5.0 PREFERRED LOWER MOKELUMNE RIVER MANAGEMENT PLAN

5.1 INTRODUCTION

Section 3.0 presented major issues and background information related to management of flows and fisheries in the Lower Mokelumne River. In Section 4.0, several alternatives for managing the fishery were presented and evaluated. In this section, the preferred production-oriented, natural emphasis alternative for managing fish habitat is described. The preferred alternative is referred to as EBMUD's Lower Mokelumne River Management Plan (LMRMP). This section details the goals and criteria of the LMRMP and also introduces some non-flow management alternatives.

The goals of the LMRMP are to:

- Maintain water supply reliability by minimizing unnecessary storage releases using intensive monitoring and real-time management.
- Sustain and enhance fisheries benefits, especially salmon and steelhead trout, and other aquatic and riparian resources.
- Recognize and reduce uncertainty and develop new opportunities through a comprehensive and flexible monitoring and research program.

Under the preferred LMRMP, smolt and yearling production and ocean harvest levels would be increased over present levels and increased returns to the Mokelumne should ensure a self-sustaining population. Other advantages of this plan include:

- Optimum habitat for salmon and steelhead spawning, rearing, and migration would be provided in normal and wet years.
- Water surface elevations in Pardee and Camanche reservoirs would be provided to guarantee water quality, reservoir fisheries, and recreational use benefits.
- Out-migration flow would be provided to control water temperature in normal and wet years and through May in dry years.
- Trapping and trucking salmon smolts would be used in critically dry years and in dry years after May to avoid high mortality in the lower river and Delta and to save substantial amounts of water for other uses.
- A large program of fall releases of yearling salmon in the river would be established, providing improved survival and imprinting.
- Spawning flows would be provided when suitable water temperatures can be obtained.

- Additional improvements to habitat and production not related to flow management would be provided.

- Steelhead management would be focused on establishing a viable anadromous fishery.

- Impacts on water supply and availability for meeting consumptive use would be substantially less severe than the CDFG plan, particularly during critical dry and dry years when there is insufficient supply to meet municipal, agricultural, and fishery demands.

- The Mokelumne River Fish Facility Master Plan developed by EBMUD would meet the LMRMP objectives.

- Reservoir and hatchery improvements and groundwater supply projects would guarantee the production capability of the MRFH in all years and provide improved water quality at Camanche.

The LMRMP contrasts with the Plan presented by CDFG (1991), which attempts to optimize conditions for the fishery. Later in Section 5.0, the balanced approach advocated by EBMUD is compared to the CDFG Plan in more detail. In summary,

- The CDFG Plan recommendations are not consistently supported by the results of their own field studies.

- The CDFG water temperature criteria are unattainable at CDFG recommended flows

- The CDFG goal of increased recreational activity and access may be inconsistent with improved natural production of salmon and steelhead.

- The CDFG continues to emphasize a catchable steelhead trout fishery that is inconsistent with developing an anadromous steelhead run.

- In dry periods, there is no balancing of water supplies. As a result, EBMUD supplies are substantially reduced or eliminated. In about 10 percent of years, EBMUD would be unable to obtain Mokelumne River water.

The CDFG Plan does not make the most efficient use of water and does not present a balanced proposal for management of the Mokelumne water resource. In particular, it does not fully consider water supply impacts and the effects of storage depletion on fishery resources.

5.1.1 Fisheries Management

Numerous species of native and introduced fish inhabit the Lower Mokelumne River. Fall-run chinook salmon and steelhead are the major focus of the LMRMP for several reasons. These species are native Mokelumne species that have important recreational and commercial value, and are thus important to the EBMUD, CDFG, National Marine Fisheries Service (NMFS), and the USFWS. Both species are representative of native coldwater fisheries of the Sierra Nevada foothills, and both have declined in recent years through most of their range. Two races of Central Valley chinook salmon have been given or are being considered for endangered or threatened status.

The LMRMP primarily addresses the needs of fall-run chinook salmon and winter-run steelhead. Populations of Mokelumne River salmon and steelhead can be increased by providing conditions that enhance spawning, rearing and emigration, and by operating the MRFH in a way that enhances returns of Mokelumne River fish to the Mokelumne River. Even if conditions in the river were close to optimal, returns to the river could not be sustained in the long run without production from the MRFH because of excessive losses in Lake Lodi and the Delta and because of high ocean harvest rates (Appendix E). Without substantial improvement of conditions in the Delta or severe harvest restrictions, full productivity of the natural Mokelumne River system cannot be realized.

The LMRMP would establish a Mokelumne River chinook run by improving survival and reducing the proportion of in-migrants which are strays from other rivers. Returns of Mokelumne River salmon would be maximized by taking eggs from fish returning to the Mokelumne River and returning them to the river as smolts and yearlings. Up to 800,000 of these would be reared to yearlings and planted in the Mokelumne River in the fall. The remaining eggs would be reared to smolts and released in the river when conditions for their survival were most favorable. Eggs imported from other hatcheries would be reared separately and planted as smolts in the Delta to enhance ocean harvest and returns to other parts of the Central Valley.

Steelhead trout are a rainbow trout (*Onchorhynchus mykiss*) with a distinct life-history pattern. The term 'steelhead' is given to fish that migrate to the ocean for part of their lives. Fish that complete their life cycle in freshwater are referred to as rainbow trout. Some populations consist of migratory and non-migratory individuals.

In recent years, CDFG has managed steelhead trout as a "catchable" fishery, commonly referred to as a "put-and-take" fishery. According to present management practices, catchable steelhead raised in the MRFH are released throughout the public fishing season. The eggs for this fishery come from steelhead returning to the Feather and American rivers. The popular recreational fishery based on these fish also contributes to runs in the American River (CDFG 1991). Since eggs and sperm used to produce steelhead to plant in the Mokelumne River have come from the American River and other Central Valley hatcheries for over 25 years, it is very unlikely that a genotypically pure Mokelumne River strain of steelhead exists.

Past efforts to reestablish a steelhead run in the Mokelumne river have not been successful. At the present time few steelhead return to the MRFH, and there is not a significant spawning population in the Mokelumne River.

Under the LMRMP, steelhead management would be altered to develop a successful anadromous steelhead fishery. This would be accomplished by changes in stocking and hatchery practices and a change in fishing regulations to a catch-and-release sport fishery. The 30,000 catchable steelhead stocked in the Mokelumne River annually show a tendency to migrate out of the river, so efforts to establish a run must focus on returning these fish to the Mokelumne. Stocking rates would be increased to 50,000 yearlings, and the fish would be planted in the Mokelumne River in the fall. Monitoring would be conducted to verify that stocking these fish in the spring (March through July) does not impact chinook salmon juveniles.

Other native species in the Mokelumne River system are of equal or greater ecological importance to the river system. Species including Sacramento sucker, squaw fish, and lamprey are more numerous than game species, but have received less attention from management agencies or the public at large. In spite of the historical lack of official and public interest in preserving species such as suckers and lampreys, there is an increasing constituency for protecting native species of fish and entire fish communities (Moyle and Williams 1990). Biodiversity and the preservation of native species is an increasingly important goal of resource management. At present, little is known about the population sizes, habitat requirements, or management of these species in the Mokelumne River, so it is difficult to make management decisions. Information on these species should be collected on a regular basis, including abundance estimates, habitat utilization, and species interactions (Section 6.0).

The present state of the flood plain and riparian habitat conditions are primarily the result of land use practices including agriculture, urbanization, and levee construction. Maintenance and protection of the riparian habitat is of critical importance to the ecology of fish populations of the Lower Mokelumne River, as well as to the wildlife associated with the river. Responsible agencies and individuals should take the necessary steps to ensure protection and enhancement of the riparian habitat. EBMUD has no authority or ability to control river conditions beyond releases of water from Camanche Reservoir; proposed LMRMP flow releases are not expected to negatively impact riparian habitat conditions.

5.1.2 Stream Flow

The general strategy of the LMRMP recognizes natural variation in stream flow, and adaptation of various fish populations to withstand periods of drought. Maintenance-level flows are provided in critical dry years and migrants are trapped and hauled to release points below the Delta or, when conditions warrant, back to the MRFH for release in the fall when conditions improve. Good conditions for all life stages are provided in other year types, with optimum conditions in normal and wet years, except for flood flows which are uncontrollable in the short run and can impact spawning habitat and success by erosion. All recommendations derive from CDFG flow/habitat studies (IFIM) (CDFG 1991), BioSystems stream temperature modeling (Appendices B and C), and the results of fisheries studies conducted by BioSystems over the last three years (Appendix A).

Under the LMRMP, stream flow in the Mokelumne River would be managed to provide habitat for chinook salmon and steelhead trout. It is assumed that the CDFG IFIM study adequately measures the relationship between flow and the habitat requirements of various life-stages of chinook and steelhead (CDFG 1991), even though stream flow would also be managed to provide suitable temperature conditions for these species whenever possible. Because of its importance in regulating coldwater fish population dynamics, temperature management would usually be given priority over other aspects of physical habitat (i.e., stream depth and velocity).

Fall flows are provided for upstream migration and spawning during the October-December spawning period. Based on the timing of historic spawning runs, spawning flows should be provided beginning in mid-October. Recent studies of emergence success conducted by BioSystems indicate that egg survival will be good if the Camanche release temperature is 15.5°C or less at the time of spawning (Section 3.0). Although historic temperature data indicate that water temperatures are suitable for spawning at this time in most years, spawning flows should not be initiated until temperature monitoring indicates that Camanche Reservoir release temperatures will be suitable for migration and spawning. To attain a temperature of 15.5° it may be necessary to delay spawning flows until Camanche Reservoir turns over.

Attraction flows are not provided because the relationship between short-term attraction flows and escapement is not well established (Section 3.2.2.3) and, even if the empirical basis for such flows was accepted, there are no benefits of attraction in relation to LMRMP goals. Although statistical analysis found that run size may be correlated with seasonal average fall flows in recent historic periods, results were not conclusive. Pulsed flows were not found to be effective in attracting fish, and sustained flows require large amounts of water. It is believed that sustained flows might attract stray salmon, but these fish would otherwise be able to spawn elsewhere, and they are not consistent with the LMRMP goal of establishing a distinct Mokelumne run.

Some evidence does suggest that increased flow during the in-migration period would increase the size of the run but, under current conditions, especially with the planting of hatchery smolts in the Delta, we believe that the additional fish brought into the run would be strays (Section 3.2.2.1). Since one goal of the LMRMP is to establish a Mokelumne River run based on fish of Mokelumne origin, flows that attract large numbers of strays are not desirable. The base flow of 200 to 300 cfs provided for spawning should be sufficient to allow salmon of Mokelumne River origin to return to the river.

For other than flood control releases, stream flow reductions in the accompanying flow schedules during the spawning and incubation period (October to March) should be implemented at a rate not exceeding 50 cfs per day. The objective of this operating rule is to control daily changes in flows for the purpose of powerplant peaking or reductions due to short-term rain/runoff events. Such diurnal changes are detrimental to the fishery habitat.

At other times (April to October), stream flow can be reduced by up to 100 cfs per day. To the extent possible, reductions from flood release levels should be minimized by planning flood storage evacuations in advance and spreading them over the summer and fall months.

C-100873

Camanche Reservoir storage can be predicted with reasonable accuracy well in advance of the October flood control limit requirements. Flow reductions following flood control evacuations should be made as quickly as practical to avoid levee damage.

The following sections detail operating plans to implement these objectives. Then, the LMRMP is compared to the CDFG Plan in terms of goals, operations, and hydrologic and water supply impacts. These impacts have been estimated with EBMUDSIM, EBMUD's model of the Mokelumne River.

5.2 CAMANCHE RESERVOIR

5.2.1 Preferred Operational Strategy

The preferred operational alternative for Camanche Reservoir is one that emphasizes a flexible management approach by which the actual operation decisions would be guided by monitoring results and actual field observations to achieve the desired hydrologic results. The alternative was developed from the operational experience gained by EBMUD in the last two years of operating Camanche Reservoir. The WQRRS model was used to predict the performance of the strategy under selected historic hydrologic conditions over 70 years of record, from 1921 to 1990 (a total of 23 years were evaluated).

The operation rules in the strategy are designed to meet the temperature criterion in the river, and also to minimize unnecessary releases from Camanche Reservoir that do not support beneficial uses of the river. Actual field monitoring results, including fishery conditions, would be carried out to confirm that the goals of the strategy are being met. This management approach would allow for optimum use of the water supply in the Mokelumne River for all beneficial uses, based on actual results. The operational goals for this strategy are described as follows:

> **Maintain stratification in Camanche Reservoir from May through October to provide cool water to release to the river and MRFH.** By maintaining stratification, the water released from Camanche Reservoir would be withdrawn through the bottom outlet, the coolest water available to the river.
>
> The minimum hypolimnion volume required to implement this goal was estimated. For the purpose of implementing this goal, the hypolimnion volume is defined as the volume of water in Camanche Reservoir colder than 16.4°C. Based on evaluation of the available reservoir monitoring data on thermal stratification in 1990 and 1991, it is estimated that approximately 20,000 to 28,000 acre-feet of hypolimnion would be required at the end of October to preserve the stratification in Camanche Reservoir until mid-November. To maintain the minimum hypolimnion volume in Camanche, release from Pardee would be made as needed to replenish the Camanche hypolimnion. Generally, WQRRS modeling results indicate that releases from Pardee are not necessary from November to April because Camanche Reservoir would be cold and not stratified.

Maintain stratification in Pardee Reservoir from May to October. This is the period in which releases from Pardee to Camanche may be needed to help maintain stratification in Camanche Reservoir. To insure the availability of cool Pardee inflow into Camanche for that purpose, a minimum storage of 100,000 acre-feet in Pardee Reservoir is estimated to be required to maintain its stratification, based on limited monitoring data (A. Horne pers. comm. 1992). Based on EBMUDSIM results, this goal would be met in 97 percent of years.

Refinement of this minimum Pardee storage requirement may be possible in the future through monitoring the temperature profile and water quality in Pardee Reservoir.

5.2.2 Non-flow Strategy

Based on a review of the alternatives discussed in Section 4.2.3 and examination of their ability to provide water quality improvements, one alternative, hypolimnetic oxygenation, was recommended as the preferred alternative for LMRMP. The alternative has the best potential for improving water quality for both the MRFH and the Lower Mokelumne River while maintaining the required downstream water release volumes.

The other alternatives were eliminated because they were impractical or would not provide reliable and effective water quality improvement. Potassium permanganate treatment and aeration for the entire lower river flow would not improve reservoir water quality and there are potential environmental problems associated with adding large amounts of chemicals to the lower river. Additional NPDES permit requirements could be required. Hypolimnetic aeration was eliminated because of the high probability of destratification stemming from the large volume of air needed to elevate the dissolved oxygen concentrations to 7 milligrams per liter (mg/l).

The Pardee diversion alternative was rejected because of operational problems, water supply impacts, costs, and a complex and long-term construction period. The multi-level outlet structure alternative was eliminated because of the inability to maintain cold release temperatures while providing water free of hydrogen sulfide.

5.2.2.1 Hypolimnetic Oxygenation

Hypolimnetic oxygenation of Camanche Reservoir is the best long-term solution for the water quality problems of both the MRFH and the Lower Mokelumne River. This alternative would be used during both drought years and in future normal and wet runoff years when flooding of the drawdown zone and decomposition of vegetation can be expected to lead to more rapid oxygen depletion and greater hydrogen sulfide production. The hypolimnetic oxygenation system is capable of maintaining a 7 mg/l dissolved oxygen concentration during releases from Camanche Dam for power generation, downstream releases, and MRFH supply.

Speece (1992) examined the alternative of adding pure oxygen to the hypolimnion of Camanche to achieve 7 mg/l dissolved oxygen concentration in the Camanche release water to oxygenate the release water and to oxidize the hydrogen sulfide before release. The basic problem in designing hypolimnetic oxygenation is to add oxygen to the deep portion of a reservoir without moving or entraining so much water that the reservoir mixes and destratifies. In many cases involving warmwater fisheries, mixing is desirable because anaerobic conditions cannot be sustained when deep water is actively and continuously moved to the surface and back to the hypolimnion. In such cases, it is often easiest to pump large amounts of air into the hypolimnion. Active aeration to oxygenate deep water in conjunction with destratification is commonly practiced in California as well as around the world (Lorenzen and Fast 1977).

In contrast, mixing at Camanche should be minimized to the extent possible as cold water through the summer and fall is needed to sustain the coldwater fishery of the lower river and the MRFH. An additional problem at Camanche is that of turbidity in the release water could be increased if reservoir bottom sediments were resuspended and released. Thus, an oxygenation system at Camanche must minimize internal hypolimnetic sediment resuspension as well as mixing of cold and warm water layers.

The preliminary design for a system for Camanche Reservoir specifies the capacity to add 8 mg/l dissolved oxygen to a 300-cfs discharge with a reservoir pool depth of 21 meters (Speece 1992). The design should provide 7 mg/l dissolved oxygen in the release water plus 1 mg/l dissolved oxygen used to oxidize the hydrogen sulfide.

Pure oxygen is difficult to dissolve in water; it must be kept in contact with water for approximately 100 seconds to achieve a high absorption efficiency. Since fine-pore rubber or ceramic diffusers generate bubbles with a nominal rise velocity of 0.3 meter/second, the hypolimnion would have to be about 31 meters deep to use porous diffusers for oxygen absorption. Furthermore, vertical circulation cells would be generated within the hypolimnion by the free-rising bubbles. In a stratified reservoir, vertical circulation could cause internal mixing that could result in the destratification of the reservoir.

For the situation that exists in Camanche Reservoir, it is more appropriate to use a Speece Cone for pure oxygen absorption. Water is pumped into the top of a cone-shaped vessel at a velocity of 3 meters/second to provide the high intensity energy required to maintain a dynamic bubble swarm within the vessel. This provides a high gas-to-liquid surface area for a high oxygen transfer rate. Due to the high inlet velocity, the oxygen bubbles cannot escape out the top. Because of the conical shape, the velocity out of the bottom of the cone is reduced to 0.09 meter/second so that the bubbles cannot escape from the bottom of the cone. Thus, the bubbles are trapped inside the cone for prolonged contact times, creating a situation for a high absorption efficiency. Another benefit of the Speece Cone is that the high turbulence and long contact time is confined within the cone and would not affect thermal stratification in the hypolimnion.

Successful operation of the system would require extensive and frequent monitoring of the water quality and thermal conditions of Camanche Reservoir, which EBMUD has proposed to continue in the operational strategy. Coupled with the operational strategy, operation of the hypolimnetic oxygenation system is the best long-term solution to provide cool, hydrogen sulfide-free water releases for the Lower Mokelumne River and the MRFH.

5.3 MOKELUMNE RIVER FISH HATCHERY

As a result of joint interviews by EBMUD and CDFG, FishPro, Inc. was selected from a list of three engineering and biological consulting firms representing the best qualifications in fish hatchery design, operation, and maintenance. In March 1992, EBMUD funded and entered into a consulting agreement with FishPro, Inc. for the development of a Hatchery Master Plan.

The Master Plan was developed to achieve the following objectives:

- Increase production capacity by providing additional rearing space for post smolt and yearling salmon and steelhead.
- Develop additional measures to improve the quality of the hatchery water supply.
- Redesign hatchery rearing units to facilitate feeding and cleaning operations, resulting in improved hygiene and healthier fish.
- Segregate rearing units to allow for more flexibility in hatchery programming and space for holding special lots of salmon and steelhead (i.e., coded wire tagged groups, imported lots of fish, and Mokelumne stock).

The Master Plan will incorporate a new hatchery building and adult salmon holding ponds to be constructed by CDFG (1992-1993). As previously mentioned, the commercial salmon trollers feel salmon production from the MRFH has made a significant contribution to their commercial landings and they have made the expansion of the MRFH a top priority. As a result, CDFG was provided with funding in fiscal year 1993 to construct a new hatchery building capable of holding 10,000 adult salmon spawners and incubating 12 million eggs. Since the current MRFH facility has a capacity to rear only 4 million salmon to post-smolt size, additional rearing units are required to meet the production goals for post smolt and yearling salmon and steelhead to meet all mitigation and enhancement objectives.

5.3.1 Production Goals

Objectives of the LMRMP include providing increased benefits to the ocean troll and sport fishery and to the adult salmon return to the Mokelumne River by increasing salmon and steelhead production at MRFH.

The goals currently set forth in the LMRMP call for the annual production of 3.66 million fall-run chinook salmon smolts, 800,000 fall-run chinook yearlings, and 53,000 steelhead yearlings. Based on minimum release sizes established in cooperation with the CDFG, the production poundage expected under this rearing program is approximately 205,000 pounds (93,000 kg: 63,000 kg mitigation and 30,000 kg enhancement; Table 5.1). In addition to these stated mitigation and enhancement goals, the MRFH facilities will be able to provide additional rearing space for an additional 90,000 pounds (40,800 kg) production (anadromous and Nimbus steelhead) collateral to EBMUD and CDFG needs (Table 5.1).

Table 5.1. Proposed production goals and constraints at MRFH.

	Number	Target Size	Release Constraints	Minimum Weight
Mitigation				
Steelhead				
Anadromous	23,000	4/lb expected	Feb-Mar best	5,750
In-river	30,000	3/lb minimum	After Jul 1	10,000
Total	53,000			17,667
Chinook				
Smolts	1,660,000	60/lb minimum	May optimum	27,667
Yearling	800,000	10/lb minimum	15-31 Oct	80,000
Natural	121,000	9/lb minimum	15-31 Oct	13,889
Total	2,585,000			121,000
Enhancement				
Four pumps	20,000	4/lb	Feb-Mar	5,000
Smolts	2,000,000	30/lb minimum	May optimum	66,667
Anadromous steelhead	47,000	4/lb expected	Feb-Mar best	11,750
Nimbus steelhead	450,000	6/lb expected	15-31 Oct	75,000
Total	2,517,000			158,417

Working in conjunction with the CDFG, size or release constraints have been established in an effort to better manage the MRFH to meet the operational goals of both agencies. These constraints are discussed below and summarized in Table 5.1. Based on the proposed goals for numbers and size, the new expanded hatchery will be designed to accommodate an annual production of 425,000 to 437,000 pounds (143,000-198,200 kg).

5.3.1.1 Steelhead

The production of yearling steelhead at MRFH is a mitigation program responsibility for EBMUD to provide two benefits:

- Anadromous steelhead that will migrate to the ocean and return to the Mokelumne River as adults.

- In-river rainbow trout for the benefit of the Mokelumne River sport anglers.

Because of cooler water temperatures and greater flows, February and March are the best months to release anadromous steelhead. In-river steelhead include fish released in late summer after 1 July. Since they may prey on juvenile salmon, it is desirable to delay in-river stocking of rainbow trout until after the peak of the juvenile salmon out-migration in

June. Consequently, the first release of the in-river rainbow trout program is set to begin after 1 July.

It is generally accepted that the average release size for the MRFH steelhead production program should be around 3 pounds, resulting in a total steelhead production of 17,667 pounds (8,013 kg). It is EBMUD's stated purpose to meet the anadromous steelhead goal; the in-river rainbow trout planting program may have to be modified to some extent by CDFG to ensure this.

5.3.1.2 Chinook Smolts

Proposed production of chinook smolts at MRFH can be divided into two categories:

- Mitigation: 1.66 million chinook smolts reared to satisfy EBMUD's mitigation objectives. The release size is 60 pounds, resulting in an annual production of 27,667 pounds (12,550 kg). These fish would be from Mokelumne River returns released to the Mokelumne River at the MRFH. This program is funded by EBMUD.

- Enhancement: 2 million chinook smolts reared for CDFG enhancement objectives, primarily to benefit the ocean troll fishery. Funds for this program are provided by the Salmon Stamp Tax. The release size goal for these fish is 30/lb, resulting in an annual production of 66,667 pounds (30,239 kg). These fish can be imported from other rivers, transported around Delta impacts, and released in or below the Delta.

5.3.1.3 Chinook Yearlings

- Mitigation: The release size goal for 800,000 chinook yearlings has been established at 10/lb, resulting in an annual production of 80,000 pounds. Release of the yearling chinook will be coordinated with the removal of the Woodbridge Dam (15 October to 15 November), and with Delta water temperatures and river water temperature conditions. This yearling chinook salmon program is part of EBMUD's long-term mitigation goal and is funded by EBMUD.

5.3.2 Water Supply Issues

Camanche Reservoir now supplies all water for the MRFH. Prolonged drought conditions in recent years have led to elevated water temperatures in the reservoir in the fall. In September 1988, when Camanche Reservoir was at its lowest level since construction, water temperatures exceeded 18°C. This is often considered the upper limit for the rearing of salmonid fish. Furthermore, degraded water quality conditions have occasionally accompanied warm water conditions, including episodes of high concentrations of hydrogen sulfide and very high turbidities within the hypolimnion. During some of these episodes, fish mortalities in the MRFH increased.

As a safeguard, the LMRMP calls for provisions to be incorporated into the MRFH to allow uninterrupted fish production even during drought years when water temperatures may be a problem. Additional measures are also called for to improve the overall quality of the MRFH water supply.

5.3.2.1 MRFH Operations Issues

Additional objectives of the LMRMP include:

- Redesign MRFH rearing units to facilitate feeding, holding, crowding, loading, shading, and cleaning operations resulting in improved hygiene and healthier fish.
- Segregate rearing units to promote better disease control and allow greater flexibility in hatchery programming and provide discrete rearing units to meet CDFG and EBMUD management objectives.

FishPro, Inc. conducted numerous analyses to determine the design requirements for the new production facilities that will meet the objectives of the LMRMP. The hatchery design to follow will take into account the water quality and MRFH operations issues while planning for the expansion requirements.

5.3.2.2 Growth Projections and Rearing Criteria

A major objective of the LMRMP is to satisfy production goals of the MRFH, even during years of extreme drought and warmwater conditions.

Water temperature conditions assumed for the purpose of production analysis are listed in Table 5.2. Values for extreme conditions are based on temperature modeling efforts being conducted by BioSystems for EBMUD. The values take into account operational changes for Pardee and Camanche reservoirs, and include the worst case (warmest) water temperatures ever expected in the hatchery water supply. Values for normal water temperatures were derived from USGS data measured in the Mokelumne River downstream of the MRFH.

The water temperature model test data set representing extreme conditions has four months, July through October, in which the average monthly temperature is above 18°C.

Recent investigations at the MRFH site indicate a potential for developing a modest supply of ground water for the MRFH. It is anticipated that groundwater with a temperature as low as 14.5°C measured during the recent EBMUD pump test is potentially available. This would provide the MRFH with a supplemental water source which, in comparison to the existing supply, would be warmer in the winter and cooler in the summer and late fall. Consequently, water temperatures could be controlled to some degree. Most notably, it would be possible to accelerate incubation and fry rearing in the spring, and gain perhaps 1 to 1½ months growth on the fish. This flexibility has been taken into account in developing the fish growth projections by assuming that swim-up dates will be controlled in the hatchery building, and that the same start month can be used in modeling fish growth, regardless of whether normal or extreme water temperature conditions are assumed.

Table 5.2.

Assumptions Used in Fish Growth Projections for Mokelumne River Fish Hatchery

Hatchery Water Supply Temperatures

Month Code	Month	Average Temp. (°C)	Average Temp. (°F)	Extreme Temp. (°C)	Extreme Temp. (°F)
1	Jan	9.9	49.7	6.2	43.2
2	Feb	10.0	49.9	6.9	44.4
3	Mar	10.0	49.9	7.9	46.2
4	Apr	10.6	51.0	8.9	48.0
5	May	13.2	55.8	10.4	50.7
6	Jun	14.3	57.7	13.9	57.0
7	Jul	16.0	60.7	22.1	71.8
8	Aug	16.6	61.8	26.3	79.3
9	Sep	15.3	59.5	25.4	77.7
10	Oct	14.9	58.7	20.3	68.5
11	Nov	14.6	58.2	11.2	52.2
12	Dec	12.4	54.3	8.2	46.8

Note: Chilling equipment will be used to assure maximum temperatures of 18.0 °C.

Fish Densities (ref. Piper)

Fish Size (grams)	Density (lb/cf)
1	0.78
2	0.82
3	0.89
4	0.94
5	1.00
10	1.11
15	1.20
20	1.33
25	1.43
30	1.55
35	1.57
40	1.78
45	1.89
50	2.00
60	2.00

Fish Loading (ref. Piper)

Temp. (°F)	lb/gpm/in (250' MSL)
45	2.24
46	2.18
47	2.11
48	2.05
49	1.98
50	1.92
51	1.86
52	1.79
53	1.73
54	1.66
55	1.60
56	1.54
57	1.48
58	1.40
59	1.36
60	1.33
61	1.29
62	1.25
63	1.21
64	1.17

Table 5.2. (continued)

Assumptions Used in Fish Growth Projections for Mokelumne River Fish Hatchery

Site Parameters		Source
Elevation (ft above MSL):	250	USGS data
Maximum pH:	7.2	Hatchery data
Inflow ammonia (NH3 mg/l):	0.0000	Assumed
Raceway size (cu ft):	1,500	Width: 10.0 Length: 100.0 Depth: 1.5

Species Parameters		Fall Chinook	Steelhead	Source
Condition factor:		2.96E-04	3.41E-04	Piper et al. 1982, "Fish Hatchery Management"
Monthly Temp. Units per inch of growth:		21.5	22.5	Mokelumne Hatchery growth data
Minimum desired oxygen level (mg/l):		6.00	6.00	California Dept. of Fish and Game
Nitrogen loading (lbs N/lbs food):		0.032	0.032	Piper et al. 1982, "Fish Hatchery Management"
Oxygen consump. factors:		T <= 50° F	T <= 50° F	Liao 1971. The Progressive Fish-Culturist
	K:	7.20E-07	1.90E-06	
	m:	-0.194	-0.138	
	n:	3.200	3.130	
		T > 50° F	T > 50° F	
	K:	4.90E-05	3.05E-04	
	m:	-0.194	-0.138	
	n:	2.120	1.855	

C—100882

Fish growth projections have been developed with the aid of historical weight sampling and water temperature records maintained at the MRFH. Sizes and growth rates vary from year to year; this is expected because of natural variations in adult run times, spawning dates, and incubation and rearing water temperatures. Data were analyzed to determine the monthly temperature units (MTUs) required to produce one inch of growth in the fish. This information was then applied to the normal and extreme water temperature sets to project expected growth conditions. MTU values were determined separately for chinook and steelhead and found to be similar to other stocks of the same species.

