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Appendix VIII. Fisheries - Historical Perspective and Bay-Delta Affected Environment

HISTORICAL PERSPECTIVE

General

Historical fishery resources of the Sacramento, American, and San Joaquin River systems; the Delta and the Bay were quite different from the fish assemblage present today. Numerous species have been introduced (Table A), and many native species have declined in abundance and are restricted in distribution. Habitat modification, species introductions, and overfishing are the major factors affecting fisheries resources in California's Central Valley. A list of historical activities impacting fisheries and fisheries habitat is presented in Table B.

The first major human-induced change to the rivers, Delta, and Bay resulted from dredging and hydraulic mining between 1850 and 1885. Large quantities of sediment and debris filled pools and riffles, silted spawning gravels, and were deposited downstream throughout the Delta and Bay, burying biological communities and changing hydrologic and hydraulic characteristics. Nearly 1.4 billion cubic yards of sediment was washed into the Sacramento River alone (California Department of Water Resources 1984). In addition to acid mine drainage, these impacts probably had a devasting effect on salmon populations and are still of concern today.

Another early impact to salmon populations was commercial fishing. From 1873 to 1910, more than 20 canneries processed 5 million pounds of salmon annually from the Sacramento-San Joaquin River system. In 1882, the commercial catch from the Sacramento River alone represented over a half-million fish. The reduction and end of in-river commercial harvest led to a concomitant rise in the ocean fishery. In the last decade, Sacramento River stocks contributed about 4.5 million pounds annually to the commercial fishery (California Department of Water Resources 1984). Fishing contributes to reduced in-river returns and changes in population structure; 3-year-old fish currently dominate the adult chinook salmon population which was formerly dominated by 4- and 5-year-old fish during the early part of the century. The decline in population age and therefore fish size has reduced the reproductive potential of existing salmon populations.

Agricultural development in the late 1800s and early 1900s resulted in major habitat modifications. Levees and dikes were built to protect development in low-lying areas. The Sacramento River Flood Control Project was initiated and by the mid-1960s consisted of over 440 miles of river, canal, and stream channels; 1,000 miles of levees; and 95 miles of bypasses (California Department of Water Resources 1984). Additions to the project are ongoing and proposed for the future. As early as 1920, nearly all of the Delta marshlands had been diked and converted to farmland. Less than 10 percent of the original Bay

Tables A. Numbers of Native and Introduced Freshwater and Anadromous Fish Species in All three Service Areas and the Sacramento-San Joaquin Delta

Species Category	Native Species	Introduced Species
Migratory game	7	2
Migratory nongame	4	0
Resident game	3	13
Resident nongame	16	14

Table B. Historical Activities Impacting Fisheries and Fisheries Habitat in the Three Service Areas, the Delta, and San Francisco Bay

Activity	Affected Area			
	Sacramento	American	San Joaquin	Delta and Bay
Hydraulic Mining	X	X	X	X
Upstream storage and controlled releases	X	X	X	X
Channel blockage	X	X	X	X
CVP export - direct	X	X	X	X
CVP export - indirect	X	X	X	X
SWP export - direct	X	X	X	X
SWP export - indirect	X	X	X	X
Channel dredging	X		X	X
Gravel extraction	X	X	X	
Agricultural diversions	X	X	X	X
Agricultural drainage	X	X	X	X
Municipal diversions	X	X	X	X
Municipal Waste Discharge	X	X	X	X
Industrial diversions	X	X	X	X
Industrial chemical waste discharge	X	X	X	X
Industrial thermal waste discharge	X			X
Power diversions	X			X
Gas Supersaturation	X			
Upstream erosion	X	X	X	X
Nonpoint pollution	X	X	X	X
Flow impedance (bridges, etc.)	X	X	X	X
Wake erosion	X	X	X	X
Riparian vegetation removal	X	X	X	X
Establishment of levees	X	X	X	X
Use of riprap	X	X	X	X
Flood flow dispersion (distributaries)	X			
Upstream flow additions	X			X
Delta Island reclamation				X
Slough conversion to channel				X
Upstream drainage and waste discharge	X			X
Upstream nonpoint pollution				X
Fill and reclamation				X
Island flooding (levee breaks)				X
Species introductions	X	X	X	X
Fish harvest	X	X	X	X
Fish hatcheries	X	X		X

marshlands are left. Physical, chemical, and biological processes were changed dramatically and production of native fish species was and is adversely affected.

Water resource development in California by federal, state, local, and private entities has had the most severe effect, persisting over time, on natural salmon stocks. A number of measures, such as fish hatchery construction, have been undertaken to offset these effects. A nonfederal dam built on the American River at Folsom in 1895 was one of the first major dams to block salmon and steelhead from historic spawning habitat. Spring-run salmon and steelhead trout, which spawn in smaller, upstream tributaries, were virtually eliminated. A fish ladder in operation from 1931 to 1950 temporarily revived these runs but the completion of Folsom and Nimbus Dams by Reclamation in 1955 permanently blocked passage to upstream reaches. Shasta and Keswick Dams on the Sacramento River blocked hundreds of miles of spawning habitat on the upper Sacramento, Pit, and McCloud River drainages. Friant Dam, built on the San Joaquin River in 1947, blocked thousands of migrating salmon and steelhead. Major dams on the Feather, Yuba, Cosumnes, Mokelumne, Stanislaus, Tuolumne, Merced, Kings, Kaweah, Tule, and Kern Rivers (all of the major rivers in the Central Valley) have blocked large amounts of spawning and rearing habitat as well. These dams have permanently changed the salmon stock composition in California, virtually eliminating wild stocks of spring-run chinook salmon, once the dominant race of chinook salmon in California. Steelhead runs also are only a fraction of historic levels. Available spawning habitat has been restricted to main river channels and small tributaries at low elevations, habitat best suited for fall- and late-fall-run chinook salmon.

Numerous smaller dams and diversions also blocked access to upstream habitats and diverted both instream flows and fish. During spring and early summer, 10's of millions of downstream salmon and steelhead migrants have been, and in some cases still are, killed in improperly screened or unscreened irrigation diversions and pumping facilities on river systems still accessible to anadromous salmonids. Instream flow releases below dams, in many cases, have been too low to maintain preproject fishery production. Flow regulation can create a complex web of adverse impacts that reduce fishery potential in a cumulative fashion.

The extensive array of habitat modifications presented in Table B have affected flows, water temperatures, pollutant concentrations, dissolved oxygen levels, nutrient concentrations, channel morphology, gravel availability and compaction, food availability, and many other factors affecting fish production. These changes have significantly modified fish abundance, distribution, and production throughout the Central Valley.

Introduced species became established during the same period of major habitat modification. In some instances, modification of natural aquatic habitats reduced native fish populations and created the need to introduce species better suited to the changed environment. Most of these introductions have been made to improve fishing or provide forage for game species. Many of these introduced species have adversely affected native species through predation, competition for habitat and food, and hybridization. At the same time, some introduced species became the major prey of native species. Introduced species are now more abundant than native species in many areas of the Central Valley. Most notable from a recreational fishing standpoint among introduced species are striped bass and American shad, both introduced in the late 1800s.

The Delta and Bay are at the terminus of the habitat modifications throughout the Central Valley. Diversions upstream of and within the Delta have gradually reduced the freshwater inflow through the Delta and Bay. Upstream storage has changed the natural flow pattern, reducing inflow primarily during winter and spring, while increasing inflow during the summer. Exports from the south Delta by state and federal water projects have greatly changed the flow patterns through the Delta, reversing flows at certain times in many of the channels and in the San Joaquin River.

The above habitat modifications, in combination with additional habitat modifications (Table B), created a complex web of fisheries resource impacts, including changes in species abundance, distribution, and production. The cumulative effect of habitat modification, species introductions, and fishing pressure has significantly impacted fish populations throughout the Central Valley.

HISTORICAL IMPACTS OF CVP FACILITIES

CVP facilities fall into three general categories: upstream storage facilities, upstream diversion facilities, and Delta diversion (and export) facilities (Table C). This section discusses historical impacts and mitigation measures for both the CVP facilities included in Reclamation's current water contracting program, and for other major CVP facilities affecting San Joaquin and Stanislaus River fisheries.

