WATER TEMPERATURE CONTROL IN THE SACRAMENTO - SAN JOAQUIN BAY/DELTA: TOWARD A REASONABLE STRATEGY

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EXECUTIVE SUMMARY

Reduced water temperatures are important to the survival of chinook salmon in the Sacramento-San Joaquin Bay/Delta (the Delta). BioSystems Analysis, Inc. (BioSystems) contracted with Technical Resources, Inc. to assist the U.S. Environmental Protection Agency (EPA) in evaluating the feasibility of measures for controlling Delta water temperature to improve habitat conditions. We reviewed the work that has been done on this issue, conducted additional statistical analyses, and developed ideas for measures that, to our knowledge, have not been considered.

Our statistical research, as well as the work of others, shows that reservoir operations can affect water temperatures in the Delta. Our statistical analysis measured the effect of flow on water temperatures at Freeport, on the Sacramento River, and Vernalis, on the San Joaquin River. Our analysis found that flow rates significantly affect temperature, and that, at Freeport, effects from the Feather and American rivers can be differentiated.

However, the extent to which reservoir releases reduce Delta temperature and improve habitat conditions depends on base flow, base temperature, time of year, reservoir used, reservoir contents, downstream water demand, status of the salmon population, and forecast and actual weather conditions. All of these factors should be considered in developing temperature standards and appropriate implementation in the Delta. In addition, the economic costs and benefits of measures should be considered. In the complex water control system that extends from reservoirs to the Delta, any action will affect other beneficial uses, and careful consideration of all costs and joint benefits is warranted before a decision on reasonableness is made.

We suggest that, in order to proceed, the following research should be conducted:

- A more detailed analysis of existing simulation results and actual temperature data to determine under what circumstances modified operations can provide beneficial Delta temperature reduction at least cost to other water uses. This work should be conducted in cooperation with the 5-Agency Salmon Team.

- Further analysis of system operations to determine system capabilities and flexibilities for water management that would reduce Delta water temperatures. This would include analysis of some recent documents such as "Interim CVP Operations Criteria and Plans" by the USBR (1992), the "Biological Assessment for U.S. Bureau of Reclamation 1992 Central Valley Project Operations" and the National Marine Fisheries Service "Biological Opinion" for the winter run chinook salmon.

- Further analysis of salmon monitoring programs to determine the potential for such programs to provide information useful for operations decisions.

- Work with the 5-Agency salmon team to analyze salmon monitoring programs to determine the potential for the programs to provide more information useful for operations decisions.

1.0 BACKGROUND AND PURPOSE

1.1 BACKGROUND

Water temperatures in the Sacramento-San Joaquin Bay/Delta (Figure 1-1) have changed over the past century as a result of the extensive modifications that have been made to the system for water storage and regulation, agricultural and industrial diversion, consumptive uses, navigation, and flood control. The temperature of Delta waters is determined by many factors. Storage and season determine the temperature of releases, but downstream water temperature is further affected by flow rate and weather. Modification of the hydrologic system for flood control, reclamation and navigation has altered the configuration of channels and modified much of the riparian habitat. This has also affected water temperatures.

Adult chinook salmon (*Oncorhynchus tshawytscha*) use the Delta as a migration corridor to reach riverine spawning habitat, and fry and smolts use the Delta for rearing and feeding during outmigration. High Delta water temperatures can kill salmon directly or delay or block upstream migration. Sublethal water temperatures affect metabolic rates and increase susceptibility to disease and predators.

In 1978, the State Water Resources Control Board (SWRCB) adopted the Water Quality Control Plan that established standards for Delta outflows and salinity. In 1986 the court ordered a reexamination of Delta water quality standards to consider all water users rather than just State and Central Valley Project water users. As a result of evidentiary hearings between 1987 and 1990, the SWRCB issued the Water Quality Control Plan for Salinity in 1991 (WQCP). The plan did not change Delta outflow standards because the implementation of these standards must involve water rights. The SWRCB is currently conducting Scoping and Water Right phases of the proceedings to determine flow requirements and to allocate responsibility for meeting water quality and flow standards.

In the WQCP, the SWRCB concluded that "temperatures no greater than 68 degrees fahrenheit (F) during the periods of April through June and September through November should be achieved by controllable factors, such as waste discharge controls, increases in riparian canopy, and bypass of warming areas (e.g., Thermalito afterbay)." Controllable activities are those that are subject to the authority of the SWRCB and may be reasonably controlled, but "controlling temperature in the delta utilizing reservoir releases does not appear to be reasonable," and the SWRCB "will require a test of reasonableness before consideration of reservoir releases for such a purpose." On the Sacramento River, the temperature objectives are applied between the I Street Bridge in Sacramento and Freeport, on the San Joaquin River they are applied at Vernalis. For protection of the winter-run chinook, the Board provides a "more conservative temperature objective of 66 degrees Fahrenheit...during the period January through March at Freeport."

1.2 PURPOSE

In 1991, the EPA rejected the Delta water temperature objectives for salmon proposed by the SWRCB on the basis that there was insufficient evidence to justify the proposed temperature objectives. In response to this, BioSystems Analysis, Inc. (BioSystems) was contracted by Technical Resources, Inc. to assist the EPA in analyzing issues related to water temperature and chinook salmon in the Delta. The primary questions addressed were:

- To what extent is water temperature in the Delta controllable?
- To what extent can operational and structural measures be used to control Delta water temperatures and improve habitat for salmon?
- To what extent would temperature control measures interact with other beneficial water uses, including the needs of salmon elsewhere in the system?

In addition, the EPA has requested that BioSystems prepare a plan for further study. This plan is provided in the summary (Section 8.0).

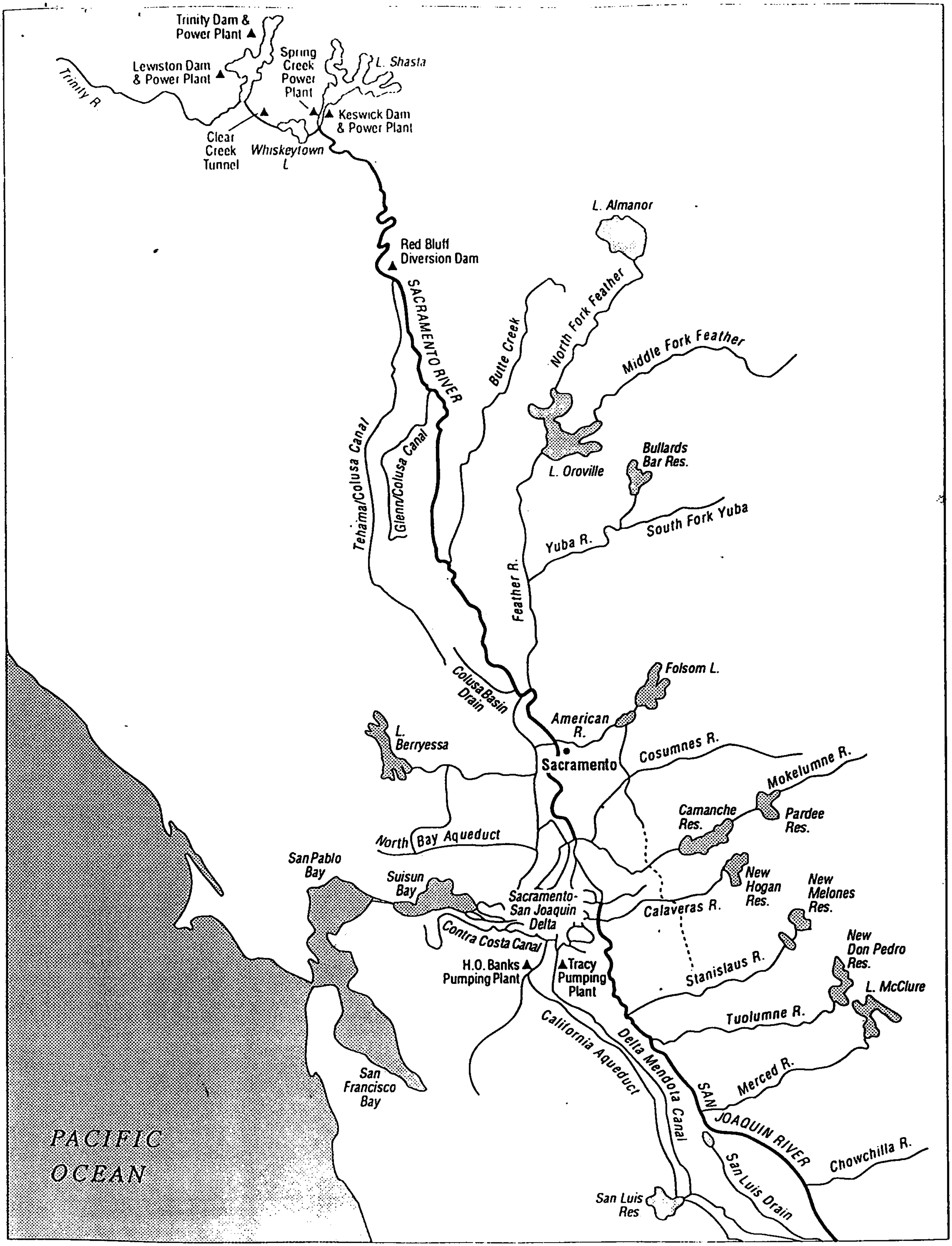

Figure 1-1. Study location map. *From California Water Map. Water Education Foundation, 10th printing.*

2.0 QUALIFICATIONS AND RELATED STUDIES

Our report should be considered very preliminary. Only a few of the measures we discuss have been tried on even an experimental basis. Some measures have been modeled using simulation techniques, and some can only be discussed theoretically.

Additional information will be provided when the U.S. Bureau of Reclamation (USBR) (Watkins 1991) conducts the Sacramento Basin Fish Habitat Improvement Study. The study plan for this project was completed in March 1992. However, the Sacramento Basin Fish Habitat Improvement Study will only address the needs of salmon in the upper Sacramento basin. Research is needed to simultaneously consider all habitat needs of salmon and other fish in the rivers and Delta. Also, more focus is needed on the San Joaquin River and Delta where temperature conditions are frequently less favorable for salmon. The San Joaquin River Management Program, sponsored by the State, and the USBR's San Joaquin River Basin Resource Management Initiative are addressing habitat needs on the San Joaquin River.

3.0 IMPORTANCE OF DELTA WATER TEMPERATURES OF MIGRATING SALMON

Field and laboratory studies have shown that the temperature of the water in the Delta during migration is important to the reproductive success of salmon. This section describes the most current and relevant summaries available.

3.1 AFFECTED RUNS AND THEIR LIFE CYCLES

Sacramento River Basin chinook salmon stocks consist of four races: fall, late fall, winter and spring. Figures 3-1 to 3-4 illustrate the life cycles of the four races and show when each occurs in the Delta. All surviving San Joaquin River stocks are fall run. Fall runs in the Mokelumne River and other Delta tributaries are affected by Delta water temperatures or associated control operations.

3.2 TYPES OF IMPACTS AND RELEVANT STUDIES

Many studies have documented relationships between Delta water temperatures and salmon behavior and survival. The SWRCB (1991) summarized testimony at that time and found that "elevated temperature is one of the factors which can affect chinook salmon during their migration through the delta." Laboratory and field evidence was presented indicating that smolts can be killed directly or can suffer sublethal effects from water temperatures that occur in the Delta.

The U.S. Fish and Wildlife Service (USFWS 1990) found positive relationships between flows in the San Joaquin River and adult escapement two years later and between flows and smolt abundance. This study estimated negative relationships between flow and temperature.