Growth projections were used to determine the flow and space requirements for the proposed facility. Various rearing criteria used in determining these requirements were discussed with the MRFH manager and with additional CDFG personnel prior to deciding on the preferred criteria. Past operations at the facility have had specific production goals which did not match the preferred criteria for operations. The rearing criteria used in this report are listed in Table 5.2 along with the temperature assumptions.

Water flow requirements have been determined assuming an inflow dissolved oxygen saturation of 90 percent when using standard aeration methods and a saturation of 120 percent when using oxygen supplementation. Recommended fish loadings in lb/gpm use a combination of the Piper Flow Index and oxygen consumption estimates developed by Liao. CDFG has expressed a desire to maintain outflow dissolved oxygen levels above 6.0 mg/l. Consequently, oxygen consumption calculations have been used to check the expected outflow dissolved oxygen resulting from Flow Index loadings. In most warm water temperature cases, the loadings must be adjusted downward from the Flow Index level so that a minimum level of 6.0 mg/l is maintained.

To examine the potential for water re-use, an analysis was conducted to determine the worst case conditions for un-ionized ammonia buildup in the facility. Available water quality data reveal a pH of 7.7 in the hatchery supply. Using the method of Westers and further assumptions of 19°C water temperature (allowing for a 1°C rise through the facility), a feeding rate of 1 percent body weight/day, and a maximum un-ionized ammonia level of 0.0125 mg/l, the results indicate a maximum re-use rate of 2.8 times. To promote the highest fish quality, it was recommended that reuse be limited to a two-pass system, with full reaeration to 90 percent minimum provided for the second pass flow.

Volume requirements have been determined following guidelines established by Piper. The lightest densities established are 0.78 pound per cubic foot for very small fish, with the highest densities being 2.0 pounds per cubic foot for fish larger than 50 grams. All new rearing units will be rectangular raceways with usable rearing space measuring 3 x 31 x .46 meters.

5.3.2.3 Facility Requirements

By developing an assumed release schedule that follows the size and timing constraints described in Section 5.3.1, a growth model was developed to determine the total fish weight on station in bi-monthly increments. Because water temperatures affect fish growth so strongly and can alter the release dates, the growth model was applied to both average and extreme temperature conditions. For the proposed production program, results indicate a combined output of over 425,000 pounds (192,770 kg) each year under normal conditions and over 437,000 pounds (198,213 kg) during extreme years.

Based on the on-station weight projections and the rearing criteria established in Section 5.3.2.2, raceway and flow requirements were determined for each bi-monthly period. Raceway requirements for average and extreme conditions are shown in Tables 5.3 and 5.4, respectively, while the two cases of flow requirements are shown in Tables 5.5 and 5.6.

For the proposed production program, the peak raceway requirements occur in late October, just prior to release of yearling chinook and return of off-station steelhead to their original hatchery. Results indicate a need for 90 raceways during extreme years. Because this peak occurs as the result of a fixed-date release requirement, it is not possible to reduce the raceway requirement without 1) decreasing the number released or 2) decreasing the fish size through temperature control for both the normal and extreme conditions.

Peak flow requirements also occur in late October. Under normal conditions, the flow requirement will be 35.4 cfs. For extreme conditions, peak flow unfortunately occurs during July to October when the water requires chilling. Since chilling is usually a very costly procedure, it has been assumed that oxygen supplementation methods will be used to reduce the flow (and chilling) requirement. By providing 120 percent saturation at the inlets of both the first and second pass raceways, the flow requirement for the facility can be reduced to 48 percent of the requirement when using conventional aeration methods. Calculations for the extreme condition flow requirements, assuming oxygen supplementation, show a peak demand of 31.3 cfs. This flow requirement subsequently becomes the chilling flow requirement as well.

5.3.3 Water Supply Treatment Alternatives

5.3.3.1 Treatment Requirements

To accommodate the production program developed for the MRFH, it will be necessary to treat the available water supply. Some of these treatments are needed on a continuous basis to provide acceptable conditions for fish culture. Other treatments are needed because of poor water quality conditions that occur only rarely, yet are necessary to guarantee uninterrupted production of fish even during critical dry years. Based on the established production goals and water supply characteristics discussed in previous sections, the following treatment requirements have been identified:

- Aeration and gas stabilization of the hatchery supply, and reaeration of water for use in second pass raceways.

- Water chilling of hatchery supply when water temperatures exceed 18°C.

Table 5.3.

Raceway Requirements at Mokelumne River Fish Hatchery under Average Temperature Conditions

Date	Mitigation Raceway Requirement					Enhancement Raceway Requirement					Total Raceways
	Steelhead 0+	Steelhead 1+	Mitigation Chinook	Natural Chinook	Subtotal	Anadromous Steelhead	Four Pumps Steelhead	Nimbus Steelhead	Enhancement Chinook	Subtotal	
Jan 1	-	6	3	0	9	5	2	-	2	9	18
Jan 15	-	6	4	0	10	5	2	-	3	10	20
Feb 1	-	8	6	0	12	5	3	-	5	13	20
Feb 15	-	6	8	0	14	4	2	-	7	13	25
Mar 1	-	6	10	0	16	3	2	-	9	13	27
Mar 15	-	5	14	0	19	2	1	-	11	14	30
Apr 1	-	5	17	0	22	-	-	-	14	14	33
Apr 15	-	5	20	0	25	-	-	-	18	16	36
May 1	-	6	24	2	32	-	-	-	20	20	41
May 15	-	8	32	3	41	-	-	-	26	26	52
Jun 1	1	7	27	3	38	1	1	3	32	37	67
Jun 15	1	7	18	4	30	1	1	4	41	47	75
Jul 1	1	8	21	4	34	1	1	5	31	38	77
Jul 15	1	7	23	5	36	1	1	7	20	29	72
Aug 1	2	6	28	5	41	2	1	9	9	21	65
Aug 15	2	4	30	6	42	2	1	10	0	13	62
Sep 1	2	3	34	7	46	2	1	13	0	16	55
Sep 15	3	0	40	8	51	2	1	14	0	17	62
Oct 1	3	0	48	10	61	2	1	16	0	19	68
Oct 15	3	0	55	11	69	3	1	17	0	21	80
Nov 1	3	0	0	0	3	3	2	0	0	5	90
Nov 15	4	0	0	0	4	3	2	0	0	5	8
Dec 1	5	0	0	0	5	4	2	0	0	6	9
Dec 15	5	0	0	0	5	4	2	0	0	6	11
											11
Maximum:	5	8	55	11	69	5	3	17	41	47	90

Notes:

1. Mitigation steelhead values include fish for both anadromous and in-river programs. 0+ and 1+ refer to the age class of the fish.
2. Mitigation chinook values include both smolt and yearling releases.

Table 5.4.

Raceway Requirements at Mokelumne River Fish Hatchery under Extreme Temperature Conditions

Date	Mitigation Raceway Requirement					Enhancement Raceway Requirement					Total Raceways
	Steelhead 0+	Steelhead 1+	Mitigation Chinook	Natural Chinook	Subtotal	Anadromous Steelhead	Four Pumps Steelhead	Nimbus Steelhead	Enhancement Chinook	Subtotal	
Jan 1	-	6	3	0	9	5	2	-	2	9	18
Jan 15	-	6	3	0	9	5	2	-	3	10	19
Feb 1	-	6	4	0	10	5	2	-	3	10	20
Feb 15	-	6	5	0	11	4	2	-	4	10	21
Mar 1	-	5	6	0	11	3	2	-	5	10	21
Mar 15	-	5	7	0	12	2	1	-	6	9	21
Apr 1	-	4	9	0	13	-	-	-	7	7	20
Apr 15	-	4	11	0	15	-	-	-	9	9	24
May 1	-	5	13	2	20	-	-	-	11	11	31
May 15	-	5	16	3	24	-	-	-	13	13	37
Jun 1	1	5	20	3	29	1	1	3	16	21	50
Jun 15	1	6	26	3	36	1	1	4	21	27	63
Jul 1	1	6	34	4	45	1	1	5	30	37	82
Jul 15	1	6	30	6	42	1	1	7	38	47	89
Aug 1	2	5	20	5	32	2	1	9	47	59	91
Aug 15	2	4	25	6	37	2	1	11	29	43	80
Sep 1	2	2	30	7	41	2	1	14	0	17	58
Sep 15	3	0	32	9	44	2	1	15	0	18	62
Oct 1	3	0	38	10	51	3	1	17	0	21	72
Oct 15	4	0	47	12	63	3	2	21	0	26	89
Nov 1	4	0	0	0	4	4	2	0	0	6	10
Nov 15	5	0	0	0	5	4	2	0	0	6	11
Dec 1	5	0	0	0	5	4	2	0	0	6	11
Dec 15	5	0	0	0	5	5	2	0	0	7	12
Maximum:	5	6	47	12	63	5	2	21	47	59	91

Notes:

1. Mitigation steelhead values include fish for both anadromous and in-river programs. 0+ and 1+ refer to the age class of the fish.
2. Mitigation chinook values include both smolt and yearling releases.

C-100887

Table 5.5.

Flow Requirements at Mokelumne River Fish Hatchery under Average Temperature Conditions

Date	Mitigation Flow Requirement (cfs)					Enhancement Flow Requirement (cfs)					Total Flow (cfs)
	Steelhead 0+	Steelhead 1+	Mitigation Chinook	Natural Chinook	Subtotal	Anadromous Steelhead	Four Pumps Steelhead	Nimbus Steelhead	Enhancement Chinook	Subtotal	
Jan 1	0.0	1.5	1.0	0.0	2.6	1.3	0.5	0.0	0.8	2.7	5.2
Jan 15	0.0	1.6	1.4	0.0	3.0	1.4	0.6	0.0	1.1	3.0	6.0
Feb 1	0.0	1.8	1.8	0.0	3.6	1.5	0.6	0.0	1.5	3.6	7.2
Feb 15	0.0	1.7	2.3	0.0	4.0	1.2	0.5	0.0	1.8	3.5	7.5
Mar 1	0.0	1.6	2.8	0.0	4.3	0.8	0.4	0.0	2.2	3.4	7.8
Mar 15	0.0	1.4	3.3	0.0	4.8	0.4	0.2	0.0	2.7	3.3	8.1
Apr 1	0.0	1.5	4.1	0.0	5.7	0.0	0.0	0.0	3.4	3.4	9.0
Apr 15	0.0	1.6	4.9	0.0	6.5	0.0	0.0	0.0	3.9	3.9	10.4
May 1	0.0	2.3	6.9	0.5	9.7	0.0	0.0	0.0	5.6	5.6	15.3
May 15	0.0	2.5	8.3	0.6	11.4	0.0	0.0	0.0	6.7	6.7	18.1
Jun 1	0.2	3.1	7.4	0.8	11.4	0.1	0.1	1.0	8.9	10.1	21.5
Jun 15	0.2	3.3	4.5	0.9	9.0	0.2	0.1	1.4	10.5	12.2	21.2
Jul 1	0.4	4.3	6.3	1.3	12.2	0.3	0.1	2.4	9.2	12.0	24.3
Jul 15	0.5	3.8	7.6	1.5	13.4	0.4	0.2	3.2	6.8	10.6	24.0
Aug 1	0.7	3.3	10.2	2.0	16.3	0.6	0.3	4.7	3.0	8.6	24.9
Aug 15	0.9	2.4	12.1	2.3	17.8	0.8	0.3	6.0	0.0	7.1	24.9
Sep 1	1.0	1.2	12.6	2.4	17.2	0.9	0.4	6.8	0.0	8.1	25.3
Sep 15	1.2	0.0	14.4	2.7	18.3	1.0	0.4	8.2	0.0	9.6	27.9
Oct 1	1.4	0.0	15.8	2.9	20.2	1.2	0.5	9.4	0.0	11.1	31.3
Oct 15	1.6	0.0	17.7	3.2	22.6	1.4	0.6	10.9	0.0	12.9	35.4
Nov 1	1.9	0.0	0.0	0.0	1.9	1.6	0.7	0.0	0.0	2.2	4.1
Nov 15	2.1	0.0	0.0	0.0	2.1	1.8	0.8	0.0	0.0	2.5	4.7
Dec 1	1.9	0.0	0.0	0.0	1.9	1.6	0.7	0.0	0.0	2.3	4.2
Dec 15	2.1	0.0	0.0	0.0	2.1	1.7	0.7	0.0	0.0	2.5	4.6
Maximum:	2.1	4.3	17.7	3.2	22.6	1.8	0.8	10.9	10.5	12.9	35.4

Notes:

1. Mitigation steelhead values include fish for both anadromous and in-river programs. 0+ and 1+ refer to the age class of the fish.
2. Mitigation chinook values include both smolt and yearling releases.
3. Flow requirements assume two pass raceway arrangement with minimum 90% DO at both first and second pass inlets.

C-100887

Table 5.6.

Flow Requirements at Mokelumne River Fish Hatchery under Extreme Temperature Conditions with Oxygen Supplementation

Date	Mitigation Flow Requirement (cfs)					Enhancement Flow Requirement (cfs)					Total Flow (cfs)
	Steelhead 0+	Steelhead 1+	Mitigation Chinook	Natural Chinook	Subtotal	Anadromous Steelhead	Four Pumps Steelhead	Nimbus Steelhead	Enhancement Chinook	Subtotal	
Jan 1	0.0	0.8	0.9	0.0	1.8	0.7	0.3	0.0	0.7	1.7	3.5
Jan 15	0.0	0.9	1.0	0.0	1.9	0.7	0.3	0.0	0.8	1.8	3.7
Feb 1	0.0	1.0	1.2	0.0	2.2	0.8	0.4	0.0	1.0	2.1	4.3
Feb 15	0.0	0.9	1.3	0.0	2.3	0.6	0.3	0.0	1.1	2.0	4.3
Mar 1	0.0	1.0	1.6	0.0	2.6	0.5	0.2	0.0	1.3	2.0	4.6
Mar 15	0.0	0.9	1.8	0.0	2.7	0.3	0.1	0.0	1.5	1.9	4.6
Apr 1	0.0	0.9	2.3	0.0	3.2	0.0	0.0	0.0	1.9	1.9	5.1
Apr 15	0.0	1.0	2.7	0.0	3.7	0.0	0.0	0.0	2.2	2.2	5.8
May 1	0.0	1.4	3.4	0.4	5.2	0.0	0.0	0.0	2.8	2.8	8.0
May 15	0.0	1.5	4.0	0.5	6.0	0.0	0.0	0.0	3.3	3.3	9.3
Jun 1	0.2	2.4	6.3	0.7	9.6	0.1	0.1	1.0	5.1	6.3	15.9
Jun 15	0.2	2.6	7.8	0.8	11.4	0.2	0.1	1.4	6.4	8.0	19.4
Jul 1	0.3	2.1	11.6	1.2	15.2	0.2	0.1	1.9	10.0	12.2	27.4
Jul 15	0.4	1.9	10.1	1.4	13.8	0.3	0.1	2.4	12.8	15.6	29.4
Aug 1	0.5	1.6	6.9	1.7	10.7	0.4	0.2	3.2	16.5	20.2	31.0
Aug 15	0.6	1.2	8.3	2.0	12.1	0.5	0.2	3.9	10.0	14.6	26.7
Sep 1	0.8	0.7	10.2	2.4	14.0	0.6	0.3	5.0	0.0	5.9	19.9
Sep 15	0.9	0.0	11.9	2.7	15.5	0.8	0.3	6.2	0.0	7.3	22.7
Oct 1	1.2	0.0	13.9	3.0	18.1	1.0	0.4	7.7	0.0	9.0	27.1
Oct 15	1.4	0.0	15.8	3.4	20.6	1.2	0.5	9.1	0.0	10.8	31.3
Nov 1	1.6	0.0	0.0	0.0	1.6	1.4	0.6	0.0	0.0	1.9	3.6
Nov 15	1.8	0.0	0.0	0.0	1.8	1.5	0.6	0.0	0.0	2.1	3.8
Dec 1	1.1	0.0	0.0	0.0	1.1	0.9	0.4	0.0	0.0	1.3	2.4
Dec 15	1.2	0.0	0.0	0.0	1.2	1.0	0.4	0.0	0.0	1.4	2.5
Maximum:	1.8	2.6	15.8	3.4	20.6	1.5	0.6	9.1	16.5	20.2	31.3

Notes:

1. Mitigation steelhead values include fish for both anadromous and in-river programs. 0+ and 1+ refer to the age class of the fish.
2. Mitigation chinook values include both smolt and yearling releases.
3. Values within dashed line indicate water supply is chilled to 16°C, with oxygen supplementation provided at both first and second pass raceways.

It is extremely costly to chill water, especially when flow rates are high and the required temperature reduction is large. The cooler water in the hatchery discharge and potential groundwater supply can be used to pre-cool the incoming reservoir supply, thereby reducing the required temperature differential. Preliminary analyses indicate that both of these strategies could be effective in reducing both the capital and operating and maintenance costs of the overall chilling requirement. Consequently, the following systems have also been included for the MRFH.

- Oxygen supply (to provide oxygen to the oxygen supplementation system)
- Oxygen supplementation
- Water pre-cooling

5.3.3.2 Recommended Treatment System

The treatment evaluation criteria included performance, initial cost, operation and maintenance costs, simplicity of construction, area requirements, reliability, compatibility with other systems, ease of operation, and safety. Based upon the selection criteria, the following treatment systems have been incorporated into the Hatchery Master Plan.

Treatment Requirement	Preferred Component
1. Aeration and gas stabilization for hatchery water supply	Centralized packed columns with a distribution head tank in conjunction with individual sealed/open combination packed columns located at each first pass raceway
2. Aeration of reuse water	Individual sealed/open combination packed columns located at each second pass raceway
3. Oxygen supply method	Cryogenic oxygen supplied commercially
4. Oxygen supplementation of hatchery water supply	Individual sealed/open combination packed columns located at each first pass raceway
5. Oxygen supplementation of reuse water	Individual sealed/open combination packed columns located at each second pass raceway
6. Water pre-cooling	Ground water development to the full extent possible for direct mixing with surface water; plus, a heat exchanger for use with hatchery discharge water
7. Water chilling	Water pre-cooling used in conjunction with a mechanical chiller

Figure 5-1 depicts the flow diagram for the proposed treatment system. The system would operate continuously with aeration and gas stabilization components, while chilling, oxygenation, and pre-cooling would be used only during periods of high surface water temperatures.

Normal Operation - Normal hatchery operation would occur at all times when the hatchery water supply was below 18°C. Under normal operation a maximum flow rate of 35.4 cfs would be required. This flow requirement would vary depending on the developmental stage of the fish being reared in the hatchery (Table 5.5). The maximum flow would occur during October. This flow could be a mixture of well and surface water or surface water only.

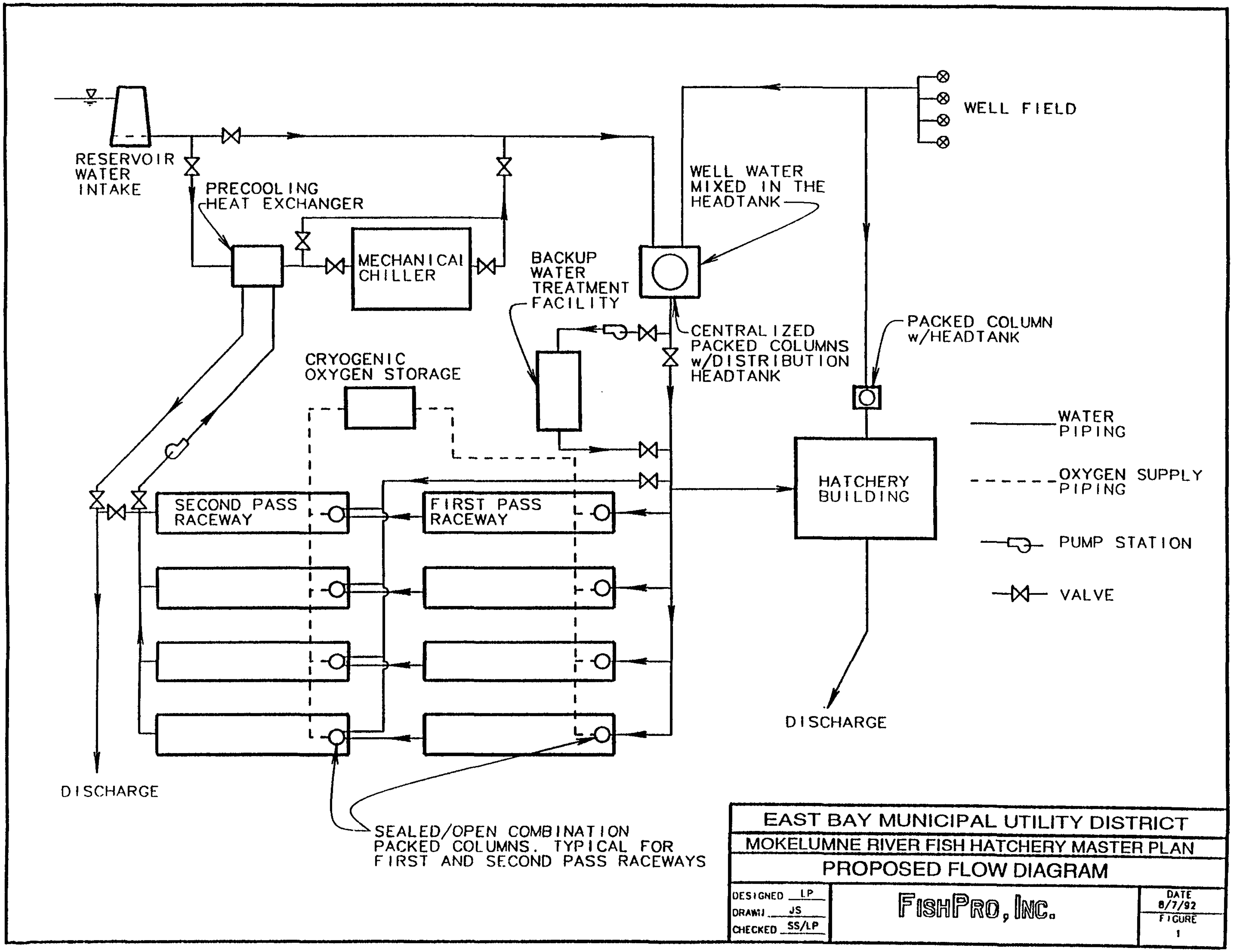
Under normal operation, the surface water would bypass the pre-cooling heat exchanger and chiller, and flow directly to the centralized packed columns. Well water, if any, would then be mixed, and the combined water stabilized. From there, the water would flow to the individual raceways, bypassing the backup treatment facility, and flow through the individual packed columns located at the inlet of each first pass raceway. The entire process would be gravity driven, using the reservoir head for water transport.

After flowing through the first pass raceways, the water would then be routed through combination sealed/open packed columns located at the inlet of each second pass raceway to reaerate the water. A minimum of 4 feet of drop between the raceways would be needed for gravity operation.

Finally, the second pass raceway would discharge to the river or polishing pond, bypassing the secondary side of the pre-cooling heat exchanger.

Emergency Operation - Emergency operation would occur any time the hatchery water supply temperature reached 18°C or above. Under emergency operation, the oxygenation system would be utilized to decrease the required water supply, thereby lowering cooling costs. The ground water system will be fully developed and used to aid in water cooling. A total of 4.4 cfs well water would be used in combination with 26.9 cfs of surface water for the hatchery supply.

The flow path of water during emergency conditions would vary depending on the temperature of the combined surface and well water. Well water mixing would handle the entire cooling load for surface water temperatures up to 18.3°C. For surface water temperatures above this, but below 19.0°C, the reservoir water would be routed first through the pre-cooling heat exchanger, bypass the mechanical chiller, and then mix with well water to provide the required cooling. Under this operating scenario, outlet water from the raceways would be pumped to the heat exchanger to be used as coolant. Finally, for surface water temperatures above 19°C, the mechanical chiller would be used in combination with the pre-cooling heat exchanger and well water mixing. Temperatures this high would be a problem only infrequently, perhaps 4 years in 70.



RESERVOIR WATER INTAKE
PRECOOLING HEAT EXCHANGER
MECHANICAL CHILLER
BACKUP WATER TREATMENT FACILITY
WELL WATER MIXED IN THE HEADTANK
WELL FIELD
CENTRALIZED PACKED COLUMNS w/DISTRIBUTION HEADTANK
PACKED COLUMN w/HEADTANK
CRYOGENIC OXYGEN STORAGE
HATCHERY BUILDING
SECOND PASS RACEWAY
FIRST PASS RACEWAY
DISCHARGE
DISCHARGE
WATER PIPING
OXYGEN SUPPLY PIPING
PUMP STATION
VALVE
SEALED/OPEN COMBINATION PACKED COLUMNS. TYPICAL FOR FIRST AND SECOND PASS RACEWAYS
EAST BAY MUNICIPAL UTILITY DISTRICT
MOKELUMNE RIVER FISH HATCHERY MASTER PLAN
PROPOSED FLOW DIAGRAM
DESIGNED LP
DRAWN JS
CHECKED SS/LP
FISHPRO, INC.
DATE 8/7/92
FIGURE 1

Figure 5-1.

The oxygen supplementation system would operate during all water cooling scenarios. During these periods, the combination packed columns at both the first and second pass raceways would be sealed and oxygen injected into them. No flow path alteration would be needed for the oxygenation process.

A backup chemical treatment facility would be located downstream of the centralized packed columns. Under normal operation the packed columns should remove the hydrogen sulfide in the surface water; however, if further treatment was required for any reason, the water could be pumped through the chemical treatment facility before entering the raceways.

5.3.3.3 Hatchery Building

The hatchery building would receive water from both the hatchery supply system as well as a separate well water line. Gas stabilization and aeration would occur for the general supply in the centralized packed columns. However, a separate packed column and head tank would be needed for the well water supply.

5.3.3.4 Second-pass Raceways

As a backup water source for the second-pass raceways, a supply line drawing fresh water would be provided to each raceway, bypassing the first-pass raceways.

5.3.3.5 Aeration and Gas Stabilization

Packed Columns - Operation of the packed columns consists of water flowing downward through a column packed with media to increase the air to water surface area. Since water has a greater affinity for oxygen than nitrogen, oxygen will generally be accepted and nitrogen driven out. Oxygen and nitrogen concentrations at or near saturation levels are attainable with this method. Packed columns are widely used in fish production applications for aeration and gas stabilization. They have proven to be efficient, reliable, and economical alternatives.

Hatchery Supply - For hatchery operation, both gas stabilization and aeration are required. Packed columns will be centrally located, because they are compatible with a greater variety of oxygenating systems. These packed columns will empty into a distribution head tank and be distributed from there to the raceways. The system would operate without pumping, using the head of Camanche Reservoir.

Water Reuse - For reuse, only aeration is required. The columns will be located at the inlet end of the reuse raceways, and aerate the water as it flows from the first pass to the second pass raceways. For a gravity system, a minimum 1.2 meter drop is required between the raceways. Since gas stabilization is not required for reuse, a specially designed packed column will be used that could operate as both an aeration system and an oxygen injection system.

Oxygen Supply - A number of oxygen supply alternatives were evaluated including high pressure oxygen commercially supplied, cryogenic oxygen commercially supplied, and generation of oxygen on site. FishPro determined that the cryogenic oxygen, commercially supplied, was the best alternative.

Cryogenic Oxygen, Commercially Supplied - Oxygenic liquid would be expanded and heated for use by oxygen injection systems. Oxygen supplied in this state is generally 95 percent pure. This method will also be used for the lake oxygenating system and, therefore, large quantities will be available.

The storage area for cryogenic oxygen containers would be centrally located to supplement both first and second pass water. The lake oxygenating system would have a separate storage area closer to the dam.

Oxygen Supplementation Alternatives - A number of oxygen supplementation alternatives were examined including sealed columns, U-tube oxygen contractor, direct application, cone oxygenators, low-head oxygen injection, stirred tank reactor, and diffused oxygen systems. FishPro determined that the most efficient and economical oxygen supplementation alternative is the sealed columns.

Sealed Columns - Oxygen is injected into a sealed packed column. As the water flows over the media inside, its surface area is increased and the transfer of oxygen into the water is increased. Sealed columns are an efficient and economical method of oxygenating water, and have proven reliable in fish hatchery operations.

Hatchery Supply - For the hatchery supply, sealed columns would be located at the inlet to each first pass raceway. It is assumed that, prior to the sealed columns, the water passes through a centralized gas stabilization system. A minimum of 1.2 meters of water head is required for this application to be effective.

Water Reuse - A specially designed combination packed/sealed column was selected for this application. The combination columns would operate as an ordinary packed column for aeration, or it could be sealed and used for oxygen injection. A minimum of 1.2 meters drop is required for this application to work without pumping.