Trinity River

Salmon production in the Trinity River system has been affected over a long period by a variety of activities. Non-CVP-related activities date back to the mid-nineteenth century and include large-scale hydraulic mining, improper land use and forest practices, and intensive fish harvest. In-basin land use practices, combined with the relatively unstable nature of the Trinity River Basin watershed soils, have resulted in the deposit of extensive sediment loads in the Trinity River and its tributaries. CVP impacts related to construction of the Trinity River Division facilities include blockage of gravel recruitment past Lewiston Dam and altered riverflow and water temperature regimes downstream of the dam. The combination of excessive sediment loading and reduced riverflow has degraded salmon habitat. The Trinity River Salmon and Steelhead Hatchery (SSH) was constructed to mitigate the reduction in the anadromous fish populations attributable to the loss of fish habitat upstream of Lewiston Dam. In addition, a minimum flow release schedule was developed to provide in-river flows for the Trinity River anadromous fish populations downstream of Lewiston Dam.

The Trinity River SSH has had lower-than-desired production efficiencies. Reclamation developed a hatchery modernization plan to upgrade the hatchery facilities to state-of-the-art standards. This plan is being implemented, and all construction is scheduled to be completed by 1990. The upgraded facilities are designed to allow the Trinity River SSH to meet its mitigation goal in all years.

Table C. Major CVP Facilities

Facilities	Completion Date	Primary Affected Area
Storage		
Clair Engle Reservoir	1960	Trinity River
Whiskeytown Reservoir	1963	Clear Creek
Shasta Reservoir	1949	Sacramento River
Folsom Reservoir	1956	American River
Millerton Reservoir	1947	San Joaquin River
New Melones Reservoir	1978	Stanislaus River
Upstream Diversion Facilities		
Lewiston Dam	1962	Trinity River
Whiskeytown Dam	1963	Clear Creek
Red Bluff Diversion Dam	1966	Sacramento River
Nimbus Dam	1956	American River
Friant Dam	1947	San Joaquin River
Delta Diversion Facilities		
Delta Cross Channel	1951	Sacramento River and Delta waterways
Tracy Pumping Plant	1951	Delta waterways

In 1974, a task force of 11 federal, state, and county agencies was formed to develop a long-term management program for the Trinity River basin. The result of this planning effort was the publication of the Trinity River Basin Fish and Wildlife Management Program report in 1982, which outlined an action plan to address the major areas of concern. The report identified an 11-point action plan to restore the fish and wildlife habitat in the Trinity River basin to levels that existed prior to the construction of the Trinity River Division CVP facilities. The federal government authorized the expenditure of $57 million over 10 years to implement the recommendations of this program. Reclamation and the USFWS are the principal federal agencies involved. The program focuses on habitat rehabilitation and instream restoration.

In addition, Reclamation is funding an instream flow evaluation of the Trinity River that is being conducted by the USFWS. This evaluation is scheduled to be completed over a 12-year period at a cost of approximately $4 million. The results of this study will be used to identify specific flow regimes for the anadromous fish in the Trinity River.

Some progress has already been achieved. Actions of the various programs, including a commercial fishing harvest reduction imposed by the Pacific Fisheries Management Council, have combined to produce significant increases in the number of steelhead trout and chinook salmon returning to the Trinity River SSH in each of the last 2 years.

Clear Creek

Whiskeytown Dam was constructed in 1963 approximately 10 miles upstream from Saeltzer Dam, a privately owned dam built in 1903. The principal sport fish in Clear Creek is chinook salmon, although rainbow and steelhead trout are also present.

The Clear Creek fishery has been affected by a number of CVP- and non-CVP-related activities. Saeltzer Dam effectively blocked the upstream migration of anadromous fish and also prevents the movement of gravel downstream past the dam site. Gravel mining downstream of Saeltzer Dam has removed much of the spawning gravel potentially available for the fish. Whiskeytown Dam has altered the flow regime in Clear Creek by stabilizing the annual flow conditions. Fall flows have been reduced and summer flows have been increased. Although Whiskeytown Dam traps much of the sediment that normally would be transported downstream, the reduced high flow events have prevented the movement of sediments out of the stream system, thereby resulting in sediment compaction in the gravels downstream of Saeltzer Dam.

DFG, DWR, and Reclamation have prepared reports describing their recent investigations on Clear Creek. The recommendations in these reports for improving the Clear Creek fishery include removing Saeltzer Dam (or, alternatively, providing fish passage past Saeltzer Dam), eliminating instream gravel mining, rehabilitating instream habitat downstream of Saeltzer Dam, and augmenting flow from Whiskeytown Reservoir.

Sacramento River

Coleman National Fish Hatchery (NFH) was constructed as partial mitigation for the reduction in the anadromous fish populations attributable to the loss of fish habitat upstream of Keswick Dam. In addition, a minimum flow release schedule was developed to provide in-river flows for the Sacramento River anadromous fish populations downstream of Keswick Dam.

Under a 1949 agreement between Reclamation and the USFWS, the USFWS assumed full responsibility for funding and operating Coleman NFH. The USFWS is presently upgrading Coleman NFH facilities to state-of-the-art standards and is expanding the hatchery's capability to include the production of winter- and spring-run chinook salmon. In 1987, Reclamation agreed to provide, at no cost to the USFWS, sufficient hydroelectric power to operate all the existing and proposed facilities at the hatchery.

In dry and critically dry years, water temperature conditions in the upper Sacramento River are frequently unsuitable for chinook salmon. Reclamation has operated CVP reservoirs to provide water of suitable temperature, balancing reservoir releases into the Sacramento River from CVP facilities in the Trinity and Sacramento River systems, and releasing water through the low-level outlets at Shasta Dam. The releases through the low-level outlets are expensive because water released in this manner must bypass the hydroelectric power generating facilities. During the past two summers, Reclamation released cold water through the low-level outlets at an additional cost (i.e. cost to purchase replacement power from alternative energy supply sources) of approximately $4.5 million. Reclamation is designing a temperature control device to be installed at Shasta Dam. This device will direct water of suitable temperature from specific water levels through the power generating facilities and will cost approximately $5.5 million; it is scheduled to be operational by 1990.

Shasta Dam has blocked gravel recruitment for downstream salmon spawning and incubation. The problem of gravel availability in the Sacramento River is exacerbated downstream by other non-CVP-related activities, such as dam construction in Sacramento River tributaries, bank protection measures in the main stem of the Sacramento River, and gravel mining enterprises. In 1988, Reclamation and DFG cooperated in an action to place salmon spawning gravel in approximately 3 miles of the Sacramento River between Keswick Dam and Anderson-Cottonwood Irrigation District Diversion Dam. Reclamation provided $250,000 for gravel purchase, and DFG supervised all actions associated with the selection and placement of the gravel.

Red Bluff Diversion Dam was constructed in 1966. The only identified mitigation requirement was to replace the fall-run chinook salmon expected to be lost due to inundation of salmon spawning habitat in the Sacramento River by Lake Red Bluff immediately upstream of the dam. The Tehama-Colusa Canal Fish Facilities were constructed, in part, to mitigate for the presence and operation of Red Bluff Diversion Dam.

Additional Red Bluff Diversion Dam-related impacts have been identified during the period the dam has been in operation. These impacts include impeded passage of upstream-migrating adult salmon past the dam, excessive losses of downstream-migrating juvenile fish due to predators in the vicinity of the dam, and passage of small fish through the fish screens into the Tehama-Colusa Canal Fish Facilities.

