: Sacramento River basin Spawning in Deer and Mill Creeks is in late August to mid-October (Moyle et al. 1995). Source of data not stated. Spawning in Deer Creek is usually completed by the end of September (Moyle, pers. obs., as cited in Moyle et al. 1995). Source of data not stated.
Spawning								□░	▓▓	░░			Geographic area: Sacramento River basin Spawning in Sacramento River basin from late August to October, with a peak in mid-September (Fisher 1994). Source of data not stated. Spawning in the Sacramento River basin in August (Rutter 1908). Source of data not stated.
Spawning								□░	▓▓	▓▓			Geographic area: Sacramento River basin, Deer Creek Intensive spawning observed in 1941 from the first week September through the end of October (Parker and Hanson 1944).
Spawning								░░	░░	░░			Jones and Stokes Foundation Runs Report Geographic area: not stated Spawning August through October, depending on water temperatures (USFWS 1995). Source of data not stated.
Incubation													Embryos hatch after 5-6 month incubation. Alevins remain in gravel an additional 2-3 weeks (Moyle et al. 1995). No source or location of data stated.

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Emergence	░	░	░								░	░	Geographic area: Sacramento River basin Emergence November to March in the Sacramento River basin (Fisher 1994). Source of data not stated. Emergence in Butte Creek from November to March (Ward and Reynolds 2001). Based on outmigrant trapping of recently emerged fry.
Rearing	░	░	░	░	░	░	░	░	░	░	░	░	Geographic area: Sacramento River basin Rear 3 to 15 months in the Sacramento River basin (Fisher 1994). Source of data not stated. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. Some juveniles outmigrate after hatching, and others move downstream during the following fall as yearlings (C. Harvey, pers.comm., as cited in Moyle et al. 1995). Source of data not stated.
Fry Dispersal	░	▓	░	░	░	░							Geographic area: San Joaquin River Before construction of Friant Dam outmigration occurred during major seasonal runoff. Fish and Game fyke netting in 1939 and 1940 at Mossdale demonstrated a measurable seaward movement of fingerling salmon between January and mid-June, with a peak in February (Hallock and Van Woert 1959).
Fry Dispersal		░	░	▓	░	░							Geographic area: San Joaquin River After construction of Friant Dam outmigration it appeared that the elimination of flood flows altered migration patterns. In 1948 fyke trapping at Mendota there was a fairly steady downstream migration between February and June, but the peak was not reached until April. In 1949 peaks were recorded in early March and again in mid-May (Hallock and Van Woert 1959).

Figure 7-2. cont.

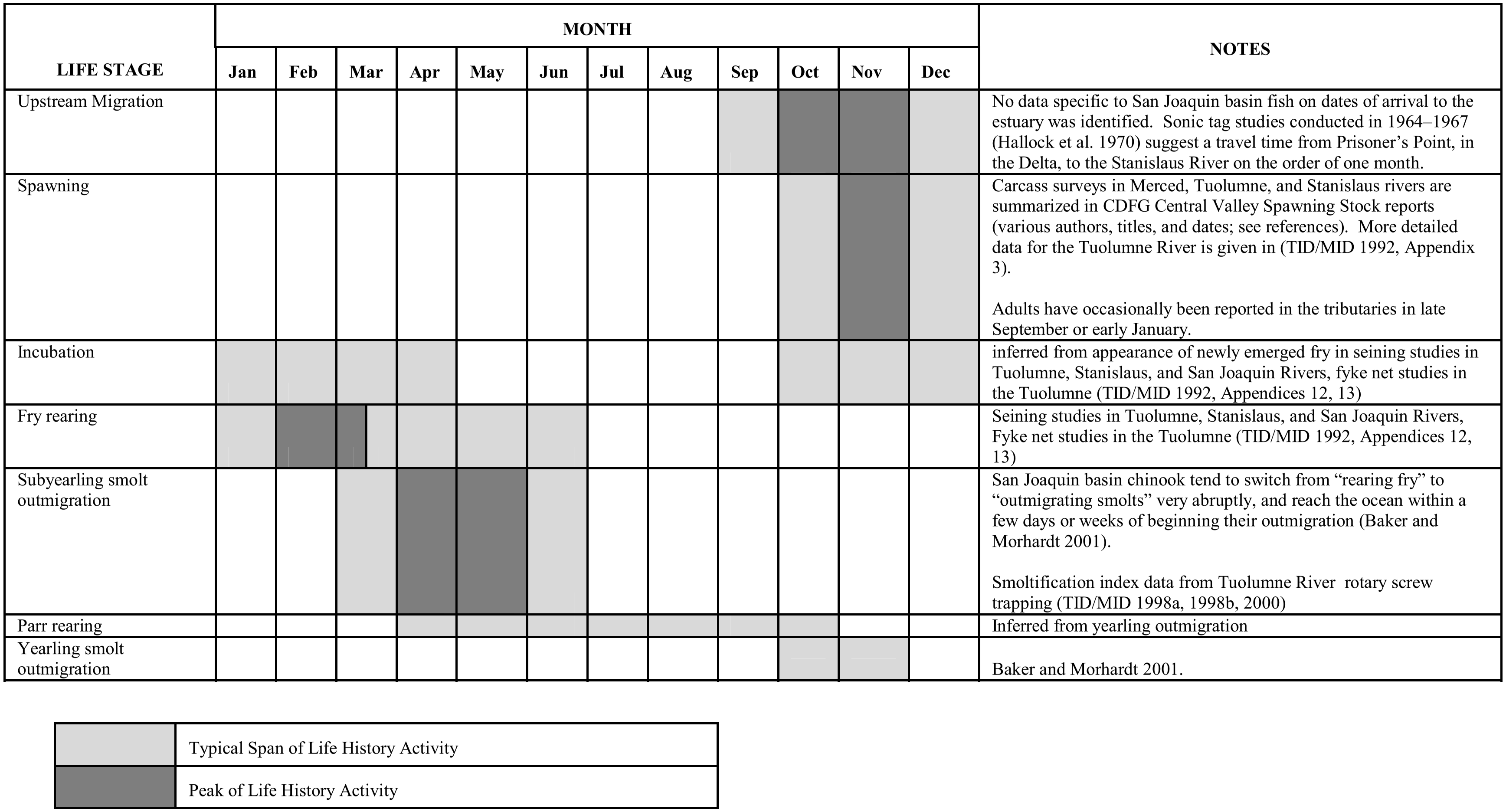
LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fry Dispersal	■	▒	▒								▒	■	Geographic area: Sacramento River basin Juveniles typically outmigrate during November through Jan. during the first high flows as subyearlings, though some stay as late as March (F.Fisher , pers. comm., as cited in USFWS 1994). Source of data not stated. Juveniles typically outmigrate as fry from Butte Creek between mid-November and mid-February, with a peak in December and January (Hill and Weber 1999, Ward and Reynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Deer and Mill Creeks juveniles typically leave the stream during their first fall, as subyearlings (Moyle et al. 1995). Source of data not stated. In the Sacramento River most downstream movement takes place December to February as parr (Vogel and Marine 1991, as cited in USFWS 1994). Source of data not stated.
Spring Smolts (subyearling)			▒	▒	▒	▒							Geographic area: Sacramento River basin Some YOY remain in Butte Creek and outmigrate in late spring or early summer (Hill and Weber 1999, Ward and Reynolds 2001). Based on outmigrant trapping during 1999 and 2000. In the Sacramento River basin ocean entry during March to June (Fisher 1994). Source of data not stated
Fall Smolts (yearling)	▒									▒	▒	▒	Geographic area: Sacramento River basin Most yearlings outmigrate from Butte Creek in October to January (Hill and Weber 1999, Ward and Reynolds 2001). Based on outmigrant trapping during 1999 and 2000. In Mill Creek some juveniles outmigrate during the following fall as yearlings (C. Harvey, pers.comm., as cited in Moyle et al. 1995). Source of data not stated.
Fall and Spring Smolts (yearling)	▒	▒	▒	▒							▒	▒	Geographic area: Sacramento River basin Ocean entry from November to April (Fisher 1994). Source of data not stated.
Spring Smolts (subyearling)				▒	▒	▒							Jones and Stokes Foundation Runs Report Geographic area: not stated May rear in freshwater for 3 to 8 months, migrating to the ocean during spring (Raleigh 1986, Moyle 1976).

Figure 7-2. cont.

LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Fall Smolts (yearlings)										░	░	░	Jones and Stokes Foundation Runs Report Geographic area: not stated Frequently rear over the summer and migrate to the ocean from October to December, after 12-14 months in freshwater (no source cited).
Juveniles enter the ocean					░								Moyle et al. (1995) “presumes” that all fish have left the Sacramento basin by mid-may. No source of data stated.

░	Span of Life History Activity
▓	Peak of Life History Activity

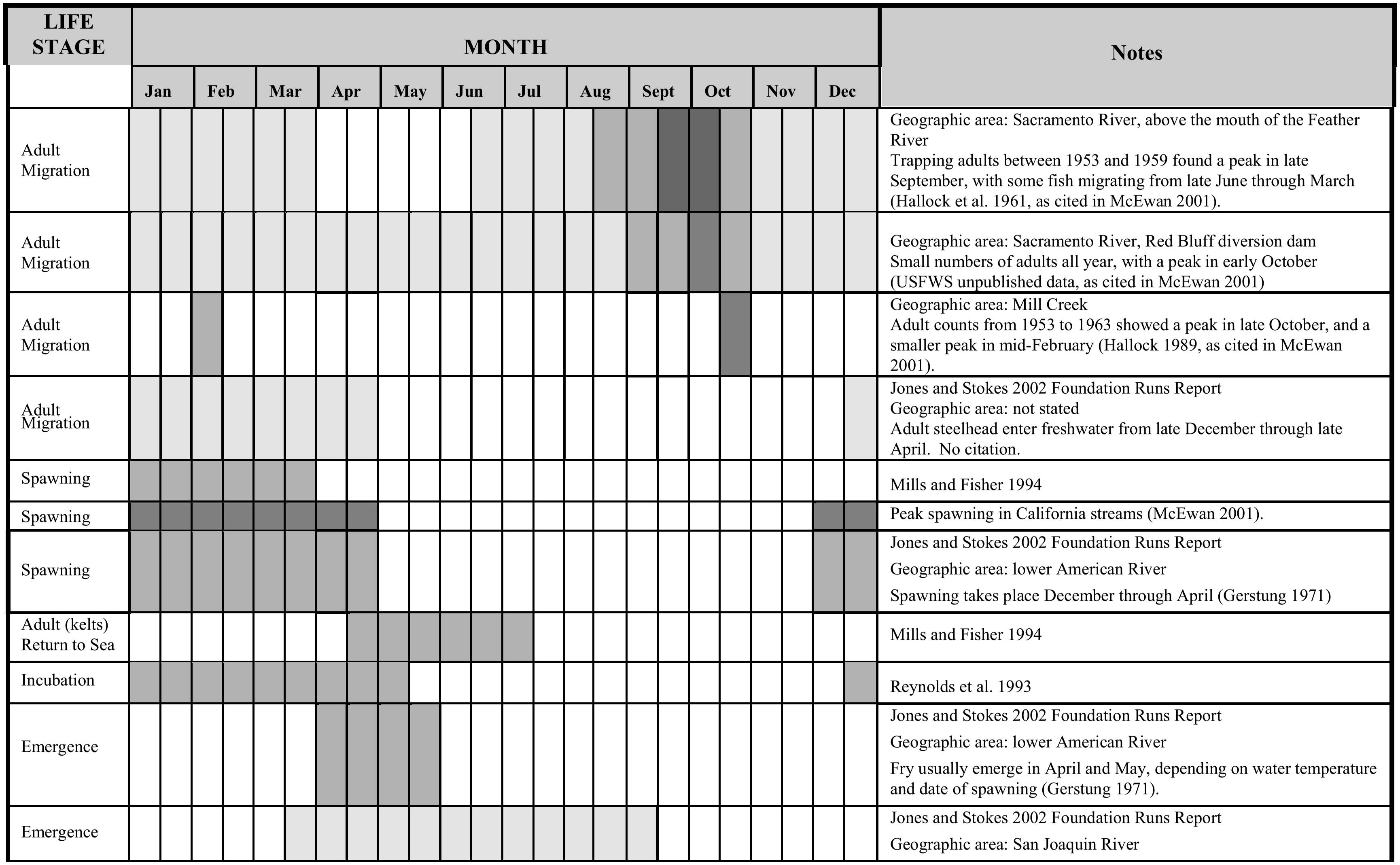
Figure 7-2. cont.



LIFE STAGE	MONTH												NOTES
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Upstream Migration									░	▓	▓	░	No data specific to San Joaquin basin fish on dates of arrival to the estuary was identified. Sonic tag studies conducted in 1964–1967 (Hallock et al. 1970) suggest a travel time from Prisoner's Point, in the Delta, to the Stanislaus River on the order of one month.
Spawning										░	▓	░	Carcass surveys in Merced, Tuolumne, and Stanislaus rivers are summarized in CDFG Central Valley Spawning Stock reports (various authors, titles, and dates; see references). More detailed data for the Tuolumne River is given in (TID/MID 1992, Appendix 3). Adults have occasionally been reported in the tributaries in late September or early January.
Incubation	░	░	░	░						░	░	░	inferred from appearance of newly emerged fry in seining studies in Tuolumne, Stanislaus, and San Joaquin Rivers, fyke net studies in the Tuolumne (TID/MID 1992, Appendices 12, 13)
Fry rearing	░	▓	▓░	░	░	░							Seining studies in Tuolumne, Stanislaus, and San Joaquin Rivers, Fyke net studies in the Tuolumne (TID/MID 1992, Appendices 12, 13)
Subyearling smolt outmigration			░	▓	▓	░							San Joaquin basin chinook tend to switch from "rearing fry" to "outmigrating smolts" very abruptly, and reach the ocean within a few days or weeks of beginning their outmigration (Baker and Morhardt 2001). Smoltification index data from Tuolumne River rotary screw trapping (TID/MID 1998a, 1998b, 2000)
Parr rearing				░	░	░	░	░	░	░			Inferred from yearling outmigration
Yearling smolt outmigration										░	░		Baker and Morhardt 2001.

░	Typical Span of Life History Activity
▓	Peak of Life History Activity

Figure 7-3. Fall-run Chinook salmon life history.



LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Adult Migration	░	░	░	░	░	░						░	░	░	░	▒	▒	█	█	▒	░	░	░	░	Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░	Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration			▒																	▓					Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░																░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning	▒	▒	▒	▒	▒	▒																			Mills and Fisher 1994
Spawning	▓	▓	▓	▓	▓	▓	▓	▓															▓	▓	Peak spawning in California streams (McEwan 2001).
Spawning	▒	▒	▒	▒	▒	▒	▒	▒															▒	▒	Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea								▒	▒	▒	▒	▒	▒												Mills and Fisher 1994
Incubation	▒	▒	▒	▒	▒	▒	▒	▒	▒															▒	Reynolds et al. 1993
Emergence							▒	▒	▒	▒															Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).
Emergence						░	░	░	░	░	░	░	░	░	░	░									Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River

Figure 7-4. Winter-run Steelhead life history.

LIFE STAGE	MONTH																								Notes
	Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sept		Oct		Nov		Dec		
Adult Migration	░	░	░	░	░	░						░	░	░	░	▒	▒	█	█	▒	░	░	░	░	Geographic area: Sacramento River, above the mouth of the Feather River Trapping adults between 1953 and 1959 found a peak in late September, with some fish migrating from late June through March (Hallock et al. 1961, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	░	▒	▒	▓	▒	░	░	░	░	Geographic area: Sacramento River, Red Bluff diversion dam Small numbers of adults all year, with a peak in early October (USFWS unpublished data, as cited in McEwan 2001)
Adult Migration			▒																	▓					Geographic area: Mill Creek Adult counts from 1953 to 1963 showed a peak in late October, and a smaller peak in mid-February (Hallock 1989, as cited in McEwan 2001).
Adult Migration	░	░	░	░	░	░	░	░																░	Jones and Stokes 2002 Foundation Runs Report Geographic area: not stated Adult steelhead enter freshwater from late December through late April. No citation.
Spawning	▒	▒	▒	▒	▒	▒																			Mills and Fisher 1994
Spawning	▓	▓	▓	▓	▓	▓	▓	▓															▓	▓	Peak spawning in California streams (McEwan 2001).
Spawning	▒	▒	▒	▒	▒	▒	▒	▒															▒	▒	Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Spawning takes place December through April (Gerstung 1971)
Adult (kelts) Return to Sea								▒	▒	▒	▒	▒	▒												Mills and Fisher 1994
Incubation	▒	▒	▒	▒	▒	▒	▒	▒	▒															▒	Reynolds et al. 1993
Emergence							▒	▒	▒	▒															Jones and Stokes 2002 Foundation Runs Report Geographic area: lower American River Fry usually emerge in April and May, depending on water temperature and date of spawning (Gerstung 1971).
Emergence						░	░	░	░	░	░	░	░	░	░	░									Jones and Stokes 2002 Foundation Runs Report Geographic area: San Joaquin River

Figure 7-4. cont.

7.5.2. Upstream Migration

Adult salmon can navigate hundreds of mile of inland rivers to migrate from the ocean to their natal streams to spawn (although a small percentage may stray into other streams, especially during high water years). In the Sacramento system (the closest population of spring-run Chinook salmon to the San Joaquin River), adult spring-run Chinook salmon typically return to fresh water between March and May (Marcotte 1984). In the San Joaquin basin, fall-run Chinook salmon typically return between October and December (EA Engineering 1991a). Steelhead in the Sacramento River generally migrate to their natal streams in fall or winter (McEwan 2001).

To successfully navigate to their natal streams, adult Chinook salmon and steelhead require sufficient flow to provide adequate water depth in stream channels and to overcome flow-related barriers. Thompson (1972, as cited in Bjornn and Reiser 1991) is commonly cited for recommending water depths greater than 0.8 feet and water velocities less than 8 ft/s for successful upstream migration of adult fall and spring-run Chinook salmon. However, other factors, such as the length of stream and percent of the wetted cross section at a particular depth and velocity, need to be considered to determine if water depth and/or velocity pose a barrier.

In 1944 and 1947, The California Department of Fish and Game (CDFG 1955) observed from 5,000 to 6,000 spring-run Chinook salmon migrating up the San Joaquin River as far as Mendota Dam in a flow that was estimated to be 100 cfs in the reach between Sack Dam and the confluence with the Merced River. CDFG observed that “many of these fish have rubbed themselves raw going over the shallow sandbars” between Sack Dam and the confluence with the Merced River (a distance of approximately 50 miles). Such abrasions can increase the risk of mortality from disease for spring-run Chinook salmon, since they must hold in pools throughout the summer before spawning. CDFG also noted that the fish were highly susceptible to poaching and temperature effects in the 100 cfs flow. In contrast, CDFG (1955) noted that during the relatively wet years of 1945 and 1946, when “the flow which passed the sack dam was entirely adequate during the period of the spring migration,” an estimated 56,000 and 30,000 fish respectively, were counted at Mendota Dam. CDFG expressed concern that if spring-run Chinook salmon were required to migrate the entire 140 miles of the San Joaquin River to spawning areas at flows near 100 cfs, then very few adults would survive to spawn.

Adult Chinook salmon appear to be less capable of upstream migration through fish ladders, culverts, and waterfalls than steelhead (Nicholas and Hankin 1989a, Table 7-3), due in part to slower swimming speeds and inferior jumping ability (Reiser and Peacock 1985; Bell 1986, as cited in Bjornn and Reiser 1991). Cruising speeds that are used primarily for long-distance travel range up to 3.3 ft/s (Bjornn and Reiser 1991). Sustained speeds, which can be maintained for several minutes, range from 3.3 ft/s to 10.8 ft/s (Bjornn and Reiser 1991). Darting speeds, which can only be sustained for a few seconds, range from 10.8 ft/s to 22.3 ft/s (Bjornn and Reiser 1991). The maximum jumping height for Chinook salmon has been calculated to be approximately 7.9 feet (Bjornn and Reiser 1991).

Table 7-3. Migration speeds and requirements for Chinook salmon and steelhead. Based on Bjornn and Reiser (1991).

Migration Abilities	Chinook salmon	Steelhead
Cruising speeds (ft/s)	0–3.3	0–5
Sustained speeds (ft/s)	3.3–10.8	5–15
Darting speeds (ft/s)	10.8–22.3	14–27
Jumping Ability (ft)	7.9	17
Required Depth for Migration (ft)	>0.8	>0.6
Required Velocity for Migration (ft/s)	<8	<8

Steelhead are among the strongest swimming freshwater fishes. Steelhead have cruising speeds up to 5 ft/s; they can sustain swimming at speeds from 5 ft/s to 15 ft/s; and they can attain darting speeds from 14 ft/s to 27 ft/s (Bell 1973, as cited in Everest et al. 1985; Roelofs 1987). Steelhead have been observed making vertical leaps of up to 17 feet over falls (W. Trush pers. comm., as cited in Roelofs 1987). Thompson (1972, as cited in Bjornn and Reiser 1991) is commonly cited for recommending water depths greater than 0.6 feet and water velocities less than 8 ft/s for successful upstream migration of steelhead.

7.5.2.1. Temperatures during upstream migration

In general, Chinook salmon and steelhead appear capable of migrating upstream under a wide range of temperatures. Bell (1986) reported that salmon and steelhead migrate upstream in water temperatures that range from 37°F to 68°F. Bell (1986) reports that temperatures ranging between 37°F and 55°F are suitable for upstream migration of spring-run Chinook salmon, and between 50 ° and 66°F for fall-run Chinook salmon. In a review of available literature, Marine (1992) reported a water temperature range of 43°–57°F as optimal for pre-spawning broodstock survival, maturation, and spawning for adult Chinook salmon.

In the San Joaquin River, spring-run Chinook salmon likely migrated during periods of relatively cold water temperatures because of high spring snowmelt runoff. Yoshiyama et al. (1996) quotes an 1853 observation of water temperature in late July that suggests unimpaired spring flows were cold. Writing of the San Joaquin River near Fort Miller in late July, 1853, Blake (1857) wrote:

> *The river was not at its highest stage at the time of our visit; but a large body of water was flowing in the channel, and it was evident that a considerable quantity of snow remained in the mountains at the sources of the river. A diurnal rise and fall of the water was constantly observed, and is, without a doubt, produced by the melting of the snow during the day. The water was remarkably pure and clear, and very cold; its temperature seldom rising above 64° Fahrenheit while that of the air varied from 99° to 104° in the shade.*

Water temperatures of 64°F in late July suggest that the spring snowmelt flood and recession produced suitably cold water temperatures in the Friant area during the expected period of spring-run Chinook salmon migration. However, there is little data to evaluate whether these adequate water temperatures continued throughout the study area.

The water temperature conditions that fall-run Chinook salmon likely encountered historically in the San Joaquin River are more difficult to conceptualize. Blake's observation of 64° F water temperatures in late July 1853 suggest that water temperatures in the vicinity of Friant were similar to water temperatures to be expected in other, more northerly river systems that support fall-run Chinook salmon. However, there is no way to determine how quickly water temperatures warmed with increasing distance downstream of Friant Dam and, therefore, the water temperatures that fall-run Chinook salmon would have been exposed to in lower reaches. Fall-run Chinook salmon in the San Joaquin River historically migrated upstream during the late summer, when water temperatures would be expected to be at their warmest. Before their extirpation, the San Joaquin population of Chinook salmon represented the southernmost extent of Chinook salmon in North America, which also suggests that the San Joaquin population experienced the warmest climatological conditions. In 1875, the California Fisheries Commission (CFC) remarked upon the apparent high water temperatures that San Joaquin Chinook salmon were able to tolerate:

> *Large numbers pass up the San Joaquin River for the purpose of spawning in July and August, swimming for one hundred and fifty miles through the hottest valley in the State, where the temperature of the air at noon is rarely less than 80° F, and often as high as 105°F, and where the average temperature of the river at the bottom is 79°F and at the surface 80°F.*

There is also limited historical temperature data, collected between 1875 and 1877, that indicates fall-run Chinook salmon may have experienced relatively high water temperatures in the San Joaquin River. The data was collected at two sites: a railroad bridge crossing in Reach 1 (near the current location of the Highway 99 bridge); and a railroad bridge crossing near Mossdale near the current location of the Hwy 120 crossing at approximately RM 50 (below Vernalis). Average monthly water temperatures during August and September at these two sites ranged between 72°F to 80.7°F, with maximum temperatures in the range of 82°F to 84°F (CFC 1877, as cited in Yoshiyama et al. 1996). The California Fisheries Commission was so impressed by the unique temperature tolerances of the San Joaquin fall-run Chinook salmon that they suggested widely transplanting the species to rivers in the eastern and southern United States (CFC 1875, as cited in Yoshiyama et al. 1996). Yoshiyama et al. (1996) also suggest that San Joaquin fall-run Chinook salmon "possibly were distinctly adapted to the demanding environmental regime of the southern Central Valley". Short-term or transient exposures to temperatures as high as 80.6°F have been reported as tolerated by adult Chinook salmon (Piper et al. 1982, Boles 1988, as cited by Marine 1992). Unfortunately, both the spring and fall run Chinook salmon have been extirpated from the upper San Joaquin River, and it is not possible to determine if actual genetic or physiological differences did exist between upper San Joaquin River populations and more northerly populations. Another explanation for their noted ability to tolerate relatively high water temperatures during upstream migration may be the historical presence of artesian springs that are known to have occurred along the lower valley floor and perhaps within the river channel, that may have provided pockets of temperature refugia during upstream migration.

More recent studies of San Joaquin basin fall-run Chinook salmon suggest that water temperatures greater than 65°F may serve as a temperature barrier, either delaying or blocking the migration of adult salmon in San Joaquin River tributaries (Hallock et al. 1970). However, there is some question about the causal relationships posited by Hallock et al. Their four years of data indicated a noticeable delay between the time the first tagged fish migrated out of the Delta into the San Joaquin River and the onset of a steady run (13 days in 1964 and 1965, 6 days in 1966 and 1967). This delay was attributed to dissolved oxygen conditions in one year (1966), and to temperature conditions in the other three years. In the three years that temperature was cited as a causal factor affecting the run timing of spawning migration, temperatures were within a few degrees Fahrenheit of one another, and in two of the three years, no temperatures were recorded at the onset of migration. There may easily have been a combination of several factors affecting the run timing, rather than temperature alone.

McEwan and Jackson (1996) suggest that adult steelhead migrate in water temperatures ranging from 46°F to 52°F. Temperatures exceeding 70°F are considered stressful (Lantz 1971, as cited in Beschta et al. 1987). Because steelhead historically migrated upstream in late-fall and winter months in the San Joaquin River, temperatures can generally be assumed to have been suitable.

7.5.3. Adult Holding

When adult spring-run Chinook salmon begin their migration to their natal streams, they are sexually immature, unable to spawn. After they arrive in their natal streams in the spring, they hold in deep pools through the summer, conserving energy until the fall when their gonads ripen and they spawn. In the Sacramento River system, adult spring-run Chinook salmon typically return to fresh water between March and May, where they hold between April and mid-July, and spawn from mid-July to September (Figure 7-2). While holding through the summer, spring-run adults minimize their activity, which is thought to lower metabolic rates and therefore conserve energy for eventual reproductive activities (NRC 1992; from Bell 1986).

To conserve energy while holding, spring-run Chinook salmon adults generally require deep pools with relatively slow water velocities. Deep pools help insulate the adults from potential solar and convectional heating of the surface water during warm summer months, and it helps them avoid predators so that they can remain relatively inactive. In addition to deep pools, instream cover (e.g., undercut banks, overhanging vegetation, boulders, large wood structure) also helps adult spring-run Chinook salmon to avoid predators. For spring-run Chinook salmon in the Sacramento River system, Marcotte (1984) reported that the suitability of holding pools declines at depths less than 8 feet. Airola and Marcotte (in prep., as cited in Marcotte 1984) found that spring-run Chinook salmon in the Deer and Antelope Creeks avoided pools less than about 6 feet. In the John Day River in Oregon, adults usually hold in pools deeper than 5 feet that contain cover from undercut banks, overhanging vegetation, boulders, or woody debris (Lindsay et al. 1986).

To conserve energy, adult spring-run Chinook salmon holding in pools require relatively slow water velocities, so that they do not have to expend energy to maintain position. For spring-run Chinook salmon in the Sacramento River system, Marcotte reported that optimal water velocities in pools range from 0.5 ft/s to 1.2 ft/s.

Fall Chinook salmon and steelhead generally do not hold in pools for long periods of time (>1 week), but they may briefly use large resting pools during upstream migration.

7.5.3.1. Temperatures During Adult Holding

Water temperatures for adult Chinook salmon holding are reportedly optimal when less than 60.8ºF, and lethal when above 80.6ºF (Moyle et al. 1995). Moyle et al. (1995) reported that spring-run Chinook salmon in the Sacramento River typically hold in pools that have temperatures below 69.8 ºF to 77ºF.

