Water Quality and Water Quantity Needs for Chinook Salmon Production in the Upper Sacramento River

Prepared by the
U. S. Fish and Wildlife Service
and
the California Department of Fish and Game
for the 1987 Hearing Process on the
San Francisco Bay/Sacramento-San Joaquin Delta Estuary

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INTRODUCTION

The work plan adopted by the State Water Resources Control Board for the hearing process on the San Francisco Bay/Sacramento-San Joaquin Delta Estuary has identified issues that relate to the fishery resources in the Sacramento River upstream of its estuary. This report addresses the water needs of the fishery resources that depend on the Sacramento River in the reach between Shasta Dam and the its confluence with the Feather River (Figure 1). The water needs in Shasta Lake for warmwater fish are not considered. Within this reach of the river, the Water Quality Control Plan for the Sacramento Basin (Basin Plan), as adopted by the Central Valley Regional Water Quality Control Board and approved by the State Board and U.S. Environmental Protection Agency, identifies beneficial uses of fish migration, spawning, and cold water habitat (Central Valley Regional Water Quality Control Board 1975). The Basin Plan also identifies water quality objectives for temperature and control of toxicity and dissolved metal concentrations to protect the beneficial use of cold water fish production.

The primary fishery resource that management efforts are focused on in the upper Sacramento River are the four distinct populations of chinook salmon. There are other fish species that are economically and recreationally important in the upper Sacramento River, including steelhead trout and resident rainbow trout. It is believed that the provision of water quality and water quantity needs for the chinook salmon populations will meet the needs of the other cold water species that are protected in the Water Quality Control Plan.

Under present conditions the operation of the Shasta Unit of the Central Valley Project has failed to consistently attain the water quality objectives for temperature and toxicity control as set forth in the Basin Plan. Future water allocations that increase the frequency of operating Shasta Lake at lower water surface elevations due to reduced carry-over storage will decrease the Shasta-Trinity Project's ability to provide adequate quantities of cool water to protect incubating salmon eggs and clean water for diluting heavy metal toxins; both are necessary for protecting the fishery resources in the upper Sacramento River. Most of the exceedances in the Basin Plan objectives can be attributed to a lack of adequate structural controls for release of cold water from Shasta reservoir as well as source control or dilution of toxic acid mine runoff from the Spring Creek drainage located downstream of Shasta Dam (Figure 1). Lacking these controls, the attainment of water quality objectives depends upon availability of large volumes of water in storage in the Shasta-Trinity project. Various studies have identified structural solutions that should allow attainment of the Basin Plan objectives (U. S. Bureau of Reclamation 1986; U.S. Environmental Protection Agency 1986).

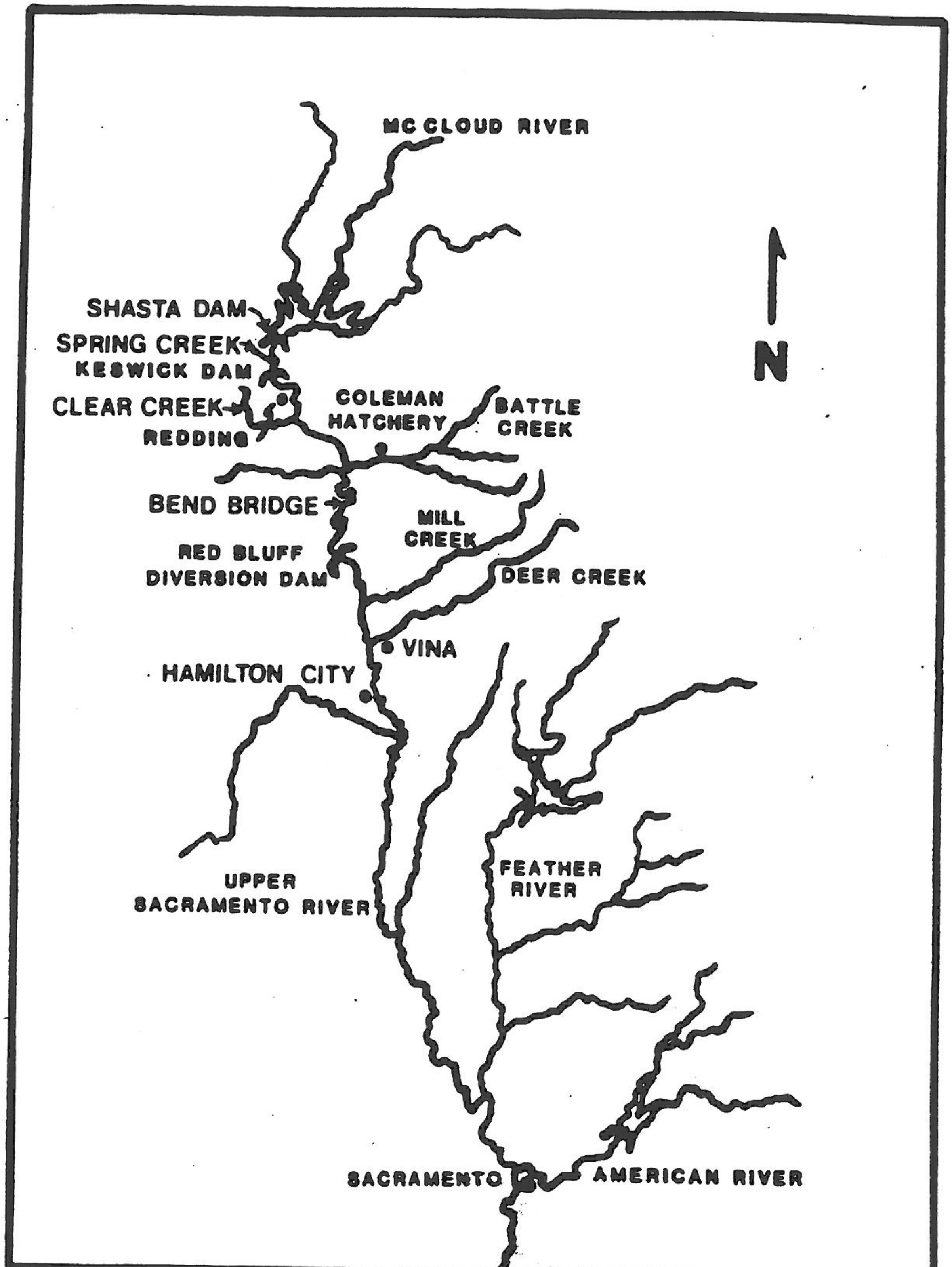


Figure 1. The Sacramento River and some of its principal tributaries

There are also water quantity needs in the upper Sacramento River that relate to providing suitable fishery habitat in the mainstem Sacramento River. Currently, fishery resource agencies are in the process of quantifying instream flows for the various life stages of chinook salmon. Fluctuating flow rates have also been a problem in the upper Sacramento River during the spawning and incubation period for chinook salmon. The quantities of water necessary to provide suitable habitat could represent a water need above current prescribed levels; however, it is recognized that optimum stream flow needs should be balanced with the needs to keep water in storage for fish and wildlife uses.

THE IMPORTANCE OF THE UPPER SACRAMENTO RIVER FOR CHINOOK SALMON PRODUCTION

The upper Sacramento River presently provides spawning habitat for more chinook salmon than any other spawning area in California. The California State Legislature recognized the importance of the spawning area in the upper Sacramento River between Keswick Dam and Woodson bridge (Vina area) (Figure 1) by the designation of this reach as one of California's major salmon spawning areas listed in Fish and Game Code Section 1505.

The salmon produced in the upper Sacramento River are of significant importance to California's commercial and sport fisheries. The economic value of the chinook salmon and steelhead trout fishery upstream of Red Bluff Diversion Dam is estimated to exceed 27 million dollars annually based on economic values developed for the Department of Fish and Game (Meyer 1985) and by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 1984a). With attainment of fishery management goals, the economic value of these resources is estimated by the same sources to increase to over 72 million dollars annually (U. S. Fish and Wildlife Service 1984a).

Recreational use in the upper Sacramento River between Keswick Dam and the Red Bluff area (Figure 1) was estimated to be 361,000 recreation days in 1980. Approximately a third of those days were spent on fishing activities (California Department of Water Resources 1980).