Reclamation is committed to resolving the fish-related problems at Red Bluff Diversion Dam. Reclamation provided funds to the USFWS to perform a 5-year, onsite field evaluation of fish passage problems at the dam. Reclamation will utilize the information the USFWS developed to justify implementation of structural and/or operational modifications, and will request the necessary funding for implementing the remedial measures. To improve passage of adult winter-run chinook salmon upstream past Red Bluff Diversion Dam, Reclamation plans to raise the gates at the dam from December through March. This dam gate operation began in December 1986 and will run through March 1992. This action is considered interim while a permanent solution is being implemented through the efforts of the USFWS-Reclamation actions discussed above. Reclamation is also in the process of replacing the louver fish screen facility at the Tehama-Colusa Canal Fish Facilities with a more efficient perforated-plate rotating drum facility; this new facility will cost approximately $15 million and is scheduled for completion by 1991.

Reclamation constructed Spring Creek Debris Dam to retain debris and to prevent toxic and acid mine drainage emanating from mines in the Spring Creek watershed from entering the Sacramento River. EPA has identified the Spring Creek acid mine waste toxicity as one of the greatest potential threats to public health drinking water supplies in the United States. In addition, the toxic wastes have entered the Sacramento River in the past and have caused large fish kills in the upper Sacramento River. EPA, Reclamation, state agencies, and private consulting firms are working cooperatively to resolve the acid mine waste problem. Reclamation is responsible for designing facilities to be constructed at various sites in the watershed to reduce toxic accumulations. These actions are funded through the EPA Superfund Program and are scheduled for completion by 1990.

Other non-CVP-related operations negatively affect survival of anadromous fish in the Sacramento River. These include but are not limited to inadequate fish passage facilities for adult salmon at Anderson-Cottonwood Irrigation District Diversion Dam, losses of juvenile fish at the Glenn-Colusa Irrigation District diversion facility, and entrainment of young fish in the unscreened diversions along the Sacramento River.

American River

The American River fishery has been affected by a variety of non-CVP- and CVP-related activities. Non-CVP-related activities in the basin dating back to the nineteenth century include extensive hydraulic mining operations and construction of water development projects, including water storage reservoirs and diversion facilities. These activities removed salmon spawning gravel from the river and blocked anadromous fish migration. CVP-related effects are associated with Folsom Dam and Nimbus Dam. The Nimbus Salmon and Steelhead Hatchery (SSH) was constructed as mitigation for the reduction in the anadromous fish populations attributable to the loss of fish habitat upstream of Nimbus Dam. In addition, a minimum flow release schedule was developed to provide in-river flows for the Sacramento River anadromous fish populations downstream of Nimbus Dam.

The production of chinook salmon at Nimbus SSH typically exceeds the mitigation goal originally identified for Folsom and Nimbus Dams. During the past 2 years, however, low water supply conditions have resulted in extensive losses, both in hatchery production at Nimbus SSH and in natural production in the American River. The lower water conditions have caused releases from Folsom Dam of water that were too warm for salmon survival. To help alleviate the crisis on the American River, Reclamation purchased hatchery incubation equipment for an emergency operation by DFG this fall at the Feather River Hatchery on the Feather River. Additional chinook salmon were spawned and incubated at the Feather River Hatchery and will be transferred to the Nimbus SSH when American River water temperatures are sufficiently cool. As a result of the excessive water temperature conditions these past 2 years, Reclamation will evaluate structural and operational alternatives to improve temperatures and flow conditions for anadromous fish.

Reclamation has also initiated a hatchery modernization effort for Nimbus SSH. This action will resolve fish rearing problems and increase production efficiency at the hatchery.

Delta Waterways

Impacts to fish and wildlife in the Delta waterways attributable to CVP operations are difficult to identify due to the complex interaction of federal, state, and local water development activities, all of which impact the same resources. In addition, water development activities upstream of the Delta can affect conditions in the Delta. Reclamation is a member of a six-agency group studying the effects of water project operations on the Delta, Suisun Marsh, and San Francisco Bay. Studies related to water quality, hydrodynamics, the food chain, and fisheries are ongoing. The results of these studies will be utilized by the SWRCB in its promulgation of new Delta water quality standards for all beneficial uses.

Operation of the Tracy Pumping Plant hinders survival of San Joaquin River salmon. Most of the young salmon salvaged at the Tracy Fish Facilities originated from the San Joaquin River. Reclamation is presently negotiating with DFG for a means of providing compensation for fish losses attributable to diversion of water by the Tracy Pumping Plant.

Stanislaus River

Water resources development in the Stanislaus River preceded construction of any CVP facilities in the basin. Goodwin Dam, a major water diversion facility owned and operated by private water users, blocks anadromous fish migration past the dam. This dam was in place and operational before the CVP facilities were constructed at New Melones Dam, which is sited upstream of Goodwin Dam. The only impacts of the New

Melones Dam on the anadromous fishery, therefore, are the effects of the altered flow regime caused by New Melones Dam operation.

According to an agreement with the state, Reclamation was obligated to release flows from New Melones Dam for the Stanislaus River fishery. In 1987, Reclamation and the state entered into a new agreement as a condition of Reclamation's water rights permits with the state. The terms of this agreement are considered interim until ongoing Stanislaus River fisheries studies by the USFWS, Reclamation, and DFG are completed. At the completion of these studies, fisheries instream flow criteria will be submitted to the SWRCB for approval. In the interim, increased flows under the terms of the 1987 agreement will be in effect.

San Joaquin River

The San Joaquin River fishery has been affected by a variety of non-CVP- and CVP-related water development activities. Non-CVP water development that began in the nineteenth century eliminated the fall-run chinook salmon that had spawned in the main stem of the river. This run was eliminated before Friant Dam was constructed. Firant Dam operation, however, has been associated with the elimination of spring-run chinook salmon in the San Joaquin River upstream from the Merced River.

Friant Dam was authorized by Congress with no mitigation obligations assigned to the CVP. Fishery impacts could be reduced through hatchery production and increased San Joaquin River discharge during the peak adult immigration and juvenile emigration periods. A new hatchery facility would probably be most successful if constructed on the Stanislaus, Tuolumne, or Merced Rivers because discharge needed to support adult and juvenile migration from Friant Dam would require high reservoir releases.

Water needs for the San Joaquin basin (i.e., water quality, fishery, and a water supply for agricultural and M&I users) are supplied by diverse and mixed federal/nonfederal water supply systems. These water requirements are met by both groundwater and surface water systems. Surface waters are both local and imported to the basin. Exports from the basin are also made to supply M&I needs in the San Francisco Bay Area. In an effort to develop an overall approach to basin needs, Reclamation is developing a San Joaquin River computer model with several nonfederal entities providing data and necessary information. This model will provide a common backdrop to address many complex issues involving San Joaquin water supply and demand within the framework of existing rights and flexibility of operating criteria.

MITIGATION OF HISTORICAL IMPACTS

Trinity River

Current activities appear to be reducing past impacts, and further reductions are expected. Completion of the 12-year flow evaluation study will provide information for future mitigation.

Clear Creek

Although fish population impacts attributable to Whiskeytown Dam cannot be clearly identified, Reclamation completed a study in 1986 indicating that increased water released down Clear Creek from Whiskeytown Reservoir could expand the spawning and rearing habitat area in the creek. The higher discharge would also reduce sediment deposition, improving spawning habitat. Temperatures would decline during spring, summer, and fall, improving conditions for spawning and rearing. Several thousand adult salmon and steelhead would probably be produced by the discharge increase. (Boyle Engineering Corporation 1986).

Sacramento River

Unmitigated Sacramento River impacts are not clearly attributable to Shasta Dam; Reclamation is installing a temperature curtain at Shasta Dam to improve temperature conditions for fisheries. Some unmitigated impacts are attributable to Red Bluff Diversion Dam. Red Bluff Diversion Dam impacts could be reduced to less-than-significant levels through several measures that Reclamation is currently evaluating and implementing in the Red Bluff Diversion Dam Fish Passage Action Program.

Upstream migration delay would be minimized by structural modification to reduce disorienting turbulence, fish ladder modification or improved fishway attraction flow. Reclamation currently opens Red Bluff Diversion Dam gates to improve winter-run chinook salmon passage during the winter months and could continue this procedure in the future. Alterations and modifications necessary to improve fish passage are currently under study.

Juvenile survival will improve with installation of more efficient fish screens, which should be operational by 1990. Mortality from other causes could be reduced through structural and operational modifications or possible predator eradication. Further study would be required to determine causes of mortality and possible solutions.

