3.0 ISSUES AND CHALLENGES

This section summarizes the current issues, existing information base, technical problems, and management challenges affecting the public trust of fishery resources of the Lower Mokelumne River and Sacramento-San Joaquin delta. Table 3.1 and Figure 3-1 delineate the main issues by reach.

Table 3.1. Summary of issues affecting fisheries management plan by reach.

Issues	Camanche Reservoir (Reach 1)	Camanche Reach (Reach 2)	Woodbridge Reach (Reach 3)	Delta (Reach 4)
Water Quality				
Temperature	X	X	X	X
Dissolved oxygen	X	X		
Hydrogen sulfide	X	X		
Salinity				X
Turbidity and suspended solids	X	X	X	
Fisheries				
Chinook Salmon and Steelhead				
In-migration		X	X	X
Escapement		X	X	X
Spawning		X		
Rearing		X		
Out-migration		X	X	X
Entrainment		X	X	X
Steelhead Trout		X		
Native Fish		X	X	X
Introduced Fish				
Largemouth bass	X	X	X	
Smallmouth bass	X	X	X	
Spotted bass	X	X	X	

3.1 WATER QUALITY ISSUES

The water quality issues discussed in detail in this section include temperature, dissolved oxygen, hydrogen sulfide, total suspended solids, and turbidity in Camanche Reservoir and the Lower Mokelumne River. A brief discussion of heavy metals is presented in Section 3.1.2; however, heavy metals issues in the watershed are currently being addressed by

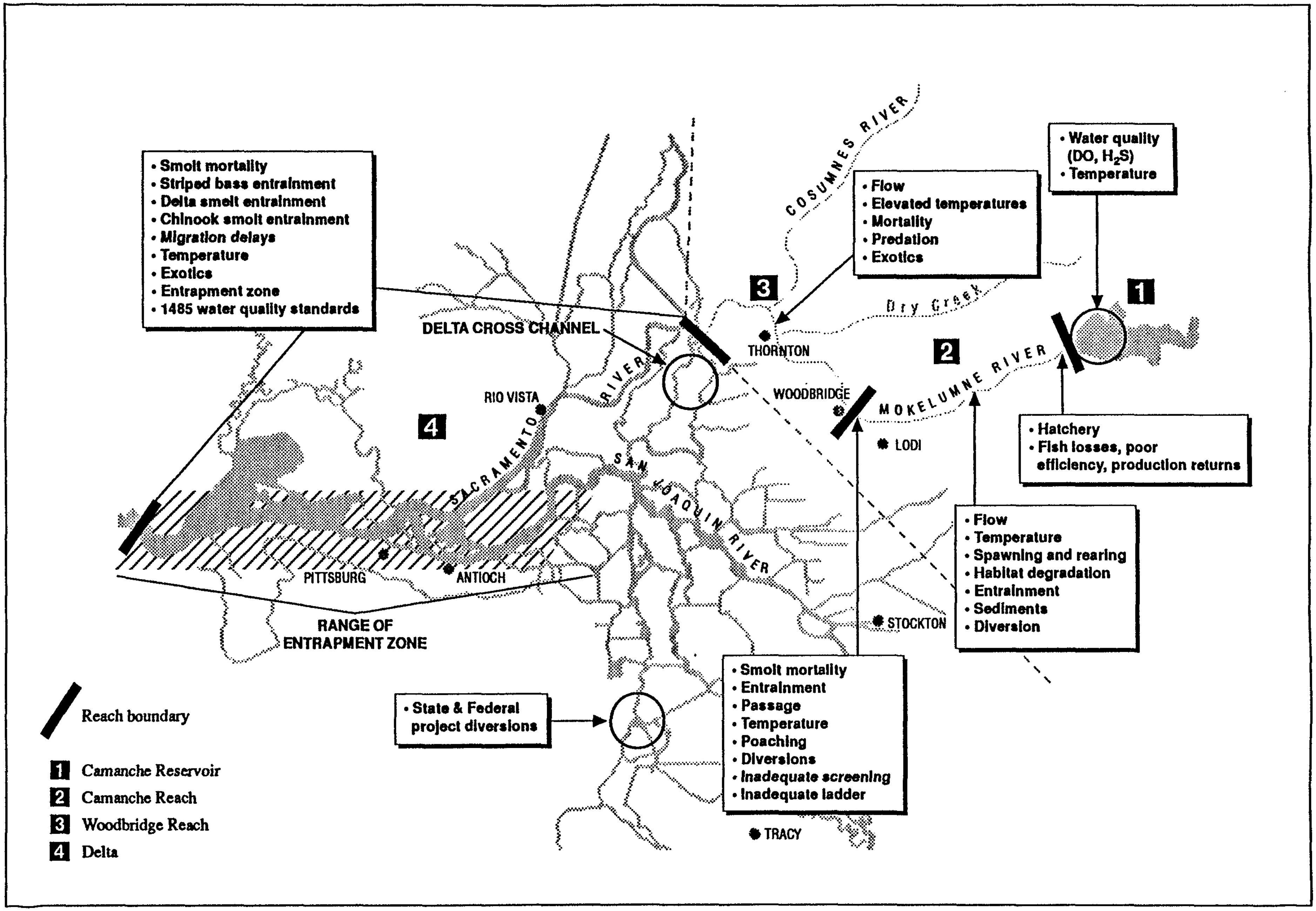

Figure 3-1. Summary of main issues in each reach of the Lower Mokelumne River.

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cooperative efforts of the EPA, the SWRCB, the CDFG, USFWS, EBMUD and others. As a result of the current efforts by state and federal agencies to address heavy metals issues, the LMRMP does not present a comprehensive review or recommend a management strategy for heavy metals in the watershed but defers to these parties for resolution of the issues.

3.1.1 Camanche Reservoir

Camanche Reservoir is typical of shallow, warm-climate reservoirs and is thermally stratified in the summer. Three zones are formed during stratification: the upper, warmer, and less dense epilimnion; the lower, cold, dense hypolimnion; and the intermediate layer, where the temperature decreases rapidly with depth, called the thermocline.

The decomposition of organic material in the reservoir and nutrient inflow from the Mokleumne River watershed basin produce a continual decline in hypolimnetic oxygen levels once the thermocline begins to form (March to May period) until the dissolved oxygen concentration reaches zero. Following the fall overturn, when the lake destratifies, in late October or November, the reservoir water quality becomes more homogeneous in the vertical profile. Oxygen levels in the vertical water column are generally around 8 parts per million (ppm) and continue to increase throughout the winter as the water cools and biological activities subside to a lower rate.

As the oxygen levels in the hypolimnion have dropped to zero during stratification, the water of the hypolimnion changes from an oxidative to a reducing chemical environment and hydrogen sulfide is formed via biological reaction. When the lake overturns and the waters of the hypolimnion are brought to the surface and aerated, the reservoir is returned to an oxidative chemical environment.

In normal water years, Camanche Reservoir water elevations fluctuate between elevation 64 and 70 meters (with corresponding volume fluctuations of from approximately 250,000 to 410,00 af). Maximum reservoir levels generally occur in the early summer, following spring runoff. There is a high-level reservoir outlet at elevation 62 meters and a low-level outlet (the main outlet) at the base of the dam at elevation 30 meters. In subnormal water years, the water level in Camanche drops below the high level outlet. This has occurred during the present drought, which began in 1987, and necessitates release of all water from the lower outlet.

Poor water quality resulting from drought conditions and nutrients deposited from the Mokelumne River Watershed Basin caused fish losses at the MRFH in 1987, 1988, and 1989. MRFH water quality parameters that have been determined to be of concern are warm temperature in the Camanche release water due to premature turnover, toxic levels of hydrogen sulfide, and low or absence of dissolved oxygen. Beginning immediately following the unpredicted 1987 fish loss at the MRFH, and continuing to date, EBMUD has instituted a series of actions to identify the water quality conditions detrimental to fish in both the MRFH and the Lower Mokelumne River, and implemented measures to prevent those conditions from causing fish losses in the future. During the past 5 years, data have been collected, special studies and investigations have been commissioned, operational modifications have been implemented, and facilities constructed. These studies and operational modifications are described in detail in Bowen (1992). For example, in the subnormal water years of 1990 and 1991, acceptable water temperatures were provided by planned releases from Pardee to maintain an adequate hypolimnion in a stable, stratified reservoir; anoxic conditions in Camanche were dealt with by re-oxygenation (by sluicing to the river and installing additional aerators at the MRFH) and destruction of hydrogen sulfide by addition of potassium permanganate to the MRFH water supply; minor turbidity increases in water from the bottom outlet were dealt with by use of the floating pumping station to blend water taken from higher in the hypolimnion.

In general, growth rates and condition factors for salmonids are excellent in the Lower Mokelumne River (EBMUD 1992, Appendix A). Recent research indicates that hatch rates per female are comparable to values in other areas (MacKenzie and Moring 1988; Fraley et. al 1986; Scrivener 1988). Invertebrate biomass is high in the river system, also indicating an absence of acute or chronic toxicity problems. Heavy metals could potentially occur at levels deleterious to fish; however, there is little biological evidence to indicate current toxicity problems in the river.

Long term operational strategies which address Camanche water quality are discussed in Section 4.2. The preferred alternatives are discussed in Section 5.2.

3.1.2 Quality of Inflow

Water quality in the Mokelumne River is affected by runoff from nearby agricultural lands and areas contaminated by past industrial activities. Penn Mine, for example, located on the south side of the Mokelumne River between Pardee and Camanche reservoirs, operated for over a century until 1952, producing copper, zinc, gold, and silver. Other wastes from Penn Mine include aluminum, iron, and lead (Finlayson and Rectenwald 1978). Historical fish losses from many causes have been documented in the Mokelumne River. Section 1.3 of the LMRMP provided a more complete discussion of historical events. Finlayson and Rectenwald (1978) attributed these kills to copper and zinc toxicity from Penn Mine and maintained that poor water quality conditions were generally contributing to the decline of anadromous salmonids in the river. In 1979, mitigation efforts were implemented by EBMUD, the CVRWQCB and the CDFG to control the runoff of metals into Camanche Reservoir.

Continuing issues related to containment of pollution from Penn Mine are being addressed by the cooperative efforts of the EPA, the SWRCB, the CDFG, USFWS, EBMUD, and others. The Penn Mine Oversight Committee has been established by the EPA for the specific purpose of developing a remedial strategy to meet water quality objectives. Accordingly, the LMRMP does not present a separate management strategy for metals issues related to Penn Mine.

3.1.3 Water Temperature

Water temperature affects all stages of aquatic life in all reaches of the Lower Mokelumne River. Chinook salmon and steelhead trout are species of particular concern. Part of the reason that water temperature is so critical to these populations is that stocks in the Mokelumne and San Joaquin river systems are in the warmest part of their geographical range.

The preferred water temperatures for salmonids are those at which growth and survival rates are highest. At temperatures above the preferred range, metabolism rates increase and, as a result, less energy is available for body maintenance, growth, reproduction, prey capture, predator avoidance, and resistance to disease. At a certain point, water temperature can become a lethal factor.

To determine upper lethal temperature thresholds, fish are acclimated to a given (high) temperature and then transferred to a series of test temperatures. The temperature at which 50 percent of the fish die within a set period of time (usually 24-168 hours) is the upper lethal temperature threshold or LF50. These studies, however, do not provide much information on the effect of water temperature on fish growth and survival in the wild. Growth and survival in the wild are influenced by other demands on metabolism (such as avoiding predators and maintaining some position in the current) and the abundance of food.

Exposure to other environmental stresses can compound the effect of thermal stress. Fish in the Mokelumne River may be simultaneously exposed to low dissolved oxygen, elevated levels of heavy metals, hydrogen sulfide, and increased turbidities.

Figure 3-1 presents an overview of the life cycle of chinook salmon and steelhead in the context of a normal hydrology and water temperature regime for the Mokelumne River Watershed Basin. As can be seen, these species can be subject to intolerable water temperatures at the beginning and end of their freshwater residence. Chinook salmon must travel the length of the river to reach the spawning grounds below Camanche Dam; most fish migrate up-river between late October and mid-December. Although adults will migrate upstream through water temperatures of 18°C or higher, spawning chinook and their eggs should not be exposed to temperatures above 15°C.

Potential rearing habitat for salmon and steelhead is also influenced by water temperature. Water temperature should be below about 18° C from the time fry emerge from the gravel until they migrate out of the river as smolts (CDFG 1991). Modeling conducted by BioSystems indicates that water temperature may become unsuitable below Woodbridge as early as April under low flow conditions, and that flows in excess of 500 cfs may be needed to maintain suitable water temperatures in the lower river reaches by June (Appendix C). To avoid these water temperature impacts in dry and critical dry years, juvenile salmonids are currently trapped and trucked from the Woodbridge Dam to the planting areas below the Delta.

The SWRCB has not adopted specific water temperature standards for the Mokelumne River, but the CDFG presented water temperature criteria for the Lower Mokelumne River in their Lower Mokelumne River Fisheries Management Plan (CDFG 1991). The CDFG recommended water temperatures optimal for chinook salmon (Table 3.2). Temperature modeling studies conducted by BioSystems show that during certain periods the CDFG recommended temperatures cannot be achieved at the CDFG recommended flow levels because of warming of the river as it travels downstream.

Table 3.2. CDFG seasonal temperature recommendations for the Mokelumne River (CDFG 1991).

	Mean Daily Temperature (°C)		
Time Period	**Elliott Road**	**Cosumnes River**	**Highway 99**
Dry Years			
1 November — 31 March	13.3		
1 April — 14 April		18.3	
15 April — 30 April		18.3	
1 May — 31 May		18.3	
1 June — 30 September			18.3
1 October — 31 October			18.3
Normal Years			
15 October — 29 February	13.3		
1 March — 31 March	13.3		
1 April — 30 April		15.6	
1 May — 31 May		15.6	
1 June — 30 June			18.3
1 July — 31 July			18.3
1 August — 30 September			18.3
1 October — 14 October			18.3
Wet Years			
15 October — 29 February	13.3		
1 March — 31 March	13.3		
1 April — 31 May		15.6	
1 June — 14 October			18.3

Table 3.3 summarizes water temperature data collected at USGS gaging stations on the Mokelumne River between 1965 and 1986. It is difficult to determine whether these water temperature conditions would meet CDFG criteria (Table 3.2) since the measurement locations do not correspond. The USGS gages are located near Camanche Dam and just below Woodbridge Dam, but the CDFG criteria locations are Elliott Road, Highway 99, and Cosumnes River (Figure 1-1). It is clear that dry year criteria would be exceeded in many years and normal year criteria would be exceeded in May and June, which is a critical time period for successful out-migration of smolts.

Table 3.3. Recorded seasonal temperatures for the Mokelumne River (USGS gage data).

Time Period	Mean Daily Temperature (°C)* at: Camanche Gage (1965-1976)	Woodbridge Gage (1965-1986)
Dry Years		
Years Included:		
Number of Years Included:	1976	1976,1977
	(1)	(2)
October	ND	17.9
November	ND	12.9
December	ND	9.5
January	13.1	7.8
February	14.2	11.4
March	13.5	13.1
April	13.9	16.6
May	14.6	19.3
June	14.9	21.7
July	15.2	23.0
August	15.3	22.0
September	15.4	21.3
Normal Years		
Years Included:	1966, '68, '71, '72, '75	1966, '68, '72, '75, '79, '81, '85
Number of Years Included:	(5)	(8)
October	12.8	15.4
November	12.4	12.5
December	11.4	9.8
January	10.1	8.8
February	10.0	10.0
March	10.3	12.1
April	11.3	14.9
May	14.5	16.8
June	14.8	18.5
July	15.9	20.5
August	16.2	20.9
September	13.2	18.8
Wet Years		
Years Included:	1965, '67, '69, '70, '73, '74	1965, '67, '69, '70, '73, '73, '74, '78, '80, '82, '83, '84, '86
Number of Years Included:	(6)	(12)
October	10.1	14.7
November	12.3	12.0
December	10.4	9.4
January	8.2	9.2
February	8.2	9.9
March	8.5	11.3
April	7.0	11.9
May	10.9	13.7
June	12.1	15.9
July	13.0	18.0
August	13.6	18.6
September	13.2	18.1

*Average of daily minimum and maximum.
ND = No data

Several factors influence water temperature in the Mokelumne River. Water is drawn from Camanche Dam through the bottom outlet structure. This is the coolest water in the reservoir. Water temperature downstream of Camanche Dam is influenced by the temperature of Camanche release water, ambient air temperatures, flow rate, and the amount of solar radiation reaching the water surface. Generally, if ambient air temperatures are higher than release water temperatures, the water becomes warmer as it flows downstream. However, if ambient air temperatures are cooler than release temperatures, lower flows result in cooler temperatures. These dynamics are important in October and November cooling periods during the adult spawning run, and in May and June warming periods during out-migration of juveniles.

Flow management can have a significant impact on water temperature but it will be influenced by variations in ambient air temperature. BioSystems used a stream temperature model developed by the USFWS to predict stream temperature and recommended flows to achieve suitable temperatures. This work is described in Appendix C.

3.1.4 Total Suspended Solids and Turbidity

The EPA states that settlable and suspended solids should not reduce the depth of the compensation point for photosynthetic activity by more than 10 percent from the seasonally established norm for aquatic life. It is not clear what the seasonally established norm for the Mokelumne River would be, or whether that condition is being met. High concentrations of heavy metals have also been associated with sediment mobilization.

The CVRWQCB standard for turbidity is that when natural turbidity is between zero and 50 nephelometric turbidity units (NTU), turbidity should not exceed natural levels by more than 20 percent. In addition, the suspended sediment load and suspended sediment discharge rate of surface waters should not be altered in such a manner as to cause a nuisance or adversely affect beneficial uses.

Total suspended solids and turbidity events were noted in the Mokelumne River in spring 1989 (Figures 3-2 and 3-3). These events occurred during high flow releases from Pardee Reservoir into Camanche Reservoir following a period of record low water in Camanche Reservoir. Camanche Reservoir levels were kept below 40 meters elevation from October 1988 through March 1989 by decreased Pardee Reservoir releases. On 26 March, Pardee release flows were increased from 146 to 488 cfs, and on 27 March they were further increased to 722 cfs.

Although turbidity and total suspended solids in Camanche release water can increase at certain times (e.g., during the fall turnover) the CDFG indicates that, based on available data, turbidity does not cause problems for migrating adult salmon, incubating eggs, or juveniles in the river.

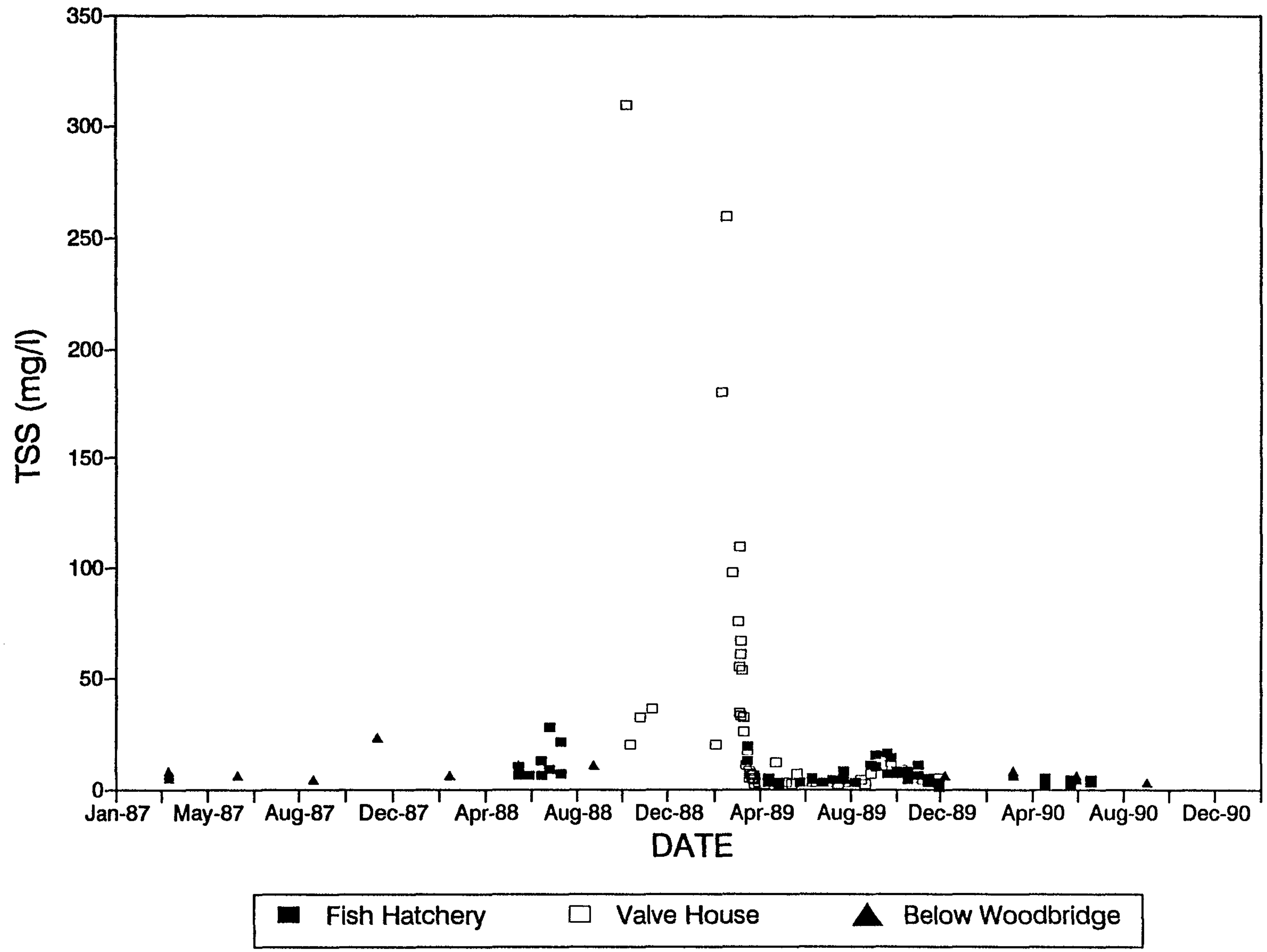

Figure 3-2. Total suspended sediments (TSS) in grab water samples collected at all river stations on the Mokelumne River.