7.5.3.2. Historical Distribution of Holding Habitat

Adult spring-run Chinook salmon held in pools above Friant Dam prior to its construction (CDFG 1921, as cited in Yoshiyama et al. 1996; Appendix C), and it is likely that they held in pools as far upstream as Mammoth Pool Reservoir (Yoshiyama et al. 1996). Hatton described "long, deep pools" in the canyon above Friant (1940, as cited in Yoshiyama et al. 1996). The amount of holding and spawning habitat available to spring-run Chinook salmon was reduced around 1920, when Kerckhoff Dam "blocked the spring-run salmon from their spawning areas upstream and seasonally dried up ~14 mi of stream, below the dam, where there were pools in which the fish would have held over the summer" (CDFG 1921, as cited in Yoshiyama et al. 1996). The completion of Friant Dam in 1941 further reduced the holding and spawning habitat available to spring-run Chinook salmon by completely blocking access to upstream areas. In July of 1942, Clark (1942) observed an estimated 5,000 adult spring-run Chinook salmon holding in two large pools directly downstream of

Friant Dam. He reported that the fish appeared to be in good condition, and that they held in large, quiet schools. Flow from the dam was approximately 1,500 cfs, and water temperatures reached a maximum of 72ºF in July. Although some fish may have held in pools downstream of Lanes Bridge, Clark (1942) concluded that the abundant spawning he observed in September and October in riffles between Friant Dam and Lanes Bridge were from fish that held in the pools below the dam that had moved back downstream to spawn.

7.5.4. Spawning and Incubation

Upon arrival at the spawning grounds, adult female Chinook salmon dig shallow depressions or pits in suitably sized gravels, where they deposit eggs during the act of spawning, and then cover the fertilized eggs with additional gravel to protect the eggs. Over a period of one to several days, the female gradually enlarges the redd by digging additional pits in an upstream direction (Burner 1951, Healey 1991). By disturbing the gravel that surrounds the egg pocket, the female loosens the bed material and cleans some of the fine sediment from the gravel, thereby improving interstitial water flow. Females can remove from 2% to 15% of fine sediment smaller than 0.04 inches (<1 mm) during the redd building process, depending on the initial proportion of fines in the gravel (Kondolf 2000). Before, during, and after spawning, female Chinook salmon defend the redd area from other potential spawners (Burner 1951). Defense of a constructed redd helps to prevent subsequent spawners from constructing redds in the vicinity of an egg pocket, which can scour the eggs and increase egg mortality. Adult Chinook salmon females generally defend their redd until they die, usually within 1–2 weeks of spawning.

Most Chinook salmon spawn in the mainstem of large rivers and lower reaches of tributaries, although spawning has been observed over a broad range of stream sizes, from small tributaries 6.6 feet to 9.8 feet wide (Vronskiy 1972) to large mainstem rivers (Healey 1991). Chinook salmon generally prefer low-gradient (<3%) reaches for spawning and rearing, but will occasionally use higher-gradient areas (Kostow 1995). Spawning site (redd) locations are mostly controlled by hydraulic conditions dictated by streambed topography (Burner 1951). Chinook salmon are capable of spawning within a wide range of water depths and velocities, provided that intragravel flow is adequate (Healey 1991). The water depths most often recorded over Chinook salmon redds range from 0.4 feet to 6.5 feet and velocities from 0.5 ft/s to 3.3 ft/s, although criteria may vary between races and stream basins. For example, fall-run Chinook salmon, because of their larger size, are generally able to spawn in deeper water with higher velocities, (Healey 1991) than spring-run Chinook salmon, which tend to dig comparatively smaller redds in finer gravels (Burner 1951). Similarly, four and five year old fish are generally larger than the average three year old fish, and can spawn in deeper, faster water with larger particle size gravels and cobbles.

Chinook salmon redds are typically located in riffles, where intra-gravel flow and dissolved oxygen are relatively high. Intra-gravel flow is an important function in constructed redds, because it delivers dissolved oxygen to incubating eggs and transports metabolic wastes from the egg pocket. Intra-gravel flow is influenced by size distribution of sediment particles that compose the channel bed (Platts et al. 1979). There are interstitial spaces between individual sediment particles that allow intra-gravel flow. When the interstitial spaces between spawning gravels are filled with fine sediments, then intra-gravel flow is generally reduced. Therefore, as the percentage of fine sediment in spawning gravels increases, the egg survival-to-emergence of Chinook salmon and steelhead generally decreases (Figure 7-5). In general, in substrate with greater than 13% fines (<2 mm), steelhead and Chinook salmon have less than 50% survival to emergence, though larger substrates also influence survival (Tappel and Bjornn 1983). D_{50} values (the median diameter of substrate particles found within a redd) for Chinook salmon have been found to range from 0.4 inches to 3.1 inches (10 mm to

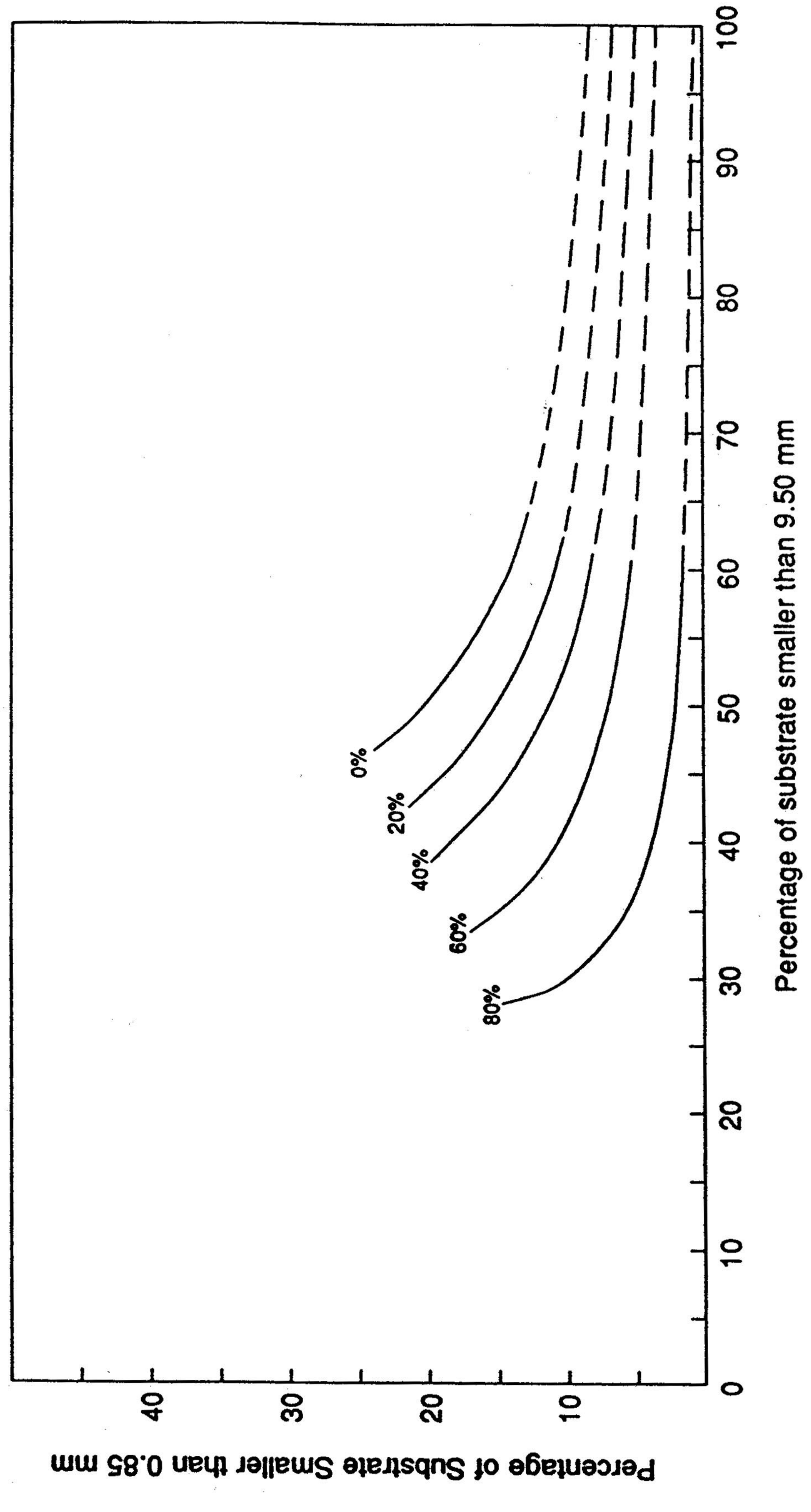


Figure 7-5. Relationship between fines (<0.085 mm) and survival to emergence. Data is from Tappel and Bjornn (1983).

80 mm) (Kondolf and Wolman 1993). Chinook salmon in the Central Valley have been observed to use spawning gravels with D_{50} values ranging from 1.2 inches to 2.6 inches (30 mm to 70 mm) (Van Woert and Smith, unpublished data 1962, as cited in Kondolf and Wolman 1993; and Kondolf and Wolman 1993).

Most steelhead spawn in the mainstem of small rivers and in tributaries. Steelhead may spawn in intermittent streams, but juveniles soon move to perennial streams after hatching (Moyle et al. 1989). Pool tailouts or heads of riffles with well-oxygenated gravels are often selected as redd locations (Shapovalov and Taft 1954). Areas of the stream with water depths from about 0.5 feet to 4.5 feet and velocities from 2.0 ft/s to 3.8 ft/s are typically preferred for spawning by adult steelhead (Moyle et al. 1989, Barnhart 1991). Steelhead generally prefer smaller spawning gravels than Chinook salmon. D_{50} values for steelhead have been found to range from 0.4 inches (10 mm) (Cederholm and Salo 1979, as cited in Kondolf and Wolman 1993) to 1.8 inches (48 mm) (Orcutt et al. 1968, as cited in Kondolf and Wolman 1993). Detailed spawning habitat requirements for each salmonid species are provided in Appendix B.

7.5.4.1. Redd Size

The number of spawning salmonids that can be supported for a given area of spawning habitat is influenced by the size of individual redds; larger redds mean fewer spawning pairs that can be accommodated. If spawning habitat is insufficient for the number of spawners that have returned to a river, then the risk of redd superimposition generally increases. Redd superimposition has been found to be an important factor affecting Chinook salmon populations in the Tuolumne River (EA Engineering 1992a), because later arriving females dig redds on top of existing redds, causing substantial mortality of the previously deposited eggs (McNeil 1964, Hayes 1987).

Published accounts of Chinook salmon redd size vary considerably, based on fish size (larger fish create larger redds), river, and habitat conditions (e.g., higher water velocities and smaller gravels can both lead to larger redds). A literature review conducted by Healey (1991) found redd size ranging from 5 ft^2 to 484 ft^2. The large variability in reported redd size is also due to differing methods or objectives between studies. Burner (1951) suggests an area of 216 ft^2 is needed for each spawning pair, but his estimate includes not only the area needed for a redd, but also the area around the redd that is defended by the female salmon. Other researchers measure just the redd itself and arrive at much smaller values. But even when just measuring the redd, there are differences in methods. For example, the egg pocket area (sometimes called the mound) is almost always measured by researchers, but the pit and/or tailspill are not always included.

EA Engineering (1992) measured 354 fall-run Chinook salmon redds on the Tuolumne River in 1988 and 1989. For each redd, the length of the mound, length of the pit, and length of the tailspill were measured. In addition, the maximum width within the mound, water depth, and velocity were measured. Figure 7-6 illustrates of the distribution of redd size that result from these measurements. The total redd area, not including the area defended by spawning adults, had a mode of 55 ft^2. This area includes the redd pit, mound, and tailspill.

Before using redd size data from previous studies, it is therefore important to determine if the data are appropriate, both biologically (e.g., fish size) and methodologically, for the intended use. One of the primary uses of redd size data in the San Joaquin restoration project is to help asses the implications of the amount of spawning gravel on the population dynamics of re-established salmon runs. An individually-based spawning model is proposed to be used to determine the effect of gravel area on the number of eggs successfully deposited for different escapement sizes. The Tuolumne River data and data from other San Joaquin River tributaries will presumably be the most applicable

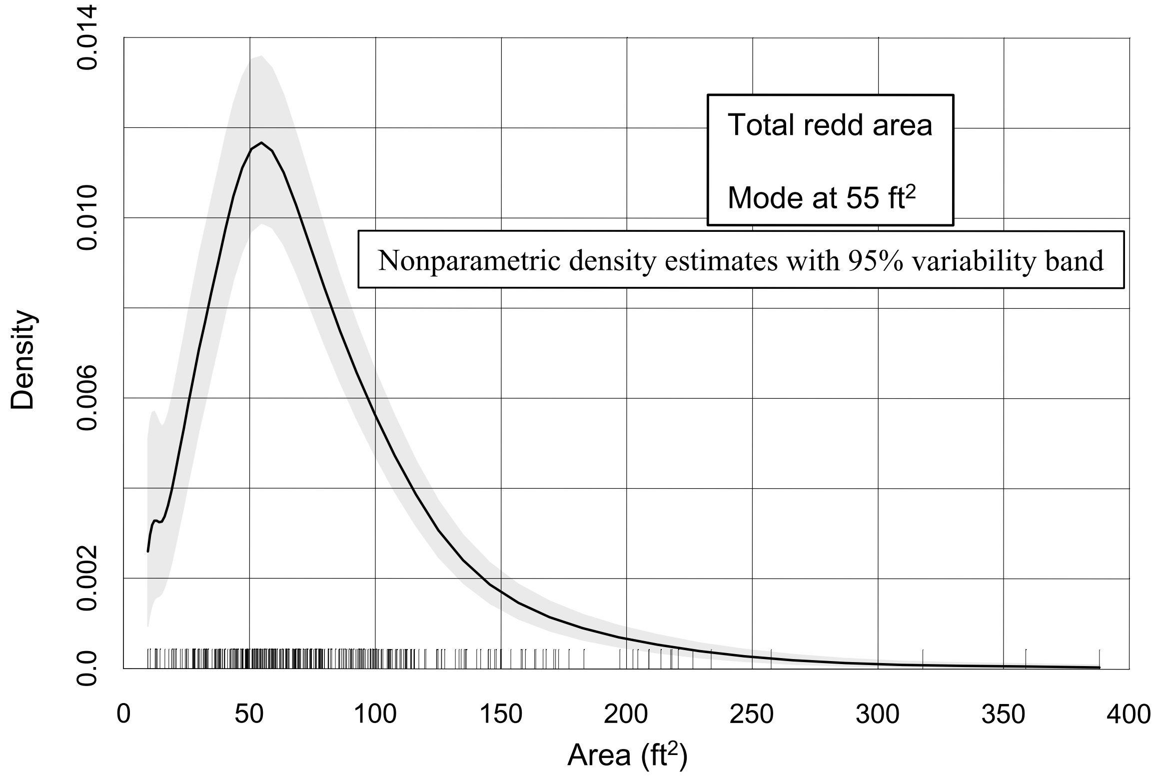


Figure 7-6. Chinook salmon redd size distributions based on total redd area, from Tuolumne River Data, 1988 and 1989, n=354.

to the restored San Joaquin mainstem. Because of the potential for redd superimposition and the direct relationship of superimposition to habitat availability and number of spawners that can be accommodated, the parent population selected for re-introducing Chinook salmon to the San Joaquin River also will be important. The parent population selected will influence average redd size, and will thus influence the amount of habitat that will need to sustain targeted population sizes.

The average size of a steelhead redd is smaller than that of a Chinook salmon redd (Reynolds et al. 1990). Reiser and White (1981, as cited in Bjornn and Reiser 1991) and Hunter (1973) estimated steelhead redd sizes from 47 ft^2 to 58 ft^2. Reynolds et al. (1990) indicated that redd sizes ranged from 22 ft^2 to 121 ft^2, averaging 56 ft^2.

7.5.4.2. Temperature During Incubation

Water temperatures during spawning and incubation are critical to successful reproduction and may be a primary evolutionary factor that has determined spawning timing (Heggberget 1988, as cited in Bjornn and Reiser 1991). Embryonic development time is a direct function of incubation temperatures, and the average incubation time can be predicted with approximately 97% accuracy or better with simple degree-day models (Myrick and Cech 2001).

Bell (1986) reports preferred spawning temperatures for spring-run and fall-run Chinook salmon of 42 °F to 57°F, and preferred (optimal) incubation temperatures of 41° F to 58°F. Temperatures above the preferred spawning range have been observed to increase the occurrence of abnormal fry, mortality, and lengthen the duration of the hatching period (Spence et al. 1996). The temperature at which incubating Chinook salmon eggs begin to experience significantly increased mortality is reported to range from a low of about 57ºF (Healey 1979) to a high of 61ºF (Olson and Foster 1957). The USFWS (1999, as cited in Myrick and Cech 2001) conducted egg thermal tolerance studies in the Sacramento River, and found that the mortality of fall-run Chinook salmon eggs held at temperatures ranging from 52ºF to 56ºF was not significant, but that mortality increased at temperatures ranging from 54ºF to 60ºF, and increased further at temperatures above 62ºF.

Seymour (1956) found substantially higher mortality in groups incubated near 60°F (n=2, 22% and 35% respectively) than in groups incubated near 58°F (n=1, 2%) or 55°F (n=2, 2% and 5%). He found high mortality (n=2, 78%, 85%) in groups incubated near 62°F, and complete or near-complete mortality in groups incubated near 65°F (n=2). Seymour reproduces data from the Entiat hatchery which follow the same general pattern, although the Entiat data showed only 12.4% mortality near 60°F. Seymour also conducted experiments involving varying temperature regimes with eggs of several broodstocks, including a Sacramento River stock. These varying-temperature experiments are harder to interpret, but the results were broadly similar to the findings in the constant-temperature experiments.

Egg mortality at different temperatures varies with exposure duration (Donaldson 1955), dissolved oxygen concentrations present during the exposure (Eddy 1972), and developmental stage (Combs and Burrows 1957). The experimental results of Donaldson (1955) indicated that mortalities of 20% would be expected after an exposure of about 10 to 12 days at a temperature of 62ºF, but 90% mortality would not be expected at this temperature even after 25 days. Donaldson (1955) found that an exposure of six days to 65ºF was sufficient to kill nearly 50% of Chinook salmon eggs. At temperatures of 67ºF, 90% mortality would be expected in about 10 days, according to Donaldson's experiments.

Preferred temperatures for steelhead egg incubation range from 48ºF to 52ºF (McEwan and Jackson 1996, FERC 1993). Temperature thresholds for steelhead spawning are provided in Table 2 of the Steelhead Summary in Appendix B, and incubation thresholds are provided in Table 3 of the Steelhead Summary in Appendix B.

7.5.4.3. Historical Spawning Distribution

Historically, spring-run Chinook salmon spawning in the San Joaquin River occurred from late August to October, with peak spawning occurring in September and October (Clark 1942, Figure 7-2). Fall-run Chinook salmon in the San Joaquin system typically spawned from October through December, with spawning activity peaking in early to mid-November (Figure 7-3). Spring Chinook salmon historically spawned as far upstream as the present site of Mammoth Pool Reservoir (RM 322), where they were blocked by a natural barrier (Yoshiyama et al. 1996). Spawning habitat in the upper San Joaquin River was historically considered to be the best of any river in the basin (Hatton 1940, as cited in Yoshiyama et al. 1996). Most spawning was concentrated between Lanes Bridge (RM 255) and the Kerchoff Powerhouse (RM 293) (Clark 1942). There is conflicting information on the areas with the most suitable and frequently used spawning habitat, but generally Clark (1942) and Hatton (1940, as cited in Yoshiyama et al. 1996) both report that highly suitable gravels were in the 10-mile reach from Lanes Bridge to the current site of the Friant Dam. The construction of the dam inundated and blocked access to about 16 miles of habitat that was historically used by spring-run Chinook salmon for spawning, representing an estimated 36% loss of the historic spawning habitat (Hatton 1940, as cited in Yoshiyama et al. 1996). Hatton (1940, as cited in Yoshiyama et al. 1996) noted that in the 1930s (before construction of Friant Dam) spawning habitat below the town of Friant appeared under-utilized, and based on spawning habitat alone he predicted that there would be no impact of the Friant Dam on spring-run Chinook salmon. Fall-run Chinook salmon spawning distribution is not as well documented, but it is likely that they spawned in Reach 1 between Gravelly Ford and Lanes Bridge (CDFG 1957, as cited in Cain 1997).

7.5.5. Juvenile Rearing

Following emergence, salmonid fry smaller than 2 inches (50 mm) occupy low-velocity, shallow areas near stream margins, including backwater eddies and areas associated with bank cover such as large woody debris or large substrate (Lister and Genoe 1970, Everest and Chapman 1972, McCain 1992). As fry grow, they move into deeper and faster water further from banks (Hillman et al. 1987, Everest and Chapman 1972, Lister and Genoe 1970). Juvenile salmonids larger than 2 inches (50 mm) in the Sacramento-San Joaquin system also rear on seasonally inundated floodplains. Sommer et al. (2001) found higher growth and survival rates of Chinook salmon juveniles that reared on the Yolo Bypass than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. Bioenergetic modeling suggested that increased prey availability on the Yolo Bypass floodplain was sufficient to offset increased metabolic demands from higher water temperatures (9ºF higher than mainstem). Sommer et al. (2001) suggested that the well-drained topography may help reduce stranding risks when floodwaters recede. Considering the historical extent of floodplain inundation in the San Joaquin system, and the expanse of Tule marsh along the San Joaquin River prior to land development, it is possible that juvenile Chinook salmon, and possibly steelhead, reared on inundated floodplains in the San Joaquin River in Reaches 2 through 5. These downstream reaches were inundated for a good portion of the year for normal and wetter years, providing suitable water temperatures for juvenile rearing from January to at least June or July of most years, and perhaps extending into August of wetter years. As snowmelt runoff declined, and ambient temperatures increased, water temperatures in slow-moving sloughs and off channel areas probably increased rapidly. The extent to which juvenile salmonids would have used the extensive Tule marshes and sloughs historically found in Reaches 2, 3, 4, and 5, is unknown.

The length of time spent rearing in freshwater varies greatly among spring-run Chinook salmon juveniles. They may disperse downstream as fry soon after emerging from redds; they may migrate downstream as fingerlings early in their first summer; they may move downstream in the fall as flows increase; or they may overwinter in freshwater and emigrate the following year as yearlings (Healey 1991). In addition to rearing on inundated floodplains during winter, juvenile spring-run Chinook salmon that stay in the river over summer to rear take advantage of instream pools and runs in the mainstem channel. Fall-run Chinook salmon typically rear in freshwater for one to three months before outmigrating to the ocean, but some rear in the river through the summer and outmigrate the following fall.

Juvenile steelhead (parr) rear in freshwater at least one year before outmigrating to the ocean as smolts. The duration of time parr spend in freshwater appears to be related to growth rate, with larger, faster-growing members of a cohort smolting earlier (Peven et al. 1994). Steelhead that rear in warmer areas, where feeding and growth are possible throughout the winter, may require a shorter period (e.g., 1 year) in freshwater before smolting, while steelhead in colder, more northern, and inland streams may require three or four years before smolting (Roelofs 1985).

7.5.5.1. Temperatures during juvenile rearing

Temperatures, in combination with food availability, have a significant effect on juvenile salmonid growth rates. On maximum daily rations, growth rates increase with temperature up to species-specific threshold temperatures, after which growth rates decline with further increases in temperature. Reduced rations can also result in reduced growth rates and influence how temperature affects growth rates; therefore, salmonid growth rates are a function of the synergistic effects of both temperature and food availability.

In addition to the effects of temperature on growth rates, high temperatures can cause direct mortality. Myrick and Cech (2001) suggest that the chronic upper lethal limit (based on prolonged exposure) for juvenile Central Valley Chinook salmon is approximately 77°F. Juvenile Chinook salmon can, however, withstand brief (acute) periods of higher temperatures up to 83.8°F when acclimated to 66.2°F (Cech and Myrick 1999). Myrick (1998) provides the only assessment of temperature tolerances specifically for Central Valley steelhead. These experiments were conduced on steelhead reared at the Mokelumne River State Fish Hatchery from eggs collected at the Nimbus Fish Hatchery (American River). Central Valley steelhead prefer higher temperature ranges than those reported in the literature for other stocks, with preferred rearing temperatures that range from 62.6 °F to 68°F and a lethal critical thermal maximum of 80°F.

Defining appropriate temperature targets for juvenile salmonids is the focus of additional analysis being conducted to revise the quantitative objectives and develop restoration strategies for the San Joaquin River. The goal of this ongoing analysis is to define temperature targets warm enough that promote faster growth of juvenile salmonids so as to enhance their downstream survival, while avoiding the deleterious effects of temperatures that are too warm.

7.5.6. Smolt Outmigration

Juvenile salmonids undergo morphological, physiological, and behavioral changes as they emigrate from their natal rivers to the ocean. Prior to smoltification, the fish exhibit positive rheotaxis (Thorpe and Morgan 1978) and maintain their position against the stream current. Upon smoltification, fish are less prone to hold position against the current, and downstream movement is initiated. Morphologically, silvering in body color and a decrease in weight per unit length occur (Wedemeyer, et al. 1980), resulting in a more slender and streamlined fish. Some evidence exists for a threshold size that may be important in the timing of seaward migration (Folmar and Dickhoff, 1980). Physiologically, several changes occur during smoltification, including heightened hypo-osmotic regulatory capability that increases salinity tolerance and preference, an increase in endocrine activity, and an increase in gill Na^+-K^+ ATPase activity.

There are several potential mechanisms that may trigger the smoltification process. Larger individuals are more likely to move downstream earlier than smaller juveniles (Nicholas and Hankin 1989a, Beckman et al. 1998), and it appears that in some systems juveniles that do not reach a critical size threshold will not emigrate as smolts (Bradford et al. 2001). Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Bjornn and Reiser (1991) suggest that seaward migrations are regulated primarily by photoperiod, with streamflow, water temperature, and flows also playing important roles. The relative importance of each individual outmigration cue remains unclear (Bjornn 1971, Healey 1991).

In the mainstem San Joaquin River, outmigration trapping at Mossdale in 1939, 1940, and 1941 indicated that spring-run Chinook salmon smolts historically outmigrated from January until mid-June (Hatton and Clark 1942, Figure 7-2). In 1939 the peak of outmigration was in April (peak flow in early February), in 1940 the peak of outmigration was in late February (peak flows in March and April), and in 1941 the peak was in March (peak flow in March). Currently, most age 0+ outmigrants in Butte Creek (Sacramento River basin) move downstream at sizes of 1.2 inches to 4.3 inches (30 mm to 110 mm) (Hill and Weber 1999), while age 1+ outmigrants are generally larger than 5 inches (130 mm), and can reach 6 inches (152 mm) or more in Butte Creek (Hill and Weber 1999). In general, fall-run Chinook salmon fry (length <2 inches) and juveniles (length >2 inches) outmigrate from spawning areas between January and May, and likely later during wetter years.

At the end of the freshwater rearing period, steelhead migrate downstream to the ocean as smolts, typically at a length of 6 inches to 8 inches (150 mm to 200 mm) (Meehan and Bjornn 1991). A length of 5.5 inches (140 mm) is typically cited as the minimum size for smolting (Wagner et al. 1963, Peven et al. 1994). In the Sacramento River, steelhead generally emigrate as 2-year-old fish during spring and early summer months. Emigration appears to be more closely associated with size than age, with 6 to 8 inches being typical for downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993).

Chinook salmon can undergo smoltification at temperatures that range from 42°F to 68°F (Zaugg and McLain 1972, Marine 1997, from Myrick and Cech 2001), but their saltwater survival is improved at lower temperatures. Marine (1997, from Myrick and Cech 2001) evaluated the smoltification patterns of juvenile Sacramento River fall-run Chinook salmon reared at low (55.4–60.8°F), moderate (62.8–68.0°F), and high (69.8–75.2°F) water temperatures. The high temperature regime appeared to impair the smoltification process compared to salmon reared at the low temperature regime. Salmon reared in the moderate temperature regime also displayed some alteration and variable impairment of smoltification patterns. Clarke et al. (1981) reported that Chinook salmon reared at 50°F survived immersion in saltwater better than fish reared at higher temperatures (59°F). Other studies (Clarke and Shelbourn 1985; Clarke et al. 1992, from Myrick and Cech 2001) indicate that Chinook salmon that complete juvenile and smolt phases in the 50–63.5°F range are optimally prepared for saltwater survival.

Studies by Baker et al. (1995) investigated the relationship between water temperature and the survival of hatchery reared fall-run Chinook salmon smolts migrating through the Delta. They observed an LT50 of 73.4±1.9°F. These modeling results were consistent with the results of several laboratory experiments reproduced in Houston (1982). These results are shown in Table 7-4. In Houston's studies, temperatures ranging from 67.6°F to 74.8°F resulted in smolt losses of 10%; higher temperatures resulted in increasingly higher smolt losses, with up to 90% losses at temperatures ranging from 73.4°F to 79.3°F.