5.3.3.6 Water Pre-cooling Alternatives

The following water pre-cooling alternatives were examined by FishPro: use of cryogenic oxygen supplied for the lake oxygenating system for water cooling, well water mixing, make-up heat exchanger, and well water cooling in combination with make-up heat exchanger.

Well Water Cooling in Combination with Make-up Heat Exchanger - One alternative includes both well water mixing and a make-up heat exchanger to pre-cool the water. Lower temperatures can be achieved if the water is passed through the heat exchanger prior to well water mixing.

This system would be located upstream of the hatchery gas stabilization system. The heat exchanger would pre-cool the water initially using the total hatchery outflow as coolant for the incoming lake water. Following this, it would be mixed with the well water. This combined system would provide pre-cooling for a mechanical cooling system when lake temperatures were 19°C and above, and handle the total load when temperatures did not reach 19°C. Pumping would be required for both the well water and the hatchery outflow water.

Water Chilling Alternatives - Water chilling may be required at the MRFH to insure that the hatchery water supply does not exceed 18°C.

A number of water chilling alternatives were examined by FishPro which included: chiller system, chiller system with pre-cooler, chiller/cooling tower combination without pre-cooling, chiller/cooling tower with pre-cooling, and ice melting/cooling tower combination with pre-cooling, and heat pump systems. Based upon the evaluation criteria from FishPro, a chiller system used in combination with pre-cooling will be examined further.

Chiller System With Pre-cooler - This system would utilize the pre-cooling method in combination with a mechanical chiller. The pre-cooling method involves both well water mixing and a makeup heat exchanger. The chiller cooling load would be substantially reduced using pre-cooling, thus a much smaller unit would be required.

In this system, all components would be located upstream of the hatchery gas stabilization system. The pre-cooling heat exchanger would be located the furthest upstream, followed by the chiller, and finally well water mixing. The heat exchanger would utilize the entire hatchery outflow to cool the surface water inflow. Since the hatchery outflow is greater than the surface inflow, the heat exchanger would be very effective.

The chiller would then cool the water to an intermediate level. The chiller will be located upstream of the well water mixing to take advantage of lower flow rates, before surface and well water are combined.

Finally, the well water mixing would cool the water and increase the flow rate to levels required for hatchery operation.

The chiller unit itself would be an indirect system utilizing a reciprocating type compressor which would employ air as the heat sink. By utilizing air as the heat sink, the need to draw extra water and discharge it at elevated temperatures is eliminated. The system would be located upstream of the hatchery gas stabilization system and it would be enclosed in a building away from occupied areas.

The system would operate only under emergency conditions estimated to occur in about 4 percent of all years. Components would be sized to handle the worst case scenario, but much of the time the entire cooling load would be handled by the pre-cooling system exclusively.

5.3.4 Expected Results (MRFH)

The MRFH will operate efficiently and cost effectively with the components proposed. Under normal conditions, the hatchery would operate using gas stabilization and aeration only. During periods of high surface water temperatures, oxygen would be used to decrease the flow rates needed for hatchery production, thereby decreasing cooling requirements. Well water would be mixed with surface water to aid in water cooling, and a mechanical chiller combined with a pre-cooling heat exchanger would handle the rest of the load. Combination sealed/open packed columns would be used for both oxygenation and aeration, with a centralized packed column system used for gas stabilization. Excluding the well water, pumping would be required only during high surface water temperature conditions or when the backup treatment facility was used. This hatchery design will provide acceptable water quality, temperatures, and flow rates under all operating scenarios, with high efficiency and reliability.

The Master Plan will meet the hatchery production goals outlined in the LMRMP. The Master Plan will provide enough rearing capacity and water of sufficient quantity and quality to meet the LMRMP hatchery goals of 3.66 million salmon smolts, 800,000 yearling fall-run chinook salmon, 125,000 fall-run chinook salmon transferred from the Mokelumne River, 53,000 yearling steelhead on an annual basis, plus contingency rearing space for an additional 100,000 pounds.

The yearling salmon and anadromous steelhead releases will result in better imprinted fish that will migrate out of the Lower Mokelumne River and the Delta when water temperature and passage conditions are most favorable. These well-imprinted salmon and steelhead will have an improved chance of being able to locate the Mokelumne River during their adult upstream migration and should make a significant contribution in the rebuilding of the salmon and steelhead runs in the Lower Mokelumne River. A number of the hatchery fish will return to the Mokelumne River to spawn naturally and the hatchery program will ensure that there will be a base population of adult fish available to take advantage of the right combination of environmental conditions to rebuild the natural spawning population.

5.4 LOWER MOKELUMNE RIVER

This section details the operational strategies required to attain the goals and strategies discussed in Section 5.1. Flows for temperature and habitat goals are described by water year type; then, non-flow improvements in the Lower Mokelumne are discussed.

For the purposes of LMRMP flow scenarios, water year type is determined by a combination of Mokelumne Basin runoff and the combined storage levels of Camanche and Pardee reservoirs. Under this system, fish-flow release decisions are made at two key points during the year. In April, water supply conditions through the following October can be accurately predicted based on projected runoff determined from snow-pack surveys.

For the period 15 April - 31 October, wet/normal-year fish flows are provided when combined Pardee/Camanche Reservoir storage is projected to be at the maximum levels allowed by the Corps of Engineers' flood space reservation requirement on 5 November (this amount varies by storage conditions in PG&E's reservoirs upstream of Pardee). Dry-year releases for fish are made if combined Pardee/Camanche storage is projected to be below the flood space reservation requirement on 5 November. If projected Pardee/Camanche storage is 260,000 acre-feet or more below the maximum flood space reservation on 5 November, critical dry-year flows are provided.

For the period 1 November to 14 April, fish releases are based on actual 5 November storage levels. If, during any month, inflow conditions are such that flood control releases must be made, releases for fish are increased up to the appropriate wet-year level. Any remaining release necessary to prevent storage from encroaching into the flood control space reservation is termed a flood control release. Using reservoir storage data in addition to runoff projections allows greater flexibility in adapting to changing conditions of supply, and avoids overcommitment of resources during times of potential water shortages. To preclude such conflicts, EBMUD, CDFG, and other resource agencies would have to agree on operational rules.

5.4.1 Critical Dry-year Operations

Based on simulated hydrology, critical dry conditions would occur in about 16 percent of years during the salmon spawning and incubation period (October-March), flow would be provided to support a small run (about half of optimum habitat) with minimum flow below Woodbridge for salmon migration (Tables 5.7 and 5.8). Spawning flows would not be provided until temperature conditions are suitable (15°C) in Camanche. Winter flow for steelhead migration would also be minimal.

During the salmon rearing period (April-July), minimum flows of at least 100 cfs would be provided in the Camanche reach. More flow is provided in June to control temperature as far as the proposed trap above Lake Lodi during the smolt out-migration period. Migrants would have to be trapped and trucked from above Lake Lodi, as no flow is provided below Woodbridge Dam.

During the summer (July-October), a base flow of 100 cfs is provided for steelhead rearing above Lake Lodi. Additional Camanche Reservoir releases for downstream irrigation demand are usually sufficient to provide cool habitat for 5 to 10 miles below Camanche Dam.

5.4.2 Dry-year Operations

Based on simulated hydrology, dry years would occur about 34 percent of the time. During the spawning period, flow would be provided to supply approximately 80 percent of optimum habitat for spawning. Spawning flows would not be provided until temperature conditions

Table 5.7. Recommended flows for production-oriented alternative, natural emphasis.

		CAMANCHE CRITICAL		CAMANCHE DRY		CAMANCHE NORMAL		CAMANCHE WET		WOODBRIDGE CRITICAL		WOODBRIDGE DRY		WOODBRIDGE NORMAL		WOODBRIDGE WET	
OCT	1	100	*	100	*	100	*	100	*	20		20		20		20	
	2	100	*	200	*	300		300		20		100	$	200	$	200	$
NOV	1	100		200		300		300		100		200		300		300	
	2	100		200		300		300		100		200		300		300	
DEC	1	100		200		300		300		100		200		300		300	
	2	100		200		300		300		50	*	100	*	100	*	100	*
JAN	1	100		200		200		200		50	*	100	*	100	*	100	*
	2	100		200		200		200		50	*	100	*	100	*	100	*
FEB	1	100		200		200		200		50	*	100	*	100	*	100	*
	2	100		200		200		200		50	*	100	*	100	*	100	*
MAR	1	100		200		200		200		50	*	100	*	100	*	100	*
	2	100		200		200		200		50	*	100	*	100	*	100	*
APR	1	100		100		100		100		20	@	100		100		100	
	2	100		100		100		100		20	@	150		150		150	
MAY	1	100		100		100		100		20	@	300		300		300	
	2	100		100		100		100		20	@	400		400		400	
JUN	1	300		300		300		300		20	@	20	@	500		500	
	2	300		300		300		300		20	@	20	@	500	#	500	#
JUL	1	100	**	200	**	450		450		20	@	20	@	20	@	20	@
	2	100	**	200	**	200	**	200	**	20	@	20	@	20	@	20	@
AUG	1	100	**	200	**	200	**	200	**	20		20		20		20	
	2	100	**	200	**	200	**	200	**	20		20		20		20	
SEP	1	100	**	100	**	100	**	100	**	20		20		20		20	
	2	100	**	100	**	100	**	100	**	20		20		20		20	
AVERAGE FLOW (cfs)		117		179		210		210		39		105		162		162	
TOTAL FLOW (TAF)		84		130		152		152		28		76		117		117	

* Flow for steelhead, no flow requirement for chinook salmon
@ Trap and truck
$ This release should only be made if Camanche release temperature is 15.5 degrees C or less.
# This release should only be made when conditions in the Delta are conducive to smolt survival, otherwise release 20 cfs below Woodbridge and trap out-migrants.

Table 5.8. Implemented flows for production-oriented alternative, natural emphasis.

		CAMANCHE								WOODBRIDGE							
		CRITICAL		DRY		NORMAL		WET		CRITICAL		DRY		NORMAL		WET	
OCT	1	103	•	103	•	161	•	161	•	20		20		20		20	
	2	103	•	200	•	341		341		20		117	$	200	$	200	$
NOV	1	157		257		357		357		100		200		300		300	
	2	157		257		357		357		100		200		300		300	
DEC	1	174		274		374		374		100		200		300		300	
	2	124		200		300		300		50	•	126	•	226	•	226	•
JAN	1	117		200		200		200		50	•	133	•	133	•	133	•
	2	117		200		200		200		50	•	133	•	133	•	133	•
FEB	1	110		200		200		200		50	•	140	•	140	•	140	•
	2	110		200		200		200		50	•	140	•	140	•	140	•
MAR	1	132		200		200		200		50	•	118	•	117	•	117	•
	2	132		200		200		200		50	•	118	•	117	•	117	•
APR	1	166		246		244		244		20	@	100		100		100	
	2	166		296		294		294		20	@	150		150		150	
MAY	1	232		512		599		599		20	@	300		300		300	
	2	232		612		699		699		20	@	400		400		400	
JUN	1	300		300		903		903		34	@	34	@	500		500	
	2	300		300		903		903		34	@	34	@	500	#	500	#
JUL	1	297	••	297	••	469		469		20	@	20	@	20	@	20	@
	2	297	••	297	••	469	••	469	••	20	@	20	@	20	@	20	@
AUG	1	257	••	257	••	398	••	398	••	20		20		20		20	
	2	257	••	257	••	398	••	398	••	20		20		20		20	
SEP	1	184	••	184	••	265	••	265	••	20		20		20		20	
	2	184	••	184	••	265	••	265	••	20		20		20		20	
AVERAGE FLOW (cfs)		184		260		375		375		40		116		175		175	
TOTAL FLOW (TAF)		133		188		271		271		29		84		127		127	

• Flow for steelhead, no flow requirement for chinook salmon
@ Trap and truck
$ This release should only be made if Camanche release temperature is 15.5 degrees C or less.
# This release should only be made when conditions in the Delta are conducive to smolt survival, otherwise release 20 cfs below Woodbridge and trap out-migrants.

are suitable in Camanche. Flow for salmon migration would be provided below Woodbridge Dam from October (at the earliest date suitable migration temperatures are available) to early December, and from December through March for steelhead migration (all life stages). Flow during the early rearing period (through March) would be maintained at the spawning level to minimize the impacts of drawdown on eggs and fry still in the river gravel. Flow should be reduced to optimum rearing level (based on CDFG data) after most of the fry emerge; however, downstream demands would require that flow be maintained at slightly higher levels (Table 5.8).

During the smolt out-migration period, flow would be provided to control water temperature as far as Lake Lodi. In addition, flow below Woodbridge Dam would be provided in April and May to maintain temperature conditions suitable for emigration. Smolts would be trapped from above Lake Lodi and trucked in June and July. During the summer, a base flow of 200 cfs would be provided for steelhead rearing above Lake Lodi, as in critically dry years, Camanche Reservoir releases for downstream irrigation demand usually provide sufficiently cool habitat for 5 to 10 miles below Camanche Dam.

5.4.3 Normal and Wet-year Operations

In normal and wet years, spawning period flow would be provided to supply approximately 100 percent of optimum habitat for spawning. Flow for salmon migration would be provided below Woodbridge Dam from October to early December, and from December through March for steelhead migration (all life stages). Flow would be higher than in dry years during the salmon migration period to keep Mokelumne River flow proportional to other Delta inflows. Spawning flows would not be provided until temperature conditions are suitable in Camanche. As in dry years, flow during the early rearing period (through March) would be maintained at the spawning level in order to minimize the impacts of drawdown on eggs and fry still in the river gravel. Flow would be reduced to optimum rearing level (based on CDFG data) after most of the fry emerge (Table 5.7). However, as in dry years, downstream demands require that flow be maintained at slightly higher levels (Table 5.8).

During the smolt out-migration period (April, May and June), flow would be provided to control water temperature as far as Ray Road. All smolts out-migrate through the river below Woodbridge Dam, so flow below the dam in these months should be maintained to provide temperature conditions suitable for out-migration. Any smolts migrating after July 1 should be trapped and trucked to a release point below the Delta as mortalities in the Delta are extreme. The summer period base flow of 200 cfs should provide for steelhead rearing above Lake Lodi. Actual flow during this period will be somewhat higher because of downstream irrigation demands (Table 5.8).

5.4.4 Temperature Criteria

Water temperatures during the fall chinook salmon upstream migration and spawning period are determined by Camanche Reservoir water temperature and local air temperature. Since most spawning occurs within a few miles of Camanche Dam, management of Camanche release rates at this time of year has little impact on downstream water temperature in the spawning reach. Releases of cold water from Pardee Reservoir during the summer and fall can also impact Camanche release temperature during the spawning season. During the spring, temperature is the determining factor in flow recommendations, and habitat criteria are secondary.

In determining out-migration flows, water temperature is the only criterion used. Temperature is maintained at or below the upper optimum level by means of flow management. In the late out-migration period (end of June), below Woodbridge Dam, it becomes impossible to meet the upper limit at most flow levels below 1000 cfs (Appendix C, Table C-1). In addition, at this time of year flow increases reduce temperature up to a certain level, and beyond that level have little incremental effect (Appendix C, Figure C-9). In these cases, the flow resulting in the coolest temperature before the point of diminishing returns is selected. Temperature was maintained in the higher suitability ranges.

Water temperature criteria for chinook and steelhead are based primarily on Raleigh et al. (1989), and are as follows:

- Spawning/fry: below 14°C is optimum, suitability decreases to zero at 17°C.
- Juvenile rearing/emigration: below 18°C is optimum, suitability decreases to zero at 24°C.
- Adult migration: below 19°C is optimum, suitability decreases to zero at 25°C.
- Temperature conditions for spawning apply to the reach from Camanche Dam to Mackville Road; for rearing, to the reach between Camanche Dam to Elliott Road; for out-migration, from the Camanche reach at Bruella Road; and for out-migration, from the Woodbridge reach at Ray Road.

The temperature implications of the LMRMP were simulated using EBMUDSIM results and the WQRRS model. The model simulated the temperature of Camanche releases for a selected subset of the entire 70 year hydrologic sequence using Camanche storage, inflows, and outflows estimated by EBMUDSIM run 5633.

The temperature of Camanche inflows for every year was assumed to be the measured bimonthly mean temperatures taken in the Pardee afterbay from 1976 through 1985. Normal year meteorological conditions, as described in Appendix C, were assumed. The January 1 elevation of Camanche in each annual simulation was the elevation determined by the previous days' (31 December) EBMUDSIM storage level, calculated by EBMUD's storage-elevation curve.

Results of these simulations showed that in three years (1931, 1977, and 1988), temperature standards for release water were substantially exceeded. In these years, simulated temperatures depart from the temperature standard in early summer, and the standard is not met again until destratification in early to late November. Simulated temperature exceeded the temperature standard by as much as 10-15°C, with release temperature reaching 20-25°C in mid-summer. These conditions would be highly unfavorable to any salmonids in the river at that time. In one additional year, (1978) standards are exceeded by 3-4°C from February through early September.

In four additional years (1958, 1976, 1982, 1983), temperature goals were exceeded during November, but the difference between the simulated temperature and the standard was not great. In these years, simulated maximum temperature fell to between 16 and 17°C. The temperature goal at this time is 15°C, so unfavorable conditions for spawning might result. All of these events coincided with destratification of Camanche.

5.4.5 Non-flow Management Alternatives

There are several factors, other than flow and temperature, that may limit salmon and steelhead production in the Mokelumne River. The following discussion outlines these limiting factors along with possible management solutions. Although all of the alternatives should be considered, EBMUD takes responsibility for implementing only a limited subset. For example, it might be the responsibility of the MRTAC to proctor and administer temperature monitoring stations.

In below-normal years, the three factors of greatest concern are the poaching of adult salmon at and below Woodbridge Dam; the mortality rate of smolts out-migrating through Lake Lodi, the Woodbridge reach, and the Delta; and the quality of spawning habitat in the upper river. In above-normal years, the significant limiting factors are the poaching of adult salmon at Woodbridge Dam, the mortality rate of smolts in Lake Lodi during out-migration and in the Delta after mid-June, and the quantity of spawning habitat in the upper river. Other factors, of concern in all water years, include warm water temperatures in the river during the early spawning period of chinook salmon, fry entrainment in agricultural pumps, in-river predation on salmon fry by resident fish and hatchery-released steelhead, and angler-induced egg mortality through redd trampling.

The following discussion outlines non-flow management alternatives for increasing salmon production in the Mokelumne River. One of two classifications (essential or experimental) are given to each alternative depending on its potential to increase production based on existing scientific data.

5.4.5.1 Camanche Reach

There are three proposed management alternatives for the Camanche reach of the Mokelumne River: enhancement of spawning success, improvement of in-river fry survival, and enhancement of smolt survival through Lake Lodi. Under each alternative, specific management recommendations are proposed.

C-100901

Enhancement of Spawning Success - Salmon production in the Mokelumne River is influenced by both the quality and quantity of spawning habitat. The ideal spawning medium is a mix of gravel and cobble that is moved easily by spawning adults and which provides a permeable matrix for incubating eggs and newly hatched fry (Raleigh et al. 1986; Reiser and Bjornn 1979). Spawning substrate quality is enhanced by periodic high flows that churn up the river bed, washing out the fine sediments and loosening the gravel matrix (Tennant 1976; Milhous 1982 and 1985; Nelson et al. 1987). High flows also affect the quantity of spawning substrate in the river. During high flows, "new" gravels are washed into spawning areas from erosion of the stream bank and downstream movement of in-river gravels. To maintain spawning substrate in a river, spawning gravels from upstream sources must be recruited periodically.

The construction of Camanche Dam and subsequent regulation of high flows in the river have interfered with these processes. Emergence studies conducted in 1991 and 1992 revealed that over 70 percent of the chinook salmon redds in the river contained fines at levels known to reduce egg survival significantly (Appendix A). Return flows from pump irrigation and water withdrawals from the bottom of Camanche Reservoir appear to be the major contributors to sediment loading in the upper river.

In other rivers, increased sediment loading and reduced flushing flows compact the gravel substrate below dams (Petts 1984; Milhous 1985; Nelson et al. 1987); this is also described as armoring. The release of calcium and clay particles from reservoirs has also been linked to armoring in tailwater areas, as has the release of nutrient-rich water that promotes dense algal growth (Nelson et al. 1987; Milhous 1982; Bell 1973; Petts 1984).

Substrate compaction may hinder or prevent salmon from digging redds in gravel areas that otherwise appear to be suitable spawning habitat (Burner 1951). During emergent studies in the Mokelumne River in 1991 and 1992, we observed armoring in many potential spawning areas (Appendix A). Although less than 500 salmon migrated into the river in both 1991 and 1992, superimposition of chinook salmon redds was observed (Appendix A). Clearly, armoring has reduced suitable spawning habitat.

The lack of suitable spawning habitat during wet years constitutes another problem for spawning chinook salmon in the Mokelumne River. In wet years, high flows (1,500 cfs or more) are sometimes unavoidable during the spawning and egg incubation periods. An IFIM study conducted in the river identified a substantial drop in spawning habitat when flows exceeded 600 cfs (Envirosphere 1988). At higher flows, where the river is confined by leveed banks, water depth and velocities exceed the chinook salmon's upper tolerance. In many unleveed rivers supporting salmon populations, high flows broaden the river channel into graveled side channels, which can be used by salmon for spawning.

River temperatures sometimes exceed 15° C just after the fall turnover in Camanche Reservoir and during chinook salmon's early spawning period (late October to mid-November). Emergence studies conducted in the river in 1992 documented that eggs exposed to temperatures above 15° C had a significantly lower survival rate than eggs incubated at lower temperatures (Appendix A).

The following discussion identifies six non-flow management strategies for enhancing spawning habitat in the Mokelumne River. The alternatives address problems with the quality and quantity of spawning habitat in the river by improving existing habitat, creating new habitat, and reducing egg losses caused by warm temperatures in the river.

Management Alternative 1. Clean and Break Up Existing Spawning Gravel

Classification	-	Essential
Implementation	-	EBMUD with other river interests and in cooperation with regulatory agencies

To improve chinook spawning habitat in the river, sediments in the spawning gravel need to be reduced. In addition, the spawning substrate needs to be "turned over" to reduce compaction. In unregulated rivers, high flows usually reduce sedimentation in spawning gravel and prevent substrate compaction. In the Mokelumne River, high flows are too infrequent to clean and break up the substrate. Gravel mobility studies conducted in the Mokelumne River indicate that flows of 1,000 cfs would mobilize only 10-20 percent of the bed material in the river from Camanche Dam to Highway 88; the substrate may be too compacted or armored for high flow alone to improve gravel quality.

Mechanical disturbance of the spawning gravels is the most effective method for reducing sedimentation and armoring. A bulldozer could loosen and "turn over" the spawning gravels. This activity could result in greater sedimentation in pool habitat as sediments are washed downstream from spawning habitat during cleaning operations. Therefore, the graves should be bulldozed just prior to high flows. High flows would presumably remove accumulated sediments from pool habitat and further clean the loosened spawning gravels. Spawning gravels probably would not require annual mechanical disturbance; however, an annual monitoring program should document sediment content and armoring. The CDFG and the Army Corps of Engineers would have to agree and support the program, and stream alteration permits would be required.

Management Alternative 2. Restrict Water Returns From Irrigation Pumps

Classification	-	Experimental
Implementation	-	State Water Resource Control Board, Agricultural Stabilization and Conservation Service (USDA)

Reduction of return flows from pump irrigation may reduce sediments, heavy metals, in-stream temperature, and pesticide concentrations in the river (Johnson 1985). Reduction of sediment input in other rivers has improved egg survival in salmon redds and increased food resources for fry and smolts (Chapman 1988; Cooper 1965; Cordone and Kelley 1961; Bjornn et al. 1977). Preventing heavy metals and pesticides from entering the Mokelumne River is important for maintaining suitable incubation and rearing conditions for salmonids. Under this alternative, the management approach would reduce all direct irrigation return flows to the river.

The magnitude of the problem created by pump irrigation return flows is unknown; therefore, the potential benefits of restricting such flows are not currently quantifiable. This alternative would require long-standing irrigation practices to be changed significantly. Before this program can be implemented, studies are needed to determine if the irrigation releases exceed current state turbidity and water quality standards for point source discharge. If the alternative is accepted, an enforcement program would probably be necessary to ensure compliance. Funding for irrigation improvements might be obtained from the Agricultural Stabilization and Conservation Service of the U.S. Department of Agriculture.

Management Alternative 3. Limit In-river Movement and Access of Anglers During Chinook Salmon Spawning and Incubation

Classification	-	Essential
Implementation	-	CDFG

Presently, in-river salmon fishing is prohibited during the salmon spawning period between Camanche Dam and Peltier Road. However, fishing for other species (particularly trout) is allowed during the incubation period of the salmon. A recent study on brown trout indicated that wading anglers may significantly reduce egg survival in trout redds. During our emergence studies in the Mokelumne River in 1991 and 1992, we frequently observed anglers walking on salmon redds. Unfortunately, most fishing activity is concentrated in the spawning areas.

One management solution would be to establish fishing regulations which restrict anglers from wading within the spawning areas of chinook salmon between 15 October and 1 April. This would minimize human impacts and increase salmon production in the river.
Any fishing restriction during spawning and incubation would have to be implemented by the CDFG. The area is already closed to fishing during the spawning period of salmon and fishing pressure is relatively light during the incubation period. The monetary costs of implementing this alternative are relatively low while the potential returns are high.

Management Alternative 4. Create Berm Areas in River

Classification	-	Experimental
Implementation	-	EBMUD with other river interests in cooperation with regulatory agencies

The quality of spawning habitat in the river in dry years, as well as the quantity of spawning habitat in wet years, is questionable. One approach to increasing spawning habitat is to create berm areas in the river at 70-90° to the direction of flow to provide suitable spawning habitat for chinook salmon under a variety of flows. During redd surveys on the Mokelumne River (1991-1992), the majority of redds (86%) were found on such berms. This phenomenon has also been documented on other systems (Vogel 1982; Tutty 1986; Shirvell 1989).

To ensure that the salmon's spawning requirements are met, construction of new berms may require that large quantities of gravel be imported into the river Separate berm areas would need to be constructed for wet and dry years. Berms could be constructed and a monitoring program developed to document salmon use and emergence success. Sedimentation and armoring in the berms would be checked annually to determine when the berms provide suitable habitat. The condition of the test berms should also be documented annually to determine whether they would be destroyed by high flows (greater than 1,500 cfs).

It is technically feasible and relatively inexpensive to construct gravel berm areas in the river. This stream bed alteration work would require permits from CDFG and the Army Corps of Engineers; however, we believe these permits could be obtained without significant objections. There are two unknown factors in this alternative: the life span of the berm areas and the magnitude of the benefit to the fishery. A monitoring program would be the only way to quantify these unknown factors.

<u>Management Alternative 5. Create High-Flow Spawning Habitat</u>

Classification	-	Experimental
Implementation	-	EBMUD with other river interests in cooperation with regulatory agencies

During wet years, flows in the Mokelumne River often exceed 1,500 cfs in Camanche reach. Based on IFIM results (Envirosphere 1988), it is doubtful that any suitable habitat exists in the main stem of the river for spawning chinook salmon during these high flows. Ironically, adult salmon escapement is generally highest in wet years when flows are high and yet spawning habitat conditions can be the worst. Substantial production may be foregone if suitable spawning habitat is unavailable. Habitat should be created to enable high production in wet years when a large number of salmon migrate into the river.

A two-phase approach would be implemented to increase spawning habitat for use when flows exceed 1,500 cfs in the river. In the first phase, the existing spawning channels in the MRFH would be improved by building numerous bermed areas. The berms can be engineered to maximize depth, velocity, and substrate conditions for spawning chinook salmon. The existing spawning channels should be redesigned for two reasons. First, flow through these channels can be regulated so that dewatering or washing out of redds can be avoided throughout the entire spawning season, regardless of flow in the river. Second, the cost of modifying the existing channels would be considerably less and would not require acquisition of land or special permits. Several different "test" berms could be constructed in the channels and monitored to determine which design provides the greatest fish utilization and emergence success.

In the second phase, full-scale modifications of the spawning channels would be initiated after a final design has been selected. The spawning channels would also be enlarged and extended into Van Assen Park if the project was successful and more habitat was needed.

Although the first attempts to construct spawning channels in the MRFH were not successful, more about the spawning and incubation requirements of chinook salmon is now known. In addition, advancements in hydrologic modeling allows simulation of the depth and velocity over berms in the spawning channels under a variety of flows. Still, a trial-and-error approach, where several different designs can be monitored for salmon spawning and fry emergence, is the key to creating successful spawning habitat.

Management Alternative 6. Provide Source of New Gravel for Recruitment Into the Stream Channel During High Flows

Classification	-	Experimental
Implementation	-	EBMUD with other river interests in cooperation with regulatory agencies

The construction of Camanche Dam and levees in the Lower Mokelumne River has resulted in poor gravel recruitment which, over time, has degraded the spawning habitat for chinook salmon. The previous alternatives identified several approaches for improving both the quality and quantity of spawning habitat in the river; however, without a continuing supply of new gravel the effectiveness of these approaches will decline considerably over time. This alternative proposes to provide a source of new gravel that would be distributed naturally in the river during high flows. The alternative relies heavily on the hydrology of the system and attempts to mimic gravel recruitment in unregulated rivers.