American River

Reclamation is proposing to modernize the hatchery to resolve fish-rearing problems and increase production efficiency. Studies will be conducted to determine if Folsom dam could be structurally and/or operationally modified to improve temperature and flow conditions for anadromous fish. In the meantime, Reclamation has purchased incubation trays for use at the state Feather River Hatchery to incubate eggs for transfer to the Nimbus Hatchery in years that temperatures are too warm in the American River for egg collection and incubation.

San Joaquin River

Impacts could be reduced but probably not to less-than-significant levels, through hatchery production and increased San Joaquin River discharge during the peak adult immigration and juvenile emigration periods. A new hatchery facility would probably be most successful if constructed on the Stanislaus, Tuolumne, or Merced Rivers because discharge needed to support adult and juvenile migration to Friant Dam would require unreasonably high reservoir releases. Additional water released by non-CVP projects on the Stanislaus, Tuolumne, or Merced Rivers to provide adequate discharge for a Reclamation hatchery-supported chinook salmon run could be compensated for by appropriate releases and exchanges from CVP projects.

Stanislaus River

Reclamation's New Melones releases and ongoing studies appear adequate to reduce fisheries impacts.

Delta Waterways

Impacts to San Joaquin River chinook salmon could be reduced to less-than-significant levels through closure of Old River at its confluence with the San Joaquin River near Mossdale and release of sufficient upstream San Joaquin River water to move the juveniles through the Delta during peak emigration periods. Reclamation is studying alternatives for facilitating salmon and striped bass migration, including improved fish screens and operational changes, and is presently negotiating a mitigation agreement with DFG for direct losses of fish at the Tracy Pumping Plant. In addition, Reclamation is part of a six-agency group studying the effects and potential effects of water project operations on the Delta and Bay. Studies related to water quality, hydrodynamics, food chain, and fisheries are ongoing.

DELTA AND BAY AFFECTED ENVIRONMENT

Physical Characteristics

Existing conditions of fishery resources for the SRSA, ARSA, and DESA have been presented in Chapter 3 of each respective EIS. The Delta-Bay environment, while it does not lie within the three service areas, is directly impacted by certain CVP activities. The existing condition of the Delta and Bay is discussed in the following paragraphs.

The Delta-Bay environment consists of several inseparable components. The Delta is connected to Suisun Bay, Suisun Bay to San Pablo Bay, San Pablo Bay to central San Francisco Bay, and central San Francisco Bay to south San Francisco Bay and the Pacific Ocean. The Delta is the most riverine component, receiving 90 percent of the freshwater inflow to the Delta-Bay system. Physical characteristics are briefly described in the following paragraphs.

Delta

The Delta is the meeting place of rivers, where river velocities slow and tidal currents become influential. Three major rivers, the Sacramento, Mokelumne, and San Joaquin, enter the Delta from the north, northeast, and south, respectively. The rivers split into distributaries, creating a complex web of channels and sloughs between 60 or more leveed islands. The channels converge into one channel near Pittsburgh, where net water flow is toward Suisun Bay.

Delta channels are generally less than 30 feet deep, unless dredged, and vary in width from less than 100 feet to more than 1 mile. Some Delta channels are edged with aquatic and riparian vegetation, but most channels are bordered by steep banks of mud or riprapped levees (Kelley 1966, DeHaven and Weinrich 1988). Vegetation is generally removed to improve flow and facilitate levee maintenance.

Delta channels, except in dead-end sloughs, are characterized by strong currents. Flows are generally from north to south. CVP and SWP pumps, however, cause water to move from the Sacramento River through the Delta Cross Channel and Georgiana Slough into the distributaries of the Mokelumne River, then across the San Joaquin River and south through Middle and Old Rivers toward the pump intakes at the south end of the Delta. Consequently, San Joaquin River water usually does not pass through the Delta but mixes with Sacramento River water and is transported toward the pumps through various channels (California Department of Water Resources 1987). During low discharge and high export conditions, the entire San Joaquin River can flow toward the pumps through Old River at Mossdale, along with Sacramento River water flowing up the San Joaquin River channel from Stockton.

Delta environmental conditions depend primarily on the physical structure of Delta channels, volume of inflow, within-Delta diversions (including many small agricultural diversions, state and federal water project diversions, and others), and tides. The CVP affects Delta environmental conditions primarily through control of upstream storage and diversions, and Delta diversions. The relationship between fish populations and CVP control of inflow and diversions is complex and often vague (Figure A).

The Sacramento, San Joaquin, and Mokelumne Rivers are the primary Delta inflow contributors, with each river carrying about 82, 11, and 3 percent of the total Delta inflow, respectively. Although inflow is dependent upon meteorological conditions, upstream reservoirs and diversions control inflow volume, timing, frequency, duration, and, in part, quality. Inflow is less controlled during winter and early spring and approaches natural conditions in wetter years. (See "Surface Water Hydrology and Water Quality" section for a detailed discussion.)

Ocean tides affect Delta environmental conditions, depending on freshwater inflow and diversions, but twice daily tidal changes in water level, velocity, and flow pattern nearly always overlay riverine conditions. Seawater intrusion depends primarily on Delta outflow but is also related to Delta flow patterns. Delta diversions, in combination with low Delta inflow, cause lower San Joaquin River (near Antioch) net flows to reverse, and seawater can be moved toward the central and south Delta. Channel dredging also exacerbates seawater intrusion into the Delta.

During critically dry years, seawater intrusion increases salinity above Walnut Grove on the Sacramento River and above Stockton on the San Joaquin River. Salinities increase in a downstream direction (except in the San Joaquin River above Terminous, where salinity from agricultural runoff can be high), and the steepness of the horizontal and vertical gradients is controlled by river discharge.

Suisun, San Pablo, and Central and South San Francisco Bays

Net freshwater flow moves from the Delta west into Suisun Bay (including Honker and Grizzly Bays). In general, Suisun Bay is deeper in the south, interspersed with shipping channels, and increasingly shallow in the north where expansive tidal flats grade into extensive brackish and freshwater marsh.

The mixing zone, an area of freshwater and saltwater mixing, generally begins in Suisun Bay. The area in which opposing forces of longitudinal and vertical salinity gradients equalize is called the null zone. Adjacent to and downstream of this null zone is the entrapment zone, where sediments, nutrients, phytoplankton, and zooplankton are concentrated. The location of these zones is dependent on Delta outflow, with the null zone moving into the Delta during outflows of less than 4,000 cfs and moving toward San Pablo Bay during outflows greater than 10,000 cfs (California Department of Water Resources 1986).

Phytoplankton productivity is highest when the entrapment zone is adjacent to the expansive shallows of Suisun Bay; however, the cause-effect mechanisms regulating phytoplankton production levels are not fully understood (Arthur and Ball 1980). Since zooplankton are directly or indirectly dependent on phytoplankton, any reduction in phytoplankton would act to reduce zooplankton (California Department of Fish and Game 1987).