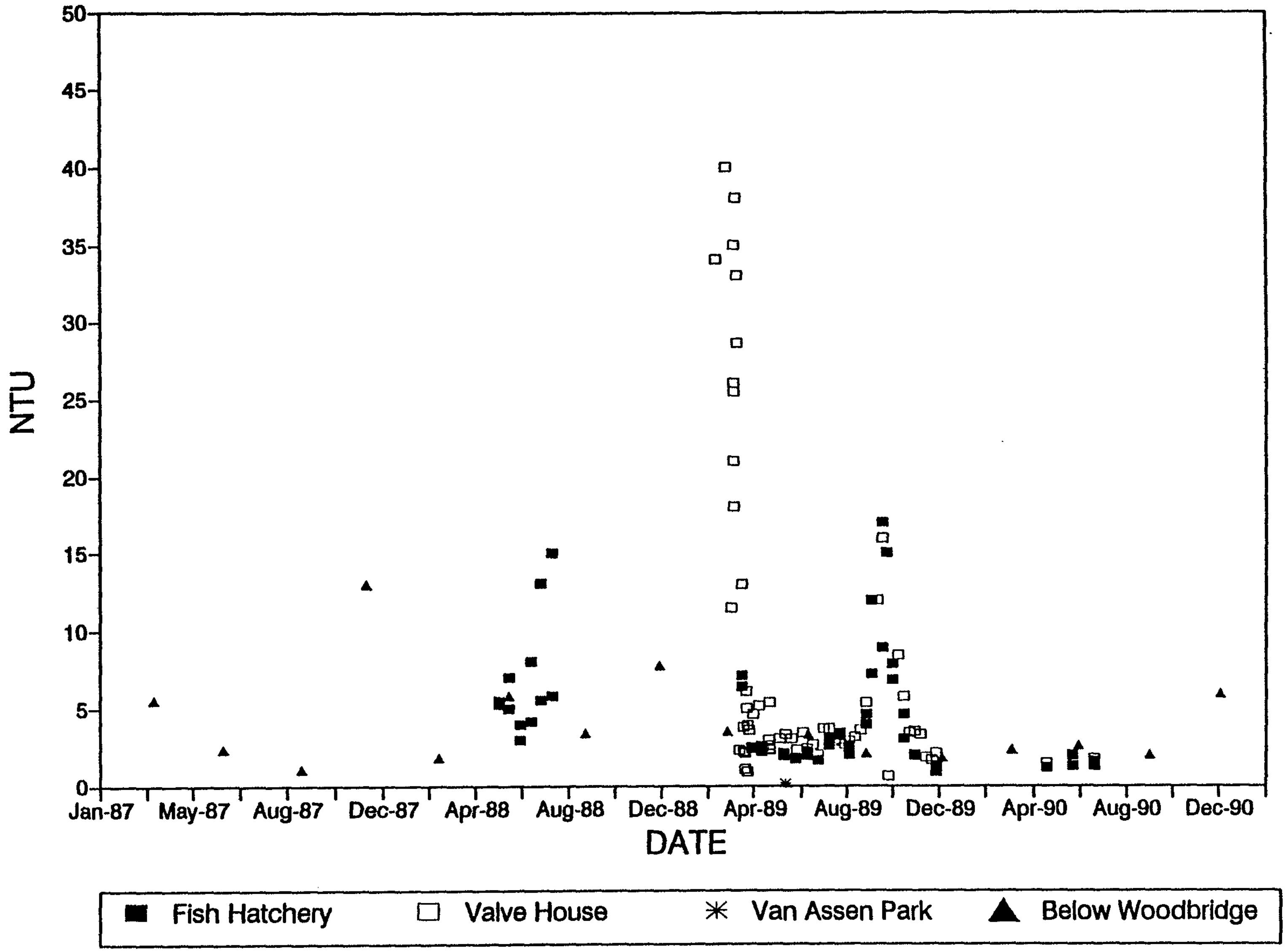

Figure 3-3. Turbidity of grab water samples collected at all Mokelumne River stations.

3.2 MOKELUMNE RIVER FISH POPULATIONS

3.2.1 Introduction

This section describes the main issues relating to the management of chinook salmon, steelhead, and other fish species in the Lower Mokelumne River, and reflects the current state of knowledge regarding species populations, factors regulating population dynamics, and the influence of flow management and water resource development on the river. The information was obtained from literature sources, studies conducted by CDFG, and studies conducted by BioSystems for EBMUD over the past three years. This discussion serves as the basis for evaluation of management alternatives in Section 4.0, and ultimately the development of the EBMUD's Lower Mokelumne River Fisheries Management Plan (Section 5.0).

3.2.2 Salmon

3.2.2.1 Status of the "Mokelumne Run"

There is some question as to how to best manage a stock of native Mokelumne salmon or whether such a stock even exists. The available scientific evidence suggests that if a native Mokelumne stock ever existed, it no longer does. This section describes how genetic stocks are identified and explains why a Mokelumne stock cannot be identified.

Several methods have been used to identify distinct stocks of salmon. These methods can be categorized into three general disciplines: biochemical analyses, physical measurements, and parasite tagging. Each of these methods involves collecting samples from different stocks and analyzing them statistically for differences. All of the stock identification techniques described involve collecting and comparing (usually statistically) specimens from a variety of stocks. The methods are based on the assumption that salmon returning to a particular stream are native to that stream.

<u>Stock Identification Techniques</u> - One of the most widespread methods of biochemical stock identification is genetic analysis. Genetic stock identification determines the amino acid sequence in a small portion of salmon DNA (less than 1% of the total DNA) (Nei 1975). These analyses identify only genetic differences among salmon stocks, and do not provide information on the fitness or physical characteristics of the salmon tested.

Another method of biochemical analysis is the investigation of the elemental composition of bony structures such as vertebrae and otoliths (Calaprice 1971; Mulligan et al. 1983). This technique is based on the knowledge that rivers vary in water chemistry as a result of geological differences in the land they drain. Specifically, the ratios of common earth elements vary from one river to the next. These differences can be recorded in the bodies of fish, particularly in bony structures. The greater the geographic and/or geologic difference between streams, the easier it should be to detect distinct stocks of salmon (Mulligan et al. 1983).

A second category of stock identification is based on differences in the physical structure of salmon. Morphology studies have focused primarily on fish length, body proportions, scale patterns and otolith measurements (Hjort and Schrek 1982; Carl and Healey 1984; Winans 1984; Neilson and Geen 1985). Meristic studies of salmon have principally focused on the number of vertebrae and gill rakers (Beacham 1985; Beacham et al. 1988; MacCrimmon and Claytor 1985). These studies have differentiated salmon stocks based on run timing (Zorbi 1990), different life histories (MacCrimmon and Claytor 1985), and different geographic regions (dePontual and Prouzet 1987; Beacham et al. 1988).

The third category of investigation is parasite tagging, which involves the identification of internal parasites that are limited to specific freshwater regions. The presence of a specific parasite thus identifies the region of origin (Helle 1987; Wood et al. 1987; Dalton 1991).

Identification of a Mokelumne Stock - Most of the progress in stock identification has been fairly recent. No previous studies document the characteristics of a Mokelumne stock as distinct from other Central Valley stocks. For several reasons, salmon returning to the Mokelumne are likely to have been born or raised elsewhere.

For over 25 years, hatchery operations on the Mokelumne River have included the importation of many eggs and fingerlings from other rivers (mostly the Feather or American rivers) into the Mokelumne system (Meyer 1982). From 1980 to 1988, over 90 percent of the salmon produced at the MRFH originated from imported eggs or fry. Significant numbers of eggs were taken from salmon returning to the hatchery in only two years during this period (MRFH annual reports). In many years, salmon produced in the hatchery were released outside of the Mokelumne system (Meyer 1982).

Large numbers of salmon produced in the Feather and American rivers have been released in the Delta. A high proportion of these released fish are poorly imprinted to their home stream and so stray to other river systems when they return to spawn (Meyer 1984). Because of the Mokelumne River's position as a Delta tributary, a large proportion of these strays enter the Mokelumne River. CWT research has shown that much of the spawning population of the Mokelumne River is composed of fish from other rivers of the Central Valley (Sacramento, Feather, American, and Merced rivers). From 1980 to 1989, over 50 percent of the CWT recoveries in the Mokelumne River were strays. The proportion of strays increased over this period (CDFG 1984, 1986). This fact is even more significant considering that most of the salmon returning to the Mokelumne were actually from Feather and American river stock. Factors that may affect straying include other inflows and diversions and water quality.

The mixing of stocks during the last 25 years would have diluted any genetically-unique Mokelumne salmon stock that may have existed. Other factors would have further diminished the frequency of unique Mokelumne-origin genes in the Mokelumne River salmon populations. Fish losses in the river resulting from winery, cannery, and mining pollution periodically eliminated all fish life, including whole year classes of salmon. In addition, life-cycle modeling studies indicate that mortality throughout the life cycle of Mokelumne River salmon is so high that, on average, the population cannot replace itself each generation (Appendix D). This results in a rapid decline of the native population.

The genetic composition of salmon stocks has been studied from California to Alaska (Kristiansson and McIntyre 1976; Carl and Healey 1984; Gharrett et al. 1987; Reisenbichler and Phelps 1987; Bartley and Gall 1990). The results of these studies indicate that within a run, it is impossible to delineate individual river stocks within a river basin.

In the most comprehensive genetic analysis of salmon in California, Bartley and Gall (1990) found little difference in the genetic composition of salmon from different river populations. Additionally, gene flow among river populations (interbreeding) was greater in the Sacramento-San Joaquin system than in the other three drainages tested. Bartley and Gall conclude that the genetic similarity of salmon throughout the system may be the result of hatchery practices and straying within the drainage.

If there ever was a pure Mokelumne River salmon, its characteristics were never documented. Now that stocks have been mixed it is not possible to obtain a sample of fish known to be native Mokelumne stock. Any stock identification studies on salmon from the Mokelumne River would merely describe the biochemical and physical attributes of the progeny resulting from generations of interbreeding.

Due to hatchery management practices and historical and present-day environmental conditions, any genetically-pure salmon stock that may have existed in the Mokelumne River has been eliminated.

It is no longer possible to re-establish a native Mokelumne stock. One could be developed by managing the river and hatchery in certain ways, but it would not be the original stock, nor would there be any guarantees that the strain developed would remain pure. Without management changes, development of a distinct stock would be difficult if not impossible. Some potential changes in management are discussed in Section 4.0.

3.2.2.2 Spawning Stock Estimates

Spawning stocks indicate how many salmon are utilizing the river for spawning. The CDFG is responsible for providing spawning stock abundance estimates for salmon on the Mokelumne River. Techniques used to estimate the size of the Mokelumne River stock have varied over the last 50 years. The earliest unofficial stock estimate of the Mokelumne River was made in 1935. The estimate for that year was zero, due to anoxic conditions below thespawning habitat (EBMUD 1990). In 1937, the second stock estimate made was also zero because of toxins from the Penn Mine (Shaw and Tower 1937). From 1940 until 1989, the CDFG estimated stocks in almost every year (Table 3.4).

Table 3.4. Methodology and results of Mokelumne River salmon stock estimates, 1940-1991. Data compiled from the CDFG Lower Mokelumne Fisheries Management Plan (total estimates); CDFG Central Valley stock reports 1972-1987 (carcass surveys); MRFH Annual Report 1988-89 (hatchery arrivals); BioSystems data files (video counts); and CDFG data files, Region 2, Rancho Cordova, California (ladder counts and carcass surveys).

			Stock Estimates			Tag-Recovery Surveys for In-river Stock Estimates[1]	
Year	Method	Dates*	Total	In-river	MRFH Arrivals		Notes
1940	Ladder count	--	5,000	4,986			
1941	Ladder count	--	12,000	11,572			
1942	Ladder count	--	12,000	10,019			
1943	No estimate	--	--	--			Toxic conditions in river
1944	No estimate	--	--	--			Toxic conditions in river
1945	Ladder count	NA	6,000	--			
1946	No estimate	--	--	--			No estimate, believed "poor"
1947	No estimate	--	--	--			No estimate
1948	Ladder count	NA	500	230			
1949	Ladder count	26 Oct-27 Dec	1,000	765			
1950	No estimate	--	--	--			Fish ladder washed out
1951	Ladder count	10 Oct-24 Dec	2,000	1,642			No fish ladder
1952	Ladder count	7 Oct-13 Dec	2,000	1,878			No fish ladder
1953	Ladder count	1 Oct-16 Nov	2,000	2,439			No fish ladder
1954	Ladder count	12 Oct-13 Dec	4,000	3,939			No fish ladder
1955	Ladder count	15 Nov-21 Dec	2,000	2,193			New fish ladder operable 11/15
1956	Ladder count	7 Oct-18 Dec	500	474			
1957	Ladder count	5 Oct-26 Dec	2,000	2,403			
1958	Ladder count	3 Oct-7 Jan	7,000	6,926			
1959	Ladder count	7 Oct-12 Jan	2,000	2,108			
1960	Ladder count	5 Oct-28 Dec	2,000	2,208			
1961	Ladder count	19 Oct-18 Dec	100	137			
1962	Ladder count	29 Sep-19 Dec	200	230			
1963	Ladder count	3 Oct-16 Dec	500	481			Camanche Dam built
1964	Ladder count	7 Oct-16 Dec	2,000	2,210	242		MRFH begins operations
1965	Ladder count	NA	1,300	NA	173		Ladder inoperable after 12 Nov
1966	Ladder count	3 Oct-16 Dec	700	689	293		
1967	Ladder count	3 Oct-29 Dec	3,000	1,989	250		
1968	Ladder count	15 Oct-17 Dec	1,700	1,657	565		
1969	Ladder count	23 Oct-7 Dec	3,000	2,085	296		
1970	Ladder count	20 Oct-23 Dec	5,000	3,516	377		
1971	Ladder count	27 Sep-13 Dec	5,000	5,091	366		

[1]No tag-recovery surveys were conducted from 1940 to 1971

Table 3.4. Methodology and results of Mokelumne River salmon stock estimates, 1940-1991 (cont.).

			Stock Estimates			Tag-Recovery Surveys for In-river Stock Estimates			Carcasses				
Year	Method	Dates*	Total	In-river	MRFH Arrivals	Trips #	Length* (km)	Viewing Condition	Total	Tagged	Recovered	Recovery Rate (%)	Notes
1972	Carcass survey	1 Nov-14 Dec	1,100	750	353	6	8	Good	150	***	***	20***	Carcass surveys begin. It was assumed that 20% of the spawning population. was observed.
1973	Carcass survey	1 Nov-21 Dec	3,000	2,193	408	7	16	****	148	47	8	17	
1974	Carcass survey	30 Oct-24 Dec	1,400	1,200	220	9	16	Good	179	61	9	15	
1975	Carcass survey	30 Oct-31 Dec	1,900	1,501	399	7	16	Good	349	85	21	25	
1976	Carcass survey	****	500	465	74	7	NA	Good	191	***	***	45***	Unusually good conditions; visibility: 1.5-2.4 m, clear weather
1977	Carcass survey	6 Dec-27 Dec	300	250	0	4	NA	Poor	49	***	***	20***	Hatchery ladder closed. Visibility poor, few live and dead fish.
1978	Carcass survey	7 Nov-5 Dec	1,100	600	484	5	16	Good	108	16	0	18***	"Based on a historical average recovery rate of 18%."
1979	Carcass survey	14 Nov-12 Dec	1,500	1,000	507	5	16	****	53	***	***	5***	"Assuming a 5% recovery rate." No basis given.
1980	Carcass survey	12 Nov-24 Dec	3,200	2,592	639	7	8,16	Fair	311	****	****	12	
1981	Carcass survey	6 Nov-16 Dec	5,000	4,454	1,386	6	6,8,10	Good	723	120	19	16	
1982	Regression	NA	9,000	6,695	2,677	NA	NA	NA	NA	NA	NA	NA	High water, no carcass surveys
1983	Regression	NA	15,900	10,793	4,573	NA	NA	NA	NA	NA	NA	NA	High water, no carcass surveys
1984	Carcass survey	9 Nov-21 Dec	5,969	5,969	959	7	8	Good	1,264	302	46	15	
1985	Carcass survey	7 Nov-27 Dec	7,702	7,475	223	8	8	Fair	1,268	112	19	17	
1986	Carcass survey	7 Nov- 23 Dec	5,000	4,450	1,913	8	8	Fair	1,052	145	34	25	
1987	Carcass survey	17 Nov-24 Dec	1,650	276	630	5	8	Fair	9	9	0	NA	Low flows (90 cfs)
1988	Carcass survey	10 Nov-29 Dec	528	400	128	8	8	Poor	9	9	0	NA	Water quality was poor
1989	Carcass survey	****	280	****	90	****	****	****	****	****	****	****	
1990	Video/trap	2 Oct-17 Dec	497	NA	64	NA	NA	NA	NA	NA	NA	NA	
1991	Video/trap	2 Oct-29 Dec	410	NA	NA	NA	NA	NA	NA	NA	NA	NA	

* 'Dates' encompass the dates of ladder counts at Woodbridge Dam (1940-71), carcass surveys (1972-89), and video counts of salmon (1990-91).
** Surveys extend downstream from Camanche Dam/MRFH area.
*** Determined recovery rate based on historic recovery rates or in-stream conditions.
**** Carcass survey data incomplete.

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From 1940 through 1971, stock estimates were based on actual counts of the number of salmon migrating past Woodbridge Dam. From 1972 through 1990, estimates were based on periodic carcass surveys. In 1982 and 1983, however, high water conditions made carcass surveys impossible, and estimates were based on the relationship between hatchery arrivals and stock estimates made between 1972 and 1981. In 1990 and 1991, BioSystems developed actual spawning stock counts by using video monitoring equipment installed at Woodbridge Dam (Appendix A) with parallel trapping.

Early counts of salmon are questionable because of the inexperience of field technicians. Fry (1961), in his overview of the 1940-1959 salmon stocks, stated that "most of the early counts were by men who had little or no work with salmon." In 1953, CDFG expressed the need for a reliable fish counter at Woodbridge because of problems during the salmon run (CDFG 1953).

From 1951 through 1971, the spawning counts at Woodbridge ranged from a high of 7,000 fish in 1958 to a low of 100 in 1961. In 1955 and 1965, the fish ladder was inoperable until the middle of November and no counts were made. The CDFG believes that ladder counts provided fairly good estimates, but the technique was labor-intensive and costly (Meyer pers. comm. 1991).

In 1972, CDFG began conducting carcass count surveys along the river rather than actually counting fish at Woodbridge (Table 3.4). Carcass surveys had been used for stock estimation in the other rivers of the Central Valley since the 1950s (Fry 1961). This method is faster and less costly than ladder counts, but is also substantially less reliable.

A carcass survey begins by surveying the spawning ground during the early salmon in-migration season to determine the onset of spawning. A week after the first spawner arrives, carcass tagging is initiated. Tags consist of a colored ribbon attached to the jaw of each carcass found in the survey area. The tagged carcass is placed back into the running water for future recovery. The survey is repeated at a consistent interval, i.e., once a week, throughout the in-migration season. New carcasses are tagged and counted, and recoveries of previously tagged carcasses are recorded. Salmon die and decompose after spawning, so tagging surveys must be frequent and must extend over the entire spawning period for estimates to be reliable.

The carcass survey method used by the CDFG is a modification of the Schaefer method (Schaefer 1951). The original Schaefer method consisted of tagging and releasing a known number of live migrating salmon before they reached the spawning grounds, and tabulating the subsequent recovery of carcasses after death. The size of the total run would then estimated from the proportion of recovered carcasses that were tagged. The modified Schaefer method (Taylor 1974) assumes that (1) the marked carcasses disperse throughout the survey areas randomly after tagging, so that untagged and tagged carcasses have an equal probability of being found; and (2) the population size remains constant between the two subsequent captures, so that the proportion of tagged fish is approximately equal to the proportion of tagged fish recovered (recovery rate) in the next catch.

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Actual recovery rates have ranged from zero to 25 percent. The reliability of the recovery rate is affected by the duration and frequency of the carcass survey, river flow conditions, and the areas covered by the survey. In the 16 years between 1972 and 1987 that carcass surveys were conducted, the date of the first survey of the season varied from 30 October to 6 December, the frequency of the surveys ranged between 4 and 10 trips per migration season, and the areas covered by the survey ranged from 7.2 to 16.4 kilometers within the spawning grounds (Table 3.4). In eight of these years the recovery rates were not calculated but were estimated based on river conditions or the historical average recovery rate (e.g., 18% or 20%) (Taylor 1974).

In 1982 and 1983, no carcass surveys were conducted because river flows were dangerously high. The escapement estimates were made by calculating a linear regression relationship (r-value = 0.88, df = 7, $p < 0.05$) (Figure 3-4) between the number of salmon entering the hatchery and the estimated annual escapement from past carcass surveys (1972-1976 and 1978-1981; 1977 was excluded because the hatchery was closed). BioSystems updated this regression analysis by including the data collected from 1984 to 1989. The linear regression relationship was also significant (r-value = 0.54, df = 13, $p < 0.05$) (Figure 3-4).

Based on the earlier regression analysis, the stock estimate for 1983 (15,800) was considerably higher than any other estimate made between 1940 and 1990. The regression relationship was based on returns to the hatchery of 74 to 1,386 salmon. In 1982 and 1983, 2,077 and 4,573 salmon returned to the hatchery, respectively. Using the 1983 hatchery returns to predict total escapement resulted in extrapolating the results well beyond the range of the original data. Because of the doubt involving stock estimates for 1982 and 1983, 1982 and 1983 are excluded (from the 1980-1987 data) and results compared to the full 8 years.