Life History of Chinook Salmon in the upper Sacramento River

The chinook salmon hatched in the upper Sacramento River spend most of their adult life in the ocean (2 to 4 years) returning to the upper Sacramento River and its tributaries to reproduce (spawn). These returning adults usually spawn in the same drainage where they where hatched as young salmon and related fish spawn in cold rivers and streams where there is a gravel bottom relatively free of fine sediment. The eggs are fertilized and buried in the river gravels where they incubate and hatch in a 40 to 60 day period. All adult salmon die after spawning.

The spawning areas in the upper Sacramento River include the river reach between Keswick dam (the upstream migration barrier) and Hamilton City and many of its tributaries. Prior to completion of Shasta Dam in 1944, salmon and steelhead migrated upstream of the damsite throughout most months of the year to spawning areas in the upper Sacramento River, Pit River, McCloud River, and numerous other tributaries. Stream surveys in the 1940's estimated that nearly 50 percent of the available spawning grounds were eliminated by the Shasta Project (Moffett 1949). All of the freshwater life stages of salmon and steelhead trout in the mainstem Sacramento River now depend on Shasta Dam to provide a sufficient volume of cold water that is free of toxins in the remaining habitat below the dam.

Suitable water temperature is one of the most important requirements for successful reproduction of salmon and trout. Chinook salmon eggs, both in the female prior to spawning and after having been deposited in the gravel nests following spawning, require water temperatures not exceeding 56 degrees Fahrenheit for normal development (California Department of Fish and Game 1959; 1980). When temperatures exceed 57.5 degrees F significant losses of Sacramento river chinook eggs will occur (Department of Fish and Game 1979). In addition to temperature, the developing eggs need a sufficient rate of water flow through the nests to provide oxygen and remove metabolic waste products.

After the eggs hatch, the young developing fish (alevins) stay in the nest for approximately one month before they emerge from the river gravels. The young emergent salmon (fry), averaging 1-1/2 inches in length, stay in the river or estuary for several months where they grow. The best temperatures for growth of young fish is 54 degrees F (Reiser and Bjorn 1979). After they reach approximately 3 inches or more in length, these salmon undergo physiological changes that enable them to survive the transition to salt water; at this life cycle stage they are known as "smolts". The smolt stage is characterized by a strong urge to migrate downstream to the ocean. After 2 to 4 years in the ocean they return as adults and complete the life cycle.

The upper Sacramento River is a unique watershed in California in that it supports four separate races or runs of chinook salmon. The runs in the upper Sacramento River are identified by the period in which they leave the ocean and enter the river system to spawn. They are designated as the fall, late-fall, winter, and spring runs. Reasonably accurate separation of the four runs of chinook was not possible until salmon counts and fish sampling were initiated at the fish ladders at Red Bluff Diversion Dam following the closure of its dam gates in 1966. Due to the overlap in their run timing, reproductive cycle, and subsequent early life history, the upper Sacramento River system supports all freshwater life phases of chinook salmon during any given month of the year (i.e. adult upstream migration, spawning, egg incubation, juvenile rearing, juvenile outmigration). The reproductive life cycles of the four races are shown in Figure 2.

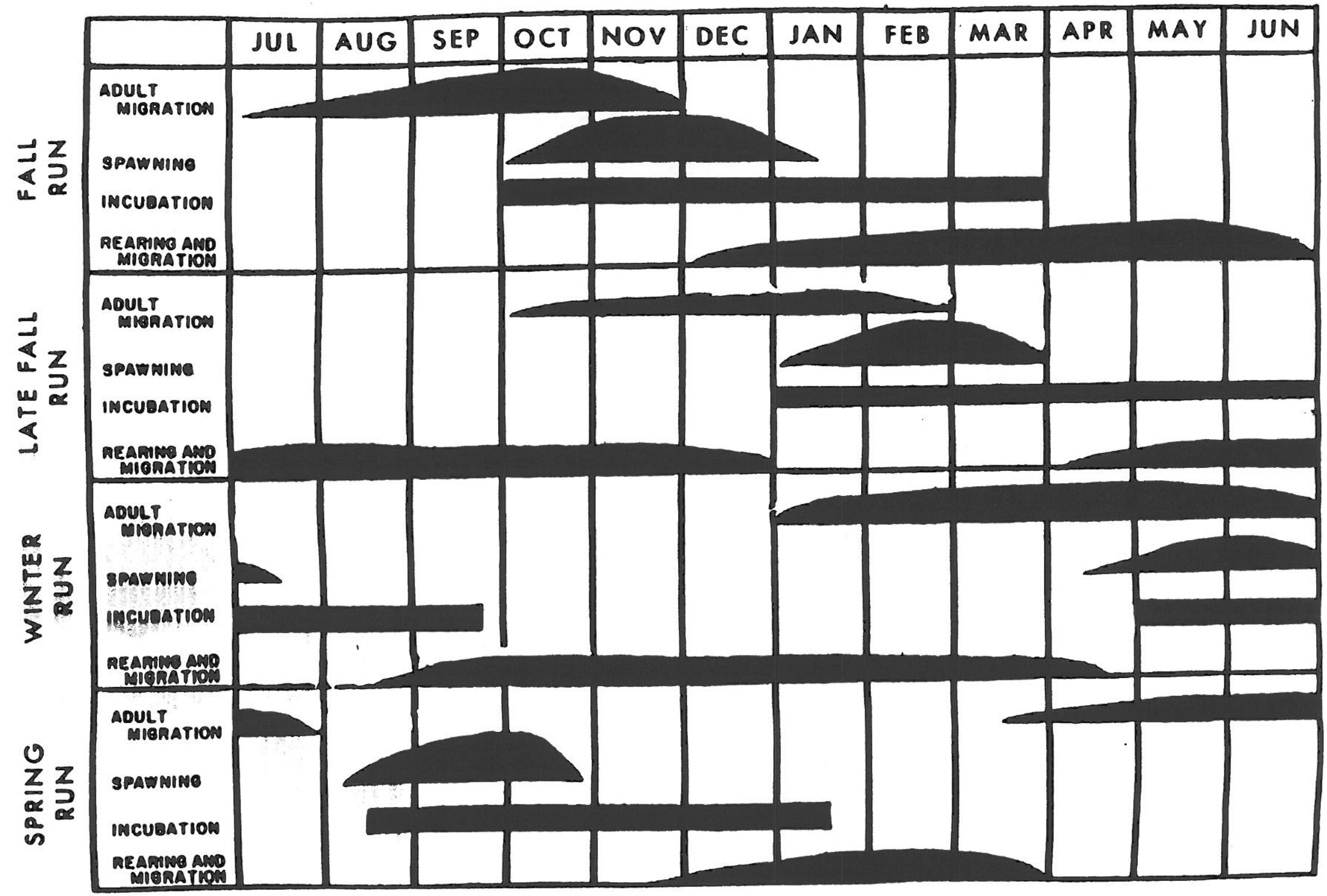


FIGURE 2. **Life history characteristics of chinook salmon in the** upper Sacramento River.

Status of Upper Sacramento River Chinook Salmon Stocks

Fall Run

The best indicator of overall trends in the fall chinook run sizes in the entire upper Sacramento River system can be obtained from the California Department of Fish and Game's annual spawning stock surveys conducted since 1956. These data show a substantial decline in fall run stocks since the late 1950's and early 1960's (Figure 3). The runs have stabilized in recent years at levels about 50 percent of the earlier years.

Spring Run

The counts of salmon passing Red Bluff Diversion Dam (conducted since 1967) are believed to provide the best indication of the overall trend in the spring, late-fall, and winter chinook run sizes. Based on these counts, spring chinook have shown dramatic fluctuations in run sizes over the last 20 years (Figure 4) and have averaged about 12,600 fish annually. There is some doubt, however, that the present-day spring run spawning in the mainstem upper Sacramento River is a true genetically distinct stock because of a significant overlap in the timing of their spawning period with fall- run chinook which may have resulted in significant transfer of genetic material between stocks (Slater 1963). In the upper Sacramento River system prior to any dams, this situation did not occur because the spring and fall runs spawned in different geographic areas of the watershed (i.e. the spring run spawned in the headwaters of the Sacramento River and upper reaches of the tributaries and the fall run spawned further downstream in the mainstem and the lower reaches of the tributaries). The two main remaining areas where significant numbers of genetically pure strains of spring-run chinook exist are in Mill and Deer Creeks (Figure 1). However, based on recent .pnll surveys, their run sizes have declined drastically in the past two decades. Mill Creek spring runs have declined 85 percent and Deer Creek spring runs have declined 80 percent during this period (Vogel 1987a; 1987b).