It appears that preferred or optimal rearing temperatures that contribute to higher growth rates are slightly higher than optimal temperatures for smoltification. Myrick and Cech (2001) conclude that "while temperatures in the 15–19°C (59–66°F) range lead to high juvenile growth rates, cooler temperatures are optimal for smoltification." Optimal temperatures for smoltification appear to be in the range of 56–64°F in the studies cited above.

According to Myrick and Cech (2001), steelhead undergo smoltification in a very narrow temperature range, with optimal temperatures from 42.8 °F to 50°F. Similar to Chinook salmon, this temperature range is lower than temperatures preferred for rearing, and may reflect evolutionary adaptations to high spring snowmelt runoff that historically would have provided cold water temperatures throughout the San Joaquin River basin during the smolt outmigration period.

7.6. RESIDENT NATIVE FISH LIFE HISTORIES AND HABITAT REQUIREMENTS

Species within the Central Valley ichthyological subprovince evolved in a region where both extended droughts and massive floods were common, leading to special adaptations for surviving these environmental extremes (Moyle 2002). Adaptations to conditions found in California include long life spans and large body size, high fecundity, and well-developed dispersal capabilities (Moyle 2002). Longevity can ensure persistence of a population when conditions are unsuitable for spawning in some years, with the result that many populations may have one or more year classes missing, which may be associated with natural cycles of drought or flooding (Moyle et al 1982). Native fishes also tend to display strong differences in diet and habitat preferences between the juvenile

Table 7-4. Results of slow-heating smolt survival laboratory experiments by Houston (1982).

Acclimation temperature	*Temperatures resulting in loss*		
	10% loss	*50% loss*	*90% loss*
50°F (10°C)	73.2°F (22.9°C)		76.1°F (24.5°C)
50°F (10°C)	68.9°F (20.5°C)		74.3°F (23.5°C)
51.8°F (11°C)	73.4°F (23.0°C)	74.3°F (23.5°C)	74.8°F (23.8°C)
55.4°F (13°C)	67.1°F (19.5°C)		73.4°F (23.0°C)
64.4°F (18°C)	68.0°F (20.0°C)		74.3°F (23.5°C)
68°F (20°C)	74.8°F (23.8°C)	76.5°F (24.7°C)	76.6°F (24.8°C)
–	67.6°F (19.8°C) [1]	73.4°F (23.0°C) [1]	79.3°F (26.3°C)[1]

[1]Temperature values predicted by the Baker et al. 1995 analysis of Chinook salmon smolt outmigration data from the Delta.

and adult life stages; therefore, disturbances affecting one type of habitat or food resource are less likely to eliminate all members of a species' population (Moyle 2002). The purpose of this section is to describe the general life-history patterns of native fish in the San Joaquin River (Appendix D). Appendix B contains more detailed information on the life histories and habitat requirements of native fishes in the San Joaquin River.

The San Joaquin River corridor historically contained a large variety of aquatic habitats for fish, which led to the evolution of different life-history strategies for exploiting various habitats and food resources. Habitat diversity and fish community complexity generally increased in a downstream direction with the addition of lower-velocity and deeper habitats associated with the valley floor, including still backwaters, shallow tule beds, deep pools, and long stretches of slow-moving water (Moyle et al. 1982). Because natural habitats that support the rainbow trout assemblage are generally restricted to areas upstream of Friant Dam, the following discussion focuses primarily on the pikeminnow-hardhead-sucker and deep-bodied fish assemblages that occupied mainstem habitats within the study area.

Two large freshwater lakes (Tulare and Buena Vista lakes) historically inundated large portions of the valley floor, providing large areas of warm, shallow, extremely productive habitat for spawning and rearing fish. The fish fauna of these lakes were not studied before their destruction, but there was a small commercial fishery in the lakes for native cyprinids in the nineteenth century (Moyle 1976). Moyle believes that these lakes, as well as the backwaters, sloughs, and other slow-water habitats of the valley floor, were probably important habitat for Sacramento perch, thicktail chub, hitch, Sacramento splittail, and tule perch. Conditions in these valley-floor aquatic habitats fluctuated a great deal in association with natural flooding and drought. The adaptations to these fluctuations that are evident in native fish include tolerance to high turbidity, extremely high water temperatures, and high salinities and alkalinities (Moyle 2002). Moyle et al. (1982) point out that, although such fluctuating conditions might be expected to result in species that are relatively unspecialized to take advantage of a variety of foods and habitats, the native fish species are "remarkable for their distinct habitat preferences, feeding habits, and life-history strategies."

A range of feeding habits is found among the native resident fishes of the lower-elevation San Joaquin River. Sacramento blackfish are primarily suspension feeders on plankton (Sanderson and Cech 1992, 1995; as cited in Moyle 2002). Hitch are open-water plantivores that feed on filamentous algae and aquatic and terrestrial insects (M.S. thesis, University of California, Davis, unpubl. data 1996; as cited in Moyle 2002) in shallow sloughs or along shoreline areas of channels. Smaller fish that feed on benthic prey include prickly sculpin, tule perch, and juvenile splittail (Moyle 2002). Bottom-feeding omnivores include adult splittail, hardhead, and Sacramento sucker; the diet of these species is composed of detritus as well as small benthic invertebrates (Moyle 2002). Larger hardhead tend to feed on filamentous algae and other aquatic plants as well as larger invertebrates (Moyle 2002). Sacramento perch and Sacramento pikeminnow were formerly the dominant piscivorous fish in the San Joaquin River. Thicktail chub are believed to have fed on small fish and large aquatic invertebrates (Bond et al. 1988, as cited in Moyle 2002).

Native resident fish also display a variety of spawning behaviors. All of the native resident species spawn in the late winter or spring when water was historically abundant in the system (Moyle 1976). Many species grow to large sizes as adults and exhibit high fecundity, such as the cyprinids and Sacramento sucker. Several of the cyprinids (e.g., hitch, Sacramento pikeminnow, hardhead) and the Sacramento sucker make upstream migrations from lakes and low-elevation valley-bottom reaches into tributaries or swifter upstream reaches to spawn. Individual cyprinids in smaller streams may move only a short distance from pools to riffles or heads of pools to spawn (e.g., Sacramento pikeminnow, hardhead). The native cyprinids and the Sacramento sucker are broadcast spawners that do not build nests, defend spawning territories, or care for young. Some of these species spawn primarily over gravel in riffles (Sacramento pikeminnow, hardhead, Sacramento sucker). Other native fishes spawn in shallow-water habitats with dense aquatic vegetation (e.g., Sacramento blackfish, Sacramento perch). Sacramento splittail spawn on floodplains inundated by high flows in the spring, with eggs adhering to submerged vegetation and debris (Moyle 2002). Some species exhibit care of young through building of nests (e.g., threespine stickleback, Sacramento perch, prickly sculpin). Tule perch bear live young, often in shoreline areas with dense aquatic vegetation or overhanging riparian vegetation.

Larvae of many native fishes rear in shallow water habitats with dense cover that provides protection from predators. The once extensive floodplains and lakes of the San Joaquin Valley likely provided important spawning and rearing habitat for many native fishes. The loss of floodplain habitats and potential effects on native fish species are discussed in more detail in Section 7.7.3. Adults of some native fish species (e.g., hitch, tule perch, and Sacramento perch) prefer slow-moving reaches with dense aquatic vegetation. Native fishes that occupy larger, open-water reaches of the mainstem as adults include streamlined cyprinids such as Sacramento blackfish, Sacramento splittail, Sacramento pikeminnow, and hardhead (Moyle 1976).

Native resident fish display considerable dispersal capabilities. Superior dispersal capabilities allow fish to rapidly recolonize portions of a stream or basin where populations have been eliminated by natural or anthropogenic disturbances (Moyle 2002). The most common dispersal pattern is for adult fish to move upstream to spawn, which results in dispersal of young downstream throughout the system (Moyle et al. 1982). Several of the native cyprinids and the Sacramento sucker employ this life-history strategy.

7.6.1. Life Histories and Habitat Requirements of Selected Native Resident Fish

This section describes the life histories and habitat requirements of representative native resident fish. Appendix B includes additional species accounts for most native and non-native resident fish.

7.6.1.1. Sacramento pikeminnow

Pikeminnows are long-lived and thus well-equipped for persisting through periods of extended drought and low reproduction (Moyle 2002). Individuals may remain in a single home pool or small area for many years (Taft and Murphy 1950, as cited in Moyle 2002) or may undertake long migrations, particularly from March through May when they may migrate upstream to spawn (USBR 1983, as cited in Moyle 2002). Adult pikeminnows in large rivers or reservoirs usually move into tributaries to spawn, while fish in small or medium-sized streams usually move to the nearest riffle (Grant 1992, Taft and Murphy 1950, Mulligan 1975; all as cited in Moyle 2002). Spawning takes place over gravel in riffles or shallow flowing water at the tails of pools (Moyle 2002). Spawning movements occur during April and May (Grant 1992, Taft and Murphy 1950, Mulligan 1975; all as cited in Moyle 2002), but larvae have been found as late as July (Wang 1986, as cited in Moyle 2002).

Pikeminnows generally inhabit streams where summer water temperatures range from 64.4°F to 82.4°F and will seek temperatures in the upper part of this range in suitable habitat (Brown and Moyle 1993, Baltz et al. 1987, Dettman 1976; all as cited in Moyle 2002). A temperature of near 78.8°F is the maximum preferred temperature and temperatures above 100.4°F are lethal (Knight 1985, as cited in Moyle 2002). The species is most abundant where summer water temperatures exceed 68°F for extended periods of time (Moyle et al. 1982). They are rarely found in water with salinities higher than 5 ppt (parts per thousand), but have been found in salinities as high as 8 ppt (Moyle 2002). Pikeminnows are opportunistic top predators. Juveniles feed primarily on aquatic insects. After reaching a length between 4 inches and 8 inches, they switch to feeding on fish and crayfish (Brown and Moyle 1996, Brown 1990, Taft and Murphy 1950, USBR 1983; all as cited in Moyle 2002). The diet of pikeminnows larger than 8 inches consists almost exclusively of fish and crayfish; however, large insects, frogs, and small mammals may also be eaten.

The Sacramento pikeminnow is still common in the Central Valley, although Moyle (2002) notes that they may be less abundant in low-elevation areas where they were once the dominant predator species. Moyle and Nichols (1973) noted that adult pikeminnows are generally scarce or absent in disturbed habitats where introduced fishes such as carp or centrarchids are present in large numbers, although juvenile pikeminnows may be numerous in the sloughs of the Delta where introduced fishes are common.

7.6.1.2. Hardhead

Hardhead are large cyprinids endemic to the Sacramento-San Joaquin drainage (Moyle 1976). In the Central Valley, the species occupies the relatively undisturbed reaches of larger low- to mid-elevation streams (Mayden et al. 1991, Moyle and Daniels 1982, both as cited in Moyle 2002) and the mainstem Sacramento River (Reeves 1964, as cited in Moyle 2002). They appear to have very restricted microhabitat preferences, being found "only in the sections of large, warm streams that contain deep, rock-bottomed pools" (Moyle et al. 1982). Juveniles are found in pools and shallower areas of these same stream reaches (Moyle et al. 1982). Deep (>2.5 feet) pools and runs with sand-gravel-boulder substrates, low turbidities, and low water velocities (0.7 ft/s to 1.3 ft/s) appear to be preferred (Mayden et al. 1991, Cooper 1983, Knight 1985, Moyle and Baltz 1985, Alley 1977; all as cited in Moyle 2002). The species belongs to the pikeminnow-hardhead-sucker assemblage, being always found in association with Sacramento pikeminnow, and often with Sacramento sucker (Moyle 2002).

Spawning by hardhead occurs primarily in April and May (Reeves 1964, Grant and Maslin 1997, both as cited in Moyle 2002), but may extend into August in some foothill streams (Wang 1986, as cited in Moyle 2002). Adult fish from larger rivers or reservoirs may undertake upstream spawning migrations into tributaries to spawn (Wales 1946, Moyle et al. 1995, both as cited in Moyle 2002). Others may move only a short distance from a home pool upstream or downstream to spawn (Grant and Maslin 1997, as cited in Moyle 2002). Although spawning activity has not been observed, hardhead are thought to spawn over gravel in riffles, runs, or the heads of pools (Moyle 2002). Little is known regarding their early life history; larval and post-larval fish likely remain along the edges of streams in dense cover and move into deeper habitats as they grow (Moyle 2002).

Hardhead most often occur in streams with temperatures over 68°F; they prefer relatively warm water temperatures, with optimal temperatures being 75.2° F to 82.4°F (Knight 1985, as cited in Moyle 2002). They are relatively intolerant of the low dissolved oxygen concentrations that occur at higher temperatures, which may be a factor influencing their distribution (Cech et al. 1990, as cited in Moyle 2002). Water velocity may act as a barrier to their movements because hardhead have relatively poor swimming ability at low temperatures (Myrick 1996, as cited in Moyle 2002).

Hardhead are omnivorous, feeding on benthic invertebrates and plant material, as well as drift (Alley 1977, both as cited in Moyle 2002). Juveniles feed on aquatic macroinvertebrates and small snails (Reeves 1964, as cited in Moyle 2002). Adults feed on large invertebrates (such as crayfish), and plants (primarily filamentous algae) (Moyle 1976).

Hardhead are usually absent where introduced species form a dominant portion of the fish community and in stream reaches that have been substantially altered by human disturbance (Baltz and Moyle 1993, as cited in Moyle 2002). Although historically widespread and abundant in the San Joaquin system (Reeves 1964, as cited in Moyle 2002), their current distribution indicates that populations have declined and that habitat fragmentation may be a factor affecting their long-term persistence (Moyle 2002). Habitat loss and predation by smallmouth bass and other non-native centrarchids appear to be the most important factors in the decline of hardhead populations.

7.6.1.3. Sacramento Sucker

The Sacramento sucker is endemic to the Sacramento-San Joaquin drainage and is currently a common and widely distributed species in central and northern California (Moyle 2002). They are an important member of the pikeminnow-hardhead-sucker assemblage. Sacramento suckers are now relatively uncommon in low-elevation reaches where they historically occurred, but their distribution has expanded in reservoirs and regulated streams (Moyle 2002). Sacramento suckers live in a variety of habitats, from cold, swift streams to warm sloughs and low-salinity areas of estuaries, but are most abundant in clear cool-water streams (Moyle and Nichols 1973, Brown and Moyle 1993, both as cited in Moyle 2002) and in lakes and reservoirs at elevations from 600 feet to 2,000 feet (Moyle 2002). Adult suckers are most numerous in larger streams and juveniles primarily inhabit tributaries or shallower reaches of large rivers inhabited by adults (Moyle 2002). Adults are generally absent from higher gradient, cool streams that lack large pools (Moyle et al. 1982). They are found both in association with native cyprinids as well as with non-native species (Moyle 2002).

Sacramento suckers in larger rivers or reservoirs often migrate into tributaries to spawn; these movements into spawning streams may begin as early as December (Moyle 2002). Spawning generally takes place over gravel riffles between late February and early June, with peak spawning in March and April (Villa 1985, Mulligan 1975, both as cited in Moyle 2002). Larvae tend to rear in shallow, warm, stream margin habitats over detritus substrate or among emergent vegetation (Moyle 2002). Juvenile suckers may move downstream into larger rivers or reservoirs after a period of rearing in the spawning tributary, or remain in shallow habitats with dense cover in streams with resident populations (Moyle 2002).

Suckers can live in streams with a wide range of water temperatures, from cool streams where temperatures are rarely above 59° F to 60.8°F, to streams where temperatures reach 84.2°F to 86°F (Cech et al. 1990, as cited in Moyle 2002). Their preferred temperature appears to be within the range of 68° F to 77°F (Knight 1985, as cited in Moyle 2002). Salinities exceeding 13 ppt may be tolerated by adult Sacramento suckers (Moyle 2002). Suckers generally feed on the bottom, with algae, detritus, and small invertebrates forming most of the diet.

Sacramento suckers are tremendously resilient to disturbance due to their longevity and ability to successfully seed an area with young in years following catastrophic population declines. Because of this, sucker populations may often be characterized by non-uniform age structures with strong and weak (or missing) year classes (Moyle 2002). It appears that reproductive success is highest in years when high flows increase the amount of available spawning habitat and increase the amount of flooded shallow habitat preferred as rearing habitat by larvae and small juvenile suckers (Moyle 2002).

7.6.1.4. Sacramento Perch

Sacramento perch are the only member of the centrarchid family native to streams west of the Rocky Mountains. In the San Joaquin Valley, Sacramento perch formerly occupied sloughs, slow-moving streams, and lakes at elevations below 328 feet and were an abundant member of the deep-bodied fish assemblage (Moyle 2002). They are associated with aquatic and emergent vegetation and other forms of underwater cover; however, they have also been found to be abundant in shallow, highly turbid reservoirs with no aquatic vegetation (Moyle 2002). The species is able to tolerate turbid water, high temperatures (preferred temperatures range from 77°F to 82.4°F), and high salinities and alkalinities (Moyle 2002).

Spawning habitat consists of shallow areas (8 inches to 20 inches deep) with dense growth of aquatic macrophytes or filamentous algae nearby. Rock piles and submerged roots or woody debris may also attract spawning fish (Moyle 2002). Spawning substrate ranges from clay and mud to rocks (Aceituno and Vanicek 1976; Mathews 1962, 1965; Murphy 1948a; all as cited in Moyle 2002). Spawning occurs from late March through early August; late May and early June are generally peak spawning times (Moyle 2002). Spawning occurs at temperatures from 64.4 °F to 84.2°F (P. Crain, University of California, unpubl. data 1998; as cited in Moyle 2002). Sacramento perch defend nests until larvae can swim well enough to leave the nests, but their eggs are still vulnerable to predation from schools of sunfish or large individual fish such as carp (Moyle et al. 2002). Larvae are planktonic for approximately 1 to 2 weeks before settling into aquatic vegetation or shallow water; during this time they are likely vulnerable to predation by many native and non-native fish species. Presence of aquatic vegetation appears essential for young-of-the-year Sacramento perch rearing in moderately clear water (Moyle 2002). Turbid water may afford similar cover. Very little is known regarding the early life history stages of Sacramento perch and whether physical or chemical factors may limit their survival (Moyle et al. 2002).

Young-of-the-year Sacramento perch “feed mostly on small crustacteans (amphipods, cladocerans, ostracods, and copepods) that are usually associated with the bottom or with aquatic plants” (Moyle 2002). As they grow, aquatic insect larvae and pupae, especially chironomids, become more important in the diet. Fish may be eaten by perch over 3.5 inches in length, as is observed in large lakes such as Pyramid Lake (Moyle 2002). In small lakes and ponds, chironomids and other aquatic macroinvertebrates continue to be important in the diet of large perch, with small crustaceans and fish of secondary importance.

Sacramento perch are currently extirpated from their historical range in the San Joaquin Valley, but persist in reservoirs where they have been introduced. Extant populations of Sacramento perch currently appear to be limited to habitats where non-native centrarchids are excluded by high alkalinities or lack of introductions. One exception is in Clear Lake, where a small population appears to persist despite the presence of six other non-native centrarchids. Black crappie and bluegill appear to be the species that most strongly compete with Sacramento perch for food and space (Moyle 2002).

7.6.1.5. Tule Perch

Tule perch are the only freshwater member of the surfperch family, and they are endemic to the Sacramento-San Joaquin drainage. They were historically distributed in most low-elevation streams in the Central Valley as part of the deep-bodied fish assemblage (Moyle 2002). Within the San Joaquin drainage, they currently occur mainly in the Stanislaus River, but are also found in the lower San Joaquin River, within the Delta, and in the lower Tuolumne River (Moyle 2002). They use a variety of valley-floor habitats from lakes and estuarine sloughs to clear streams (Moyle 2002). Within streams, they are associated with "beds of emergent aquatic plants, deep pools, and banks with complex cover, such as overhanging bushes, fallen trees, and undercutting" (Moyle 2002). The cover provided by large boulders along the edges of large deep pools (Moyle and Daniels 1982, Brown 2000, both as cited in Moyle 2002) or riprap may also be used (Moyle 2002).

Tule perch give birth to as many as 60 live young in low-velocity aquatic habitats or backwaters with aquatic vegetation or dense overhanging riparian vegetation (Moyle 2002). Young are born in May and June and may begin to form aggregations soon after (Moyle 2002). Tule perch are associated with cool waters and high dissolved oxygen concentrations; they are rarely found in streams that are warmer than 77°F for extended periods of time, and generally prefer temperatures below 71.6°F (Knight 1985, as cited in Moyle 2002). Tule perch tolerate high salinities and are found where salinities fluctuate annually from 0 to 19 ppt (Moyle 2002), and may occur in salinities as high as 30 ppt (R. Leidy, U. S. Environmental Protection Agency, pers. comm., as cited in Moyle 2002). Tule perch feed on small invertebrates associated with the benthos or aquatic vegetation, but may also feed on zooplankton in the water column (Moyle 2002).

This species has been extirpated from most of its habitat within the San Joaquin basin. The reasons for their disappearance appear to be poor water quality and contaminants (Moyle 2002). Isolated populations are extremely vulnerable to extinction from catastrophic disturbances. The species remains abundant in the regulated mainstem of the Sacramento River in areas with heavy cover or growth of aquatic plants (Moyle 2002).

7.6.1.6. Sacramento Splittail

The Sacramento splittail is endemic to the Sacramento-San Joaquin drainage, including the Sacramento-San Joaquin Delta, Suisun Bay, Suisun Marsh, and other portions of the Sacramento-San Joaquin estuary. The species' original range included much of the San Joaquin Valley in the zone occupied by the deep-bodied fish assemblage. Sacramento splittail are a relatively long-lived cyprinid species found primarily in marshes, turbid sloughs and slow-moving river reaches. The species' dependency on floodplains for spawning has made the species a key indicator for floodplain habitat quality and quantity.

Adult splittail tend to congregate and feed for two to three months before spawning in areas of inundated floodplain vegetation. Splittail spawn from February through June on floodplains inundated by spring high flows, with peak spawning in March and April. Splittail are broadcast spawners with adhesive eggs that attach to submerged vegetation and woody debris, which can make the eggs susceptible to dessication if water levels recede too quickly. After spawning, adults move into the lower Delta, where they remain until the fall rains begin. Larvae are believed to rear in the vicinity of the spawning grounds for up to two weeks (Wang 1986, as cited in Moyle 2000, Sommer et al. 1997) before moving into deeper water as they become stronger swimmers. Juvenile splittail rear in upstream areas for a few weeks to a year or more before moving to tidal fresh and brackish waters (Moyle et al. 2000). Juvenile splittail spend their first year of life in the lower Delta and lower reaches of streams. There is an increase in Sacramento splittail spawning habitat and access to spawning habitat during high flow years where floodplain inundation occurs. The Sutter and Yolo bypasses currently provide essential spawning and rearing habitat for splittail (Moyle et al. 2000). At least a month of bypass inundation appears to be needed for the development of a strong year-class (Sommer et al. 1997).

Splittail primarily inhabit fresh water, but are also found in water with salinities of 10 ppt to 18 ppt (Moyle et al. 1995). Not much is known about water quality tolerances of Sacramento splittail. Juvenile and adult splittail demonstrate optimal growth at 68^{o}F, and signs of physiological distress only above 84.2^{o}F (Cech and Young 1995 as cited in Winternitz and Wadsworth 1997). Splittail can survive very low dissolved oxygen concentrations (0.6 ppm to 1.2 ppm for young-of-the-year, juveniles, and subadults) (Young and Cech 1995, 1996).

Splittail forage benthically for invertebrates and detrital material (Daniels and Moyle 1983), and are thought to feed extensively on opossum shrimp (*Neomysis mercedis*) (Moyle et al. 1995). Inundated areas can provide abundant food sources and vegetated cover from predators (Sommer et al. 1997). Cladocerans have been documented as important prey of splittail (Stevens 1966). Feyrer and Matern (2000) found that splittail also consume *Potamocorbula amurensis*, the estuarine Asian clam found in San Pablo Bay through Suisun Bay, and most abundant in the Suisun Marsh region. Terrestrial invertebrate prey may also be important for splittail.

Sacramento splittail were listed as federally threatened in 1999. The loss of floodplain and large lake spawning habitat is believed to have been a major contributor to their decline in the San Joaquin basin (Moyle 2002). Moyle (2002) notes that splittail have "disappeared as permanent residents from portions of the Sacramento and San Joaquin Valleys because dams, diversions, channelization, and agricultural drainage have either eliminated or drastically altered much of the lowland habitat they once occupied or else made it inaccessible except during wet years." Most splittail are currently found in the San Francisco Estuary, primarily in the Delta and Suisun Marsh (Moyle 2002). The Yolo Bypass appears to provide high quality spawning habitat for splittail during years when outflows are high during April and May when the species spawns.

7.6.1.7. Sacramento Blackfish

Sacramento blackfish are a cyprinid endemic to low-elevation reaches of the Sacramento and San Joaquin rivers and their tributaries; they are also native to Clear Lake and the Pajaro and Salinas rivers (Moyle 2002). They are one of the few native species of the deep-bodied fish assemblage that have persisted on the valley floor despite extreme changes to Central Valley habitats (Saiki 1984), although they may be less abundant in low-elevation habitats than historically (Moyle 2002).

Blackfish are most abundant in warm and usually turbid habitats of the Central Valley floor. Habitats used by blackfish include: oxbow lakes and sloughs in the Sacramento-San Joaquin Delta (Turner 1966, as cited in Moyle 2002); large, sluggish mainstem channels (Moyle 2002); and deep turbid pools with fine substrates of mud or clay in streams and rivers (Smith 1977, 1982, both as cited in Moyle 2002). They are believed to have been formerly abundant in the large Tulare and Buena Vista lakes of the San Joaquin Valley (Moyle 2002).

Observations of spawning are rare due to their preference for turbid habitats. Spawning in Clear Lake has been observed to take place in shallow areas with dense aquatic vegetation between April and July at temperatures of 53.6°F to 5.2°F (Moyle 2002). Larvae remain in shallow water, particularly where aquatic vegetation is present, but may also be found in open water (Wang 1986, as cited in Moyle 2002). Blackfish appear well-adapted for spawning in floodplain habitats of the valley floor.

The species is very tolerant of poor water quality (Brown and Moyle 1993). Adult blackfish are found where temperatures in the summer exceed 86°F and dissolved oxygen concentrations are low (Moyle 2002). Optimal temperatures appear to be from 71.6°F to 77°F (Smith 1977, 1982, Cech et al. 1979; all as cited in Moyle 2002). Upper lethal temperatures may be near 98.6°F (Knight 1985, as cited as Moyle 2002), suggesting that blackfish have adapted to survive through periods of drought and extreme low flows (Moyle 2002).

Blackfish are filter-feeding herbivores that feed primarily on plankton in suspension as adults (Monaco et al. 1981, Staley 1980, Murphy 1950, Cook et al. 1964, Johnson and Vinyard 1987, Sanderson and Cech 1992, 1995; all as cited in Moyle 2002). Juveniles feed on zooplankton and insects picked from the water column or substrate (Murphy 1950, Sanderson and Cech 1992, 1995, Cech and Linden 1987; all as cited in Moyle 2002). In lakes and ponds, blackfish may also feed off the bottom on soft material rich in organic matter and small invertebrates (Moyle 2002).

7.6.1.8. Hitch

Hitch are medium-sized cyprinids endemic to the Sacramento-San Joaquin basin that currently occur in scattered populations throughout the Central Valley in warm, low-elevation lakes, sloughs, and slow-moving reaches of streams (Moyle 2002). They may also be found in cool, sand-bottom streams (Brown and Moyle 1993, Leidy 1984, Moyle and Nichols 1973, Smith 1982; all as cited in Moyle 2002). Adults in lakes are usually pelagic (Moyle 2002). Hitch are omnivorous open water feeders on filamentous algae and aquatic and terrestrial insects (Moyle 2002).

Hitch spawn primarily in riffles of streams tributary to larger open-water habitats after flows increase following spring rains (Moyle 2002). Large spawning migrations from lakes may take place from March into June. Larvae and juvenile hitch rear in shallow areas with dense cover from aquatic or emergent vegetation or debris.

Hitch can tolerate the highest temperatures of any Central Valley native fish. They select temperatures from 80.6 °F to 82.4°F, and can withstand temperatures up to 100.4°F for short periods (Knight 1985, as cited in Moyle 2002). They have been found in water with salinities as high as 9 ppt (J. Smith, California State University, San Jose, pers. comm., as cited in Moyle 2002).

Hitch were formerly associated with the native deep-bodied fish assemblage, but are now most commonly found with non-native species that occupy low-elevation habitats (Moyle 2002). Sacramento blackfish, Sacramento sucker, and Sacramento pikeminnow may be found with hitch in less disturbed areas (Leidy 1984, Moyle and Nichols 1973, both as cited in Moyle 2002). Populations of hitch appear to be declining and increasingly isolated from one another (Moyle 2002). Some populations in the San Joaquin River appear to have been extirpated in recent years (Brown and Moyle 1993). Potential factors contributing to their decline include reductions in high spring flows for spawning, loss of summer rearing and holding habitat, increased pollution, and predation by non-native species (Moyle 2002).