Statistical associations demonstrate the difficulty of differentiating the effects of temperature from other flow attributes. Increased flows also decrease out-migration time. If the rate of mortality (mortality per day) is higher during out-migration than after, then survival is increased by reducing the time required for out-migration. Increased flow also improves other water quality parameters, increases the share of flow routed through favorable channels, improves food conditions, reduces the proportion of water diverted, and provides other benefits to salmon. Unfortunately, it is not possible to isolate the importance of each flow attribute to survival, but laboratory and field evidence indicates that water temperature is an important attribute of flow.

Kjelson et al. (1989) modelled smolt mortality in three reaches of the Delta. In the Sacramento River from Sacramento to Walnut Grove, mortality increased linearly from 0 to 100 percent between 59° to 80° F, or about 5 percent per degree. From Walnut Grove, downstream mortality was calculated in two reaches: Walnut Grove to Chipps Island via the Sacramento, or via the Mokelumne and lower San Joaquin rivers. In the first reach, mortality increased from 15 to 100 percent between 55° and 80° F, or about 3.5 percent per degree. In the second reach, mortality increased from 62 to 100 percent between 55° and 75° F, or about 2 percent per degree. The model therefore calculated an increase in mortality of 7 or 8.5 percent per degree between 59° and 75° F, depending on which lower outmigration route was taken.

On the San Joaquin River, Loudermilk (1987) reported a positive relationship between flow and escapement two years later. "Escapements, two years after each May when chronic stress occurred, were consistently lower than the previous or following years." Flows below 5,000 cubic feet per second (cfs) at Vernalis exposed smolts to stressful temperature conditions in May, but mean monthly temperatures were not significantly related to flow in March or April. Hallock et al. (1970) reported that a temperature of 70° F stopped upstream migration on the San Joaquin River, and temperatures between 65° and 70° F created a partial block.

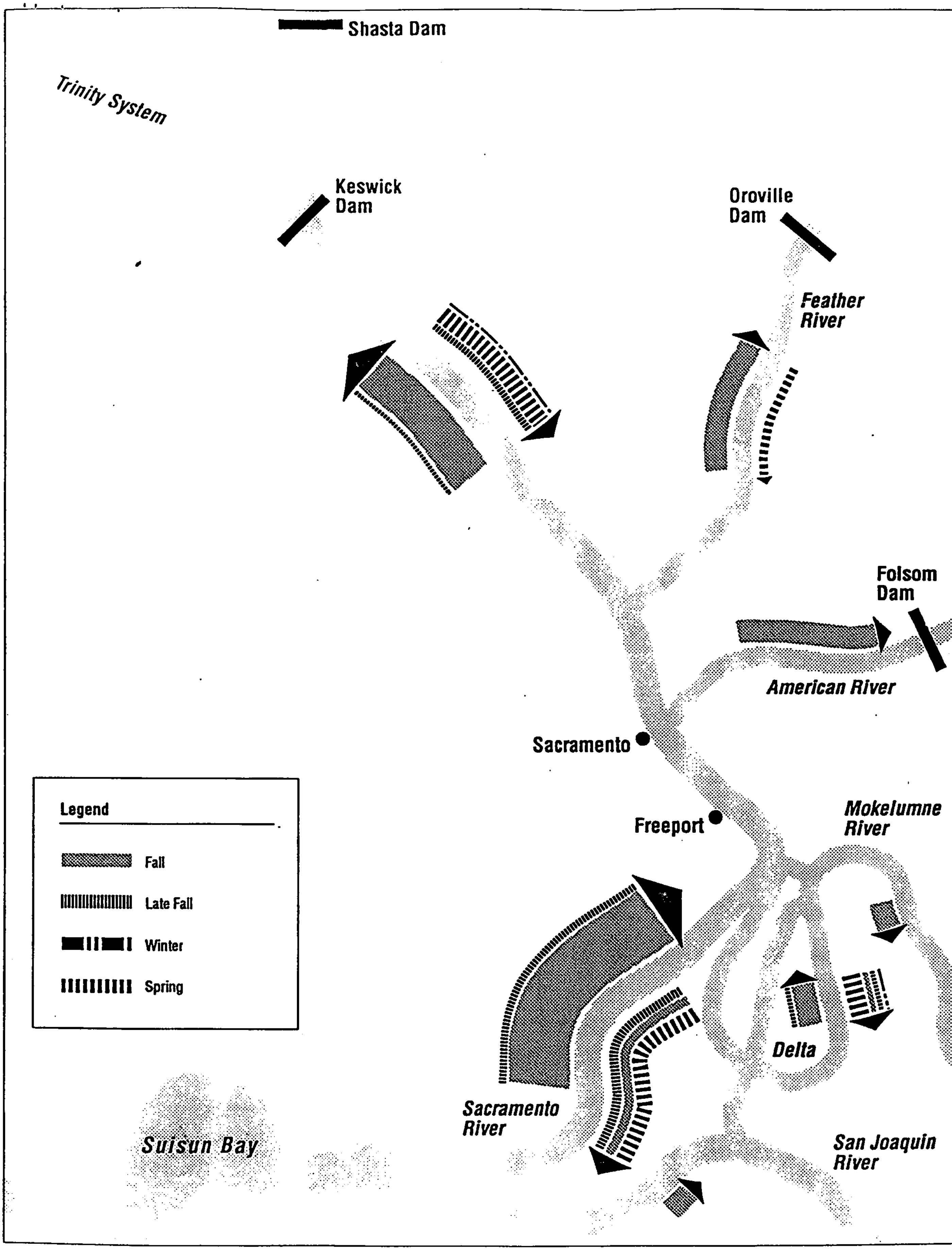

Figure 3-1. Salmon migrations in fall (September–November).

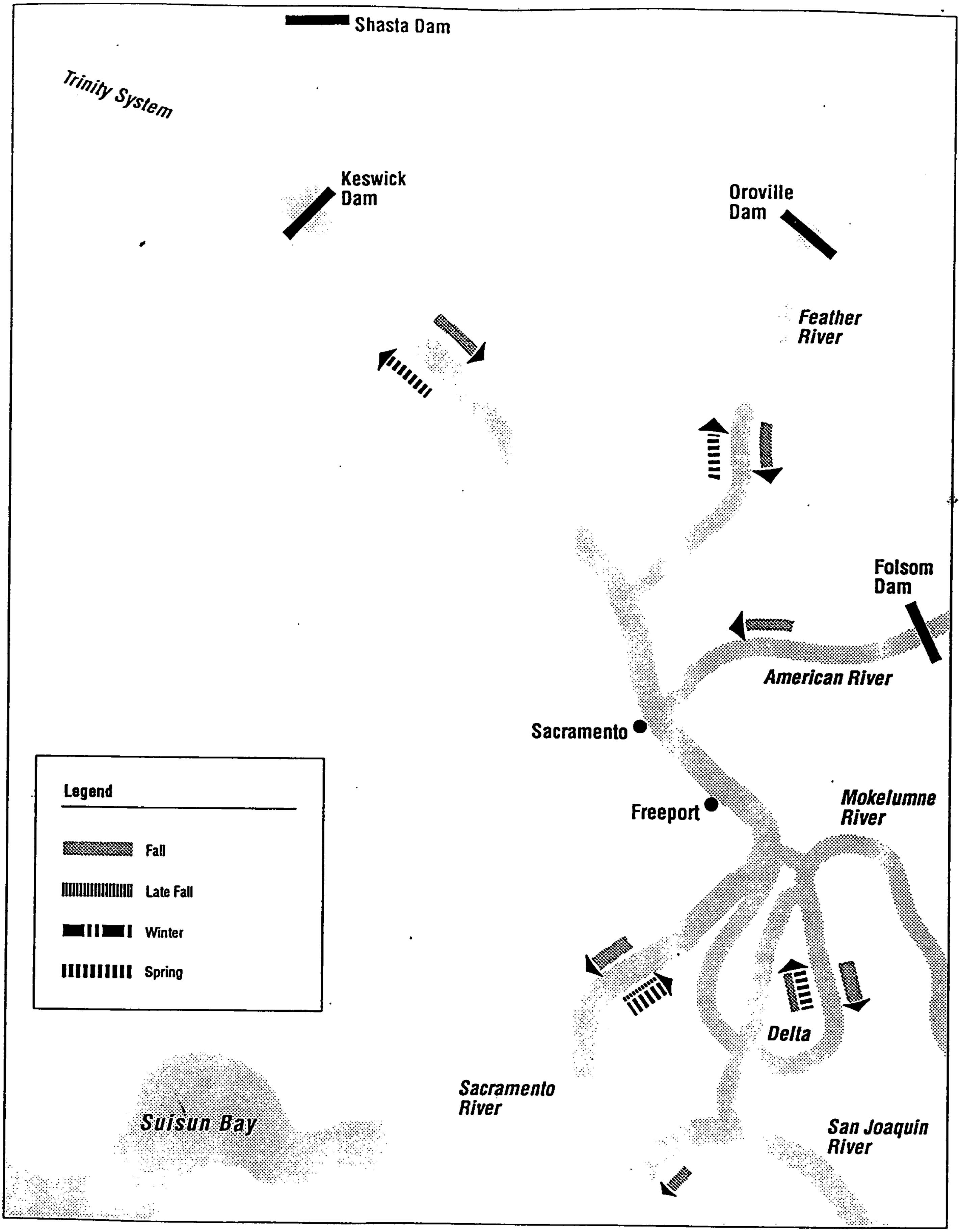

Figure 3-2. Salmon migrations in summer (June–August).

