CENTRAL VALLEY FISH AND WILDLIFE MANAGEMENT STUDY

Fishery Management Problems at Major Central Valley Reservoirs, California

SPECIAL REPORT
August 1984

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

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THIS REPORT WAS PREPARED BY THE FISH AND WILDLIFE SERVICE FOR THE BUREAU OF RECLAMATION PURSUANT TO FEDERAL RECLAMATION LAWS (ACT OF JUNE 17, 1902, 32 STAT. 388 AND ACTS AMENDATORY THEREOF OR SUPPLEMENTARY THERETO). PUBLICATION OF THE FINDINGS AND CONCLUSIONS HEREIN SHOULD NOT BE CONSTRUED AS REPRESENTING EITHER THE APPROVAL OR DISAPPROVAL OF THE SECRETARY OF THE INTERIOR. THE PURPOSE OF THIS REPORT IS TO PROVIDE INFORMATION FOR FURTHER CONSIDERATION BY THE BUREAU OF RECLAMATION, THE SECRETARY OF THE INTERIOR, AND OTHER FEDERAL AGENCIES.

SPECIAL REPORT
August 1984

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
MID-PACIFIC REGION • SACRAMENTO, CALIFORNIA

Special Report

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ABBREVIATIONS USED

Aug.	August
°C	Centigrade
CDFG	California Department of Fish and Game
CDPR	California Department of Parks and Recreation
CDWR	California Department of Water Resources
cfs	cubic feet per second
cm	centimeter
CVF&WMS	Central Valley Fish and Wildlife Management Study
DO	Dissolved oxygen
°F	Fahrenheit
HIP	Habitat Improvement Program
lbs	pounds
LMB	largemouth bass
mg/l	milligrams per liter
MOU	Memorandum of Understanding
No.	number
NRRP	National Reservoir Research Program
Oct.	October
ORRRC	Outdoor Recreation Resource Review Commission
R^2	coefficient of determination
Rel	Released
Ret	Retained
Sept.	September
TDS	Total dissolved solids
USACE	U.S. Army Corps of Engineers
USBR	U.S. Bureau of Reclamation
USFWS	U.S. Fish and Wildlife Service
USNPS	U.S. National Park Service
WCB	Wildlife Conservation Board
YOY	Young-of-the-year
%	percent

SUMMARY

Fishery management problems limiting optimal sport fishery development in 23 Central Valley reservoirs have been appraised as a part of the Central Valley Fish and Wildlife Management Study (CVF&WMS). Attention in this study was focused on reservoirs owned by the U.S. Bureau of Reclamation, U.S. Army Corps of Engineers, and State of California Department of Water Resources.

The study identified 16 separate problem categories. All 23 reservoirs investigated had at least three identified fishery management problems, while four reservoirs had eight problems.

Of the environmental problems identified, extreme water-level fluctuation was most frequently noted as adversely affecting fish production. Because reservoirs characterized by extreme water-level fluctuations are used for purposes of flood control and irrigation water supply, the options available to fishery managers to address this problem are limited by operating constraints.

The second principal environmental problem limiting sport fish production in most of the reservoirs studied is the limited cover habitat available to fish for shelter. This problem, while related to that of water-level fluctuation, can be adequately addressed by the long-term development of habitat improvements.

Two institutional problems were identified as affecting reservoir fishery management. The first and more important problem was the lack of specific written fishery management plans for 21 of the 23 reservoirs investigated. Without fishery management plans that identified specific management goals and objectives, it was difficult to evaluate the fishery management needs of each reservoir. Therefore, the solutions to many fishery problems could only be stated in general terms. For some specific problems, clear solutions were identified.

The second institutional problem was identified as the limited amount of fishery data which was usable for management purposes. Much of the data available were fragmented and of limited aid to the fishery biologist attempting to manage reservoirs on scientific principles.

The first step in improving the management of Central Valley reservoirs for the ultimate benefit of the angling public is to develop specific written fishery management plans for each reservoir, and then to use those plans as the basis for formulating research needs as well as management programs. The development of these reservoir-specific plans should be a cooperative effort among the resource agencies responsible for reservoir management and operation. Specific solutions to fishery management problems can only be resolved within the framework of professional fishery management planning that is based on accurate biological and reservoir operational data.

PART I

INTRODUCTION

Purpose and Scope

This report presents the results of an investigation of fishery management problems at selected Central Valley reservoirs. In the Federal Water Project Recreation Act, Congress directed that ". . . full consideration shall be given to the opportunities, if any, which the project affords for outdoor recreation and for fish and wildlife enhancement. . ." However, the operation of Central Valley Reservoirs for flood control, hydroelectric power generation, irrigation, and municipal and industrial purposes often conflicts with management practices that would enhance reservoir fish populations and their availability to anglers. Historically, proponents of water resource development in California claimed that the creation of reservoir sport fisheries was a public recreational benefit. Yet for many water projects, little or no consideration was given to the needs of the reservoir fishery during project formulation. To most project proponents, reservoir fisheries were simply a bonus achieved automatically when a stream was impounded.

Many resource managers discovered that the predicted post-impoundment fisheries did not materialize as expected, or, if they did, were not of the quality desired. Such results often led to remedial fishery management actions designed to correct observed problems. The success of these corrective measures has been mixed.