In 1988, CDFG again changed its technique for estimating spawning stocks. Carcass surveys were still used, but the Jolly-Seber method (Seber 1962, 1965; Jolly 1963, 1965) replaced the modified Schaefer method. The Jolly-Seber method is an application of the more general multiple recapture technique (Ricker 1977), which was modified for use in the salmon carcass survey. One of the major differences between these two methods is that fresh carcasses representing all ages are tagged for the Schaefer method, but only adult carcasses (regardless of their condition) are tagged for the Jolly-Seber method. Since the disappearance rate of older carcasses may be higher than that of fresh carcasses, the recovery rate obtained from the Schaefer method may be deflated and may thus overestimate the escapement. On the other hand, because the carcasses are continually being added to and removed (decomposition, wash-out, animal removals, etc.) from the population throughout the in-migration season, the Jolly-Seber method was considered to be more appropriate (CDFG 1988).

In 1990 and 1991, BioSystems documented chinook salmon escapement into the Mokelumne River using a video monitoring system and a fish trap installed in the Woodbridge Dam fish ladders. These systems allowed all adult salmon migrating into the river to be counted. In 1990, our studies documented 497 chinook salmon migrating past Woodbridge Dam between 1 October and 15 December. In 1991, similar methods documented 410 chinook salmon between 1 October and 31 December.

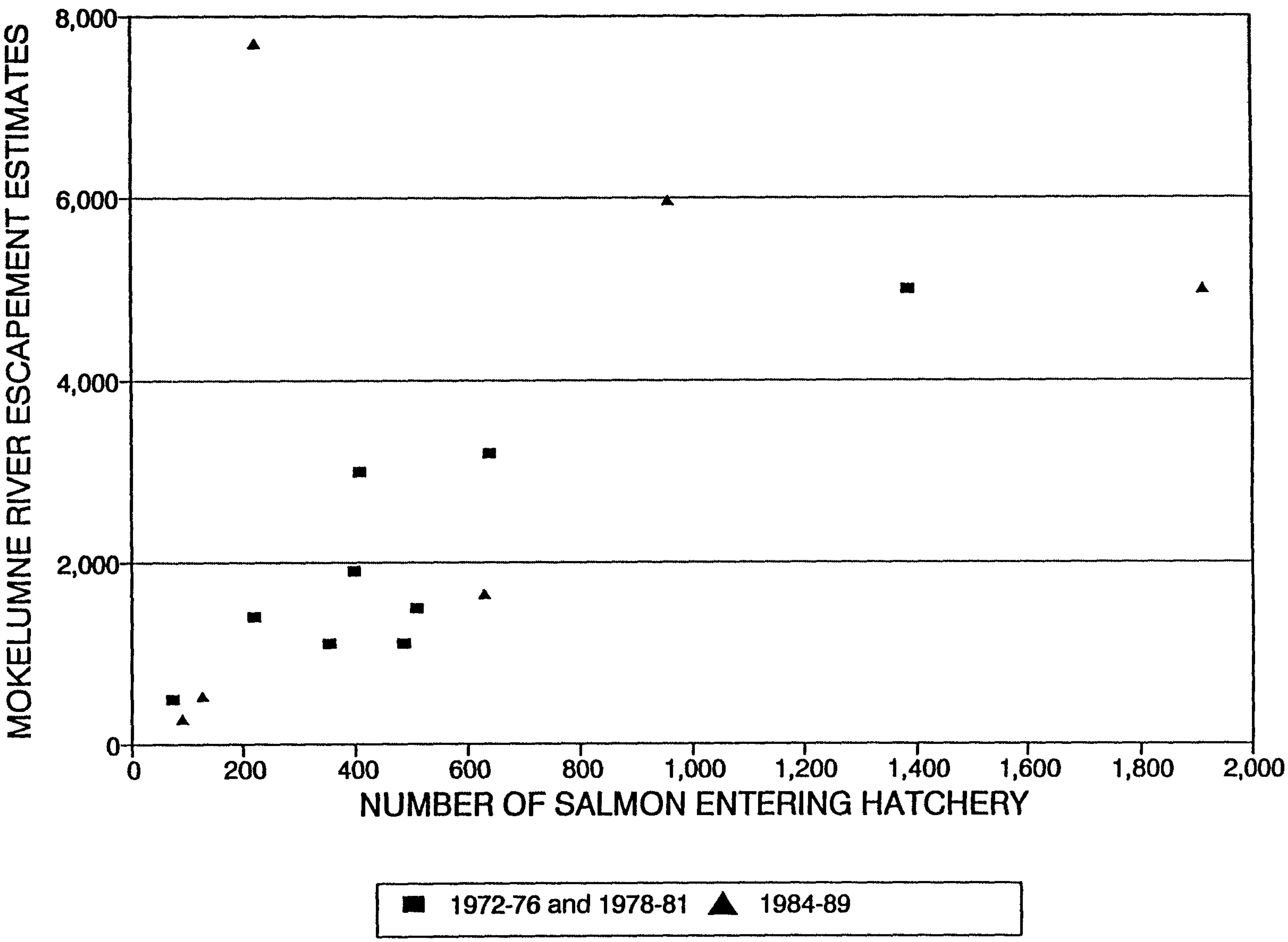

Figure 3-4. Relationship of Mokelumne River escapement estimates to the number of salmon entering hatchery.

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The preceding discussion illustrates some of the difficulties in obtaining an accurate measure of salmon spawning stocks. These difficulties lead to uncertainty in the escapement estimates. At best, the estimates are probably more useful as an index of abundance rather than a precise and unbiased population measure. Since methods have varied over the years it is inappropriate to compare data from periods using different estimation methods (i.e., ladder counts are not directly comparable with carcass surveys). Any conclusions from use of the spawning stock estimates should be drawn with full recognition of these limitations. Any management actions based on these estimates should be considered experimental and should only be undertaken in conjunction with improved Mokelumne River spawning escapement estimates. Nevertheless, in resource management one must begin with the information available and proceed to refine that knowledge; use of the CDFG estimates provides the only possible starting point for this analysis.

3.2.2.3 Factors Influencing Escapement

Escapement refers to the number of salmon that survive the ocean or inland fishery and return to the spawning grounds. Spawning run estimates in the Mokelumne River have ranged from less than 200 to over 15,000 salmon since counts began in 1940. Factors influencing the size of the run may include hatching, rearing, and out-migration success of year classes contributing to the run (i.e., the progeny of runs 2, 3 or 4 years prior), ocean rearing conditions, harvest, the ability of returning Mokelumne salmon to find the river, and straying of salmon from other rivers into the Mokelumne.

Hatching, rearing, and out-migration success have not been measured or have been measured sporadically in the Mokelumne River. The only consistent measure of year class strength is the size of the parent run (spawning stock estimates). This is a poor indicator since many factors can cause wide variations in spawning stock estimates, survival rates between the spawning of one run and the return of its progeny; however, it is the only indicator available at this time.

Run size may also be influenced by the ability of Mokelumne fish to find the Mokelumne River or by fish straying from other rivers into the Mokelumne. Under high flow conditions, or when Mokelumne flows are high as compared to other Delta tributaries, Mokelumne River fish may be more likely to find and enter the river. Also, fish from other runs are more likely to stray there.

Straying is strongly influenced by Central Valley salmon hatchery management practices. Salmon smolts taken from hatcheries on their natal rivers and released in the estuary have been shown to have higher survival rates than smolts released in their natal rivers (Meyer 1984). Salmon have an innate ability to return to spawn in their natal stream (Hasler and Scholz 1983); however, smolts released in the estuary tend to return to rivers other than their natal rivers with much higher frequency (Meyer 1984). This is probably because they fail to imprint on their natal stream, although the exact mechanism is unclear. Since the late 1970s, the major salmon hatcheries (including the Feather River, Nimbus, and the MRFH) have increasingly released their salmon into the estuary. This has greatly increased the proportion of straying salmon. For example, the Napa River, which historically never had a chinook run, now receives significant numbers of salmon; one of the major planting locations is just upstream near the Carquinez Strait (Emig pers. comm. 1991).

Many factors probably contribute to the size of spawning stocks in any given year, and some factors may be critical in one year but less important in the next. This analysis attempts to identify those factors that have a consistent effect and are therefore important management tools.

In the past few years, releases of water from Camanche Dam for periods of a few days to several weeks have been used in an attempt to attract salmon into the river. During the fall of 1990 and 1991, BioSystems monitored the salmon run on a daily basis to provide an accurate count of the run, document the timing of the run, determine the sex and size of fish, and determine the success of the flow management program. In this section, the effect of daily flow variations on daily escapement is examined. Other environmental parameters including water temperature, precipitation, and barometric pressure are also considered to determine their influence on these runs.

Next, existing data are used in an attempt to assess factors which may affect the annual salmon escapement in the Mokelumne River (Table 3.5). The annual data are used to construct hypothesis tests to determine whether Mokelumne run size may be related to such factors as precipitation, instream flow below Woodbridge, size of parent runs, and the status of runs in other Central Valley river systems.

Most of the analyses were conducted for four time periods: 1956-1963, 1964-1971, 1972-1979 and 1980-1987. Camanche Dam was built on the Mokelumne River in 1963. In 1972, CDFG changed the techniques for estimating spawning stocks from actually counting fish at Woodbridge Dam to carcass survey. Central Valley salmon hatchery management practices changed in 1979, when CDFG started trucking large numbers of young salmon around the Delta. The years after 1987 were not used since CDFG changed its carcass survey technique after 1987. Other changes, such as changes in Delta pumping rates (particularly the SWP and CVP) and operation of the Delta Cross Channel, are also believed to be important but were not accounted for in these analyses. The results of these tests are described in the following sections and summarized in Table 3.6.

<u>Fall Mokelumne River and Delta Flows</u> - For many seasonally-migrating species of fish, including salmon, river flow can be an important factor affecting the onset of migration and the size of the spawning run. Since the lower portion of the river provides a path for salmon migrating from the Delta to the Mokelumne River, its discharge is important in attracting salmon upriver and allowing their successful passage. Delta inflow, which is the total freshwater discharged from all rivers into the Delta, may also be an important factor in attracting salmon back to the river when they in-migrate.

The first question addressed was whether daily variations in salmon migration are affected by variation in daily river flow in the Lower Mokelumne River. To address this question, we

Table 3.5. Factors influencing escapement of Mokelumne River chinook salmon.

Independent Variable	Dependant Variable	Time Period 1949-1971	1956-1963	1964-1971	1972-1979	1980-1987	1980-1987 (Not 82-83)
Mokelumne Daily Fall Flow	Mokelumne escapement (year t)	N.S.					
Mokelumne Monthly Fall Flow:							
October	Mokelumne escapement (year t)		N.S.	N.S.	N.S.	**	N.S.
November	Mokelumne escapement (year t)		N.S.	N.S.	***	***	N.S.
December	Mokelumne escapement (year t)		N.S.	N.S.	***	***	N.S.
Migration Season	Mokelumne escapement (year t)		N.S.	N.S.	***	***	N.S.
Delta Inflow:							
October	Mokelumne escapement (year t)		N.S.	N.S.	**	***	N.S.
November	Mokelumne escapement (year t)		N.S.	N.S.	***	***	N.S.
December	Mokelumne escapement (year t)		N.S.	N.S.	***	**	N.S.
Migration Season	Mokelumne escapement (year t)		N.S.	N.S.	***	***	N.S.
Daily Precipitation:							
Number of Days with Rain	Mokelumne escapement (year t)	N.S.[1]		N.S.	N.S.	N.S.	N.S.
Accumulated Precipitation	Mokelumne escapement (year t)	N.S.		N.S.	N.S.	*	N.S.
Average Daily Precipitation	Mokelumne escapement (year t)	N.S.		N.S.	N.S.	N.S.	N.S.
Mokelumne Stocks:							
Year t-2	Mokelumne escapement (year t)		N.S.	N.S.	N.S.	N.S.	N.S.
Year t-3	Mokelumne escapement (year t)		N.S.	N.S.	N.S.	N.S.	N.S.
Central Valley Stocks:							
Year t	Mokelumne escapement (year t)		**	N.S.	*	N.S.	N.S.
Year t-2	Mokelumne escapement (year t)		N.S.	N.S.	N.S.	N.S.	N.S.
Year t-3	Mokelumne escapement (year t)		N.S.	N.S.	N.S.	N.S.	N.S.
Mokelumne Monthly Spring Flow at Year t+1:	Mokelumne Escapement:						
May	Year t+2		N.S.	N.S.	N.S.	N.S.	[3]
	Year t+3		N.S.	N.S.	N.S.	*	N.S.
June	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		*	N.S.	N.S.	N.S.	N.S.
Migration Season	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		*	N.S.	N.S.	N.S.	N.S.

Table 3.5. Factors influencing escapement of Mokelumne River chinook salmon (cont.).

Independent Variable	Dependant Variable	Time Period: 1949-1971	1956-1963	1964-1971	1972-1979	1980-1987	1980-1987 (Not 82-83)
Delta Monthly Outflow at Year t+1:	Central Valley Escapement:						
May	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		N.S.	*	N.S.	*	N.S.
June	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		N.S.	**	N.S.	*	N.S.
Migration Season	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		N.S.	**	N.S.	*	N.S.
Delta Monthly Outflow at Year t+1:	Mokelumne Escapement:						
May	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		N.S.	N.S.	N.S.	N.S.	N.S.
June	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		N.S.	N.S.	N.S.	N.S.	N.S.
Migration Season	Year t+2		N.S.	N.S.	N.S.	N.S.	N.S.
	Year t+3		N.S.	N.S.	N.S.	N.S.	N.S.
MRFH Releases :	Mokelumne Escapement:						
Year t+1	t+2			N.S.[2]		N.S.	[4]
	t+3			N.S.		[3]	[4]

[1]1949-1963
[2]1964-1976
[3]Significant negative correlation 0.1 significance level
[4]Significant negative correlation 0.05 to 0.01 significance level

* 0.1 significance level ** 0.05 significance level *** 0.01 significance level

Table 3.6. Database used to analyze factors influencing run size of Mokelumne River chinook salmon.[1]

	River Flow							Spawning Stocks		Delta Inflow				Delta Outflow		
Year	May	Jun	Out-Mig.	Oct	Nov	Dec	In-Mig.	Mokelumne River	Central Valley	Oct	Nov	Dec	In-Mig.	May	Jun	Out-Mig.
1956	2,435	2,142	2,288	378	672	687	579	500	185,000	14,807	17,532	15,789	16,043	59,667	35,498	47,583
1957	477	1,451	964	314	400	421	378.	2,000	120,000	20,792	21,482	26,466	22,913	32,732	15,581	24,157
1958	2,124	2,743	2,433	435	218	166	273	7,000	288,000	16,034	16,968	15,896	16,299	78,859	50,529	64,694
1959	38	33	35	33	27	29	29	2,000	479,000	8,836	8,426	8,431	8,564	7,303	1,322	4,313
1960	30	178	104	41	163	193	132	2,000	484,000	8,450	12,901	20,244	13,865	12,407	3,847	8,127
1961	14	19	16	31	33	87	50	100	259,000	7,529	8,898	16,773	11,067	8,580	3,541	6,061
1962	372	1,170	771	212	255	273	247	200	257,000	44,394	18,645	35,242	32,760	18,173	10,317	14,245
1963	2,646	1,525	2,085	154	281	199	211	500	303,000	17,125	26,589	24,907	22,874	53,124	19,180	36,152
1964	20	80	50	65	113	299	159	2,200	322,000	11,267	16,670	106,371	44,769	9,784	5,302	7,543
1965	1,541	1,519	1,530	1,716	1,639	520	1,292	1,300	198,000	18,692	25,868	30,118	24,893	32,370	16,190	24,280
1966	24	29	26	65	98	55	73	700	197,000	10,378	20,396	59,083	29,952	9,835	2,460	6,148
1967	2,603	1,358	1,980	1,195	351	84	543	3,000	182,000	20,228	18,512	21,087	19,942	74,550	61,265	67,908
1968	38	34	36	74	88	76	79	1,700	210,000	13,174	15,425	27,076	18,558	6,737	3,666	5,202
1969	2,230	941	1,585	957	366	411	578	3,000	341,000	22,274	22,001	46,101	30,125	64,564	46,596	55,580
1970	45	77	61	418	393	971	594	5,000	243,000	17,224	25,409	84,076	42,236	10,761	6,214	8,488
1971	199	322	260	910	280	95	428	5,000	248,000	19,310	17,833	25,150	20,764	26,406	21,218	23,812
1972	46	44	45	92	76	153	107	1,102	162,000	18,231	26,341	30,864	25,145	5,140	2,891	4,016
1973	348	561	454	377	1,390	839	869	2,600	276,200	19,751	63,291	79,012	54,018	11,699	7,211	9,455
1974	771	919	845	639	439	184	421	1,422	240,600	24,398	26,812	30,721	27,310	25,544	16,943	21,244
1975	900	781	840	770	801	268	613	1,900	207,800	24,647	27,059	29,674	27,127	28,796	22,508	25,652
1976	17	14	15	20	66	49	45	500	197,700	9,405	9,059	8,767	9,077	4,066	3,915	3,991
1977	8	8	8	2	23	42	22	250	193,100	4,749	7,151	12,526	8,142	3,999	2,521	3,260
1978	760	338	549	716	398	267	460	1,100	159,150	16,620	16,414	16,335	16,456	40,874	9,086	24,980
1979	447	745	596	551	579	368	499	1,507	228,060	16,035	18,181	24,317	19,511	13,435	5,326	9,381
1980	1,063	1,143	1,103	355	541	227	374	3,231	172,800	15,880	14,723	19,917	16,840	20,912	14,870	17,891
1981	38	55	46	76	94	1,017	396	4,954	259,700	11,441	39,336	91,853	47,543	9,143	4,596	6,870
1982	3,507	1,882	2,694	1,074	1,564	2,300	1,646	9,000	236,000	28,817	42,769	95,552	55,713	57,876	28,515	43,196
1983	2,338	2,735	2,536	1,285	1,979	2,825	2,030	15,700	205,290	36,150	71,675	155,567	87,797	98,707	71,038	84,873
1984	271	348	309	596	676	752	675	5,969	266,206	18,057	31,819	39,733	29,870	11,204	8,038	9,621
1985	96	70	83	112	149	165	142	7,702	356,513	12,012	12,681	19,091	14,595	7,378	5,215	6,297
1986	1,414	792	1,103	704	631	459	598	5,000	289,226	20,058	16,284	17,406	17,916	15,911	9,322	12,617
1987	28	44	36	65	48	50	54	1,650	275,191	11,025	9,815	17,202	12,681	4,951	3,496	4,224

[1]The daily river flow (cfs) for the lower portion of the Mokelumne River was recorded by the USGS below Woodbridge Dam, and the magnitudes of daily Delta inflow and outflow were estimated by the DWR in the DAYFLOW program.

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used Box-Jenkins models, also known as ARIMA (Autoregressive Integrated Moving Average) models to assess the relationship between daily salmon escapement and daily river flow. The ARIMA models are stochastic empirical models used to assess the causal relationship among natural phenomena. The models have two categories: univariate ARIMA models and transfer function noise models. The univariate ARIMA models take into account the effect of previous values of a variable (AR component, e.g., daily spawning escapement), but also reflect the influence of current and previous perturbations. The transfer function noise models are single output-multiple input time series models. The models incorporate the past values of the output variable (e.g., daily spawning escapement), and the current and past history of input variables (e.g., daily river flow). The model building procedures are identification, estimation, and diagnostic checking (Figures 3-5 and 3-6). A microcomputer package, Auto Forecasting System (AFS), was used to perform the model analyses.

The univariate ARIMA models were used to examine the stochastic behavior of daily numbers of salmon moving past Woodbridge Dam during the in-migration season (from early October to late December or January in the next year) for each year from 1949 to 1971 (except 1950, 1955 and 1965). The bivariate transfer function noise models were used to formulate the relationships between daily salmon spawning escapement (output variable) and daily river flow (input variable) for each year from 1949 to 1971. The daily river flows (cfs) were recorded at Woodbridge Dam, 1949-1971.

The results of univariate ARIMA analyses show that daily salmon escapement was autoregressive (auto-correlated) and related to the escapement of the previous day and two days earlier. This occurred in 16 of 21 years studied. The results of transfer function analyses between daily spawning escapement and daily river flow indicate that there were significant correlations. However, the improvement of R^2-values from the univariate models to the bivariate models is very limited (<0.1). This suggests that the variation of daily river flow in the Lower Mokelumne River has very little effect on the daily movement of salmon past Woodbridge Dam. In other words, the fluctuations of river flow over the short term (several days) are not likely to stimulate the movement of fall-run salmon in the Lower Mokelumne River.

The second question was whether annual Mokelumne River spawning escapement is affected by the average Mokelumne River flow over a longer period, such as a month or the entire migration season (October-December). Data used included annual salmon spawning escapement in the Mokelumne River, monthly average flows for October, November, and December, and seasonal average flows of the same months at Woodbridge Dam from 1956 to 1987.