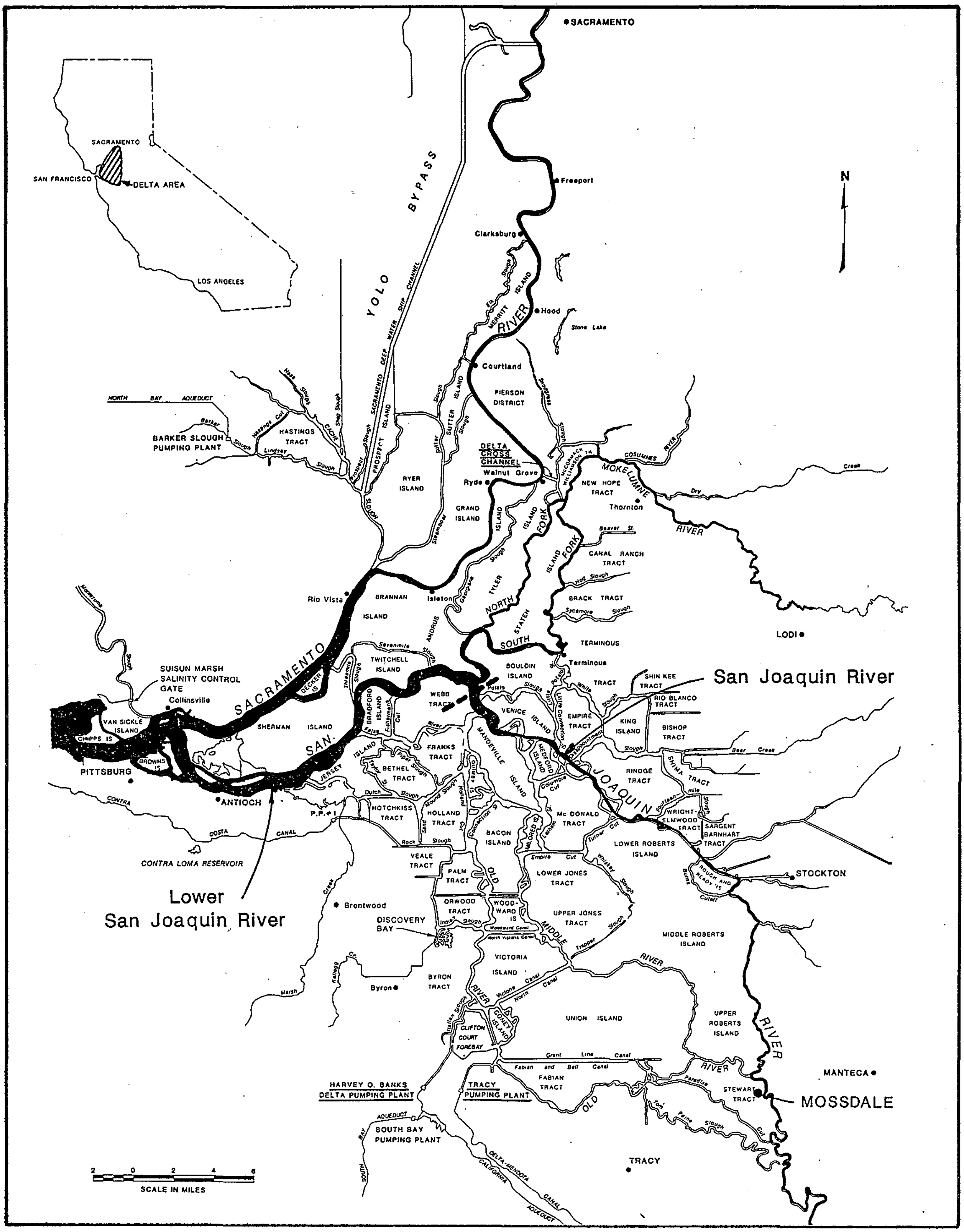

FIGURE A. DELTA WATERWAYS

Source: DWR 1987

Suisun Bay environmental conditions depend primarily on the physical structure of the bay, inflow, tides, and wind. As in the Delta, the CVP affects Suisun Bay environmental conditions, primarily through control and modification of Delta outflow (Figure A).

San Pablo and Suisun Bays, both of which are connected by the Carquinez Strait, are characterized by extensive shallow areas. In general, San Pablo Bay is deeper on the eastern side, with expansive shallow areas on the west and north grading into salt and brackish marsh. Environmental conditions are less dependent on freshwater inflow and more dependent on wind and tides, except during storm events when large amounts of freshwater are discharged from the Delta.

Central San Francisco Bay connects with San Pablo Bay, south San Francisco Bay, and the Pacific Ocean. Central San Francisco Bay is deeper than the other bays and environmental conditions are more dependent on tides. Estuarine circulation patterns, which generally begin in Suisun Bay because of salinity gradients created by freshwater inflow, are still present in the central Bay.

South San Francisco Bay is the least affected by freshwater inflow from the Delta and does not exhibit estuarine circulation except after major runoff events when Delta outflow exceeds 35,000 cfs. Events of this magnitude appear to be important to the flushing characteristics of south Bay and may relate to environmental conditions important to south San Francisco Bay fish populations.

Chinook Salmon

The Delta and Bay serve as a migration path and holding area for chinook salmon returning to their natal rivers to spawn. Four races of chinook salmon migrate up the Sacramento River and two races migrate up the San Joaquin River and other Delta tributaries.

Run timing is an inherent characteristic of each race, modified by response to river temperature and flow. Fall, late fall, and winter races are stimulated by decreasing temperature and increasing flow in the lower river. The spring race is probably stimulated by increasing temperatures in the spring. Temperatures exceeding 65°F can delay upstream migrating fall chinook salmon (Hallock et al. 1970); although chinook salmon will move up the rivers at these temperatures.

Emigrating adult chinook salmon follow the salinity gradient through San Francisco Bay to the western Delta (U. S. Fish and Wildlife Service 1987). Once in freshwater, adults use their olfactory sense to find their home stream. Sacramento River chinook salmon primarily migrate up the mainstem Sacramento River, although some fish use the distributaries of the Mokelumne River and enter the Sacramento River via Georgiana Slough and the Cross Delta Channel. The presence of Sacramento River water in the central and southern Delta, a result of high CVP and SWP pumping rates, draws more Sacramento River chinook salmon along the Mokelumne River path and delays immigration of both Sacramento and San Joaquin River chinook salmon (Hallock et al. 1970). Delays from Delta outflow volumes and patterns do not appear to have a major effect on subsequent run size.

Juvenile chinook salmon are found in the Delta and Bay from about October through June or July. Emigration timing is partially dependent on race. Fall run progeny emigrate as yearlings (95-160 mm) from about November through December, as fry (about 40 mm) from January through March, and as sub-yearlings (75-90 mm) from April through June. Late fall sub-yearlings (75-90 mm) emigrate in fall, about the same time as fall yearlings, while spring- and winter-run smolt (95-160 mm) emigrate from January through April (Schaffter 1980, U. S. Fish and Wildlife Service 1987).

Emigrant juveniles depend on the Delta and Bay as rearing habitat before entering the ocean. The estuary provides an abundant food supply, shallow low-velocity habitat, and generally good temperatures for growth. Fry rear in the Delta for several months and feed in the marshes, tide flats, and sloughs. The fry leave the Delta and Bay environment when they grow to a threshold size between 70-100 mm (Cannon 1982, Kjelson et al. 1982), or when water temperatures increase. Water temperatures exceeding 64°F occur in the upper estuary by May or June and earlier in parts of the Delta (Cannon 1982).

Fry abundance in the estuary appears to depend on river discharge; high discharge during wet years results in greater fry abundance (U. S. Fish and Wildlife Service 1987). Higher discharge also extends the rearing habitat farther down the estuary, since rearing occurs primarily in freshwater, and high flows can move the mixing zone down the estuary toward central San Francisco Bay.

Sacramento River fall run smolt emigrate primarily in April, May and June, with 25, 50, and 25 percent of the fish entering the Delta and Bay each month, respectively (U. S. Fish and Wildlife Service 1987). San Joaquin fall run fish follow the same percentage split over 3 months; however, emigration shifts about 1 month earlier in spring (California Department of Fish and Game 1987a). The time smolts spend in the Delta and Bay varies, but they generally move through at 5-15 miles per day, approaching the higher rate as the season progresses (Wickwire and Stevens 1971).

Generally speaking, juvenile chinook survival is positively related to Delta flows (U. S. Fish and Wildlife Service 1987). This relationship appears to result from two factors. First, with a smaller proportion of water, more juvenile chinook salmon are diverted from the migration path at high flows than at low flows. Second, high flows reduce the time salmon are exposed to detrimental temperatures. Recent studies indicate that higher flows are more important to smolt survival during periods of detrimental temperatures, which accounts for the strong relationship between flow and smolt survival during May and June, when temperatures in the lower Sacramento River and Delta become detrimental to chinook salmon survival.