We propose to provide a gravel source along the riverbank at several locations in the upper Camanche reach. At low flows, most of the gravel would be out of water; however, at high flows, the gravel would be inundated and washed downstream to replenish spawning gravels. There may be some potential problems with this approach. Although the gravel source may be depleted rapidly at high flows, it may not be deposited in the desired locations (i.e., spawning habitat). Also, the amount of gravel necessary to improve spawning habitat significantly is unknown. The one advantage of this approach is that it attempts to mimic natural rivers by replenishing spawning gravels and it could improve spawning habitat throughout the river rather than at specific locations where EBMUD has access to build berms. Stream bed alteration permits would be required.

Improve In-river Fry Survival - The only data available on in-river survival of chinook salmon in the Lower Mokelumne River were collected by BioSystems in 1990 and 1991 (Appendix A). In these studies, smolts reared at the MRFH were marked and released into the river at two sites (the hatchery and Bruella Road). Results indicated that the in-river mortality rate of smolts from Camanche Dam to the confluence of Lake Lodi was low (<5%), but the study did not address mortality of young-of-the-year (YOY) chinook salmon from emergence to smoltification.

The two most likely sources of mortality for YOY chinook salmon in the Mokelumne River are predation by resident fish or hatchery trout planted into the river from April through June, and entrainment of fry in irrigation pumps. Although these factors may decrease fry survival in the river, the losses cannot be quantified. Studies conducted in other rivers suggest that predation by trout may significantly reduce the survival of salmon fry (Hallock and Sholes 1979; Fresh and Schroder 1987; Ginetz and Larkin 1976; Thompson and Tufts

1967). Therefore, it is not unreasonable to believe the same mortality may occur in the Mokelumne River.

Similarly, water diversions from other rivers have been shown to reduce survival of salmon fry substantially (CDFG 1984; Hallock and Van Woert 1959). There are approximately 50 privately-owned irrigation pumps drawing water from the Mokelumne River in the salmon-rearing areas. Typically, these pumps are operated from April through September, which overlaps with the period of freshwater residency of salmon fry (April through June). Most of the irrigation pumps are unscreened and represent a potential threat to salmon fry. This threat is probably most serious in dry water years when irrigation needs are high and river flow is relatively low.

The following discussion identifies two non-flow management strategies for improving fry survival in the Mokelumne River. The alternatives address concerns with fry survival by recommending a delay in planting of hatchery trout in the river and screening irrigation pumps.

Management Alternative 7. Delay Planting Hatchery Trout in the River Until After the Salmon Out-Migration Period

Classification	-	Essential
Implementation	-	CDFG

Hatchery trout predation on salmon fry may decrease salmon productivity in the river considerably. By changing the release schedule of hatchery trout, predation on salmon fry could be reduced and escapement into the Mokelumne River ultimately increased. Hatchery trout could be released between mid-June and December when there are few, if any, young salmon in the river. Trout populations should be monitored during the period when fry are present (April through July) to determine the potential for predation.

This alternative would require trout to be held in the hatchery through the spring and early summer. The cost of this appears to be minimal. However, this alternative would require CDFG to change their stocking schedule, and angling opportunities in the river in the spring would decrease. The trout fishing season would need to be altered to offer the most protection to salmon.

Management Alternative 8. Screen All Water Pumps on the River, Including Irrigation Pumps and Pumps Operated by NSJWCD

Classification	-	Experimental
Implementation	-	CDFG, SWRCB

Entrainment of salmon fry in irrigation pumps may reduce the survival rate of salmon fry in the river (Hallock and Van Woert 1959), leading to lower escapement of adult fish in subsequent years. To deal with this problem effectively, pumps diverting Mokelumne River water need to be adequately screened. This action should eliminate salmon fry mortality directly associated with pump operations. Irrigation pumps should be screened in conjunction with screen improvements at the WID Canal (Alternative 11).

Currently, screens are available that could be fitted to the irrigation intake pipes to reduce entrainment; however, installation and maintenance of such screens are not cheap. Considerable resistance is anticipated from the farming community to any restrictions placed on their diversion practices. The success of this alternative depends on pump operators' compliance and may raise enforcement issues. It may be advisable to conduct a study to determine the magnitude of the entrainment problem and determine the course of action based on the study results.

Enhancement of Smolt Survival Through Lake Lodi - BioSystems conducted mark-and-recapture studies in 1990 and 1991 (both dry years) to determine the mortality of out-migrating smolts through Lake Lodi. The study revealed that mortality was very high, ranging from 65 percent in May to 90 percent in June. This mortality rate is clearly incompatible with efforts to maintain and enhance the anadromous fishery. Potential sources of salmon smolt mortality in Lake Lodi include entrainment at the WID Canal screens, predation by resident fish, and high water temperatures in the impoundment.

The loss of migrating fish at diversion screens has been a major problem in California (Leitriz 1951; Hallock and Van Woert 1959; Bureau of Reclamation 1985; USFWS 1987; Ward 1989; Cramer et al. 1990). The WID Canal diverts a significant percentage of Mokelumne River flow in most years. Inadequate screens similar to those used in the WID Canal have been responsible for losses at other installations such as the Glenn-Colusa facility on the Sacramento River (Decoto 1978; Ward 1989; Cramer et al. 1990). Mortality rates in the Glenn-Colusa Canal appear to be correlated to diversion rates (Cramer et al. 1990).

After examining the screen and bypass facilities at the WID Canal, Vogel (1992) identified several potential problems with the design and maintenance of the facility. Vogel concluded that the mesh size in the canal screens was too large, velocity into the bypass was too low, gaps were present in the fish screen, velocity through the screens was too high, and piers placed at the bottom of the screens produced an entrapment zone for migrating salmon smolts. Vogel also identified problems in the maintenance of the bypass facility.

While water temperatures in the Lake Lodi may not reach lethal levels during the out-migration period, they frequently exceed 20° C during June and July. CDFG recommends that temperatures during out-migration not exceed 18° C. Stressed smolts may be more susceptible to predators, entrainment, or impingement. We observed that the smolt mortality rate in Lake Lodi was correlated with water temperatures (Appendix A).

If smolt mortality in Lake Lodi is reduced, overall production out of the Mokelumne River should increase significantly. In dry years, more than three times more smolts would be caught and trucked to the Delta if all mortality in the lake were eliminated (Appendix A). We cannot quantify potential increases in production in normal and wet years, because we do not have any data on smolt mortality through Lake Lodi when diversion rates are considerably different from dry years. However, based on the dry year data, an increase in production would be expected in normal and wet years. The following discussion outlines two management alternatives for reducing smolt mortality through Lake Lodi.

Management Alternative 9. Construct a Permanent Trapping Facility Upstream of Lake Lodi

Classification	-	Essential
Implementation	-	EBMUD, in cooperation with CDFG and WID

This alternative would result in construction of a new smolt trapping facility upstream of Lake Lodi, possibly near Elliott Road, for use during the entire out-migration period in dry years, and after mid-June in wet and normal years. Although trapping and trucking smolts is not a primary objective of the LMRMP in most years, it is necessary in dry years when water supplies are low. By trapping smolts above Lake Lodi in dry years, three times more salmon smolts would be caught and trucked beyond the Delta than under current practices smolts trapped at Woodbridge Dam). Trapping and trucking of smolts after 1 July in wet and normal years is recommended because of the high mortality in the Delta (M. Kjelson pers. comm.).

The advantage of this program is that less water would be released at Camanche Dam to control temperature in the river downstream of the trap after 1 July, mortality in Lake Lodi would be eliminated, and the number of smolts surviving in the ocean would increase significantly. A high priority is placed on this alternative because the increase in salmon production can be quantified and the program may reduce the need for water in all water years.

Management Alternative 10. Improve Screens at WID Canal, Improve Bypass Attraction at WID Screens, Install a Smolt Trap in the Upper Ladder, and Reduce Predator Populations in Lake Lodi.

Classification	-	Essential
Implementation	-	CDFG and WID and other river interests

Since the new trapping facility above Lake Lodi would operate through the out-migration season only in below normal years, smolts would still die in Lake Lodi in wet and normal years. Dry year smolt mortality through Lake Lodi ranges from 90 percent to 65 percent, depending on the month (Appendix A). It is not known if most of the mortality is caused by inadequate screening facilities at the WID Canal, high predator populations in the lake, high temperature, or a combination of these factors. Several investigators have identified problems in maintenance and design of the WID screens and bypass facility (Fisher 1976; Vogel 1992).

This alternative would include some combination of increasing the size of the by-pass pipeline, improving the gate to the upper ladder, improving screens at the WID Canal, improving bypass attraction at the WID screens, installing a smolt trap in the upper ladder, and reducing predator populations in Lake Lodi.

Although the improvement to the screens and bypass attraction flows at the WID Canal are relatively easy to design and install, the costs are quite high. It is possible that predators or high temperatures in the lake may be causing most of the problems for out-migrating smolts.

Therefore, a study should be conducted to identify the major cause of smolt deaths in Lake Lodi before fixing the screens.

Contingent on results of this study, the recommended program would first improve the screens at the WID Canal and monitor out-migration survival. If mortality is not significantly reduced, the bypass attraction at the screens should then be improved by increasing entrance size and bypass velocity (Vogel 1992). Finally, predator populations in the lake should be reduced if improvements at the screens and bypass do not reduce mortality. Predator surveys near the WID Canal in 1991 documented the presence of large rainbow trout, northern squawfish and largemouth bass (Appendix A).

We also recommend that a smolt trap be installed in the upper ladder at Woodbridge Dam. During out-migration studies in 1991 and 1992, a trap placed in the upper ladder accounted for 24 percent and 64 percent, respectively, of smolts collected at the dam (Appendix A). In the past, CDFG did not place a smolt trap in the upper ladder and it is unlikely that any of the smolts migrating through the upper ladder into the lower river survived in dry years.

Reduction of predators in the lake through chemical or physical removal is likely to result in opposition from the community and may present significant permitting problems for CDFG. While the benefit of reducing predation on mortality to out-migrating smolts in Lake Lodi could be quantified, we are not sure that this program would achieve the desired results.

5.4.5.2 Woodbridge Reach

The proposed management alternatives in the Woodbridge reach of the Mokelumne River can be described under two general purposes: improve in-river survival of adult salmon, and improve fish facilities at Woodbridge Dam. Under each purpose, specific management recommendations are proposed.

Improve In-river Survival of Adult Salmon - Poaching in the Lower Mokelumne River is believed to a significant problem and may reduce the number of up-migrating chinook salmon in dry years by up to 50 percent (Meyer pers.comm., 1991). High flows in wet years reduce poaching losses to approximately 10 percent of total escapement (Meyer pers.comm., 1991). In past years, most poaching has been concentrated around Woodbridge Dam and the fish ladders; however, fish barriers have occasionally been placed in the lower river between Woodbridge Dam and Peltier Road by poachers to make salmon more vulnerable. When 24-hour security is provided at the dam, poachers move downstream. Because poaching represents a significant obstacle to improving salmon escapement, any management plan adopted for the river must reduce this problem..

Management Alternative 11. Remove Barriers From Lower River and Increase CDFG Warden Patrols

Classification	-	Essential
Implementation	-	CDFG with assistance from EBMUD and other river interests

Weekly float patrols would be conducted in the lower river between Woodbridge Dam and the town of Thornton from 15 October through 15 December to identify and remove potential fish barriers. CDFG game wardens should be responsible for these patrols. Landowners along the river and local sportsmen's groups should be informed of the objectives of the patrols and asked to assist in reducing poaching.

Such patrols would substantially reduce large-scale poaching in the lower river and should be given a high priority. The biggest obstacle to patrols is allocating the money and personnel to implement them.

Improve Fish Facilities at Woodbridge Dam - Dams often impede upstream migration of salmon by hindering or delaying upstream passage (Hallock and Vogel 1982; Monan and Liscom 1975). Poaching may be centered around the dam and fish ladders if there is concentration of fish holding downstream. Delayed passage of adult salmon at Woodbridge Dam is thought to be caused by inadequate attraction into fish ladders and poor entrance design (Vogel 1992), although actual passage problems at the dam have never been documented. Salmon poaching at the dam is a significant problem. In the past, CDFG placed 24-hour guards at the dam to reduce poaching, but the program was discontinued because of its high costs.

The following discussion outlines three management alternatives for improving fish passage at Woodbridge Dam by modifying existing facilities and one alternative (15) which recommends constructing a new facility. Three alternatives that would improve passage are considered experimental pending information that passage is actually a problem at the dam.

Management Alternative 12. Improve Lower Fish Ladder - Convert to Pool and Weir System and Eliminate Denil Fishway

Classification	-	Experimental
Implementation	-	CDFG and USFWS

The design of the lower fish ladder at Woodbridge Dam is thought to impede salmon up-migration (Vogel 1992). The ladder is not a pool-and-weir system where salmon jump up from one chamber to the next. Instead, the fish swim along the bottom of ladder chambers and pass through a small rectangular opening (0.6 m x 0.9 m). The Denil fish ladder was built in 1972 to improve salmon up-migration at the dam rather than improve the existing fish ladder. We recommend that the lower fish ladder be converted to a pool-and-weir system and the denil fishway be eliminated.

The pool-and-weir system is thought to be more advantageous because it provides resting habitat within each chamber. It would be relatively inexpensive to convert the lower ladder to a pool-and-weir system. Some hydraulic modeling would be needed to finalize the design of the system.

Management Alternative 13. Improve Entrance to Upper and Lower Fish Ladders and Enlarge Holding Pool

Weekly float patrols would be conducted in the lower river between Woodbridge Dam and the town of Thornton from 15 October through 15 December to identify and remove potential fish barriers. CDFG game wardens should be responsible for these patrols. Landowners along the river and local sportsmen's groups should be informed of the objectives of the patrols and asked to assist in reducing poaching.

Such patrols would substantially reduce large-scale poaching in the lower river and should be given a high priority. The biggest obstacle to patrols is allocating the money and personnel to implement them.

Improve Fish Facilities at Woodbridge Dam - Dams often impede upstream migration of salmon by hindering or delaying upstream passage (Hallock and Vogel 1982; Monan and Liscom 1975). Poaching may be centered around the dam and fish ladders if there is concentration of fish holding downstream. Delayed passage of adult salmon at Woodbridge Dam is thought to be caused by inadequate attraction into fish ladders and poor entrance design (Vogel 1992), although actual passage problems at the dam have never been documented. Salmon poaching at the dam is a significant problem. In the past, CDFG placed 24-hour guards at the dam to reduce poaching, but the program was discontinued because of its high costs.

The following discussion outlines three management alternatives for improving fish passage at Woodbridge Dam by modifying existing facilities and one alternative (15) which recommends constructing a new facility. Three alternatives that would improve passage are considered experimental pending information that passage is actually a problem at the dam.

Management Alternative 12. Improve Lower Fish Ladder - Convert to Pool and Weir System and Eliminate Denil Fishway

Classification	-	Experimental
Implementation	-	CDFG and USFWS

The design of the lower fish ladder at Woodbridge Dam is thought to impede salmon up-migration (Vogel 1992). The ladder is not a pool-and-weir system where salmon jump up from one chamber to the next. Instead, the fish swim along the bottom of ladder chambers and pass through a small rectangular opening (0.6 m x 0.9 m). The Denil fish ladder was built in 1972 to improve salmon up-migration at the dam rather than improve the existing fish ladder. We recommend that the lower fish ladder be converted to a pool-and-weir system and the denil fishway be eliminated.

The pool-and-weir system is thought to be more advantageous because it provides resting habitat within each chamber. It would be relatively inexpensive to convert the lower ladder to a pool-and-weir system. Some hydraulic modeling would be needed to finalize the design of the system.

Management Alternative 13. Improve Entrance to Upper and Lower Fish Ladders and Enlarge Holding Pool

C-100912

Management Alternative 15. Construct a New Fish Ladder in Center of Dam

Classification	-	Experimental
Implementation	-	CDFG and USFWS

Rather than improve the existing fish passage facilities at Woodbridge Dam (Alternative 12-14), a new fish ladder constructed at the center of the dam would pass most of the water downstream during all water years. A fish ladder in the center of the dam should eliminate the potential passage problems of the current fish ladders. Poaching at the dam would probably decrease if the new fish ladder was constructed.

A better fish ladder could be constructed at the center of the dam using existing information on salmon up-migration requirements and current fish ladder design requirements. A new fish ladder will be expensive and would require significant modifications to Woodbridge Dam. The most pressing issue is how such an expensive project would be funded.

5.5 COMPARISON WITH CDFG PLAN GOALS AND OBJECTIVES

5.5.1 Spawning Escapement Goal

The CDFG Plan has a goal of 15,000 adult chinook salmon, of which 10,000 would be spawned in the hatchery. Historically, only about a third of the run has entered the hatchery voluntarily, so that if a run of 15,000 salmon occurred it is likely that only 5,000 would enter the hatchery. A run of 15,000 salmon would about equal the largest run ever estimated (15,900) and exceed the largest run ever counted (12,000) in the river.

The LMRMP has no specific escapement goal, but is designed to increase and re-build the run over time. A monitoring program should be initiated to determine the size of run that can be supported by the habitat. Current habitat information indicates the usable habitat could be saturated by as few as 3,000 adults (Appendix A).

5.5.2 Adult Upstream Migration

The CDFG Plan would reserve 20,000 acre-feet in normal and wet years and 10,000 acre-feet in dry years, for attracting salmon into the Mokelumne River. BioSystems' analysis of available data indicates that short-term flow fluctuation appears to have little influence on overall run size (Section 3.0).

The LMRMP maintains fall flow at spawning levels throughout the period. Attraction flows are not provided. The LMRMP focuses on increasing returns to the Mokelumne River by enhancing natural production in the river and increasing releases of smolts and yearlings in the Mokelumne rather than trucking them to the Delta, and by enhancing the physical habitat to promote additional in-river salmon production.

5.5.3 Fish Passage

CDFG recommends a variety of physical alterations at Woodbridge Dam to improve fish passage. The LMRMP considers improvements to passage facilities to be contingent on a demonstrated need. Potential problems with fish passage at Woodbridge Dam are related to physical conditions at the site and should be solved by the responsible agencies. These physical conditions do not appear to be influenced by flow beyond the design capacity of the fish ladders.

5.5.4 Egg Incubation and Fry Rearing

The CDFG-recommended flows for the rearing period are higher than the optimum flow determined by the CDFG instream flow studies. The LMRMP recommends rearing flows equal to the optimum determined by the CDFG.

5.5.5 Out-migration Flow

The CDFG Plan reserves 10,000 acre-feet in normal and wet years and 5,000 acre-feet in dry years for short-duration pulses to increase survival of young chinook salmon and steelhead trout during out-migration. Studies conducted recently by BioSystems indicate that there is no benefit to short-term flow pulses for this purpose. Rather, smolt out-migration in the Mokelumne appears to occur over an extended period (April through early July), and out-migration timing is a function of size. Furthermore, BioSystems' temperature modeling indicates that CDFG temperature criteria for out-migration could not be maintained at the level of flow recommended by CDFG.

In wet and normal years, the LMRMP provides flow to maintain suitable temperatures during the out-migration period. The LMRMP requires trapping smolts above Lake Lodi and trucking them to the Delta when water supply is inadequate to provide out-migration flows. Trapping and trucking would not be conducted under the CDFG Plan.

5.5.6 Water Diversions and Fish Screens

Water diversions, particularly into the WID Canal, may represent a significant source of mortality for emigrating salmon and steelhead trout. Improvements suggested by CDFG should be undertaken by the agencies responsible as part of any program to improve fishery resources in the Lower Mokelumne River. Serious consideration should be given to improvement projects that reduce the WID diversion from the river during the salmon out-migration period from April through the end of June. This could minimize the losses of migrants that occur in Lake Lodi and also reduce the need to provide high flows to control temperature.

5.5.7 Spawning Habitat Improvement

Both the CDFG Plan and the LMRMP recognize that spawning habitat may be somewhat degraded below Camanche Dam, and both would provide for spawning habitat improvement projects.

C-100914

5.5.8 Water Quality

The CDFG Plan proposes specific criteria for dissolved oxygen, pH, heavy metals, and other constituents consistent with EPA recommended levels for maintenance and protection of fresh water aquatic life. It also proposes a minimum surface elevation of 210 feet msl for Camanche Reservoir and a minimum inflow from Pardee Reservoir to Camanche Reservoir of 250 cfs at all times in order to maintain good water quality conditions.

The LMRMP proposes operational and physical improvements at Camanche Reservoir to avoid water quality problems (Section 5.2), and would use cod releases from Pardee to maintain the Camanche hypolimnion.

5.5.9 Public Access for Recreation

The CDFG Plan calls for increased recreation access at three sites on the Lower Mokelumne River between Camanche Dam and the Cosumnes River confluence. EBMUD provides public access for recreation at several sites at Pardee and Camanche reservoirs and at Van Assen Park below Camanche Dam. Provision of public access at other points is not within the authority of EBMUD. Provision of additional public access to the river should be undertaken only with full consideration of potential impacts in terms of poaching and other disturbance of spawning salmon during the fall run.

5.6 IMPACTS OF THE TWO PLANS ON HYDROLOGY, WATER SUPPLY AND QUALITY, AND FISHERIES

This section evaluates the two plans in terms of their impacts on water resources and fisheries. This evaluation is conducted by use of several models. First, the hydrologic model EBMUDSIM is used to evaluate impacts on reservoir storage, water supply, and stream flows. EBMUDSIM results were provided by EBMUD. Then SCIES model results for the two plans provide a basis for comparing their impacts on fisheries. These runs consider only the difference in average flow regimes between the two plans; temperature effects following from differences in reservoir storage conditions are not considered.

The CDFG Plan and the LMRMP have different water year classification schemes. The CDFG Plan does not consider storage conditions to determine water year type whereas the LMRMP does. In the CDFG Plan, a year is dry if runoff into Pardee is less than 50 percent of normal, and a year is wet if runoff is greater than 110 percent of normal. The CDFG dry year is roughly comparable to the LMRMP critical dry year, and the CDFG normal year is roughly the same as a LMRMP dry year.

EBMUDSIM is a hydrologic model of the Mokelumne River. The model operates on a monthly time step for a 1921 to 1990 hydrologic sequence. The hydrologic sequence represents historical hydrology except that it includes a modified 1978 hydrology. To estimate the effects of an unprecedented drought, 1978 runoff is assumed equal to the average of 1976 and 1977 runoff. Ending storage and monthly deliveries and flows were simulated for each month under a fixed demand condition and the variable hydrology of the hydrologic sequence. All of the scenarios described in this analysis used year 2020 level demand conditions for the entire hydrologic sequence.

C-100915

Each model run varies because of the operations required for fisheries. Under the CDFG Plan (run 92 250 10-5588-WSIP), Camanche must be held no lower than 210 feet elevation (260 TAF of storage) and releases for the fishery also have priority over water supply.

Under the LMRMP (run 92 250 10-5633-WSIP), Pardee releases to maintain the hypolimnion in Camanche are determined by an equation that creates a relationship between Pardee and Camanche storage and the hypolimnion. Releases from Camanche for fisheries are determined by year type. Fishery releases are provided first priority and maintaining the Camanche hypolimnion is given second priority.

A third scenario (92 250 10-5502-WSIP) is used to represent the current 1961 agreement with CDFG. This scenario is used only for analysis of Delta inflow and provides a general indication of how the two plans compare with a no-action alternative.

5.6.1 Reservoir Storage

Table 5.9 summarizes average storage levels from the CDFG Plan and LMRMP simulations. Storage levels are important to fisheries because they affect the temperatures of water releases, and storage can affect the size of spills and releases in later periods. The months of ending storage data in Table 5.9 were chosen based on their importance to salmon spawning (September and November) and out-migration (March and May).

Table 5.9. EBMUDSIM CDFG and LMRMP runs, average end-of-month storage values in acre feet.

	CDFG	LMRMP	CDFG/LMRMP
Pardee Reservoir			
End of September	107,183	161,425	66.40%
End of November	96,056	161,782	9.37%
End of March	122,301	180,876	67.62%
End of May	135,813	191,523	70.91%
Camanche Reservoir			
End of September	287,493	250,249	114.88%
End of November	266,798	230,583	115.71%
End of March	277,090	247,859	111.79%
End of May	296,393	274,766	107.87%

On average, the CDFG Plan provides more releases from Pardee Reservoir to keep Camanche full, so Pardee storage is lower and Camanche is higher. On average, Pardee storage differences between the two plans are quite large but, in relative terms, are not so large for Camanche.

Figures 5-2 and 5-3 show cumulative distributions of end-of-month storage levels for 31 October and 30 April, respectively. A cumulative distribution shows the percentage of years of the simulation in which storage fell below any level. The distributions are made by sorting values by size and graphing them against their cumulative frequency. In this case, 7 years correspond to 10 percent of the simulated years. Any point on the distribution provides the frequency of a storage level in terms of the percentage of years in which storage was less than that level.

Figure 5-2 also shows a large difference in storage levels between the two plans. For Pardee Reservoir, the LMRMP keeps 31 October storage above 100,000 acre-feet in all but 1 of 70 years, while storage falls below 100,000 acre-feet in more than half of years under the CDFG Plan. Under the CDFG Plan, Pardee is frequently emptied by releases to keep Camanche full. For about a third of the years, 31 October storage is about the same in both plans.

At these times it is uncertain if downstream fisheries would be protected by CDFG's Camanche pool or downstream releases due to water quality (particularly temperature) conditions (A. Horne pers. comm. 1992). These storage levels would also be damaging to the Pardee Reservoir fishery and recreation.

The CDFG Plan requires that Camanche storage be kept at or above 260,000 acre-feet. In the LMRMP plan, end-of-October storage falls below 250,000 and 100,000 acre-feet in about 40 and 10 percent of years, respectively. However, Camanche storage under the LMRMP actually exceeds that under the CDFG Plan in most years.

Figure 5-3 shows similar storage patterns for end-of-April storage. Even in April the CDFG plan would nearly empty Pardee in about 20 percent of years.

Table 5.10 shows average Camanche Reservoir elevations under the two plans based on a set of equations relating elevation to storage provided by EBMUD. The 70 years of simulated hydrology were broken into three water year types based on the CDFG 70-year classification series based on inflow.

Table 5.10 shows that, on an average basis, the two plans do not differ much in terms of storage elevation, except in the 16 percent of years that are dry. Under the LMRMP, average elevation in dry years is lowest at the end of September, and is about 35 feet below the minimum elevation specified under the CDFG Plan.

Figure 5-4 shows the cumulative probability of 31 October storage elevations for the two plans. Again, storage elevations between the two plans do not differ by much except in critical years.

5.6.2 Water Supply

EBMUDSIM indicates that the CDFG Plan would have important impacts on EBMUD water supply from the Mokelumne River. On average, 265,400 acre-feet are delivered annually under the LMRMP, but only 219,600 acre-feet, or 17 percent less, are delivered under the CDFG Plan.

C-100917

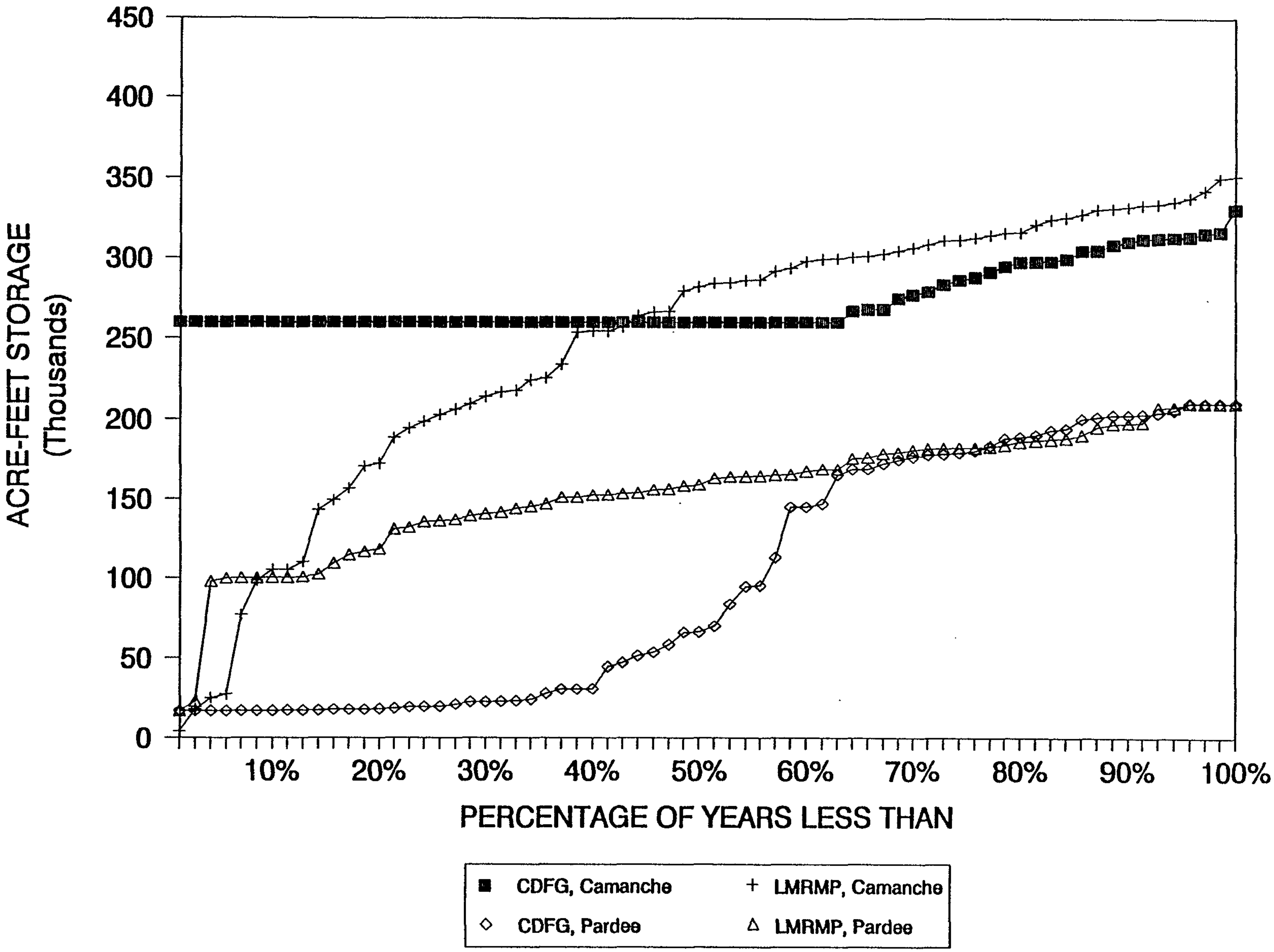


Figure 5-2. Cumulative distribution of storage (TAF) on 31 October for EBMUDSIM simulated years 1921-1990.