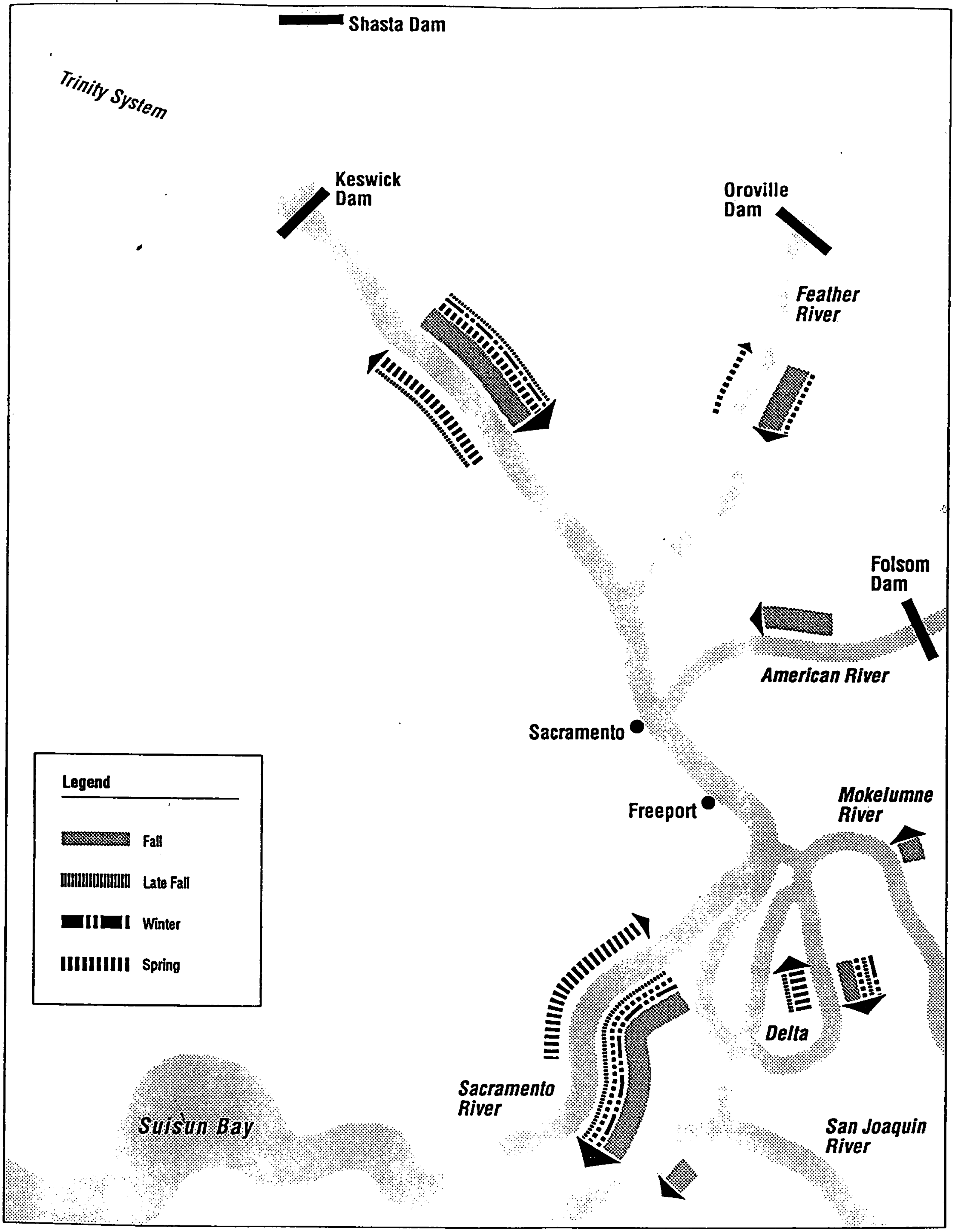

Figure 3-3. Salmon migrations in spring (March-May).

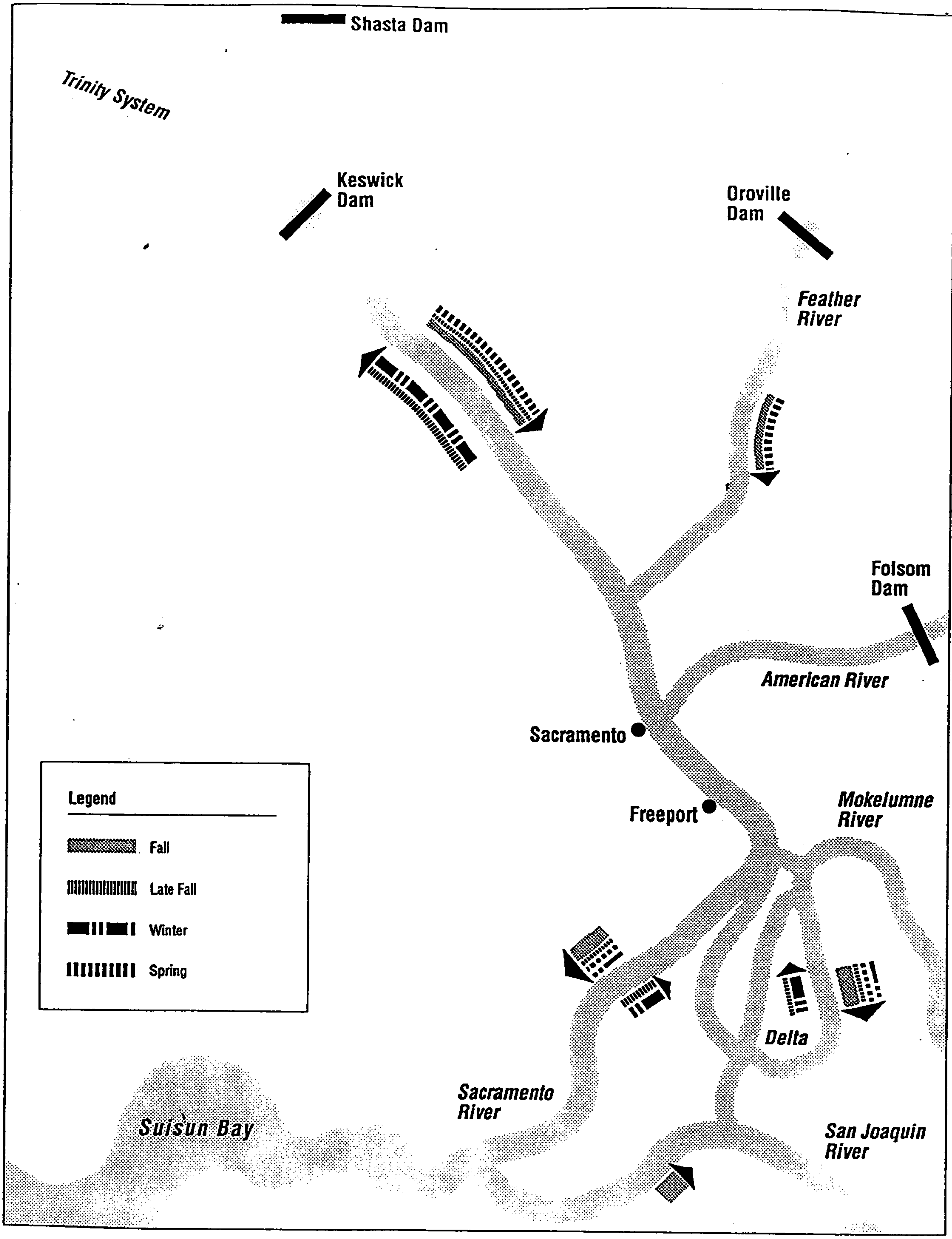

Figure 3-4. Salmon migrations in winter (December–February)

4.0 SUMMARY OF WATER TEMPERATURE DATA AT CRITICAL POINTS

Since the WQCP designates Freeport and Vernalis for temperature objectives, we analyzed temperatures at these points using water temperature data collected by the U.S. Geological Survey (USGS) at Freeport since 1962 and at Vernalis since 1961. For both stations, we used the average of the daily minimum and maximum temperature to estimate the true daily average.

4.1 SACRAMENTO RIVER AT FREEPORT

A summary of the average water temperatures from the Freeport gage (gage 11447650) for 1962 - 1990 is provided in Table 4.1. From 1962 to 1990, the average daily temperature never exceeded 68° F (by the available observations) during April and November, but temperatures were over 68° F on 52 percent of the days in June and 38 percent of days in September.

Historically, water temperatures in November and April did not exceed WQCP water temperature objectives and 68° F was rarely exceeded in October. Our summary statistics suggest that water temperature management to meet WQCP goals would focus on attaining the 68° F average daily maximum in September, May, and June.

4.2 SAN JOAQUIN RIVER AT VERNALIS

Table 4.2 summarizes the 1962 to 1990 average water temperatures from the Vernalis gage (gage 11303500). These data show that temperatures at Vernalis were unfavorable for migrating adults and smolts more frequently than at Freeport. Temperatures exceeded the SWRCB 68° F standard on most days in September and June, but the criterion was exceeded less frequently (10 - 26 percent of days) in October and May and was only rarely exceeded in April. Statistical results from both Freeport and Vernalis show that water temperatures in the Delta frequently exceed the WQCP standards. Since temperature generally increases downstream in the Delta, it is likely that Delta temperatures frequently reach levels that reduce salmon reproduction and survival. At certain times of the year or under some weather conditions, temperatures can decrease downstream into the Delta (Patterson, 1992).

Water temperatures decline in September. If the reservoir water available for temperature control is limited, the fixed 68° F standard in September could deplete limited supplies when few salmon are migrating up through the Delta. Later in the fall, when cooler water could benefit more salmon, no water would be available. This illustrates that a standard based on temperature alone could be counterproductive.

Water temperatures rise in the spring, as air temperatures and the amount of sunlight increase. Because of this, management should focus on decreasing temperatures later in the outmigration period. However, the effectiveness of storage releases for temperature control varies with many factors as discussed in Section 7.0. Again, the status of the water system

Table 4.1. Water temperature data summary, Sacramento River at Freeport

	SEPT	OCT	NOV	APR	MAY	JUNE
NUMBER OF OBSERVATIONS	774	797	812	834	851	799
AVERAGE °F	67.6	62.0	54.2	57.6	63.5	68.4
PERCENTAGE OF DAYS EXCEEDING:						
69°	30	1	0	0	9	46
68°	38	4	0	0	13	52
67°	52	9	0	0	21	63
66°	70	15	0	0	27	79
65°	79	21	0	2	34	85
64°	92	29	0	5	46	92

Table 4.2. Water temperature data summary, San Joaquin River at Vernalis

	SEPT	OCT	NOV	APR	MAY	JUNE
NUMBER OF OBSERVATIONS[1]	587	571	597	649	638	582
AVERAGE °F	69.1	62.4	54.5	60.4	64.8	69.5
PERCENTAGE OF DAYS EXCEEDING:						
69°	55	6	0	3	20	60
68°	68	10	0	5	26	69
67°	78	17	0	10	38	80
66°	82	23	0	13	47	85
65°	85	31	0	19	56	88
64°	90	42	0	26	63	92

[1] October and November include 1961 but not 1991. All months exclude 1964, 1969, 1971, and 1972. 1984 is excluded in September, November, and May, and 1985 is excluded in October.

and the population should be considered to maximize the benefit of water used for temperature control. A temperature standard based only on time of year is too simplistic to provide real assistance and could be counterproductive.

5.0 MODELS OF DELTA WATER TEMPERATURES

5.1 THE USBR MODEL

The USBR temperature model (Rowell 1990) simulates monthly average water temperatures in many locations in the Sacramento River Basin. This model has been used extensively to estimate river water temperatures associated with structural and operational management changes, including the Shasta temperature control device (USBR 1991) and a variety of proposed operation scenarios (Rowell 1990; Hydrosphere 1991; Kelley et al. 1991). The model has been calibrated and verified by comparison to actual temperatures.

The USBR model simulates monthly temperature versus depth profiles in the major reservoirs (Clair Engle, Whiskeytown, Shasta, Oroville and Folsom) and computes release temperatures. These data are input for the core river model, which computes temperature at 52 locations on the Sacramento River, 10 locations on the Feather River, and 8 locations on the American River.

The model is deficient in that it cannot be applied to problems where the impact of hydrology on short-run extremes, such as a daily temperature maximum, is important. The model could, however, be modified to operate on a shorter time step. Also it is possible to estimate a distribution of daily extremes based on monthly averages using historical data and to interpolate using model output. This model has proved its worth and has been an extremely useful tool for many conceptual problems.

5.2 THE FEATHER RIVER MODEL

The California Department of Fish and Game (CDFG) has plans to develop a temperature model of the Feather River using SNTEMP software developed by the USFWS. The model will be similar in principle to the USBR temperature model but will use a three-day time step and would be an improvement for modeling minimums and maximums (Green 1992).

5.3 STATISTICAL APPROACHES

Several authors have used statistical techniques to estimate the relationships between temperature and flow on the Sacramento River. The USFWS (1990) presented flow versus temperature relationships for Freeport using five-day average temperature data during May and June from 1967 to 1985. The simple correlation between flow and temperature was .71 in May and .78 in June, but regression equations were not provided. Loudermilk (1987) found that the relationship between flow and temperature at Vernalis on the San Joaquin was insignificant in March and April but significant ($r=.6$) in May. Other statistical analyses (D.W. Kelley and Associates 1987; Greene 1989) have also been conducted (Patterson 1992).

Statistical approaches attempt to estimate relationships between water temperature and causative factors using regression and correlation techniques. Statistical models can be useful for hypothesis testing and results can frequently be used for prediction. Results can indicate not only the probability that there is an effect, but also, the expected magnitude of the effect.