7.7. CHANGES IN FISH HABITAT FROM HISTORICAL CONDITIONS

The San Joaquin River was historically an alluvial river downstream of the present-day Friant Dam, with several morphological transitions that often delineate the Reaches used in this report (i.e., Reaches 1-5). Within this broader alluvial river context, the gravel-bedded Reach 1 had several bedrock exposures that controlled gradient of the river, was often multiple-channeled, was low slope, and periodically migrated or avulsed during large floods. In downstream reaches (Reach 2 through 5), the river was sand-bedded, meandering, and in some reaches, multiple-channeled. Downstream reaches were also noted for their flood basins adjacent to the river (Reaches 3 through 5), which had extensive tule marsh and sloughs. Riparian vegetation varied between the reaches, with patchy riparian vegetation in Reach 1, more extensive but narrow riparian forests in Reaches 2 and 3, extensive tule marsh in Reach 3 through 5, and riparian levees in Reaches 3 through 5. Floodplains and flood basins were vast and were seasonally inundated to allow fish access to high quality ephemeral aquatic habitat. Portions of less-disturbed, lower elevation floodplain developed dense forest flora and was a highly productive interface between aquatic and terrestrial habitats. Our understanding of how certain fish species used floodplain and flood basin habitat is better known (e.g., threadfin shad, delta smelt); however, other resident fish are less understood (e.g., fry, juvenile, and smolting Chinook salmon).

Significant changes in physical (fluvial geomorphic) processes and streamflows in the San Joaquin River have resulted in large-scale alterations to the river channel and associated aquatic, riparian, and floodplain habitats. This section presents a conceptual model of how fluvial geomorphic processes and the natural flow regime created and maintained aquatic habitat and native fish populations, then summarizes the major hydrologic, geomorphic, and habitat changes that have occurred as a result of regulation from Friant Dam and land use impacts. This section finally assesses the potential effects of these changes on native fish species.

7.7.1. Hydrograph Components and Connectivity to Fish Life History and Habitat

Typical of Central Valley rivers and a semi-arid climate, the natural or “unimpaired” flow regime of the San Joaquin River historically provided large variation in the magnitude, timing, duration, and frequency of streamflows, both inter-annually and seasonally. Variability in streamflows provided conditions that partially helped sustain multiple salmonid life history trajectories, as well as life history phases of numerous resident native fish species. To understand the importance of streamflows to fish life history patterns, we evaluated key components of the natural flow regime, using historical and synthetic unimpaired streamflow data for the San Joaquin River at Friant (USGS STN# 11-251000) for the period of record 1896–1999. See Chapter 2 for a description of the analytical process used to develop this combination of measured and modeled daily average flow records. This data provides an approximate representation of streamflow conditions to which the native resident fish assemblages had adapted to best survive over the long-term.

We evaluated unimpaired hydrograph components, and the associated variability in magnitude, timing, duration, and frequency to determine a median or mean value, peak value, and/or minima and maxima representative of each water year class (see Chapter 2). We then related these hydrograph components to the distinct life history stages of anadromous salmonids (and other fish species). Unimpaired hydrograph components were then compared to regulated flow conditions, again using San Joaquin River at Friant (USGS STN # 11-251000) for the period 1950–2000. Five water year classes were developed for this analysis in Chapter 2, and the streamflow ranges expressed for each hydrograph component represent typical or median conditions ranging from Critically Dry to Extremely Wet water year conditions (these water year classes do not reflect any water year designations that may be used by USBR or DWR). The hydrograph component analysis in Chapter

2 identified five distinct components: Summer-Fall baseflows, Fall and Winter Floods, Winter Baseflows, Snowmelt Peak Flows, and Snowmelt Recession Limb. The following discussion includes Reach 1 and Reach 2 where the Friant gaging station reasonably reflects hydrology; however, Reaches 3 through 5 had inflows (e.g., Fresno Slough and tributaries) and extensive flood basins such that the Friant gaging station hydrology magnitude does not reflect actual conditions in those reaches, but the hydrograph component timing and patterns are very similar.

7.7.1.1. Summer-Fall Baseflows

Summer/fall baseflows represent minimum annual streamflow conditions, which typically commenced in the San Joaquin River with the cessation of the spring snowmelt hydrograph in July or early August and extended into October or November of most water years. Typical baseflows during this period ranged from approximately 200 to 600 cfs during normal and drier years and infrequently higher (600 to 800 cfs) early in summer during wetter water years when winter snow pack was high (Figure 7-7). Minimum flows during this period sometimes fell to 100 cfs and infrequently lower during extreme drought conditions. Flows generally decreased as the season progressed, allowing water temperatures to increase with increases in air temperatures. Spring Chinook salmon were present during this period, holding in deeper pools in Reach 1 and upstream reaches now blocked by Friant Dam (CDFG 1921; Hatton 1940, both as cited in Yoshiyama et al. 1996; Clark 1942), until ambient and water temperatures decreased to allow spawning activity to initiate. These moderate magnitude baseflows were historically supplemented in downstream reaches by artesian springs and shallow groundwater contributions (see Chapter 4), but the unimpaired accretion flows is unknown because the earliest downstream gaging station began in 1910, well after substantial diversions had begun upstream.

Under regulated conditions, summer and fall baseflows in Reach 1 is strictly controlled by Friant Dam releases, typically ranging from 50 cfs to 90 cfs in the winter months, and 150 cfs to 250 cfs in the summer months. The change in baseflows from historical conditions depends on the water year and season, but can be reduced to 10% or more of unimpaired values in winter months, and can be slightly increased during dry summers due to flow releases for riparian diversions. These baseflows in Reach 1 are quickly diverted and/or infiltrate into the shallow groundwater table, such that the river is typically dry in Reach 2. Friant Dam releases baseflows for riparian diverters and groundwater infiltration so that minimum instream flow at the last riparian diversion (approximately at Gravelly Ford, RM 229) is 5 cfs. Below Gravelly Ford (Reach 2), the channel is typically dry down to the Mendota Pool, where the Delta Mendota Canal (DMC) adds 300 cfs during the winter to Reach 3 and up to 600 cfs in the summer. This baseflow is conveyed downstream to Sack Dam, where it is diverted into the Arroyo Canal. The San Joaquin River is again dewatered downstream of Sack Dam (Reach 4), and agricultural return water begins to rewater the river in the downstream half of Reach 4B. Much more flow is contributed to Reach 5 by agricultural return flows from the Eastside Bypass and Bear Creek, then Salt and Mud Sloughs.

Historically, baseflows in all reaches supported native resident warm water species, and allowed free migration upstream and downstream. Warm water temperatures probably limited salmonid use of downstream reaches during the summer baseflow periods, with the possible exception of cold-water refugia that may have occurred under unimpaired groundwater conditions (local artesian springs and groundwater seeps). Fall baseflows were important migration periods for adult fall-run Chinook salmon, and the moderate baseflows provided adequate hydraulic and depth conditions for adult fish passage (Figure 7-7). Historical references described fish migrating through Reaches 3 through 5 at flows as low as 100 cfs, but the observer noted extensive damage to the fishes bellies from abrasion while swimming across sand bars (CDFG 1955). Present day conditions for all native

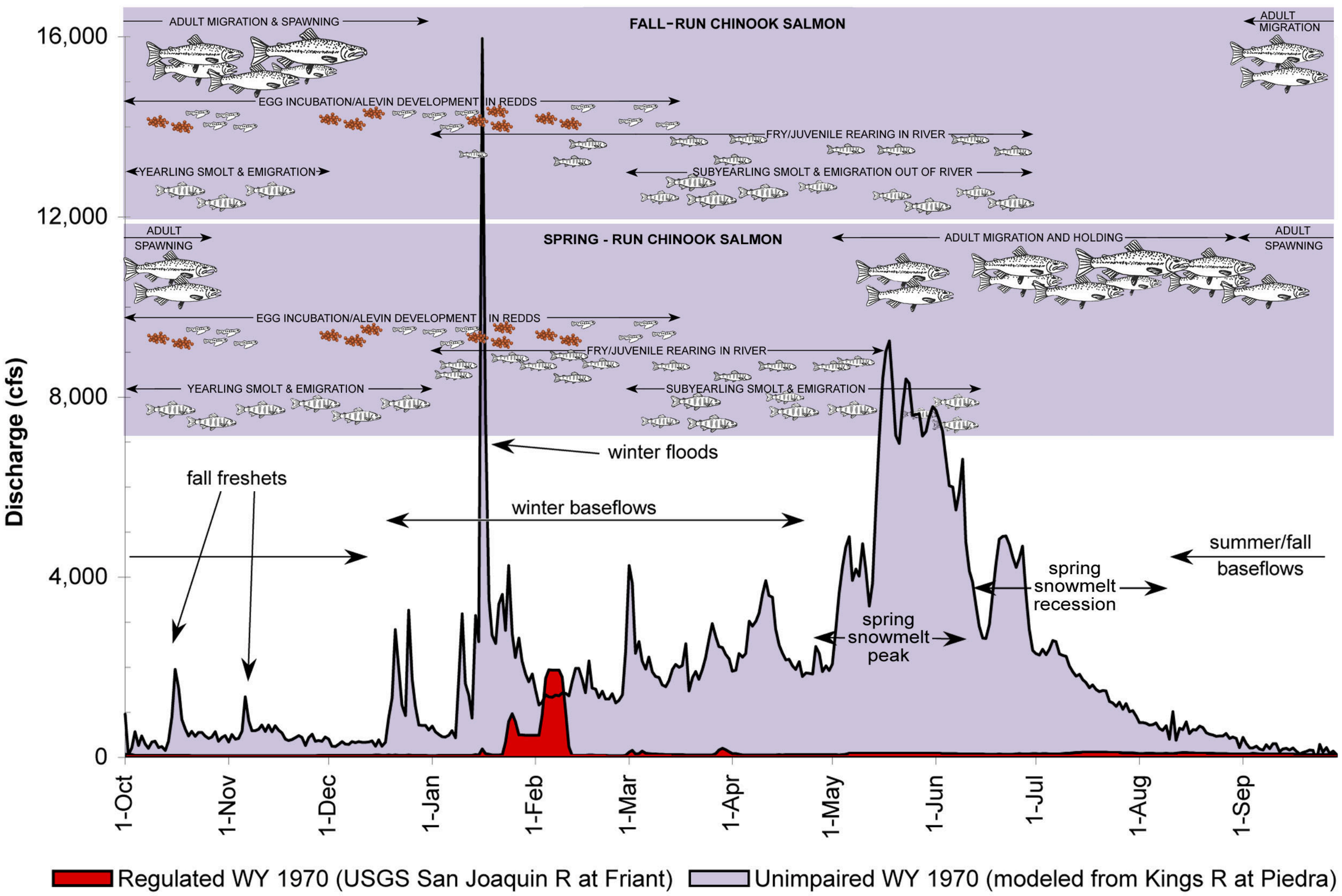


Figure 7-7. Annual unimpaired hydrograph of the San Joaquin River at Friant (reconstructed based on data from Kings River at Piedra USGS #11-222000) and regulated flows at Friant (USGS #11-251000) for WY 1970 (approximately average water year conditions), showing typical hydrograph components and the important life history stages of fall-run Chinook salmon.

species are only favorable for migration and rearing in Reaches 1, 3, and 5, since Reaches 2 and 4 are nearly always dry. During the summer months, Reach 1 is the only reach that would have suitable water temperatures to support juvenile salmonids (with moderate flow releases from Friant Dam). Holding habitat for adult spring-run Chinook salmon would be reduced due to lower water depths and higher water temperatures (shorter length of river with suitable temperatures). Juvenile rearing habitat would probably be reduced slightly in all years but the driest due to reduced baseflows and higher water temperatures. Lower baseflows also reduces access to lateral habitats, and increases vulnerability to predation, and can impact macroinvertebrate food production (Everest et al. 1985). Restoring salmonid populations would require continuous flows through all reaches of at least 100 cfs during the periods of adult migration, and potentially more for juvenile salmonids depending on their outmigration timing (to provide suitable water temperatures).

7.7.1.2. Fall and Winter Floods

Between October and late December, early seasonal storms provided relatively low magnitude, short duration freshets in the San Joaquin River (Figure 7-7). These unimpaired flows ranged from approximately 1,000 cfs to 2,500 cfs (median values), and generally increased in magnitude as the winter storms intensified and soils in the watershed became saturated. Fall storms may have contributed to triggering upstream migration of fall-run Chinook salmon, and perhaps allowed late spawning adult spring-run Chinook salmon to migrate further upstream to additional spawning areas. Historical fall baseflows probably provided adequate flow magnitude to allow adult salmonid passage through all reaches, but the freshets may have had some effect of concentrating the specific timing of larger groups of fish migrating up the river. Since these freshets were a function of individual rainstorms, they are absent from many unimpaired annual hydrographs, generally reflecting local weather patterns for those years (Appendix A). The fall freshets may have also played a role in the reducing inter-breeding of fall-run Chinook salmon and spring-run Chinook salmon. Spring-run tended to spawn in September and October (generally prior to the freshets), and the fall freshets may have provided later spawners the ability to migrate upstream further if necessary. Additionally, if the fall freshets did provide a migratory cue for fall-run Chinook salmon (debatable), they would have arrived at the spawning areas after the spring-run had already spawned, reducing the possibility of inter-breeding.

Under regulated conditions, runoff from fall freshets is captured by Millerton Lake and thus natural fall storm hydrographs are virtually absent in the lower San Joaquin River. The exception is during years following Extremely Wet water years, in which flows up to approximately 1,000 cfs are released from Friant Dam to evacuate flood storage space prior to the onset of winter. This situation occurred in 1983, 1984, 1999, and 2000. It is debatable whether adult fall-run Chinook salmon on the San Joaquin River historically required fall freshets to allow migration, so we do not fully understand the full ecological significance of losing these fall freshets. The impacts of losing the fall freshet on spring-run and fall-run Chinook salmon interbreeding is probably minor compared to the potential impact of Friant Dam forcing both to spawn in the same reach. Elimination of fall freshets under the regulated flow regime may have additional ecological consequences that we are currently unaware of, and should be considered in Restoration Study development.

Typically occurring between mid-December and April, winter floods were generated by rainfall or rain-on-snow storm events (Figure 7-7). These floods were usually the largest over the period of record as larger magnitude, short duration rain-on-snow events generally occurred in late December through January. Smaller magnitude rainfall-only events produced moderate magnitude floods through April, but the magnitude of these storms generally tapered off as winter progressed and precipitation fell primarily as snowfall. Unimpaired median winter floods ranged between 4,000 and

28,000 cfs depending on water year type. Annual instantaneous flood magnitudes from the pre-dam period of record commonly ranged from 10,000 to 30,000 cfs, with several floods exceeding 50,000. The peak hourly inflow into Millerton Reservoir during the 1997 flood was 95,000 cfs (ACOE, 1999). These historic high flows would occur during the time that salmonid eggs were incubating in gravels in Reach 1 and upstream reaches, and bed scour during larger floods certainly caused some mortality to the incubating eggs. Furthermore, emerging fry are not well suited to survive high velocities immediately after hatching and emerging from the gravels, such that there was probably fry mortality caused by these floods. However, the diversity of the pre-dam channel distributed spawners over many locations of the channel (including side-channels), and this distribution of spawning location ensured that a catastrophic loss of the cohort during a large flood would not occur. Likewise, the complex channel morphology and accessible floodplains mitigated water velocities during these large floods, providing velocity refugia to fry.

Under regulated conditions, most winter floods are either captured entirely by Millerton Reservoir or severely attenuated before passing downstream. However, the relatively small storage capacity of Millerton Reservoir (520,500 ac-ft) compared to the average annual inflow (1,801,000 ac-ft) still allows flows in the range of 5,000 to 16,000 cfs to be released under flood control conditions from Friant Dam. Most winters, however, have relatively small magnitude flood peaks, well below 1,000 cfs. The reduction in high flows has many significant geomorphic impacts to channel morphology, which is described in more detail in Chapter 3. Common impacts to fish habitat by the severe reduction in high flow regime includes buildup of fine sediment (sand) in spawning areas (Reach 1), virtual cessation of lateral channel migration and avulsion in all reaches, riparian encroachment in reaches with perennial flows that has confined the low flow channel and simplified channel morphology, local imbalances in the sediment budget, and reduction in the magnitude, frequency, and duration of bedload transport events in Reach 1. These geomorphic processes were responsible for creating and maintaining suitable salmonid habitat, as well as aquatic and terrestrial habitats for other species. These flood events likely partially distributed juveniles into downstream reaches and onto floodplains where flood magnitudes were attenuated and inundated floodplain habitat was available for rearing. Reduced winter floods have greatly decreased the magnitude, duration and frequency of floodplain inundation, thus decreasing available overwinter habitat for juvenile salmonids and other native fishes.

7.7.1.3. Winter Baseflows

In the unimpaired hydrograph, winter baseflows were low to moderate flows between individual winter storm events that generally occurred between December and April (Figure 7-7). Winter baseflows were maintained by the receding limbs of individual storm hydrographs and shallow groundwater discharge, and generally increased in magnitude throughout the winter as soil moisture content increased, shallow groundwater tables rose, and soils became saturated. Flow conditions during winter months were highly variable, and wetter years generally exhibited higher baseflow magnitudes. Unimpaired median winter baseflows ranged between 300 cfs to 900 cfs depending on water year class and sequence of storm events, and occasionally reached as high as 1,700 cfs during wetter water years.

Regulated winter baseflows have been significantly reduced in most water years, and are now strictly Friant Dam releases between 50 cfs to 100 cfs. Winter baseflows have been reduced by up to 95% in Reach 1, and 100% in Reach 2 and Reach 4. These baseflows vary between 50 cfs and 100 cfs through the winter, and do not tend to exceed 200 cfs except during wetter water years when flood releases from Friant Dam are necessary. These infrequent flood control releases generally range between 1,000 cfs and 3,000 cfs, and usually are less than 8,000 cfs per Army Corps of Engineers

(ACOE) requirements (see Chapter 5). The reduced winter baseflows impact salmonid adult migration (particularly winter-run steelhead) through Reaches 2 and 4, as well as greatly reducing juvenile rearing habitat in all reaches. The most significant impacts of reduced winter baseflows would likely be reduced access to off-channel habitat and floodplain rearing for fry and juvenile salmonids, and creation of favorable conditions for non-native fish that predate on salmonids and other native fish.

7.7.1.4. Snowmelt Peak Flows

Snowmelt floods were generally smaller in magnitude, but longer in duration, than winter floods, and generally began in April, peaked in June–July, then receded into late-July and August of wetter years (Figure 7-7). Prior to construction of Friant Dam, the spring snowmelt flood hydrograph component was the largest contributor to the total annual water yield, with sustained flows ranging from 5,000 cfs to 19,000 cfs (median values) depending on the water year, with occasional peaks in excess of 25,000 cfs. Many snowmelt floods had multiple peaks, responding to cycles of hotter ambient air temperatures. These unimpaired snowmelt floods likely transported gravels and cobbles in Reach 1 and upstream reaches, increased turbidity, probably kept water temperatures reasonably low in downstream reaches, and inundated extensive areas of floodplain in the lower reaches of the San Joaquin River at a time when cottonwood and willows were distributing seed. This latter process was important in causing natural regeneration of these species on an infrequent basis when the peak flow was large enough and recession limb were gradual enough for a successful recruitment year. Additionally, fall-run Chinook salmon, steelhead, and likely spring-run Chinook salmon juveniles and smolts outmigrated during the spring snowmelt flood, which likely provided adequate water temperatures for outmigration, overbank flows for juvenile rearing on floodplains and side channels, and moderate turbidity to increase outmigration success (Figure 7-7). Adult spring-run Chinook salmon also migrated into Reach 1 and upstream reaches during the snowmelt floods.

Similar to winter floods, most spring snowmelt floods are captured or attenuated by Millerton Reservoir. Most years have no snowmelt runoff release from Friant Dam, except during wetter years when the flood storage space is encroached and flood control releases are invoked. These flood control releases usually range between 2,000 and 5,000 cfs, but can be as high as 8,000 cfs. Normal and drier water years receive only summer baseflow releases. The loss of snowmelt floods in the mid 1940's ultimately led to the extirpation of the remaining spring-run Chinook salmon. The near loss of the spring snowlmelt floods would have severely impacted the ability of fall-run Chinook salmon smolts from outmigrating (had fall-run still been in the river at that time). The loss of the spring snowmelt hydrograph has also greatly reduced riparian recruitment on floodplains and encouraged riparian encroachment along the low flow channel, which has simplified channel morphology and aquatic habitats. These snowmelt floods and subsequent gradual increases in water temperatures that accompanied the snowmelt recession likely encouraged smolting of juvenile fall-run Chinook salmon, and may have also provided cues for migrating towards the Delta. These floods also distributed juveniles onto floodplains where flood magnitudes were attenuated and inundated floodplain habitat was available for rearing. The near elimination of snowmelt floods has greatly decreased the magnitude, duration and frequency of floodplain inundation, thus decreasing available springtime rearing habitat for juvenile salmonids and other native fishes. Remediating the loss of the snowmelt floods and the geomorphic and ecological functions that it provided will be a significant challenge for future restoration of the San Joaquin River.

7.7.1.5. Snowmelt Recession Limb

The snowmelt recession limb connects the snowmelt floods to the summer baseflows (Figure 7-7). During wetter years, the snowmelt recession extended into July and August in wetter years, but generally ended in June in drier water year types (Appendix A). The timing, magnitude, and duration of the snowmelt recession depended on the water year type, with larger, longer, and later recessions occurring during wetter years than drier years. The snowmelt recession provided many of the same ecological functions as the snowmelt peak floods, but was usually geomorphically less significant than the snowmelt peak floods. Sand transport in downstream reaches certainly occurred, and some channel migration or bank calving may have occurred, but gravel transport in Reach 1 and upstream reaches was probably minimal. Fall-run Chinook salmon smolt outmigration and spring-run Chinook salmon adult immigration occurred during this period, with migration ending as flows decreased and water temperatures increased. The snowmelt recession generally maintained extensive floodplain inundation rearing, particularly important for juvenile and smolting salmonids slowly migrating from spawning grounds through the lower river and into the Delta. Later (and larger) recession limbs extended the duration of lower river and Delta rearing, before water temperatures increased and smolts exited to the ocean. Additionally, the snowmelt recession rate was important factor in whether riparian seedlings survived to establishment phase (discussed more in Chapter 8).

As with the snowmelt flood hydrograph component, the recession has also been eliminated in most water years. In those infrequent years with flood control releases during the historic snowmelt recession, Friant Dam releases are operated such that once the flood control space is achieved, releases to the river are abruptly dropped to summer baseflows. These sudden drops in flow can occur over 1-2 days, which is much faster than the historical recession rates. The loss of the snowmelt recession component has similar ecological impacts as the loss of the snowmelt flood component. Elimination of the snowmelt recession reduced access to complex habitat for emigrating salmonids, likely resulting in decreased growth rates and increased exposure to predation. The steep recession caused by Friant Dam operations at the end of infrequent flood control releases also reduces the survival of cottonwood and willow seedlings that may have initiated during the snowmelt peak (flood control releases). The root system on a seedling on a high surface cannot grow its taproot fast enough to keep up with the rapidly declining capillary fringe, and the seedling dies. The exception is for seedlings that establish along the low flow channel. Because their roots are already at the summer baseflow water table, they survive and often cause riparian encroachment.

7.7.1.6. Hydrograph Component Considerations for Non-Native Species

Changes in seasonal flow patterns may reduce the abundance and distribution of native resident fish species and promote the persistence of non-native fish species. Streams in the western United States may be quickly invaded by non-native fishes when they are dammed and natural fluctuations in seasonal flow patterns are reduced (Moyle 1976, Minckley and Meffe 1987; both as cited in Moyle and Light 1996). Moyle and Light (1996) suggest that established native fish communities can maintain their integrity despite continued invasions by non-native fish where highly fluctuating natural conditions exist, with non-native fish persisting only where habitats have been highly disturbed by human activities (Moyle and Light 1996). Increasing flows in the fall and winter to improve spawning and rearing habitat for Chinook salmon and other anadromous fish does not provide the spring flows needed by resident fish for spawning and rearing (Moyle et al. 1998). Moyle (2002) attributes the decline of hitch in the San Joaquin River at least partially to loss of spring spawning flows. Sacramento splittail are another native cyprinid that spawned on floodplains inundated by spring high flows (Moyle 2002). To improve conditions in Putah Creek (a tributary to Yolo Bypass in the Sacramento Valley) for native resident fish, Moyle et al. (1998) proposed increasing flows in February and March to favor the spawning and rearing of native resident fishes in that stream, and to provide pulse flows every three to five years to reduce numbers of non-native species that are not adapted to high flow events.

7.7.2. Fluvial Processes, Channel Form, and Aquatic Habitat

Contemporary understanding of river ecosystems now recognizes that the underlying hydrology (water) and geology (sediment, techtonics) are the primary governing variables of these systems; how water, sediment, vegetation and human influences interact together (fluvial processes) define the resulting channel form (Figure 7-8). Correspondingly, the resulting channel form defines aquatic and terrestrial habitat within the river corridor, which influences the biota that humans are usually interested in managing. Figure 7-8 can be put in a hierarchical perspective: SUPPLY ➔ PROCESSES ➔ FORM ➔ HABITAT ➔ BIOTA. Changes to the input variables (SUPPLY) in this conceptual system usually cascades down to the biota, but this cascading effect is usually not adequately considered before the change is imposed on the system (e.g., how will Friant Dam impact aquatic habitat downstream of the dam). The primary natural components of the SUPPLY tier are water and sediment, with some influence by large wood. The primary natural components of the PROCESSES tier are sediment transport, sediment deposition, channel migration, channel avulsion, nutrient exchange, and surface water-groundwater exchange. Sediment transport and deposition form alluvial features, including alternate bars and floodplain surfaces. In turn, these channel and floodplain features provide the physical location and suitable conditions that define habitat for aquatic organisms, including native fish species. Channel morphology is thus a critical linkage between physical riverine processes and the native biota that use the river corridor.

Alternating bars are considered basic units of alluvial rivers (Dietrich 1987), and this conceptual framework is also useful in describing links between alluvial river form and aquatic habitat (Trush et al. 2000). Each alternate bar is composed of an aggradational lobe (point bar) and scour hole (pool) connected by a riffle (Figure 7-9). A variable flow regime caused spatial and temporal differences in sediment transport, scour, and deposition on alternate bar features to create morphologic and hydraulic complexity, which in turn produces diverse, high quality aquatic habitat (Figure 7-9), including:

- adult holding habitat in pools;
- preferred hydraulic conditions and substrates for spawning in riffles and pool tails;
- high quality egg incubation environment in permeable, frequently mobilized spawning gravels;
- winter and spring rearing habitat in cobble substrates along slack-water bar surfaces, and in shallow backwater zones behind point bars;
- fry and juvenile velocity refugia and ephemeral rearing habitat on inundated bar and floodplain surfaces during high flows;
- abundant primary and secondary (food) production areas on the surface of gravels and cobbles, on woody debris, and on floodplains (terrestrial invertebrates);
- large organic debris and nutrient input (logs, root-wad, leaf litter, salmon carcasses) that provides structural diversity as well as a primary source of nutrients for lower trophic levels.

A dynamic alternating bar morphology is only one indicator of a properly functioning alluvial channel. Floodplains, terrace complexes, and side channel networks are also key morphological indicators. These depositional features may not be the direct consequence of alternate bar formation, but all are interdependent to varying degrees. As the channel migrates (over a time span of years to decades), large wood is contributed into the channel, cobbles and gravels are deposited on the inside of the bend in the gravel bedded reaches, sand bars are deposited on the inside bend in the sand-bedded reaches, and fine sediment is deposited on developing floodplains at the backside of alternate bars (Figure 7-10). Riparian vegetation initiates on these new floodplain surfaces, and as it matures and the channel eventually migrates again, this mature riparian vegetation is again contributed to the river.