Late-Fall Run

Late-fall run chinook have shown a dramatic decline in their run sizes over the last 20 years (Figure 5). The runs during the 1980's are only about one-third of those observed during the late 1960's.

Winter Run

Winter-run chinook have suffered a precipitous decline since the late 1960's (Figure 6). The runs during the 1980's are only about 5 percent of

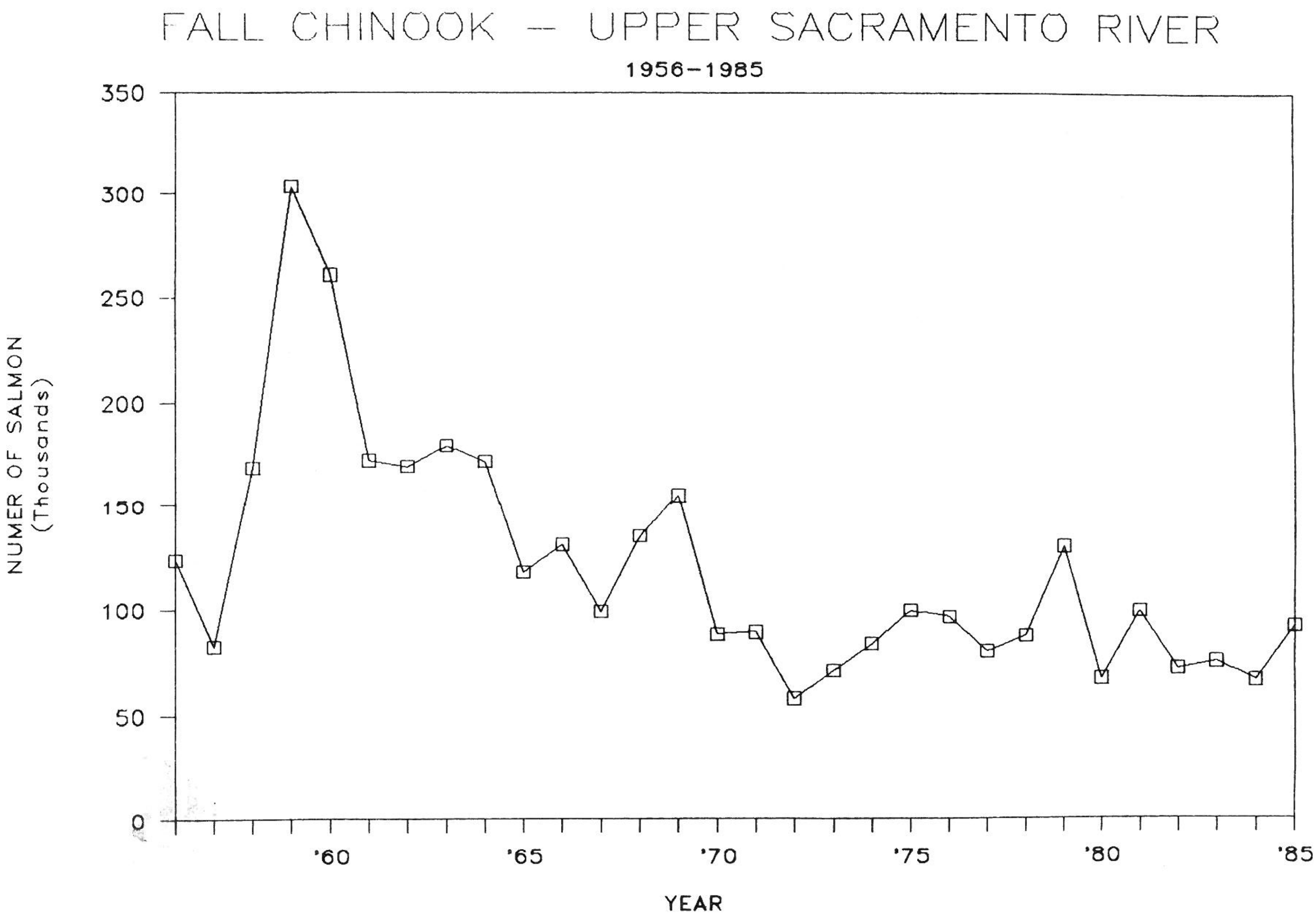


Figure 3. Spawning escapement of fall chinook salmon in the upper Sacramento River, 1956-1985.

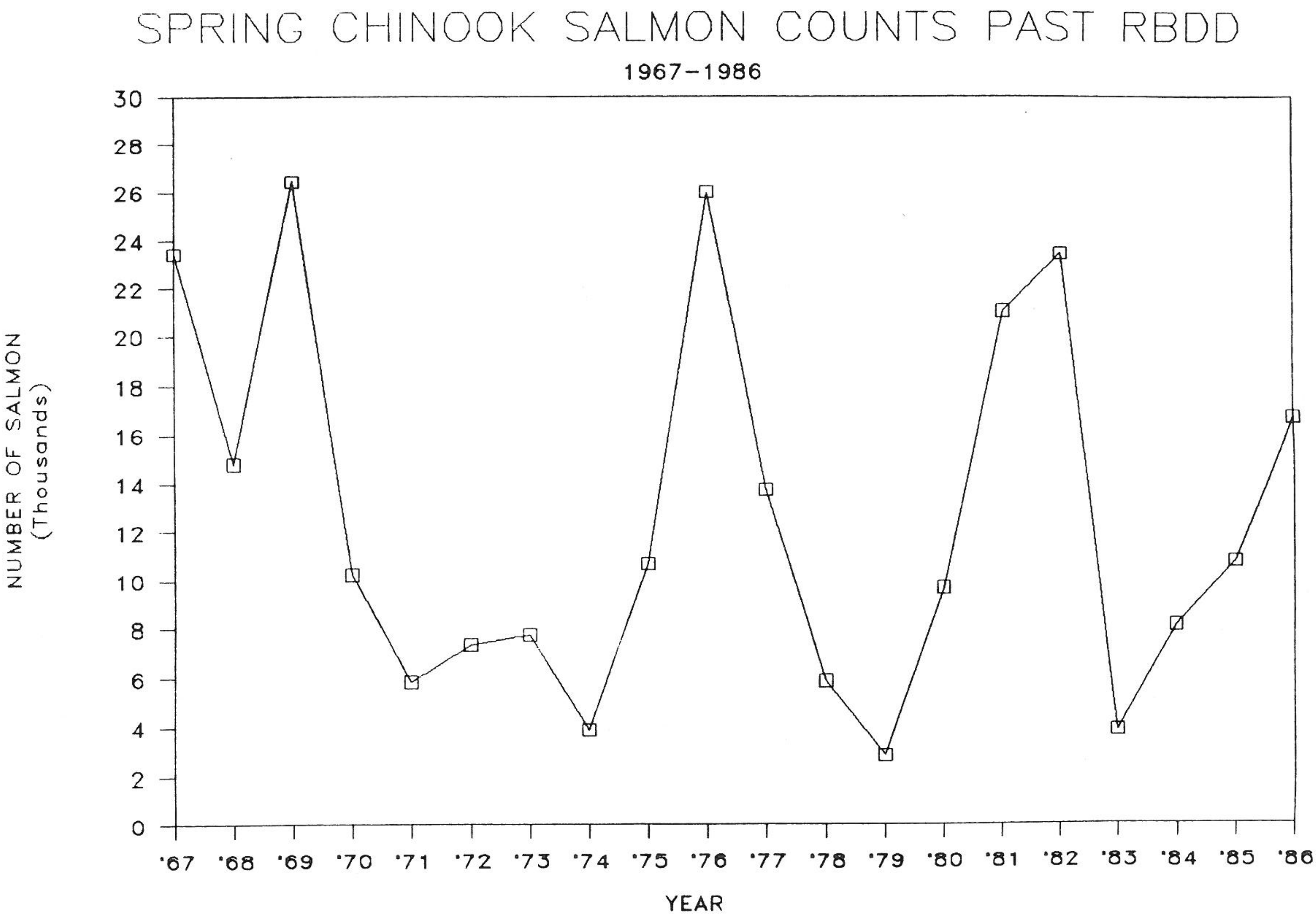


Figure 4. Counts of spring chinook salmon past Red Bluff Diversion Dam, 1967-1986.