In our analysis, ordinary least squares regression analysis considered springtime daily average temperature (measured as the average of the daily maximum and minimum) as a function of flow and trend variables for the year and day of the month. Equations were estimated for April, May, and June. An annual trend variable was used to test for increases or decreases in temperature over years. A daily trend variable over the month was used as a proxy for increasing air temperature, longer days, and changing solar aspect during spring.

To estimate temperature at Freeport (USGS Station 11447650), we used flow and temperature data from USGS stations at Freeport, the Feather River near Gridley (Station 11407150), and the American River at Fair Oaks (Station 11446500). For predictions at Vernalis and the San Joaquin River, we used flow and temperature data from gage 11303500 at Vernalis.

Regression tests were conducted with and without a dummy variable representing year type. The addition of water year types in the equation specification provides a hypothesis test that water year type has an effect on water temperature that is distinguishable from flow alone. However, since the number of some water year types was limited, the water year dummies might capture effects of other factors affecting temperature in those years.

5.3.1 Results at Freeport

We used about 400 (13 x 30) daily observations to compute the regression analyses at Freeport. This represents nearly complete data sets from 1974 to 1986. Results are summarized in Table 5.1 and detailed regression results are provided in Appendix A.

The equations explained 63 to 74 percent of the variation in daily temperatures. Our results showed that flow, year, some year types, and day of the month were significantly related to daily water temperature at Freeport. In Table 5.1, four equations are reported for April and May, two for each month. They differ only in that one equation does not include the year-type dummy variables. Some year-type dummies significantly affected temperature, but the additional variation explained by the dummies was small. The dummies added only 3 to 4 percent to the R-square in April and June and only 1 percent in May. The coefficients on flow are affected, as expected, by the inclusion of the dummy variables in the specification. Since year type is a function of flow, coefficients on flow in equations without the year type dummy variables are best used for estimating the total effect of flow on temperature.

We estimated that flow at Freeport had more effect on water temperature in April and June than in May. An additional 1,000 cubic feet per second (cfs) at Freeport was associated with a decline in water temperature of 0.11° F in April, 0.04° F in May, and 0.19° F in June.

Flow from the American River decreased Freeport temperatures by 0.21° F to 0.32° F per 1000 cfs. However, these flows also add to flow at Freeport. The two coefficients can be

Table 5.1. Results of regression analyses, Freeport temperature[1].

	ESTIMATED CHANGE IN TEMPERATURE (°F)						
	PER 1,000 CFS FLOW AT			PER	PER	IF YEAR TYPE IS:	
MONTH	FREEPORT	FAIR OAKS	GRIDLEY	YEAR	DAY	ABOVE	WET
April	-.066	-.15	.06	.33	.13	-2.0	-2.3
S.E.[2]	.011	.04	.02	.03	.01	.35	.32
April[3]	-.11	-.21	-.13	.30	.11		
S.E.	.01	.04	.02	.03	.01		
May	-.015	-.27	-.21	.20	.20	-1.00	-.72
S.E.	(ns)	.069	.074	.03	.01	.32	.26
May[3]	-.038	-.28	-.14	.20	.20		
S.E.	(ns)	.07	.07	.03	.02		
June	-.19	-.32	.17	.16	.07		
S.E.	.032	.12	.09	.03	.01		

[1] Data from 1974 to 1986 used in analyses.
[2] S.E. is standard error, ns is not significant (pr = .05).
[3] Does not include year type dummy variables.

added together, so the total reduction per 1000 cfs from the American River ranges from 0.32° (0.21+0.11 F) to 0.51° (0.19+0.32) F. These results show that the temperature reduction per unit of water of American River flows is several times that provided by mainstem or Feather River flows. Feather River flows at Gridley were positively related to Freeport temperature in June and negatively related to temperature in May. The total expected effect of Feather River flow is close to zero in April (+0.06-0.066 °F) and in June (.17-.19 °F).

The coefficient on the year trend variable indicated that Freeport water temperatures increased significantly from 1974 to 1986. Expected temperatures increased by 0.31° F per year in April, 0.20° F per year in May, and 0.16° F per year in June. Expected temperatures increased by 0.13° F per day during April, 0.20° F in May, and 0.07° F in June. The low estimated standard errors on the time trend coefficients indicate highly significant effects in all months.

Water year type frequently had a significant effect on water temperature. Expected water temperatures in above normal and wet year water types were about 0.75° to 2.25° F cooler than other years. In general, critical years were not distinguishable from dry or below normal years after including the flow variables.

5.3.2 Results at Vernalis

For regressions at Vernalis, river flow at Vernalis (Station 11303500) was the only flow variable used to predict temperature. Data were available from 1961 to 1990, except for 1964 - 1968, 1971, and 1972. 1977 data were not available for June and 1984 data were not available for May. Results are summarized in Table 5.2.

The equations at Vernalis explained only 18 to 33 percent of the variation in water temperatures. This suggests that some variables not included in the specification, such as weather conditions and return flow patterns, were more important determinants of water temperature at Vernalis than at Freeport. Also, results differed from those at Freeport in that the water year dummy explained a larger proportion of the variation in temperature.

Table 5.2. Results of regression analyses at Vernalis.

	ESTIMATED CHANGE IN TEMPERATURE (°F)			
MONTH	PER 1,000 CFS FLOW AT VERNALIS	PER YEAR	PER DAY	IF YEAR TYPE IS WET
April	-.09	.34	.13	-4.64
S.E.[1]	.02	.03	.02	.44
May	-.07	.31	.12	-3.42
S.E.	.03	.03	.025	.49
May[2]	-.09	.32	.13	
S.E.	-.03	.03	.03	
June	-.142	.29	.16	
S.E.	.045	.03	.03	

[1] In April, the regression excluding the year type had no effect (after rounding) on the coefficients and is, therefore, not reported.
[2] Excludes year type variable.

Flow, trend, and water year type variables were significant in most months. The regression equation estimates that a 1,000 cfs increase in flow at Vernalis resulted in a 0.09° F to 0.14° F decline in water temperature. In all months, results indicated significantly increasing temperatures over the years and during the course of each month. Wet years, as identified by the Sacramento Basin 40-30-30 water year index, were associated with significantly cooler water temperatures. However, dry or critical years were not significantly different from the other four year types.

Our statistical results suggest that temperature at Freeport and Vernalis is controllable, but only to the extent that flows at these locations are actually controlled by upstream reservoir releases. On the San Joaquin River, releasing more water from upstream reservoirs may not increase flows at Vernalis if the extra water is diverted by intermediate water users. Our analyses further show that water temperatures have been increasing over time, although the reasons for this trend cannot be determined from our analysis.

In comparing results from Freeport and Vernalis, it is important that much more of the variation in temperature at Freeport is explained by flow than is true at Vernalis. Temperature at Vernalis may be more affected by weather conditions and other unpredictable factors and, therefore, would be more difficult to control below a specified temperature or within a given range. However, results indicate that increased flows were significantly associated with decreased temperatures over the 1974 to 1986 period. At Vernalis, additional flow of 400,000 to 600,000 acre feet per month was associated with a one degree reduction in temperature.

At Freeport, releases from Folsom Dam often provided much more temperature reduction per unit of water released than releases from other reservoirs. Only 100,000 to 200,000 acre feet per month was required to obtain a one degree reduction in temperature. This difference has been noted in other studies (Rowell 1990) but, to our knowledge, coordinated Folsom releases for Delta temperature control have not been studied in an operational context.

6.0 GENERAL CONCERNS IN FEASIBILITY ANALYSIS

This section reviews the important factors that bear on the feasibility of Delta water temperature control. Important aspects of operational feasibility are contrasted with factors affecting feasibility of temperature control structures. The feasibility of structures is largely related to technical and financing factors, but the feasibility of operations is tied to their ability to respond to conditions and the requirements of other water users.

6.1 GENERAL CONSIDERATIONS OF FEASIBILITY

Any activities to modify water temperatures are likely to interact with other water uses. These interactions may be competitive, such as when water for increased flows reduces the water supply available for others; or beneficial, as when upstream temperature reduction for spawning or rearing improves downstream migration conditions. Interactions and joint benefits should be included in any analysis of the relative merits of alternative temperature control strategies.

The feasibility of measures to control water temperatures has a physical, economic, and institutional aspect. Physical aspects are the primary concern of this analysis. Economic aspects are discussed in terms of the types of costs and benefits that might be realized but are not quantified. Institutional constraints are considered surmountable, but some strategies would require substantial institutional change.

Activities to improve water temperatures should be fully integrated into system operations to minimize costs to other water users and to maximize joint economic benefits. The best changes improve temperature conditions without harm to other uses. These are clearly a "reasonable" use of water. Other changes might have benefits greater than their costs, but consideration of existing water users might be desirable or required under existing institutional arrangements.

6.2 PROBLEMS OF LAGS, PREDICTION, AND TIMING IN OPERATIONS

Weather affects Delta water temperature directly through ambient air temperatures and cloud cover that reduce solar heating, but also because rainfall and snowmelt can contribute to unregulated runoff below reservoirs. Delta water temperature can be affected by the temperature of reservoir releases, but the duration of exposure to weather conditions are also important.

Travel time refers to the time it takes for water to flow from one point to another. Water travel time decreases with flow rate, but is also influenced by channel characteristics and gradient. A flow rate of 1,000 cfs can be associated with velocity as fast as a waterfall or as slow as a meandering river. Travel time from Keswick to Freeport varies from a few days to a week, but from Oroville to Freeport it is about three days, and from Folsom Lake to Freeport is perhaps two days (Rowell 1991). Again, travel time depends on flow.

To influence downstream temperature using reservoir releases, travel time to the downstream point must be considered. Water must be released in advance of the time at which the downstream change in flow is desired. Also, an allowance must be made for operational response time from prediction of conditions to the actual reservoir release. Before water is released, information that indicates a change in flow is desirable must be obtained, the decision to change flow must be made, and operators must be informed. Activities required during the response time might include collection and analysis of data, integration with other sources of information, communications, and coordination with other operations.

A significant problem with reservoir releases for temperature control involves weather, the quality of weather forecasting, and travel time plus operations lags. If weather forecasts were perfect, reservoir releases could always be timed to provide the desired flow rate and temperature. Actually, the potential benefit of releases for water temperature control is decreased by weather forecasting reliability that declines with time between the forecast and the outcome. A one-day forecast is somewhat reliable; a five-day forecast is not much better than a guess.

A reservoir such as Folsom that is closer to a temperature control point has two potential advantages for temperature control. Since travel time to Freeport is less, weather predictions might provide useful information on timing of releases; such as avoiding unfavorably warm temperatures two days in advance. Also, releases from the closer reservoir are exposed to unfavorable weather conditions for less time and, as was implied for Folsom Lake releases in Section 5.0, this can reduce downstream temperature more per unit of water released.

However, there are also disadvantages to use of Folsom for temperature control. Folsom releases do not affect water temperatures upstream of the confluence of the Sacramento and American River, where temperature conditions are often very unfavorable for migrating salmon. The stock of cold water available for fisheries downstream of Folsom and any other purposes is limited in dry years, and Folsom flood control rules may be changed, leaving even less water in storage in many years (Patterson 1992).

For releases from Keswick, the expected error in weather forecasting would severely limit the ability of reservoir releases to improve on average expected conditions. Reservoir releases provided according to average historical downstream temperature conditions would provide about the same benefit as releases timed to weather forecasts. For releases from Folsom Lake and Lake Oroville, weather forecasting might significantly improve the efficiency of reservoir releases for lower river and Delta temperature control. This improvement would make the releases more reasonable, especially in comparison to simulated results (Sections 7.10, 7.13) where no such capability is implicitly assumed.