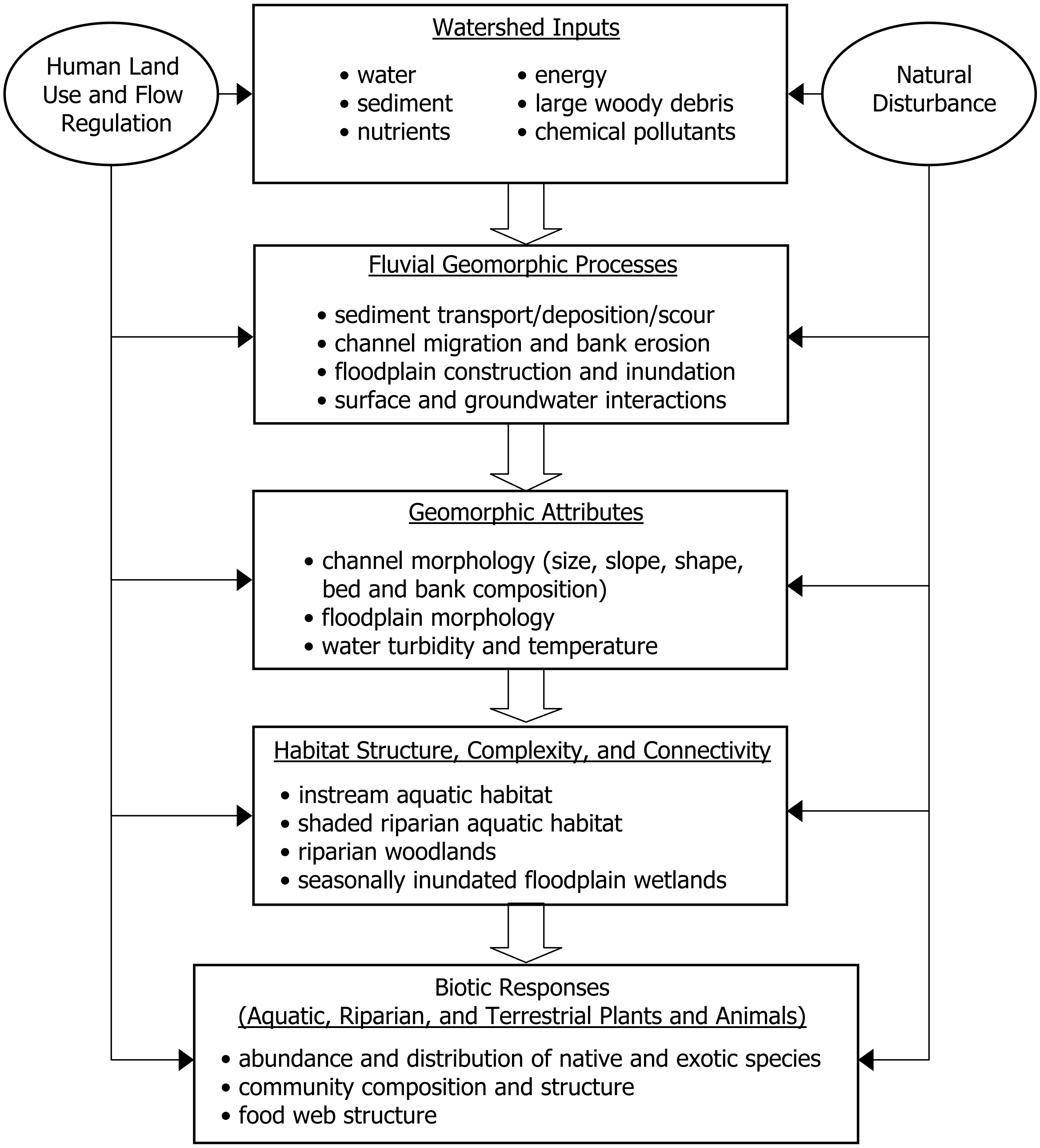
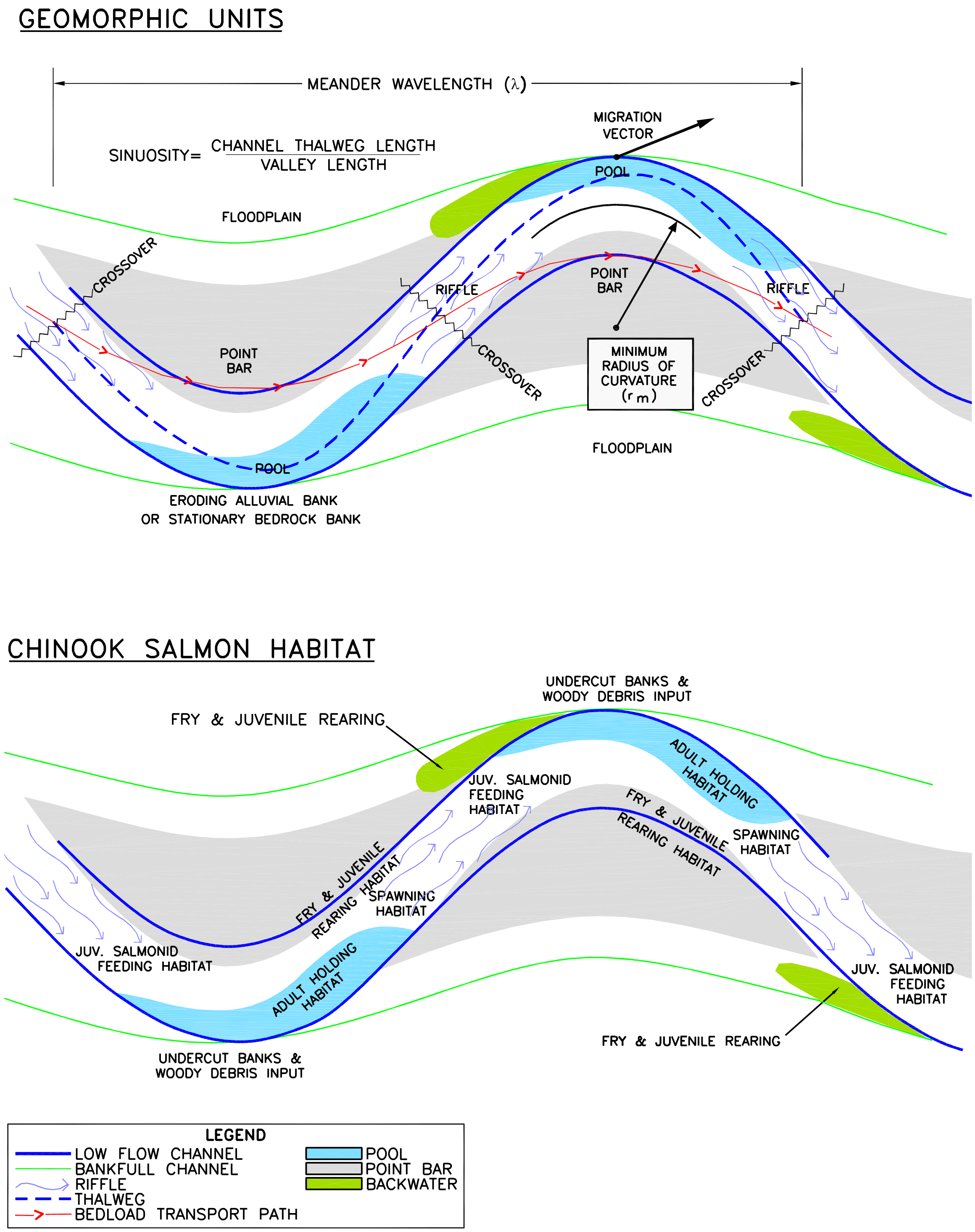


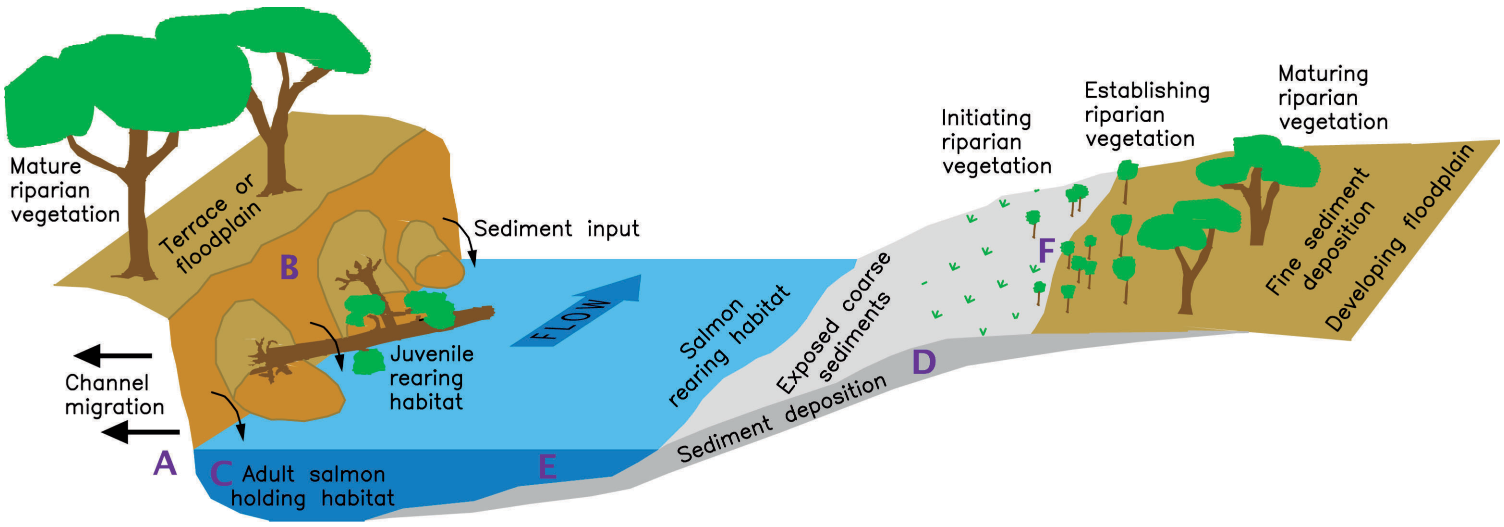
Figure 7-8. A simplified conceptual model of the physical and ecological linkages in alluvial river-floodplain systems.



GEOMORPHIC UNITS

CHINOOK SALMON HABITAT

Figure 7-9. Idealized alternate bar morphology (modified from Dietrich 1987), showing conceptual relationships between alternate bar features and Chinook salmon habitat (modified from Trush et al. 2000).



Conceptual linkages between channel migration and fish habitat. (A) A channel with adequate space to migrate erodes the channel bank on the outside of the meander bend during high flows, (B) encouraging mature riparian trees to topple into the channel. (C) The pool along with large wood on the outside of the bend provide structural complexity for good fish habitat. As bank erosion continues, the pool “migrates” laterally and downstream, but high quality habitat is maintained. (D) On the inside of the bend high flows scour and redeposit sediments (gravel in Reach 1, sand in downstream reaches), forming a shallow bar on the inside of the bend. (E) In Reach 1, this area provides slow-water rearing conditions for fry and juvenile chinook salmon, as well as habitat for aquatic insects (fish food), amphibians and reptiles. (F) Progressively higher up the gravel bar surface, receding water levels during the spring snowmelt allow riparian seedlings to establish. Newly established woody riparian seedlings are sporadically scoured out, but those established high enough on the bank become mature to eventually topple into the channel as the river migrates back across the valley (A). Large floods create scour channels on upper bar surfaces and inundate floodplains, providing juvenile salmon rearing habitat during higher flows.

Figure 7-10. Idealized channel migration process, showing relationship between migration and salmonid habitat contributions by migration.

This idealistic description of alluvial channel dynamics and morphology is much more complex in a natural riverine setting. The San Joaquin River has several reaches (e.g., Reach 1, Reach 4, and portions of other reaches) with multiple split channels, side channels, or sloughs. In Reach 1, these split channels and side channels were likely very important spawning areas, as well as fry and juvenile rearing habitat. Figure 7-11 shows an example of this relatively complex channel morphology in Reach 1 (RM 258.5) in 1938. A larger-scale alternate bar encompasses the entire figure (does not have a dashed box around it), while smaller-scale alternate bars in split channels nested within this larger feature. Riparian vegetation, while evident in the 1938 photograph, does not dominate channel morphology due to frequent high flows, sediment transport, and lateral channel movement. As discussed in Chapter 8, removal of the high flow disturbance regime often results in the riparian vegetation establishing and maturing along the low flow channel (riparian encroachment), which has a net result of simplifying channel morphology and reducing habitat quantity, quality, and diversity. The 1938 photograph attempts to illustrate the habitat benefits of the historic channel morphology and historic hydrologic regime: baseflows provide adequate spawning and rearing habitat, but as flows increase during storm events or snowmelt runoff, flows spill into side channels, high flow scour channels, and floodplains to provide additional habitat and/or high water velocity refugia.

In reaches downstream of that shown in Figure 7-11, the river loses confinement from the bluffs and terraces in Reach 1, and enters the valley floor of the Central Valley. As described in Chapter 3 and Chapter 8, the valley floor over the study reach was an extensive flood basin that frequently had prolonged inundation, particularly in during the spring snowmelt runoff period. Numerous sloughs, oxbows, and high flow scour channels in these downstream reaches (in addition to the flood basins and tule marshes) likely provided enormous amounts of salmonid rearing habitat during winter and spring months. These inundated flood basins and tule marshes provided substantial habitat for other native resident fish species, including threadfin shad and others. Due to the limited amount of historical temperature data available in these downstream reaches, it is unknown how late into the spring and summer that water temperatures would have been low enough to support salmonids, although there may have been local artesian springs and groundwater seeps that may have provided local refugia.

This historical channel morphology, and the habitat provided by it, was radically changed with the arrival of Euro-Americans in the late 1700's, culminating in the river conditions of the present. The frequency and distribution of habitat types and micro-habitat features have changed substantially compared to historical conditions. A reach-by-reach description of channel and floodplain changes, and the potential impacts to different life stages of anadromous salmonids as well as native fish species is provided below.

7.7.3. Changes in Fluvial Processes and Channel Morphology

The historical descriptions of fluvial processes and channel morphology contained in Chapter 3 and summarized above have been severely altered by Euro-American activities, which have had corresponding impacts to fish habitat and life history. There is very little site-specific information available on the San Joaquin River to describe these changes; therefore, our description below relies heavily on observations of impacts on tributaries to the San Joaquin River where one would expect the impacts to be similar.

7.7.3.1. Channel Morphology

There have been many changes to channel morphology over the study reach, with the most pronounced as follows:

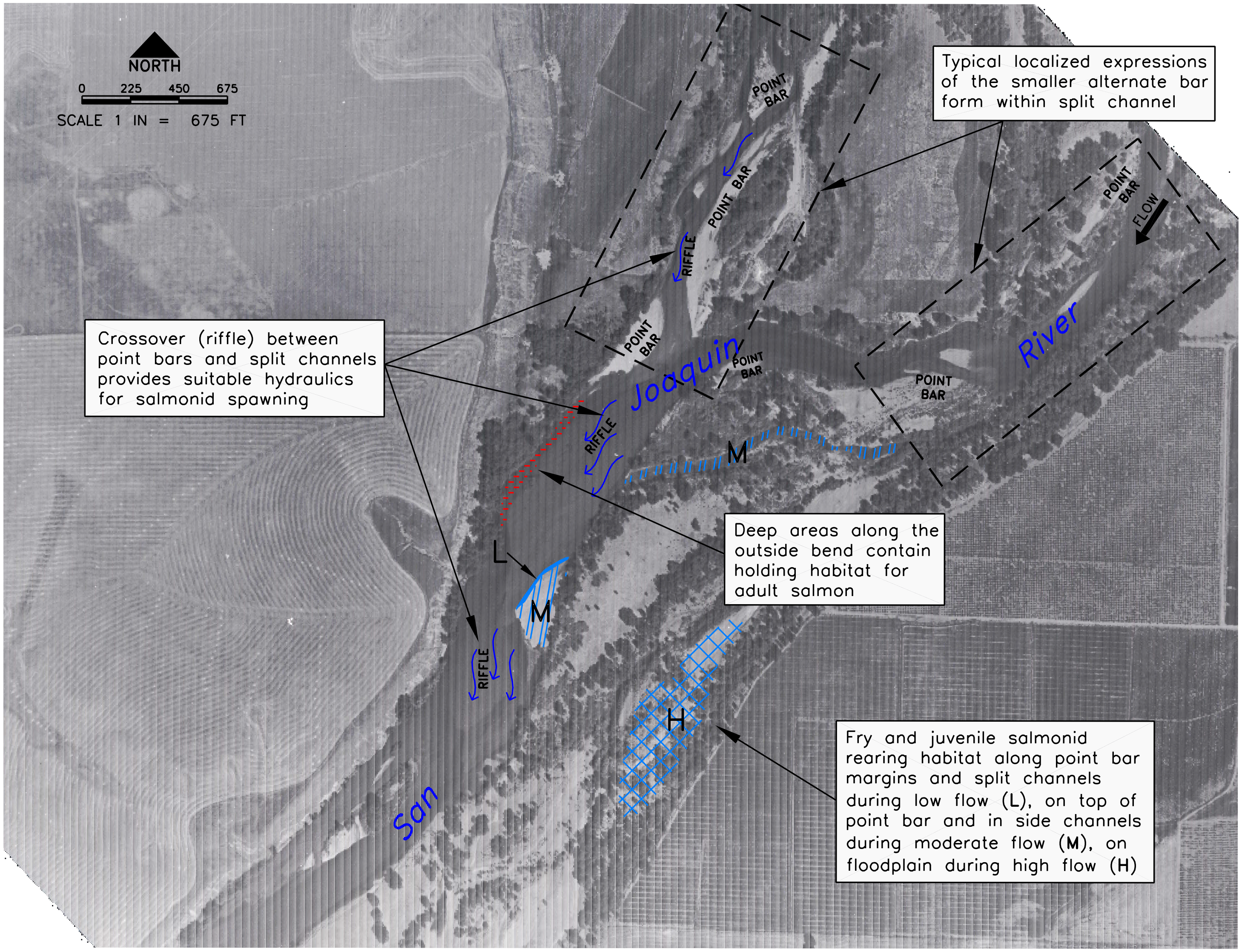


Figure 7-11. 1938 aerial photograph of the San Joaquin River in Reach 1 (RM 258.5) showing diverse alluvial features of the historic San Joaquin River channel that provided different habitat components for Chinook salmon. Similar channel form-habitat linkages exist for other native fishes, but are not shown on this figure.

- Reach 1: Pits from instream gravel mining, loss of exposed gravel bars and floodplains from "off-channel" gravel mining, riparian encroachment, probable accumulation of fine sediment in the channel, and probable small amount of channel incision
- Reach 2-4: Agricultural encroachment has reclaimed floodplains, levees confine the river during high flows and reduce inundated floodplain, and riparian encroachment (except in Reach 2).
- Reach 5: Project levees confine the river during high flows

Implications of gravel mining pits on salmonids in Reach 1 include impacts to coarse sediment routing, direct loss of spawning and rearing habitat, and predation. As has been demonstrated on the Tuolumne River, these pits provide habitat conducive to fish species that prey on juvenile salmonids, such as largemouth, smallmouth, and red eye bass (EA Engineering, 1991b). Gravel pits have also converted what was historically lotic habitat, to lentic habitat that may provide habitat for Sacramento pikeminnow. Direct loss of spawning habitat by gravel mining, combined with blocked access to upstream spawning areas and loss of upstream gravel supply by Friant Dam, has likely greatly reduced the historical quantity of spawning habitat on the San Joaquin River. Rearing habitat was also significantly reduced by the direct loss of habitat from gravel mining, as well as loss of floodplain access, loss of side channels, and reduced flows. Pools used for spring-run Chinook salmon holding over the summer downstream of Friant Dam still remain; however, field observations may suggest that they may have partially filled in with sand and gravel as a result of the reduced flow regime after Friant Dam was completed, although there is no quantitative data to evaluate this. There has been additional field reconnaissance to evaluate the quantity and suitability of potential holding pools in Reach 1 as part of the restoration strategies, but the results have not been summarized to date.

Habitat conditions for salmonids in Reaches 2 through 5 have been substantially modified by levee/dike construction, agricultural encroachment, and water diversions. These have reduced the quantity of floodplain habitat, as well reduced main channel complexity and off-channel habitat in these reaches. Because these reaches are sand bedded, the primary impact to salmonids has been a decrease in the amount of complex rearing, refuge, and foraging habitat for juvenile salmonids during the winter and early spring months. Floodplain habitat in these downstream reaches of the San Joaquin River was historically extensive and vegetated with tule marsh, with narrower bands of willow, cottonwood, box elder, and Oregon ash along the channel margins and flood basin margins (see Chapter 8 for more description). Much of this floodplain habitat has been isolated from the river by dikes and levees, and that remaining floodplain habitat is rarely inundated under current hydrologic conditions. Under current conditions, juvenile anadromous salmonids produced in Reach 1 would be forced to rear in the main channel, and based on recent research of juvenile growth rates on inundated floodplains (Sommer et al. 2001), growth rates in the main channel may be less than historically occurred on inundated floodplains, with increased predation mortality and increased vulnerability to displacement by high flows. Developing a strategy for juvenile rearing and growth will be an important component of the restoration strategies developed as part of the Restoration Study.

Habitat conditions for native warm water fish have likewise been negatively impacted in Reach 2 through 5. Shallow floodplain and lake habitats historically present on the San Joaquin Valley floor provided warm, productive shallow-water habitat with dense vegetative cover for spawning and rearing of native fish. Floodplain and off-channel habitat in Reaches 4 and 5 would have provided substantial areas of vegetated floodplain habitat used by Sacramento splittail, Sacramento perch, and Sacramento blackfish for spawning, rearing, and overwintering. Fry and juvenile fish dispersed in these habitats would have been less vulnerable to predation by larger fish that reside in deeper, main-channel habitats. These shallow-water habitats have been substantially reduced in area from historical conditions. Loss of these shallow vegetated habitats, combined with the introduction of numerous non-native predaceous fish have likely worked in combination to reduce the abundance and distribution of several native fish species, particularly Sacramento splittail. Other species that likely used floodplains for spawning, including Sacramento blackfish and Sacramento suckers, appear to be doing well, although they may not be as abundant as they formerly were on the valley floor (Moyle 2002). Deeper oxbow lakes and off-channel pools in floodplains may have provided oversummering habitat and areas where fish might persist during periods of extended drought; the loss of these oxbows may also have affected native fish populations.

7.7.3.2. Sediment Supply and Spawning Gravels

Sediment is supplied to rivers as a result of erosional processes in headwater streams and tributaries. In addition to erosion/transport processes, the bed and banks of alluvial rivers also supply the channel with sediment. In concept, an alluvial channel morphology is maintained in a “dynamic quasi-equilibrium” by transporting its sediment load downstream at a rate approximately equal to the sediment supply (Lane 1955). This process maintains the channel in a generally constant form over time, despite the continual routing of sediment through the system. Sediment moving through the system is intermittently stored in depositional features such as gravel and cobble point bars in Reach 1, sandy point bars in Reaches 2 through 5, or on floodplains and terraces in all reaches. These sediment deposits become sorted by particle size and provide an additional level of complexity and habitat for aquatic organisms. The most obvious example is salmonid spawning gravels.

As described in Chapter 3, Friant Dam has eliminated sediment supply from the upper watershed, and combined with the modified flow regime and land used downstream of Friant Dam, varying degrees of sediment budget imbalance has occurred in downstream reaches. These local imbalances have caused local aggradation (sedimentation) and degradation (incision) over the reaches, which can have significant consequences for the channel morphology within the study reaches. The current paradigm of dam impacts to sediment supply downstream of the dams is that periodic high flow releases from the dam transports sediment stored in the bed, and because the sediment supply from the upper watershed is blocked, channel degradation occurs downstream of the dam (Collier et al., 1996). Instream gravel mining would exacerbate this sediment deficit. However, the low slope in Reach 1 probably resulted in very low coarse sediment transport rates, and combined with intermittent bedrock control in the upper portions of Reach 1, the amount of channel degradation has probably been fairly modest. Cain (1997) reports 1939-1996 thalweg elevations increasing at two cross sections by approximately 3 feet, with thalweg elevations at the remaining six cross sections lowering between 5 feet to 18 feet due to a combination of dam impacts and gravel mining. Typically, if unreplenished from upstream sources, alluvial features (bars and riffles) slowly diminish, causing channel widening and bed degradation. Smaller particle clasts, such as spawning gravels, are more readily mobilized, and spawning gravel storage in reaches below Friant Dam may have gradually been reduced over time. The combination of reduced sediment storage and blocked supply has likely reduced the amount of suitable spawning gravel and habitat in Reaches 1 and 2 relative to historical conditions.

Clark (1942) conducted detailed surveys of the San Joaquin River for available spawning gravel, though it is not clear what criteria were used to determine suitability. An estimated 417,000 ft^2 of suitable spawning gravel was found in 26 miles of channel between Lanes Bridge (RM 255) and the Kerchoff Powerhouse (14 miles upstream of Friant Dam), where most spawning was historically observed (Table 7-5). Friant Dam inundated 36% of this spawning gravel estimate, leaving about 266,800 ft^2 of suitable spawning gravel in the channel in the reach between Lanes Bridge and Friant Dam. In 1943, an estimate of 1,000,000 ft^2 of suitable spawning gravel at 350 cfs was made in the reach between Gravelly Ford and Friant Dam (38 miles of channel) (Fry and Hughes 1958, as cited in Cain 1997). In 1957 Ehlers (R. Ehlers, pers. comm., as cited in Cain 1997) estimated over twice as much (2,600,000 ft^2) of suitable spawning gravel occurred in the same reach, only 70% of which (1,820,000 ft^2) was useable for spawning. By the late 1950s, CDFG (1957) was concerned that heavy silt and sand deposited by gravel mining operations was damaging the last of the available suitable spawning habitat, which at that time they believed was confined to the 13 miles below Friant Dam (Reach 1 upstream of Lanes Bridge).

Several recent estimates of spawning gravel quantity have been made. Cain (1997) estimated a total of 303,000 ft^2 of spawning gravel between Gravelly Ford and Friant Dam (Table 7-5). Most riffles in this reach were described as having suitable gravels, and Cain (1997) attributed the decline of spawning gravel in this reach to effects of Friant Dam, gravel mining operations, and riparian vegetation encroachment.

In summer and fall of 2000, Jones and Stokes Associates (JSA) and Entrix conducted surveys of potential spawning gravel in the upper San Joaquin River. Areas considered suitable were delineated, recorded on aerial photos, and transferred to a GIS. These surveys estimated 773,000 ft^2 of spawning habitat for salmon and steelhead available between Friant Dam (RM 267) and Skaggs Bridge (RM 234), of which 408,000 ft^2 contained less than 40% fines based on ocular estimates (Table 7-4).

In spring 2002, a second survey was conducted to map suitable spawning gravel in the reach from the RM 267 (Friant Dam) to RM 243 (Highway 99). Spawning habitat suitability was based on the depth, velocity, and substrate requirements for Chinook salmon and steelhead, as described in detail in Appendix B. Thirty-nine riffles were observed in the 12 miles of river between Lanes Bridge and Friant Dam, and an additional 26 riffles were observed in the 12 miles of river between Highway 99 and Lanes Bridge. Many riffles were composed of two or more sub-patches, often varying in substrate quality and hydraulic suitability. Over 357,000 ft^2 of suitable spawning gravel was delineated between Highway 99 Bridge and Friant Dam, of which approximately 281,400 ft^2 of suitable spawning gravel occurred between Lanes Bridge and Friant Dam (Table 7-5). Riffles were typically small (average = 5,500 ft^2) and infrequent. Many riffles were adjacent to suitable rearing habitat, particularly upstream of Lanes Bridge, but very few riffles were adjacent to suitable holding habitat. Substrate was generally well-rounded, with low embededdness, and low fines. There appeared to be a high proportion of coarse sand (>0.08 inches) upstream of Lanes Bridge, and a higher proportion of fine sand (<0.08 inches) downstream of Lanes Bridge. Table 7-5 summarizes spawning gravel quantity estimates from Friant Dam to Gravelly Ford as reported both historically and currently.

Table 7-5. Summary of anadromous salmonid spawning habitat estimates on the upper San Joaquin River.