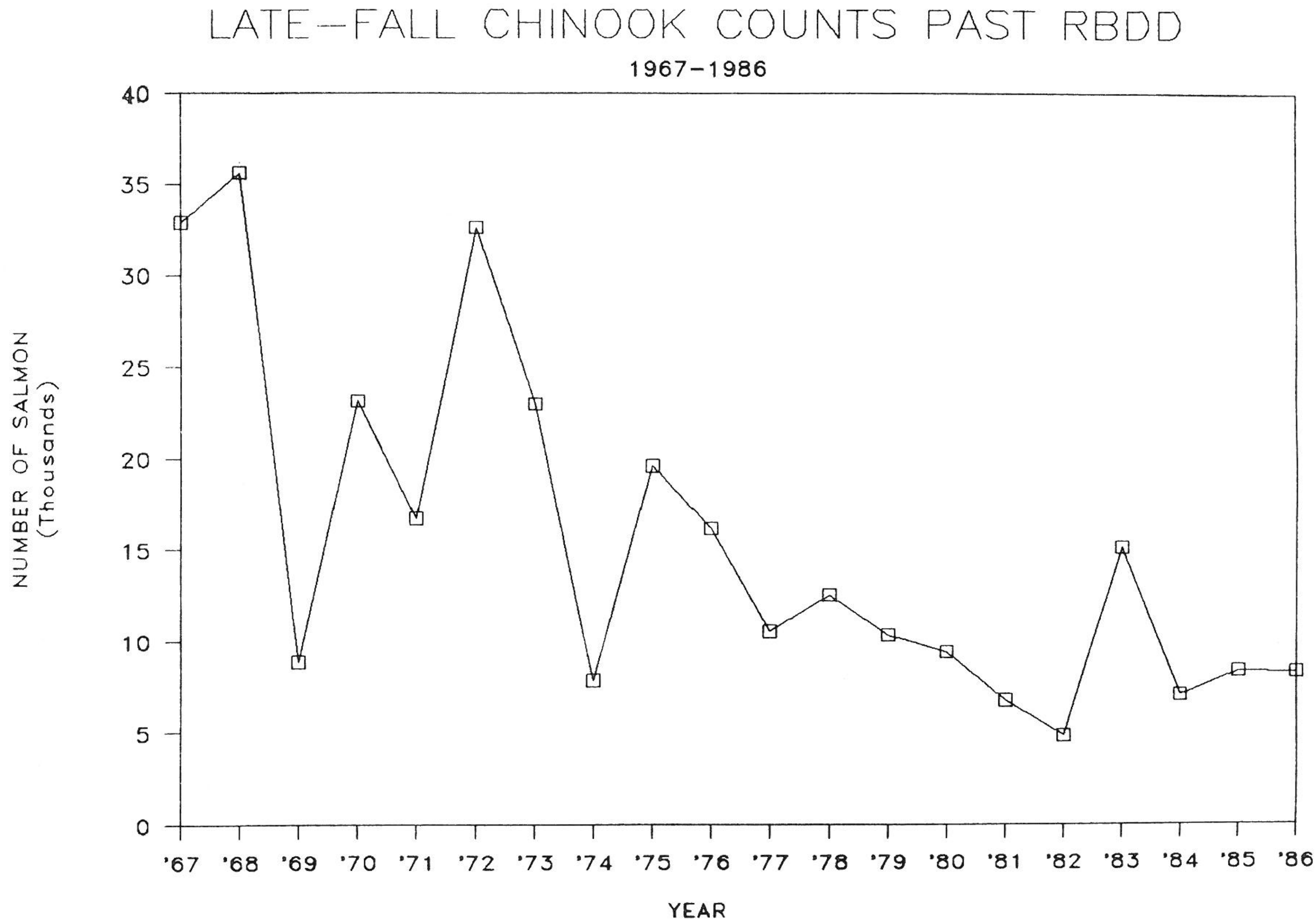


Figure 5. Counts of late-fall chinook salmon past Red Bluff Diversion Dam, 1967-1986.

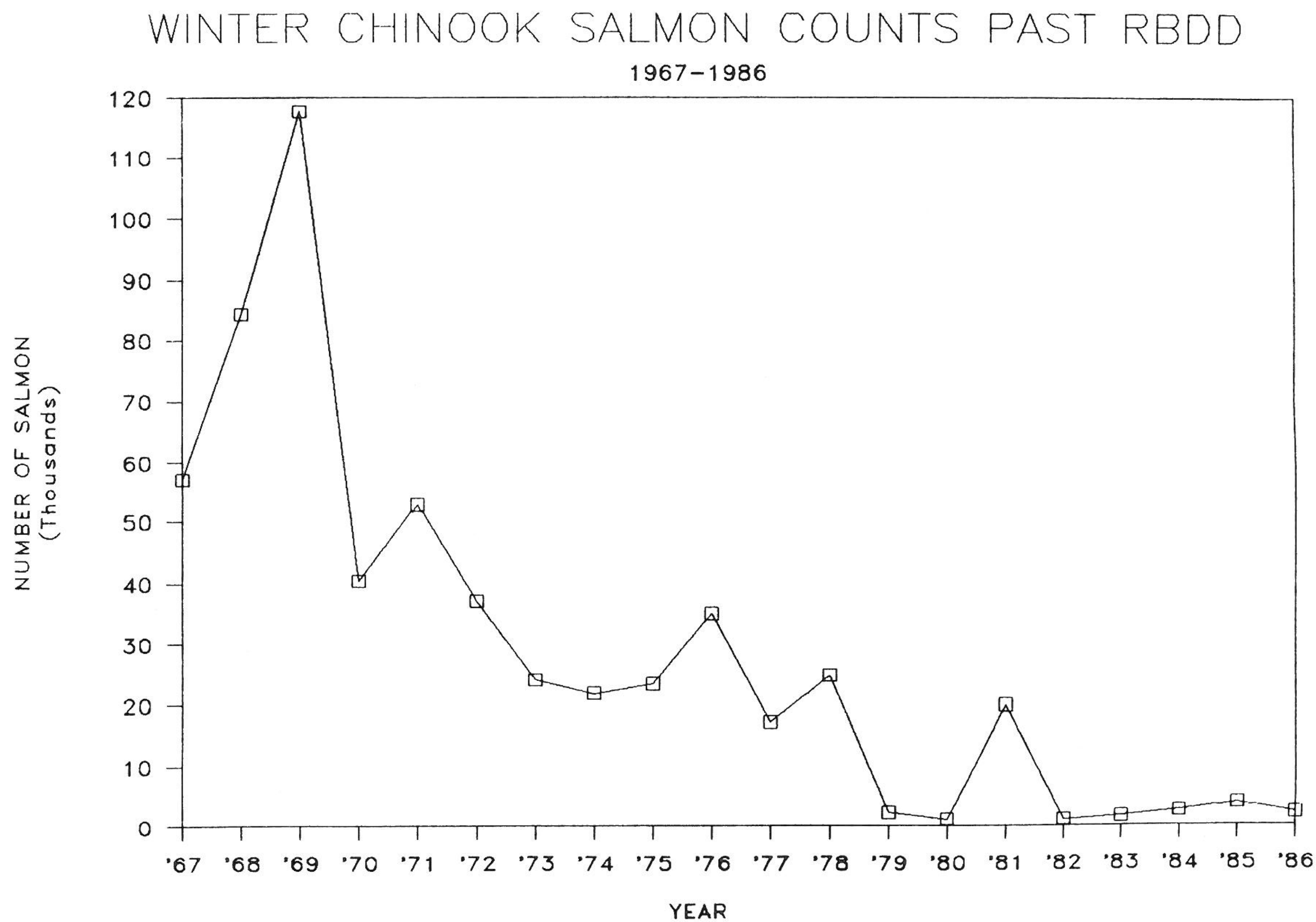


Figure 6. Counts of winter chinook salmon past Red Bluff Diversion Dam, 1967-1986.

those observed during the late 1960's. The decline is so severe that the American Fisheries Society petitioned the U. S. Department of Commerce in 1985 to list the winter run as a federally threatened species (American Fisheries Society 1985). Although the Commerce Department found the petition to be warranted and decided the winter run is a unique species according to the Endangered Species Act, it recently decided not to list the winter run primarily because of actions identified as ongoing or planned by federal and state agencies in the upper Sacramento River to restore the winter run (52 Fed. Reg. 6041, February 27, 1987). A similar petition was recently filed on state listing with the California Fish and Game Commission by the Sacramento River Preservation Trust and other conservation groups.