The correlation coefficients (r-values) between total salmon escapement and average flow in the three time periods are listed in Table 3.7. Prior to the construction of Camanche Dam (1956-1963), salmon escapement correlated poorly with the average flows in each of the migration months, and with a particular in-migration season (r-values ranged from -0.22 to

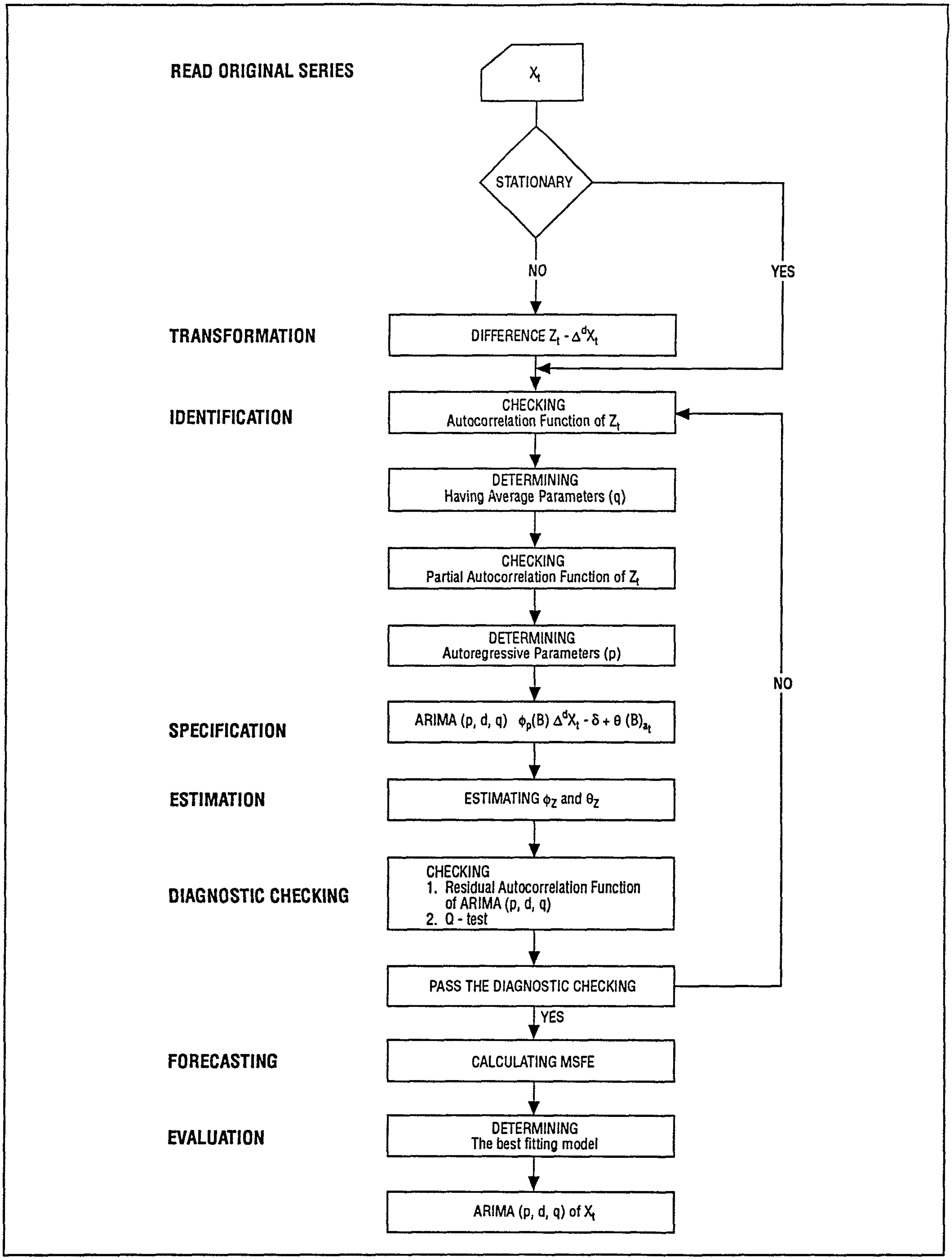

Figure 3-5. A flow chart of the univariate ARIMA process.

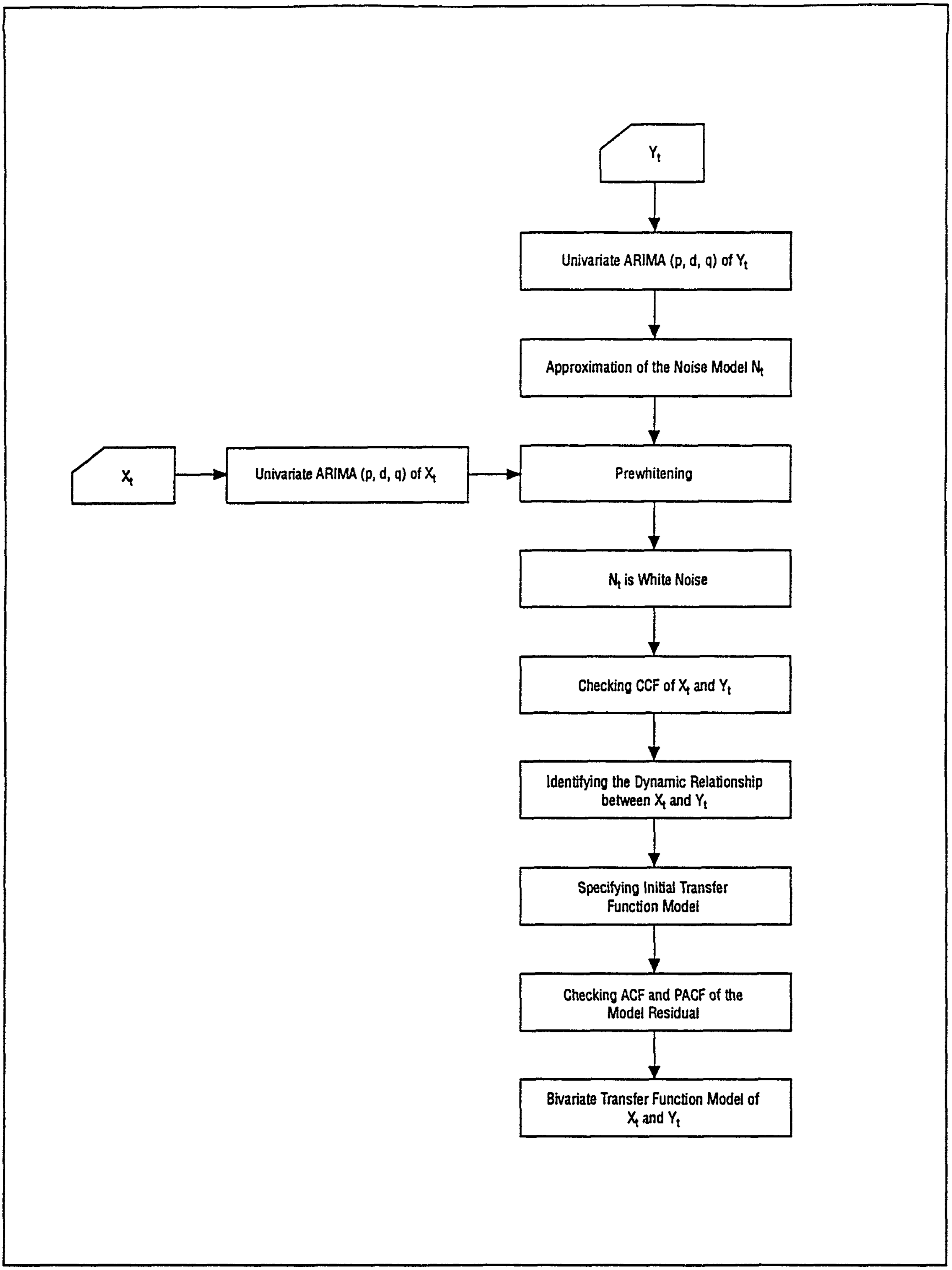

Figure 3-6. A schematic chart of the bivariate ARIMA transfer function process.

0.50, $p > 0.1$). During 1964-1971, after Camanche Dam was built and before hatchery fish trucking practices were altered, salmon escapement was estimated by actual counts done at Woodbridge Dam. These correlated poorly with monthly and seasonal average flows. During 1972-1979, however, salmon escapement was positively and significantly correlated with average flows in November and December, as well as average flows in the migration season. After the Central Valley hatchery practices were altered (1980-1987), salmon escapement was positively and significantly correlated with average flows in each of the migration months and the overall average for the in-migration season (r-values ranged from 0.78 to 0.86, $p < 0.1$).

Table 3.7. Correlation coefficients between Mokelumne River salmon escapement and average flow (cfs) in the lower river in the migration months (October, November, and December) and in-migration season (the three months combined).

	Mokelumne Escapement				
Average Flows	**1956-1963**	**1964-1971**	**1972-1979**	**1980-1987**	**1980-1987 (excl. 1982-1983)**
October	0.50	0.12	0.58	0.78**	0.17
November	-0.13	-0.17	0.95***	0.84***	0.15
December	-0.22	0.40	0.89***	0.86***	0.31
Migration Season	0.02	0.33	0.94***	0.86***	0.29

** 0.05 significance level.
*** 0.01 significance level.

As previously discussed, salmon management practices in the Central Valley have greatly increased the straying rates of adult salmon. Because the Mokelumne River is one of the first tributaries of the Delta that returning salmon encounter, they may be more likely to enter the river when flows are high.

The results of regression analyses comparing total salmon escapement with average flows in 1972 to 1979 and 1980-1987 (Table 3.8) suggest that higher flows in the Lower Mokelumne River are associated with a larger escapement to the river. However, the escapement estimates for 1982 and 1983 are uncertain because they were based on the historical average relationship between escapement and hatchery arrivals which, when applied to 1982 and 1983 arrivals, extrapolates well beyond the original data. When 1982 and 1983 were excluded, the flow/escapement relationship for the 1980 to 1987 period was not significant.

Another approach to dealing with the 1982 and 1983 data problem is to recognize that escapement almost certainly fell somewhere between the estimated escapement and the number of hatchery arrivals, and to test alternative escapement levels to determine what ratio of escapement to hatchery arrivals is required to make the 1980 to 1987 correlation just significant. Alternatively, the minimum ratio required to obtain a specified level of significance can be determined.

Table 3.8. Linear regression relationships between Mokelumne River salmon escapement (x) and average flows (cfs) in the lower river (y) in each of the migration months (October, November and December) and in-migration season (the three months combined), 1980-1987.

Migration Month	Linear Regression Relationship	df	R^2
October	y = 10.36x	6	0.41
November	y = 7.39x	6	0.45
December	y = 5.21x	6	0.44
Migration Season	y = 7.29x	6	0.53

The 1982 and 1983 escapement estimates are 3.36 times the hatchery arrivals in those years. If a significance level of .05 is accepted, then escapement in 1982 and 1983 must have been at least 2.4 times the number of arrivals to obtain a significant migration season flow/ escapement correlation. If a significance level of .1 is accepted, then the escapement/arrival ratio must have been 2.1 to obtain a significant correlation. Therefore, if escapement was actually less than twice the number of hatchery arrivals in 1982 and 1983, the 1980-1987 flow/escapement correlation was not significant.

Overall, the importance of flow to escapement is uncertain. There is not a significant relationship before 1972. The correlation between flow and escapement in later years may be due to intercorrelation of Mokelumne River flow with other variables such as delta inflow or flow in previous years. A small sample size for each eight year period means that any unreliable data point may bias results.

Even if the existence of attraction flows is accepted, the worth of attraction flows is limited because they attract strays which would otherwise spawn elsewhere, and the amount of water required for attraction is large. By the above equation for the migration season, about 2,400 acre feet of water would be required to attract 100 salmon up the Mokelumne.

The third question was whether annual total salmon escapement in the Mokelumne River is affected by the average Delta inflows in each of the migration months or in the migration season overall.

The average monthly Delta inflows of October, November, and December, and seasonal average Delta inflows of the three months used in this analysis were from 1956 to 1987 (DWR 1987).

The correlation coefficients (r-values) between total salmon escapement and average Delta inflows in the three time periods are listed in Table 3.9. For 1956-1963 and 1964-1971, salmon escapement was poorly correlated with average Delta inflows in each of the migration months and with that of the in-migration season overall (r-values ranged from -0.32 to 0.53, $p > 0.1$). After 1972, salmon escapement was significantly correlated with average flows in each of the migration months and for the migration season overall (r-values ranged from 0.77 to 0.92, $p < 0.1$), but, again, the correlation for the 1980-1987 period is not significant without 1982 and 1983.

Table 3.9. Correlation coefficients between Mokelumne River salmon escapement and average Delta inflow (cfs) in each migration month (October, November, and December) and in-migration season (the three months combined).

Average Delta Inflows	Mokelumne Escapement 1956-1963	1964-1971	1972-1979	1980-1987	1980-1987 (excl. 1982-1983)
October	-0.17	0.53	0.77**	0.85***	0.16
November	-0.04	0.11	0.90***	0.86***	0.28
December	-0.32	0.04	0.87***	0.82**	0.14
Migration Season	-0.21	0.14	0.92***	0.86***	0.20

**0.05 significance level.
***0.01 significance level.

Since Delta inflow is the total amount of fresh water discharged into the Delta from all rivers, and precipitation patterns tend to be similar across river basins, fluctuations of flows in the Mokelumne River tend to be correlated with Delta inflow. Cross-correlations among the monthly average flows in the Mokelumne River and the Delta inflows in October, November, December and migration season overall from 1956 to 1987 were positive and strong (r-values ranged from 0.25 to 0.81, $p < 0.1$) (Table 3.10).

Therefore, the correlation between the size of salmon spawning escapement and the Delta inflow may be an artifact of the high correlation between flow in the Mokelumne River and Delta inflow. We cannot identify whether escapement is influenced by Mokelumne River flow, Delta outflow, or both. In general, the correlations with escapement could be inflated by the correlation among the environmental factors.

In addition to the analysis above, recent experimental data address the effect of attraction flows on salmon migration in the Mokelumne River. In 1990, a flow of 250 cfs was maintained below Woodbridge Dam from 17 October through 15 November (Figure 3-7), except that flows were increased to over 400 cfs for one day, and to almost 400 cfs for a 5-day period beginning 25 October. After 15 November, flows below Woodbridge Dam were reduced to an average level of 55 cfs. Salmon began to appear at Woodbridge immediately

Table 3.10. Correlation coefficients among monthly average flows in the Mokelumne River and Delta inflows in October, November, December and overall average for the migration season, 1956-1987.

	Delta Inflow			
Flows in the Mokelumne River	**October**	**November**	**December**	**Migration Season**
October	0.54*	0.43*	0.25	0.38*
November	0.56*	0.77*	0.53*	0.67*
December	0.51*	0.81*	0.81*	0.86*
Migration Season	0.61*	0.78*	0.64*	0.75*

*.01 or .1 significance level.

following the 17 October increase in flow. Migration was fairly consistent over the entire spawning period but the overall run size was quite small (497 estimated).

In 1991, flow was maintained at very low levels (less than 50 cfs) until 1 November (Figure 3-8), when it was increased abruptly to around 400 cfs and maintained at this level for about a week. After 10 November, flow was maintained at about 120-130 cfs through 15 December and at about 100 cfs through the end of December. No significant movement of salmon occurred until after flows were increased in early November. Salmon movement did not appear to be influenced by flow changes later in the migration period.

The regression analysis results presented in Table 3.8 can be used to predict 1990 and 1991 runs of 704 and 997, respectively, based on the average flow for the migration season. These estimates compare to 497 and 410 spawners counted in 1990 and 1991, respectively.

<u>Fall Precipitation</u> - During video monitoring in 1990 and 1991, observations indicated that the number of salmon moving past Woodbridge Dam increased during periods of precipitation. An intervention analysis (Box and Tiao 1975) was conducted with the daily salmon movement data to determine whether movement abruptly increased or decreased during periods of precipitation (Table 3.11). The analysis identifies changes as pulses (short increase or decrease followed by return to earlier values) or as steps (abrupt increase or decrease with equilibration at a new level). The video count and precipitation data were examined to see if changes in daily escapement coincided with precipitation events during the migration season in the Lower Mokelumne River.

For the intervention analysis, changes in daily salmon escapement (Y_t) were examined to determine the occurrences of the dates as a pulse and/or as a step effect resulting from intervention(s) ($v(B)$). Daily salmon escapement Y_t was modeled as a function of its own past

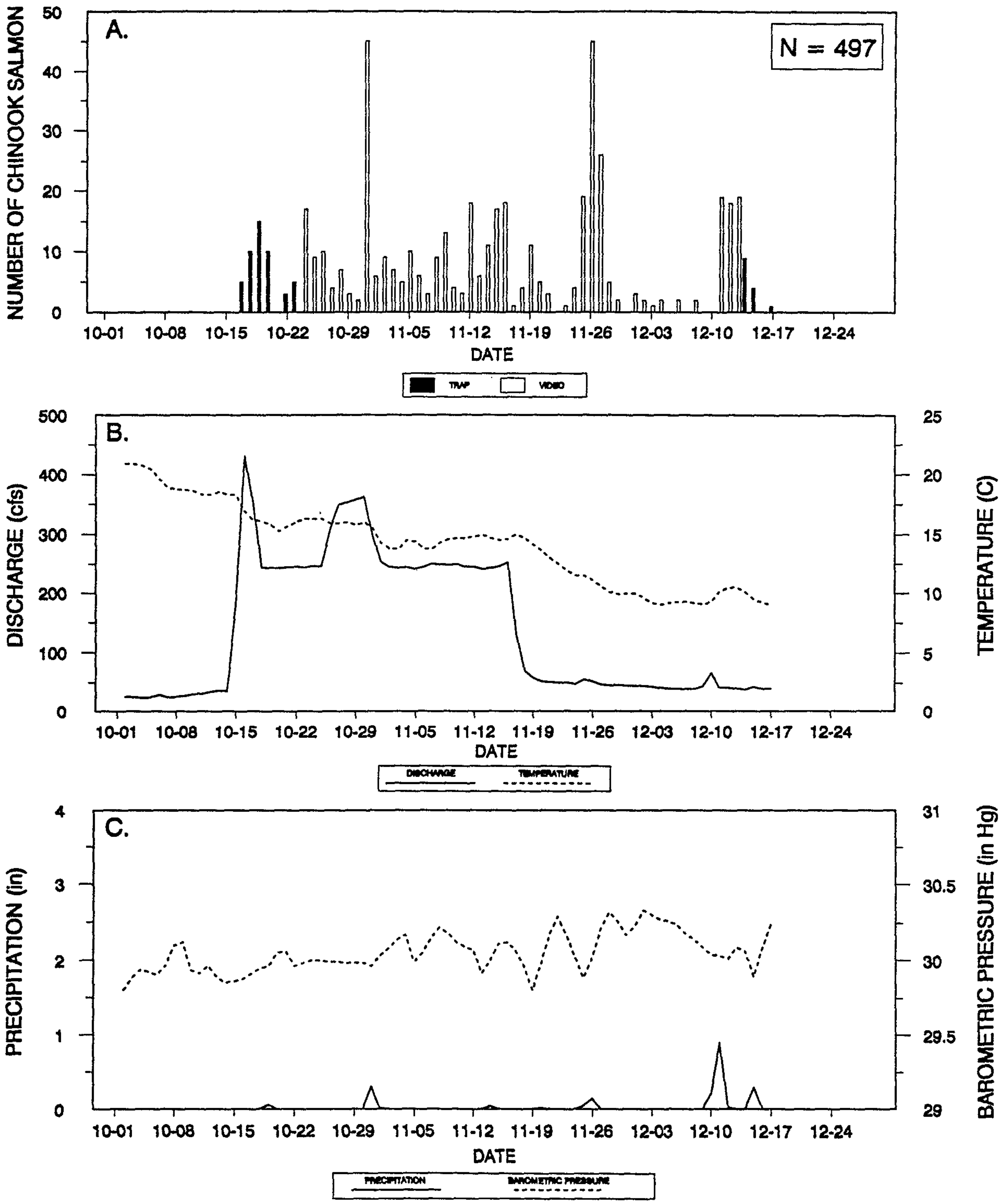

Figure 3-7. A) Daily salmon counts collected at Woodbridge Dam during the 1990 escapement study on the Mokelumne River. Data is from the combined results of the video and trap monitoring systems (inclusive of the salmon removed from the riprap).
B) Mean daily flow (USGS Station #11325500) and mean water temperature (EBMUD datapod at Woodbridge Golf Course) measured downstream of Woodbridge Dam during the escapement period.
C) Total rainfall (Lodi Fire Department) and average barometric pressure (Sacramento Executive Airport) recorded during the escapement period.

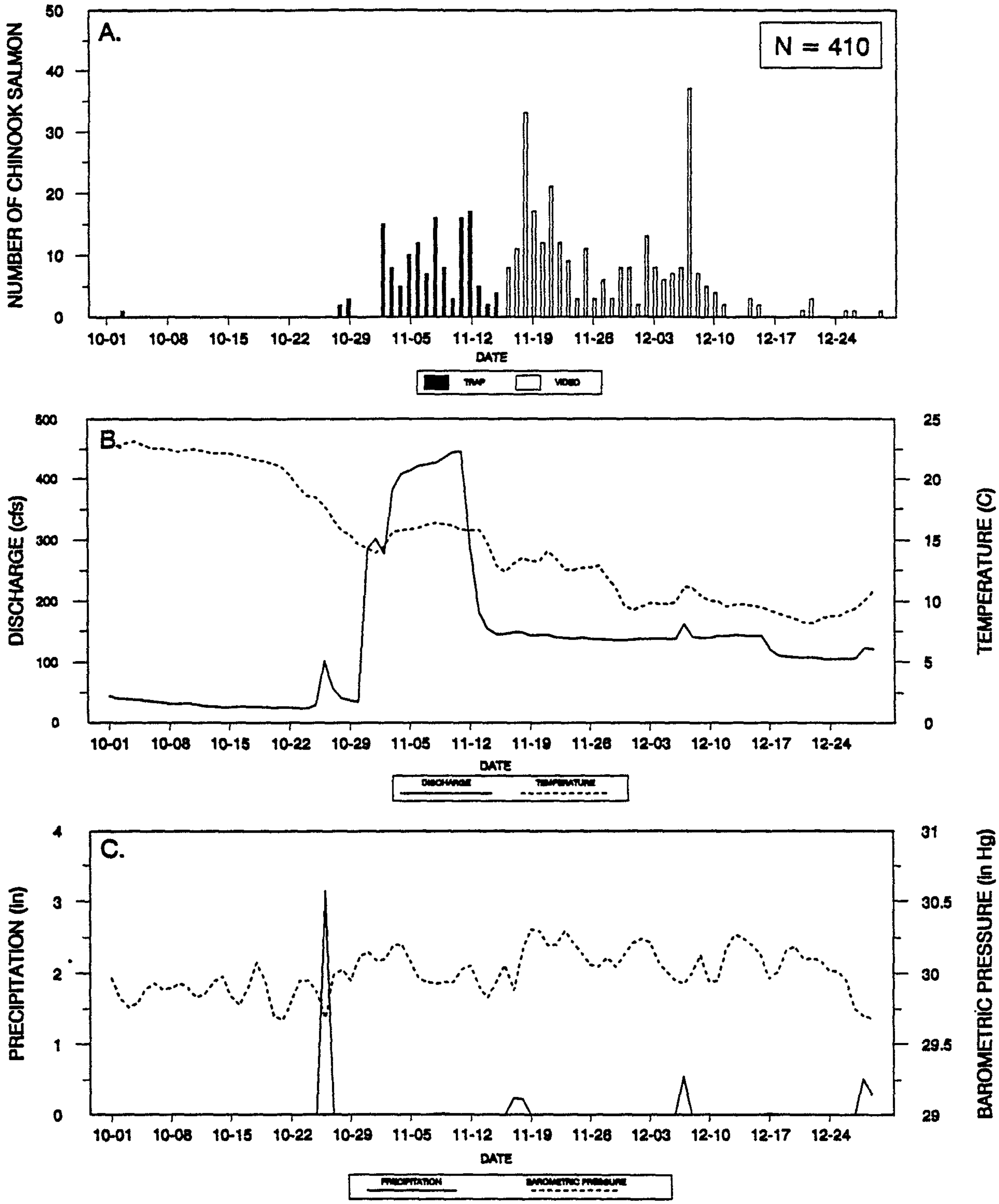

Figure 3-8. A) Daily salmon counts collected at Woodbridge Dam during the 1991 escapement study on the Mokelumne River. Data is from the combined results of the video and trap monitoring systems.