C-100918

C-100918

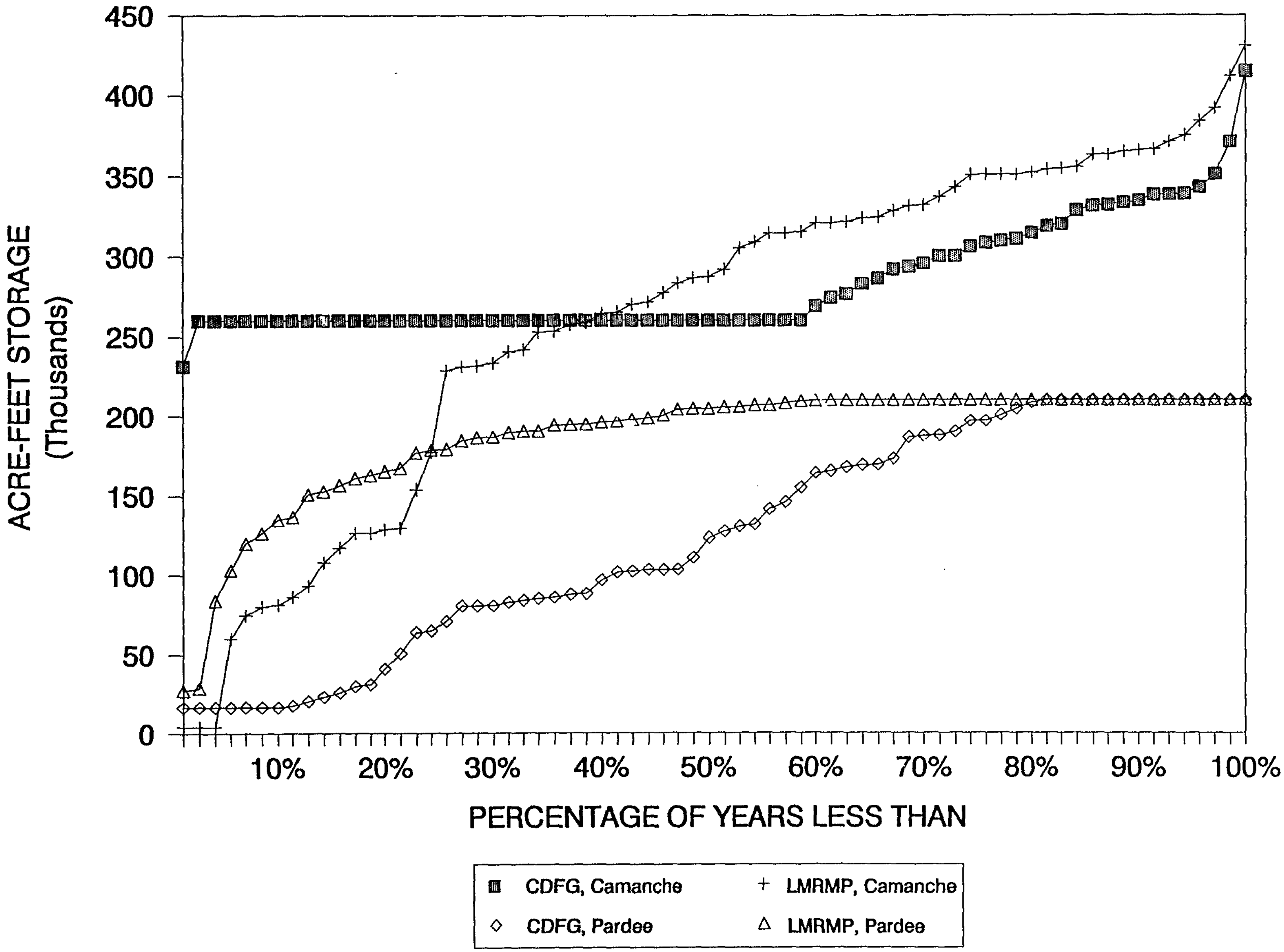


Figure 5-3. Cumulative distribution of storage (TAF) on 30 April for EBMUDSIM simulated years 1921-1990 in Camanche and Pardee reservoirs.

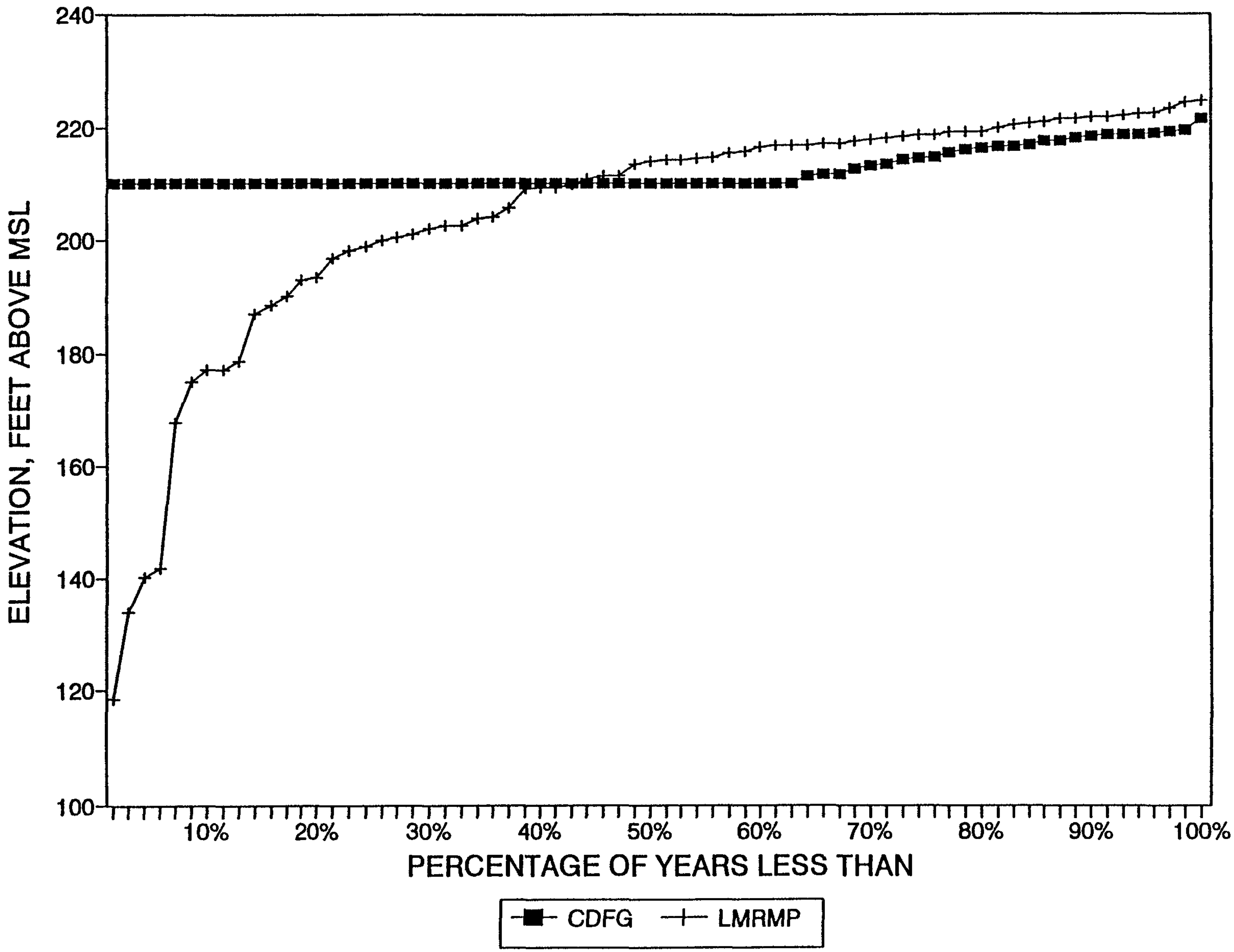


Figure 5-4. Cumulative distribution of annual average Camanche water surface elevation (feet above mean sea level) for EBMUDSIM simulated years 1921-1990.

Table 5.10. Average simulated end-of-month Camanche Reservoir elevations, feet above mean sea level.

	CDFG			LMRMP		
	Dry	**Normal**	**Wet**	**Dry**	**Normal**	**Wet**
January	211	212	210	196	201	204
February	210	212	211	194	200	207
March	210	212	216	192	202	212
April	210	212	218	188	204	217
May	210	212	223	185	205	223
June	210	213	231	183	209	229
July	210	213	228	179	207	226
August	210	212	223	176	206	221
September	210	212	220	175	206	216
October	212	213	212	201	205	207
November	211	212	211	198	202	203
December	211	212	211	196	201	203
Average	**211**	**212**	**218**	**189**	**204**	**214**

As shown in Figure 5-5, this percentage masks supply reductions that are much larger in some years. In roughly 40 percent of years, maximum water supplies are provided under both plans. In below normal years, much more supply reduction occurs under the CDFG Plan.

Under the CDFG Plan, about 150,000 acre-feet or less supply is provided in 20 percent of years, and almost no water supply is provided in about 10 percent of years. Shortages of this magnitude would be disastrous for the EBMUD service area, requiring complete curtailment of most water uses or substantial use of alternative supplies such as the American River.

Figure 5-6 shows that CDFG Plan, water supply shortages during the hydrologic period tend to be grouped during five dry periods. This would make the shortages even more disruptive because alternative stored supplies would also be depleted. The bottom part of Figure 5-6 shows that, during all of the shortage periods, Pardee Reservoir is drawn down to dead storage under the CDFG Plan.

5.6.3 Stream Flows

The reduction in annual average EBMUD water supply of about 45,800 acre-feet under the CDFG Plan, in comparison to the LMRMP, results in a similar increase in releases to the lower river from Camanche dam. An average of 409,600 and 455,100 acre-feet are released annually from Camanche Reservoir to the lower river under the LMRMP and CDFG Plans, respectively.

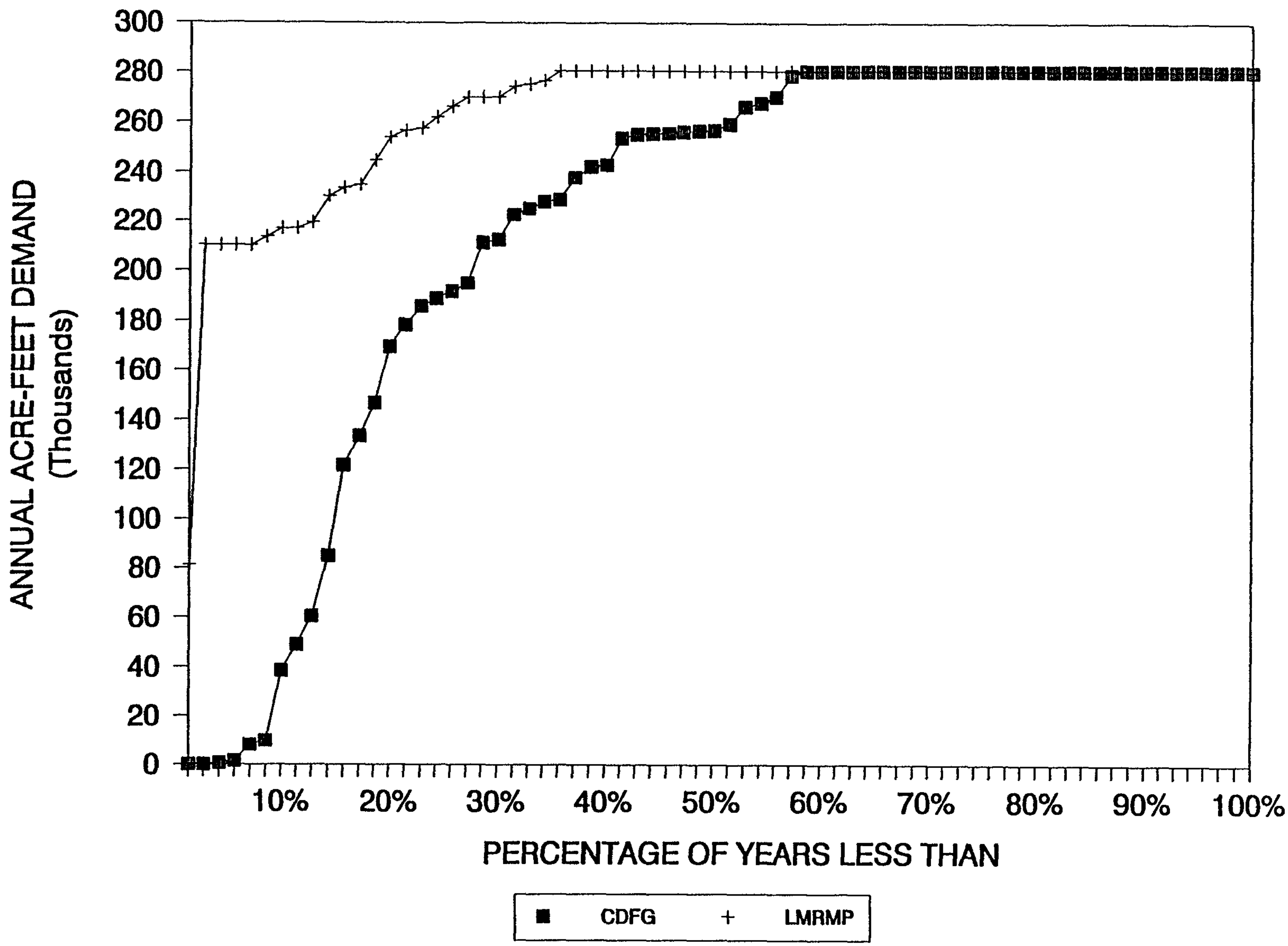
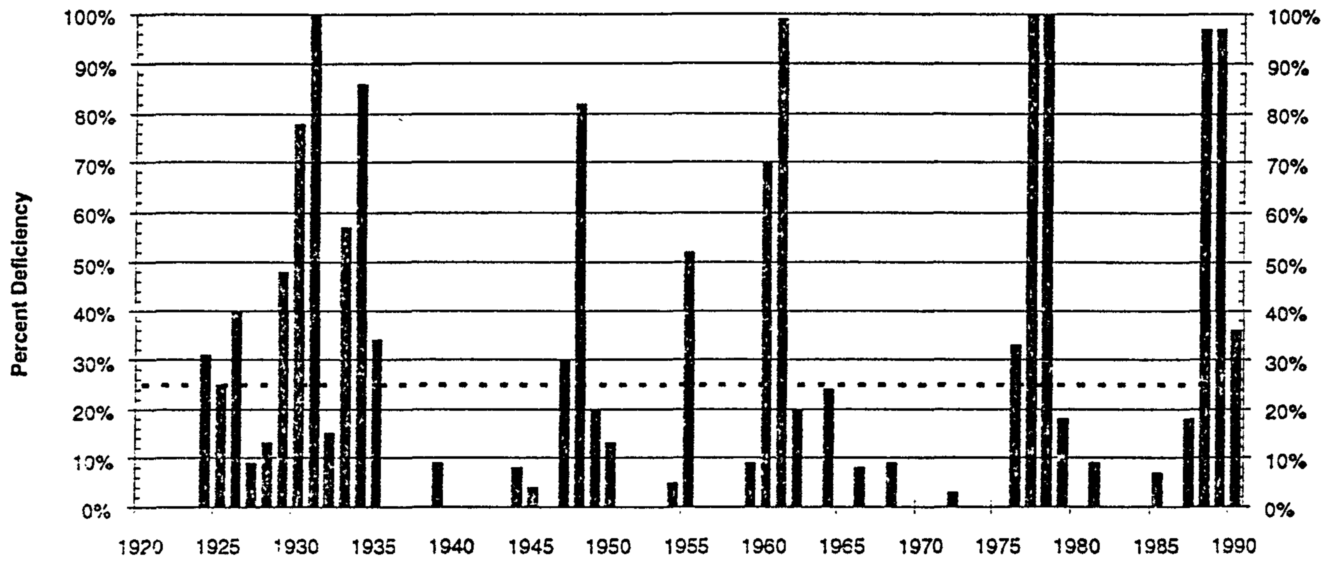


Figure 5-5. Cumulative distribution of annual average demands (TAF) met for EBMUDSIM simulated years 1921-1990.

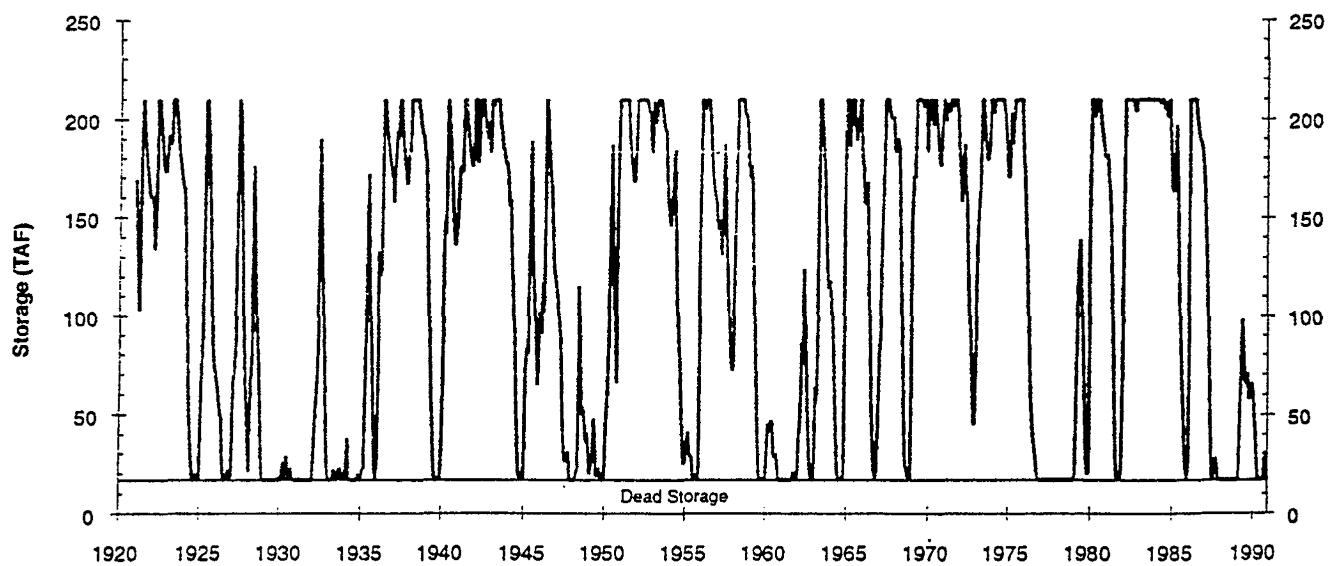
Figure 5-6.

Water Supply Conditions Under DF&G's Plan Without Temperature Criteria Using 2020 Level of Development

Annualized Customer Deficiencies



Pardee Reservoir Storage



WR:ajl:7/23/92

Study Number 5588

Average quarterly flow rates under the two plans are compared in Table 5.11. Flow rates in the lower river during the October through December spawning period differ most, being 38 to 52 percent larger in the CDFG Plan. To meet Camanche storage targets, the CDFG Plan also increases flows from Pardee to Camanche in the summer. The CDFG Plan also results in flows in the lower river about 15 and 11 percent larger in the winter and spring quarters, respectively.

Table 5.11. EBMUDSIM CDFG and LMRMP runs, average simulated flows in cfs.

	CDFG	LMRMP	CDFG/LMRMP
Pardee releases			
Oct-Dec	430	273	157.31%
Jan-Mar	558	538	103.72%
Apr-Jun	1,161	1,145	101.40%
Jul-Sep	427	347	123.16%
Camanche releases			
Oct-Dec	541	392	137.95%
Jan-Mar	552	493	112.09%
Apr-Jun	879	832	105.73%
Jul-Sep	549	553	99.25%
Flow below Lake Lodi			
Oct-Dec	455	303	150.23%
Jan-Mar	476	414	114.86%
Apr-Jun	618	557	111.01%
Jul-Sep	235	220	106.55%
Delta inflow			
Oct-Dec	445	293	151.86%
Jan-Mar	468	406	115.17%
Apr-Jun	596	534	111.60%
Jul-Sep	214	199	107.56%

Figures 5-7 to 5-11 shows cumulative distributions of simulated releases and flows for the two plans. Annual releases from Camanche for fishery purposes average 84,400 acre-feet under the LMRMP and 230,400 acre-feet under the CDFG Plan, but Figure 5-7 shows these releases to be unevenly distributed between above and below-normal years. The difference between the two plans is greater in above-normal years (up to 170,000 acre feet) than in below-normal years (as little as 100,000 acre-feet).

Figure 5-8 shows that releases from Camanche during the October through December spawning period are higher under the CDFG Plan in about 90 percent of years. In about 20 percent of years, corresponding to some of the driest years, Camanche releases under the CDFG Plan average about 100 to 150 cfs greater than under the LMRMP. CDFG Plan releases are actually less than LMRMP releases in two dry years, falling to 19 cfs below Lake Lodi in one year. The CDFG Plan, with a strict priority on Camanche storage, would

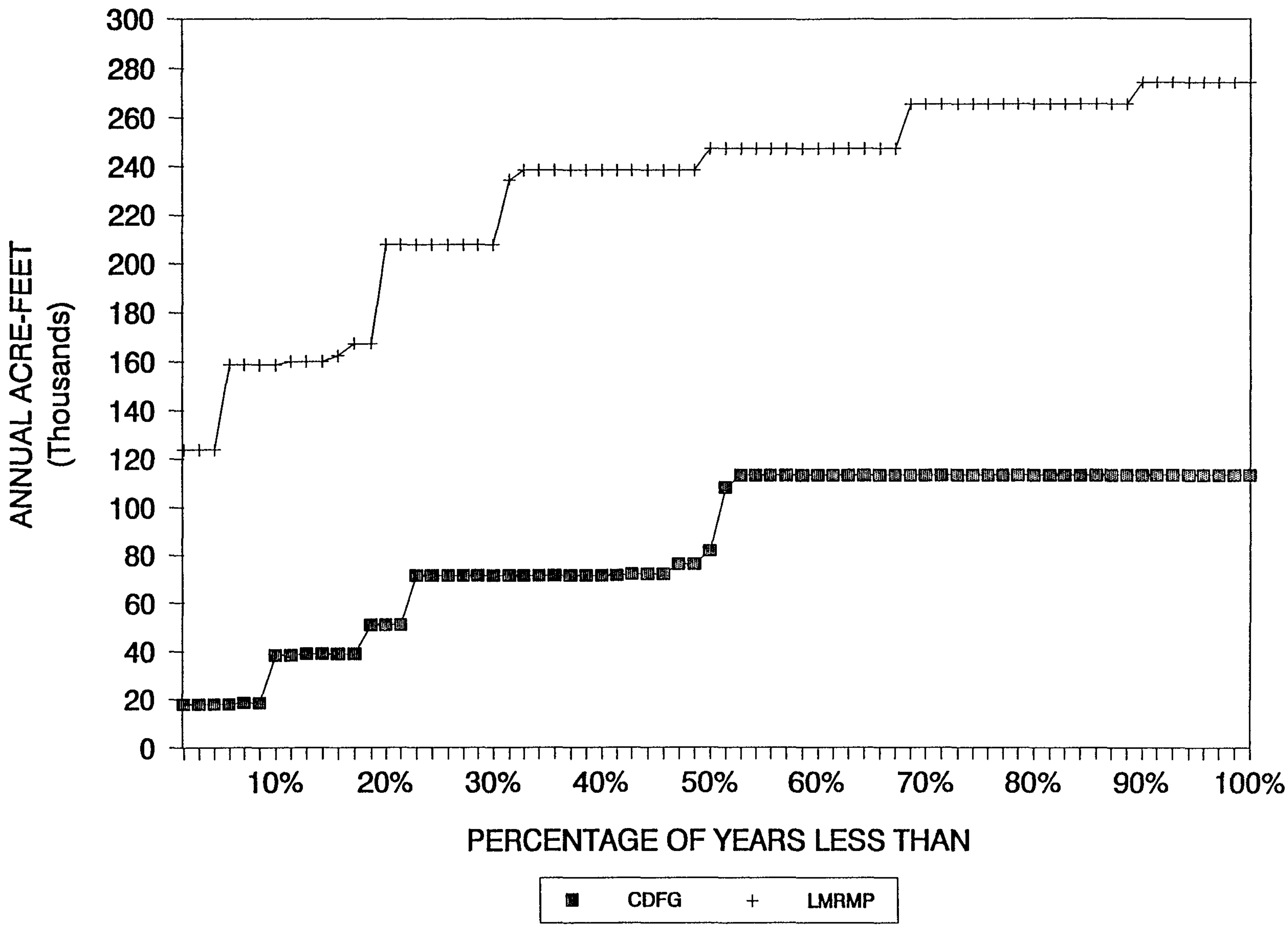


Figure 5-7. Cumulative distribution of Camanche releases (cfs) for fisheries purposes for EBMUDSIM simulated years 1921-1990.

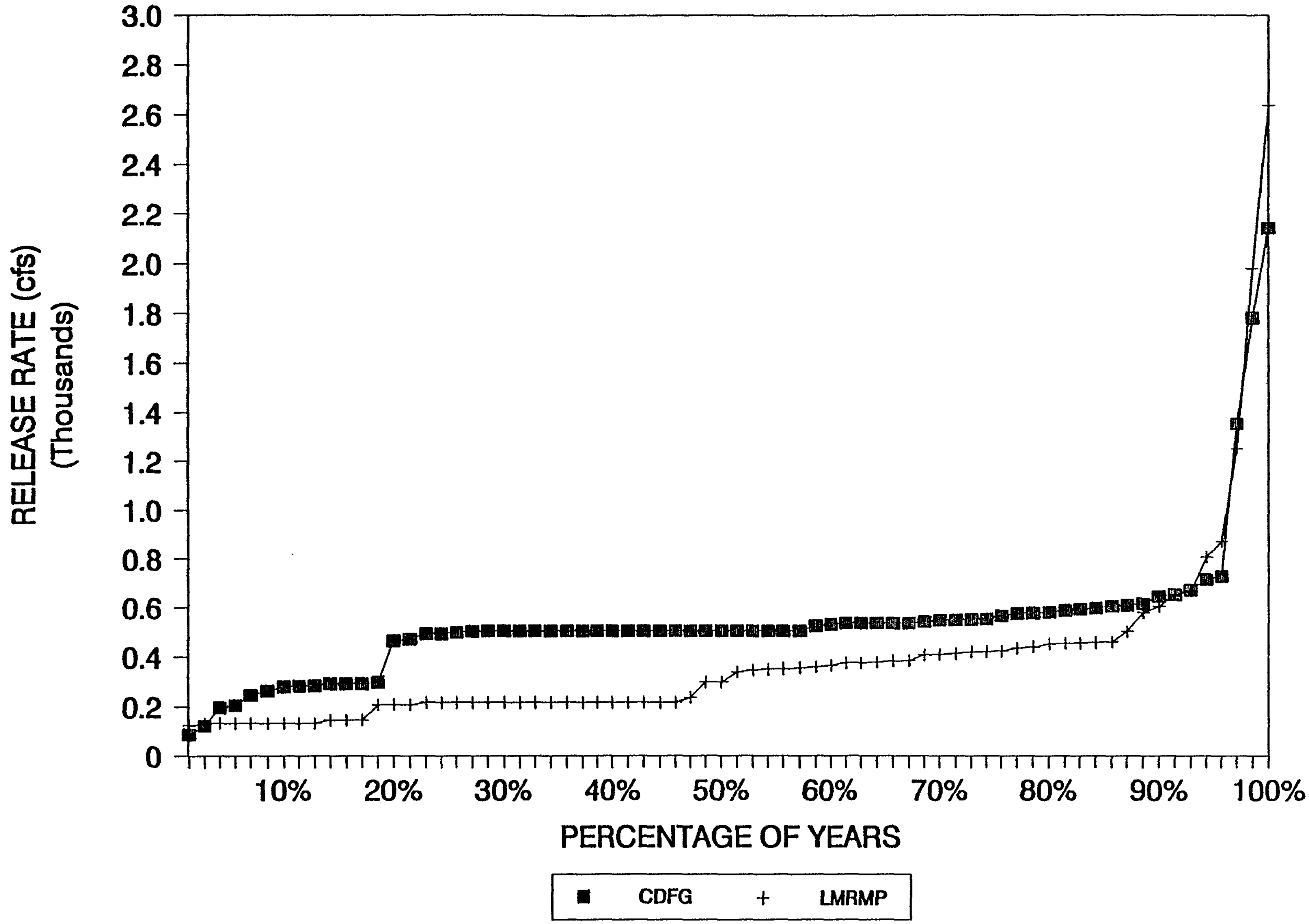


Figure 5-8. Cumulative distribution of Camanche release rates (October through December average, in cfs) for EBMUDSIM simulated years 1921-1990.