Role of Coleman National Fish Hatchery

Coleman National Fish Hatchery (Figure 1) was constructed in 1942 as one aspect of the mitigation for the salmon habitat eliminated by the Shasta Project (U. S. Fish and Wildlife Service 1984b). The hatchery's original objective was to help maintain a portion of chinook salmon populations lost due to Shasta Dam (in conjunction with other mitigation efforts). Today this hatchery is the only remaining element of the attempted mitigation efforts for Shasta Dam. As a result of an agreement executed in 1948, the operation, maintenance and funding of the facility, with the exception of providing power, is the responsibility of the U. S. Fish and Wildlife Service. Current and future juvenile salmon production goals for Coleman Hatchery are as follows (U. S. Fish and Wildlife Service 1984b):

Species	Size at Release (Fish/lb.)	Present Number	Future Number	Distribution Area
Fall Chinook	90/lb	12,000,000	11,000,000	Upper Sacramento River
Late-Fall Chinook	40/lb.	2,000,000	1,000,000	Upper Sacramento River
Winter Chinook	---	---	1,500,000	Upper Sacramento River
Spring Chinook	---	---	2,000,000	Upper Sacramento River

These goals are designed to increase the chinook salmon contribution to commercial and sport fisheries and increase their spawning escapement to the upper Sacramento River. Current plans call for the expenditure of an additional $15 million to renovate the hatchery to achieve these production goals. Additionally, Coleman Hatchery is a significant producer of steelhead trout for the upper Sacramento River.

Planned expansion of Coleman Hatchery will help achieve the Service's chinook salmon goals for the upper Sacramento which are as follows:

"To restore chinook salmon stocks of the upper Sacramento River drainage to levels of the 1950's (adult contribution of 673,000 fall chinook, 50,000 late-fall chinook, 80,000 winter chinook, and 130,000 spring chinook) 1/ (U. S. Fish and Wildlife Service 1982).

1/ Figures are catch plus escapement.

Based on spawning escapement estimates by the Department of Fish and Game, the contribution of Coleman Hatchery to the fall-run chinook salmon spawning escapement in the upper Sacramento River was at least 16 percent of the entire run during the 1980's (1980-1985) (Table 1).

Table 1. Upper Sacramento River Fall-Run Chinook Salmon Spawning Escapement.

	Numbers of Chinook Salmon	
Year	System Total	Coleman Hatchery
1980	67,538	9,503
1981	99,076	10,272
1982	72,191	19,525
1983	75,567	8,756
1984	98,014	21,581
1985	125,706	16,320
Mean	89,682	14,326

Salmon Restoration Programs

There are several ongoing restoration programs for chinook salmon in the upper Sacramento River basin. The State Legislature recently enacted legislation (SB 1086) instituting development of an upper Sacramento River fisheries and riparian habitat management plan. This plan is currently being developed by a group comprised of 25 representatives from government agencies and special interest groups which will submit the final plan and a proposed implementation program to the Legislature by January 1, 1989. The National Marine Fisheries Service, on behalf of the U. S. Department of Commerce, recently developed and is implementing a restoration program for the severely depleted stock of winter-run chinook salmon in the upper Sacramento River. Most elements in this program are designed to improve the fresh water habitat for winter chinook to improve their survival. The U. S. Bureau of Reclamation is currently funding the Fish Passage Action Program for Red Bluff Diversion Dam with the objective of improving passage for salmon migrating past the dam to upstream spawning areas that have cooler temperatures and improving the survival of downstream migrant salmon enroute to the estuary. This latter program is scheduled for completion in 1988.

The U.S. Bureau of Reclamation is also conducting the Tehama Colusa Canal Diversion and Fish Passage Study which includes the design and construction of new fish screening facilities to replace the existing inefficient facilities at the Tehama Colusa Canal headworks. Construction is scheduled to be initiated by January 1988. The U.S. Environmental Protection Agency Superfund Program is in the process of implementing major pollution control measures on the Iron Mountain Mine pollution problem in the upper Sacramento River. A salmon and steelhead restoration program is planned by the Department of Fish and Game on Clear Creek (Figure 1) that includes instream flow reservations.

POTENTIAL EFFECTS OF THE 1987 HEARINGS ON FISHERY BENEFICIAL USES IN THE UPPER SACRAMENTO RIVER BASIN

The allocation of water from the Shasta-Trinity Unit of the Central Valley Project through the Bay/Delta Hearing Process may affect fishery production in the upper Sacramento River in the following areas:

1) Provision of minimum instream flows forthe various salmon life stages.

2) Attainmentof Basin Plan objectives for temperatures required for the beneficial use of salmon spawning and cold water fish habitat.

3) Attainment of Basin Plan objectives for control of toxicity and dissolved metal concentrations required for the protection of the most sensitive life stages of salmon and steelhead.

The mechanism by which these three areas are affected by increased water allocations is through decreased availability of water at the times needed due to either 1) low reservoir storage after export during the irrigation season or 2) diminished carryover storage decreasing overall availability of water during the subsequent water year.

The following is a discussion on each of these items.

1) Instream Flow Requirements

There have been few data developed on the specific instream flow requirements for the various life stages of chinook salmon in the main stem upper Sacramento River. The emphasis in the past has been on the maintenance of adequate salmon spawning flows.

Spawning and Incubation

According to an April 5, 1960 Memorandum of Agreement between the U. S. Bureau of Reclamation (Bureau) and the California Department of Fish and Game, the Bureau is to maintain the river flows below its dams and diversions on the mainstem Sacramento River for the maintenance of fish and wildlife resources (primarily for salmon spawning) according to the following schedule:

Time Period	Flow (in Cubic Feet Per Second) Normal to Wet Year	Critically Dry Year
January 1 through February 28	2600 cfs	2000 cfs
March 1 through August 31	2300 cfs	2300 cfs
September 1 through November 30	3900 cfs	2800 cfs
December 1 through December 31	2600 cfs	2000 cfs

An agreement between the Bureau and the Department in 1981 modified flow requirements for September 1 through February 28 to 3250 cfs to eliminate the possibility of a dramatic decrease in instream flow on December 1 and its resultant adverse impact on salmon spawning and egg incubation (California Department of Fish and Game 1981).

Brown (1977) examined flow versus spawning habitat at four spawning riffles in the upper Sacramento River and found that optimal spawning flow was around 6,000 to 8,000 cfs. Flow less than 6,000 cfs fail to inundate all usable gravels (U. S. Bureau of Reclamation 1986). The consensus of some Federal and State fishery biologists familiar with the upper Sacramento River is that, based on what little information is available, 6,000 cfs is likely the year-round optimum spawning flow for the four races of chinook salmon. The proper flow for successful egg incubation should equal or exceed the spawning flow; lower flows may adversely affect the salmon eggs by dewatering, elevated water temperatures, and/or depressed oxygen levels.

Flow fluctuations can cause mortality to both incubating eggs and juvenile fish as lowered flows result in dewatering of nests containing eggs and alevins, (Neitzel and Becker 1985) and stranding of very young fish in pools that become isolated from the river. A damaging operational pattern has been observed below Shasta Dam during water years having reduced refill potential because of low reservoir storage or reservoir inflow. For example, approximately 6,000 cfs is often present in the river during the early fall spawning period. Then, during the storage phase of reservoir operations, releases can be reduced to the minimum streamflow requirement of 3,250 cfs which dewaters incubating eggs and alevins in nests in higher gravel bars. The flow available for chinook salmon during the peak of their spawning periods should be maintained throughout the incubation periods to prevent mortality associated with dewatering of the nests. It is not possible to achieve desired stable flows during high runoff periods when the reservoir is encroached into the flood pool and high releases are made followed by flow reductions when storage can resume.

Rapid changes in water releases from Shasta and Keswick Dams should be minimized where possible to reduce the mortality associated with stranding of juvenile fish. An existing agreement between the Bureau and the Department of Fish and Game prescribes no more than a 15 percent change in releases during a 12-hour period.