6.3 FEASIBILITY CONSIDERATIONS FOR STRUCTURES

Several structural modifications have been studied and/or proposed that could result in cooler water temperatures when needed by salmon, without additional reservoir releases. Temperature control structures at Shasta Dam and within the Trinity diversion system could improve Delta temperature conditions, improve upriver conditions for spawning, hatching and rearing, and increase the flexibility of the system for other uses. Whereas operational measures frequently require the use of water that otherwise would be put to other beneficial uses, structural measures often require no additional water.

On the other hand, structural measures are often associated with large investments not immediately required for operational changes. Structures at upstream reservoirs are limited for Delta temperature control by the distance to the Delta, and, to the extent that they operate by selective withdrawal of cold water stocks, result in less cold water available later for other purposes.

To make the best use of limited water, structures that can respond to weather or other conditions are preferred. The proposed Shasta Dam temperature control shutter would allow water to be drawn from several depths. The choice of which depth to draw water from could vary with the needs of salmon or weather conditions. Structures proposed for the Trinity system would be designed "with sufficient flexibility to react to changing conditions."

7.0 REVIEW OF STUDIES OF OPERATIONS AND STRUCTURES FOR TEMPERATURE CONTROL

7.1 SHASTA TEMPERATURE CONTROL SHUTTER

The proposed Shasta temperature control shutter would improve regulation of water temperatures in the Sacramento River below the dam. A schematic of the device is included as Figure 7-1. An Environmental Impact Statement (EIS) has been prepared (USBR 1991) and measures to secure financing have been proposed in Congress. The device will cost about $50 million.

Rowell (1990) modelled the device using the USBR simulation model discussed in Section 3.0. Operation was simulated to reduce upstream temperatures from August through October. Water temperature at Freeport was reduced by an average of 0.3° F in August, 0.2° F in September, and 0.2° F in October.

As noted in the EIS, power production would actually be increased because it would no longer be necessary to bypass the power turbines as is now done to provide cool water for winter-run chinook habitat upriver. The device would add to the flexibility of the system by making it easier to attain temperature goals upriver. It could also provide joint benefits by improving temperature conditions for most salmon runs using the Sacramento River and Delta.

7.2 TRINITY SYSTEM MODIFICATIONS

The temperatures of water from the Trinity River system could be lowered by building new or modifying existing structures. Measures that have been investigated (Value Engineering 1990) include modifications at the Clear Creek Intake, the Judge Francis Carr Power Plant (Carr Power Plant), and/or the Spring Creek Tunnel intake. A schematic of these project features is provided in Figure 7-2. Additional studies of these modifications will be conducted as part of the USBR's Sacramento Basin Fish Habitat Improvement Study.

The Value Engineering study (1990) found that water temperatures rose by about 2° F between the deep water in Lewiston Reservoir and the Carr Power Plant tailrace, because the Clear Creek Tunnel intake, positioned high in Lewiston Reservoir, draws warm water from the surface of the reservoir. One remedial structural measure was studied - an underflow curtain at the Clear Creek Tunnel intake. This curtain would exclude the warmer surface waters of Lewiston Reservoir from the intake and could reduce temperatures at the Carr Power Plant tailrace by 1° to 2° F.

Water temperatures increased 3° to 5° F between the Carr Power Plant tailrace and the deep waters in Whiskeytown Lake, probably due to the mixing of power plant inflows with the warm surface waters of Whiskeytown Lake. An underflow curtain at the Carr Power Plant tailrace would reduce mixing of cool power plant discharges with warmer Whiskeytown Lake surface waters and might reduce warming of Whiskeytown Lake stored water by 2° to 3° F.

Water warms an additional 3° to 4° F between the deep water of Whiskeytown Lake and the Spring Creek Power Plant tailrace because some warmer upper strata water from Whiskeytown Lake enters the intake channel. Seven remedial measures were studied. The preferred alternative was an underflow curtain across the Spring Creek Power Plant intake channel. It was estimated that this structure would cool the water at the Spring Creek tailrace by an additional 1° to 2° F.The Value Engineering Study estimated that building curtains at all three sites could reduce water temperatures at the Spring Creek Power Plant tailrace by 4° to 7° F. Total construction cost would be about $8.6 million, but construction of the Clear Creek Tunnel and Carr Power Plant tailrace curtains would cost only $860,000.

The use of cooler Trinity system water to reduce Delta water temperature is limited by the proportion of water at Keswick that originates from the Trinity River and by the distance to Freeport. The proportion of flow from the Trinity system is sometimes small to nonexistent, and water from Keswick takes three days to a week to reach Freeport. However, simulation studies have indicated that reducing the water temperature at Keswick will reduce the temperature at Freeport.

7.3 OTHER MAJOR RESERVOIRS

Folsom Reservoir has temperature shutters but access to water at all elevations is limited. If the reservoir is low (about 400,000 acre feet or less), the shutters are useless (Rowell 1991). A study of modifying temperature control structures at Folsom Reservoir has been completed by the U.S. Army Corps of Engineers (COE) (1992). Temperature control systems at Oroville Reservoir are flexible, so modifications or new structures should not be needed.

The other major reservoirs in the basin are under federal administration or are controlled by municipal water providers or other private interests. Of the 32 reservoirs in the Central Valley with more than 100,000 acre feet capacity, only eight are components of the State Water Project and federal Central Valley Project (Bay Delta Proceedings Operations Study Workgroup 1991). The potential for structural or operational modifications to "non-project" reservoirs to improve temperature conditions for salmon has not been studied extensively, but the SWRCB will consider all water users in the basin in assigning responsibility for meeting water quality goals. Table 7.1 lists non-Central Valley Project/State Water Project reservoirs in the basin with more that 300,000 acre feet storage.

Lake Berryessa and Clear Lake discharge into the Yolo Bypass (Figure 7-3) so they could contribute only marginally to temperature control in the Sacramento River. However, these reservoirs could be used to dilute agricultural drainage water diverted into the Yolo Bypass, as discussed in Section 7.6 below. Some reservoirs, such as Lake Almanor, are upstream of other major storage reservoirs and, therefore, could not be used directly for temperature control. However, water from these reservoirs could replace water released from the downstream reservoir. Sequential reservoirs could be operated to improve downstream

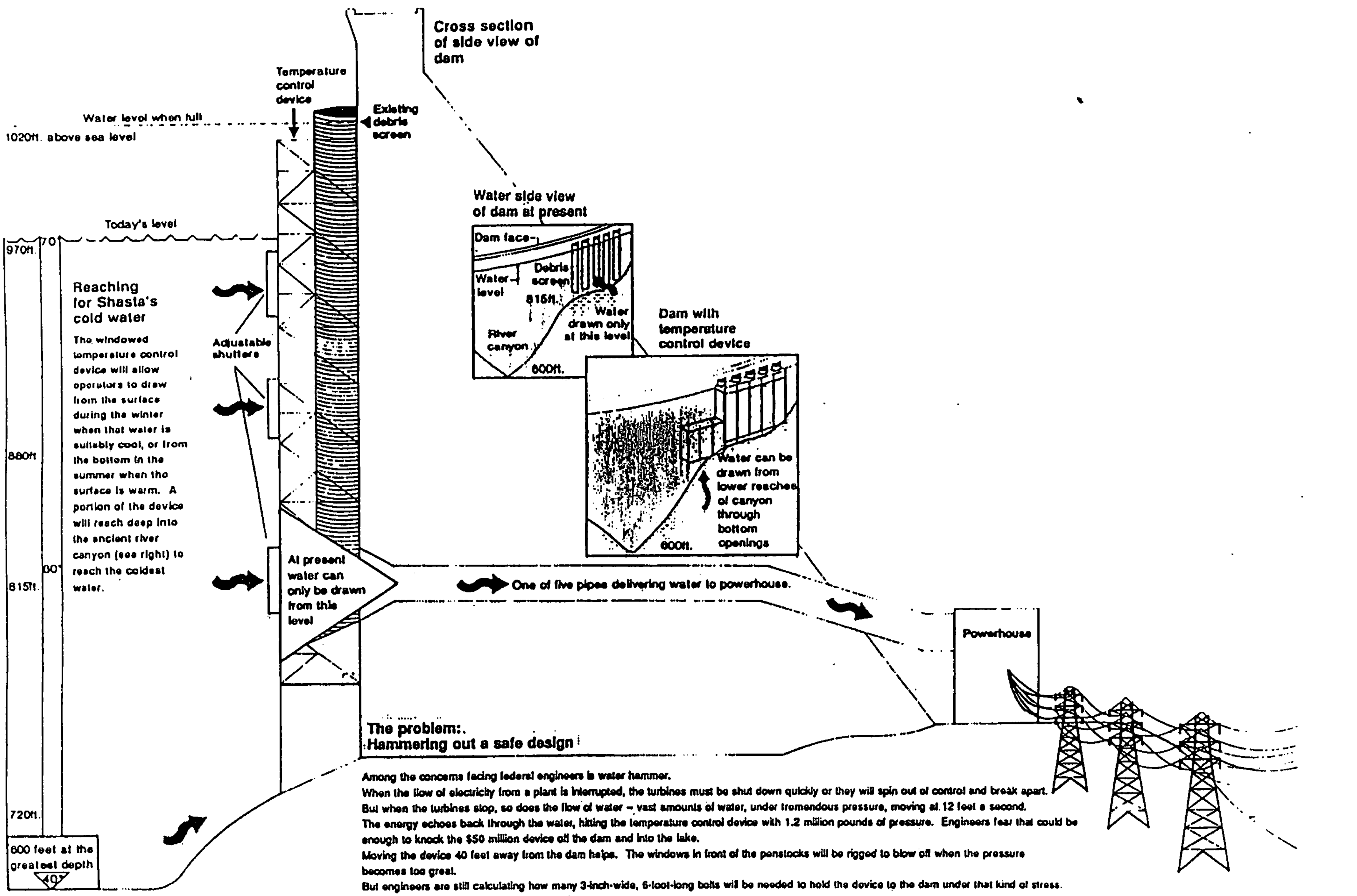

Figure 7-1. Lake Shasta temperature control device.