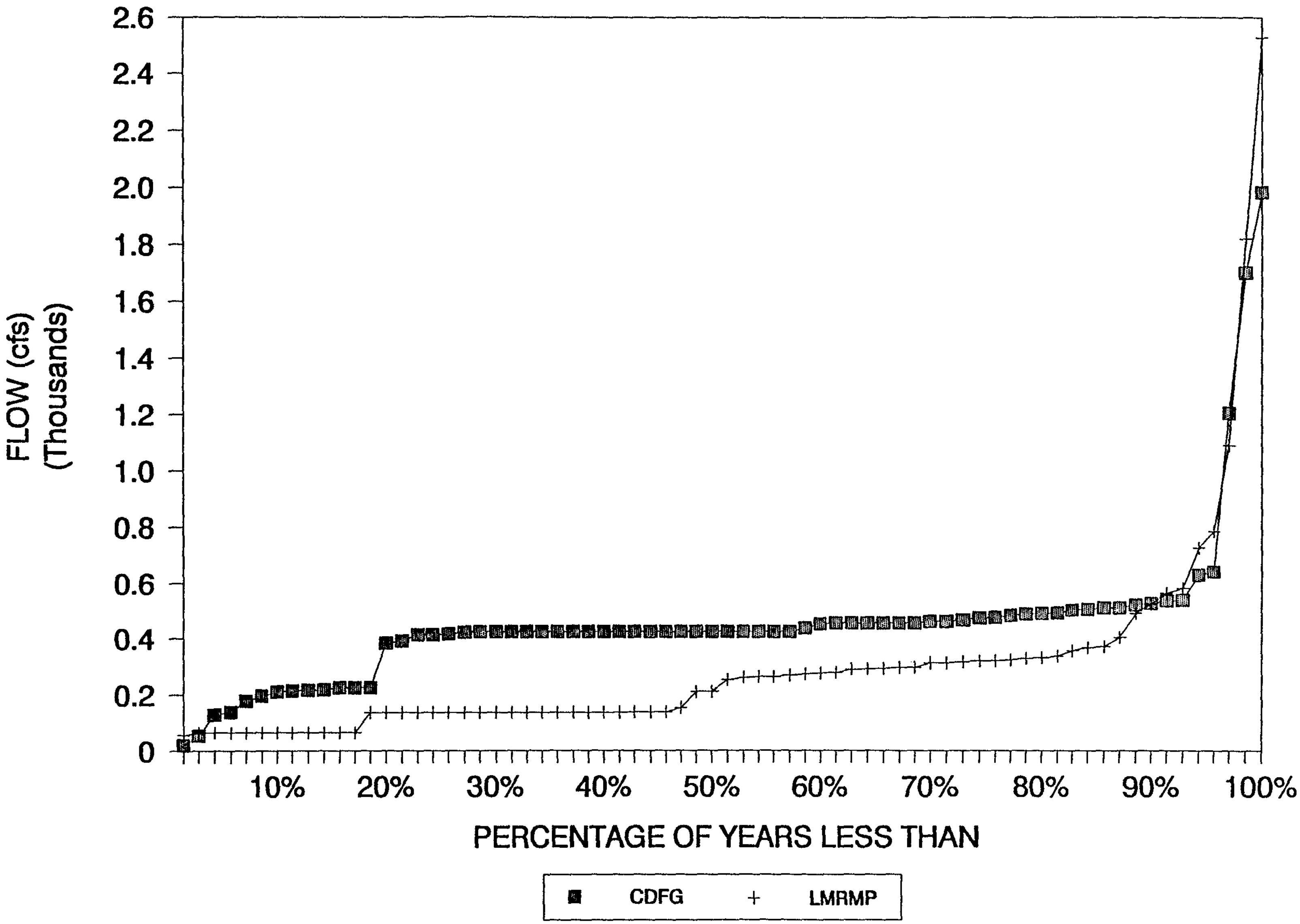


Figure 5-9. Cumulative distribution of flow below Lake Lodi (October through December average, in cfs) for EBMUDSIM simulated years 1921-1990.

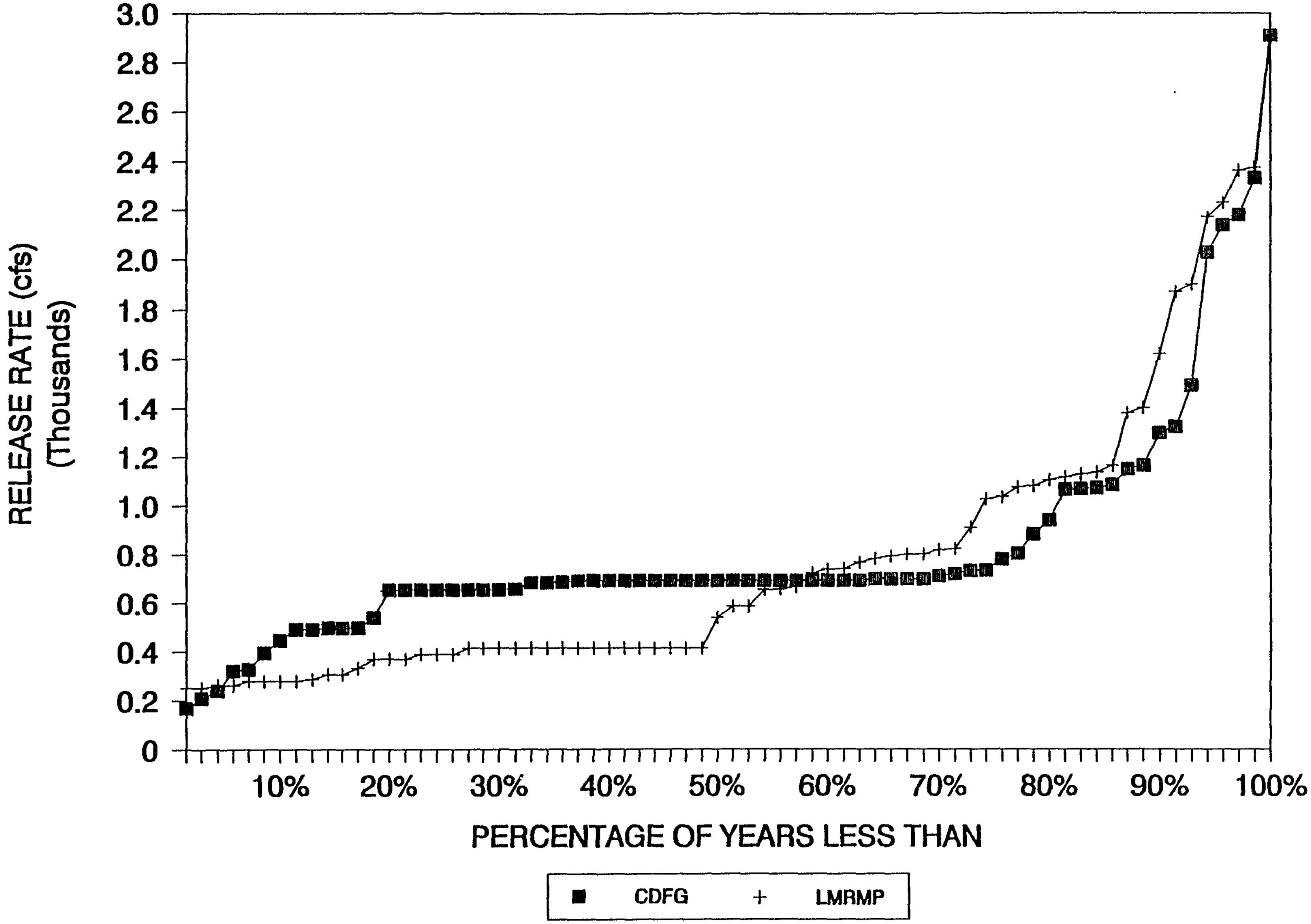


Figure 5-10. Cumulative distribution of Camanche release rates (April through July average, in cfs) for EBMUDSIM simulated years 1921-1990.

C—100928

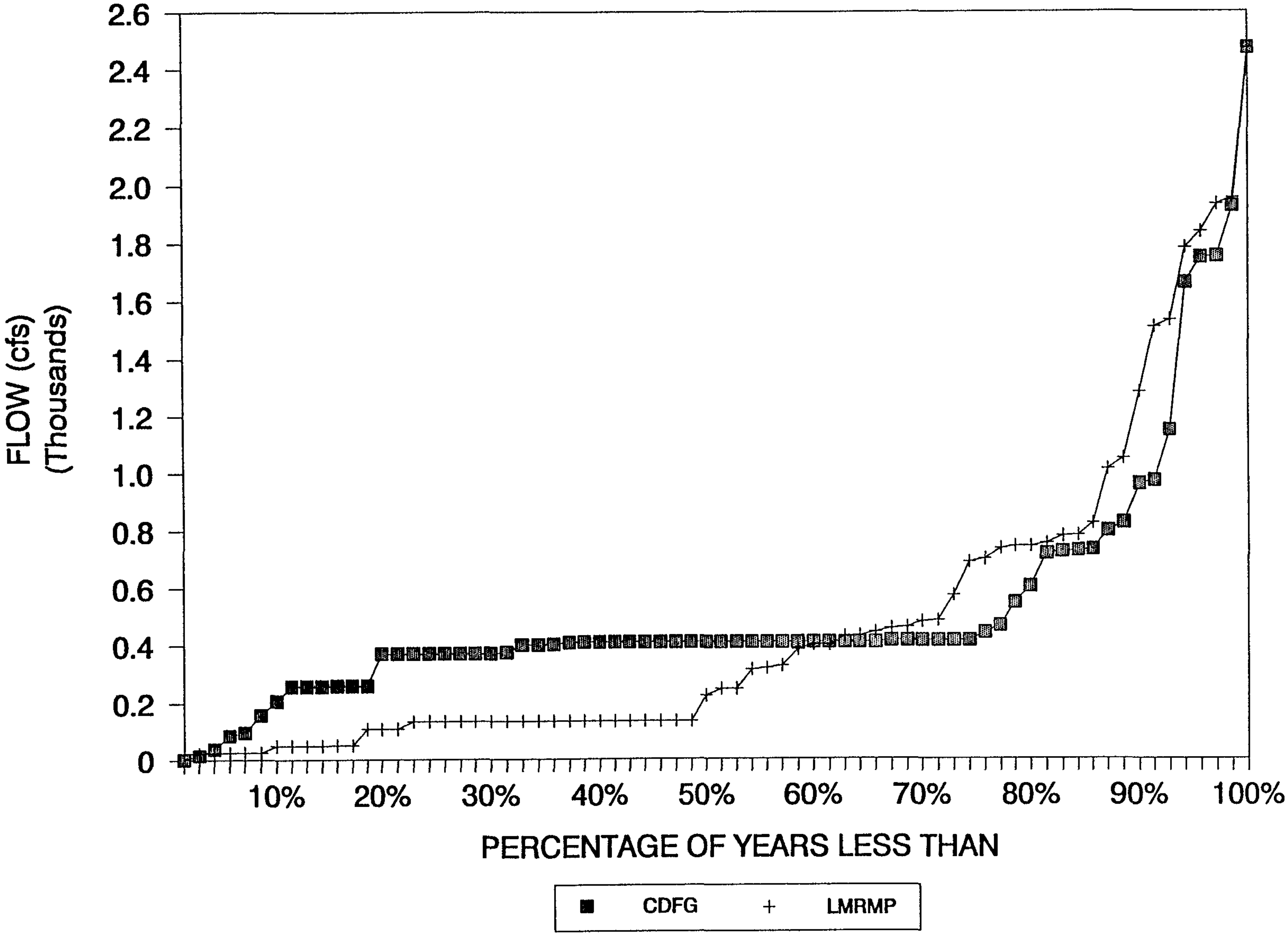


Figure 5-11. Cumulative distribution of flow below Lake Lodi (April through July average, in cfs) for EBMUDSIM simulated years 1921-1990.

occasionally result in unacceptable flow levels in the lower river. In practice, Camanche storage might be sacrificed to maintain desirable flows.

In about 30 percent of years corresponding to wetter but below normal conditions, the relative difference in October-December releases in the two plans is great. Releases average about 500 cfs for the CDFG Plan and 200 cfs for the LMRMP. Since optimum flow for salmon spawning is about 300 cfs (CDFG 1991), there is little benefit to the higher CDFG flow at this time of year. The relative difference between the plans becomes less during above normal years, and the two plans provide about the same flows in 10 percent of years. Figure 5-9 shows that this pattern is extended downstream to the reach below Lake Lodi.

Figures 5-10 and 5-11 show distributions of flows during the April through July out-migration period. The pattern is significantly different in this period. The LMRMP provides greater average flows in about 40 percent of years. In the other 60 percent of drier years, the CDFG Plan provides more flow.

Table 5.12 shows the monthly average release rate from Camanche Reservoir for the two plans, broken out by water year type. Differences between the plans are greatest in dry years, and the LMRMP actually results in larger flows in wet years.

Table 5.12. Average simulated release from Camanche Reservoir in cfs.

	CDFG			LMRMP		
	Dry	Normal	Wet	Dry	Normal	Wet
January	325	364	840	177	228	897
February	313	358	809	175	234	1,021
March	362	424	813	181	241	820
April	467	587	950	251	263	869
May	414	740	1,510	335	655	1,819
June	386	800	1,327	309	603	1,590
July	322	611	838	301	495	938
August	252	444	752	257	434	857
September	236	381	636	186	312	720
October	564	589	605	285	333	316
November	531	494	641	280	335	566
December	357	373	686	243	299	735
Average	374	516	871	247	371	933

5.6.4 Water Quality

As discussed in Section 5.4.4, detailed water temperature simulations were conducted only for the LMRMP. For the CDFG, uncertainty about impacts to the temperature of Pardee outflows would make modeling difficult without an explicit physical model of the reservoir.

5.6.5 Fisheries

Results from Sections 5.5.3 and 5.5.4 provide the basis for input to the Stream Corridor Inventory and Evaluation System (SCIES) model, EBMUDSIM flow results for 70 years for each of the two alternatives were broken down into dry, normal and wet water year type using the CDFG Plan water year system. Year types were defined by annual Mokelumne runoff with annual runoff of less than 50 percent of the period average defined as dry and more than 110 percent of the average defined as wet. The SCIES and Life-cycle models were use toevaluate impacts of the two plans on the fishery using EBMUDSIM results as displayed in Table 5.12.

The SCIES application considered flow differences between the two plans on a monthly average basis by year type, and temperature differences arising from different flow rates. Temperature differences arising from differences in reservoir storage were not considered. This is justifiable since there is no data or model results on the temperature of Camanche inflow under either plan.

The lowest habitat scores for Chinook salmon under the CDFG Plan occur during out-migration below Woodbridge Dam because of low flows, and during the rearing period in normal and wet years because of high flows from Camanche Dam (Table 5.13). The LMRMP has similar results, but rearing scores are better in below average years and spawning scores are not as good (Table 5.14). However, trapping and trucking would be used to avoid effects of the poor out-migration conditions.

The habitat values for steelhead follow the same general trends as for chinook salmon. One exception is that under both plans the predicted conditions for fry and juvenile rearing are much worse for steelhead than for chinook salmon. The lower scores for fry and juvenile rearing in normal and wet years can be attributed to higher than optimum flows during this period. In comparison to the CDFG Plan, the LMRMP exhibits better fry and juvenile scores in dry and normal years because simulated winter flows are lower. Migration scores are high for juvenile and adult steelhead under both plans.

For chinook salmon, the frequency distribution of combined average SCIES scores (Table 5.15 and Figure 5-12) indicate that there are more very high scores under the LMRMP than under the CDFG Plan (Figure 5-12). There are only 16 percent of the scores above a value of 85 for the CDFG Plan as opposed to 27 percent for the LMRMP alternative (Table 5.15). However, CDFG Plan scores are higher in about 60 percent of years.

For steelhead trout, (Tables 5.16 and 5.17) average scores for the combined reaches are much higher than for the chinook salmon under both plans. The frequency distribution of the combined average SCIES scores for the steelhead trout indicate 79 percent of the scores under the CDFG Plan are above 85 values, as opposed to 73 percent under LMRMP (Table 5.15 and Figure 5-12). However, a large proportion of the scores are 92 or above values for LMRMP (47%) compared to 15 percent for CDFG Plan. There are variations in the limiting

Table 5.13. SCIES average scores by species and lifestage for EBMUDSIM Model results using CDFG agreement.

SPECIES/REACH	LIFESTAGE	CRITICAL DRY	DRY	NORMAL	WET
CHINOOK SALMON					
Camanche Reach	In-migration		100	100	100
	Spawning		95	95	82
	Fry		52	45	22
	Juvenile		63	39	23
	Out-migration		99	100	100
Woodbridge Reach	In-migration		100	100	100
	Out-migration		39	82	88
Combined Reaches Scores			76	83	80
STEELHEAD TROUT					
Camanche Reach	In-migration		100	100	100
	Spawning		92	91	70
	Fry		49	37	8
	Juvenile		70	53	25
	Out-migration		100	100	100
Woodbridge Reach	In-migration		100	100	100
	Out-migration		98	100	100
Combined Reaches Scores			90	88	80

C—100932

Table 5.14. SCIES average scores by species and lifestage for EBMUDSIM Model results using LMRMP agreement.

SPECIES/REACH	LIFESTAGE	CRITICAL DRY	DRY	WET/NORMAL
CHINOOK SALMON				
Camanche Reach	In-migration	100	100	100
	Spawning	76	89	86
	Fry	87	80	23
	Juvenile	81	67	27
	Out-migration	99	100	100
Woodbridge Reach	In-migration	99	100	100
	Out-migration	24	51	88
Combined Reaches Scores		75	81	81
STEELHEAD TROUT				
Camanche Reach	In-migration	100	100	100
	Spawning	82	89	79
	Fry	74	60	11
	Juvenile	85	75	30
	Out-migration	100	100	100
Woodbridge Reach	In-migration	100	100	100
	Out-migration	96	99	100
Combined Reaches Scores		93	92	82

C-100933

Table 5.15. Frequency of SCIES scores and its corresponding cumulative distribution.

COMBINED SCIES SCORES	CHINOOK						STEELHEAD					
	CDFG COMBINED SCORE	CDFG Cum. Frequency	DFG Cum. %	LMRMP COMBINED SCORE	LMRMP Cum. Frequency	LMRMP Cum. %	CDFG COMBINED SCORE	CDFG Cum. Frequency	DFG Cum. %	LMRMP COMBINED SCORE	LMRMP Cum. Frequency	LMRMP Cum. %
70	2	2	3%	0	0	0%	0	0	0%	0	0	0%
71	0	2	3%	0	0	0%	0	0	0%	0	0	0%
72	0	2	3%	0	0	0%	0	0	0%	0	0	0%
73	2	4	6%	5	5	7%	0	0	0%	0	0	0%
74	0	4	6%	1	6	9%	0	0	0%	0	0	0%
75	1	5	7%	4	10	14%	0	0	0%	0	0	0%
76	0	5	7%	2	12	17%	0	0	0%	0	0	0%
77	3	8	11%	1	13	19%	1	1	1%	2	2	3%
78	7	15	21%	1	14	20%	1	2	3%	1	3	4%
79	0	15	21%	5	19	27%	2	4	6%	1	4	6%
80	4	19	27%	15	34	49%	1	5	7%	0	4	6%
81	3	22	31%	2	36	51%	1	6	9%	3	7	10%
82	9	31	44%	6	42	60%	5	11	16%	1	8	11%
83	21	52	74%	4	46	66%	3	14	20%	2	10	14%
84	7	59	84%	5	51	73%	1	15	21%	9	19	27%
85	2	61	87%	5	56	80%	1	16	23%	0	19	27%
86	9	70	100%	3	59	84%	7	23	33%	2	21	30%
87	0	70	100%	1	60	86%	14	37	53%	2	23	33%
88	0	70	100%	3	63	90%	14	51	73%	3	26	37%
89	0	70	100%	6	69	99%	10	61	87%	6	32	46%
90	0	70	100%	1	70	100%	5	66	94%	2	34	49%
91	0	70	100%	0	70	100%	2	68	97%	3	37	53%
92	0	70	100%	0	70	100%	2	70	100%	30	67	96%
93	0	70	100%	0	70	100%	0	70	100%	3	70	100%
94	0	70	100%	0	70	100%	0	70	100%	0	70	100%
95	0	70	100%	0	70	100%	0	70	100%	0	70	100%
No. & % above 85	11	16%		19	27%		55	79%		51	73%	
No. & % above 92				0	0%		2	3%		33	47%	

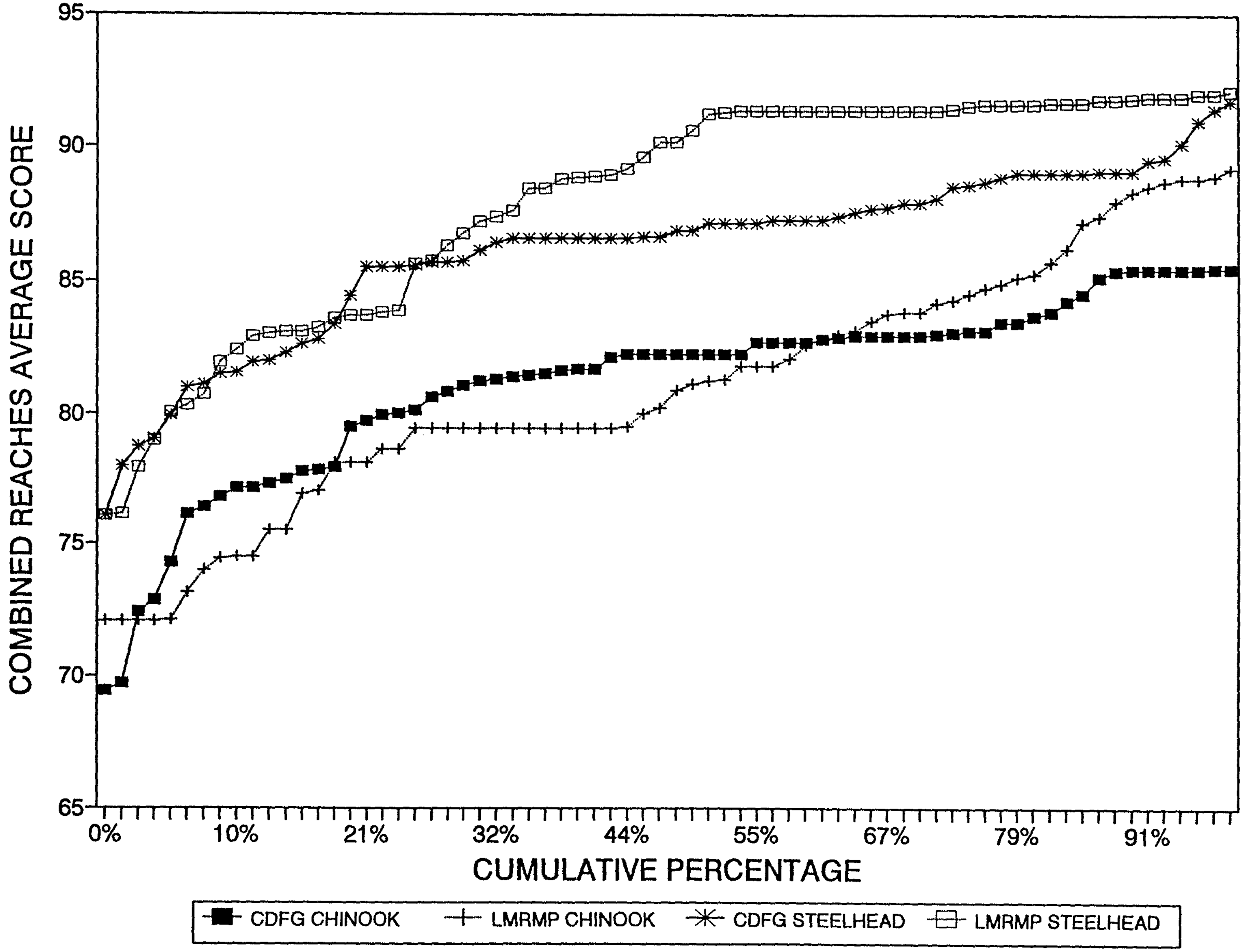


Figure 5-12. Cumulative distribution of combined SCIES scores for chinook salmon and steelhead trout for EBMUDSIM simulated years 1921-1990.

Table 5.16. Minimum/combined SCIES scores by year for EBMUDSIM Model results using CDFG alternative fish releases.

YEAR	CHINOOK: REACH, LIFESTAGE AND MIN. AVG. SCORES			CHINOOK	STEELHEAD: REACH, LIFESTAGE AND MIN. AVG. SCORES			STEELHEAD
	REACH	LIFESTAGE	MINIMUM	COMBINED REACHES AVERAGE SCORE	REACH	LIFESTAGE	MINIMUM	COMBINED REACHES AVERAGE SCORE
1921	Camanche	Fry	25	81	Camanche	Fry	15	83
1922	Camanche	Juvenile	32	83	Camanche	Fry	31	85
1923	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1924	Camanche	Fry	45	78	Camanche	Fry	38	89
1925	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1926	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1927	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1928	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1929	Camanche	Fry	49	78	Camanche	Fry	45	89
1930	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1931	Woodbridge	Outmigration	28	73	Camanche	Fry	60	92
1932	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1933	Camanche	Juvenile	38	84	Camanche	Fry	44	88
1934	Woodbridge	Outmigration	32	72	Camanche	Fry	44	89
1935	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1936	Camanche	Juvenile	37	83	Camanche	Fry	36	87
1937	Camanche	Juvenile	36	81	Camanche	Fry	32	85
1938	Camanche	Juvenile	22	81	Camanche	Fry	10	80
1939	Camanche	Fry	39	77	Camanche	Fry	34	88
1940	Camanche	Juvenile	46	85	Camanche	Juvenile	47	89
1941	Camanche	Juvenile	35	83	Camanche	Fry	32	86
1942	Camanche	Fry	25	81	Camanche	Fry	15	81
1943	Camanche	Fry	21	80	Camanche	Fry	7	79
1944	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1945	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1946	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1947	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1948	Camanche	Juvenile	38	84	Camanche	Fry	39	88
1949	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1950	Camanche	Juvenile	38	82	Camanche	Fry	36	86
1951	Camanche	Fry	29	80	Camanche	Fry	21	82
1952	Camanche	Fry	21	80	Camanche	Fry	6	79
1953	Camanche	Fry	34	82	Camanche	Fry	29	86
1954	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1955	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1956	Camanche	Fry	27	81	Camanche	Fry	18	82
1957	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1958	Camanche	Juvenile	32	84	Camanche	Juvenile	32	86
1959	Camanche	Fry	39	78	Camanche	Fry	34	88
1960	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1961	Woodbridge	Outmigration	33	76	Camanche	Fry	59	91
1962	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1963	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1964	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1965	Camanche	Fry	30	82	Camanche	Fry	22	83
1966	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1967	Camanche	Juvenile	33	84	Camanche	Juvenile	32	86
1968	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1969	Camanche	Juvenile	26	83	Camanche	Fry	29	84
1970	Camanche	Fry	25	79	Camanche	Fry	16	82
1971	Camanche	Fry	30	81	Camanche	Fry	24	86
1972	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1973	Camanche	Juvenile	38	83	Camanche	Fry	37	87
1974	Camanche	Juvenile	26	81	Camanche	Fry	18	81
1975	Camanche	Juvenile	32	83	Camanche	Fry	31	85
1976	Camanche	Fry	45	76	Camanche	Fry	39	88
1977	Woodbridge	Outmigration	20	70	Camanche	Spawning	52	90
1978	Woodbridge	Outmigration	24	69	Camanche	Spawning	67	90
1979	Camanche	Juvenile	46	85	Camanche	Fry	48	89
1980	Camanche	Fry	32	83	Camanche	Fry	26	83
1981	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1982	Camanche	Juvenile	21	78	Camanche	Fry	10	78
1983	Camanche	Fry	21	77	Camanche	Fry	5	76
1984	Camanche	Fry	27	80	Camanche	Fry	19	82
1985	Camanche	Juvenile	37	82	Camanche	Fry	32	87
1986	Camanche	Fry	25	81	Camanche	Fry	14	81
1987	Camanche	Fry	39	77	Camanche	Fry	34	88
1988	Woodbridge	Outmigration	31	74	Camanche	Fry	59	91
1989	Camanche	Juvenile	46	85	Camanche	Fry	49	89
1990	Camanche	Fry	45	77	Camanche	Fry	38	88
		Minimum	20	69			5	76
		Maximum	49	85			67	92
		Average	35	81			34	86

C-100936

Table 5.17. Minimum/combined SCIES scores by year for EBMUDSIM Model results using LMRMP alternative fish releases.