The objective of providing a stable streamflow regime for optimum spawning and egg incubation during the storage phase of reservoir operation may need to be balanced with the need to provide water in storage for other fishery purposes such as attainment of water quality objectives for fishery protection and spring-time migration flows through the Delta.

Rearing Flow

The proper flow needed for rearing of young salmon is unknown. Flows 6,000 cfs or higher would probably provide good to optimal rearing habitat for young salmon in the upper Sacramento River.

Out-Migration Flow

As young salmon naturally migrate to the ocean, adequate flow is needed to ensure their safe passage out of the upper Sacramento River, through the estuary and into the ocean. Significant numbers of young salmon have been observed migrating downstream past Red Bluff during every month of the year (Vogel 1984; U.S. Fish and Wildlife Service 1987) enroute to the lower river reaches or estuary. Although extensive data have been developed on this downstream migration since January 1982, the specified flow requirements for optimal outmigration conditions have not been determined. The environmental conditions (e.g. water diversions, water temperatures) in the river vary considerably by season which would have varying effects on the four races of chinook salmon because of their different outmigration patterns.

Fall Run. Recent data have been developed by the U. S. Fish and Wildlife Service that show that the fall-run chinook outmigration pattern varies considerably depending on the type of water year. Generally stated, it is believed that during a year with wet winter conditions, the largest proportion of the fall run move downstream in the winter whereas in a year with dry winter-time conditions most fall-run chinook move downstream in the spring (U. S. Fish and Wildlife Service 1987). In all years, a large downstream migration of hatchery fall chinook occurs following the spring-time release of smolts from Coleman National Fish Hatchery. These fish are released in the upper Sacramento River (50 percent in Battle Creek and 50 percent below Red Bluff Diversion Dam) to ensure their homing back to the upper Sacramento as adult spawners. Previous studies have demonstrated that trucking Coleman production to downstream reaches and the estuary result in considerable straying of returning adults and a reduction of returning broodstock to the hatchery (Hallock and Reisenbichler 1978, Table 2).

Table 2. Inland recoveries of Coleman Hatchery coded-wire tagged juvenile chinook released at various locations during 1982.

Tag Code	Release Location	Number Released	Recovery Year	Recovery Location: Coleman Hatchery	Battle Creek	Tehama-Colusa Fish Facilities	Feather River Hatchery	Nimbus Hatchery
06-60-28	Below Red Bluff	44,308	1983	9		2		
	Diversion Dam		1984	116		2		
	(River Mile 243)		1985					
			1986					
06-60-29	Below Red Bluff	45,817	1983	7				
	Diversion Dam		1984	90				
	(River Mile 243)		1985					
			1986					
06-60-31	Knights Landing	44,540	1983	4	7			
			1984	55	22			
	(River Mile 90)		1985					
			1986					
06-62-18	Discovery Park	89,780	1983	1			5	9
			1984	11		11	58	24
	(River Mile 60)		1985					
			1986					
06-62-19	Suisun Bay	86,877	1983					
			1984	12		2	6	26
	(River Mile 0)		1985					
			1986					

For the past three years, efforts have been made to reduce the hazards downstream migrant fall-run salmon encounter during their spring downstream migration by increasing the releases from Keswick Dam up to 14,000 cfs for brief periods during May. This measure is believed to significantly improve the survival of the outmigrants by reducing their exposure time to hazards such as water withdrawals and predatory fish (U. S. Fish and Wildlife Service 1985) yet still ensure their homing tendency back to the upper Sacramento River as adults. The brief periods of elevated flow (3 to 5 days) during the past three years were primarily intended to assist the downstream migration of Coleman Hatchery smolts; longer periods would be necessary to significantly benefit naturally-produced chinook because of their more protracted outmigration period compared to the hatchery smolts.

Late-Fall, Winter, Spring Runs. There are no available data as to the specific outmigration flow needed to ensure safe passage of late-fall, winter, and spring run downstream migrant chinook but the flow should not be less than 6,000 cfs to avoid adverse effects on spawning of other runs.

Because of the significant lack of data for specific flow requirements for the various life stages of chinook salmon in the upper Sacramento River, the Department of Fish and Game recently initiated an instream flow study to identify the specific flow needs (California Department of Fish and Game 1986). However, results of that study will not be available until 1989.

2) Water Temperature Requirements

Sacramento River water temperatures limit the geographic range where chinook salmon can successfully spawn. Although the coldest river temperatures observed in the Sacramento River are not a limiting factor for any of the four races of Sacramento River chinook, the highest water temperatures observed during the summer and fall can limit the range of successful spawning for the winter, spring, and fall runs during the July through October period of some years. Based on data developed by Combs and Burrows (1957) the tolerable temperature range for salmon egg incubation and hatching is from 42.5 degrees (F) to 57.5 degrees F. Experiments conducted by California Department of Fish and Game (1979) demonstrated that Sacramento River chinook eggs begin to experience significant mortality when water temperatures exceed 57.5 degrees F with 80 percent mortality occurring when water temperatures during egg incubation were 60-61 degrees F for a prolonged period and a 100 percent mortality at temperatures greater than 62 degrees F. At Nimbus Hatchery on the American River a 100 percent mortality occurred when chinook eggs were incubated in water above 62 degrees F (California Department of Fish and Game 1959). Physical abnormalities have been observed in fish surviving incubation at 60 degrees F (Seymor 1956).

Although cold water released from below the thermocline in Shasta Lake usually provides salmon with good water temperatures for spawning in river reaches immediately downstream of Keswick Dam, warm air temperatures during the summer and early fall often warm the river water in downstream reaches to the point where the water is no longer suitable for salmon spawning even though suitable water velocities and substrates exist at these locations. The downstream limit of suitable temperature for fall-run chinook in most years is around Hamilton City and for winter and spring run salmon it is around Red Bluff Diversion Dam (Figure 1). Undelayed passage of winter and spring run salmon through Red Bluff Diversion Dam is needed to assure egg survival. The California State Legislature recognized the importance of the river reach between Keswick Dam and Vina by designating this reach as a salmon spawning area in Section 1505 of the Fish and Game Code. Additionally the Central Valley Regional Water Quality Control Board Basin Plan specifies a water temperature objective of 56 degrees F throughout this designated spawning area during all times of the year (Central Valley Regional Water Quality Control Board 1975).

Examination of the available water temperature records for the spawning area above Red Bluff at Bend during the critical July through October spawning period demonstrates (Figure 7) that during the last 15 years there has been a number of occurrences of temperatures exceeding the Basin Plan Objective (56 degrees F), the mortality threshold temperature (57.5 degrees F), and temperatures capable of causing over 50 percent mortality (60 degrees F). Interpretation of these data for actual mortality estimates requires further analysis since these data do not represent consecutive exposure periods.

Beginning in late spring, large releases from the Shasta-Trinity project maintain cool water temperatures through the early summer. Temperatures gradually increase through late summer and early fall as water elevations in Shasta Lake drop to the point that the single level intake to the powerhouse cannot reach the colder water below the intake elevation; additionally, the elevations of colder water itself drops. During the fall, the warmer upper reservoir layers can be discharged under low reservoir conditions. The tendency of an increased occurrence of temperatures unsuitable for successful spawning to be associated with lower reservoir storage elevations is graphically illustrated in Figure 7. This graph compares river water temperatures among years having minimum storage elevations in Shasta that are normal, slightly low, and very low as determined from water storage records shown in Figure 8. The mean monthly air temperatures recorded at the Redding weather station (U. S. Weather Service, Redding, CA) were examined to determine that air temperature was not a causative factor in the observed trends.

Figure 7 Duration curves of daily average temperatures in the Sacramento River at Bend Bridge during the months October, July, August, and September for water years having minimum fall reservoir elevations that were normal (water years 1970-75, 1980, 1983, 1984), low (1985, 1986) and very low (1976, 1977, 1978). Data source: U. S. Geological Survey surface water records, California Department of Water Resources monitoring reports and California Department of Fish and Game.