B) Mean daily flow (USGS Station #11325500) and mean water temperature (EBMUD datapod at Woodbridge Golf Course) measured downstream of Woodbridge Dam during the escapement period.

C) Total rainfall (Lodi Fire Department) and average barometric pressure (Sacramento Executive Airport) recorded during the escapement period.

values and an input dummy variable (I_t). The values of I_t were set to either 1 or 0, indicating off or on of the intervention events. Therefore, a bivariate transfer function noise model between Y_t and I_t was constructed for the intervention analysis as:

$$Y_t = v(B)I_t + z_t \tag{1}$$

where z_t is the same as Y_t before the intervention occurred. Therefore, daily salmon escapement can be represented by an univariate ARIMA model.

Table 3.11. Changes in daily salmon migration patterns identified by intervention analysis, 1990 and 1991 spawning seasons.

	Intervention	
Year	**Type**	**Date**
1990	Pulse effect	31 October
	Pulse effect	26 November
1991	Pulse effect	18 November
	Pulse effect	7 December

Daily salmon escapement data recorded during BioSystems' video monitoring surveys in 1990 and 1991 were used to conduct the intervention analysis. In 1990, two significantly positive pulse effects were found on 31 October and 26 November; precipitation also occurred on both days (Figure 3-7). In 1991, two significantly positive pulse effects were detected on 18 November and 7 December, and precipitation occurred on those two days (Figure 3-8).

The results show that precipitation appeared to stimulate short-term increases in salmon movement past Woodbridge Dam. However, the influence of precipitation on the overall size of the run did not appear to be significant. During the 1990 migration season, 38 percent of all salmon passed the dam while it was raining, while 62 percent migrated during periods with no rain. In 1991, 30 percent of all salmon passed the dam during precipitation and 70 percent migrated during periods with no precipitation. Several precipitation events (19 October, 10 December, and 15 December 1990; and 26 October 1991) did not appear to be associated with pulses in migration. Precipitation may influence the short-term movement of salmon but it did not affect the overall size of the run.

The data were further analyzed to determine whether total salmon escapement in the Mokelumne River is affected by the number of days with precipitation, total accumulated precipitation, or average daily precipitation during the migration season (from 1 October to 31 December).

Since the occurrence of precipitation indicates an increase in daily salmon escapement, the number of days with precipitation may be correlated with the total salmon migration for any given year. Also, more accumulated precipitation may result in attracting more salmon during a given migration season. Therefore, the correlation coefficients (r-values) between each of the three independent variables: the number of raining days, accumulated precipitation, and average daily precipitation during the migration season, as well as the dependent variable of total salmon escapement were examined for four time periods: 1949-1963, 1964-1971, 1972-1979, and 1980-1987 (Table 3.12).

Table 3.12. Correlation coefficients between Mokelumne River salmon escapement and precipitation during the migration season.

	Mokelumne Escapement				
	1949-1963	1964-1971	1972-1979	1980-1987	1980-1987 (excl. 1982-1983)
Number of days with rain	-0.16	0.37	0.51	0.41	0.13
Accumulated precipitation	-0.21	-0.06	0.44	0.63*	0.27
Average daily precipitation	-0.39	-0.56	0.33	0.62	0.29

*0.1 significance level.

Correlation coefficients for all r-values were not significant ($p > 0.05$). These results indicate that salmon escapement correlated weakly with the number of days with rain, accumulated precipitation, and average daily precipitation. Therefore, it may be said that occurrences of precipitation, regardless of their magnitude, stimulate some salmon to in-migrate earlier. Salmon escapement increased abruptly on those days (i.e., significantly positive pulse effects), but precipitation events have little effect on total salmon escapement in the Lower Mokelumne River during the migration season for any given year.

<u>Parent Stock Size</u> - In general, larger spawning runs produce more progeny that will return two and/or three years later to the same stream. This is known as the recruitment-stock relationship (Ricker 1977). Though many factors act to obscure this relationship, spawning escapement in the Mokelumne River may be related to the size of spawning escapement two and/or three years previously in the river. Since straying is an important factor among Central Valley salmon stocks under current management, the Mokelumne stock size may also be correlated with stock sizes in the entire Central Valley two and/or three years before. Mokelumne stock size may also be correlated with Central Valley stock size in the same year.

To determine whether salmon escapement in the Mokelumne River is affected by the size of escapement, two or three years prior correlation coefficients were examined for the relationships of total annual salmon spawning stocks of the current year (t) in the Mokelumne River and that of two and three years prior (t-2 and t-3) in the river. The estimates of annual salmon spawning stocks in the Mokelumne River from 1956 to 1987 were used for the analysis.

In 1964-1971, spawning stocks of the current year were correlated with those of three years prior. Table 3.13 shows that the size of current-year salmon spawning stock in the Mokelumne River does not significantly correlate with the sizes recorded two or three years before for the other time periods. This poor correlation could be due to different sampling techniques used for the parent stock in some years of some periods.

Table 3.13. Correlation coefficients between total salmon spawning stocks in the Mokelumne River for current year (t) and stocks two and three years earlier (t-2 and t-3).

Mokelumne Stocks	Mokelumne Escapement				
	1956-1963 N=6,5	1964-1971 N=8	1972-1979 N=8	1980-1987 N=8	1980-1987 (excl. 1982-1983)
year t-2	-0.20	0.47	0.41	0.06	0.59
year t-3	-0.26	0.75*	0.39	-0.13	0.30

*0.1 significance level.

To determine whether the Mokelumne River stock size is correlated with the stock sizes in the entire Central Valley, we examined the correlation coefficients between the total annual salmon spawning stocks of the current year (t) in the Mokelumne River, and the total annual salmon spawning stocks of the current year (t) or those of two or three years prior (t-2 and t-3) in the Central Valley. The estimates of annual salmon spawning stocks in the Mokelumne River, as well as the entire Central Valley, were available for the years from 1956 to 1987.

With the exception of the correlations for the spawning stock in the Mokelumne River and in the Central Valley in the same year during the 1956-1963 and 1972-1979 time periods, Table 3.14 shows that there was poor correlation between Mokelumne River stock size and Central Valley stock size two or three years prior.

The results in Tables 3.13 and 3.14 suggest that Mokelumne salmon escapement was not affected by the size of salmon stocks in the river two or three years prior, nor was it affected by the size of the salmon stock in the Central Valley in the current year and that of two and three years prior, until after the significant change in salmon hatchery management in 1979. The results may indicate that the recruitment-stock relationship of Mokelumne salmon stocks is not significant. A number of factors can alter this basic relationship and result in a nonsignificant correlation between the spawning stocks and their parental runs as shown in these analyses. The life cycle model provides plausible explanations for this insignificance; high mortality at Lake Lodi and in the Delta.

Table 3.14. Correlation coefficients between total salmon spawning stocks in the Mokelumne River for current year (t) and stocks two and three years earlier (t-2 and t-3) in the Central Valley.

Central Valley Stocks	Mokelumne Escapement 1956-1963 N=8,6,5	1964-1971 N=8	1972-1979 N=8	1980-1987 N=8	1980-1987 (excl. 1982-1983)
year t	0.99**	0.26	0.67*	-0.17	0.62
year t-2	-0.79	-0.12	0.28	-0.18	-0.49
year t-3	-0.80	-0.52	-0.33	-0.36	-0.05

* 0.1 significance level.
**0.05 significance level.

<u>Spring Out-migration Conditions</u> - The survival and out-migration success of young salmon (0+ to one-year-old) may be affected by water flows during out-migration. Spring flows in the Mokelumne River and the Delta outflow may affect out-migration success and the size of spawning stocks when these fish mature and return to the river as adults.

Mokelumne River and Delta flow data were analyzed to determine whether spring flows during the smolt out-migration affect the size of the salmon spawning stock one or two years later when the progeny return to the river.

Annual data include total number of salmon returning to the Mokelumne River in the fall, monthly average flows for May and June, and combined May/June average flows at Woodbridge Dam from 1956 to 1987.

The correlation coefficients (r-values) of the relationships among the spring flows in the Mokelumne River of year t+1 and the total salmon return of two and three years later (t+2 and t+3) for each of the three time periods are listed in Table 3.15. With the exception of the r-values for the average flows in June and during the out-migration season, and stock size in the river three years later during the time period 1956-1963 (r-values are 0.65 and 0.66, $p < 0.1$), the spring flows correlated poorly with the escapement two or three years later (r-values ranged from -0.13 to 0.60, $p > 0.1$). The results suggest that prior to 1964, higher flow in June and the out-migration season in the Mokelumne River increased survival rates among fall-run salmon smolts and increased the return to the river three years later. However, this relationship ceased after 1964. Speculatively, this could be related to a number of factors including increased pumping from the Delta, increased planting of salmon in the Delta, or construction of Camanche Dam.

Delta outflow data also were examined to determine whether spring flow affects the size of salmon spawning stock one or two years later when the progeny return to the Central Valley and the Mokelumne River.

Annual data include total number of salmon returning to the Central Valley and Mokelumne River in the fall, monthly average Delta outflows for May and June, and combined May/June average Delta outflows from 1956 to 1987. Correlation analyses between Delta outflow and stock size were also conducted for four time periods: 1956-1963, 1964-1971, 1972-1979, and 1980-1987.

Table 3.15. Correlation coefficients between Mokelumne River flow during the out-migration months (May and June) and the overall average for the out-migration season in the Mokelumne River at year t+1, and the total salmon return two and three years later (t+2 and t+3)[1].

Average Flows t+1	1956-1963 t+2	1956-1963 t+3	Mokelumne Salmon Return 1964-1971 t+2	1964-1971 t+3	1972-1979 t+2	1972-1979 t+3	1980-1987 t+2	1980-1987 t+3	1980-1987 (excl. 1982-1983) t+2	1980-1987 (excl. 1982-1983) t+3
May	0.13	0.60	-0.01	0.47	-0.01	-0.02	0.50	-0.13	-0.82*	0.02
June	0.35	0.65*	-0.30	0.35	0.24	0.06	0.23	-0.06	-0.58	0.04
Out-migration Season	0.24	0.66*	-0.12	-0.44	0.12	0.02	0.40	-0.10	-0.74	0.03

*0.1 significance level.
[1]N=8 for all periods except 1956-1963 (N=6,7) and 1980-1987 (N=6)

The correlation coefficients (r-values) for Delta outflow at year t+1 and the number of salmon returning one and two years later (t+2 and t+3) to the Central Valley and Mokelumne River are presented in Tables 3.16 and 3.17 for each of the time periods. There was a nonsignificant correlation between average Delta outflows and the stock size in the Central Valley during 1956-1963 and 1972-1979. Delta outflow was significantly correlated to stock size in the Central Valley two years later during 1964-1971 and 1980-1987, not one year later. However, the correlation coefficients between Delta outflow during out-migration and salmon return to the Mokelumne River two or three years later were not significant (Table 3.17), which suggests that Delta outflow did not affect the size of the salmon run in the Mokelumne River.

<u>MRFH Production Levels</u> - Large numbers of salmon are produced at the MRFH and released in the Mokelumne River and Sacramento-San Joaquin delta. In the last few years, record numbers of salmon and steelhead have been produced and released. Spawning runs (two- or three-year-old) may be affected by the number of young salmon (0+ to one-year-old) released by MRFH one or two years previously.

The young salmon released by MRFH include fingerlings (smolt size), advanced fingerlings (post smolt size), and yearlings. Fingerlings are released between May and July, advanced fingerlings in July through October, and yearlings after October. The numbers released were totaled for each brood-year, with the brood year defined by the year of the adult spawning run.

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Table 3.16. Correlation coefficients between Delta outflow in the out-migration months (May and June) and the out-migration season at year t+1, and the total salmon return to the Central Valley two and three years later (t+2 and t+3)[1].

	Central Valley Return									
	1956-1963		1964-1971		1972-1979		1980-1987		1980-1987 (excl. 1982-1983)	
Delta Outflows t+1	t+2	t+3	t+2	t+3	t+2	t+3	t+2	t+3	t+2	t+3
May	0.04	0.38	-0.16	0.69*	0.09	-0.40	-0.35	0.74*	-0.19	-0.21
June	0.06	0.50	-0.14	0.77**	-0.05	-0.32	-0.23	0.79*	-0.03	-0.03
Out-migration Season	0.05	0.43	-0.15	0.73**	0.05	-0.40	-0.30	0.76*	-0.13	-0.13

*0.1 significance level.
**0.05 significance level.
[1]N=8 for all periods except 1956-1963 (N=6,7) and 1980-1987 (N=6)

Table 3.17. Correlation coefficients between Delta outflow in the out-migration months (May and June) and the out-migration season at year t+1, and the total salmon return to the Mokelumne River two and three years later (t+2 and t+3).

	Mokelumne River Return									
	1956-1963		1964-1971		1972-1979		1980-1987		1980-1987 (excl. 1982-1983)	
Delta Outflows t+1	t+2	t+3	t+2	t+3	t+2	t+3	t+2	t+3	t+2	t+3
May	0.26	0.57	0.02	0.44	-0.06	-0.07	0.28	-0.04	-0.48	0.17
June	0.20	0.60	0.02	0.41	-0.28	-0.45	0.21	-0.03	-0.42	-0.02
Out-migration Season	0.24	0.59	0.02	0.43	-0.15	-0.12	0.22	-0.04	-0.46	0.09

For example, brood-year 1964 fish were spawned in the fall of 1964 (year t) and released in 1965 (year t+1). They would return as two-year-olds in the fall of 1966 (year t+2) and as three-year-olds in 1967 (year t+3). Records of the numbers of salmon released were available for the years from 1964 to 1987. The young salmon were released at the hatchery before 1976, at Rio Vista in 1977, and released in equal numbers at the hatchery and Delta in 1978, and back to the river in 1979. After 1979, the young salmon were trucked and released below the Delta. The annual total number of returning fall-run salmon in the Mokelumne River were estimated based on the spawning stock surveys conducted by CDFG from 1964 to 1987.

The correlation coefficients between salmon released from the hatchery and those returning to the Mokelumne River were examined. Releases of salmon of brood year t at year t+1 were compared to returns to the Mokelumne River in years t+2 and t+3. Since release sites were changed to the Delta after 1979, the correlation coefficients analyses were conducted for two time periods: 1964-1976 and 1980-1987.

The correlation coefficients (r-value) between salmon released and salmon returning one or two years later for the two time periods are listed in Table 3.18. With the exception of the r-value for returning salmon two years later in 1980-1987, the number of salmon released correlated poorly with the number of salmon returning either one or two years later (r-values ranged from -0.60 to 0.42, $p > 0.1$). The correlation coefficient between the number of salmon released and the number of salmon returning two years later significantly correlated in the 1980-1987 period; however, the correlation is negative (r-value = -0.91).

Table 3.18. Correlation coefficients between salmon released from MRFH at year t+1 and salmon returning to the Mokelumne River two or three years (t+2 and t+3) later during 1964-1976 and 1980-1987.

Salmon Returning	Salmon Released (Year t+1)		
	1964-1976	1980-1987	1980-1987 (excl. 1982-1983)
year t+2	0.42	-0.60	-0.84**
year t+3	0.20	-0.91*	-0.98***

*0.1 significance level.
**0.05 significance level.
***0.01 significance level.

3.2.2.4 Spawning Habitat

Since the construction of Camanche Dam, the only suitable spawning habitat in the Mokelumne River has been the area extending for a few miles immediately downstream from Camanche Dam. Historically, the size and carrying capacity of the spawning habitat has been an unresolved issue.

In 1955, before construction of Camanche Dam, the CDFG speculated that "spawning areas could accommodate 40,000 adults easily" at a flow of 400 cfs; and at 200 cfs "it might accommodate 10,000-15,000" (CDFG 1955). Field measurements, however, established that the carrying capacity was much lower. Hatton (1940) estimated the maximum carrying capacity of the Mokelumne River at 19,070 salmon, based on the total available spawning habitat (3,543 m^2). In 1957, CDFG reported that the habitat could support 5,000-11,000 salmon based on normal flow (CDFG 1957a). Although surveys have been conducted on the Mokelumne River for over 50 years, no salmon stock estimates have been higher than 16,000, and no actual counts have been above 12,000 fish (Table 3.4; CDFG 1991).

Construction of Camanche Dam (1964) blocked access to 80 percent of the original spawning grounds in the Mokelumne River (Menchen 1961; Groh 1965). Based on the highest estimate of pre-Camanche spawning area by CDFG (for 40,000 salmon), construction of the dam would have left adequate habitat for only 8,000 fish. BioSystems used information on chinook salmon spawning habitat preferences and aquatic habitat quality and quantity in the Mokelumne River to estimate the number of female spawners the river can support (Appendix A). Three types of spawning habitat (potential, weighted usable area [WUA], and preferred) were considered in the analysis. Potential habitat encompassed all spawning habitat identified and measured during BioSystems' mapping surveys on the river in spring 1990. Chinook salmon spawning WUA was determined from the 1987 IFIM studies (Envirosphere 1988). Preferred habitat is more narrowly defined than potential spawning habitat and is based on spawning habitat selection as described in the scientific literature and observed during redd surveys in 1990-1992 (Appendix A).

The estimated area of potential spawning habitat was 87,382 m^2, the WUA was 28,665 m^2, and the estimated area of preferred habitat was 12,549 m^2. The total area of spawning habitat (potential, WUA, and preferred) was divided by the mean redd area determined from the 1991-1992 spawning surveys (5.5 m^2) to predict the maximum number of females the river could support at flows around 250 cfs. Using our estimates of preferred and WUA spawning habitat, we predicted that from 2,282 to 5,212 spawning females could construct redds without superimposition. Using our estimate of potential habitat, the predicted number of female spawners is 15,888. Spawning data collected in the Mokelumne River in 1990-1992 suggest that the estimate of 2,282 female spawners is more realistic (Appendix A).

To replace salmon productivity lost because of Camanche Dam, an artificial spawning channel was constructed at the MRFH to provide spawning habitat for 4,700 fish, including 2,000 females (Groh 1965). During the first 15 years of hatchery operations, few adults returned to the hatchery and spawned in the artificial channel (mean <150 females/year) (Jewett 1982).

In 1979, half of the spawning channel was converted by the CDFG into a series of wide rearing ponds to raise yearling salmon (Jewett 1982). According to MRFH annual reports of the spawning stocks from 1977-1988, the remaining artificial spawning habitat has only been used once for spawning (in 1982). Since 1979, salmon production at the hatchery has relied almost entirely on the importation of eggs and fingerlings from other hatcheries, and the artificial spawning of a few adult spawners that return to the hatchery.

Because the spawning channel is no longer used, the only spawning habitat along the Mokelumne River is in the river section downstream from Camanche Dam. The CDFG reported that 95 percent of spawning occurs in a 5.6 kilometer section immediately downstream from Camanche Dam (Taylor 1974). However, spawning surveys conducted in 1990-1991 and 1991-1992 documented significant spawning up to 11.2 kilometers downstream, and as much as 51 percent of spawning activity occurred below Mackville Road (about 8 km below Camanche Dam) (Appendix A).

Extensive aquatic habitat mapping conducted by BioSystems revealed that spawning habitat occurred at least 13 kilometers below Camanche Dam (Appendix A). In May-June 1990, a total of 87,382 square meters of potential spawning habitat were identified during these surveys (flows 170-290 cfs). Most of this habitat (96%) occurs in a 13 kilometer section below Camanche Dam.

The major determinants of spawning success are flow velocity and depth, habitat availability, quality, and temperature. Fish habitat is typically measured by applying the Instream Flow Incremental Methodology (IFIM), initially developed by the USFWS. The IFIM measures substrate, water velocity, and water depth to calculate the amount of WUA as a function of flow for a given fish species and lifestage. Flow volume not only determines the areal extent of suitable habitat, it also influences water temperature and, thereby, temperature suitability for these species.

The CDFG has measured habitat value (expressed as WUA) for salmon in the Mokelumne River during three life stages (spawning, fry, and juvenile rearing) in the Camanche reach (CDFG 1991). The results of this study indicate that the maximum potential spawning habitat is available when flow is near 300 cfs. The amount of habitat declines gradually at higher flows and decreases rapidly at flows below 200 cfs.

In addition to WUA, water temperature is an important variable that can influence habitat suitability and spawning success. Adult salmon can survive temperatures of up to 25.6°C (Bell 1973), and have been observed migrating at temperatures as high as 24.4°C (Dunhan 1968). However, in the Sacramento-San Joaquin delta, salmon are unlikely to enter water warmer than about 20°C (Hallock et al. 1970). During egg incubation the maximum suitable (or preferred) temperature is between 14° and 14.8°C (Healy 1979; Reiser and Bjornn 1979; Raleigh et al. 1986; CDWR 1988). Exposure of pre-spawning females to temperatures in excess of 14°C may be detrimental to egg development (CDWR 1988), but this has not been well documented. BioSystems studies indicate that temperatures as high as 15°C may not be detrimental.