	CHINOOK				STEELHEAD			
	REACH, LIFESTAGE AND MINIMUM AVG. SCO			COMBINED REACHES	REACH, LIFESTAGE AND MINIMUM AVG. SCO			COMBINED REACHES
YEAR	REACH	LIFESTAGE	MINIMUM	AVERAGE SCORE	REACH	LIFESTAGE	MINIMUM	AVERAGE SCORE
1921	Camanche	Fry	27	83	Camanche	Fry	22	84
1922	Camanche	Juvenile	50	89	Camanche	Juvenile	43	89
1923	Camanche	Juvenile	52	87	Camanche	Juvenile	46	88
1924	Woodbridge	Outmigration	24	72	Camanche	Fry	62	92
1925	Camanche	Juvenile	62	89	Camanche	Juvenile	65	91
1926	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1927	Camanche	Juvenile	51	89	Camanche	Juvenile	45	89
1928	Camanche	Juvenile	46	85	Camanche	Fry	39	88
1929	Woodbridge	Outmigration	45	78	Camanche	Fry	57	92
1930	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1931	Woodbridge	Outmigration	24	72	Camanche	Fry	62	92
1932	Woodbridge	Outmigration	51	82	Camanche	Spawning	67	92
1933	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1934	Woodbridge	Outmigration	24	72	Camanche	Fry	62	92
1935	Woodbridge	Outmigration	51	82	Camanche	Spawning	67	92
1936	Camanche	Juvenile	31	85	Camanche	Fry	36	87
1937	Camanche	Juvenile	44	85	Camanche	Juvenile	39	86
1938	Camanche	Juvenile	21	81	Camanche	Fry	13	80
1939	Woodbridge	Outmigration	45	78	Camanche	Fry	57	92
1940	Camanche	Juvenile	51	89	Camanche	Juvenile	50	90
1941	Camanche	Fry	30	84	Camanche	Fry	25	84
1942	Camanche	Fry	42	85	Camanche	Juvenile	29	83
1943	Camanche	Fry	21	80	Camanche	Fry	7	79
1944	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1945	Camanche	Juvenile	51	87	Camanche	Juvenile	45	88
1946	Camanche	Juvenile	52	88	Camanche	Juvenile	47	89
1947	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1948	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1949	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1950	Camanche	Juvenile	50	86	Camanche	Juvenile	41	87
1951	Camanche	Fry	32	83	Camanche	Fry	28	84
1952	Camanche	Fry	21	80	Camanche	Fry	5	78
1953	Camanche	Fry	51	86	Camanche	Fry	42	87
1954	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1955	Woodbridge	Outmigration	51	79	Camanche	Fry	56	90
1956	Camanche	Fry	39	84	Camanche	Juvenile	30	83
1957	Camanche	Juvenile	55	88	Camanche	Fry	56	91
1958	Camanche	Juvenile	21	81	Camanche	Fry	13	81
1959	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1960	Woodbridge	Outmigration	27	73	Camanche	Fry	62	91
1961	Woodbridge	Outmigration	24	74	Camanche	Spawning	62	92
1962	Woodbridge	Outmigration	51	82	Camanche	Spawning	67	92
1963	Camanche	Juvenile	50	89	Camanche	Juvenile	42	89
1964	Woodbridge	Outmigration	51	79	Camanche	Fry	56	90
1965	Camanche	Fry	42	85	Camanche	Juvenile	29	84
1966	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1967	Camanche	Juvenile	22	84	Camanche	Fry	26	84
1968	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1969	Camanche	Fry	22	81	Camanche	Fry	8	80
1970	Camanche	Fry	29	82	Camanche	Fry	25	83
1971	Camanche	Fry	31	84	Camanche	Fry	28	86
1972	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1973	Camanche	Fry	29	81	Camanche	Fry	25	83
1974	Camanche	Juvenile	26	83	Camanche	Fry	20	82
1975	Camanche	Juvenile	50	89	Camanche	Juvenile	42	89
1976	Woodbridge	Outmigration	24	72	Camanche	Fry	62	92
1977	Woodbridge	Outmigration	24	74	Camanche	Spawning	62	92
1978	Woodbridge	Outmigration	24	74	Camanche	Spawning	59	92
1979	Woodbridge	Outmigration	27	76	Camanche	Spawning	62	92
1980	Camanche	Fry	40	84	Camanche	Juvenile	36	86
1981	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1982	Camanche	Fry	21	77	Camanche	Fry	5	76
1983	Camanche	Fry	21	77	Camanche	Fry	5	76
1984	Camanche	Fry	33	83	Camanche	Fry	29	83
1985	Woodbridge	Outmigration	51	79	Camanche	Fry	56	91
1986	Camanche	Fry	31	83	Camanche	Fry	22	82
1987	Woodbridge	Outmigration	45	78	Camanche	Fry	57	92
1988	Woodbridge	Outmigration	24	72	Camanche	Fry	62	92
1989	Woodbridge	Outmigration	27	76	Camanche	Spawning	62	92
1990	Woodbridge	Outmigration	24	74	Camanche	Spawning	62	92
		Minimum	21	72			5	76
		Maximum	62	89			67	92
		Average	39	81			45	88

C —1 0 0 9 3 7

minimum SCIES scores from year to year under the two plans. Overall, results indicate that the LMRMP would provide slightly better conditions for steelhead.

Life Cycle Model Results - Life cycle model results presented in Section 4.0 are based on flow projections without consideration of actual operations. To account for differences due to actual project operation, the life cycle models were rerun for the CDFG and the LMRMP using EBMUDSIM hydrologic output for the 70 year period of record (Tables 5.18 and 5.19). The biggest difference between the results here, and those presented in Section 4.0, are that flood releases are now considered.

Life Cycle Model results show the highest predicted return to the Mokelumne River under the CDFG alternative (13,309 compared to 8,590 under LMRMP alternative). The higher return is largely due to the higher predicted survival of yearling hatchery salmon released below Camanche Dam. Results for both plans indicate an increase in the population of salmon to the Mokelumne River from an initial run of 5,000 adults. The CDFG alternative also has the highest number of natural smolts (606,149) predicted at the mouth of the Mokelumne River, although the LMRMP is very close (534,121). The difference between the two plans in terms of returns to the Mokelumne River is because of the larger number of yearlings released from the MRFH under the CDFG Plan.

5.6.6 Delta Water Quality

This section considers the potential impact of the two plans on the Sacramento-San Joaquin Delta Estuary. This section also incorporates results from a EBMUDSIM scenario operated according to the 1961 agreement. This scenario provides a base case for comparison to the CDFG Plan and the LMRMP.

In general, the differences in flows between the two plans are maintained to the Delta. Figure 5-13 shows cumulative distributions of Delta inflow for the three alternatives. In the driest 10 percent of years, the LMRMP and the 1961 agreement result in about the same level of Delta inflow, but the CDFG Plan results in more inflow. In the next 50 percent of years, the LMRMP results in slightly more Delta inflow than the 1961 agreement, but the CDFG Plan results in much more Delta inflow. All three plans show about the same level of inflow in wet years when, presumably, incremental inflow would have the least value for water quality purposes.

Table 5.20 compares the two plans to the 1961 agreement base case in terms of average monthly flows for different year types. In comparison to the 1961 agreement, the LMRMP increases average Delta inflow in November through June of normal and dry years. However, average flows in most months of wet years are decreased. The lower part of Table 5.20 shows these changes to be important on a percentage basis. Average flows in July through October are generally decreased, although the effect in October is probably not significant.

C-100938

Table 5.18. CDFG EBMUDSIM alternative life cycle model output.

Rates in the top part of Table are used to calculate numbers in lower part of table. Equations for each calculation are given to the right of the appropriate row.

ROW	SURVIVAL RATES	CRITICAL YEAR	DRY YEAR	NORMAL YEAR	WET YEAR
1	YEAR TYPE FREQUENCY OF OCCURENCE	0%	14%	47%	39%
2	FEMALES IN RUN	35%	35%	35%	35%
3	NUMBER OF EGGS PER FEMALE	4600	4600	4600	4600
4	EGG TO FRY SURVIVAL	25%	25%	25%	25%
5	FRY TO SMOLT SURVIVAL	68%	68%	68%	68%
6	OUTMIGRANT SURVIVAL TO L. LODI	95%	95%	95%	95%
7	SURVIVAL THROUGH L. LODI	0%	60%	72%	85%
8	OUTMIGRANTS TRAPPED AND TRUCKED	0%	0%	0%	0%
9	OUTMIGRANT SURVIVAL FROM WOODBRIDGE TO DELTA	0%	39%	82%	88%
10	OUTMIGRANT SURVIVAL THROUGH DELTA	15%	15%	15%	15%
11	SURVIVAL OF SMOLTS RELEASED IN DELTA	80%	80%	80%	80%
12	SURVIVAL OF YEARLINGS RELEASED IN DELTA	90%	90%	90%	90%
13	SURVIVAL OF YEARLINGS RELEASED AT MRFH	45%	45%	45%	45%
14	OCEAN SURVIVAL OF SMOLTS	3%	3%	3%	3%
15	OCEAN SURVIVAL OF YEARLINGS	6%	6%	6%	6%
16	SURVIVING HARVEST	34%	34%	34%	34%
17	NATURAL OUTMIGRANT STRAYING RATE	15%	15%	15%	15%
18	DELTA RELEASE STRAYING RATE	95%	95%	95%	95%

ROW	NUMBERS OF FISH	CRITICAL YEAR	DRY YEAR	NORMAL YEAR	WET YEAR	WEIGHTED AVERAGE		EXPLANATION
19	INITIAL TOTAL NUMBER OF SPAWNERS	0	5000	5000	5000	5000		Initial size of spawning run
	HATCHERY							
20	NUMBER OF SPAWNERS ENTERING HATCHERY	0	1150	1150	1150	1150		Initial total number of spawners x 23%
21	EGGS FROM FISH RETURNING TO HATCHERY	0	1851500	1851500	1851500	1851500		number spawning in hatchery x % females x eggs per female
22	TOTAL HATCHERY EGGS NEEDED	0	5833333	5833333	5833333	5833333		1.25 x number of smolts and yearlings
23	EGGS OR FRY IMPORTED FROM OTHER HATCHERY	0	3981833	3981833	3981833	3981833		total hatchery eggs needed - eggs from fish returning
24	NUMBER OF SMOLTS RELEASED AT MRFH	0	0	0	0	0		determined by management plan
25	NUMBER OF SMOLTS RELEASED IN DELTA	0	2000000	2000000	2000000	2000000		determined by management plan
26	NUMBER OF YEARLINGS RELEASED AT MRFH	0	1500000	1500000	1500000	1500000		determined by management plan
27	NUMBER OF YEARLINGS RELEASED IN DELTA	0	0	0	0	0		determined by management plan
	RIVER							
28	NUMBER SPAWNING NATURALLY IN RIVER	0	3850	3850	3850	3850		Initial total number of spawners - number spawning in hatchery
29	EGGS DEPOSITED IN RIVER	0	6198500	6198500	6198500	6198500		number spawning naturally x % female x eggs per female
30	FRY HATCHING IN RIVER	0	1549625	1549625	1549625	1549625		Row 29 x egg to fry survival
31	NATURAL SMOLTS ENTERING LAKE LODI	0	1006946	1006946	1006946	1006946		Row 30 x fry to smolt survival x outmigrant survival to L. Lodi
32	TOTAL SMOLTS ENTERING LAKE LODI	0	1006946	1006946	1006946	1006946		Row 31 + (smolts released at MRFH x outmigrant survival to L. Lodi)
33	SMOLTS SURVIVING LAKE LODI	0	604168	725001	855904	759137		Row 32 x survival through L. Lodi
34	NUMBER OF SMOLTS TRAPPED AND TRUCKED	0	0	0	0	0		Row 33 x % trapped and trucked
35	SMOLTS MIGRATING NATURALLY TO DELTA	0	235625	594501	753196	606149		(Row 33 - Row 34) x outmigrant survival from Woodbridge to Delta
36	NATURALLY PRODUCED SMOLTS TO DELTA	0	235625	594501	753196	606149		(Row 33 - Row 34 - surviving hatchery plants) x outmigrant survival from Woodbridge to Delta
37	SMOLTS MIGRATING NATURALLY TO CHIPPS ISLAND	0	35344	89175	112979	90922		Row 35 x outmigrant survival through Delta
38	SMOLTS TRUCKED TO CHIPPS ISLAND	0	1600000	1600000	1600000	1600000		(Row 34 + Row 25) x survival of smolts released in Delta
39	TOTAL SMOLTS TO CHIPPS ISLAND	0	1635344	1689175	1712979	1690922		Row 36 + Row 37
40	YEARLINGS TO CHIPPS ISLAND	0	675000	675000	675000	675000		Row 26 x survival of yearlings released at MRFH + Row 27 x survival of yearlings released in Delta
41	NUMBER SURVIVING TO BE HARVESTED OR SPAWN	0	89560	91175	91889	91228		Row 38 x ocean survival for smolts + Row 39 x ocean survival for yearlings
42	NUMBER HARVESTED	0	59110	60176	60647	60210		Row 40 x (1 - percent survivng harvest)
43	TOTAL NUMBER LEFT TO SPAWN	0	30451	31000	31242	31017		Row 40 x percent surviving harvest
44	NUMBER STRAYING TO OTHER RIVERS	0	17624	17706	17742	17709		(Row 36 x Row 14 x Row 16 x Row 17)+(Row 37 x Row 14 x Row 16 x Row 18) + (Row 26 x Row 13 x Row 15 x Row 16 x Row 17) + (Row 27 x Row 12 x Row 15 x Row 16 x Row 18)
45	NUMBER RETURNING TO MOKELUMNE	0	12827	13294	13500	13309		Row 42 - Row 43
.	NATURAL SMOLTS RETURNING	0	306	773	980	788	6%	
	TRUCKED SMOLTS RETURNING	0	816	816	816	816	6%	
	RIVER YEARLINGS RETURNING	0	11704	11704	11704	11704	88%	
	DELTA YEARLINGS RETURNING	0	0	0	0	0	0%	
		0	12827	13294	13500	13309		

C-100940

Table 5.19. Life cycle model output, LMRMP-EBMUDSIM production oriented alternative, natural emphasis.

Rates in the top part of Table are used to calculate numbers in lower part of table. Equations for each calculation are given to the right of the appropriate row.

ROW	SURVIVAL RATES	CRITICAL YEAR	DRY YEAR	NORMAL YEAR	WET YEAR
1	YEAR TYPE FREQUENCY OF OCCURENCE	17%	31%	26%	26%
2	FEMALES IN RUN	35%	35%	35%	35%
3	NUMBER OF EGGS PER FEMALE	4600	4600	4600	4600
4	EGG TO FRY SURVIVAL	25%	25%	25%	25%
5	FRY TO SMOLT SURVIVAL	68%	68%	68%	68%
6	OUTMIGRANT SURVIVAL TO L. LODI	95%	95%	95%	95%
7	SURVIVAL THROUGH L. LODI	32%	77%	85%	86%
8	OUTMIGRANTS TRAPPED AND TRUCKED	100%	50%	0%	0%
9	OUTMIGRANT SURVIVAL FROM WOODBRIDGE TO DELTA	24%	96%	88%	88%
10	OUTMIGRANT SURVIVAL THROUGH DELTA	15%	15%	15%	15%
11	SURVIVAL OF SMOLTS RELEASED IN DELTA	80%	80%	80%	80%
12	SURVIVAL OF YEARLINGS RELEASED IN DELTA	90%	90%	90%	90%
13	SURVIVAL OF YEARLINGS RELEASED AT MRFH	45%	45%	45%	45%
14	OCEAN SURVIVAL OF SMOLTS	3%	3%	3%	3%
15	OCEAN SURVIVAL OF YEARLINGS	6%	6%	6%	6%
16	SURVIVING HARVEST	34%	34%	34%	34%
17	NATURAL OUTMIGRANT STRAYING RATE	15%	15%	15%	15%
18	DELTA RELEASE STRAYING RATE	95%	95%	95%	95%

ROW	NUMBERS OF FISH	CRITICAL YEAR	DRY YEAR	NORMAL YEAR	WET YEAR	WEIGHTED AVERAGE		EXPLANATION
19	INITIAL TOTAL NUMBER OF SPAWNERS	5000	5000	5000	5000	5000		Initial size of spawning run
	HATCHERY							
20	NUMBER OF SPAWNERS ENTERING HATCHERY	1150	1150	1150	1150	1150		Initial total number of spawners x 23%
21	EGGS FROM FISH RETURNING TO HATCHERY	1851500	1851500	1851500	1851500	1851500		number spawning in hatchery x % females x eggs per female
22	TOTAL HATCHERY EGGS NEEDED	7184833	7184833	7184833	7184833	7184833		1.25 x number of smolts and yearlings
23	EGGS OR FRY IMPORTED FROM OTHER HATCHERY	5333333	5333333	5333333	5333333	5333333		total hatchery eggs needed - eggs from fish returning
24	NUMBER OF SMOLTS RELEASED AT MRFH	0	155450	310900	310900	209857		determined by management plan
25	NUMBER OF SMOLTS RELEASED IN DELTA	3510900	3355450	3200000	3200000	3301043		determined by management plan
26	NUMBER OF YEARLINGS RELEASED AT MRFH	800000	800000	800000	800000	800000		determined by management plan
27	NUMBER OF YEARLINGS RELEASED IN DELTA	0	0	0	0	0		determined by management plan
	RIVER							
28	NUMBER SPAWNING NATURALLY IN RIVER	3850	3850	3850	3850	3850		Initial total number of spawners - number spawning in hatchery
29	EGGS DEPOSITED IN RIVER	6198500	6198500	6198500	6198500	6198500		number spawning naturally x % female x eggs per female
30	FRY HATCHING IN RIVER	1549625	1549625	1549625	1549625	1549625		Row 29 x egg to fry survival
31	NATURAL SMOLTS ENTERING LAKE LODI	1006946	1006946	1006946	1006946	1006946		Row 30 x fry to smolt survival x outmigrant survival to L. Lodi
32	TOTAL SMOLTS ENTERING LAKE LODI	0	658923	1317846	1317846	889546		Row 32 x survival through L. Lodi
33	SMOLTS SURVIVING LAKE LODI	0	507371	1120169	1133348	743199		Row 31 + (smolts released at MRFH x outmigrant survival to L. Lodi)
34	NUMBER OF SMOLTS TRAPPED AND TRUCKED	1006946	503473	0	0	327258		Row 33 x % trapped and trucked
35	SMOLTS MIGRATING NATURALLY TO DELTA	0	487076	985749	997346	666598		(Row 33 - Row 34) x outmigrant survival from Woodbridge to Delta
36	NATURALLY PRODUCED SMOLTS TO DELTA	0	432494	764824	773821	534121		(Row 33 - Row 34 - surviving hatchery plants) x outmigrant survival from Woodbridge to Delta
37	SMOLTS MIGRATING NATURALLY TO CHIPPS ISLAND	0	73061	147862	149602	99990		Row 35 x outmigrant survival through Delta
38	SMOLTS TRUCKED TO CHIPPS ISLAND	3614277	3087139	2560000	2560000	2902640		(Row 34 + Row 25) x survival of smolts released in Delta
39	TOTAL SMOLTS TO CHIPPS ISLAND	3614277	3160200	2707862	2709602	3002630		Row 36 + Row 37
40	YEARLINGS TO CHIPPS ISLAND	360000	360000	360000	360000	360000		Row 26 x survival of yearlings released at MRFH + Row 27 x survival of yearlings released in Delta
41	NUMBER SURVIVING TO BE HARVESTED OR SPAWN	130028	116406	102836	102888	111679		Row 38 x ocean survival for smolts + Row 39 x ocean survival for yearlings
42	NUMBER HARVESTED	85819	76828	67872	67906	73708		Row 40 x (1 - percent survivng harvest)
43	TOTAL NUMBER LEFT TO SPAWN	44210	39578	34964	34982	37971		Row 40 x percent surviving harvest
44	NUMBER STRAYING TO OTHER RIVERS	36124	31128	26134	26137	29381		(Row 36 x Row 14 x Row 16 x Row 17)+(Row 37 x Row 14 x Row 16 x Row 18)+ (Row 26 x Row 13 x Row 15 x Row 16 x Row 17) + (Row 27 x Row 12 x Row 15 x Row 16 x Row 18)
45	NUMBER RETURNING TO MOKELUMNE	8086	8450	8830	8845	8590		Row 42 - Row 43
	NATURAL SMOLTS RETURNING	0	633	1282	1297	867	10%	
	TRUCKED SMOLTS RETURNING	1843	1574	1306	1306	1480	17%	
	RIVER YEARLINGS RETURNING	6242	6242	6242	6242	6242	73%	
	DELTA YEARLINGS RETURNING	0	0	0	0	0	0%	
		8086	8450	8830	8845	8590		

C-100940

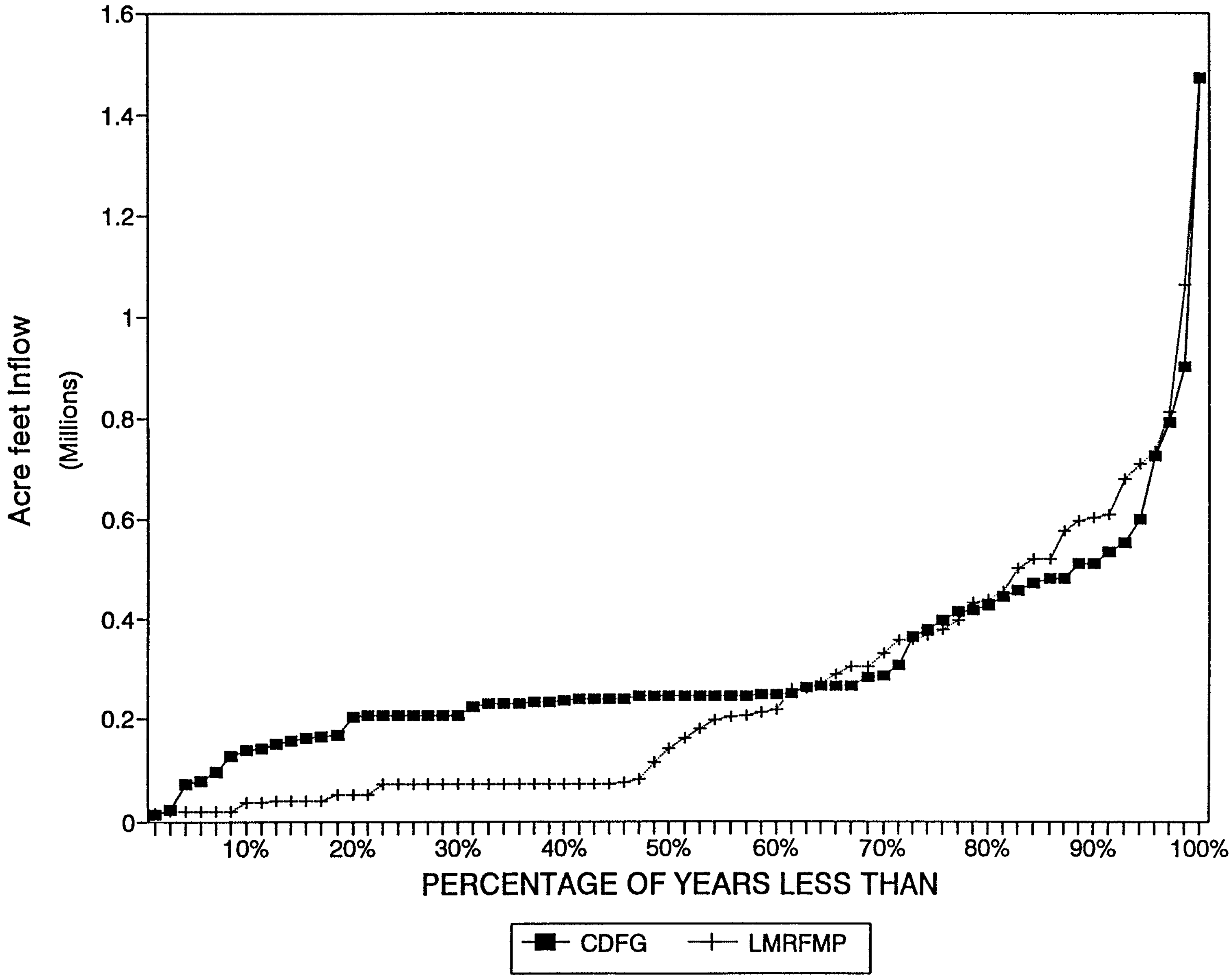


Figure 5-13. Cumulative distribution of annual inflow to the Delta (million acre-feet) for EBMUDSIM simulated years 1921-1990.

Table 5.20. CDFG Plan and LMRMP in comparison to CDFG 1961 Agreement: difference in flows in cfs and percentage [1].

	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
LMRMP Inflow Minus Base Case Inflow (cfs)												
Dry Avg	-11	· 50	59	73	86	64	90	130	0	0	2	6
Norm Avg	-9	77	45	27	10	46	86	185	28	-50	-50	-46
Wet Avg	-1	112	-65	-21	-180	-12	22	-47	90	-63	-63	-58
AVERAGE	-7	85	9	18	-43	29	64	94	45	-46	-46	-41
CDFG Inflow Minus Base Case Inflow (cfs)												
Dry Avg	275	273	169	221	220	238	283	174	126	51	29	67
Norm Avg	261	242	119	154	77	222	411	248	197	70	-40	15
Wet Avg	296	150	-158	-105	-407	-31	40	-345	-94	-142	-147	-138
AVERAGE	275	215	30	75	-69	136	260	28	83	-7	-66	-30
LMRMP Percent Change in Inflow [2]												
Dry Avg	-6%	29%	56%	181%	288%	219%	inf	inf	0%	inf	inf	inf
Norm Avg	-5%	40%	26%	19%	5%	43%	844%	87%	12%	-37%	-37%	-33%
Wet Avg	-1%	25%	-8%	-2%	-14%	-1%	3%	-3%	9%	-12%	-12%	-11%
AVERAGE[3]	-3%	30%	2%	4%	-8%	8%	22%	14%	9%	-18%	-18%	-16%
CDFG Plan Percent Change in Inflow												
Dry Avg	150%	159%	161%	553%	735%	821%	inf	inf	inf	inf	inf	inf
Norm Avg	131%	126%	69%	104%	35%	206%	4031%	117%	86%	51%	-29%	11%
Wet Avg	158%	34%	-19%	-10%	-32%	-4%	5%	-21%	-9%	-26%	-27%	-25%
AVERAGE[3]	143%	77%	8%	18%	-13%	40%	91%	4%	18%	-3%	-26%	-12%

1 1929 to 1986 results used in this analysis.
2 "inf" is infinity; a positive change divided by zero base quantity.
3 Sum of change in monthly flows divided by sum of base flow.

The CDFG Plan substantially increases average Delta inflow in most months of normal and dry years. Average flows are frequently doubled over base levels. As for the LMRMP, average flows in wet years are decreased.

The average monthly flow changes in Table 5.20 are sometimes deceiving in that the distributions of flow changes are not normal. In winter months, the means are substantially less than the medians. The simulation results include occasional large flow decreases in some winter months. For example, the 43 cfs (8 percent) reduction in average February flow under the LMRMP results from only 10 years of reduced monthly flow, but includes 48 years of increased flow. Mokelumne River reservoirs would store less water under either plan and would, therefore, be able to store more flood flows, resulting in infrequent but large decreases in Delta inflows. High winter flow can be detrimental when salmon eggs are in the gravel or fry are just emerging, so reducing the frequency and severity of these winter high-flow events would probably benefit chinook salmon and steelhead fry production.

While flow changes in the Lower Mokelumne River are significant, this does not imply that the Delta would be significantly affected. Changes in Delta inflow due to the LMRMP or the CDFG Plan would be large in comparison to base case inflow, but Mokelumne River inflow is generally a small portion of all Delta inflow. The central Delta receives Sacramento River water through the Delta Cross Channel and Georgiana Slough as well as water from the Mokelumne, Consumes and San Joaquin rivers and numerous smaller tributaries.

DWR (Various years) developed estimates of flow at various points in the Delta which can be used for comparison to EBMUDSIM Delta inflow estimates. The XGEO series estimates Sacramento River inflow to the central Delta from the Delta Cross Channel and Georgiana Slough. These data were obtained for 1976 to 1990, a more recent and representative period, and compared to the EBMUDSIM Delta inflow estimates for the two plans simulated for the same period. Results are provided in Table 5.21.

Table 5.21. LMRMP and CDFG Plan Delta inflows as a percentage of XGEO (Sacramento River inflow to central Delta), 1976-1990 average.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LMRMP												
Average	5%	9%	6%	5%	12%	7%	3%	3%	3%	3%	6%	5%
Maximum	18%	44%	30%	30%	44%	43%	19%	13%	13%	9%	23%	25%
CDFG												
Average	7%	9%	9%	9%	13%	9%	4%	3%	3%	7%	9%	6%
Maximum	18%	19%	30%	29%	42%	6%	19%	11%	11%	15%	23%	25%

Simulated Delta inflow from the Mokelumne River is a small part (3 to 13%) of total central Delta inflow on an average basis, but occasional large flood flows from the Mokelumne result in an occasional large share; up to 40 percent in several months. Apparently, flood events do not have much effect on central Delta inflows from the Sacramento River, so a large share of central Delta inflow can originate from the east side rivers during flood events. The Mokelumne is a smaller share of total Delta in-flow.

The difference in inflow share between the two plans is generally not large. The CDFG Plan does provide a larger share of average central Delta inflow in some months, most notably in March-April and October-November, and some difference between the two plans in their maximum monthly inflow share indicates different flood control capabilities between the two plans.

The DAYFLOW variable QWEST is an estimate of flow past Jersey Point. Simulated Delta inflows from the two plans were compared to QWEST data for the 1976 to 1990 period. Again, both plans generally had small impacts on QWEST, but occasional large impacts were associated with small net QWEST flows and/or large flood events.

In summary, the difference in central Delta inflows from the Mokelumne River between the two plans is nearly negligible in comparison to all inflows into the central Delta, and the two plans have even less effect on flow at Jersey Point. Therefore, the LMRMP or CDFG Plan could substantially affect aquatic resources in the Lower Mokelumne channels upstream of the Delta Cross Channel, but would normally have no significant influence further downstream.