(USBR 1991)

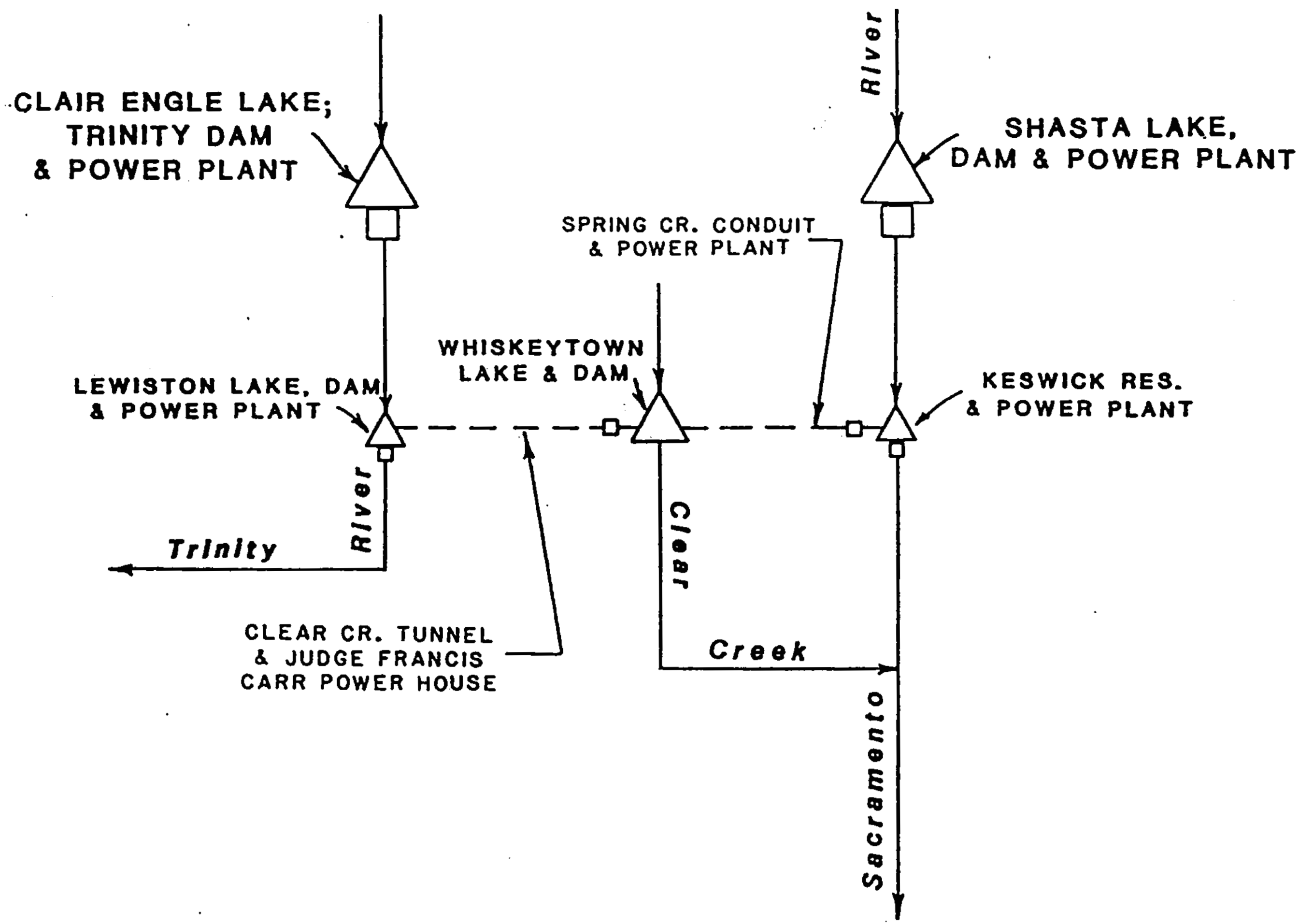

Figure 7-2. Schematic representation of Trinity River and Upper Sacramento River systems.
(DWR 1986)

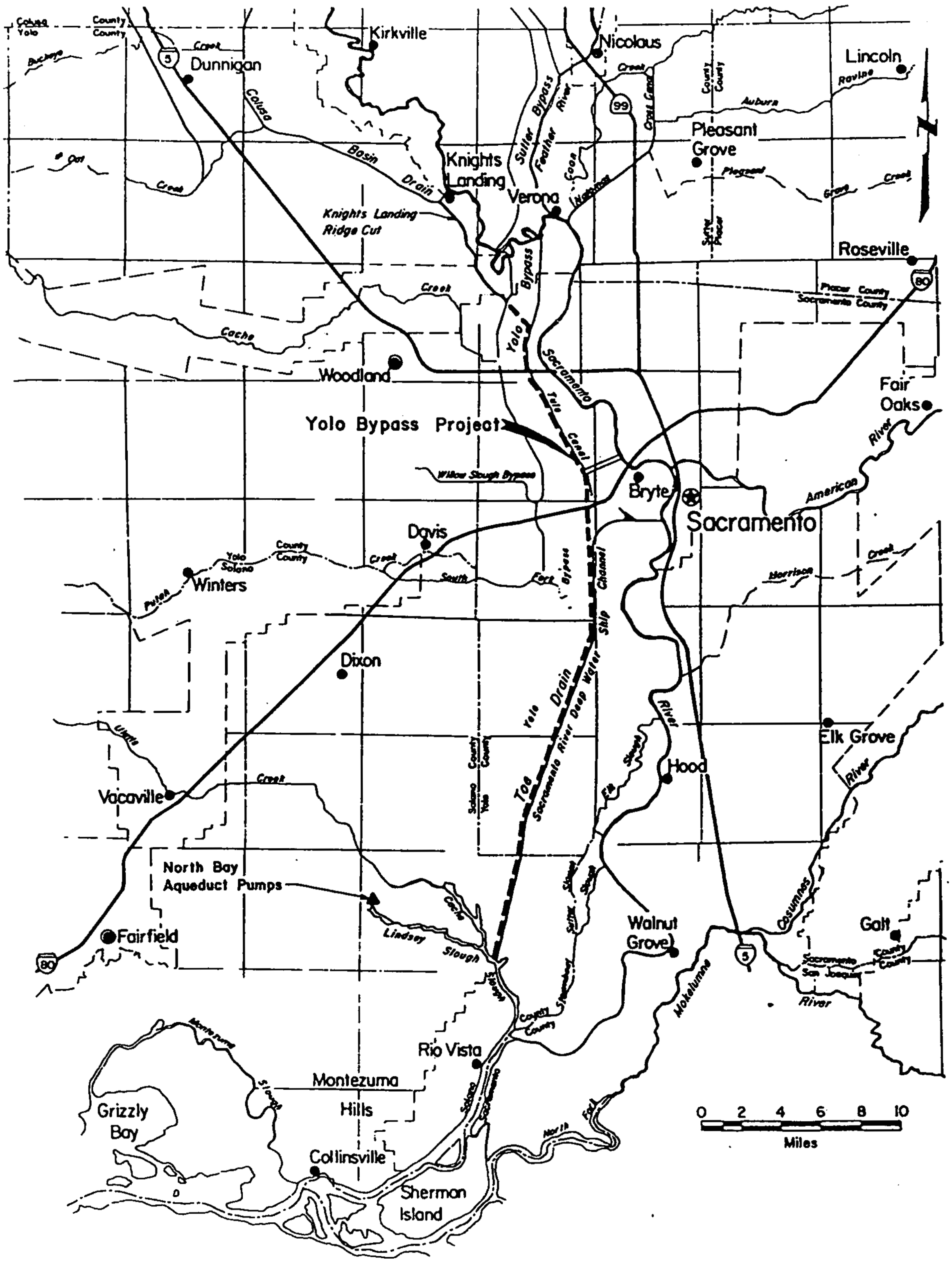

Figure 7-3. Colusa Basin and Yolo Bypass Project.

(DWR 1990)

Table 7.1. Non-Central Valley Project reservoirs with capacity in excess of 300,000 acre feet.

RESERVOIR	ACRE FEET CAPACITY	STREAM	OWNER
New Don Pedro	2,030,000	Tuolumne River	Turlock-Modesto Irrigation District
Lake Berryessa	1,602,340	Putah Creek	USBR
Lake Almanor	1,142,964	N. Fork Feather	PG&E
Lake McClure	1,024,000	Merced River	Merced Irrigation District
Bullards Bar	961,300	N. Yuba River	Yuba County Water Agency
Clear Lake	536,800	Cache Creek	Highlands Water Co.
Camanche	430,834	Mokelumne River	EBMUD/N. San Joaquin Water Control District
Hetch Hetchy	360,400	Tuolumne River	City/County of San Francisco
New Hogan Lake	317,055	Calaveras River	COE

temperatures by keeping the lower reservoir as full as possible using water from the upper reservoir. Since the lower reservoir would be fuller, water would be released from deeper cooler strata. Joint benefits would result from improved migration conditions (The Advisory Council 1989). No stored water need be lost using this form of operation. Power production and recreational value would increase in the lower reservoir but decrease in the upper facility.

7.4 CHANGE IN STRUCTURE OR OPERATION OF DIVERSION DAMS

Diversion dams warm water by reducing the velocity of flow and increasing warming time. Major diversion dams on the Sacramento River include the Red Bluff Diversion Dam and the Anderson Cottonwood Diversion Dam. It is thought that flow delays caused by these dams contribute little to river warming. On the other hand, modifying operations during non-irrigation seasons may have only a small impact on the associated water supply operations. Both structures could be operated to decrease water travel times by using gates or flashboards.

7.5 CHANGE IN STRUCTURE OR OPERATION OF REREGULATING RESERVOIRS

Reregulating dams such as Keswick and Natoma allow reservoir releases to produce power during peak power demand, when power is most valuable, by smoothing downstream flow patterns. Generally, reregulating reservoirs are drawn down when demand for power is low and filled when demand is high.

Like diversion dams, reregulating reservoirs warm water slightly by delaying flows. Structural modifications to reduce downstream temperatures may be possible. The USBR is currently evaluating temperature control curtains for Lewiston Lake. Reregulating reservoirs could be drawn down to reduce water retention and travel time. However, drawing down reregulating reservoirs could reduce hydropower value because upstream storage releases would have to be timed for downstream flow requirements, not peak power needs. If upstream storage releases were timed for power without reregulation, uneven river flows could seriously impact downstream beneficial uses. For example, stranding of salmon redds could increase.

7.6 IRRIGATION DRAINAGE AND THE YOLO BYPASS PROJECT

During the late spring, summer, and early fall, irrigation drainage waters are frequently warmer than the receiving river. If these drainage waters could be reduced, eliminated, or relocated, river water temperatures could be decreased. For example, Rowell (1990) estimated that eliminating agricultural drains on the Sacramento River would reduce water temperatures at Freeport by up to 0.5° F. He provides data from 1950 to 1959 showing that eight large drains contributed an average 1.075 million acre feet annually. The two largest, the Sacramento Slough and Colusa Basin Drain, each contributed roughly 300,000 acre feet.

The Colusa Basin Drain discharges irrigation and runoff into the Sacramento River at Knight's Landing, about 20 miles above Sacramento (Figure 7-3). The amount of discharge varies with irrigation practices, rainfall, and river stage. The lower end of the drainage basin floods when inflows exceed the hydraulic capacity of the drain. This capacity decreases with increasing flow in the Sacramento River.

The Colusa Basin Drain typically experiences two peak outflows. One occurs in the spring at the end of the rainy season, and the second is in the late summer when rice fields are drained before harvest. In wet years, the spring peak is often larger than the late summer peak, while in dry years this pattern is reversed. The California Department of Water Resources (DWR) (1990) shows that maximum spring outflow from May 9 - 24 in the years 1984 - 1988 ranged from 1,130 to 1,730 cfs. In 1983, a wet year, discharge reached 2,590 cfs on April 1, but discharge was only 1,600 cfs on August 23. The maximum late summer discharge occurred between August 23 and September 11 in every year from 1978 to 1988.

Temperature conditions just below the Colusa Basin Drain are often unfavorable for salmon. The USFWS (1990) compared biweekly temperatures at Grimes (about 15 miles downriver from Colusa), just above the confluence of the Sacramento and American Rivers, and at Freeport between 1965 and 1984. Some of the highest temperatures occurred at the intermediate point, and they were often suboptimal. During several years in the late 1970s, June temperatures were within the lethal range.

Table 7.2 summarizes daily water temperatures in the Sacramento River just above the Colusa Basin Drain, in the drain, and just below the drain (data from DWR 1991). The average temperature of the drainage water in June was in the 70s (°F). During the peak outmigration in May of 1991, the drainage water averaged 67° F. During April, drainage temperatures were in the low to mid 60s. In 1991, the river downstream of the drain was warmed by .7° to 1.4° F. In September, the drain water warmed the river by only 0.1° to 0.5° F. Drainage water probably has little effect on river water temperatures during most of the fall upmigration period and might even reduce river temperatures in the mid to late fall.