The Mokelumne River is usually too warm in the early fall when adults may be returning to the river, and temperatures as high as 16°C can occur through October. Elevated water temperatures influence the viability of salmon eggs, fertilization success, and embryo survival. However, salmon do enter the river and spawn with water temperatures in excess of published criteria for preferred spawning.

River water temperatures below Camanche Dam during the fall are determined by the Camanche release temperature and downstream warming or cooling trends that depend on the weather (Appendices B and C). Camanche release water temperature can be influenced by the Camanche hypolimnetic volume. Below Camanche Dam, water temperature increases when air temperature is high and decreases when air temperature is low. Typically, downstream cooling begins from late October to mid-November.

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To more fully explore the effects of warm spawning temperatures, a pilot study was conducted using fry emergence traps in 1990-1991. Redds were divided into two groups, based on water temperature at the time of construction, to compare the number of fry emerging under different temperature conditions. Traps were placed over redds constructed when the temperature exceeded 14° C and also over redds constructed when the temperature was below 14° C. The study failed to document a strong water temperature effect but results of this study were inconclusive because of the small sample size, high variability in emergence between redds, and low emergence under all conditions (Appendix A).

Based on the results of the 1991 study, we modified our study design in 1992 to include the use of incubation capsules in controlled laboratory and field experiments to quantify the effect of water temperature on spawning success. In 1992, we found a significant difference in the mean survival of eggs exposed to warm temperatures (>15.2°C), characteristic of the river shortly after reservoir turnover, as compared to eggs exposed to cooler temperatures (<12.8°C) (Appendix A).

Successful spawning and emergence also requires suitable substrate. The preferred substrate for spawning consists of loose gravel that is low in fine sediments (fines) and large enough to allow adequate interstitial water flow to oxygenate eggs. Much of the gravel substrate in the Mokelumne River may be only marginally suitable for spawning because of large amounts of fines and streambed armoring (Appendix A).

Sediment loads from agricultural return flows may increase the amount of fines in spawning gravel and reduce the quality of spawning habitat. Eighteen of 25 redds (72%) sampled during BioSystems' 1991 emergence studies contained fines at levels detrimental to egg survival (Appendix A). Similarly, in 1992, 75 percent of the redds sampled (9 of 12) contained high amounts of fines. During these studies, BioSystems found that the number of emerging fry decreased significantly as the amount of fines increased. Spawning gravel in some areas, particularly near the dam, is degraded through armoring, a typical tailwater phenomenon characterized by a subsurface hard pan of gravel.

3.2.2.5 Rearing Habitat

Salmon rearing occurs between January and July. The suitability of habitat for rearing is influenced by water temperature and microhabitat variables (water depth, flow velocity, substrate, etc.). Flow influences the amount of suitable microhabitat and also influences water temperature. Based on the IFIM study conducted by CDFG (1991), rearing habitat (as measured by WUA) is greatest for both fry and juveniles at 100 cfs and decreases at higher flows. CDFG did not evaluate habitat availability at flows of less than 100 cfs, and therefore it is unknown whether the optimal habitat availability occurs at flows below 100 cfs. Since juveniles typically prefer areas with reduced velocity in other systems (Raleigh et al. 1986), lower flows may result in higher WUA estimates, especially in channelized sections of the river. In channelized sections, minimal increases in flow can result in a rapid increase in velocity. Based on observations of the river at rearing flows of around 100 cfs, optimal flow for rearing may well be higher.

BioSystems' aquatic habitat mapping in spring 1990 confirmed that most of the suitable rearing habitat is restricted to the upper segment of Camanche reach (13 km downstream of Camanche Dam) (Appendix A). Areas below Elliott Road contain few riffles and the substrate is primarily sand; these conditions are not conducive to food production and cover for juvenile salmon. The river below Woodbridge Dam has marginal rearing habitat because of poor substrate and the low numbers of benthic invertebrates (Appendix A).

Juvenile salmon can tolerate temperatures approaching 25°C; however, elevated temperatures may result in an increase in metabolic rate and a decrease in disease resistance, feeding and swimming efficiency (Brett 1952; Orsi 1971; Brett et al. 1982). During the development from intra-gravel fry to out-migrating juvenile, the preferred water temperature range gradually increases. Typically, the maximum preferred water temperature during fry or fingerling development is between 14.0 and 15.6°C (Brett 1952; Brett et al. 1969; Raleigh et al. 1986; CDWR 1988). During juvenile rearing, water temperatures as high as 17.0 to 19.0°C are optimal (Raleigh et al. 1986; Brett et al. 1982; Kelley et al. 1985; USFWS 1986).

In most years, temperatures below Camanche Dam are within the suitable water temperature range during the fry rearing period (January-March) (CDFG 1992). Suitable water temperature conditions are maintained during most of the smolt rearing period (April-June).

3.2.2.6 Out-migrations

Salmon may migrate downstream soon after their emergence (as fry), or after several months of rearing (as smolts) (Moyle 1976). A small number may rear over the summer and migrate in the fall as yearlings (Appendix A). Several studies of salmon in California's Central Valley have shown that there are two distinct peaks in out-migration within the same river system during the year (Hatton and Clark 1942; Menchen 1974; Schaffter 1980). To evaluate instream smolt production and the factors that influence it, smolt out-migration studies were conducted during the spring of 1990-1992. These studies were designed to provide information on the timing and size of out-migration, and to determine the size and physical condition of out-migrating fry and smolts. In conjunction with these studies, trapping and tagging studies were conducted to assess relative mortality in different reaches of the river and Delta (Camanche reach, Lake Lodi, Woodbridge reach and the Delta).

Fry Out-migration - Fry out-migration in the Mokelumne River has not been fully evaluated, and the contribution of these fish to instream production and subsequent adult populations is uncertain. In 1992, a total of 1,122 salmon fry were captured in the Bruella fry traps between 19 February and 29 March (Appendix A). There were three clear peaks in the daily catch rates, with the greatest peak occurring in early March. Based on mark-recapture studies, BioSystems estimated that approximately 16.6 percent (95% confidence interval = 6.9% - 26.3%) of fry are captured in these traps; therefore, the estimated total number of salmon fry migrating past Bruella Road was 6,759.

Smolt Out-migration Timing - Since 1968, the CDFG has operated a smolt trap at Woodbridge Dam during low flow years. During 1990-1992, BioSystems operated the CDFG smolt trap in conjunction with out-migration studies. The historical trap data was evaluated to determine historical migration patterns based on nine years of data (1968, 1970, 1972, 1976, 1977, 1981, 1985, 1990 and 1991). CDFG trapping data was incomplete and therefore not incorporated into the evaluation during five years (1971, 1973, 1987, 1988, and 1989). During this time, catch in the Woodbridge smolt trap has varied from 31,025 salmon in 1991 to 175,377 fish in 1976 (Table 3.19). These results may be biased since the duration of trapping has varied between 9 and 17 weeks, and the initiation of trapping operations has ranged from mid-March (1976) to early May (1968 and 1985). Results may also be biased by large releases of MRFH fish in some years.

Overall, 95 percent of the historical out-migration occurred between the first week of May and the end of June (Table 3.19). The peak catch usually occurred in late May, but ranged from the second week of May (1977 and 1991) to the second week of June (1981, 1985 and 1990).

The timing and peak of the 1990-1992 out-migrations are consistent with previous CDFG records for the Woodbridge smolt trap (Appendix A). In 1990, the peak catch occurred during June. Only a small percentage of the total catch occurred during April (1%), May (28%), and July (10%). In 1991, most salmon were caught in May (>80%) with the peak during early May. In 1992, most smolts (67%) were captured during May and 31 percent were caught in June.

During 1990-1992, diel migration studies were conducted to determine the time of day when smolts moved downstream. In all years, the majority of fish were caught between approximately 0400 and 1000 hrs (4:00 AM to 10:00 AM) (Appendix A). The catch was relatively low during the afternoon and evening and dropped to almost zero between 2200 and 0400 hours.

Factors Influencing Smolt Out-migration Timing and Magnitude - The timing of downstream migration in salmon has been associated with numerous variables. Various research has indicated that changes in flow volume, including large-scale pulses of water or "freshets," influence downstream migration (Hartman et al. 1982; Bilby and Bisson 1987; MacMahon and Hartman 1989). Gradual increases in flow (Youngson et al. 1983) and decreases in flow (Painter et al. 1977; Montgomery et al. 1983) have also been associated with downstream migration. Several authors report that when water temperature reaches a certain level, salmon will immediately migrate downstream (Keenleyside and Hoar 1954; Mills 1964; Solomon 1978; Hartman et al. 1982). Photoperiod has also been reported to influence out-migration (Saunders and Henderson 1970; Giorgio et al. 1990). Giorgio et al. (1990) found that salmon exposed to artificially increased photoperiods migrated downstream before salmon exposed to natural photoperiods. Other factors associated with the timing of out-migration have been turbidity (Berg and Northcote 1985; Hale 1987), prey abundance

Table 3.19. Timing of chinook salmon out-migration as recorded at Woodbridge Dam by CDFG in selected years from 1968-1985 and by BioSystems Analysis, Inc. in 1990 - 1992. Percentages reported are derived from total smolts passing through Woodbridge in a given year.

Month/ Week No.	1968 Bel. Normal	1970 Wet	1972 Bel. Normal	1976 Critical	1977 Critical	1981 Dry	1985 Dry	1990 Critical	1991 Critical	1992	MEAN % OF TOTAL NUMBER
March											
Week 3				0.0							0.0
Week 4			0.1	0.0	0.5				0.0		0.1
April											
Week 1			0.0	0.1	1.4			0.0	0.1		0.1
Week 2		0.0	0.1		0.4	0.0		0.0	0.5		0.1
Week 3		0.0	0.0		0.3	0.2		0.0	2.6		0.1
Week 4		1.7	0.1	2.3	0.5	0.9		0.6	2.6		0.9
May											
Week 1	0.5	7.9	0.0	6.6	10.0	2.5	2.0	4.0	16.7		4.4
Week 2	1.3	25.7	3.7	14.5	22.5	1.9	6.3	5.7	27.4		9.5
Week 3	4.7	42.4	6.4	28.2	18.3	34.9	12.9	10.1	23.6		18.9
Week 4	28.6	14.3	31.7	15.7	21.9	7.7	13.0	9.4	18.7		18.1
June											
Week 1	27.1	3.2	43.4	13.8	4.5	21.3	9.6	10.1	5.1		16.6
Week 2	24.3	4.7	10.8	9.1	12.7	21.7	20.0	26.6	1.8		16.1
Week 3	8.5		1.9	6.7	4.9	7.5	12.5	18.8	0.6		8.2
Week 4	3.0		1.4	1.8	1.1	1.4	11.3	9.0	0.3		3.9
July											
Week 1	1.3		0.5	0.8	0.6		6.7	3.9			1.9
Week 2	0.6			0.3	0.5		3.4	1.1			0.7
Week 3				0.1			2.2	0.5			0.4
Week 4								0.1			0.0
N =	105,882	25,512	51,309	175,377	51,638	73,121	94,782	78,179	31,025	69,993	
Estimated Hatchery Releases	177,542[1]	383,163[2]	553,451[1]	68,070[4]	71,280[3]	167,034[4]	- -	350,600[5]	18,500[6]	0	

[1]All smolts released at MRFH from January - June.

[2]All smolts released at MRFH from March - August.

[3]All smolts released at MRFH from May - August.

[4]All smolts released at MRFH in June.

[5]All smolts released at MRFH in March.

[6]Smolts accidentally released on 28 March.

(Simenstad and Salo 1982), fish density (Chapman 1962), and growth rates (Shapovalov and Taft 1954; Hartman et al. 1982).

Much of the research on salmon out-migration in California has indicated that the timing of out-migration is influenced by flow and growth rates (size-dependent) (Rutter 1903; Menchen 1974; Painter et al. 1977; Painter pers. comm. 1992). The results of these studies suggest the downstream movement of fry is influenced by flow volume (Rutter 1903; Menchen 1974; Painter et al. 1977), although it is uncertain whether flow stimulates active migration or causes passive displacement. During the smolt out-migration, there is considerable consistency in the length of the fish within specific streams. This indicates that smolt out-migration is size-dependent (Menchen 1974; Schaffter 1980), although the size at migration differs among streams.

Results from BioSystems' outmigration studies in 1990-1992 indicate that at times there may be a relationship between daily counts of outmigrating smolts and fluctuations in daily temperature and/or daily flow (Appendix A). The remarkable consistency in size of out-migrating smolts and the bell-shaped distribution of out-migrants over time strongly suggests that smolts rear in the upper river until they reach a certain size (about 110 mm total length [TL]) and then migrate. If smolt out-migration is size-dependent, then many other variables associated with timing (flow, water temperature, prey abundance, and fish densities) could influence growth rates and the timing of the out-migration.

The size of Mokelumne River out-migrants (mean fork length [FL] ranged from 98.5-101.4 mm in 1990-1992) is considerably greater than that of out-migrants in other streams in California (range about 40-80 mm FL) (Rutter 1903; Hatton 1940; Hatton and Clark 1942; Sasaki 1966a; Menchen 1974; Painter et al. 1977; Schaffter 1980; Kjelson et al. 1982). This difference may be due to differences in rearing conditions in the Mokelumne River as compared to other Central Valley streams. Sasaki (1966a) reports that many studies of salmon out-migration in the Central Valley inadequately sample salmon smolts; this would result in an underestimate of mean size. In contrast to trapping on the Mokelumne River, most studies of out-migration only sample a portion of a river, thereby allowing for avoidance by larger smolts. Furthermore, trapping at Woodbridge Dam has only been conducted during the smolt out-migration (usually April-June), and therefore mean size does not include smaller salmon that may pass Woodbridge earlier in the spring. If data from other streams are evaluated only for the period during the peak Mokelumne River out-migration (May-June), Merced River smolts average 93 mm FL (Menchen 1974), and Feather River smolts average approximately 80 mm FL (Painter et al. 1977).

Out-migration peaked earlier in 1991 and 1992 than in 1990. This could be the result of differences in the timing of the parental spawning run or differences in the growth rates during rearing. In 1990, the Woodbridge Diversion Dam was removed on 15 October, which resulted in a substantial increase in downstream passage flow. In 1989, the flashboards were not removed until 1 November, which may have delayed the spawning run by two weeks. It is possible that earlier in-migration and spawning in the fall of 1990 led to earlier out-migration in the spring of 1991. EBMUD seining data indicates that, as early as March, fry were slightly larger in 1991 than in 1990. Furthermore, the peak abundance of salmon in the rearing habitat was a month earlier in 1991 (6 March) than in 1990 (6 April).

The timing of out-migration in relation to water year type was investigated. Based on the CDFG trap data, water year type and the timing or size of the out-migration are not related. In the four critically dry years (1976-1977 and 1990-1991), the peak out-migration was both the earliest on record (1977 and 1991) and the latest on record (1990). Additionally, the largest catch on record (175,377 in 1976) was during a critically dry year when only 1,900 spawning salmon were in the river (CDFG 1991). One of the lowest smolt catches on record (25,512 in 1970) was during a wet year when 3,000 spawners were in the river (CDFG

1991). However, the trap is inefficient in wet years and actual out-migration rates may have been much higher.

Unfortunately, no firm conclusions can be drawn from these data since several factors may influence the catch rate and obscure any evidence of a relationship. These factors include hatchery release practices and the efficiency of the trap at different flows. Instream smolt production may have been overestimated in many years because of the release of salmon fry and fingerlings from the MRFH upstream from the trap. Between 1965 and 1977, MRFH released all fingerlings into the river during the natural out-migration. The greatest annual catch in the traps (1976) coincided with a release of over 70,000 fingerlings upstream from the trap (Jewett 1978). In 1981, a second peak in the catch occurred at the trap shortly after the hatchery released 167,000 fingerlings into the river (Table 3.19) (Jewett 1982). Although most hatchery releases in recent years have been downstream from Woodbridge Dam, there were upstream releases in 1990 (350,000 fry) and 1991 (18,500 smolts). No smolts were released in 1992 from the MRFH.

The efficiency of the smolt trap may also bias estimates of the timing and size of out-migration, since the catch rate appears to be influenced by flows into the WID Canal and flow downstream from Woodbridge Dam. Since the intake pipe for the smolt trap is located off the main river channel at the head of the WID Canal, the trap operates most efficiently when the diversion rate is high. During the 1990-1992 outmigration studies, BioSystems installed both a lower trap, which captures fish coming through the bypass, and a upper trap, which captures fish passing through the main river channel (Appendix A). Trapping results indicate that a significant proportion of fish use the main channel. In 1990, 11 percent of the total outmigrating chinook smolts were captured in the upper trap; in 1991 and 1992, this percentage rose to 24 percent and 64 percent, respectively.

The efficiency of the smolt trap may also be influenced by flows that attract fish away from the trap, such as water spilling over Woodbridge Dam. In 1990 (27 May), a decrease in the catch coincided with the release of a large amount of water (100-200 cfs) over Woodbridge Dam (Appendix A). This spill resulted in an unknown number of smolts passing over Woodbridge Dam without being counted.

Historic trapping records cover only migration during dry and critically dry water years; there is little information on the timing or size of the out-migration in normal or wet water years.

<u>Factors Influencing Migration Success</u> - Mortality of emigrating smolts and fry can occur throughout the downstream migration from the rearing habitat near Camanche Dam to the ocean (Figure 3-9). There is no data on the mortality of fry migrating from the Mokelumne River. Factors influencing smolt migration success are not constant but are related to environmental variables such as river flow, timing of out-migration, operation of the WID Dam and Canal, operation of Camanche Dam, pumping rates, and other factors in the Delta. In general, survival increases if out-migration occurs earlier in the season because of lower water temperatures and diversion rates.

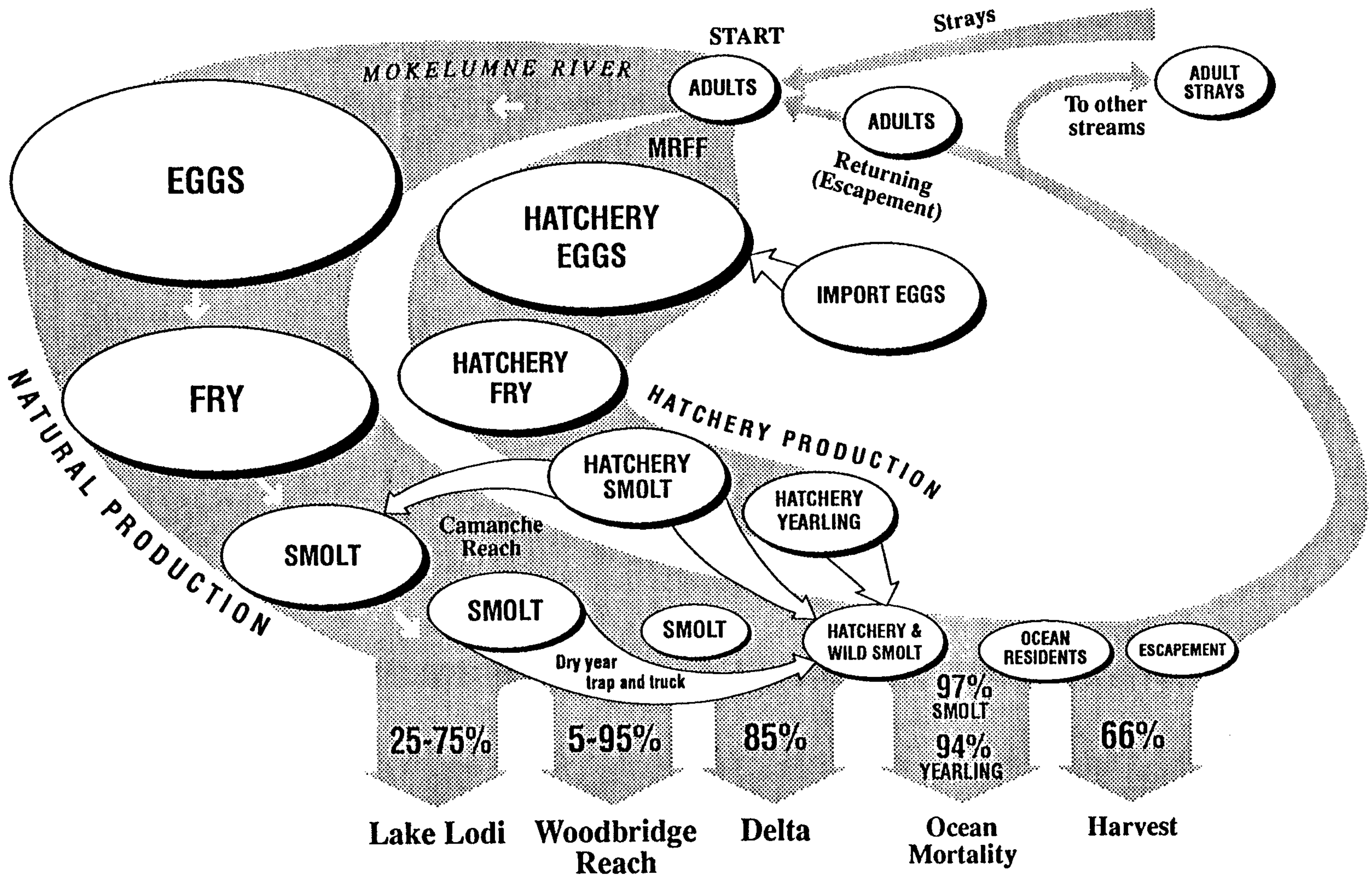

Figure 3-9. Mokelumne chinook salmon life cycle.