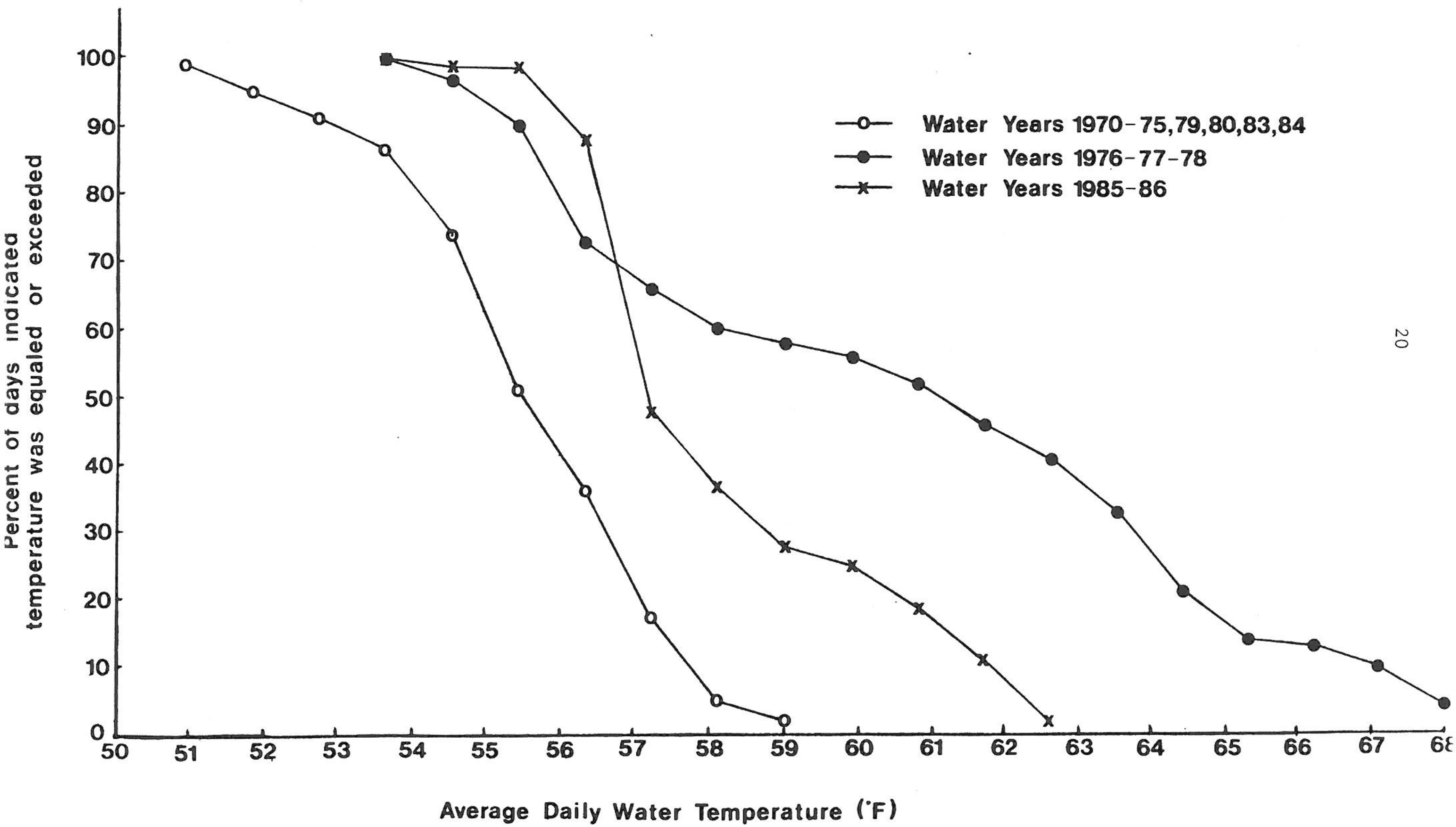
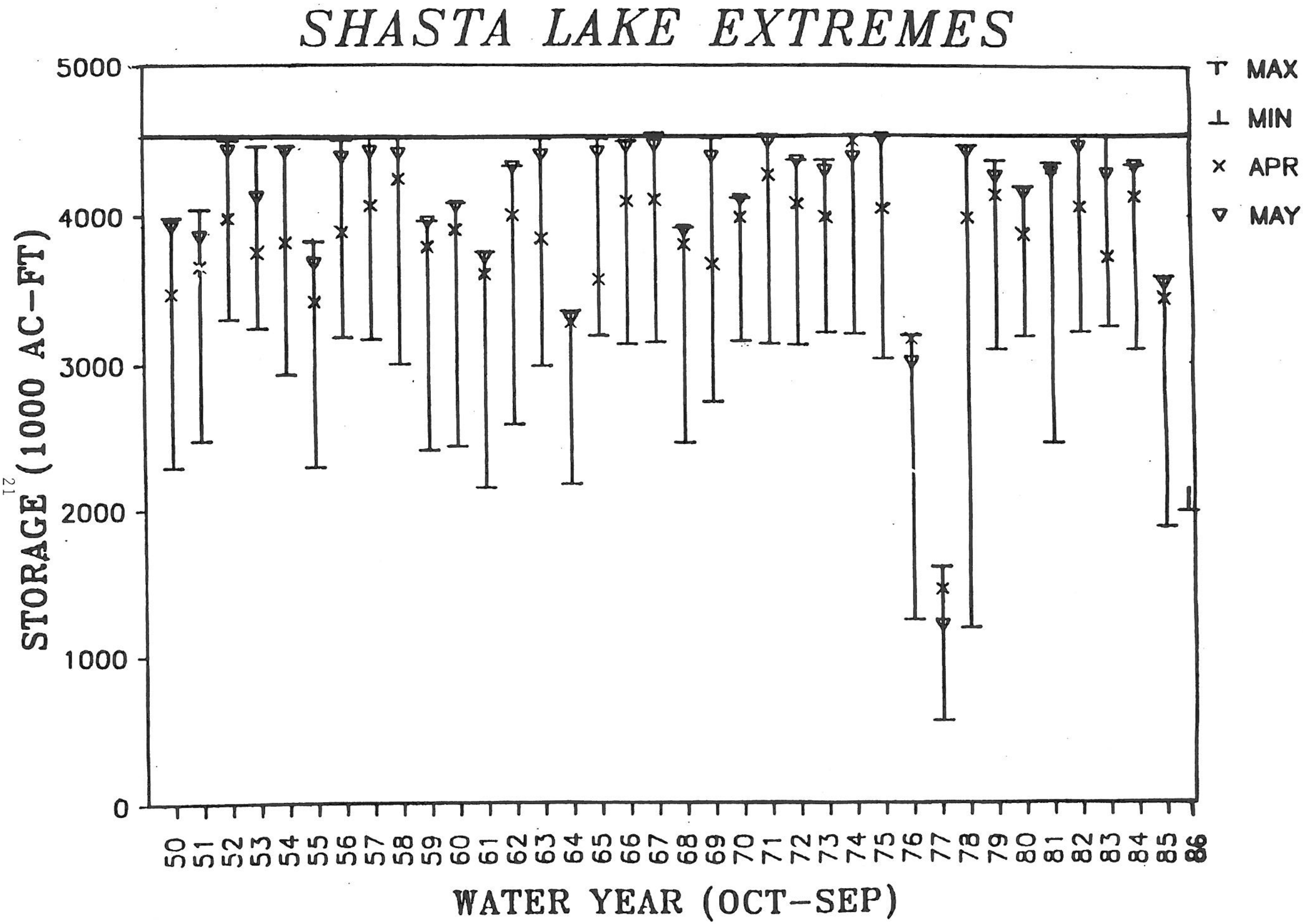


Figure 8. Water storage in Shasta Lake, 1950-1986. (Data source, U. S. Bureau of Reclamation).



The occurrence of prolonged temperature exceedances can have disastrous long reaching effects on the salmon populations, even though such occurrences represent a small portion of the temperature record observed over the years. This type of population destruction was demonstrated with the winter run salmon during the 1976-1977 drought years when the average daily temperatures equaled or exceeded the value capable of destroying over 50 percent of the developing eggs over 58 percent of the time during the spawning and incubation period as measured at Bend. The progeny for winter-run chinook showed very poor survival as shown by their poor return in 1979 and 1980 (Figure 6).

As early as the 1940's fishery resource agencies recognized that future water demands could result in a loss of cold water temperatures causing mortality problems for salmon dependent on mainstem spawning (Hanson et al 1940; Moffett 1949; Department of Fish and Game 1971). The export of large amounts of stored water during the dry season significantly increases the risk of acute temperature problems the following year due to minimal carry-over storage.