Table 7.2. Summary of water temperature data in and near the Colusa Basin Drain, 1990-1991

	TEMPERATURE °F			
PERIOD	ABOVE DRAIN	BELOW DRAIN	CHANGE	IN DRAIN
1990				
Apr 10-11				65.3
Jun 6-10				76.6
Jul 1-30				80.3
Jul 31-Aug 31	71.5	72.1	0.6	76.5
Sep 1-5	70.3	70.9	0.5	73.8
Sep 6-30	69.4	69.5	0.1	
Oct 1-25	63.5	63.4	-0.0	
Oct 16-Nov 26	55.9	55.5	-0.4	54.1
1991				
Apr 1-30	59.0	60.4	1.4	62.3
May (excl. May 10)	63.1	64.5	1.4	67.4
June 1-22	70.2	70.9	0.7	72.7
Jun 23-Jul 7		71.5		76.0
Sep 14-Oct 2		71.7		70.9

A further benefit of reducing irrigation return flows would be improved water quality. Pesticide contamination and salt loading would be reduced and dissolved oxygen concentrations might be increased. Pesticide contamination in the river above Sacramento is a problem for the city water supply, and fish losses have been linked to pesticides in the drainage water. Reducing the amount of drainage water would also reduce flooding caused by poor drainage in some areas. The amount of drainage water could be reduced by reducing irrigation application, temporarily storing water, and/or routing the drainage elsewhere. Rice irrigation results in a disproportionate return flow per acre since the amount of water applied far exceeds the amount needed for crop evapotranspiration. An estimated 6.4 feet per acre was applied to 213,000 acres in the Colusa Basin in 1980 (DWR 1990).

Rice irrigation techniques have changed in recent years. Deep-water culture required deep standing water to control weeds, but laser leveling of fields, improved herbicides, and new varieties allow rice to be produced with less water. More recently, growers have begun flooding fields before flowering to increase yields, and this has increased drainage in the late season.

Other techniques, such as "PureHarvest" have been developed that use less water (Hollis 1990). A Rice Herbicide Management Plan incidentally reduced irrigation drainage to the Colusa Basin Drain by increasing the holding time of water in the rice fields, recirculating water, and recovering tail water (DWR 1990). Drainage water discharge could be substantially reduced by improved irrigation techniques and water reuse. However, irrigation reuse concentrates some contaminants and can result in additional water quality problems.

The proposed Yolo Bypass Project would route agricultural drainage water away from the mainstem of the Sacramento River through an enlarged Knight's Landing Ridge Cut, through the Yolo bypass, down the Tule Canal, into the Sacramento River deep water ship channel, and into Cache Slough in the Delta (Figure 7-3).

In 1990 the estimated capital cost of this project was estimated to be $8 million with annual operating costs of $700,000. The benefit/cost ratio was low, but only benefits of improved drainage were included. The project would reduce mainstem flows at times, which would necessitate larger upstream releases for navigation. Water quality in the Delta around Cache Slough would also be degraded. The North Bay Aqueduct intake would probably have to be moved from Lindsey Slough (an arm of Cache Slough) to Miner Slough.

During the summers, most of the flow in the San Joaquin River comes from drainage water (San Francisco Estuary Project 1991). Improving the efficiency of irrigation in the San Joaquin Basin would reduce the amount of drainage water, which could leave more water in reservoirs for other purposes. However, flows would be reduced without additional releases, so the net effects of improved irrigation efficiency are unclear.

7.7 INCREASE RIPARIAN SHADING

Simulation studies using the USBR temperature model (Rowell 1990) estimated that if the amount of shade along the length of the Sacramento River was increased by 10 percent, the average water temperature at Freeport would be reduced by 0.5° F in April, 0.7° F in May, 0.6° F in June and September, and 0.5° F in October.

Under current flood control guidelines, vegetation is not permitted to grow on some levees because uprooting of trees during floods could cause levee failure. The U.S. Army Corp of Engineers (COE) is currently studying this problem and the potential for allowing vegetation on levees.

One drawback to increasing riparian shading is that the additional trees would consume water. However, increasing the amount of riparian vegetation would improve the habitat for many fishes. Insects dropping from overhanging branches provide food for fish and decaying leaves and branches provide food for herbivorous aquatic insects and worms.

7.8 CHANGE FLOOD CONTROL OPERATIONS

Current flood control operations require that reservoir storage not exceed specified levels during the wet season so that storage can be used to capture and regulate flood flows. If reservoirs enter the flood control season above specified levels, then water must be released to the river. Most flood control operations in the basin are specified by the COE, but the actual operations are conducted by the owner. Although space reservations may not be required until late fall, releases required to meet flood control space requirements usually serve other downstream uses.

In some years this released water might be managed to improve downstream temperature conditions. The timing of flood control releases is flexible in that the releases can be made anytime prior to COE specifications, and this release period usually coincides with the salmon upmigration. A program using fall flood control evacuation to improve habitat conditions could be keyed to the status of the fishery and water temperatures in the lower river and Delta.

The largest and most frequent reservoir evacuations for flood control occur during wet years when reservoirs contain more water. Since water temperatures are usually lower during these periods, the potential for beneficial improvement is limited. Reservoir releases for flood control are rarely needed during drought when the need to reduce temperature is greatest. However, flood control releases from Folsom Reservoir were required in 1989 (Patterson, 1992).

Without sufficient spring and summer runoff, reservoirs may not fill following flood control evacuations. Modifying flood control rules to be less "conservative" could increase average storage and reduce water temperatures later in the season. However, the increased potential for flooding would be an expected, and perhaps unacceptable, cost of this strategy.

Storage of water for a flood-prone location is often divided between upstream reservoirs. It may be possible to shift responsibility between reservoirs while keeping the same level of downstream protection.

7.9 BYPASS THERMALITO FOREBAY AND AFTERBAY

Bypassing water past Thermalito forebay and afterbay, below Lake Oroville, could reduce water warming. Rowell (1990) simulated this operational change and estimated average Freeport temperature decreases of 0.4° F in April, 0.4° F in May, and 0.6° F in June, but only 0.1° F in September and 0.2° F in October.

A Thermalito bypass experiment was conducted at the facility in June of 1989 to determine "if curtailing the warmer Thermalito afterbay releases into the Feather River could maintain cooler water temperatures in the Feather and Sacramento Rivers" (Greene 1991). Unfortunately, changes in air temperature over the course of the experiment confused the results, but "increased air temperature during the bypass test did not produce a corresponding increase in water temperature," as would be expected if the bypass had no cooling effect on water temperatures.

7.10 RESERVOIR RELEASES FOR TEMPERATURE CONTROL

Rowell (1990) used the USBR temperature simulation model to estimate the temperature change at Freeport caused by increased reservoir releases. He calculated the average additional Keswick Reservoir releases needed over May and June to attain specified 56-year average monthly temperature reductions at Freeport as:

Specified Temperature (°F)	69	68	67	66	65
Average Annual Release (thousands of acre feet)	205	368	587	842	1171

In comparison, average flow in a baseline case was about 1.2 million acre feet. Average flow during May and June would have to be doubled to attain the 65° F goal.

The model also was used to estimate temperature reductions resulting from releases from each reservoir, while holding other reservoir releases constant. The experiment assumed all releases began at 50° F with a base flow of 11,000 cfs at Freeport. May 1976 climatic conditions were used in the analysis. The release of additional Folsom Reservoir water reduced the temperature more per unit than releases from other reservoirs. At incremental flow increases of 1,000 to 3,000 cfs, a unit of water released from Folsom Reservoir provided up to five times the temperature reduction as a unit from Lake Shasta or Lake Oroville. This ratio (5:1) decreased to about three to one (3:1) with a 5,000 cfs incremental increase over the 11,000 cfs base level.

The Coleman fish flush of 1989 provided incidental information on the temperature effect of a large reservoir release. The operation "was used to provide high flows of short duration to enhance the emigration of the juvenile salmon released from the Coleman Fish Hatchery" (Greene 1991). An increase in flow from 6,500 to 12,500 cfs at Wilkins Slough was associated with a 7° F decrease in water temperature at that point.

The SWRCB considered the use of reservoir releases for temperature control in the Delta unreasonable. However, reservoir releases have joint benefits, only one of which involves temperature. Releasing reservoir water for joint benefits may be reasonable, whereas releasing water for temperature control alone may not be. Increasing flows speeds out-migration, which reduces exposure time of smolts to unfavorable temperatures and can improve downstream water quality and navigation conditions. On the other hand, reservoir releases for Delta temperature control can adversely affect upstream spawning by reducing available cold water storage.

Another possibility is that existing reservoir releases could be managed more effectively to control temperature. It has been noted that monthly simulations are inadequate for considering potential improvement in a shorter time frame; other measures that might increase the benefit of releases for temperature control could be studied.

In summary, the effectiveness of releasing storage to control temperature is affected by:

- **Base level of flow:** If base flow (without additional releases) is small, an increment of water will reduce temperatures more than if base flow is large.

- **Base level of temperature:** If Delta temperatures are below harmful levels, additional flows are of no value. Also, if both base and modified temperatures are too high for survival, there is no value in releasing more water. However, if base temperatures are near lethal levels, releasing more water may increase in the number of smolts that survive and the success of the year-class may be greatly improved.

- **Time of year:** A unit of water may affect Delta temperatures more in the spring and fall than in the summer. Greene (1991) reported on simulation studies and found that "releases from Shasta Reservoir...were most effective in May, and less effective in June." In June "water temperatures are usually high and the weather is usually so warm that [temperatures] cannot be reduced with higher flows."

- **Source of the release:** Clearly, it is preferable that the travel time of releases between reservoirs be as short as possible to reduce exposure to sun and warm ambient temperatures and to minimize problems associated with weather forecasting.

- **Status of the reservoirs:** The temperature of release water depends on storage and release options. Even if a reservoir is close by, downstream temperature will not be reduced if storage is depleted and the accessible water is warm.

- **Downstream water demands:** Incremental reservoir releases are sometimes diverted. This problem is most acute under dry conditions and when the release cannot be protected, such as occurs when water rights cannot be enforced.

- **Status of the population:** The benefit derived from a unit of temperature reduction depends on the location, condition, and size of a population. Other environmental factors can interact with temperature; for example, poor feeding conditions could justify lower water temperatures. A large proportion of smolts might use the Delta for rearing habitat in wet years, while most may stay upstream to rear in dry years (Hagar 1992).

- **Forecast weather conditions over the travel time:** Weather conditions will influence the effect of releases for temperature control.

Releases from Folsom Reservoir on the American River are frequently most effective for reducing water temperatures at Freeport. However, temperatures unfavorable for salmon migration sometimes occur just above the confluence of the Sacramento with the American River. If more water was released from Folsom Reservoir and releases from Oroville or Keswick were decreased accordingly, then even more unfavorable temperatures could occur upstream of the American River. Therefore, a strict temperature standard at Freeport may be counterproductive unless a standard on the river near Sacramento also can be implemented.

7.11 INCREASE STORAGE TO REDUCE RELEASE TEMPERATURES

Increasing storage in reservoirs reduces the temperature of river releases because outlets then draw from deeper water. Increased storage during the runoff season also increases the risk of warmer surface water spilling over spillways. Storage levels can be increased by delaying or reducing releases or by increasing reservoir inflows by increasing releases from an upstream reservoir.