Source	Date of survey	Extent of survey	Estimate 1 (ft^2)	Estimate 2 (ft^2)
Clark (1942)	1942	Lanes Bridge (RM 255.2) to Kirkhoff Powerhouse (281.5)	417,000	266,800[a]
Fry and Hughes (1958)	1943	Gravelly Ford (RM 229) to Friant Dam (267.5)	1,000,000[b]	none
R. Ehlers, pers. comm., in Cain (1997)	1957	Gravelly Ford (RM 229) to Friant Dam (267.5)	2,600,000	1,820,000[c]
Cain (1997)	1996	Gravelly Ford (RM 229) to Friant Dam (267.5)	303,000	none
Jones and Stokes Assoc./Entrix, this document	2001	Friant Dam to Skaggs Bridge	773,000[d]	408,000[d,e]
Stillwater Sciences, this document	2002	Friant Dam to Highway 99 Bridge	357,000[f]	281,400[a,f]

[a] spawning habitat between Lanes Bridge and Friant Dam (RM 267.5)

[b] estimated at 350 cfs, so incorporated hydraulic suitability

[c] 70% of 2,600,000 ft^2 was suitable, presumable criteria was quality (limit of fines in gravel)

[d] included gravel beyond the baseflow channel (e.g., on point bars, etc.), probable over-estimate

[e] based on portion of spawning gravel with less than 40% fines (ocular estimate)

[f] incorporated hydraulic suitability at potential spawning baseflows

Between Friant Dam and Lanes Bridge (12 miles of channel), historical estimates of spawning gravel quantity of 266,800 ft^2 (Clark 1942) are mostly comparable to current estimates of 281,400 ft^2 (based on recent surveys, and assuming use of similar suitability criteria). Looking at a more expanded reach between Friant Dam and Gravelly Ford (38 miles of channel), historical estimates of 1,000,000 ft^2 and 1,820,000 ft^2 (Ehlers 1957, Fry and Hughes 1958, both as cited in Cain 1997) are significantly greater than current estimates of 303,000 ft^2 (Cain 1997). The various spawning gravel surveys are somewhat difficult to compare due to differing (or unknown) suitability criteria and methods, so a conclusion cannot be confidently made to the degree of spawning habitat loss. Simple review of historical photographs and obvious effects of gravel mining impacts dictates that some significant loss of suitable spawning habitat has occurred. Further, infiltration of fine sediment from gravel mining and other fine sediment sources downstream of Friant Dam, as well as high water temperatures during the fall in downstream portions of Reach 1 may reduce the incubation success of salmonid eggs. However, the impact of reduced spawning gravel quantity and quality on future salmon populations has not been quantified, and can only be properly evaluated in relation to other potential limiting factors.

7.7.3.3. Channel Migration and Avulsion

Channel migration and avulsion are typically considered undesirable because migration can damage human structures (bridges, etc.), cause property loss on the eroding bank, and reduce agricultural production. However, as described above, channel migration and avulsion was a critical process for salmonid habitat, as well as for riparian regeneration and large wood debris recruitment into the channel. The steady conversion of land for agricultural production, and correlated levees and dikes, has channelized the river channel. Agricultural conversion has directly reduced the amount of floodplains, and levees and dikes have further isolated historic floodplains from the channel. Additionally, bank protection along channel margins and reduced flow regime has stabilized the channel, reduced bank erosion, reduced lateral migration, and greatly reduced the processes that create complex side channels and high flow scour channels.

Impacts of these activities to fish habitat has been significant. Undercut banks, riparian vegetation, and recruitment of large woody debris have all been reduced or eliminated as a consequence of channel stabilization, and the corresponding habitat benefits realized by these processes have been largely eliminated. Reduced channel migration has eliminated off-channel habitats, reduced complex side channels, and reduced instream habitat complexity for native fish species. The loss of undercut banks and large woody debris reduces cover and velocity refuge for salmonids, increasing exposure to predation and high flows. The loss of riparian vegetation recruitment may contribute to increased stream temperatures, and reduced complexity during the now rare periods of floodplain inundation. Overall, reduced channel migration has contributed to conditions in which future salmonids produced in the river would be forced to rear in a simplified channel, possibly reducing growth rates and increasing exposure to predation.

7.7.4. Habitat Connectivity

7.7.4.1. Physical Barriers

Physical structures and environmental conditions can reduce habitat connectivity and migratory access between habitats. Upstream and downstream movement past physical structures such as dams or weirs requires depth and velocity conditions conducive to unimpeded passage. If structures are not designed to provide passage, fish ladders or other modifications may be necessary to provide conditions that attract migrating fish and enable them to pass successfully. Signicifant structures in the study area that are impediments to both upstream and downstream fish movement are illustrated in Figure 7-12, and include:

- a weir located just upstream of the confluence with the Merced River (RM 118) to direct migrating adult salmonid into the Merced River and prevent them from entering the San Joaquin River, which has been operated by the California Department of Fish and Game since 1950;
- a drop structure on the Eastside Bypass near its confluence with the San Joaquin River (RM 138);
- a drop structure on the Mariposa Bypass near its confluence with the San Joaquin River (RM 147.6);
- culverts with slide gates on the San Joaquin River at the confluence at the Sand Slough Control Structure (RM 168);
- a drop structure at the upper end of the Eastside Bypass near its confluence with the San Joaquin River (RM 168);
- Sack Dam, a diversion dam for the Arroyo Canal (RM 182);
- Mendota Dam, delivery point of the Delta-Mendota Canal and diversion point for several irrigation canals and pumps (RM 205);
- radial gates and control structure on the Chowchilla Bifurcation Structure on the San Joaquin River and Chowchilla Bypass (RM 216);
- at least one earthen diversion dam just downstream of Gravelly Ford (RM 227);
- culverts on the San Joaquin River between the gravel-mining ponds (RM 253);
- Friant Dam, primary storage dam on the San Joaquin River and upper limit of potential salmonid migration (RM 267.5).

Fish ladders are on Mendota Dam and Sack Dam; however, the fish ladder on Mendota Dam would require substantial modification for it to function properly. The fish ladder at Sack Dam is in good condition, and would only require placement of flashboards and other minor modification for it to function well. The other impediments listed above would require substantial modification to provide adequate fish passage.

In addition to physical barriers such as dams and gates, other environmental conditions such as high water temperature or salinity, or low instream flows (discussed below), may impede or eliminate access. For example, in 1994, the Central Valley Regional Water Quality Control Board (CVRWQCB) classified the San Joaquin River Deep Water Ship Channel (DWSC) near Stockton, as Clean Water Act 303(d) impaired because dissolved oxygen (DO) concentrations routinely fell below the water quality objective in the fall (CVRWQCB 1998). Low dissolved oxygen concentrations in the DWSC may cause delays in the onset of upstream migration until later in the fall when DO concentrations improve. The 303(d) listing requires that a total maximum daily load (TMDL) be developed to control the loads/conditions that cause violations of the DO Water Quality Objective. Adult salmon migrating upstream from the Delta may also encounter near-lethal stream temperatures that would delay migration until temperatures decline.

7.7.4.2. Flow Continuity

In the San Joaquin River, a variety of structures and channel modifications disrupt flow continuity under current conditions. Flow continuity refers to the need for unbroken depth and velocity conditions that enable species movement between channel types and between reaches. Poor flow continuity and dewatered channels, particularly in Reaches 2 and 4, inhibits fish passage between Reaches 1 and 5. Reaches 2 and 4 are typically dry, restricting fish migration through these reaches and access to upstream or downstream habitats. Friant Dam releases flows for downstream riparian diversions, and releases enough flow such that a minimum flows of at least 5 cfs flows past the last riparian diversion (near Gravelly Ford, top of Reach 2). The lower part of Reach 2 (Mendota Pool) and Reach 3 receive water year-round from the Delta Mendota Canal (DMC). Water released from Mendota Dam maintains flow through Reach 3. There is no base-flow requirement below Sack Dam at the bottom of Reach 3, however, leaving Reach 4 dry much of the time. Irrigation return flows and stormwater runoff do not compensate for the water lost to irrigation (Hazel et al. 1976 *in* Saiki 1984, Friant Water Users Authority 1992). Flow in Reach 5, dominated by DMC releases much of the year, is maintained by storm and agricultural runoff from Bear Creek, Salt Slough, and Mud Slough.

7.7.4.3. False Migration Pathways

False migration pathways lead fish away from the life history trajectory (pathway) that would otherwise allow it to survive, grow, and complete its life cycle. Fish may be passively diverted into false pathways or, when attracted by flow conditions, may actively move into a false pathway. Canals divert juvenile migratory fish and others along false pathways, removing individuals from the population (Figure 7-12). Mendota and Sack Dams play an important role in diverting water for irrigation. The San Joaquin River also has an extensive system of bypasses that divert and carry water around the mainstem San Joaquin River channel. Bypasses lead fish away from their required habitat and expose them to higher water temperatures, low dissolved oxygen concentrations, high dissolved salts, and high risks of predation. The Chowchilla Bypass is the primary bypass on the San Joaquin River and diverts floodflows from the San Joaquin River at Gravelly Ford (Reach 2). Other potential false pathways created by the bypass and levee system are Salt Slough, Mud Slough, Bear Creek, Ash Slough, Berenda Slough, Dry Creek, Fresno River, Lone Willow Slough, Mariposa Bypass, East Side Bypass, Arroyo Canal, Main Canal, other canals, and Little Dry Creek (Figure 7-12). Gravel-mining ponds in Reach 1 may also be minor false pathways that can confuse downstream and upstream migrating fish and delay migration.

In addition to false pathways between Friant Dam and Hills Ferry, water diversions and pumping facilities in the Lower San Joaquin River and Delta modify natural currents and direction of flows through migration pathways in this area. These diversion structures are discussed in Chapter 12.

7.7.4.4. Effects of Loss of Habitat Connectivity on Native Fish

The loss of habitat connectivity has likely had the greatest single impact on anadromous salmonids in the San Joaquin River. Chinook salmon and steelhead are currently blocked from migrating into the upper reaches of the San Joaquin River where they historically spawned and reared. Although they are not complete barriers at all flows, Mendota Dam and Sack Dam are major barriers to both upstream and downstream movement of fish. Adult fall-run Chinook salmon migrating up the San Joaquin River historically arrived at Mendota Dam and Sack Dam during low flows in late summer, when they formed nearly complete barriers to migration. Adult spring-run Chinook salmon migrated upstream during high spring flows when Sack Dam was dismantled and Mendota Dam had better passage conditions]. The construction of Friant Dam in 1941 prevented salmon from accessing historical holding, spawning, and rearing habitat upstream of RM 267.

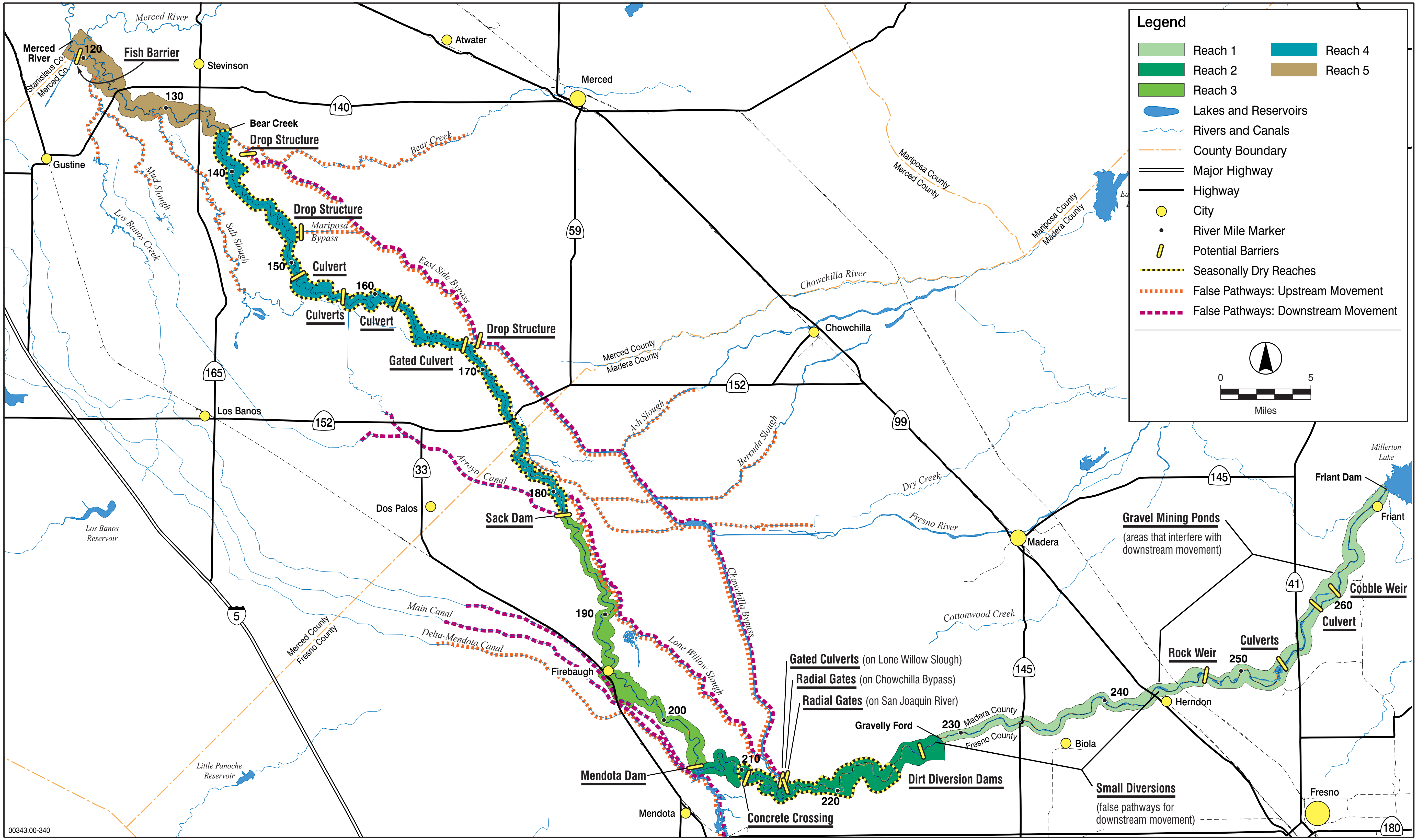


Figure 7-12. Potential and probable salmonid migration barriers along the San Joaquin River study reaches.

In most years, Reaches 2 and 4 are dry (Jones & Stokes Associates 1998), restricting migration through these reaches and access to upstream or downstream habitats. For example, a record run of 56,000 spring-run Chinook salmon was observed in 1948, after closure of the dam (Fry 1961). However, the fry from the record run were stranded in a dry reach below Sack Dam during their outmigration due to increased water diversion to meet demands in the lower valley during that year. In 1950 the last run of spring-run Chinook salmon was observed, by which time increased diversions from Friant Dam consistently eliminated flows in about 60 miles of river below Sack Dam (Yoshiyama et al. 1998), eliminating habitat connectivity for anadromous salmonids between their spawning grounds and the Delta.

False pathways lead fish away from the life history trajectory (pathway) that would otherwise allow it to survive, grow, and complete its life cycle. False pathways affect both upstream and downstream fish movement. During upstream movement, flow may attract fish into drains and bypasses that do not provide habitat because spawning substrate or cover, food availability, water temperatures, dissolved oxygen concentrations, salinity, and other environmental conditions are unsuitable. If upstream habitat exists, such as in a bypass that reconnects to the main river, barriers may block or delay upstream movement, and potentially result in mortality.

Canals generally do not provide habitat that can sustain populations of most fish species, and frequently end in an irrigated agricultural field. Bypasses may not provide environmental conditions that support movement to downstream habitat, especially if flow entering the bypass is interrupted and fish are stranded. Fish may also be adversely affected by increased vulnerability to predation or poaching. Appropriately designed fish screens and timing of barrier and diversion operations can minimize movement of downstream-migrating fish into bypasses, canals, and other diversions.

Currently unscreened canals could divert juvenile anadromous salmonids, lamprey, and other fish into habitats and agricultural fields where they would not survive, removing individuals from the population (Figure 7-12). The San Joaquin River also has an extensive system of bypasses that divert and carry water around the mainstem San Joaquin River channel. Bypasses lead fish away from suitable habitat and expose them to higher water temperatures, low dissolved oxygen concentrations, high dissolved salts, and areas where large non-native predaceous fish may be more common. Gravel-mining ponds in Reach 1 may also delay fish during upstream and downstream migration because they lack the strong directional flow that would be found in natural stream reaches. The individual impacts of the numerous unscreened water diversions, false pathways, and canals, on juvenile and adult salmonids will be evaluated during the development of restoration strategies.

Modifications to natural flow directions and flow reversals in the Delta that result from potentially alter migration. Outmigrating juvenile salmonids follow the direction of flow, and upon encountering reverse flows may reverse direction, delaying migration and increasing potential mortality. Effects of changes in Delta dynamics on native fish are discussed in Section 7.7.9.

Habitat connectivity for resident native fish has been reduced by physical barriers, reaches with poor water quality, the presence of predator fish populations, or other factors. Habitat fragmentation may isolate subpopulations and increase potential for their extirpation during catastrophic natural or anthropogenic disturbances, reduce genetic exchange between subpopulations, and reduce the potential for long-term persistence for species in the Central Valley as a whole. Tule perch have been extirpated from most of their native range within the San Joaquin basin and exist only as isolated populations that are extremely vulnerable to extinction from natural or anthropogenic disturbances (Moyle 2002). Water quality may affect their ability to persist in some areas of the valley (Moyle 2002). Hitch populations in the San Joaquin basin also appear to be increasingly isolated from each other (Moyle 2002).

Many native cyprinids and Sacramento suckers make upstream spawning migrations within their home stream or from larger reaches or lakes and reservoirs into tributaries to spawn. The juveniles of these species may require a period of rearing in these habitats to avoid predation that might occur in the habitats occupied by the larger adults. Barriers to resident fish movements may result in spawning in habitats where substantial predation on fry and juvenile fish may occur.

7.7.5. Water Quality

The historical water quality of the San Joaquin River likely provided suitable conditions for native fish, including anadromous salmonid populations. Cold, clear snowmelt runoff flowing from the granitic upper-basins of the southern Sierra Nevada provided optimal conditions for freshwater life-history stages of salmonids in the upper San Joaquin River, and for invertebrate production, the primary food resource for salmonids. The abundant cold water in the upper San Joaquin River also had high (saturated) dissolved oxygen concentrations, low salinity, and neutral pH levels. Suspended sediment and turbidity levels were low, even during high runoff events, due to the predominantly granitic geology in the upper San Joaquin River basin. Historically, warm water temperatures occurred in the lower San Joaquin River in the summer, influenced by low summer baseflows and high ambient air temperatures.

As reported in Chapter 6, water quality in the San Joaquin River has changed dramatically in many locations. While relatively good water quality probably still exists upstream of Millerton Reservoir, and water quality is generally quite good in Reach 1 below Friant Dam, water temperatures downstream of Friant Dam are severely degraded by numerous factors. For example, temperature stratification in Millerton Reservoir maintains fairly constant year-round instream release temperatures between 50°F to 60°F, but the decreased flow rates in most seasons has subsequently allowed more rapid increases in water temperature in Reaches 1 and 2.

7.7.5.1. Temperature

Water temperature has a direct influence on fish populations. Virtually all-biological and ecological processes are affected by ambient water temperature (Spence et al. 1996). Not only does temperature directly influence life history timing, habitat suitability, and the survival of individual fish in certain circumstances, but the indirect (and cumulative) effects of water temperature as manifested by reduced growth rates, altered life history timing, increased rates of infection, metabolic stress, and mortality from disease, increased DO, and toxic chemicals, and increased exposure to predators better adapted to warm water temperatures, all influence the production of juvenile salmonids. Incredibly, despite the central importance of water temperature to salmonids, much less research has been devoted to this subject than many other parameters or life-history stages (Myrick and Cech 2001) in the Central Valley.

In the San Joaquin River basin, low water temperatures are rarely a concern because of the extremely low frequency of periods of extreme cold in areas used by salmonids. However, warm water temperatures (exceeding 70^{o}F) are an important management concern. Hot summer ambient temperatures combined with low summer baseflows result in elevated summer and fall water temperatures in reaches 2 to 5.

The temperature of water released from Friant Dam is controlled by two outlets delivering water to the Friant fish hatchery. Minimum annual temperatures recorded at the hatchery in winter months range between 45°F and 50°F from January through March. Hatchery water temperatures increase during the spring from about 50°F to 55°F by the end of June. Summer hatchery temperature remains below 60°F, with the maximum daily temperatures often recorded at the end of September.

Water temperatures below Friant Dam increase rapidly during hot summer months. In general, mean monthly temperatures under the current flow regime remain suitable for salmonids and other temperature-sensitive fish species (<65°F) from November to April in most years, with temperatures rising above 68°F from May through October. Note that these mean monthly values do not reflect daily or monthly maxima at these sites, which can be much higher with resulting fish kills in the absence of cold water pools or other refugia for fish. Table 6-6 shows a compilation of the daily temperature record at Vernalis with mean temperature, and the maximum and minimum temperatures recorded at this station for the entire period of record (1961–2000). The maximum temperatures recorded at Vernalis above 68°F occurred in the period between April 1 and November 1, with daily maxima occasionally approaching 85°F).

7.7.5.2. Suspended Sediment and Turbidity

In most streams, there are periods when the water is relatively turbid and contains variable amounts of suspended sediment, and other periods when water is relatively clear. Turbidity and total suspended solids (TSS) are closely related. Turbidity is an optical property (light scattering), and is not a major health concern by itself. But high turbidity can interfere with temperature, DO, photosynthesis, the feeding habits of aquatic species, and is associated with total metals loadings and sorption of contaminants from the water column. TSS and turbidity sources to the San Joaquin River include suspended sediment from storm-generated tributary inflows, agricultural return flows, bank erosion, resuspension of sediments during high flows, and summer algae production.The effects of suspended sediment and turbidity on fish and aquatic life have been fairly well documented (e.g., Newcombe and MacDonald, 1991).

Historical data on suspended sediment and turbidity levels are not available for the San Joaquin River prior to 1960. It is probable that the San Joaquin River (and tributaries) historically carried relatively low suspended sediment loads and generally had low turbidity levels due to the predominantly granitic geology of the upper basin as well as relatively low rates of primary productivity (algae growth). Perhaps the best description of the historical turbidity levels in the upper river is from Blake (1857 quoted in 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.”

The USGS gauge at Vernalis (USGS STN # 11-303500) provided daily average suspended sediment data from 1960 to 1996. Although our research was not exhaustive, we found no other sites upstream of Vernalis with suspended sediment or turbidity data. Data from the Kings River and Cosumnes River were also evaluated. The San Joaquin River at Vernalis data were plotted as daily average suspended sediment concentrations over the water years where suspended sediment was measured. These graphs indicate that daily average suspended sediment concentrations exceeded a lower threshold of 84 mg/L in all years (1960–96), exceeded 200 mg/L in 27 out of 36 years, and exceeded 500 mg/L in 9 out of 36 years. Many of these concentrations were chronic (long-duration exposure times). On average, for the period of record, daily average suspended sediment concentrations exceeded 100 mg/L during 95 days out of every year. By comparison, daily average suspended sediment data for the Cosumnes River at Michigan Bar (USGS STN # 11-335000; 1962–1970) exceeded 100 mg/L on average during only 10 days per year. Sedi-graphs for the Cosumnes also appear much flashier, indicating that suspended sediment loads are more closely associated with short-duration storm events as opposed to chronic exposure periods that are potentially much more harmful to fish. Chapter 6 provides additional information on the available historical and current suspended sediment conditions in the San Joaquin River.

Newcombe and MacDonald (1991) developed a concentration-duration response model to assess the environmental effects caused by chronic exposure to elevated concentrations of suspended sediment.

Their data review summarized effects of suspended sediment concentration and exposure duration on Chinook salmon, including gill hyperplasia and poor condition of fry at 1.5 mg/L to 2.0 mg/L (60 day exposure duration), reduction in growth rates in the range of 6 mg/L to 84 mg/L (60 to 14 day exposure duration), and 50% mortality of smolts at 488 mg/L (4 day exposure duration). Numerous additional studies have been conducted that document the effects on rainbow trout as well as other salmonid species, but are not presented here.

Newcombe and Jensen (1996) provide a synthesis of literature describing fish responses to suspended sediment in streams and rivers. Their research describes suspended sediment concentrations and exposure durations (sediment doses) that achieve a range of effects from no effect, behavioral effects, sublethal effects (including short-term reductions in feeding success), and lethal/paralethal effects (including direct mortality, reduced growth, reduced fish density, delayed hatching, habitat damage, etc.). They develop quantitative metrics (dose-response equations) that allow researchers and managers to document the sediment concentration and duration of exposure, and use these data to infer the most probable severity of impact to aquatic resources. Applying the above Vernalis data to the Newcombe and Jensen model (1996) shows that the long-term daily average suspended sediment concentrations of 100 mg/L for an average of 95 days/year would result in a 9 or 10 (out of 14) on the scale of severity of ill effects for juvenile salmonids, corresponding to lethal and paralethal effects (0% to 20% mortality, reduced growth rates, habitat damage, etc.).

7.7.5.3. Salinity and Trace Elements

Historically the San Joaquin River likely had good water quality and low concentrations of salinity and trace elements. Current measurement of these constituents from the lower San Joaquin River eastside tributaries indicate trace elements are all below their reported detection limits, and with salinity EC values ranging from 50 µmhos/cm to 100 µmhos/cm. These conditions are probably similar to historical San Joaquin River conditions.

The San Joaquin-Tulare Basin was selected as one of the first 20 National Water Quality Assessment Program (NAQWA) study units, based primarily on data indicating elevated concentrations of salinity and trace elements (Brown 1996). Salinity and trace element concentrations in the San Joaquin River basin are a primary water quality concern, potentially influencing several beneficial uses in the basin, including agriculture, municipal supplies, and aquatic resources. Salinity results from accumulation of anions (e.g., carbonates, chlorides, sulfates) and cations (e.g., potassium, magnesium, calcium, sodium), and is derived from irrigation of west-side soils that are high in salts and boron, and from imported irrigation water from the Delta via the Delta-Mendota canal. Salinity and boron are discussed in Section 6.7. Trace elements of concern include 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 direct mortality, birth defects and behavioral and carcinogenic consequences. Selenium and mercury are discussed in Section 6.10.

Available data suggest that water quality objectives for salinity set by the Central Valley Regional Water Quality Control Board (CVRWQCB) are routinely exceeded (CVRWQCB 2002) in lower study reaches (Reaches 3 to 5), Mud and Salt Sloughs, and the lower San Joaquin River to Vernalis (see Figure 6-1).

Much of the focus on trace elements as a water quality concern has been toward selenium, particularly in the lower San Joaquin River reaches, Mud Slough, and Salt Slough. Historically, concentrations of trace elements in the study area were likely similar to present-day water quality in streams flowing from the foothills of the Sierra’s, i.e, generally low in trace element concentrations. Problems generally become significant in the lower reaches (Reaches 3 to 5), along the valley floor.

Selenium concentrations have been demonstrated in fish and food-chain organisms exposed to agricultural drain water, and numerous studies have focused on the selenium problem, particularly in the Kesterson National Wildlife Refuge (NWR). But studies have also recognized 29 inorganic compounds in addition to selenium and salinity as a concern for public health and aquatic resources, and 21 trace elements have been detected in tissues of biota in the NAQWA San Joaquin-Tulare study unit (Brown 1996; also see Section 6.10.3).

Selenium and mercury are of particular concern because of their ability to convert to methylated compounds, which then accumulate in tissues and can become toxic. Presently, Reaches 3 to 5 are listed as impaired for selenium by the CVRWQCB 303d list, and the limited amount of data available suggest that water quality objectives for selenium are still being exceeded for Mud and Salt Sloughs and Reaches 3 to 5. Mercury problems seem to be islolated to Bear Creek and Reach 5 of the study area, due to historic mining in that drainage. Other trace element constituents were not detected in high enough concentrations to warrant concern to human and aquatic resources. The continued impairment of these reaches due to mercury and selenium will definitely be an important factor in attempts to restore native fish populations, particularly for migratory species.

7.7.5.4. Effects of Changes in Water Quality on Native Fish

Increased temperatures in the San Joaquin River would be most likely to have an effect on juvenile salmonid rearing during the summer, adult upstream migration during the spring and summer, adult spring-run Chinook salmon holding during the summer, and on salmonid egg incubation during the fall. Low flow releases from Friant Dam during the summer and fall lead to rapid increases in stream temperatures in Reach 1, and further increases in Reaches 2 to 5. The amount of time for adult salmonids to migrate from the Delta to upstream spawning locations would have a strong influence on the effect of temperatures on adults in the lower reaches of the San Joaquin River, but is not known. Migration times will be evaluated during the development of a restoration strategy. Current water temperatures would likely be suitable for holding and rearing only in the upper portion of Reach 1. Increased water temperatures have also increased the distribution of non-natives upstream, potentially increasing predation risk for juvenile salmonids. During the development of restoration strategies instream flows will be modeled to evaluate potential effects of temperature on summer juvenile rearing, and adult spring-run Chinook salmon holding habitat.

Incubating salmon eggs may be exposed to lethal temperatures during the fall (Myrick and Cech 2001). Spring-run Chinook salmon are particularly susceptible because they spawn in the early fall when water temperatures are still high, (Vogel and Marine 1991, Myrick and Cech 2001). Fall-run Chinook salmon eggs are less likely to encounter water temperatures above 57°F, except during the start of the spawning period. Increases in temperature during egg-incubation can cause direct mortality, and even slight increases in temperature can decrease incubation period, and alter emergence timing. During the development of restoration strategies water temperatures will be modeled to evaluate potential lethal thresholds and alterations to emergence timing.

Although data are limited, it appears that suspended sediment has increased in the San Joaquin River. Increased sediment can contribute to the decline of fish populations through several mechanisms, including clogging spawning gravel (Chapman 1988), impacting feeding ability and growth rates (Newcombe and MacDonald 1991, Newcombe and Jensen 1996), and simplifying habitat by filling in pools and low gradient reaches (Frissel, 1992). Particulate materials can also physically abrade fish respiratory structures, fill gravel interstices used as habitat by juveniles, and affect light transmission that disrupts primary and secondary production (Spence et al. 1996). On the other hand, some moderate level of increased turbidity may improve juvenile salmonid survival by reducing predation during emigration.