Dettman et al. (1986) determined that the effects of flow could be discerned in trends in adult returns, but found no observable relationship between flow and adult returns since 1968. The absence of a relationship is attributable to the increase in hatchery plants in the lower Delta and estuary, which appears to have dramatically reduced the influence of river and Delta environmental conditions on fingerling to adult survival.

Juvenile Sacramento River salmon are diverted into the Cross-Delta Channel in roughly the same proportion as water is diverted (U. S. Fish and Wildlife Service 1987). Survival rates for diverted fish are lower than for fish continuing down the Sacramento River and may be more than 50 percent lower, depending on environmental conditions (especially temperature).

Decreasing Delta inflow increases fish losses to diversions attributable to CVP and SWP and to the several thousand, mostly unscreened agricultural diversions located throughout the Delta and the Sacramento and San Joaquin River system. Losses increase because the diversions remove fairly constant amounts of water each year, and the proportion of flow and fish diverted varies with flow rate (Stevens and Miller 1983).

Although the Sacramento River produces more than 80 percent of the fall run chinook salmon, the majority of juveniles salvaged at the CVP and SWP pumps are from the San Joaquin River. About 90 percent of the juvenile chinook salmon salvaged at the CVP pumps are San Joaquin River stock. San Joaquin River juveniles are pulled toward the pumps through Old River near Mossdale and through Old River, Middle River, and other sloughs transporting water across the central Delta. Juvenile salmon moving down the mainstem San Joaquin River appear to survive better than those diverted, and studies are currently underway to estimate these impacts (California Department of Fish and Game 1987a).

Screening rates for chinook salmon are believed to be nearly 100 percent (California Department of Fish and Game 1987b). However, screen efficiencies at the approach to the CVP pumps change with tidal stages. Velocities can vary from 0.5 fps to 5.4 fps, due to tide effects interacting with pumping rates (Shimamoto pers. comm.). Reclamation is presently negotiating a mitigation agreement with DFG for direct losses of fish at the Tracy Pumping Plant.

Other Delta and Bay environmental conditions undoubtedly have had an impact on juvenile chinook salmon survival and growth (Herrgesell et al. 1983, California Department of Fish and Game 1987b, Rozengurt et al. 1987). Primary among these conditions are predation, food production and availability, and pollutant concentration. Vulnerability to predation is increased through disorientation, such as diversion from the most direct migration route, and concentration of predators, such as appears to occur in Clifton Court Forebay.

Relationships between food production and chinook salmon survival have not been conclusively established, although Neomysis density may have some effect on chinook salmon survival (Dettman and Kelley 1987). (A discussion of food production in relation to fish needs occurs toward the end of this section.)

The relationship between toxics concentration and salmon survival in the Delta and Bay system is unknown. However, higher outflows reduce residence times (Smith 1987) and flush potentially toxic substances from the system, thereby reducing the chance of increased mortality.

Striped Bass

Adult striped bass can be found in the Delta and Bay environment throughout the year. Adults begin concentrating in the Bay, primarily San Pablo and Suisun Bay, in the fall and move into the Delta and up the Sacramento River during winter and early spring (California Department of Fish and Game 1987c). About 55 percent of the stock spawns in the Sacramento River above the Delta during May and June, and about 45 percent of the stock spawns in the San Joaquin Delta during April and May. The adults usually leave freshwater by June or July, but many remain in the Bay.

Striped bass spawn in fresh water, and optimum spawning success generally occurs at salinities of less than 1 part per thousand (California Department of Fish and Game 1987c). Spawning areas in the Delta are generally limited by the salinity gradient, usually just downstream from Antioch Point, and by agricultural salt concentration in the San Joaquin River above Venice Island.

Semibuoyant eggs are broadcast-spawned in open water, drift with the current, and hatch in about 2 days (California Department of Fish and Game 1987c). The newly hatched larvae continue drifting with the current, and Sacramento River larvae generally reach the Delta within a few days. High river flows carry the newly hatched larvae into Suisun Bay, or even farther downstream depending on flow. Lower flows concentrate the larvae in the Delta, and under extremely low flows the larvae concentrate at the very eastern edge of their normal range. In general, peak juvenile abundance occurs near the entrapment zone.

Larvae begin feeding at a length of 5-6 mm (Turner 1987). The initial diet includes Cladocera (Bosmina and Daphnia) and Copepoda (Eurytemora and Sinocalanus), with copepods dominating the diet of 7-11 mm larvae. As the larvae grow, copepods continue to be important, but the mysid, Neomysis, becomes the primary food organism (California Department of Fish and Game 1987c).

After a year the juvenile bass generally measure at least 100 mm. Neomysis is the primary food during the first year and remains important for at least another year, although fish are an increasingly important diet item (Stevens 1966).

Young bass become increasingly more mobile with size and less dependent on currents for transport. During their second year, the young bass begin to move out of the Delta and Suisun Marsh and disperse throughout the estuary.

Adult striped bass abundance has declined to about 20 percent of 1960 population levels (Cannon 1982). Four major conditions are thought to have caused the decline: direct and indirect entrainment at pumping facilities, decreased food supply, toxics, and reduced egg production.

Striped bass are most vulnerable to entrainment-related mortality from April to mid-July, during their egg, larval, and early juvenile stages (California Department of Fish and Game 1987b). The impact of entrainment depends on population density and distribution, Delta inflow and outflow, and the volume and timing of diversions. As with chinook salmon, decreasing Delta inflow increases striped bass losses to diversions. Low inflow also moves striped bass larvae out of the Delta more slowly and can concentrate larvae in the Delta where they remain vulnerable to mortality throughout the rearing period.

Salvage loss of striped bass (> 18 mm) at the John E. Skinner Delta Fish Facility was shown to be significantly related to flow (quantity and direction) in the lower San Joaquin River, combined exports of the CVP and SWP pumps, total striped bass abundance, and mean striped bass size (Wendt 1987). Increasing exports and decreasing San Joaquin River flow (or increasing reverse flow) increases the salvage loss of striped bass larger than 18 mm.

Entrainment mortality to eggs, larvae, and juveniles is significant, and this mortality may affect future adult populations (Turner 1987). Mortality from entrainment alone, however, cannot explain the decline in striped bass abundance (California Department of Fish and Game 1987c).

In general, striped bass mortality is highest during the earliest life stages, and slowed growth subjects larvae to higher mortality rates over a longer period. Low prey density may contribute to lower growth rates. Although declines in first-year growth rates have occurred (California Department of Fish and Game 1987c), the relationship between prey density in the Delta-Bay environment and early striped bass growth has not been conclusively shown.

Striped bass survival may be reduced by the presence of toxic substances in the estuary. Some adult bass have accumulated toxins and appear to be in poor health compared to bass in other populations (Brown 1987). Further studies are needed to better understand the relationship between toxics concentration and striped bass survival and abundance.

Since the 1970s, egg production has declined nearly 90 percent because of a younger, less abundant bass population. Year class strengths may be reduced, but the tremendous fecundity of striped bass, coupled with favorable environmental conditions, provides the potential for substantial population increases (Striped Bass Working Group 1982).

American Shad

Adult American shad migrate to freshwater from the ocean, and some from the Bay, during March, April, and May (California Department of Fish and Game 1987e). Adults actively feed during their migration, preying on Neomysis and various cladocerans (Stevens 1966). Active spawning begins in May and continues into early July (California Department of Fish and Game 1987e). After spawning, the adults leave the spawning grounds and return to the ocean and Bay by September.

The primary spawning grounds are in the upper Sacramento River and its tributaries. The northern Delta, including the northern portion of Old River, also is an important spawning area (California Department of Fish and Game 1987e). Shad broadcast-spawn their eggs and sperm into the currents, where the semi-buoyant eggs sink slowly and drift with the flow. The eggs hatch in 4 to 6 days and as the larvae grow they begin feeding on copepods and cladocerans. Ganssle (1966) reported Neomysis, copepods, larval fish, and Corophium as the primary prey of young-of-the-year American shad.