9/2/92

The success of migration through Camanche Reach may be influenced by pump diversions and predation. From the rearing areas near Camanche Dam downstream to Lake Lodi, over 50 river pumps withdraw water from the river for irrigation (EBMUD data files, Lodi, California). Few, if any, of these pumps are screened and their impact on migrating salmon has not been quantified. In-river smolt mortality, however, is low compared to mortality observed in the lower reaches of the Mokelumne River and Lake Lodi. Studies conducted by BioSystems in 1991 showed that smolts marked and released at three release sites (Camanche Dam, Bruella Road, and the WID Canal) experienced similar recapture rates (Appendix A). If river pumping was contributing to high mortality, a higher mortality rate in smolts released in the river as compared to smolts released further downstream would be expected.

In Lake Lodi, warm water temperatures, predators, and the large WID diversion may influence migrant mortality. Water temperatures during out-migration can exceed 18° C toward the end of the out-migration, especially in low flow years. Elevated temperatures can indirectly increase mortality by decreasing swimming and feeding efficiency and thereby increasing susceptibility to predation by warmwater fishes such as Sacramento squawfish and largemouth bass. Under extreme conditions, temperatures may become lethal. Entrainment at the WID screens is not well documented; however, salmon up to about 40 mm FL can pass through the screens (Fisher 1976). Recent observations at the screens revealed several potential problems including inefficient fish guidance structures (pier noses prevent movement along the screen face), debris accumulation in front of the screens and in the bypass, improper seals at the screen joints, and faulty design or alteration of the by-pass intake (Vogel 1992).

During low flow years, these impacts can result in substantial smolt mortality (over 60%) in Lake Lodi (Appendix A). Based on studies conducted by BioSystems, survival through the lake is more than three times higher in early May (35-40%) than in early June (5-15%) (Appendix A). Speculatively, high mortality rates may be caused by elevated water temperatures and reduced attraction flows through the lake during low flow conditions. Since no mortality research was conducted in the lake before 1990, the mortality rates associated with passage through Lake Lodi during normal and wet water years are unknown.

Conditions downstream from Woodbridge Dam (Woodbridge Reach) pose significant problems related to high temperature, predation, and water diversions, especially during dry years. Instream conditions probably deteriorate as the out-migration season progresses, because temperatures rise and the rate of diversions increase. In years when little water passes Lake Lodi, the temperatures in the Woodbridge Reach can exceed the lethal limits for juvenile salmon (25° C, Brett 1952) during most of the out-migration period (temperature modeling results, Appendix C). Sub-lethal temperatures can increase predation by warmwater fishes in Woodbridge Reach, such as squawfish, black bass, catfish, and large sunfish (Appendix A).

Current salmon management practices address the problem in capturing out-migrating juveniles at Woodbridge Dam and releasing them below the Delta or San Francisco Bay during low flow years. This strategy increases the rate at which Mokelumne River stock strays to other river systems. During wet and normal water years, temperatures in the Woodbridge Reach are more conducive to successful out-migration, so trapping operations are not necessary.

In recent years, the survival index of Mokelumne River smolts migrating from the lower Mokelumne River through the Delta has ranged from approximately 20-100 percent with an average of 52 percent (USFWS 1988). This is based on releases of CWT smolts in the North and South Forks of the Mokelumne River in 1983-1986. Smolts were recovered by trawl in the Lower Sacramento River at Chipps Island. Survival of Mokelumne smolts migrating through the lower Mokelumne River and Delta has also been estimated from releases of CWT smolts in the Sacramento River above the Delta Cross Channel and subsequent recoveries at Chipps Island (Kjelson et al. 1989). Modeled survival in this study averaged 15 percent with a range of 0-37 percent for CWT releases in 1983-1989 (Kjelson et al. 1989). Mortality rates have been correlated with water temperatures and water diversions in the central Delta and are believed to be influenced by Delta outflow (Kjelson et al. 1989). In many years, large scale water exports by the Delta pumps reverse the flow in the San Joaquin River. This results in smolts being drawn away from the sea and towards the export pumps (USFWS 1987). Delta conditions for out-migrating smolts are also discussed in Section 3.3.1.1.

3.2.2.7 Conclusions

Based on the data and analysis presented, it was concluded that under the present management strategies:

- There is presently no distinct run of native Mokelumne River salmon.
- The Mokelumne River salmon run is composed largely of strays from other river systems, primarily the Feather and American rivers.
- Since the early 1970s, sustained fall flow in the Mokelumne River has been correlated to the size of the salmon run in the River. This could be because of intercorrelation with other variables, biased data, or the attraction of stray salmon to the Mokelumne. In any case, the amount of water required to attract salmon is large, and these salmon are likely to spawn elsewhere if not attracted to the Mokelumne.
- Short-term (from one to several days duration) flow fluctuations appear to have little influence on the size of the Mokelumne River salmon run, whereas longer-term flow conditions (monthly or migration season averages) appear to be influential. In 1990 and 1991, the salmon run began when flow below Woodbridge Dam was increased to 250 or more cfs. Flow changes after the run was initiated appeared to have little influence on the salmon migration rate.
- Precipitation during the migration season appears to influence short-term (daily) movement of salmon but probably has little effect on the overall run size.

- There is no significant relationship between Mokelumne River run size in a given year and Mokelumne River run size two or three years later.

- Before 1979, there was a significant relationship between Mokelumne River run size and overall Central Valley run size (total run in the Sacramento and San Joaquin river basins) in two of three eight-year periods. This suggests that prior to widespread planting of hatchery fish in the Delta, all Central Valley stocks may have been influenced by similar factors (i.e., Delta conditions, ocean conditions, and harvest).

- Before 1964 (Camanche Dam constructed), there was a significant relationship between spring out-migration flow levels and the size of the Mokelumne River spawning run two years later. This suggests that high flows during out-migration increased salmon survival. This relationship could have been ended by increased pumping from the Delta, increased planting of salmon in the Delta, or effects linked to the construction of Camanche Dam.

- There has been no significant relationship between the number of salmon released by the MRFH and the Mokelumne River spawning run two or three years later. This could be because MRFH fish planted in the Delta have a high tendency to stray to other rivers.

- Spawning habitat in the Lower Mokelumne has been degraded by sediment deposition and armoring.

- The timing of outmigration does not appear to be influenced by environmental factors except those which affect smolt growth rates.

- Survival of outmigrants is related to flow and water temperature.

3.2.3 Steelhead

Steelhead trout are the anadromous (sea-run) form of rainbow trout. Prior to the construction of Camanche Dam, no records were kept on the steelhead population of the Mokelumne River (Groh 1965). Since the construction of Camanche Dam, there has never been an official stock estimate of steelhead in the Mokelumne River, and there is little evidence that substantial spawning occurs. The only counts of spawning steelhead are from returns to the MRFH. Since hatchery operations began in 1964, an average of fewer than 30 fish a year have returned to the hatchery (range from 0 to 215). According to MRFH annual reports, no steelhead trout returned to the hatchery during the 1975-76 and 1985-86 seasons as the ladder was not operated by the CDFG. The CDFG goal of 2,000 spawning steelhead in the Mokelumne system per year has never been approached.

Historical spawning grounds were principally found above Camanche Dam (CDFG 1959). This habitat was lost with the construction of the dam in 1964. However, based on the IFIM study by CDFG (1991) and BioSystems (Appendix A), spawning habitat is still available downstream from Camanche Dam. CDFG's study showed that optimal habitat availability occurred at flows ranging from 200-700 cfs and that the optimal rearing habitat is available in the Mokelumne River at low flows (100 cfs) (CDFG 1991). BioSystems studies revealed that most potential spawning habitat is available on a 13 kilometer segment of the Mokelumne River immediately below Camanche Dam.

Habitat requirements (temperature, depth, velocity) for steelhead trout are similar to those for salmon during spawning and rearing. Based on these requirements, suitable conditions exist for successful steelhead reproduction during most years in the Mokelumne River. Suitable habitat for spawning and rearing does not appear to be the primary limiting factor in the establishment of a steelhead stock in the Mokelumne River.

There has been no evidence of self-sustaining reproduction in the river during rearing or out-migration studies (Appendix A). Up-migration and spawning studies conducted in 1990 and 1991 found little evidence of adult steelhead spawning in the river (Appendix A). During the trapping of out-migrants at Woodbridge Dam in 1991, approximately 2,500 steelhead were caught; however, only about 15 of these fish appeared to be naturally produced based on size (< 15 cm TL). The remaining catch appeared to be hatchery releases for the recreational fishery (mean length approximately 24 cm TL).

As with salmon, the MRFH has compensated for poor instream production and survival by importing excess eggs and fry from other hatcheries and releasing the subsequent production in the river. Therefore, there is no reason to believe that a genetically identifiable, native-run steelhead population exists in the Mokelumne River.

Because earlier attempts to create a natural run of steelhead in the Mokelumne River were unsuccessful, the fishery is currently managed by the CDFG as a catchable rainbow trout fishery (CDFG 1991). Steelhead averaging three to a pound are periodically released during spring and summer to support a popular local recreational fishery. An average of about 29,000 fish have been released annually since 1979. Planting these yearling trout before June is inconsistent with salmon production goals, because the planted fish may prey on smaller salmon prior to out-migration. CDFG refers to these yearling trout as "catchable steelhead trout" because the fish are capable of migrating to the sea. However, very few return to the Mokelumne River as adults.

It is not clear why so few steelhead return to the river or why some proportion of the released fish do not remain in the river as residents, which is typical in the Sacramento system. Instream survival of steelhead trout is influenced by some of the same factors as salmon. Unlike salmon, steelhead must spend at least one summer in the river; however, steelhead can migrate downstream in winter when temperatures are low and before Woodbridge Dam is operating. As with salmon, conditions below Woodbridge Dam can be very poor towards the end of the out-migration period, but many steelhead could leave the river before conditions deteriorate. Since the hatchery releases steelhead as yearlings, their mortality should theoretically be reduced and their rate of return enhanced.

3.2.4 Other Species

Historically, the Mokelumne River from Camanche Dam downstream to the confluence with the San Joaquin River has provided habitat or served as a migration route for several native and introduced fishes, in addition to salmon and steelhead rainbow trout. Native species include California roach, hitch, Pacific lamprey, Sacramento blackfish, Sacramento squawfish, Sacramento sucker, tule perch, and white sturgeon (Turner and Kelley 1966; Moyle 1976). Numerous introduced fish species also use the Delta portion of the Mokelumne River system, including American shad, striped bass, bullhead, white catfish, golden shiner, mosquitofish, largemouth and smallmouth bass (Hatton 1940; Turner 1966a; CDFG 1991). Some of these species (Sacramento blackfish, white sturgeon, American shad, and striped bass) have primarily been sampled in the Delta between tidal influence and the confluence with the San Joaquin River.

In the Mokelumne River upstream from the extent of tidal influence, salmon are the only run that has been studied in any detail. Most of the information on other species is anecdotal information included in salmon studies, or included by brief reference in overviews of Central Valley fishery resources. Most of this information pertains to the lower forks of the Mokelumne River within the Delta and very little is applicable to the fishery resources between Camanche Dam and the area where tidal influence begins.

Between Camanche Dam and the area of tidal influence, species composition and abundance shifts because of increases in flow and water temperature and changes in habitat characteristics (hydrology, gradient, and substrate). The upper reach (Camanche Reach) has higher minimum flows and lower temperatures and provides most of the habitat for salmon and steelhead/rainbow trout. The river from Lake Lodi downstream through the Woodbridge Reach is dominated by introduced warmwater fishes such as sunfish, catfish, and bass.

There have been three studies of the fish assemblage of the Lower Mokelumne River conducted in recent years (CDFG 1991, EBMUD and BioSystems data files). Because the CDFG study included sampling sites within tidally influenced areas, evaluation of the fish assemblage of the river section between Camanche Dam and tidal influence will focus on the EBMUD and BioSystems studies conducted exclusively within this river section. The EBMUD study includes data for Camanche Reach and Woodbridge Reach; BioSystems study was limited to Woodbridge Reach.

EBMUD conducted 18 seining surveys in Camanche Reach in 1991 (Feb.-May) and 1992 (Jan.-May) and documented the presence of 17 species (Table 3.20). Seven native species collected include chinook salmon, steelhead rainbow trout, hitch and prickly sculpin. Ten introduced species were caught including largemouth bass, mosquitofish, golden shiner, catfish, sunfish and other basses.

EBMUD conducted 12 seine surveys between Woodbridge Dam and the area of tidal influence in 1990 (April-May), 1991 (February-May), and 1992 (March and May). These surveys verified the presence of 15 species (Table 3.20). The most abundant species were

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mosquitofish, bluegill, and suckers. Salmon, rainbow trout, largemouth bass, and catfish were captured in smaller numbers.

Table 3.20. Fishes occurring in the Camanche (CAM) and Woodbridge (WB) reaches of the lower Mokelumne River based on electrofishing surveys by BioSystems (1) in the Woodbridge Reach in 1990, and seining surveys by EBMUD (2) in the Woodbridge and Camanche reaches, 1990 - 1992 (Appendix A).

Common Name	Scientific Name	Distribution[1]	Reference
Native Species			
Pacific lamprey	*Lampetra tridentata*	CAM, WB	2
Lamprey[2]	*Lamprey* spp.	WB	1
Chinook salmon	*Oncorhynchus tshawytscha*	CAM, WB	1, 2
Steelhead rainbow trout	*Oncorhynchus mykiss*	CAM, WB	1, 2
Hitch	*Lavinia exilicauda*	CAM, WB	1, 2
Sacramento squawfish	*Ptychocheilus grandis*	CAM, WB	1, 2
Sacramento sucker	*Catostomus occidentalis*	CAM, WB	1, 2
Tule perch	*Hysterocarpus traski*	WB	1
Prickly sculpin	*Cottus asper*	CAM, WB	2
Sculpin[2]	*Cottus* spp.	WB	1
Introduced Species			
Goldfish	*Carassius auratus*	WB	1
Golden shiner	*Notemigonus crysoleuces*	CAM, WB	1, 2
Channel catfish	*Ictalurus punctatus*	CAM, WB	2
White catfish	*Ictalurus catus*	CAM, WB	1, 2
Brown bullhead	*Ictalurus nebulosus*	WB	1
Black bullhead	*Ictalurus melas*	CAM, WB	1, 2
Mosquitofish	*Gambusia affinis*	CAM, WB	1, 2
Inland silverside	*Medina audens*	WB	2
Black crappie	*Pomoxis nigromaculatus*	CAM, WB	1, 2
White crappie	*Pomoxis annularis*	WB	2
Green sunfish	*Lepomis cyanellus*	CAM, WB	1, 2
Bluegill	*Lepomis macrochirus*	CAM, WB	1, 2
Pumpkinseed	*Lepomis gibbosus*	WB	1
Redear sunfish	*Lepomis microlophus*	CAM, WB	1, 2
Sunfish	*Lepomis* spp.	WB	1
Largemouth bass	*Micropterus salmoides*	CAM, WB	1, 2
Spotted bass	*Micropterus punctulatus*	WB	1
Smallmouth bass	*Micropterus dolomieui*	WB	1, 2
Redeye bass	*Micropterus coosae*	WB	1

[1]CAM is camanche reach; WB is reach from Woodbridge to tidal influence
[2]Generic fishes are classified (native or introduced) based on the most likely species composition

BioSystems conducted 30 electrofishing surveys between Woodbridge Dam and the area of tidal influence in April and June of 1990 to document the fishery resources and species composition (Appendix A). These electrofishing surveys verified the presence of 23 fish species (Table 3.20). The most abundant fish were bluegill, smallmouth bass, spotted bass, redear sunfish, golden shiner, and suckers. Other species of interest included steelhead rainbow trout, largemouth bass, and white catfish. Only two salmon were found at the time of these surveys.

These two studies document the presence of 26 species in the Lower Mokelumne River, including several of economic importance. Neither study found American shad and striped bass, in the Lower Mokelumne River above the area of tidal influence. Since both surveys were conducted during the typical spawning and rearing period for these fish, the results indicate that the Lower Mokelumne River was not utilized extensively by these species in 1990, 1991, or 1992. However, all three years were dry and the fish assemblage documented in these surveys may not be representative of that utilizing the Lower Mokelumne River in normal or wet years. Flow below Woodbridge Dam during the summer was very low in all three years (less than 50 cfs).

Both American shad and striped bass are economically important species. It has been asserted that they may utilize the Mokelumne River as far upstream as Woodbridge Dam during high water years (Meyer pers. comm. 1991; CDFG 1991). However, there is no documentation of significant runs of either species. Neither American shad nor striped bass are thought to use fish ladders (Moyle 1976). Since Woodbridge Dam is in place when these species of fish up-migrate and spawn, the available habitat for spawning and rearing on the Mokelumne River may be limited to the reach below Woodbridge Dam. Unfortunately, there are no records of the frequency with which spawning runs occur in the Mokelumne River, their magnitudes, the success of spawners, or their contribution to the overall Central Valley populations, if any.

Most American shad in the Central Delta are in the main channel and sloughs of the Lower Mokelumne River below the Delta Cross Channel (Stevens 1966); however, the role of the Woodbridge Reach as spawning and nursery habitat is unclear since no sampling has documented shad upstream of tidal influence. During much of the year, the large majority of flow in the lower forks of the Mokelumne River consists of water diverted from the Sacramento River via the Delta Cross Channel. It is uncertain whether the majority of shad continue the spawning run into the Sacramento River or if they remain in the Mokelumne River (Stevens 1966).

CDFG does not have habitat criteria or management plans for American shad in the Mokelumne River. The Mokelumne River above the Delta Cross Channel has never been evaluated to determine if it supports American shad or under what circumstances it might do so. There has been no research on American shad in the Mokelumne River during the last decade.

Few striped bass (eggs, larvae or juveniles) are found in the San Joaquin drainage (including the Mokelumne River) as compared with the Sacramento River (Scofield 1910; Hatton 1942; Errikla et al. 1950; Radtke 1966a; Sasaki 1966b). In recent years, the striped bass population has declined considerably (Stevens et al. 1985) and appears to be shifting from the San

Joaquin system to the Sacramento system because of deteriorating habitat in the San Joaquin River delta (Turner 1976). There has been no research on striped bass in the Mokelumne in over 25 years, and no evidence of a striped bass fishery or spawning run on the Mokelumne River in recent years (Meyer pers. comm. 1991).

CDFG does not have specific management goals for striped bass in the Mokelumne River. The overall goal for the Central Valley is 3 million fish.

Native Species - In addition to the species listed in Table 3.20, several other native and introduced species may be in Woodbridge Reach based on habitat conditions (Moyle 1976; Moyle et al. 1989). Native species potentially inhabiting the reach include white sturgeon, Sacramento blackfish, hardhead, and Sacramento splittail. Introduced species potentially utilizing this reach include the bigscale logperch. The most abundant species in Woodbridge Reach are opportunistic species that persist in moderately to highly disturbed habitats. Of the native species, Sacramento sucker and prickly sculpin were the most abundant in the 1990 surveys. They are generally tolerant of moderately disturbed stream environments (Leidy 1984). Native fish species common to undisturbed habitat were also present, although less abundantly, including: salmon, steelhead trout, California roach, tule perch, and Sacramento squawfish.

State and federal agencies in California are responding to widespread declines in species diversity, especially declines in native species, by changing their conservation tactics. Agency scientists traditionally have managed fish and wildlife by preserving individual sites, species and resources instead of protecting biological communities as a whole. The strategy of agency scientists is now shifting toward protecting resources on a broader basis by managing for ecosystems, biological communities, and landscapes.

Aquatic systems have been vastly disturbed by the construction of dams, water diversions, the introduction of non-native species, and the alteration of streams by overgrazing and channelization (Moyle and Williams 1990). As a result, native fish have undergone tremendous declines. In California, 12 percent of the native fishes are officially listed as threatened or endangered, 6 percent are in peril in their native range and may require listing if present trends continue, and 22 percent show declining populations but are not in immediate peril or naturally have a very limited ranges (Moyle and Williams 1990).

In developing a management plan for the Lower Mokelumne River, it is important to realize that it may not be enough to protect and enhance only one or two highly valued species. The river and its native fish community have value independent of salmon. A management plan that provides flows only when salmon or steelhead are present in the river will not protect that value. However, not enough is known of the life-history requirements of these species to determine the level of flow needed to protect the native fish community.

3.3 DELTA INFLOW

3.3.1 Importance

For purposes of this document, the Delta is important as a migration corridor and habitat for anadromous fish, and because Mokelumne River inflows may have localized water quality impacts. However, from 1955-1988, the average annual contribution of the Mokelumne River to total Delta inflow was estimated at about 1.5 percent and the magnitude of Mokelumne River flows were estimated to be about 2 percent of Delta outflow (range 0.7-5.4%). Therefore, changes in Delta inflows into the Delta due to changes in Mokelumne River management would be very small in relation to all Delta inflows. This quantity is probably less than the flow measurement error.

Major physical alterations to the Sacramento-San Joaquin Estuary over the past 150 years include the draining and channelization of 95 percent of the land for agriculture and urbanization, elimination of 95 percent of the marshland (Atwater et al. 1979), and reduction of outflow to the estuary by over 60 percent (Nichols et al. 1986). In addition, the amount of water diverted from the Delta and estuary has increased steadily since the late 1950s. Since 1984 the percentage of inflow diverted is higher — and remains higher for longer periods of time — than any period in the past (Moyle et al. MS). The major water diversion facilities are located in the south Delta, and include pumps operated by the Central Valley Project (CVP) and the State Water Project (SWP). Since 1983, water project pump demand has increased and resulted in more days of reverse flow in the San Joaquin River than during any previous period. These water diversion plants effectively remove fish and their food supply from the Delta (Stevens et al. 1990). The harmful effects of increased chemical pollution have been documented for only a few fish species, but may affect other species and further degrade the environment.

Native fish species in the pristine Delta evolved with an environment that varied as to seasonal patterns and annual runoff, but was highly productive, with abundant marshland and shallow waters where food production was high. The introduction of numerous exotic fish species (more than half the species currently in the Delta), combined with the extensive alteration and loss of habitat to agriculture and urbanization, has coincided with the extinction of the thicktail chub, the disappearance from the Delta of Sacramento perch, and serious declines in abundance of at least six more species or district runs: chinook salmon (winter, spring and late-fall runs), delta smelt, longfin smelt, and splittail (Herbold and Moyle 1989; Moyle et al. 1989; Moyle et al. MS; and Moyle pers. comm. 1991).