In recent years, the severity of the temperature problem during years with low water storage in Shasta Lake has been reduced by an operational change that increases the relative amounts of cold water from the Trinity River Diversion received by the upper Sacramento River. Structural solutions have been proposed at Shasta Dam including a permanent multi-level outlet at Shasta Dam (U.S. Bureau of Reclamation 1986) and a temporary curtain for use during the 76-77 drought (CH2M Hill 1977). There is also an existing outlet below the Shasta powerhouse inlet that can deliver large amounts of cold water; however, at the present time this outlet cannot produce power. A continued dependable supply of cold water from Trinity Dam to the Sacramento River is also necessary for successful temperature control. Lacking structural solutions, the only method of assuring compliance with Basin Plan Objectives is to maintain a sufficiently high reservoir pool for the powerhouse intake to release water from below the thermocline.

Attainment of a temperature reduction as small as two degrees Fahrenheit can significantly increase chinook salmon egg survival because, on the average, most of the temperature exceedances at Bend (44 river miles downstream of Keswick Dam) are very close to the threshold temperature that causes mortality. By examining Figure 7 it can be seen that if the average daily temperature had been two degrees Fahrenheit cooler there would have been significantly less exposure to temperatures equal or exceeding threshold mortality values. If the average temperature had been reduced four degrees Fahrenheit at Bend the frequency of occurrence for temperatures causing severe mortality in excess of 50 percent would have been extremely low except for the drought. Without structural modification and minimum reservoir pools in the Shasta-Trinity Project, additional water allocations will exacerbate the temperature problems.

Attainment of the Basin Plan objective of 56 degrees F will benefit other salmon life stages besides eggs and fry. At this cooler temperature young fish in the wild are expected to experience better growth and better food supplies (Davis 1974). An additional benefit of cooler temperatures to fish is that many of the more important diseases afflicting chinook salmon decrease in virulence as temperatures decrease (Wood 1979).

3) Attainment of Water Quality Objectives for Toxicity and Dissolved Metals

The acid mine drainage from past mining activities in the Spring Creek watershed has polluted the upper Sacramento River since the early 1900's. The mine drainage, principally from Iron Mountain Mines, enters the Sacramento River a short distance below the present site of Shasta Dam (Figure 1). Peak discharge of acid mine drainage occurs during periods of high runoff during the wet weather season. Prior to the construction of the Shasta-Keswick Dam Complex in the 1940,s, natural high water flows from the upper Sacramento River basin coincided with those from Spring Creek, automatically diluting the drainage from the mine. Fish kills were reported prior to Shasta Dam during the time the large smelters discharged effluent, slag and other wastes directly into the river (Smith 1902).

When Shasta Dam was completed, high flows during winter storms were held for storage in Shasta Lake while those from Spring Creek went unobstructed into the Sacramento River. The Shasta Project also acted as a barrier forcing all the upper Sacramento River salmon and steelhead to spawn below the acid mine drainage discharge where historically only a portion of the fish had spawned. Large numbers of salmon were killed in response to the increased concentration of dissolved metals and acid; in one recorded incident one third of the chinook salmon run died before spawning (Department of Fish and Game 1953).

The discharge of Spring Creek acid mine waste was partially controlled by the construction of the Spring Creek Debris Dam in 1963. This project allows for temporary storage and controlled release of the contaminated Spring Creek water. The amount released is dependent on the water available from Shasta Reservoir releases upstream. This release manipulation scheme is stipulated in a 1980 Memorandum of Understanding between the U.S. Bureau of Reclamation, State Water Resources Control Board and Department of Fish and Game. The agreement, currently in effect, stipulates that the Bureau will operate the Shasta Unit facilities to meet specified water quality goals provided the required releases do not interfere unreasonably with authorized project uses.

Since Spring Creek Debris Dam has been put into operation mortality of adult, juvenile and fingerling trout and salmon still occurs in the upper Sacramento River (U. S. Environmental Protection Agency 1986). Concentrations of copper and zinc in the upper Sacramento River have equaled or exceeded values capable of killing 10 percent of a population of young chinook salmon in approximately 18 percent of the 924 weekly measurements taken during the past seven years by the U. S. Bureau of Reclamation (Central Valley Regional Water Quality Control Board files). This record is based on a comparison of the average dissolved fraction of metal (as estimated from the average ratio of dissolved to total metal in 219 samples taken by the Regional Board) to toxicity data developed by Fish and Game (Finlayson and Verue 1982; Finlayson and Ashuckian 1979). Interpretation of these data for acute mortality requires further analysis to examine exposure periods and species (steelhead are more sensitive than salmon). Additionally, exposure of juvenile salmon to lower concentrations of copper and zinc, cause chronic toxicity effects including impairments of the immune system (Stevens 1977), smoltification problems (Lorz, et al. 1978), and reduced growth (Seim et al. 1984; and Farmer et al. 1979). In instances where Spring Creek Reservoir fills to capacity and spills uncontrollably, extremely high concentrations of copper, zinc, and cadmium have been measured in the river (Table 3). Typically, toxicity problems occur following water years having poor carryover storage in Shasta Reservoir and releases to the Sacramento River are minimal to low.

The Basin Plan for the Sacramento River contains a general toxicity objective that states: "All waters shall be maintained free of toxic substances in concentrations that are toxic to or that produce detrimental physiological responses in human, plant animal or aquatic life. Compliance with this objective will be determined by use of indicator organisms, analyses of species diversity, population density, growth anomalies, bioassays of appropriate duration or other appropriate methods as specified by the Regional Board." The Department of Fish and Game has conducted a series of laboratory and on-site field toxicity tests to determine acute levels of metal toxicity in the upper Sacramento River. This data has been used to develop release criteria for dilution manipulations that would prevent acute toxicity downstream of Keswick Dam. The studies were also used to establish water quality objectives for the complete protection of the most sensitive life stage of steelhead trout and chinook salmon in the upper Sacramento River (Finlayson and Verue 1982; Finlayson and Wilson In press). In 1984, the Regional Board adopted Basin Plan water quality objectives for copper zinc, and cadmium in the Sacramento River (Table 3) based on the criteria developed by the Department of Fish and Game (Resolution 84-054). The Basin Plan objectives were approved by the State Board (Resolution 84-55) and the U. S. Environmental Protection Agency (letter August 7, 1985).

Table 3. Dissolved metal concentrations measured below Keswick Dam.

	Sacramento River Below Keswick Dam 1/ Range	Ave.	Basin Plan Objective 2/	96 Hour 3/ LC10 for Chinook Salmon	96 hour 4/ LC50 for Chinook Salmon
Copper (Diss)	10-52	24	5.6	19	32
Zinc (Diss)	23-500	24	16	40	84
Cadmium (Diss)	1.8-4.0	2.5	0.2	0.8	1.1

1/ Metal concentrations recorded by RWQCB below Keswick Dam during three periods of uncontrolled release at Spring Creek Reservoir - January 1978, January 1983, and March 1983

2/ At water hardness = 40 mg/l.

3/ Concentration of metal that kills 10 percent of a juvenile chinook population in 96 hours.

4 The concentration of metal that kills 50 percent of a juvenile chinook population in 96 hours.

Attainment of the Basin Plan objectives for copper, zinc, and cadmium is not possible using only the existing water manipulation schemes. Appropriate source control measures have been identified by the U.S. Environmental Protection Agency Superfund Program based on numerous studies conducted by the U.S. Environmental Protection Agency, Bureau of Reclamation, and State agencies. A decision has been made to implement a remedial action program at the site beginning in 1987 (U.S. Environmental Protection Agency 1986).

The implementation of the source control and water management measures of the identified remedial action will reduce the levels of contaminants entering the system. However, the extent of the effectiveness cannot be determined at this time. The recommended Superfund cleanup strategy and the predicted water quality improvements are based on current and historical patterns of operation of the Shasta Trinity Unit. Achievement of the cleanup objective (i.e. meeting Federal and State water quality standards below Keswick Dam) is, in part, dependent on appropriate manipulation of water from the Shasta-Trinity Unit, particularly during the critical winter and spring periods. Anticipated future modifications to the Shasta-Trinity Unit operation has the potential for reducing the accomplishments of a cleanup program. (Letter, Central Valley Regional Water Quality Control Board to U.S. Environmental Protection Agency, June 23, 1987).

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