Hydrosphere (1991) reported on PROSIM and USBR temperature model results in which shortages to agricultural contracts were increased in dry and critical years to keep more water in storage and to provide for an increased minimum flow requirement at Keswick. PROSIM estimated that storage in Lake Shasta increased an average of 6.5 percent and as much as 36 percent during the critical 1930 to 1936 period. (The hydrology of the 6.5 year critical period is often used in planning studies because it is the worst drought on record.) The study estimated that temperatures at Red Bluff were reduced, but results for Freeport were not provided. Power supply was incidentally increased as a result of the increased storage.

7.12 CHANGE TIMING OF RELEASES FOR DELTA PUMPS

Temperature conditions in the Delta could be improved by changing the timing of upstream storage releases for Delta export. Currently, Central Valley Project and State Water Project pumping is limited to 6,000 cfs or less during May and June to comply with D-1485 criteria for striped bass survival. These criteria could result in conditions that are detrimental to salmon in the Sacramento River and Delta to the extent that less water is released from Sacramento Basin reservoirs for export.

Temperature standards and operations would interact with operations of the Delta cross-channel. Closing the cross-channel would increase flows down the mainstem of the Sacramento River and, presumably, would reduce downstream temperatures. Kjelson et al. (1989) found that "a relatively large increase in survival can be gained at lower water temperatures by eliminating high levels of diversion at Walnut Grove, but relatively little can be gained at higher water temperatures". The influence of tidal stage on diversion of young salmon through the cross-channel has been studied (Brandes 1992). Research in other basins has shown that young salmon tend to migrate at certain times of the day (Hagar 1992). If similar patterns occur in the Central Valley, it may be possible to improve management of the cross-channel gates with temperature management to reduce diversions of fish into the central Delta.

7.13 COMBINATIONS OF MEASURES AND ANALYSES

Rowell (1990) calculated the combined effect of four temperature reduction methods: increased riparian shading, elimination of agricultural drainage, the Shasta temperature control device, and the bypass around the Thermalito forebay and afterbay. The combination of these measures reduced the temperature at Freeport by an average of 1.5° F in May, 1.4° F in June, 1.1° F in September, and 1.1° F in October. However, the simulation assumed that the Shasta temperature control shutter would operate in August, September, and October. Consequently, simulated temperatures were warmer during the other summer months. The device could actually be operated to provide cooler water during May and June, but this would detract from temperature goals in other seasons.

Kelly et al. (1991), Rowell (1990) and Green (1991) reported on reservoir release simulation experiments using DWRSIM and the USBR temperature model (144C). The purposes of run 144C were to 1) obtain mean maximum monthly temperatures of 63° F in May and 67° F in June at Freeport, 2) to close the Delta cross-channel in May and June, and 3) to keep the frequency of Shasta storage below 3 million acre feet, the same as in the base studies.

The model simulated average temperature reductions at Freeport of about 1.3° F in May and 0.5° F in June, but monthly temperature reductions were as great as 6° F. These deductions frequently occurred in the driest years when most needed by salmon. However, average July through September water temperatures at Red Bluff were increased by an average of 0.5-1.0° F with maximum increases of 6° F. These increases would be detrimental to spawning and rearing of winter run salmon in the upper Sacramento.

Using the smolt survival results of Kjelson et al. (1989), the authors estimated a 6 percent increase in smolt survival. Since only 25 percent of smolts survived in the base case, the number of smolts surviving increased by 24 percent (.06/.25). Run 144C resulted in a 6 percent reduction in average Delta exports in comparison to the base case (6,149 acre feet were exported in the base case and 5,795 acre feet in run 144C).

Hydrosphere (1991) used the USBR temperature model and PROSIM to simulate the results of critical habitat designation for the winter-run chinook. Their modified case included temperature control devices in the Trinity system, the Shasta temperature control device, an increased minimum flow standard in May through October, and increased reservoir storage through reduced deliveries. An average temperature reduction of up to 3.5° F at Keswick was estimated for September. An analysis of these results using the CPOP model (BioSystems 1991) found that the fall run incidentally benefitted from these measures. The average annual catch of fall-run chinook was increased by 36,000 fish.

These studies show that combinations of operations could provide reduced water temperatures in the Delta throughout the salmon migration season. Although temperature reductions may seem small, the biological benefits may be substantial. The affects of operations on temperature are somewhat cumulative, and impacts on salmon vary substantially depending on background conditions. Over the years, operational changes might increase the size of some runs, but tradeoffs between runs might result from operations that merely change the timing of use of limited cold-water stocks. The trick for use of water for Delta temperature control is to avoid negative impacts on other species and water users by more efficient management.

7.14 MONITORING ACTIVITIES

Temperature control operations could be more effective if the operations were tailored to the location and status of populations. The USFWS conducts smolt abundance surveys in the Delta. Historically, salmon fry populations were monitored by seining from shore in the Delta during January to March, and smolts were sampled by trawling at Chipps Island and near Sacramento from April through June. As of December 1, 1991, the methodology was changed and mid-water trawls are now conducted from December through June to monitor smolt and fry populations concurrently (Brandes 1992).

These surveys are used to obtain abundance and survival data, and the results of these surveys can affect the operation of the cross-channel gate. When fry are abundant in the Sacramento area, the USBR is notified and the cross-channel gates may be closed. Abundance of fry near Sacramento could also provide a cue for increased storage releases to reduce temperatures and hasten outmigration.

8.0 SUMMARY AND DEVELOPMENT OF PLANS FOR TEMPERATURE CONTROL

Our analyses and numerous other studies have found that Delta water temperatures can be affected by reservoir operations. The regulation of Delta water temperatures with storage releases could have beneficial or detrimental effects on many other water uses.

In the past, operational and economic analyses have focused on a limited set of impacts. To fully investigate the value of operational changes, all beneficial uses should be simultaneously considered. All benefits and costs, not just the obvious or easily measured, should be counted. All facilities in the basin should be included, not just Central Valley Project and State Water Project facilities. The best solutions will be those that consider all potential facilities as well as ways in which they might work together. In short, analysis of the "reasonableness" of operations should be more encompassing than in the past.

We are concerned that the water temperature standards provided in the WQCP are too simplistic to be useful and could be counterproductive. If implemented with stored water, the standards could make conditions worse for salmon by depleting limited supplies when salmon are not present. Also, limited supplies might best be used for up-river temperature control. If supply responsibility is shifted among reservoirs to obtain Delta standards, upriver water temperatures could be increased. Temperature conditions are especially poor in the Sacramento River just above its confluence with the American River, so a temperature standard for this reach might be useful. Poor temperature conditions in this area may justify research on ways to decrease temperatures there.

Many water control operations that could reduce Delta water temperatures have been investigated. Few experiments have been conducted to test their feasibility, and information is often available only from models or has been generated incidental to operations for other purposes. Nonetheless, these models and existing data should be evaluated in more detail to determine circumstances in which operations might provide temperature reduction at minimal costs to other water users.

We suggest that USEPA obtain detailed results of runs 144C and 144C.test (a DWRSIM run using Oroville Reservoir to obtain Delta temperature goals) and these results should be inspected for more information than is provided by the summaries discussed here. Kelley, Greene and Mitchell (1991) may provide a useful summary. Also, the daily temperature data from Freeport and Vernalis summarized in this report might be analyzed in more detail to determine how operations and weather affect Delta water temperatures.

This report has shown that there are many potential changes in operations and structures that would reduce Delta water temperatures. We suggest that ongoing water temperature studies and programs upriver be monitored to determine their progress, and operations and salmon experts should be contacted to discuss some of the ideas developed in this report. These discussions should cover:

- Integration of Delta smolt abundance surveys into operations decisions.

- Improvement of monitoring and forecasting of weather and water temperatures to assist in management decisions.

- Management of reservoir releases and storage for joint benefits.

- Analysis of the costs and joint benefits of measures that would keep more water in reservoirs during dry periods.

- Continuation of use of pulse flows to reduce temperatures and hasten outmigration of hatchery smolts.

- Analysis of operations on the San Joaquin River to improve river temperature conditions.

- Modification of irrigation practices to reduce warm irrigation drainage during May, June and September.

The Lake Shasta temperature control shutter has been studied in great detail and is needed to improve upriver conditions for the four races of chinook salmon using the Sacramento River. The other structural measures should be analyzed in more detail before financing, construction, and implementation. Most structural measures could be implemented within three to ten years. Information needs include:

- Analysis and planning for Trinity system improvements, as well as their financing and construction if feasible.

- Analysis of Folsom Reservoir modifications to improve temperature control.

- Further study of water quality aspects of the Yolo bypass project and the potential for economical construction considering all joint benefits.

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APPENDIX A REGRESSION RESULTS TO PREDICT SPRING WATER TEMPERATURES AT VERNALIS AND FREEPORT

TEMPERATURES AT FREEPORT
reported in °F

APRIL 1974-1986 data
Significant water year types

Regression Output	Constant	53.55222
	Std Err of Y Est	1.955533
	R Squared	0.743439
	No. of Observations	387
	Degrees of Freedom	379

	Above	Wet	Day	Year	Sacramento	American	Feather
X Coefficient(s)	-1.99405	-2.271909	0.133742	0.332316	-6.6E-05	-0.00015	-5.87E-05
Std Err of Coef.	0.355548	0.324082	0.012372	0.028403	1.08E-05	3.65E-05	2.35E-05
T-stat	-5.608	-7.008	10.810	11.700	-6.137	-4.097	2.504

APRIL
No water year types

Regression Output	Constant	54.37061
	Std Err of Y Est	2.083178
	R Squared	0.707316
	No. of Observations	387
	Degrees of Freedom	381

	Day	Year	Sacramento	American	Feather
X Coefficient(s)	0.109895	0.301358	-0.00011	-0.00021	0.000127
Std Err of Coef.	0.012707	0.029275	9.6E-06	3.78E-05	2.25E-05
T-stat	8.648	10.294	-11.426	-5.431	5.626

MAY 1974-1986 data
Significant water year types

Regression Output	Constant	59.54661
	Std Err of Y Est	1.955867
	R Squared	0.691693
	No. of Observations	400
	Degrees of Freedom	392

APPENDIX A

REGRESSION RESULTS TO PREDICT SPRING WATER TEMPERATURES AT VERNALIS AND FREEPORT

REGRESSIONS OF DAILY WATER TEMPERATURE (CELCIUS) AT VERNALIS ON WATER YEAR TYPE, YEAR (1961=1), FLOW (CFS), AND DAY OF MONTH

APRIL

Not 1964-1968, and 1971

Regression Output		
	Constant	12.20926
	Std Err of Y Est	2.918357
	R Squared	0.330693
	No. of Observations	649
	Degrees of Freedom	644

	Wet	Year	Flow	Day
X Coefficient(s)	-2.57899	0.19301	-4.8E-05	0.073984
Std Err of Coef.	0.245373	0.014725	1.23E-05	0.013264
T-stat	-10.5105	13.10799	-3.85846	-5.577699

APRIL

No water year types

Regression Output		
	Constant	11.4636
	Std Err of Y Est	3.156309
	R Squared	0.215882
	No. of Observations	649
	Degrees of Freedom	645

	Year	Flow	Day
X Coefficient(s)	0.187755	-5E-05	-0.075797
Std Err of Coef.	0.015916	1.33E-05	0.014344
T-stat	11.7966	-3.72772	5.28403

MAY

Not 1963-1968, and 1971

Regression Output		
	Constant	14.709776
	Std Err of Y Est	3.193804
	R Squared	0.243236
	No. of Observations	638
	Degrees of Freedom	633

	Wet	Year	Flow	Day
X Coefficient(s)	-1.89933	0.173881	-3.9E-05	0.069156
Std Err of Coef.	0.273826	0.016041	1.63E-05	0.014073
T-stat	-6.93626	10.83977	-2.39531	4.913965