The Delta is a complex environment. The following discussion focuses on certain important issues for which data have been collected that may be suitable for a certain level of quantification. These include chinook salmon migration; entrainment; delta smelt, splittail and other declining native species; position of the estuary mixing zone; and water quality standards. These issues were selected because they are commercially or politically important and/or because they can be quantified to some degree. The impact of proposed Mokelumne River flow management is explored in more detail in Section 5.4.

3.3.1.1 Chinook Salmon Out-migration

Production of Mokelumne River salmon is greatly influenced by their successful out-migration through the Delta. A recent model has been developed by the USFWS and DWR to assess the mortality of fall-run chinook salmon smolts in the Sacramento River delta between Sacramento and Chipps Island (Kjelson et al. 1989). This multiple regression model estimates mortality rates among salmon smolts passing through three reaches of the Sacramento River and central Delta. Of most relevance to this analysis is the reach from Walnut Grove on the Sacramento through the Delta Cross Channel, Georgiana Slough, and the lower forks of the Mokelumne River and out through the lower San Joaquin River to Chipps Island (Reach 2). This is the most likely route for smolts migrating out of the Mokelumne River to the ocean.

Kjelson et al. (1989) looked at several environmental variables that may influence smolt mortality in this reach. These included water temperature at the release site (Walnut Grove on the Sacramento), water temperature at Freeport (also on the Sacramento), flow in the lower San Joaquin at Jersey Point, flow at Chipps Island, and daily CVP and SWP exports.

Mortality of smolts in Reach 2 was positively correlated to water temperature at Freeport and water temperature at the release site (both of these temperature factors are significantly correlated with water temperature in the Mokelumne River system; $r = 0.92$ and 0.97, respectively). Outflow at Chipps Island and flow at Jersey Point showed a weak negative correlation (Figure 3-10). A combination of water temperature at Freeport and total SWPplus CVP exports explained 66 percent of the variation in smolt mortality in Reach 2.

Mortality of salmon smolts in this reach was uniformly high, averaging 85 percent and ranging from 63-100 percent. Mortality rates do not appear to be influenced by flow in this reach; Kjelson et al. state that reverse flows in the lower San Joaquin River may increase smolt mortality but errors in estimating these flows may obscure any such relationship. Also, mortality was significantly correlated with water temperature and water temperature is usually correlated with flow at the time of salmon smolt migration. Flow in the Mokelumne River will influence smolt mortality to the extent that it alters water temperatures in the central Delta reach. This colinearity of water temperature and flow may prevent identification of a flow/mortality relationship, if one exists (Brandes pers. comm. 1991). No water temperature modeling has been conducted to address this issue.

Flow management in the Mokelumne River will have little effect on Delta temperatures because it is a relatively small component of Delta inflow (Section 5.6). The best management strategy needs to focus on getting adult salmon into the river and spawning as soon as temperature conditions are acceptable, and getting the smolts back out as early as possible in the spring. When conditions in the Delta are adverse (high temperatures and diversions), transporting migrants around the Delta or holding them in the MRFH may be a useful strategy for rebuilding the run.

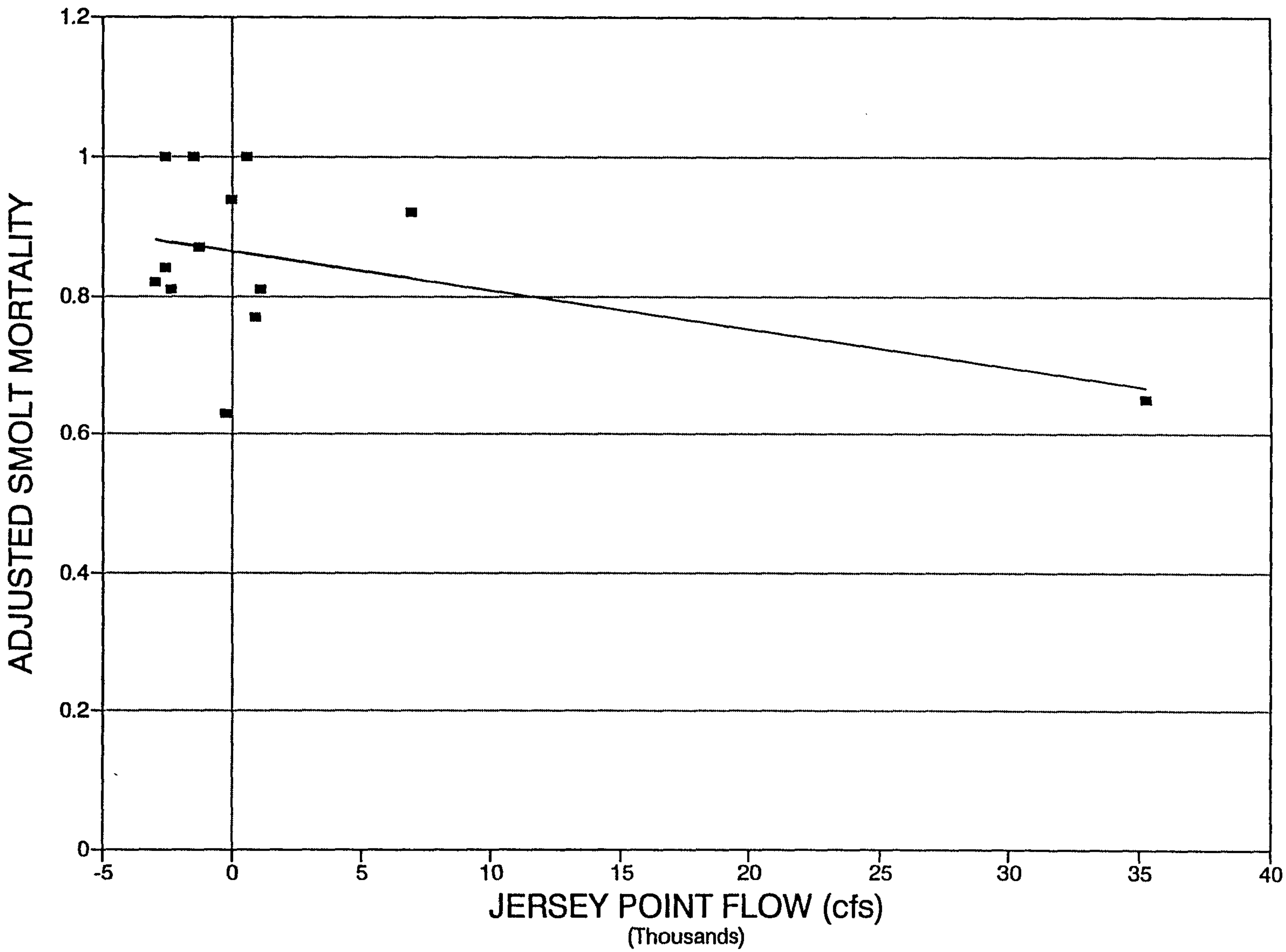

Figure 3-10. Adjusted salmon smolt mortality in reach from Walnut Grove to Chipps Island compared to flow at Jersey Point, 1983-1989.

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3.3.1.2 Entrainment

Entrainment refers to the incidental capture or loss of fish at diversion facilities. Young fish are especially susceptible to entrainment, as they may be unable to swim against flows created by diversion.

Entrainment is a substantial cause of mortality for young salmon, steelhead trout, and other fish living in the Delta. Flow conditions affect Delta hydraulics, out-migration time, and entrainment. Entrainment at the CVP and SWP export facilities are of particular concern, because of the large amounts of water diverted there.

Change in Mokelumne river flow could potentially affect entrainment of fish at the CVP and SWP export facilities through change in Delta flow patterns. The striped bass and salmon loss model developed by Glen Rothrock (1990) and EBMUDSIM results were used to estimate the potential for entrainment impacts. Striped bass entrainment is estimated by monthly equations (June, July and August) using mean levels of exports, the striped bass index, striped bass size, and flow at Jersey Point.

Flow at Jersey Point consists of Delta Cross Channel flow, Georgiana Slough and eastside streams, including the Mokelumne River, adjusted downward for diversions and 65 percent of net channel depletions. The DAYFLOW database (Greene 1987) provides QWEST, an estimate of flow at Jersey Point. For this entrainment simulation, QWEST data from 1976 through 1990 were used as a base case. For the modified scenarios, LMRMP and CDFG Plan Delta inflows in excess of the base case (Section 5.5.6) were added to the QWEST flows. QWEST can be negative, representing reverse flows toward the export pumps.

Results indicated that the CDFG or LMRMP plan could have small to insignificant effects on entrainment of striped bass eggs. Both plans are estimated to reduce average entrainment in June (.8 and 3.1 percent for the LMRMP and CDFG Plan, respectively). From Table 5.20, both plans would increase Delta inflow in June and, in Rothrock's model, this reduces entrainment. In July and August, the model estimates that entrainment would be affected by less than one percent in either plan; certainly insignificant given the uncertainties in simulated hydrology and the modeling process.

3.3.1.3 Delta Smelt, Splittail, and Other Species

Alteration of the Delta environment has resulted in conditions that are vastly different than those under which the Delta's native fish and other aquatic organisms have evolved. In an evolutionary sense, these changes have been rapid and extreme. Some species may benefit from the changes and a few may be relatively unaffected. For other species, the Delta is becoming an increasingly hostile environment and, under present conditions, we should expect to witness the continued decline of these species.

C-100793

Low freshwater outflow is correlated with poor year classes for many native fishes including chinook salmon, delta smelt, longfin smelt, white sturgeon, and splittail (Turner and Chadwick 1972; Stevens 1977; Kjelson et al. 1982; Daniels and Moyle 1983; Stevens and Miller 1983; Stevens et al. MS).

Some have concluded that increased water diversions, combined with recent drought conditions, have contributed to the decline of the delta smelt (Moyle et al. MS). In the past, delta smelt inhabited the dead-end sloughs of the south and north forks of the Mokelumne River in the Delta (Radtke 1966b). They have not been collected in the Delta portion of the Mokelumne River in over 20 years.

Historically, delta smelt ranged throughout the upper Sacramento-San Joaquin estuary from Suisun Bay to about Sacramento on the Sacramento River, and to Mossdale on the San Joaquin River (Moyle et al. 1989). Since 1982, the greatest abundance of delta smelt has been in the northwestern Delta in the Sacramento River, with virtually no smelt in Suisun Bay. The reduced range is thought to be the result of increased water diversions and the recent five year drought (Moyle et al. 1989).

In addition to a diminished range, the abundance of delta smelt in the estuary and Delta has declined sharply since 1983 (Moyle et al. 1989). Prior to 1983 (1967-1982), the population fluctuated considerably but, whenever the population was low, it usually rebounded within one or two years. Since 1983, the population has remained at about 20 percent of its previous average size. Because these fish live for only one year, the species is particularly vulnerable to extinction when its population size is low.

Additional factors may have influenced the decline of the delta smelt population including the loss of spawning and nursery habitat from channelization of Delta streams and increased water exports that may have resulted in the diversion and entrainment of smelt as well as their food supply. In years of exceptionally high outflow (as in February 1986, spawning season), delta smelt can be flushed out of the Delta and Suisun Bay and into the less productive San Pablo Bay. The recovery of the delta smelt is probably inhibited by the decline in the dominant forage species (*Eurytemora affinis*) as a result of the introduction of an exotic clam (*Potamocorbula*) (Stevens et al. 1990, Moyle et al. MS).

All of the Delta is critical to the recovery of delta smelt. The conversion of marshy and riparian habitats to dikes and channelized streams and rivers eliminates suitable spawning and nursery grounds. Flow changes in the Delta, particularly reduced spring inflow and/or increased spring water diversions, will likely have a negative impact on the delta smelt's already threatened existence.

The CDFG and the DWR have been directed to monitor the smelt population, reduce losses at water diversion sites, increase spring and summer Delta outflows, restrict ship ballast discharges (to decrease exotic species introductions), and assess culture techniques for delta smelt.

C-100794

Sacramento splittail also were once widely distributed throughout the Central Valley. Historically, the species was found in fast-flowing rivers and streams, but it is now confined primarily to the sloughs of the northern and western Delta, Suisun Bay, Suisun marsh, and Napa marsh (Daniels and Moyle 1983; Moyle et al. 1989). Splittail were more widely distributed (Turner 1966c) in the mid-1960s than they are now, so their range appears to be shrinking (Moyle et al. 1989).

Splittail populations are considered dangerously low, and management is needed to prevent them from becoming threatened (Moyle et al. 1989). Splittail have disappeared from much of their former range, largely as a result of human alteration of their natural habitat. Dams, water diversions, and agricultural development in and around the Delta have removed most of the suitable spawning habitat.

Although the longfin smelt was until recently considered abundant or common (Wang 1986; Stevens and Miller 1983; Herbold and Moyle 1989), the population has declined substantially and is low enough to merit management to prevent it from becoming a threatened species (Moyle, pers. comm. 1991). There is a significant correlation ($p < 0.05$) between Delta outflow and monthly estimates of smelt abundance (data from 1967-1978) (Stevens and Miller 1983). Correlation coefficients were highest for the spring months of April through July. The data suggest that spring and early-summer outflow control longfin smelt survival. The recent five years of drought, coupled with an increase in water diversions, has no doubt adversely affected smelt survival.

The white sturgeon population is also thought to have been impacted by flow reductions in the Sacramento-San Joaquin estuary (Kolhurst et al. 1989). White sturgeon is a commercially important species found primarily in the Sacramento-San Joaquin estuary. It has also been collected in the lower forks of the Mokelumne River (Radtke 1966b). The DWR (1990) found a negative correlation between year class strength and spring outflow to the Delta (April and May average monthly outflow). These data suggest that sturgeon produce poor year classes when flows are below 20,000 cfs. The CDFG has initiated a study to determine flow requirements for white sturgeon juveniles (Kolhurst et al. 1989).

The native range of tule perch extends throughout the lower elevations of the Sacramento-San Joaquin River system; however, the species is now extinct in the San Joaquin River (Moyle 1976). Some perch have been collected in the Lower Mokelumne River, the flooded islands of the western Delta (Franks tract and Big Break), and in the south Delta (Fabian Canal) (Turner 1966b).

The tule perch has three subspecies; *Hysterocarpus traski* is the subspecies occurring in the Delta (Baltz and Moyle 1976). This subspecies is believed to have a stable population at the present time (Moyle et al. 1989). However, the population has apparently fallen sharply from its levels during the early 1900s (Evermann and Clark 1931). Tule perch are particularly sensitive to the loss of habitat with emergent vegetation. The amount of this habitat has been drastically reduced because of increased agriculture and channelization of the Delta (Atwater et al. 1979). Tule perch also disappear from streams with reduced flow, increased turbidity, heavy pollution, or reduced cover (Moyle 1976).

Apparently, some native fishes have not been adversely impacted by the flow reductions in the Delta in recent years. The hitch population appears stable, and changes in flow would have relatively minor impact on this population (Moyle et al. 1989). Sacramento blackfish tolerate warm water and turbidity and are not likely to be affected by changes in flow (Moyle 1976). Sacramento sucker populations are relatively stable and do not appear to be affected by flow changes. However, these populations have decreased in the Delta in recent years because of competition from non-native fishes, primarily ictalurids. Another native fish population that appears fairly stable is the prickly sculpin. This species adapts to a wide variety of habitats and can withstand considerable habitat alteration (Moyle 1976).

Although many introduced species can adapt to habitat alterations, some commercially important species have been impacted by recent changes in the Delta. Besides striped bass and American shad (see Section 3.2.4), white catfish have become much less abundant in recent years. Although white catfish tolerate high temperatures and turbidity, their abundance declined during the 1980s by about 75 percent as compared to mean abundance during the 1960s and 1970s (Stevens et al. 1990). The decline of this introduced species apparently is not related to reduced outflow, but it may be related to the amount of water diverted from the Delta (Stevens pers. comm.).

3.3.1.4 Position of the Entrapment Zone/Productivity

The entrapment zone occurs in the estuary where a landward-flowing, tidally-averaged bottom current underlies a seaward-flowing surface layer. Particles are entrapped in this zone because of the interaction of these currents (Kimmerer in prep.). The location of the entrapment zone in the estuary is influenced by freshwater inflow; it moves downstream with high inflows and upstream when flow is low. This relationship was quantified by Kimmerer (in prep.) (Figure 3-11). In the San Francisco Bay estuary, the entrapment zone is the site of the highest concentrations of specific phytoplankton and zooplankton.

3.3.1.5 Bay/Delta Water Quality Standards

The DWR has developed a model (DWRSIM), which calculates the monthly carriage water as the additional water which must be provided in the Delta to meet the D-1485 water quality standards using 1990 levels of demand (DWR - Study A). These carriage water volumes must be provided by the DWR and the Bureau of Reclamation from upstream water storage facilities, reduction of direct diversion at project pumps, or by operation of the Delta Cross Channel gates. Carriage water volumes could also be provided by other regulated systems that are not part of the state and federal systems.

Historically, the greatest need for additional carriage water in the Delta is from July through October. From December through March the Delta is either in surplus or at zero carriage water requirement most of the time with respect to meeting D-1485 water quality

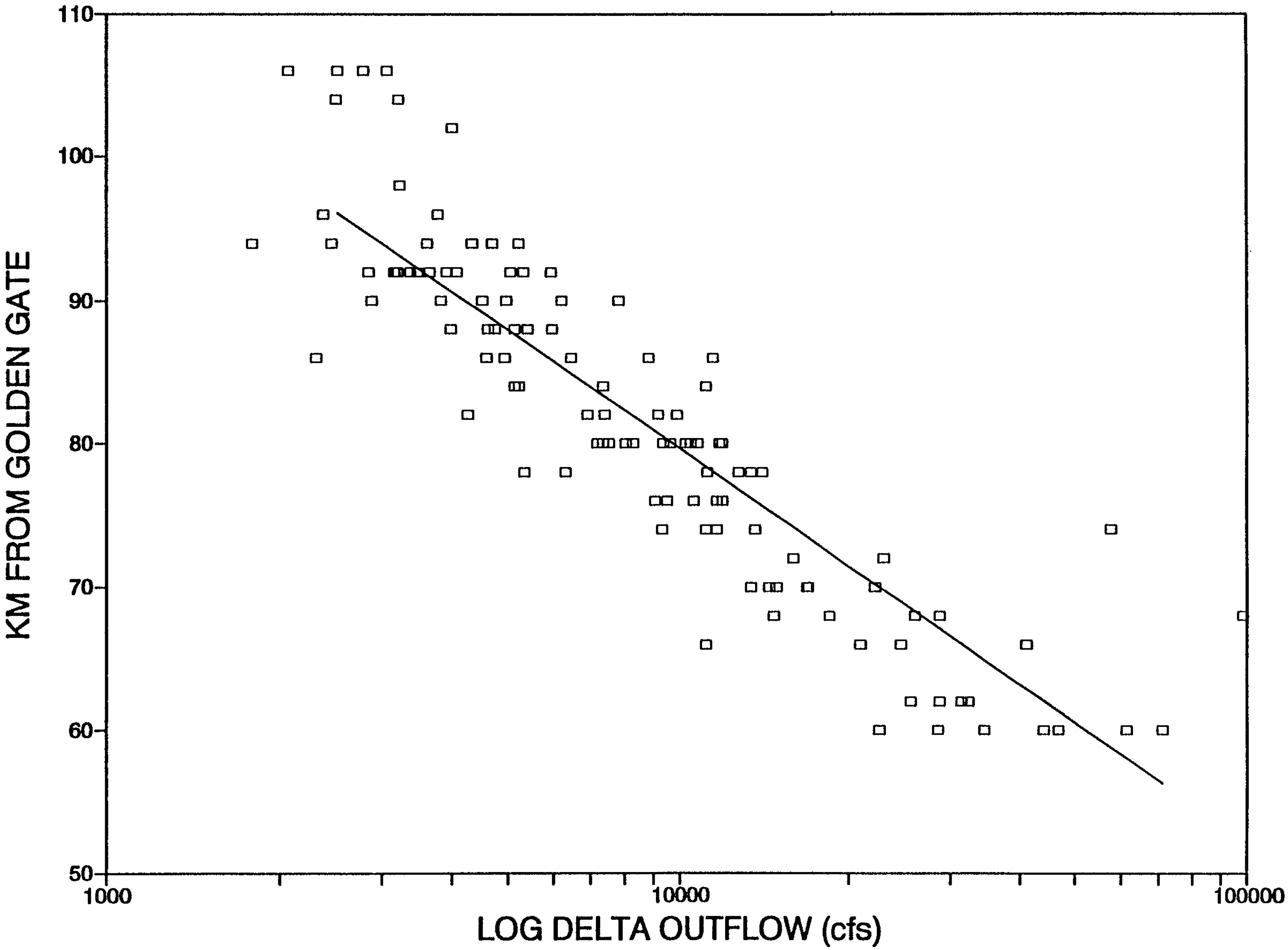

Figure 3-11. Entrapment zone position vs. flow.

standards.requirements in the Delta. In this model, the carriage water requirement is generally defined. These requirements are at odds with management of Mokelumne River flows for the benefit of chinook salmon, since salmon require relatively higher flows from November through June and less during the critical summer months.

Summary - - Management of flows in the Mokelumne River also influences beneficial uses of waters of the Delta. Fisheries impacts may include chinook salmon migration, striped bass entrainment losses, abundance and distribution of declining native species, position of the estuary entrapment zone, and Delta water quality standards. In general, the degree of impact will depend on the relative change in Delta flow conditions brought about by changes in Mokelumne River management. Mokelumne River flows have historically comprised a relatively minor percentage of total Delta outflow, and any change in outflow because of Mokelumne River management will be even less significant (Section 5.0)

Chinook salmon migration will be impaired by reduced Delta flow (particularly in the spring) or increased water temperature. Striped bass entrainment at the Delta pumping facilities may increase with reduced Delta outflow. The impact on declining native species is hard to predict, but the abundance of many of these species is positively correlated with Delta flows. The position of the entrapment zone is also influenced by Delta outflow, as is the attainment of Delta water quality standards.