Moderate and higher levels of suspended sediment (125 mg/L to 275 mg/L) and turbidities (25 to 50 NTU's) can interfere with feeding patterns of newly emerged fry and juveniles, resulting in reduced growth rates (Bjornn and Reiser 1991). Other reports indicate that juvenile salmonids avoided chronically turbid streams carrying high suspended sediment loads (Sigler et al 1984; Lloyd 1987; both from Spence et al. 1996). Adult salmonids appear to be less effected by high concentrations of suspended sediment (Bjornn and Reiser 1991), but have been documented to cease migrating when turbidity is high (Cordone and Kelley 1961; from Bjornn and Reiser 1991), potentially delaying migration. Short-term increases in turbidity may have occurred historically coincident with the spring snowmelt runoff, rainfall events, and with season juvenile and smolt emigration. Results of studies conducted elsewhere within the Central Valley have shown a pattern of juvenile salmonid emigration coincident with short-term increases in turbidity. Management programs on the Tuolumne River have recommended high flow releases to temporarily increase turbidity under the assumption that reduced water clarity during smolt outmigration would reduce predation on juvenile salmon (EA Engineering 1991b). It is likely that short-term increases in turbidity would have occurred naturally on the San Joaquin River.

Salinity is one of the strongest physical factors structuring biological communities, and may represent a critical limiting factor inhibiting restoration of native fish fauna and salmonid populations in the San Joaquin River. In addition to triggering behavioral cues that may directly influence broad distribution patterns of different fish species, and further disrupt the structure of fish assemblages, chronic exposure to higher concentrations of some salinity constituents (e.g., sodium chloride) is lethal to Chinook salmon and striped bass (Moyle and Cech 1988, Saiki et al. 1992), and causes reduced growth rates at lower concentrations (Saiki et al. 1992). Bio-accumulation of several trace elements also resulted from exposure to undiluted agricultural drainwater (Saiki et al. 1992). Salinity can also affect the diversity and distribution of macroinvertebrate species, potentially altering the availability of food resources for fish (Brown 1996).

Chinook salmon and steelhead inhabiting the lower reaches of the San Joaquin River are likely to suffer from synergistic effects of temperature, suspended sediment, salinity, other water quality and environmental parameters, such as DO levels, presence of pesticides, trace elements, disease, food availability, and predators. For example, increased water temperatures may lower resistance to disease, and decrease predator avoidance ability. During the development of restoration strategies suitable holding, spawning, and rearing will be evaluated while considering the combined effects with other water quality parameters, instream flows, and environmental conditions.

Declines in water quality may be contributing to the decline of some native resident fish. Although many native resident species are adapted to withstand high temperatures, low dissolved oxygen, and high salinities, many non-native species can withstand even higher temperatures, lower dissolved oxygen concentrations, and levels of contaminants not tolerated by native species. Moyle (2002) notes that tule perch may have disappeared from most of its habitat within the San Joaquin basin due to water quality and contaminants. Contaminants may also be contributing to the decline of hitch in the basin (Moyle 2002).

7.7.6. Introduced Species

7.7.6.1. Overview

Many non-native fish species appear better adapted than native species to the aquatic habitat and water quality conditions currently present in the San Joaquin River basin (Brown 2000, Moyle 2002). Interspecific interactions between native and non-native fish, including competition, predation, and hybridization may influence the abundance and distribution of native fish and alter fish assemblages. Table 7-1 lists non-native fish species that are currently found in the San Joaquin River basin. Changes in channel morphology may have increased habitat for non-native species. Gravel mining, for example, has created large areas characterized by low water velocities, warm water temperatures (>75°F), and dense aquatic vegetation. These areas provide high-quality habitat for largemouth bass and many other non-native warmwater species. Non-native fish species that are successful in the San Joaquin River generally have long reproductive seasons that result in populations that are very resilient to the effects of environmental disturbances. In contrast, native species with restricted reproductive seasons may lose entire year-classes as a result of short-term environmental disturbances such as floods or droughts. Moyle (2002) noted that native fish species may be more likely to persist in aquatic habitats that still resemble conditions under which they evolved, while non-native fish may quickly colonize more disturbed habitat.

Streams in the western United States may be quickly invaded by non-native fishes when they are dammed and natural fluctuations in seasonal flow patterns are reduced (Moyle 1976, Minckley and Meffe 1987; both as cited in Moyle and Light 1996). Moyle and Light (1996) suggest that established native fish communities can maintain their integrity despite continued invasions by non-native fish where highly fluctuating natural conditions exist, with non-native fish persisting only where habitats have been highly disturbed by human activities (Moyle and Light 1976). In the Sacramento-San Joaquin Delta, CDFG (1987) reports that the abundance of introduced centrarchids is correlated primarily with the dead-end slough channel type and secondarily with the intermediate conductivities and water transparencies typical of these habitats. They were also reported to be abundant in oxbows, channels behind berm islands, and small embayments where calm water and riparian or aquatic vegetation was common.

7.7.6.2. Competition for Food and Space

Competition may result in reduced growth and survival of native fish species, and may increase the likelihood that their populations are affected by other anthropogenic or natural disturbances. Elimination of a species solely through competition for a resource is rare, however (Moyle 2002). Some non-native fish species have habitat requirements that overlap with those of native species; these species may be more aggressive and territorial than native species and result in their exclusion from certain habitats. Many of the non-native species, such as green sunfish, also tolerate extremely high water temperatures and appear better able to persist in water with low dissolved oxygen, high turbidity, and contaminants than native fishes.

7.7.6.3. Predation

Native resident fish populations have likely been substantially impacted by the addition of non-native piscivores. Non-native fish species in the San Joaquin River and Delta that feed primarily on fish include largemouth bass, smallmouth bass, green sunfish, warmouth, black crappie, and striped bass. Largemouth bass have been at least partially blamed for the elimination of native species through predation (Minckley 1973, as cited in Moyle 1976). Many introduced piscivorous species, such as redeye bass, are opportunistic feeders, focusing on a prey species when they become sufficiently abundant. Due to their small size and weaker swimming abilities, larval and early life-stages of fish are particularly vulnerable to predation. Anadromous salmonids may be vulnerable to predation by non-native fish species during their outmigration, when they must pass through low-elevation reaches and the Sacramento-San Joaquin Delta and Estuary.

7.7.6.4. Potential Effects of Introduced Species on Selected Native Fish

Native fish species that may have been particularly affected by introductions of non-native fish in the San Joaquin River include Sacramento perch, Chinook salmon, hardhead, California roach, and hitch. Potential effects of non-native species on some of these species are described below.

7.7.6.5. Chinook salmon

Juvenile anadromous salmonids may be vulnerable to predation during the fry and juvenile stages and during their outmigration to the ocean. Before the introduction of non-native fish, the only fishes that would have preyed on the salmon were Sacramento pikeminnow, Sacramento perch, and rainbow trout (including juvenile steelhead). Sculpins may also feed on salmon eggs and fry, but predation by this species is not believed to result in substantial mortality. Due to the preference of salmonids for cool, well-oxygenated water, fry and juvenile rearing generally takes place in stream reaches with temperatures that are less suitable for non-native predaceous species such as black bass. Predation may be most important during outmigration, when juvenile and smolt Chinook salmon and steelhead must pass downstream through reaches occupied historically by Sacramento pikeminnow and Sacramento perch, and currently occupied by many additional piscivorous species now abundant in these areas, including largemouth and smallmouth bass, black crappie, warmouth, and striped bass. In addition, redeye bass, which prefer clear, warm streams and more lotic habitats than many other bass species, may also be abundant in the San Joaquin River, and may prey on juvenile Chinook salmon. Because juvenile salmonids become an abundant prey for a relatively short period of time, it is possible for predaceous fish to switch to feeding on them as a preferred prey and to take large numbers of them. Piscivorous fish seem to be able to substantially reduce the numbers of salmon smolts emigrating to the ocean when smolt numbers are inadequate to have a swamping effect on the predators. Mainstem habitats used as migration corridors by juvenile salmon in the San Joaquin basin have been altered by channelization, which reduces the availability of shallow-water habitats that could have offered refuge from predation, and by instream gravel mining, which has provided high-quality habitat for piscivorous species such as largemouth bass. Striped bass are likely the most important predators of salmon in the Delta.

Many juveniles of non-native species utilize similar food resources as juvenile salmonids, but because production appears to be high in the lower San Joaquin River, competition for food is not likely as significant an effect on salmonids as other interactions.

7.7.6.6. Sacramento perch

There are three primary hypotheses offered to explain the extirpation of Sacramento perch from most of their native habitat in California’s Central Valley: (1) habitat degradation, (2) embryo predation by introduced fish species, and (3) interspecific competition with introduced fish species for food and space (Moyle 2002). It is likely that a combination of all three factors has been responsible for the species’ decline. Black crappie and bluegill appear to be the species that most strongly compete with Sacramento perch (Moyle 2002). Extant populations of Sacramento perch in California currently appear to be limited to habitats where non-native centrarchids are excluded by high alkalinities or lack of introductions. One exception is in Clear Lake, where a small population appears to persist despite the presence of six other non-native centrarchids.

Moyle et al. (2002) have discussed the following potential difficulties of re-introducing Sacramento perch into Central Valley stream habitats where non-native fish species have become established. Black crappie and bluegill are likely important competitors with Sacramento perch for food (primarily benthic invertebrates). Bluegill and green sunfish have been observed to dominate Sacramento perch; displacement of Sacramento perch from preferred cover may increase their vulnerability to predation by piscivorous species. Early life-history stages of Sacramento perch may be particularly vulnerable to predation by introduced species. Although Sacramento perch defend their nests until larvae disperse, their eggs are still vulnerable to predation from schools of sunfish such as bluegill or from large fish such as carp. Larvae are planktonic for approximately 1 to 2 weeks before settling into aquatic vegetation or shallow water; during this time they are likely vulnerable to predation by many native and non-native fish species.

7.7.6.7. Hardhead

Hardhead and smallmouth bass may occupy similar stream reaches and habitats and both feed on introduced crayfish, which may also result in competition between the two species for food and space (Brown and Moyle 1993). Hardhead populations typically decline where smallmouth bass are present (Brown and Moyle 1993). Moyle (2002) notes that predation by smallmouth bass and other centrarchid basses may be an important factor contributing to the decline of hardhead populations. Brown and Moyle (1993, as cited in Moyle 2002) reported that hardhead disappeared in the upper Kings River following the establishment of smallmouth bass in that stream.

7.7.6.8. Other Species

California roach may be particularly vulnerable to predation by green sunfish in small and intermittent streams in the San Joaquin drainage; they appear to have been extirpated from many of these streams since 1970 (Moyle 2002). Moyle (2002) lists predation by non-native species as one factor potentially contributing to the decline of hitch populations in the San Joaquin River. Other native species appear to persist despite the introduction of non-native species, including Sacramento sucker, Sacramento pikeminnow, and blackfish. Tule perch appear less affected by predation by non-native species, which may be a result of their live-bearing reproductive strategy (Moyle 2002).

7.7.7. Life Histories and Habitat Requirements of Selected Non-Native Species and Their Potential Effects on Native Fish Species

Moyle and Light (1996) suggested that invasions of piscivorous fish are most likely to alter native fish assemblages, while omnivores and detritivores are the least likely to do so. Native fish may be maladapted to recognizing non-native piscivores and their predatory behavior (Moyle and Light 1996). Non-native omnivorous and detritivorous fish are less likely to alter fish communities because they exploit a food resource that is not often limiting in aquatic systems (Moyle and Light 1996); however, these species may still have the capacity to alter ecosystem functions (Power 1990, as cited in Moyle and Light 1996). Certain non-native species in the San Joaquin River basin are believed to be stronger interactors than others. Introduced centrarchids (basses, sunfish) have the potential to more strongly influence the abundance and populations of native fish species in the San Joaquin River. Information on these species may be crucial for developing restoration strategies that discourage persistence of these species and promote native fish or assemblages with a higher number of native species. For this reason, we have included more detail on specific centrarchid species believed to have strong influences on native fish populations.

7.7.7.1. Largemouth Bass

7.7.7.1.1. Life history and habitat requirements

Largemouth bass are a large non-native centrarchid that is widely distributed in the Central Valley. In their native range, lacustrine habitats are preferred by largemouth bass (Emig 1966, Scott and

Crossman 1973, both as cited by Stuber et al. 1982); however, the species can also be abundant in streams. Optimal riverine habitat for largemouth bass consists of large, slow-moving rivers or pools with fine-grained (sand or mud) substrates, some aquatic vegetation, and relatively clear water (Trautman 1957, Larimore and Smith 1963, Scott and Crossman 1973, all as cited in Stuber et al. 1982). Streams suitable for bass are generally low gradient and have a high percentage of pool and backwater habitat (Stuber et al. 1982). Moyle (2002) notes that largemouth bass in low elevation streams of the Central Valley occur primarily in disturbed areas where there are large, permanent pools with heavy growths of aquatic plants and 2 to 5 other introduced species (Moyle and Nichols 1973, Brown and Moyle 1993, Moyle and Daniels 1982; all as cited in Moyle 2002).

Streams used by largemouth bass often contain many other species (Fajen 1975), including bluegill, redear sunfish, black and brown bullheads, golden shiners, threadfin shad, and mosquitofish (Moyle 2002). Bain et al. (1991) group largemouth bass into a guild of fish using depositional shoreline microhabitats which are described as having deep water, slow current, fine substrate, and cover. Moyle (1976) describes their usual habitat as warm, quiet waters with low turbidities and beds of aquatic plants.

Optimal velocities are generally under ≤0.2 ft/s and velocities >0.34 ft/s are avoided by the species (Hardin and Bovee 1978, as cited in Stuber et al. 1982). Current velocities of over 0.66 ft/s are believed to be unsuitable (Hardin and Bovee 1978, as cited in Stuber et al. 1982). A broad range of depths is used by adult largemouth bass, which may be due to the fact that they have few predators of their own once they reach adult size. Because of their preference for areas that support aquatic vegetation (used as cover for sit-and-wait feeding and also used as cover by the smaller fish that are the bass preferred prey), it is possible that depths less than about 20 feet that support submergent vegetation are more suitable as adult bass habitat.

Spawning begins in March or April when water temperatures reach 59 ^{o}F to 60.8^{o}F (Weaver and Ziebell 1976, Emig 1966, Miller and Kramer 1971; all as cited in Moyle 2002) and may continue through June in water temperatures up to 75.2^{o}F (Moyle 2002). Males build nests in a wide variety of substrates including sand, mud, cobble, and vegetation, but gravel seems to be preferred (Newell 1960, Robinson 1961, Mraz 1964). Silty substrates are unsuitable, however (Robinson 1961, as cited in Stuber et al. 1982). Male bass do not feed during spawning or during the 2 to 4 week period after hatching while they guard their fry. After being abandoned by the male, fry form schools in shallow habitats where risk of predation is lower; flooded terrestrial vegetation may provide high quality for fry and juvenile bass (Aggus and Elliot 1975, as cited in Stuber et al. 1982).

Largemouth bass tolerate extreme water quality conditions, including temperatures of 96.8 ^{o}F to 98.6^{o}F with dissolved oxygen concentrations as low as 1 mg/l (Coutant 1975, Smale and Rabeni 1995, both as cited in Moyle 2002). Water temperatures optimum for largemouth bass growth range from 77 ^{o}F to 86^{o}F (Coutant 1975, as cited in Moyle 2002). Very little growth of largemouth bass occurs at temperatures below 59^{o}F (Mohler 1966, as cited in Stuber et al. 1982) or above 96.8^{o}F (Carlander 1977, as cited in Stuber et al. 1982).

7.7.7.1.2. Potential effects on native fish

Adult largemouth bass feed on a variety of prey, including fish, crayfish, and amphibians and are capable of changing foraging behavior based on prey availability, habitat type, experience, and size (Schindler et al. 1997, as cited in Moyle 2002). They may become completely piscivorous by the time they attain lengths of 3.1 inches to 3.9 inches (Keast 1970, Clady 1974, Kramer and Smith 1962; all as cited in Werner et al. 1977). Their ability to forage on a wide variety of prey under many conditions, and their broad environmental tolerances allow largemouth bass to play the role of a keystone predator in many aquatic environments (Moyle 2002). These fish may cause changes throughout the aquatic ecosystem, primarily through changing abundances of their preferred prey. In the large, low-elevation reaches of the valley floor, native cyprinids do not persist where populations of largemouth bass are present, even with continual colonization from upstream areas (Moyle 2002). Largemouth bass in the Delta appear to be expanding with an increase in the exotic aquatic weed *Egeria densa*, which provides cover for bass and their prey (Moyle 2002). There are deep pools in the Tuolumne River (a tributary to the San Joaquin River) created by instream gravel mining where adult largemouth bass are found in large numbers. Stomach sampling efforts conducted in these habitats have shown that these fish may take a substantial number of juvenile Chinook salmon during their outmigration (EA Engineering 1992b). This type of predation is expected to be most important during years when smolt production is low because of the short amount of time that smolts are exposed to the predators, and the fact that predator populations are not likely to respond to changes in smolt abundance from year to year.

7.7.7.2. Smallmouth Bass

7.7.7.2.1. Life history and habitat requirements

Smallmouth bass are a large non-native centrarchid now found in most of the larger streams and reservoirs in the Central Valley (Moyle 2002). In the San Joaquin River basin, they are most abundant in the mainstem and larger tributaries at elevations between 328 feet and 3281 feet (Moyle 2002). Smallmouth bass occur in large clear-water lakes (Coble 1975) and in streams of moderate gradient with riffle-pool morphology, relatively low turbidity, and rocky substrates (Hubbs and Bailey 1938, Reynolds 1965, Coble 1975, Lee et al. 1980, Todd and Rabeni 1989). Optimal stream reaches for adult smallmouth contain large pools, slow runs, eddies, or backwaters with abundant cover (e.g., boulders, rock ledges, undercut banks, and Large Woody debris (LWD)) and prey (especially small fish and crayfish) and cobble-boulder substrates. In streams, larger adult smallmouth bass have been described variously as pool guild members (Schlosser 1982), run or pool inhabitants (Leonard and Orth 1988), and habitat generalists (Bain et al. 1988, Lobb and Orth 1991). The biology of the smallmouth bass is quite similar to that of the largemouth bass; however, the smallmouth bass shows a somewhat greater preference for cooler streams with areas of swifter current and adult smallmouth bass may be less piscivorous than largemouth bass where crayfish are abundant (McGinnis 1984). Restricted home ranges have been observed for smallmouth bass in both lakes and streams (Larimore 1952, Gerking 1953, Fraser 1955, Funk 1957, Latta 1963, Munther 1970, White 1970; all as cited in Coble 1975).

Male smallmouth bass build nests near instream cover primarily on rubble, gravel, or sand substrates (Moyle 2002). In California, spawning occurs from May through July when water temperatures reach 55.4 °F to 60.8°F (Moyle 2002). Nests are built at depths ranging from 1.6 feet to 16.4 feet, but are generally situated at depths of about 3 feet (Moyle 2002). Males guard the young fry for 1–4 weeks until fry disperse into shallow water habitats (Moyle 2002). Predation mortality is very high during the fry stage. High flows may disrupt nesting and reduce reproductive success in streams through displacement of eggs and fry by flow or through disruption of spawning behavior by low temperatures (Graham and Orth 1986, Lukas and Orth 1995, both as cited in Moyle 2002). Water velocities 0.26 ft/s over the nest may displace fry as they emerge from the nests and may result in high mortality (Simonson and Swanson 1990, as cited in Moyle 2002).

Most smallmouth bass in California are found in areas where summer temperatures are in the range of 69.8 °F to 71.6°F; the species rarely establishes populations in areas where temperatures do not exceed 66.2°F for extended periods (Moyle 2002). Optimal growth of smallmouth bass in the laboratory occurs at temperatures of about 79 °F to 84°F (Rowan 1962, Peek 1965, Horning and Pearson 1973; all as cited in Coble 1975). More often, smallmouth bass are reported as occupying temperatures of

68 °F to 78.8°F in summer (Coble 1975, Coutant 1975, as cited in Bevelhimer 1996). Selection of cooler temperatures may reflect prey abundance or availability (Armour 1993). Similar to largemouth bass, juveniles will select areas with water temperatures that are warmer than those selected by adults, which would be beneficial for rearing in shallow water where small prey are abundant, but larger cannibalistic adult bass are not (Coble 1975). Temperatures below about 50°F result in pronounced cover-seeking behavior (Beeman 1924, Hubbs and Bailey 1938, Webster 1954; all as cited in Coble 1975).

Juvenile smallmouth bass feed primarily on insects and other small invertebrates until they reach total lengths of 1.2 inches to 2.0 inches, when larger prey such as fish and crayfish become more important (Moyle 2002). However, these prey do not tend to dominate the diet until the young bass reach lengths of 3.9 inches to 5.9 inches (Moyle 2002). Adult smallmouth in California prey primarily on crayfish, which are also an introduced species in many areas (Moyle 2002). Smallmouth bass may become piscivorous at sizes as small as 1.6 inches to 2.0 inches in length (Tester 1932, Lachner 1950, Webster 1954, all as cited in Coble 1975). All sizes may exhibit cannibalism (Moyle 2002). In a study conducted by Probst et al. (1984), adult smallmouth bass over 10.0 inches fed about equally on crayfish and cyprinids less than about 3.9 inches long (mean length of fish eaten was 3.2 inches). Larger adults also fed on larger fish, but did not ignore smaller prey fish.

7.7.7.2.2. Potential effects on native fish

Smallmouth bass often coexist with native fishes in the streams of the Central Valley, but this may depend on smallmouth bass population densities remaining low (Moyle 2002). Moyle (2002) notes that this may be because they feed primarily on crayfish, which are also introduced to the system. Hardhead populations tend to decline when smallmouth bass are present, perhaps because they also feed on crayfish (Brown and Moyle 1993). The maintenance of natural flow regimes may keep smallmouth bass numbers to levels at which they can coexist with native fish species. Moyle (2002) states that “Where flows are reduced, water temperatures may be warmer early in the season, favoring smallmouth bass spawning. During drought years, even in natural streams, smallmouth bass often show an increase in numbers for similar reasons. In ‘normal’ or wet years, however, native fishes typically spawn a couple of months before smallmouth bass can spawn. It is possible that the large numbers of young-of-year pikeminnows that develop in shallows may reduce the success of bass spawning by preying on bass fry.” Smallmouth bass residing in pools created by instream gravel mining in the Tuolumne River were found to prey on outmigrating Chinook salmon, but were less abundant than largemouth bass in these habitats (EA Engineering 1992b).

7.7.7.3. Green Sunfish

7.7.7.3.1. Life history and habitat requirements

Green sunfish are found throughout California in small, warm streams, ponds, and lakes (Moyle 2002). In the Central Valley, they are most abundant in intermittent streams that have warm, turbid, muddy-bottom pools with beds of aquatic vegetation (Moyle and Nichols 1973). They appear to be less common where there are more than three or four other species already present in the fish community (Moyle 1976). In streams that are extremely disturbed or polluted, they may be the only fish species present. Moyle (2002) notes that riprap may be used as cover by green sunfish. They have extremely well-developed dispersal and colonizing abilities and are often the first species to colonize stream reaches that have been dry (Moyle 2002). Under historical conditions, such streams in the Central Valley would have supported California roach, which would persist in pools through long periods of drought (Moyle 2002).

Green sunfish in California spawn when water temperatures reach 66.2°F. At this time, males congregate in shallow (1.6 inches to 19.7 inches deep) water and build nests. Fine gravel substrates near overhanging riparian vegetation or other cover is preferred as nest sites (Moyle 2002). Larvae settle in or near vegetation soon after hatching; heavy mortality from predation occurs during this early life history stage (Moyle 2002). Green sunfish are uniquely suited for colonizing new habitat and persisting in disturbed habitats; they can reproduce at a length of 2.0 inches to 2.8 inches, and typically reach sexual maturity at the beginning of their third year (Moyle 2002). Wang (1986, as cited in Moyle 2002) notes that they can spawn in water with dissolved oxygen concentrations too low for other fish to spawn in. Spawning may be heaviest in May and June, but can continue into July and August (Moyle 2002).

Adult green sunfish feed on invertebrates and small fish, feeding opportunistically on a wider range of items than most other sunfish species (Moyle 2002). Both green sunfish and the closely related warmouth are known to prey as adults on small fishes and crayfish.

7.7.7.3.2. Potential effects on native fish

Green sunfish are highly aggressive and territorial. Moyle and Nichols (1974) believe that the green sunfish, because of its ability to colonize warm intermittent tributaries and its predaceous diet, has probably been responsible for the elimination of the California roach in parts of the San Joaquin Valley. Smith (1982, as cited in Moyle 2002) reports that whenever green sunfish invade a small stream or pool of a larger stream, small native fishes tend to disappear. California roach and other small cyprinids and threespine stickleback may be especially vulnerable to competition and predation by this species (Smith 1982, as cited in Moyle 2002). Green sunfish rarely reach a size large enough to be significant predators of juvenile salmon, primarily because salmon would normally be found in the same habitats as green sunfish only during outmigration to the ocean.

7.7.7.4. Bluegill

7.7.7.4.1. Life history and habitat requirements

Bluegill are distributed throughout California and the Central Valley and are one of the most abundant fishes in the state (Moyle 2002). Moyle (2002) notes that they do best in “warm, shallow lakes, reservoirs, ponds, streams, and sloughs at low elevations” and that they are “often associated with rooted aquatic vegetation...and with bottoms of silt, sand, or gravel.” Bluegill prefer relatively shallow water with depths usually less than 16.4 feet (Moyle 2002). They may be common in streams with warm summer temperatures that have deep pools with aquatic vegetation or other cover (Moyle and Nichols 1973, Brown 2000; both as cited in Moyle 2002).

Spawning begins when temperature reach 64.4°F to 69.8°F and can continue into September (Moyle 2002). Nests are built in gravel, sand, or mud substrate where there are twigs or dead leaves (Moyle 2002). Bluegill have high fecundity; from 2,000 to 18,000 young are produced for each nest (Emig 1966, as cited by Moyle 2002). Bluegill fry in streams tend to enter the water column after the period of male guarding is over and settle into backwaters (Marchetti 1998, Rockriver 1998; both as cited by Moyle 2002). As with other sunfish, predation mortality is high during this stage. After guarding the fry for about a week, males begin another breeding cycle (Moyle 2002).

Bluegill tolerate a very wide range of water temperatures, from lows of 35.6°F to 41°F in winter to as high as 104°F to 105.8°F in the summer for short periods (Houston 1982, as cited by Moyle 2002). Optimal temperatures appear to be nearer to 80.6°F to 89.6°F (Houston 1982). Salinities up to 5 ppt are tolerated in the San Francisco Estuary (Moyle 2002). Dissolved oxygen concentrations less than 1 ppm may be tolerated as well (Moyle 2002). The food of bluegills includes many types of organisms from aquatic insects to plankton, snails, small fish, fish eggs, and crayfish (Moyle 2002).

7.7.7.4.2. Potential effects on native fish

Because of their abundance and high reproductive rates, bluegills may have strong influences on native fish populations in low elevation streams of the Central Valley, primarily through eating their eggs and young and by competing for food with native fish (Moyle 2002). Laboratory studies conducted by Marchetti (1999, as cited in Moyle 2002) suggest that they may have been a major factor contributing to the decline of Sacramento perch.

7.7.7.5. Redeye Bass

7.7.7.5.1. Life History and Habitat Requirements

Redeye bass are locally abundant in foothill portions of the South Fork Stanislaus River and the Cosumnes River, where they have displaced most other fish. This species is adapted for living in small, clear, upland streams with warm water 79°F to 82°F (26°C to 28°C). They prefer pools, undercut banks, and pocket water. Their small size, aggressive behavior, and generalized habitat and feeding requirements presumably allow them to dominate the foothill streams where they have been introduced. Because they are easily confused with smallmouth bass, with which they are known to hybridize (Pipas and Bulow 1998), it is likely that redey bass are more widespread than is currently known in the Stanislaus River and other San Joaquin basin streams.

Redeye bass are voracious predators that feed opportunistically on insects, fish, crayfish, salamanders, and other prey. Redeye bass tend to feed at night, after emerging from daytime cover, and take prey from the surface, in the water column, and on the bottom. It is believed that they have considerable ability to displace native fishes, presumably by predation on juveniles. Spawning takes place in small tributary streams or at the head of pools in larger streams, where males construct and guard nests in gravel beds. Spawning occurs in late spring when water temperatures rise to 60–70°F (16-21°C). Fecundity is high for such a small fish, but growth rates are known to grow very slowly in streams.