Average effects on Delta outflow at Chipps Island would be even less significant because of other inflows, but also because changes in Mokelumne River inflows are likely to result in equal and opposite project (Central Valley and State Water projects) inflows when the Delta is in balanced condition. In meeting water quality criteria, the projects would reduce other Delta inflows to offset increased inflow from the Mokelumne River. This suggests that the LMRMP would have a very small effect on water quality and aquatic resources that depend on Delta outflow.

5.7 AFFECTS OF RAPID FLOW CHANGES ON SPAWNING AND REARING FISH

Sensitivity of salmon redds and early life stages to changes in discharge rates from Camanche Reservoir were evaluated for the CDFG Plan and the LMRMP using EBMUDSIM. The time period from October to March (spawning through beginning of the rearing period) was used for analysis of the two plans. For each year of the simulation, the maximum and the minimum Camanche release rates within this time period were determined to find the range of flows for that year. From this information, the magnitude and frequency of flow change that occurred during the 70 year simulation period could be assessed. Figures 5-14 and 5-15 show the range of flow rates simulated during each of the 70 years for the CDFG Plan and the LMRMP plans. Figures 5-16 and 5-17 show the frequency distribution of the range of flows from both studies.

For spawning, a flow rate of 300 cfs is optimal and flow rates between 100 and 600 cfs are acceptable (CDFG 1991). As shown in Table 5.22, there is only an 11 percent increase in wetted perimeter between 200 and 600 cfs at the upper section of the Camanche reach of the Mokelumne River where spawning and rearing occur. Flow changes within this range are expected to have minimal effects on redd dewatering or incubation conditions. Decreases to 100 cfs or less may dewater redds or substantially alter conditions for incubation. Higher flows during spawning, or radical flow increases after spawning, will decrease spawning and incubation success.

Under the LMRMP, a flow rate of 600 cfs or less occurs 64 percent of the time, while under the CDFG Plan it would occur 53 percent of the time (Figures 5-18 and 5-19). Most significant change in the wetted perimeter occurs between 200 and 100 cfs. There is a 10 percent reduction in wetted perimeter between 200 and 100 cfs. Thus, it is not desirable to have flow drop below 200 cfs. Of the 64 percent of years in the LMRMP when maximum flow rate is less than 600 cfs, the corresponding minimum flow rates dropped below 200 cfs 39 percent (27 years) of the time, while in the CDFG Plan, of the 53 percent of the years in which maximum flow is less than 600 cfs, minimum flow rates dropped below 200 cfs 9 percent (6 years) of the time.

C-100944

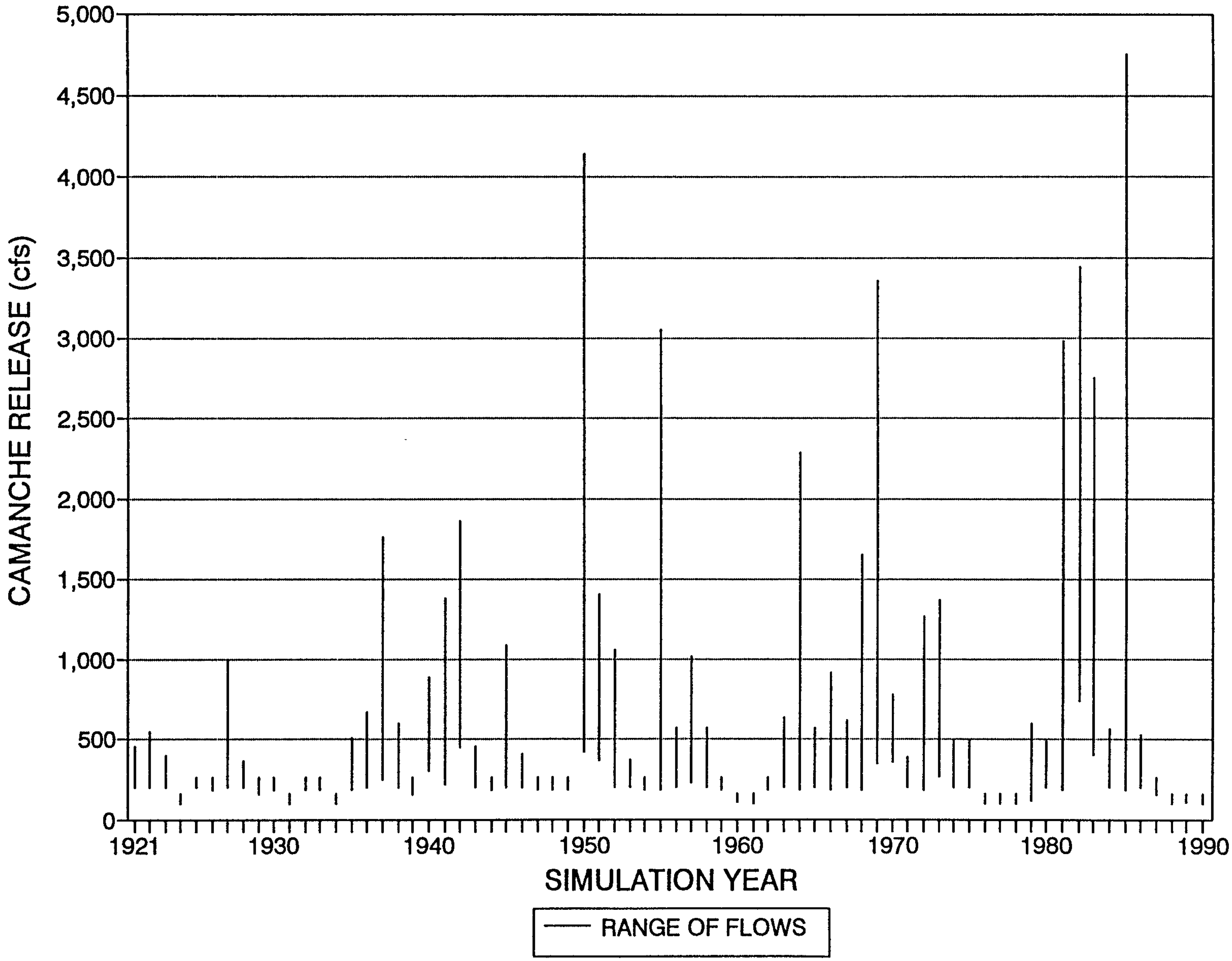


Figure 5-14. Range of flows (cfs) under LMRMP (Camanche release rates) between October and March for EBMUDSIM simulated years 1921-1990.

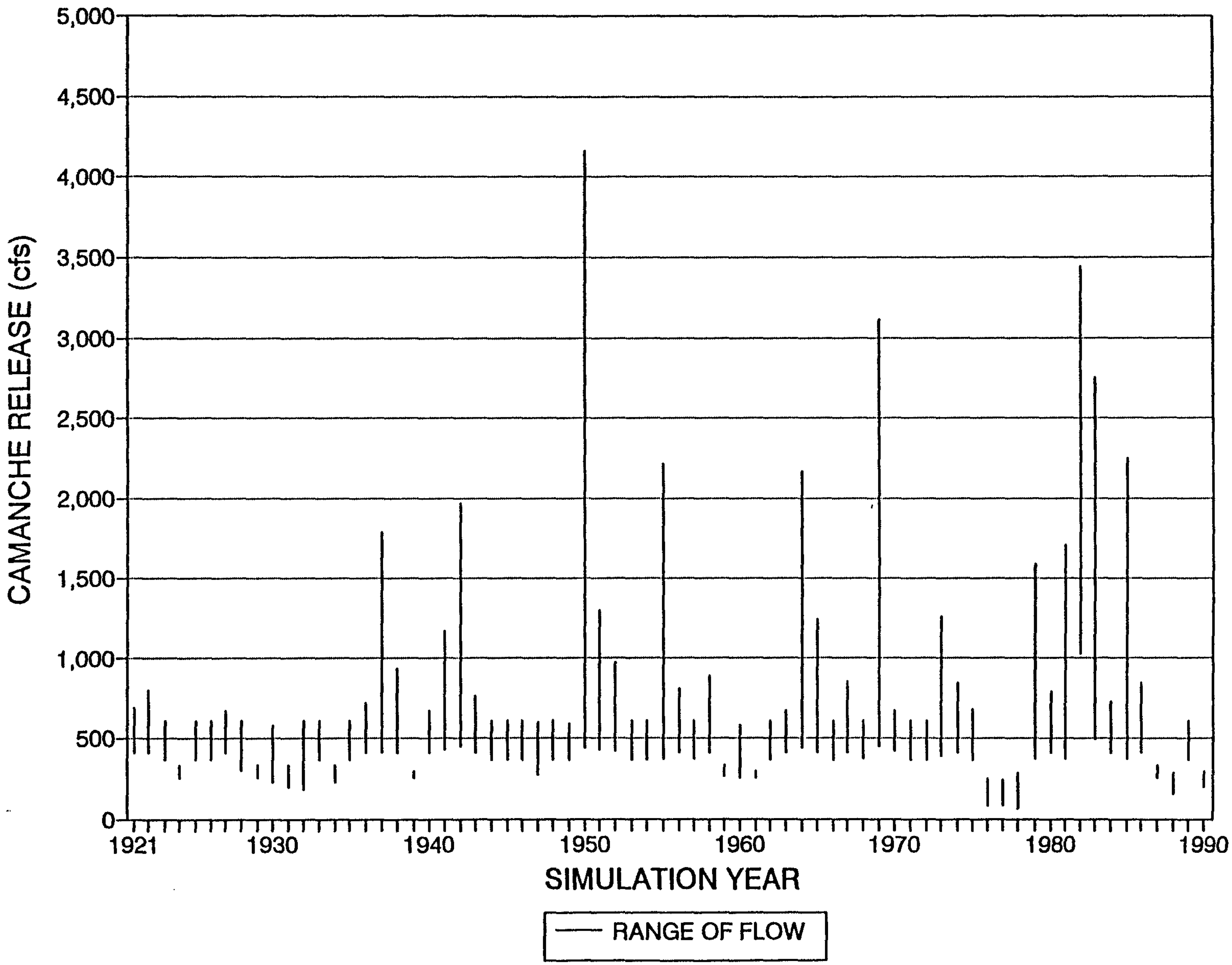


Figure 5-15. Range of flows (cfs) under CDFG Plan (Camanche release rates) between October and March for EBMUDSIM simulated years 1921-1990.

C —1 0 0 9 4 6

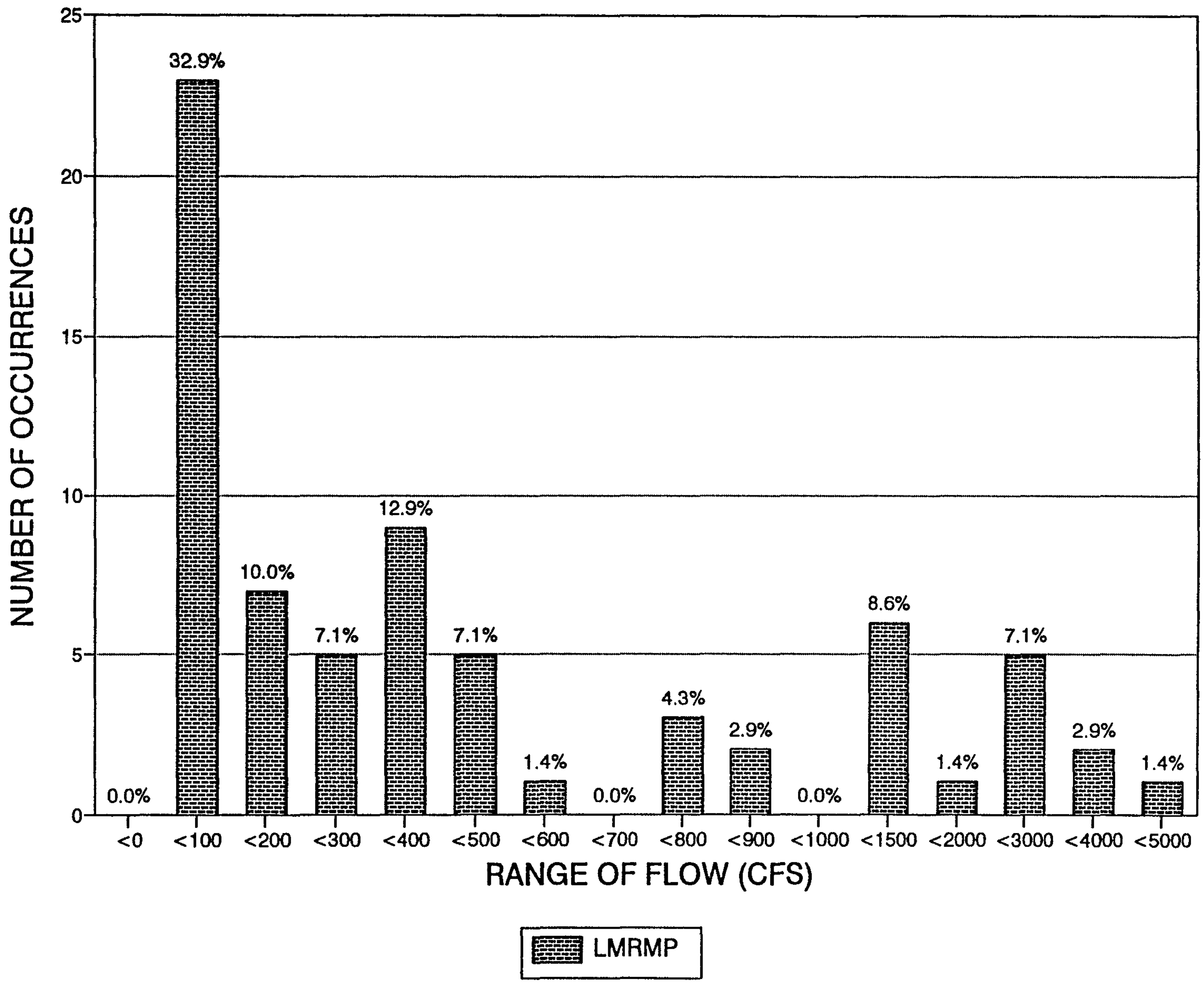


Figure 5-16. Frequency distribution of flow ranges for the period between October and March under LMRMP.

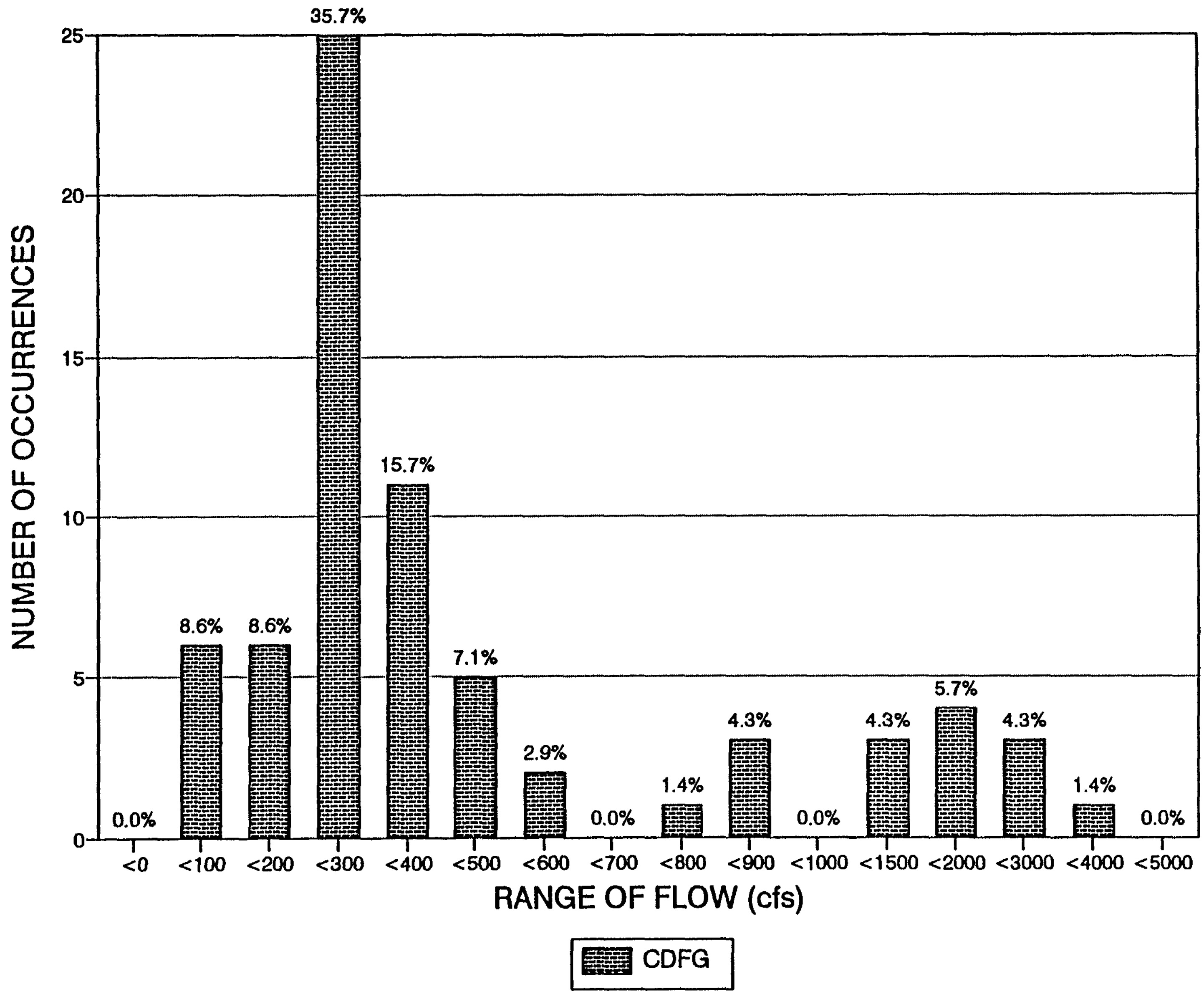


Figure 5-17. Frequency distribution of flow ranges for the period between October and March under CDFG Plan.

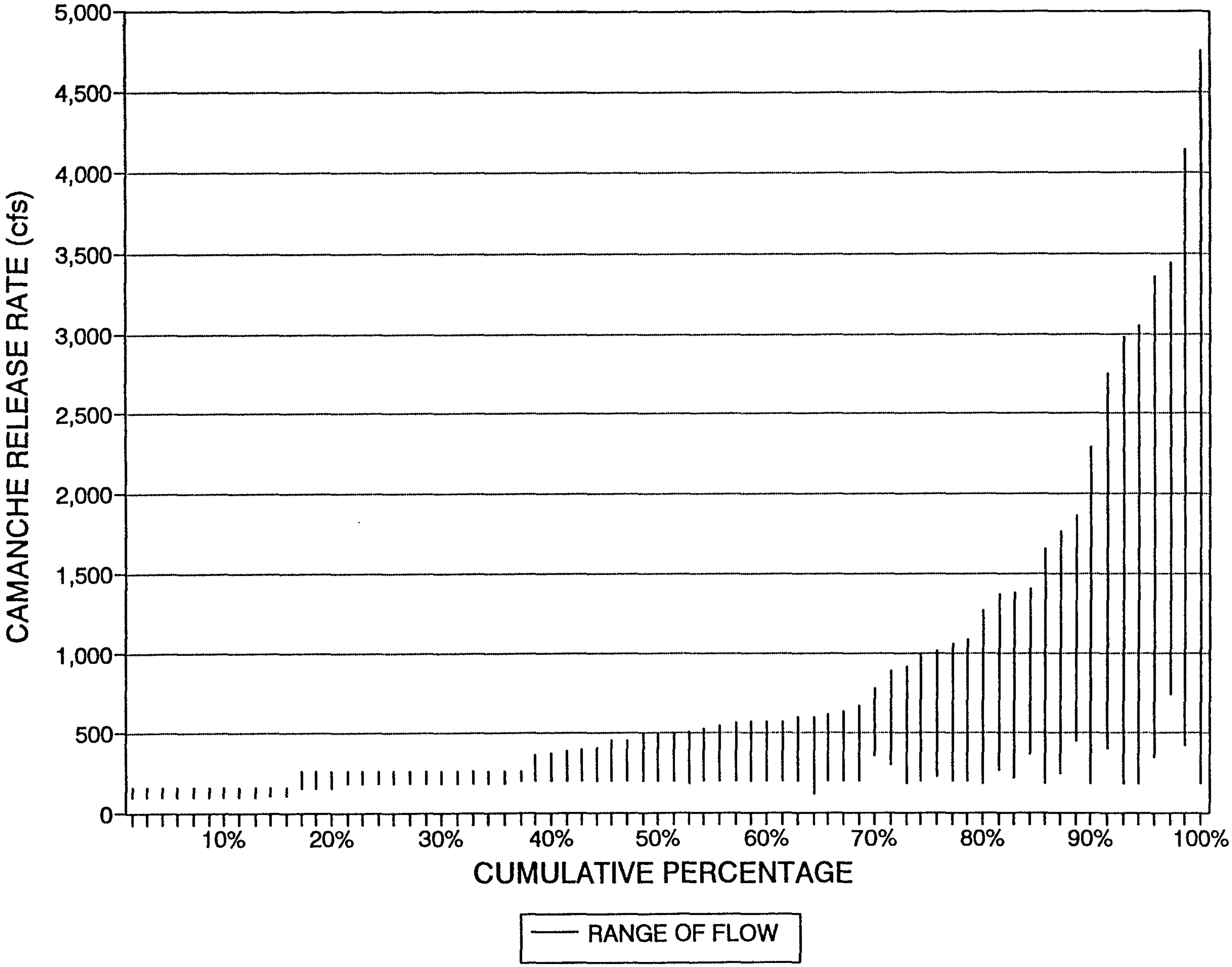


Figure 5-18. Cumulative distribution of flow ranges (Camanche release rates) for the LMRMP. Ranked in ascending order using the maximum flows.

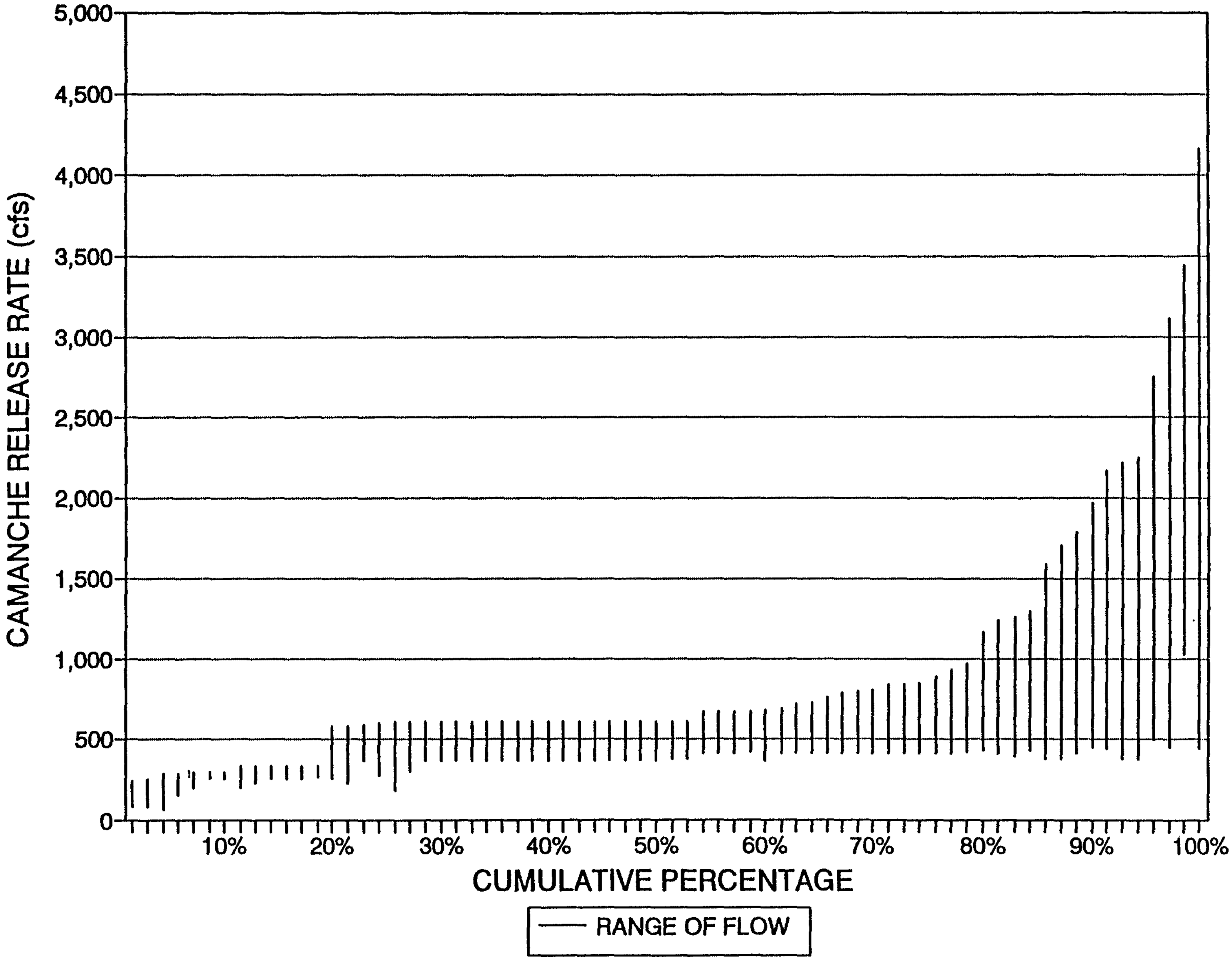


Figure 5-19. Cumulative distribution of flow ranges (Camanche release rates) for the CDFG Plan. Ranked in ascending order using the maximum flows.

C—100950

Table 5.22 Percentage of wetted perimeter for the upper section of the Camanche Reach of the Mokelumne River. (Calculations performed with IFG4 model using CDFG transect data from spillway, pasture, and fish screen sites. Wetted perimeter for 600 cfs is considered 100%.)[1]

Site	% Wetted Perimeter for simulated flow rates					
	600 cfs	500 cfs	400 cfs	300 cfs	200 cfs	100 cfs
Spillway (5 transect average)	100	99	98	96	94	89
Pasture (7 transect average)	100	99	98	96	93	86
Fish Screen (4 transect average)	100	99	97	91	80	63
Average of all three sites	100	99	98	94	89	79

[1] Calculated with IFG4 model using CDFG 's transect data.

If the flow rate at the beginning of the season (October) is below 200 cfs and is maintained throughout the year, the changes in the wetted perimeter are minimal. This flow pattern occurs 14 percent of the time (10 years) in the LMRMP, which brings down the number of years that affect redds from reduction of flows from 39 percent to 25 percent. Thus, effects to the redds arising from reduction of release rates from Camanche Reservoir when maximum flow rate is less than 600 cfs occurs less frequently under the CDFG Plan than under the LMRMP.

There are years in which the maximum Camanche release rate exceeds 600 cfs, but the range of flows for these years is not extreme enough to create drastic flow changes. There are four such years (6%) under the LMRMP and 12 such years (17%) under the CDFG Plan. The years and the flow ranges are listed in Table 5.23. During these years, flow rates do not drop below 200 cfs and more water is consistently provided than in years in which maximum flow rates are less than 600 cfs. However, three of the four years in this category in the LMRMP show greater flow reductions than any of the CDFG Plan years in this category.

During all other years, the maximum flow rate exceeds 801 cfs. There are 21 such years (30%) in each of the two studies. During these years, one of three events can occur:

1. High flow rates in February and/or March can flush alevin out of the gravel, or flush newly-emerged fry out of the river.
2. High flows in December and/or January can mobilize substrates and, subsequently, eggs.
3. High flows in October followed by substantial reduction in flows in subsequent months can cause dewatering of redds.

Table 5.24 shows the percentage of occurrence and the years in which these events occurred. No dewatering of redds (event type 3) is predicted under the LMRMP. While dewatering would occur in 7 years under the CDFG Plan, there is also a lower incidence of high flows in the period from December through March. Both plans produce negative effects from flooding on salmon production in 21 years.

Table 5.23. Years and flow ranges for the CDFG Plan and the LMRMP (all flow rates in cfs).

CDFG Plan			LMRMP		
Year	Max.Flow	Min. Flow	Year	Max. Flow	Min. Flow
1921	687	409	1936	664	200
1922	799	409	1963	632	200
1927	668	409	1967	617	200
1936	716	409	1970	777	351
1940	668	409			
1943	762	409			
1956	801	409			
1963	668	409			
1970	668	416			
1975	673	359			
1980	785	409			
1984	723	409			

Table 5.24. High flow event years for the LMRMP and the CDFG Plan.

Event Type[1]	# of Years	% of Years	Years
LMRMP			
Event 1	10	14	1927, 37, 42, 52, 57, 66, 72, 81, 82, & 85
Event 2	11	16	1940, 41, 45, 50, 51, 55, 64, 68, 69, 73, & 83
Event 3	0	0	N/A
CDFG Plan			
Event 1	6	9	1942, 51, 79, 81, 83, & 85
Event 2	8	11	1937, 41, 50, 55, 64, 69, 73, & 82
Event 3	7	10	1938, 52, 58, 65, 67, 74, & 80

[1] **Event Description:**
Event 1 High flow rates in February and/or March which can flush alevins out of gravels
Event 2 High flow rates in December and/or January which can mobilize substrates, thus, eggs
Event 3 High flow rate in October followed by substantial reduction in flows in subsequent months which can cause dewatering of redds