Young shad do not continue to drift with the currents, but actively maintain their position. Shad spawned in the Sacramento River system generally rear in the rivers downstream from the spawning area. Shad spawned in the Delta appear to rear primarily in the Delta. The precise location of major rearing areas varies from year to year and seems to be dependent on river flow, i.e., high flows transport eggs and larvae farther downstream (California Department of Fish and Game 1987e).

Most juvenile American shad emigrate from their freshwater rearing areas between September and December and enter the Bay environment (Stevens 1966). Timing of the seaward emigration is probably dependent on size, usually 5 to 15 cm, and the final exodus may be triggered by declining water temperatures (Chittendon 1972). By January, most juveniles have migrated to the ocean although some remain in the estuary until maturity.

American shad are probably limited by the same factors that affect striped bass, except that fall abundance of young-of-the-year shad seems to be related to mean Delta outflow during April, May, and June (California Department of Fish and Game 1987e). The strongest American shad year classes, which vary more than an order of magnitude from year to year, occur in the years with the highest river flows during the spawning and nursery period (Stevens and Miller 1983). Adult population estimates are not sufficient to determine the relationship between young-of-the-year abundance and adult abundance.

American shad exhibit two peaks of vulnerability to entrainment at the SWP and CVP pumps, and are the third most common fish entrained (California Department of Fish and Game 1987e). The first peak occurs in early summer, usually around July, and impacts the newly metamorphosed juveniles. These juveniles are probably the progeny of Delta spawning adults. Undoubtedly, eggs and smaller larvae are also entrained, but they can not be screened.

The second peak occurs in fall, usually around November, and impacts 5-15 cm juveniles. The majority of these fish are probably the progeny of upstream-spawning adults and are diverted toward the pumps during their outmigration. The proportion of water diverted through the Cross Delta Channel and Georgiana Slough, as well as flows in the lower San Joaquin River, are the primary factors affecting the proportion of the stock entrained at the pumps.

Decreasing Delta inflow increases fish losses to diversions for reasons previously discussed. Food supply factors affecting striped bass may also impact American shad. (A discussion of food production in relation to fish occurs toward the end of this section.)

Other Species

At least 100 additional fish species occur in the Delta and Bay environment, with about 40 in the Delta alone (Appendix V). These species are not discussed in the same detail as the three species above either because they are numerically less significant, their value to commercial and sport fisheries is minor, or information relating to their Delta-Bay environmental needs and population abundance is currently unavailable. Some of the species are discussed generally, either as representative species or groups of species. Included in the list are three invertebrate species (crayfish, Asian clam, and Dungeness crab) that support commercial and sport fishing activities.

Steelhead Trout

Adult steelhead trout pass upstream through the estuary, primarily from August through January, and most proceed up the Sacramento River to spawn. After spawning, the surviving adults migrate back down through the estuary during March, April, May, and June. Peak steelhead trout smolt migration occurs primarily from March through May, following a riverine rearing period of a year or more. Hatchery reared smolt are generally released in February (Hallock et al. 1961).

Production-limiting factors are similar to those for chinook salmon, although the timing of smolt migration may precede the occurrence of deleterious Delta temperatures.

Sturgeon

White and green sturgeon inhabit the Delta and Bay environment throughout the year and are believed to have similar environmental requirements. The white sturgeon is the more abundant and more studied. Spawning occurs in spring, primarily in the Sacramento River above the Delta, and adults return to the estuary after spawning. Juvenile sturgeon are found throughout the Delta, although they are most abundant in the Sacramento River (Radtke 1966). The primary food items of juveniles in the Delta are the amphipod Corophium and the mysid Neomysis.

Production-limiting factors are relatively unknown although young sturgeon abundance is probably affected by entrainment, toxics, and reduced food supply. Salvage at the SWP screens totals about 3,000 fish annually. Food availability may be a significant limiting factor and is partially controlled by the same factors discussed for striped bass and American shad prey.

Other Freshwater Resident Species

Three major groups dominate the freshwater resident species: sunfish and black basses, catfish, and minnows (California Department of Fish and Game 1987f). Sunfish and black basses (bluegill, largemouth bass, etc.) are most abundant in the eastern Delta but are found throughout the freshwater portions of the estuary. Generally, most species are abundant in transport channels, which may reflect a preference for greater amounts of aquatic vegetation. All species spawn in the spring and summer and lay adhesive eggs in nests on the bottom. Diet varies with size and species, but Neomysis, Corophium, isopods, and copepods are important in the diet of small juveniles (Turner 1966a). Fish and crayfish become more important prey items as the fish increase in size.

White catfish are more than 35 times more abundant, on average, than any of the other species of catfish (including bullhead) in the Delta (California Department of Fish and Game 1987f). White catfish is the dominant fish species in the south Delta, and their abundance is correlated with low water transparency and conductivity. Catfish generally spawn in summer and lay their adhesive eggs in nests on the bottom. Corophium is the most important item in the diets of all catfish species, especially the diet of juveniles (Turner 1966b). Neomysis, other amphipods, and isopods are also eaten by small juveniles, while larger juveniles and adults consume proportionately more fish, crayfish, and Asian clams.

The most abundant minnows are introduced, e.g., carp, goldfish, and golden shiner. Native minnows include hardhead, hitch, Sacramento squawfish, Sacramento splittail, and Sacramento blackfish. Less is known about this group than the others.

Crayfish are abundant in the Delta year-round, are important in the diet of many fish, and support significant sport and commercial fisheries. Crayfish eggs are carried by the female until hatching begins between March and June. The diet of crayfish consists primarily of benthic invertebrates.

Production-limiting factors may include many of the characteristics discussed for other species. Factors of primary concern include habitat loss (due to changes in flow patterns, flow velocity, water level fluctuations, and salinity distributions), entrainment, toxics, and food availability. An average of 300,000 white catfish and 810,000 threadfin shad were entrained annually by the SWP facility (California Department of Fish and Game 1987f). White catfish entrainment peaks in June, July, and August, while threadfin shad entrainment peaks in July and August. Significant numbers of resident fish are entrained by water diversions, but the actual entrainment impact on populations cannot be determined because information on population size, screening efficiency (except for a few species), and indirect entrainment losses is unavailable. Open water pelagic fish (threadfin shad, Delta smelt, etc.) are probably most susceptible to entrainment, followed by catfish and minnows, with sunfish and black basses having the lowest susceptibility.

Special-Status Species

The Delta smelt is native to the estuary and, since 1982, has declined to the lowest levels on record. This species has been added to the candidate species list for possible addition to the list of endangered and threatened wildlife (Lorentzen 1987). Smelt range from the Delta into Suisun Bay, where they are generally found schooling in open surface waters (Moyle 1976). Migration into the upper channels of Suisun Bay and the lower reaches of the Delta occurs in the fall.

Spawning occurs in deadend sloughs and channels and the adhesive eggs are deposited over submerged tree branches or over sandy and rocky substrate (Radtke 1966, Wang 1986). Delta smelt are fast growing and reach sexual maturity after their first year.

The population is probably more sensitive to short-term environmental changes than some other species since they do not live much beyond their first year, and spawning failure in two successive years could eliminate the species. Smelt feed primarily on copepods, insect larvae, and Neomysis.

Production-limiting factors may include many of the factors discussed for other species. Factors of primary concern include habitat loss (due to changes in flow patterns and salinity distributions), entrainment, and food availability. Stevens and Miller (1983) found no significant correlations between abundance of Delta smelt and river flows.

The Sacramento splittail, native to the estuary, has declined significantly in distribution and abundance. This species has been added to the candidate species list for possible addition to the list of endangered and threatened wildlife (Lorentzen 1987). The population does appear to be thriving in Suisun and San Pablo Bays (Wang 1986).

Sacramento splittail range from the lower reaches of the Sacramento and San Joaquin Rivers, through the Delta, and into Suisun and San Pablo Bays (Caywood 1974, Wang 1986, Jones & Stokes Associates 1987). They inhabit slow-moving waters of the main channels and backwater sloughs, and can tolerate brackish water.

From early February to July, adhesive eggs are broadcast-spawned over flooded streambank vegetation or over beds of aquatic plants (Caywood 1974, Moyle 1976, Wang 1986). Larvae remain in the shallow, weedy areas where spawning occurred. Juveniles move into deeper waters and feed on algae, pelecypods, and amphipods.