7.7.7.5.2. Potential effects on native fish

Their establishment in the Cosumnes and Stanislaus Rivers indicates that redeye bass are capable of invading San Joaquin basin foothill streams and displacing native fishes. Moyle (2002) believes redeye bass are likely to spread to other streams and reservoirs and are highly likely to become a major problem for conservation of native species. Creation of holding pools or other types of spring and fall Chinook salmon habitat may improve habitat conditions for redeye bass. Due to their small size, however, redeye bass presumably cannot use spawning gravels suitable for salmonids. Turbidity may preclude this species from using certain areas of the mainstem San Joaquin River, regardless of habitat availability. Redeye bass, if established in the San Joaquin River, could become important predators of native fishes. Juvenile fish would be the most likely prey items, due to the small size of this species.

7.7.8. Food Webs

After spawning, adult Chinook salmon carcasses remain in the stream corridor to decompose, and are an important food and nutrient source within a watershed (Cederholm et al. 1999). Decomposing salmon carcasses are recognized as a source of marine-derived nutrients that play an important role in the ecology of Pacific Northwest streams (Gresh et al. 2000). On the Olympic Peninsula in Washington, 22 different animal species were observed feeding on salmon carcasses (Cederholm et al. 1999). Carcass nutrients can affect the productivity of algal and macroinvertebrate communities that are food sources for juvenile salmonids. And decomposing salmon carcasses have been shown be vital to the growth of juvenile salmonids (Bilby et al 1998; Bilby et al. 1996, as cited in Gresh et al 2000).

The relatively low abundance of salmon and steelhead has significantly reduced this important nutrient source in the Central Valley, and throughout the Pacific Northwest. The study by Gresh (et al. 2000) estimated that the annual biomass of salmon entering Pacific Northwest streams (California, Oregon, Washington, Idaho) was historically on the order of 352 million pounds, and has been reduced to only approximately 26 million pounds, a reduction of over 93%. Channelization and removal of large woody debris can also decrease the retention of salmon carcasses and reduce nutrient input.

Inundated floodplains that support riparian vegetation and wetlands are also a primary source of nutrients that propagate through the ecosystem. Floodplain habitats produce small invertebrates with short life cycles such as chironomids and cladocerans. Native species adapted to using these flooded areas for feeding include juvenile salmonids, cyprinids, and suckers. The frequency and magnitude of floodplain inundation required to sustain high levels of macroinvertebrate production is being evaluated as part of the effort to develop restoration strategies.

Benthic macroinvertebrates and algal communities are poorly documented in the San Joaquin River, so the effects of disturbances on community structure and function are not fully understood (Brown 1996). However, it is fairly certain that modifications to habitat and introduction of three species of crayfish and other introduced biota have undoubtedly had impacts to the native macroinvertebrate and algal communities (Brown 1996).

Gravel substrates and riffles in Reach 1 provide productive habitat for benthic invertebrates. Increased fine sediment from gravel mining operations may reduce invertebrate production by filling in interstitial spaces between substrate particles (Chutter 1968, Bourassa and Morin 1995). Aquatic invertebrate sampling in pool and riffle habitat throughout Reach 1 is being conducted to aid in the developing restoration strategies. The unstable sand substrates and extreme flow variability in upper Reach 2 and Reach 4 are not likely to support high invertebrate densities. Sand substrates found in Reaches 2 through 5 are likely to have low taxa richness species diversity and primarily support specialized chironomids, small annelids, microturbellarians, and introduced *Corbicula* clams. Poor water quality in Reach 5 may also be limiting aquatic production in this reach.

7.7.9. Bay-Delta Conditions

7.7.9.1. Overview

Salmonids produced in the upper San Joaquin River must migrate through the lower San Joaquin River and the Bay-Delta to the sea. The lower San Joaquin River below Reach 5 provides similar physical habitat and water quality conditions as found in Reach 5; however tributaries including the Merced, Tuolumne, and Stanislaus rivers increase flows. The historical Delta consisted of low-lying islands and marshes that flooded during high spring flows. The current Delta consists of islands generally below sea level that are surrounded by levees to keep out water. In addition, federal and state pumping plants near Tracy send water from the Delta to various parts of the State utilizing a network of upstream and downstream storage reservoirs and aqueducts. Water to be exported from the Delta generally originates from excess runoff, flood control of upstream reservoirs, or planned release from upstream reservoirs. Within the central and southern Delta, the diversion facilities have a large effect on channel net flow direction and magnitude, including Old and Middle rivers, the Grant Line Canal, and the San Joaquin River.

In addition to the large export facilities, water is removed from Delta channels by approximately 2,500 pumps, siphons, and floodgates to irrigate agricultural lands surrounding and within the Delta. Because the elevation of island land surfaces is below the channel surface elevation, approximately half of the diversions are siphons (with the remainder divided evenly between pumps and floodgates) and most of the return drains require pumping over levees into channels (CDWR 2000). Almost all Delta agricultural diversions are rated to less than 250 cfs (Cook and Buffaloe 1998). The latest CDFG data indicates that less than a tenth of the 2,500 floodgates, siphons and pumps are screened (Raquel et al. 2002).

7.7.9.2. Effects on Native Fish

Delta flow patterns affect adult migration to upstream spawning areas and tributaries as well as juvenile outmigration to the sea. River discharge is an important migration cue for adult salmonids attempting to enter their natal streams to spawn, and increases in discharge may improve water quality and habitat conditions in the Bay/Delta – particularly dissolved oxygen in the Stockton Deep Water Ship Channel – allowing adult salmon to successfully migrate through the Delta.

Discharge is also a key factor for smolts outmigrating to sea from their spawning and rearing areas. Direct losses of salmonids occur from a variety of mortality agents within the Delta, primarily at the Central Valley Project (CVP) and State Water Project (SWP) pumps near Tracy as a result of entrainment into pumping facilities, from predation in pump forebays, predation within the Delta, and from fish salvage operations at the pumping facilities. Recognizing the importance of reducing mortality caused by SWP and CVP exports in the South Delta, the Vernalis Adaptive Management Program (VAMP) was developed to investigate Chinook salmon smolt survival during outmigration through the Delta in April and May, in response to alterations in San Joaquin River flows at Vernalis (USGS STN# 11-303500) and SWP and CVP exports. As part of the VAMP program, in years when spring flow in the San Joaquin River is less than 7,000 cfs, a temporary barrier is placed at the Head of Old River (HORB) to prevent outmigrating San Joaquin Basin salmon from migrating directly down the Old River channel toward the pumps.

The VAMP program has collected smolt survival data for two years (2000 and 2001) and has also included earlier survival estimates from the 1990's in their annual technical reports (SJRGA 2002). Survival indices and absolute survival rates are based on releases of Chinook salmon smolts marked with coded wire tags at Durham Ferry (RM 67) and Mossdale (RM 60), marked salmon releases at Jersey Point (RM 10), and the relative proportion of salmon recaptured at Antioch (RM 5) and Chipps Island (RM 0). Key study conclusions indicate:

- The relative proportions of salmon released and recaptured during 2001 (target flow 4,450 cfs and 1,500 cfs exports) did not differ significantly from the relative proportions released during 2000 (target flow 5,700 cfs and 2,250 cfs exports);
- Approximately 65% of the unmarked salmon migrating past Mossdale in 2001 migrated during the VAMP period, and were therefore protected by increased San Joaquin River flow and the HORB barrier;
- Absolute survival rates of marked, hatchery Chinook salmon smolts for the 2001 VAMP experiments ranged from 14% to 34% for the Durham Ferry releases, and 11% to 31% for the Mossdale releases. These survival rates were not significantly different from those recorded during the 2000 VAMP experiments. Chipps Island recaptures showed higher absolute survival rates than did Antioch recaptures, possibly attributed to the marked salmon not being equally distributed or vulnerable to the trawls throughout the 24-hour period;
- The variability inherent in conducting salmon smolt survival studies in the lower San Joaquin River and Delta makes it difficult to detect statistically significant differences in salmon survival between VAMP flow and export conditions; no conclusions on the relative roles of San Joaquin River flow and SWP/CVP exports on juvenile Chinook salmon smolt survival can be made with these two years of data;

In addition to mortality resulting from the SWP/CVP export facilities, abundance and survival of salmonids are influenced by an interconnected complex of Delta environmental factors, including food and habitat availability and quality, water quality, and distribution of predators and conditions affecting susceptibility to predation. All of these factors are also affected to some degree by Delta hydrodynamics (Bennett and Moyle 1996). At present, salmonid mortality relating to these factors is not being evaluated quantitatively, except as they contribute to survival during the VAMP studies.

7.8. IMPLICATIONS FOR FISHERY RESTORATION

This chapter distills a large body of knowledge about the fish resources of the San Joaquin River and its tributaries, including information about historical and current fish abundance, distribution, and habitat. The summary information provided in this chapter describes:

1) the life history timing and habitat requirements for numerous fish species native to the San Joaquin River;
2) historical and existing conditions of both habitat and fish populations; and,
3) hydrologic and geomorphic linkages to fish habitat and life history.

Though this chapter focuses on anadromous salmonids (fall-run and spring-run Chinook salmon, and winter-run steelhead), it also includes descriptions of native resident fish, as well as non-native fish species that may influence efforts to restore native fish populations. This chapter is accompanied by Appendix B, which provides brief summaries of the life history and habitat requirements for 45 fish species. Rather than summarize the information presented in this chapter, this section identifies key issues that will need to be considered in the development of restoration strategies in order to achieve fishery components of the Mutual Goals statement (see Chapter 1).

Experience from other river systems that are regulated by large dams demonstrate that it is possible to restore and maintain some measure of ecosystem functioning and, by extension, fish populations. The resilience of rivers and fish populations in these other regulated systems promotes optimism for restoring, in some measure, the San Joaquin River and its associated fish resources.

As with other regulated river systems, there are a number of general challenges to restoration of the San Joaquin River. For example, while it seems feasible to “scale down” a river to be in balance with a reduced, regulated flow regime so as to restore some level of ecosystem function, it is unclear how to achieve this balance specifically for a given river. Another general challenge involves compensating for some of the inherent effects of dams, such as the trapping of sediment from upper watershed areas. In addition to these general challenges to restoring the San Joaquin River and its fish resources, there are a number of additional challenges specific to the San Joaquin River based upon local conditions in the river channel and surrounding area.

This section briefly describes some of the reasons for optimism that the fish resources of the San Joaquin River can be restored successfully, then it describes some of the unique challenges to achieving this restoration. By identifying the challenges to restoring the fish resources of the San Joaquin River, this section helps to lay the groundwork for the development of general restoration strategies for the San Joaquin River.

This summary of opportunities and challenges to restoration focuses on anadromous salmonids because: (1) they are the focus of numerous other restoration efforts in the Central Valley due to their sport, commercial, and intrinsic value; and, (2) as anadromous species, salmonids use the entire river corridor within the San Joaquin River Restoration Study planning area, so improving conditions for anadromous salmonids will likely benefit native resident fish that use only a portion of the San Joaquin River channel (Moyle, pers. comm.).

7.8.1. Restoring Fish Resources in the San Joaquin River

There are a number of reasons to be encouraged that efforts to restore the fish resources of the mainstem San Joaquin River will be successful. Adult escapements of fall-run Chinook salmon on the San Joaquin River tributaries have been strong recently, and though it is too soon to tell if these higher escapements are the combined result of fishing restrictions and restoration efforts, there is optimism that restoration is contributing to the rebounding fish population. There are several physical and biological factors (e.g., habitat conditions) and social and human factors (e.g., recent collaboration between environmental and agricultural interests) in the San Joaquin Basin that will contribute to the successful restoration of San Joaquin River fish resources.

7.8.1.1. Resiliency of San Joaquin River Fall-Run Chinook salmon

Each of the major tributaries to the San Joaquin River (e.g., the Merced, Tuolumne, and Stanislaus Rivers) is regulated by a large water-supply dam that has blocked access to upstream salmonid habitat and degraded downstream habitat conditions through flow regulation and sediment trapping. The San Joaquin River tributaries have also been disturbed by extensive gold (dredger) mining, which left windrows of tailings on floodplains, and commercial aggregate mining, which left large instream and floodplain mining pits that pose a hazard to salmonid migration. Despite such extensive human disturbances to the river channel and nearby floodplains, each of the major San Joaquin River tributaries maintains a population of fall-run Chinook salmon, testifying to the resiliency of Chinook salmon. Fall-run populations in the San Joaquin River tributaries have experienced dangerous population crashes in some years, but the populations have been able to rebound quickly. For example, escapement on the Tuolumne River in the early 1990s was as low as 100 adults; however, recent returns have been consistently between 10,000 and 20,000 adults.

The fact that Chinook salmon populations persist on San Joaquin River tributaries in the face of significant human disturbance stimulates confidence that populations of salmonids can be restored successfully on the mainstem San Joaquin River.

7.8.1.2. Fish Habitat Remains on the San Joaquin River

The different habitat components required by different life history stages of salmonids are generally available in the mainstem San Joaquin River, although it is not yet clear if the extent and quality of existing habitat is sufficient to support long-term population needs. For example, there are still holding pools below Friant Dam suitable for adult spring-run Chinook salmon; moderate quantities of salmonid spawning habitat still remain in Reach 1A; and the river channel in Reach 1 seems capable of providing instream rearing habitat for juvenile salmonids in certain months. Even if the amount and quality of existing habitat is inadequate to achieve the objectives set forth in the Mutual Goals statement, the amount and quality of existing habitat seem sufficient to at least *initiate* the process of restoring salmonid populations.

7.8.1.3. Expanded Knowledge of Fishery and Restoration Science

There are numerous restoration activities on other Central Valley tributaries, including each of the three lower San Joaquin River tributaries, targeted at improving salmonid habitat conditions and populations. The wealth of experience gained in restoring these other river systems can be applied to the restoration of the San Joaquin River, such that restoration activities for the mainstem San Joaquin River benefit from the lessons learned in other river systems. The restoration of salmonid populations in the San Joaquin River also presents a unique opportunity for testing restoration concepts and approaches that can make significant contributions to both restoration and fishery science. For example, the selection of parent stock for salmonid species will provide unique opportunities for examining concepts and hypotheses related to fish phenotype. The San Joaquin River can become a prominent location for learning for both the scientific and resource management communities.

7.8.1.4. Complementary Restoration Programs and Efforts

As described in Chapter 12, there are many other restoration efforts underway in the lower San Joaquin Valley that will complement efforts to restore the anadromous salmonid fishery in the study area. First, CALFED has made significant investments in river restoration and preservation in the lower San Joaquin River (e.g., San Joaquin River Wildlife Refuge). Secondly, there are several current and proposed activities for increasing smolt survival in the lower San Joaquin River and Delta, including reoperation of the State and Federal pumps at Tracy and flow management during the smolt outmigration period (e.g., the Vernalis Adaptive Management Program). These downstream restoration efforts will likely benefit future San Joaquin River salmonid production by enhancing smolt survival. Similarly, current efforts to improve water quality in the lower San Joaquin River (described in Chapter 6) will likely provide benefits to future salmonids produced in the mainstem San Joaquin River.

7.8.1.5. Friant Dam Infrastructure Capabilities

Friant Dam has a capacity for managed flow releases up to 16,000 cfs, which provides future management flexibility for releasing flows to restore fluvial geomorphic processes and riverine habitat (once downstream flood management issues are resolved) without costly and time-consuming retrofitting of the dam. In contrast, some dams on other river systems (e.g., Whiskeytown Dam on Clear Creek) do not have the current outlet capacity to support managed flow releases for restoring fluvial geomorphic processes. The outlet infrastructure of Friant Dam also provides the opportunity for hypolimnial cold water releases to the river, which make it possible to restore cold-water fishes, including those that require cold water temperatures year-round (e.g., spring-run Chinook salmon, winter-run steelhead). These opportunities will allow managed releases from Friant Dam to occur without requiring costly and lengthy retrofitting to the dam (as has been required on Shasta Dam and others).

7.8.1.6. Increasing Public Support and Participation in River and Fishery Restoration

There is growing public awareness and support for restoring river habitats and fish populations, as evidenced by: public approval of recent restoration bonds (Proposition 204) and parks bonds (Proposition 13); recent funding and support for the CALFED Bay-Delta Program; and the development of the San Joaquin River Parkway. More active public participation in restoration efforts have accompanied this growing public awareness. For example, landowners and local interests played a significant role in the development of the Merced River Corridor Restoration Plan (Stillwater Sciences 2002). Local stakeholders have also played a significant role in developing and implementing numerous restoration projects funded by the CALFED Bay-Delta Program. More active local participation allows restoration planning and implementation to benefit from local experience and expertise.

7.8.1.7. Salmonids Can Co-Exist With Agriculture and Urban Land Uses

Recent restoration experience on other San Joaquin River tributaries have demonstrated that enhancing riverine habitat and salmonid populations can be compatible with continued economic uses of land and water resources, thereby avoiding the contentious and counter-productive polarization of the issue into fish/wildlife vs. people. Furthermore, numerous partnerships have been developed on other tributaries between funding agencies, regulatory agencies, local agencies, landowners, restoration groups and environmental groups to develop mutually beneficial solutions to common problems. Cooperative conservation and floodway easement programs facilitated by the Natural Resources Conservation Service (NRCS) is a prime example of where floodway conveyance is improved, riparian habitat is improved, fee title and riparian water rights are retained by the owner, and fair compensation is provided to the landowner. These success stories can be transferred to upper San Joaquin River restoration efforts.

7.8.2. Challenges to Restoring the Fish Resources of the San Joaquin River

There are a number of significant challenges to restoring the fish resources of a river that has been de-watered in several reaches for over half a century. There are several general challenges common to San Joaquin River tributaries, such as understanding, and planning for, how downstream biological effects will affect the population dynamics of restored San Joaquin River salmonid populations. For example, the southern Sacramento-San Joaquin River Delta has been called a “black hole” for juvenile salmon because it harbors several significant sources of mortality (e.g., entrainment in Delta pumps; water quality; predation by non-native fish species, etc.). The design of restoration actions in the San Joaquin River, such as pulse flows to stimulate juvenile outmigration, will need to consider downstream conditions, such as the timing of Vernalis Adaptive Management Plan (VAMP) flows. Similarly, periods of low dissolved oxygen have been documented in the Stockton Ship Channel and have been hypothesized to be a barrier to the upstream migration of adult salmon. Actions applied in the mainstem San Joaquin River that are designed to stimulate the upstream migration of fall-run Chinook salmon, such as the release of fall attraction/passage flows, will need to consider the implications of low DO conditions downstream and its potential effects upon the success of San Joaquin River restoration actions.

In addition to these general challenges, there are challenges to the restoration of fish resources that are grounded in the unique conditions of the mainstem San Joaquin River. Several of these more specific challenges are described below.

7.8.2.1. Restoring an Extirpated Species

Unlike the other San Joaquin River tributaries, salmonids were extirpated from the mainstem San Joaquin River by 1950. Consequently, a restored salmonid population will require using a parent stock from some other tributary. Parent stock for fall-run Chinook salmon will likely come from one of the San Joaquin River tributaries. However, there are no significant populations of spring-run Chinook salmon or steelhead in the San Joaquin basin. As a result, parent stock for these species will likely come from Sacramento River tributaries.

One consequence of salmonids being extirpated from the mainstem San Joaquin River is that restoration planning will not have the benefit of examining how a local population uses the existing habitat, to see the unique adaptations a local stock makes to local conditions. Restoration strategies will have to be grounded in historical accounts, general scientific understanding of salmonid ecology, and conceptual approaches appropriate to the life history of the selected phenotype.

7.8.2.2. Supporting two Chinook salmon Populations

It will be a challenge to support two populations of Chinook salmon in the mainstem San Joaquin River. Hatton (1940, as cited in Yoshiyama et al. 1996) estimated that the completion of Friant Dam blocked access to approximately 36% of the salmonid spawning habitat that was available historically. As a result, spring-run Chinook salmon holding, spawning, and rearing have been concentrated downstream of Friant Dam. Early Euro-American development of San Joaquin River water resources (e.g., Sack Dam) greatly reduced the fall-run fishery (Hatton, 1940, Clark 1929, as cited in Yoshiyama et al. 1996), so that the adult spring-run Chinook salmon displaced by the closure of Friant Dam likely encountered little competition for the spawning habitat downstream of the dam. However, the restoration strategies will need to contemplate supporting two salmon populations with substantially less spawning habitat than was available historically to support the spring-run population and a meager fall-run fishery.

7.8.2.3. Competition and/or Hybridization of Fall-Run and Spring-Run Chinook salmon

Fall-run and spring-run Chinook salmon can occupy and use similar habitats. In rivers that support both fall-run and spring-run Chinook salmon populations, spawning is generally segregated spatially. Fall-run tend to use downstream riffles and spring-run spawn in upstream riffles that are closer to the pools where they hold over the summer (typically found higher in a drainage basin). Despite this general segregation of spawning between the two species, there is still the potential for overlap, which is exacerbated by dams that block access to upstream spawning habitat historically used by spring-run Chinook salmon, forcing them to spawn lower in the drainage.

When fall-run and spring-run Chinook salmon use the same spawning riffles, the risk of redd superimposition and genetic hybridization increase. Fall-run generally spawn later in the season than spring-run, so if they use the same spawning riffles, they can dig their redds atop existing spring-run redds (superimposition), thereby scouring the spring-run eggs and increasing the risk of egg mortality. There can also be a temporal overlap in fall-run and spring-run spawning so that individuals of the two different species are using the same spawning riffles at the same time. In such a scenario, individual fall-run and spring-run Chinook salmon may spawn together, thereby leading to genetic hybridization.

Friant Dam eliminates access to a substantial amount of historical spawning habitat used by spring-run Chinook salmon, concentrating them downstream. Consequently, fall-run and spring-run Chinook salmon may use the same spawning riffles in Reach 1. The restoration strategies will need to assess the risk of both redd superimposition and genetic hybridization and develop approaches for segregating, both spatially and temporally, fall-run and spring-run Chinook salmon spawning as a means of preventing or reducing the threat of redd superimposition and hybridization.

7.8.2.4. Carrying Capacity of Existing Habitat

Though the mainstem San Joaquin River contains most of the habitat components required by the different life history stages of salmonids, it is not clear if there is adequate habitat of sufficient quality to support target populations of salmonids. For example, there are two large pools immediately downstream of Friant Dam that will likely provide holding habitat for spring-run Chinook salmon. However, the capacity of the pools is unknown. If the existing pool habitat is insufficient to support the number of adult spring-run Chinook salmon required for a self-sustaining population, then additional holding habitat may be required to satisfy salmonid population targets. The restoration strategies, and the revision of the quantitative objectives, will require developing a better understanding of the capacity of existing habitat components for salmonids.

7.8.2.5. Geomorphic Limitations for Dynamic Channel Morphology in Gravel-Bedded Reach

The stream gradient in the gravel-bedded reach of the mainstem San Joaquin River is one-half to one-third as steep as the gravel-bedded reaches of the San Joaquin River tributaries (e.g., Merced, Tuolumne, and Stanislaus Rivers). The gentler slope of the mainstem San Joaquin River gravel-bedded reach generally limits the amount of salmonid habitat available, both directly and indirectly. There are areas of Reach 1 with suitable spawning gravels, but the relatively gradual slope of the channel reduces water velocities below those generally preferred by adult salmonids, thereby rendering those gravel-bedded reaches unavailable as spawning habitat. Also, the relatively gentle slope of Reach 1, combined with flow regulation through the operation of Friant Dam, may deprive the reach of sufficient energy to drive the fluvial geomorphic processes (e.g., bedload routing, channel migration, etc.) that may be necessary for maintaining habitats. In other river systems with steeper slopes, it has been possible to scale down the channel morphology and particle size to better match the post-dam flow regime while still achieving important fluvial geomorphic thresholds, thereby restoring fluvial geomorphic processes. However, it will likely be more difficult to restore fluvial geomorphic processes in the gravel-bedded reach of the mainstem San Joaquin River through channel alterations, because it is more difficult to alter channel slope conditions to create desired channel morphology (e.g., spawning riffles). Attempts to change reachwide slope have been attempted in smaller streams, but it is considerably more difficult to alter the slope of a river as large as the San Joaquin River. The restoration strategies will have to account for the low slope of Reach 1, especially since it has significant implications for attempting to restore the frequency of fluvial processes and the maintenance of aquatic habitat.

7.8.2.6. Balancing Juvenile Salmonid Growth and Smolt Outmigration

Water temperature modeling of the mainstem San Joaquin River suggests that water temperatures in certain spring months may get too warm in the lower sand-bedded reaches of the study area for juvenile salmonid outmigrants (assuming average meteorological conditions). To prevent juvenile mortality, it will be important to move them out of the study reach before water temperatures become harmful or lethal. However, the survival of juvenile salmonids is correlated positively with size; larger juveniles have higher survival rates. Moving juvenile salmonid outmigrants out of the study area sooner to avoid high water temperatures will compress the window of opportunity for promoting juvenile growth. It will be a challenge to provide rearing opportunities that promote juvenile growth fast enough to enhance the downstream survival of outmigrants that are moved out of the study area to avoid high water temperatures in the spring.

7.8.2.7. Poaching

Adult salmonids may be vulnerable to poaching in the mainstem San Joaquin River, especially because adult salmon will be holding and spawning in reaches of the river that support both recreational and subsistence fishing. Spring-run Chinook salmon will be especially vulnerable to poaching because they tend to group in high densities; they have long exposure time to poaching opportunities during their holding phase (all summer); and much of the San Joaquin River channel in Reach 1 has public access.

7.8.2.8. Water Quality

Poor water quality in Reaches 3-5 will likely affect fishery restoration efforts for both anadromous salmonids and certain native warm-water resident species. While release of Delta-Mendota Canal water into Reach 3 provides perennial flow over the entire reach, this water is much more saline than water released from Friant Dam (and it may cause imprinting problems on anadromous salmonid smolts outmigrating through the reach). Application of this saline water to naturally saline soils on the west side of the San Joaquin Valley increases the concentration of salts in agricultural return flows in Reach 5, further impairing water quality. Other contaminants are contributed by these agricultural return flows into Reach 5, and are discussed in more detail in Chapter 6. Flows released from Friant

Dam to meet fishery and other ecological objectives may also provide incidental benefits to water quality by reducing concentrations of salts and other contaminants. However, until expanding efforts to reduce source contributions begins to reverse contaminant loading rates, water quality in Reach 5 (and downstream reaches) will continue to be an issue to consider for fishery restoration efforts.

7.8.2.9. Mendota Dam and Pool

Mendota Dam and Pool functions as a manifold system where imported water from the Delta Mendota Canal (and periodic flows from the San Joaquin River and Fresno Slough) is distributed to several large canals, as well as numerous pumps adjacent to the pool. Some of the diversions have a capacity of up to 1,500 cfs, and experience on Sacramento River has shown that diversions of this size can entrain large numbers of juvenile salmonids. Screening these large diversions to meet entrance velocity criteria can be difficult and expensive. Therefore, routing adult and juvenile fish through Mendota Pool poses a significant challenge to salmonid restoration efforts.

7.8.2.10. Competition and Predation by Non-Native Fishes

Because of the introduction of non-native fish species, it is infeasible to restore native fish assemblages that occurred in the San Joaquin River historically. While it may be possible to control the abundance of, and contain the spread of, certain non-native fish species, it is very difficult to eradicate them. Therefore, the target fish assemblage for the San Joaquin River will be a mix of both native and non-native species. Determining the mix of native and non-native fish species that will be part of the target assemblage will require additional analysis. For example, it will be important to understand:

- inter-specific competition and predation between native and non-native fish species;
- how non-native fish species that inhabit the mainstem San Joaquin River have capitalized on current habitat conditions; and,
- which non-native fish species are more susceptible to control/eradication efforts.

Such analysis will support an assessment of which native and non-native species can co-exist and, therefore, which species will be part of the target assemblage. On the Tuolumne River and other Central Valley rivers, predation on salmonid juveniles by non-native fish species can be a significant factor limiting production from the basin. Since Chinook salmon are a focus of restoration efforts, it will be important to identify which non-native fish species pose a significant predation risk to juvenile salmonids. The restoration strategies will need to explore actions that simultaneously inhibit non-native species while supporting the restoration of native species.

7.8.2.11. Availability of Habitat to Support a Steelhead Population

It is likely that the watershed upstream of Friant Dam historically provided most of the habitat to satisfy steelhead life history needs on the San Joaquin River. Cold water habitats are needed for juvenile over-summering, which can still be provided by cold-water releases from Friant Dam in Reach 1, but steelhead tend to spawn and rear in smaller tributary streams rather than larger mainstem channels. Friant Dam has blocked access to many of these traditional headwater streams, and steelhead restoration opportunities may be limited to Reach 1 of the mainstem San Joaquin River, Cottonwood Creek, and Little Dry Creek. The restoration strategies will need to assess if sufficient steelhead habitat can be restored in Reach 1 to support a self-sustaining population of steelhead. Also, steelhead can prey upon juvenile salmon, so the restoration strategies will also need to consider balancing a restored steelhead population with restored Chinook salmon populations.

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