Production-limiting factors may include many of the factors discussed for other species. Factors of primary concern include habitat loss (due to changes in flow patterns and salinity distributions), entrainment, toxics, and food availability.

Estuarine and Marine Species

The number of estuarine and marine species in the Delta-Bay environment greatly exceeds the number of freshwater species. In general, less is known about their habitat requirements and factors that affect their abundance. A few species are discussed to illustrate possible relationships between environmental changes and population impacts.

English sole is a commercially important species that spawns in the ocean over the continental shelf during winter, with peak spawning in January and February (Herrgesell et al. 1983). The larvae and juveniles are carried into the Bay by currents and actively respond to circulation patterns to enhance their transport and remain in the estuary. Nursery grounds are typically shallow areas with fine sandy substrate and relatively quiet water, such as is found in San Pablo and Suisun Bays. Nursery areas generally lack large predators, and competition among age groups of the same species is reduced (sexually mature English sole have not been observed in the nursery areas); survival may be enhanced as compared to open coast nurseries. Most immature sole leave the estuary and move into oceanic water during September and November of their first year.

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Longfin smelt are most abundant in San Pablo and Suisun Bays in salinities greater than 10 parts per thousand (Herrgesell et al. 1983). They are considered to be anadromous and move into the Delta during winter and early spring to spawn. Most spawning occurs in the lower Sacramento River, where adhesive eggs are deposited on rocks, aquatic plants, or the river bottom. The young fish move downstream after hatching in spring. The abundance of young longfin smelt increases directly with river flow rates that occur during the spawning and nursery period, particularly spring and early summer flows (Stevens and Miller 1983).

Pacific herring migrate into protected bays and estuaries to spawn, generally returning to their birthplace (Herrgesell et al. 1983). Spawning migrations are variable, but mass spawning usually occurs at roughly 2-week intervals from December to March. Laboratory tests have shown that eggs and larvae are tolerant of salinities ranging from 8 to 28 parts per thousand, with maximum spawning success occurring at about 17 parts per thousand. San Francisco Bay is the largest spawning region south of Puget Sound that provides the apparent spawning requirement of protected waters, reduced salinities, and adequate temperatures.

The exact relationship between freshwater inflow (i.e., Delta outflow) and fish abundance and distribution cannot be determined at this time, but several mechanisms are possible (Armor and Herrgesell 1985). Increased flow may directly or indirectly distribute a species, decreasing intra- and interspecific competition (Stevens and Miller 1983). Increased flow may increase recruitment of marine species into the Bay and move freshwater and estuarine species farther downstream into the Bay. Higher Delta outflows are associated with stronger and more consistent bottom flows in central San Francisco, San Pablo, and Suisun Bays. These bottom flows probably result in the wider distribution of English sole larvae and juveniles.

Increased freshwater flows may also bring more food into the Bay or cause food production to increase. Finally, environmental conditions that maximize fish survival may be dependent on seasonal freshwater inflow or factors affected by inflow. Exposure time of organisms to toxics is one of these factors. Delta outflow has a major effect on residence times (Smith 1987). Residence times in Suisun and San Pablo Bay range from weeks at outflows around 4,000 cfs to days at outflows around 30,000 cfs. In south San Francisco Bay, residence times range from months during low outflows (4,000 cfs) to weeks at very high outflows (350,000 cfs).

Biological responses of estuarine and marine species to Delta outflow conditions will be highly variable. Some populations will remain stable regardless of outflow conditions, particularly species with wide salinity and temperature ranges and no specific food requirements. Some marine species could become more abundant if Delta outflow decreases, resulting in increased salinity. Under these same conditions, estuarine species populations might be reduced or eliminated, depending on the magnitude of the change and the resulting decline in favorable environmental conditions. At the present time, our knowledge of the relationships between Delta outflow and the physical, chemical, and biological responses in the estuary is limited.

Food Supply

Food is believed to be a major factor limiting the abundance, distribution, and production of fish and invertebrate species. A basic Delta-Bay food web consists of phytoplankton and other aquatic plants, zooplankton, zoobenthos, vertebrates (including fish), and detritus. The complexity of physical and biological relationships between individual plants and animals, and the numbers of species involved, precludes a comprehensive evaluation of food supply impacts. The following discussion presents information on species and groups of species that may be affected by the project and appear to affect the abundance and distribution of fish and invertebrate species previously discussed.

Many zoobenthos species are important in the diets of Bay and Delta fish and invertebrates. Corophium is one of the most common and numerous benthic prey items (Ganssle 1966, Hazel and Kelley 1966, Radtke 1966, and Turner 1966a, 1966b). Corophium may also be significant in the diet of striped bass when other food items are scarce (Markmann 1986).

The western Delta supports the highest benthic population densities, and peak densities usually occur in June and July (Markmann 1986). Interior Delta densities were lower, but species diversity was higher. The more stable salinity regime of the interior Delta appears to provide favorable habitat for the persistence of benthic populations, as opposed to the western Delta and Suisun Bay, which are impacted by large freshwater outflow and salinity changes.

Salinity appears to influence benthic population distribution and density. Under dry conditions (e.g., 1976 and 1977), Corophium numbers decreased in the western Delta, allowing temporary colonization by saltwater-adapted species.

The lowest benthic population densities occur in either very slow or very rapid currents (Markmann 1986). High flows remove substrate and benthic stocks. Low benthic population densities at Mossdale on the San Joaquin River, where rapid current velocities occur during water exports, suggest a reduction in density and diversity of benthic populations due to removal of fine substrate particles or the organisms themselves. Slow currents may transport insufficient detrital materials for surface-feeding benthos. The ideal current velocities cannot be determined from the available data.

SWP and CVP operations may affect benthic populations through changes in seasonal salinity patterns, localized current velocities, and transport of the benthic species' pelagic larvae and juveniles. Continuing studies will enable a better understanding of these effects.

Zooplankton are more important than zoobenthos in the diet of many of the fish species previously discussed (Radtke 1966, Turner 1966a and b, California Department of Fish and Game 1987c and e and 1988, Dettman and Kelley 1987). Neomysis is probably the single most important zooplankton species in the diet of Delta and Suisun Bay fish. Eurytemora, other copepods, and cladocerans may be equally important, depending on fish life stage and the abundance of other zooplankton.

A general decline in zooplankton is not supported by existing data, but certain species have declined (Eurytemora) while others have increased (Sinocalanus) (California Department of Fish and Game 1987c). Striped bass larvae survival may be related to Eurytemora abundance. Larvae bass seem to avoid Sinocalanus, a species whose population has increased as the Eurytemora population has decreased. More information is needed before relationships can be determined between the copepod species and their environment.

Neomysis have been abundant in only 2 years since 1977, years characterized by high spring outflow (California Department of Fish and Game 1987d). Some of the annual fluctuations in abundance and shifts of population distribution between Suisun Bay and the Delta can be attributed to variations in Delta outflow, which regulate water residence times, position of the entrapment zone and salinity gradient, and the distribution of Neomysis.

Movement of the entrapment zone and salinity gradient into the Delta reduces both the habitat area available to Neomysis and phytoplankton concentration, a major food in the striped bass diet for Neomysis and other zooplankters (Orsi and Knutson 1979, Arthur and Ball 1980). The highest Neomysis densities occur between 1.2 and 2.6 parts per thousand salinity (Knutson and Orsi 1983). The relationship between Neomysis density and salinity is probably due to estuarine circulation patterns, light, and tidally influenced vertical migrations that concentrate Neomysis in the entrapment zone.

Zooplankton abundance in the Delta has been reduced by increased flow velocities in the Delta channels, reduced water residence times, and carriage of zooplankton-deficient Sacramento River water into the central and south Delta (California Department of Fish and Game 1987e). The CVP and SWP pumps are the main cause of these environmental changes. Reduced water residence times may move Neomysis (and other zooplankton) along faster than they can reproduce (California Department of Fish and Game 1987d).