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For the most part, solutions to fishery management problems have been coordinated with individual reservoir operations. While the solutions to some of these problems have been effective, other problems remain unsolvable due to reservoir operating constraints, biological limitations, factors extrinsic to the reservoirs themselves, and limited institutional means.

With these considerations in mind, this study was designed to address the issues related to successful reservoir fisheries management. The investigation of fishery management problems utilized existing available information. No new data were collected. This analysis is limited to the state and federal reservoirs of the Central Valley, identified in Figure 1. Due to time and budget constraints, those reservoirs covering less than 500 surface acres and those which are privately owned were not investigated.

The report focuses on four objectives:

1. To summarize the status of reservoir fisheries research.
2. To identify reservoir fishery management problems restricting optimum sport fishery development.
3. To evaluate options for improving the recreational fishery.
4. To determine the recreational fishery benefits resulting from improved fishery management.

While each of these objectives was considered achievable, the degree to which they were achieved varied with each reservoir, depending on the quality of the existing information base. This outcome was not detrimental

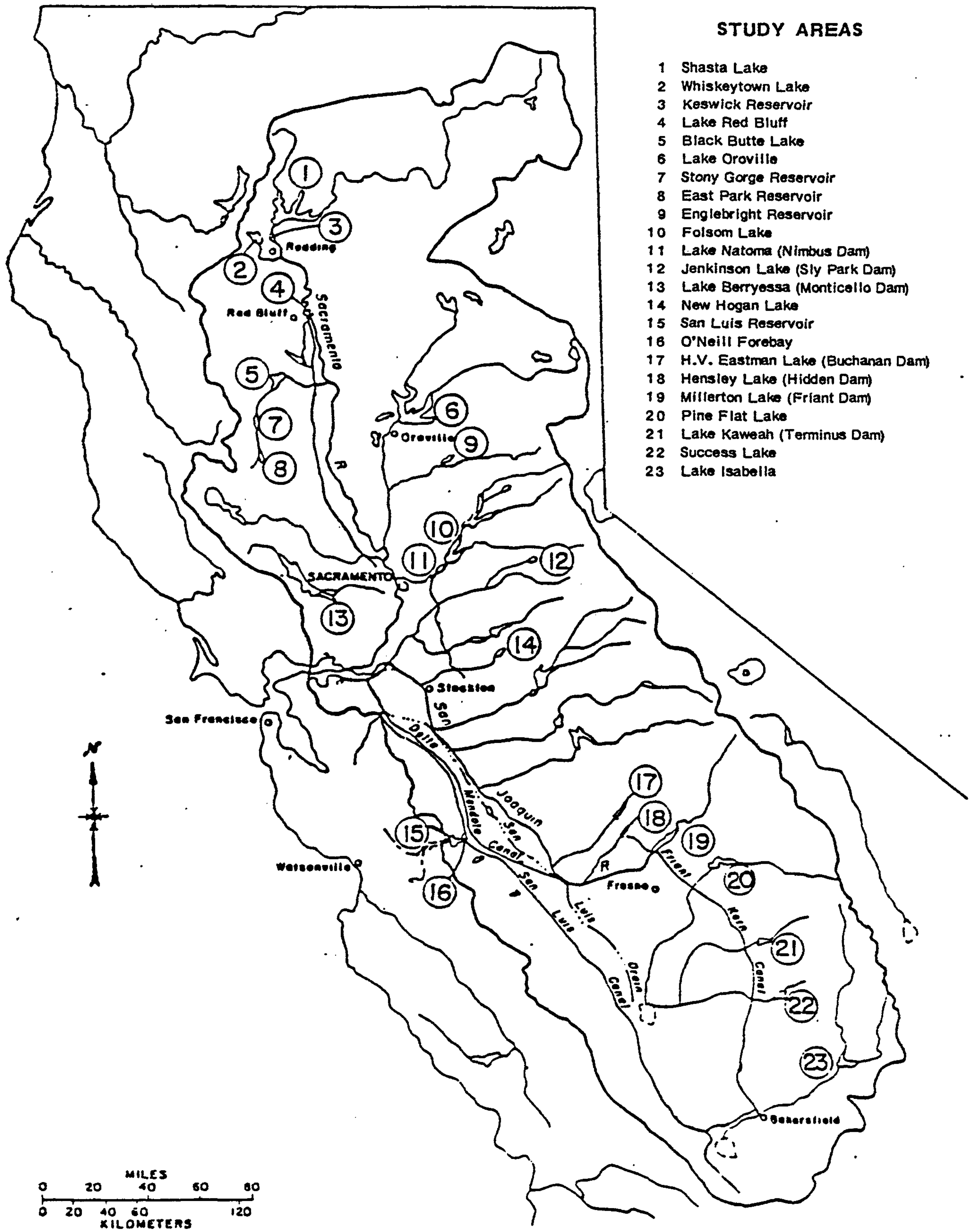


Figure 1.

LOCATION MAP

Central Valley Reservoirs

to the assessment of reservoir fishery management problems. One purpose of evaluating the fishery problems was to identify specific data needs and areas for further research and action. This investigation satisfies that purpose.

Cooperating in preparation of the report for the Bureau of Reclamation were the staffs of the California Department of Fish and Game and Bureau of Reclamation.

Relationship to CVF&WMS

This report is one of a series planned for the Central Valley Fish and Wildlife Management Study. The study area, shown on Figure 2, is the Central Valley hydrologic basin. Objectives of the overall study are as follows:

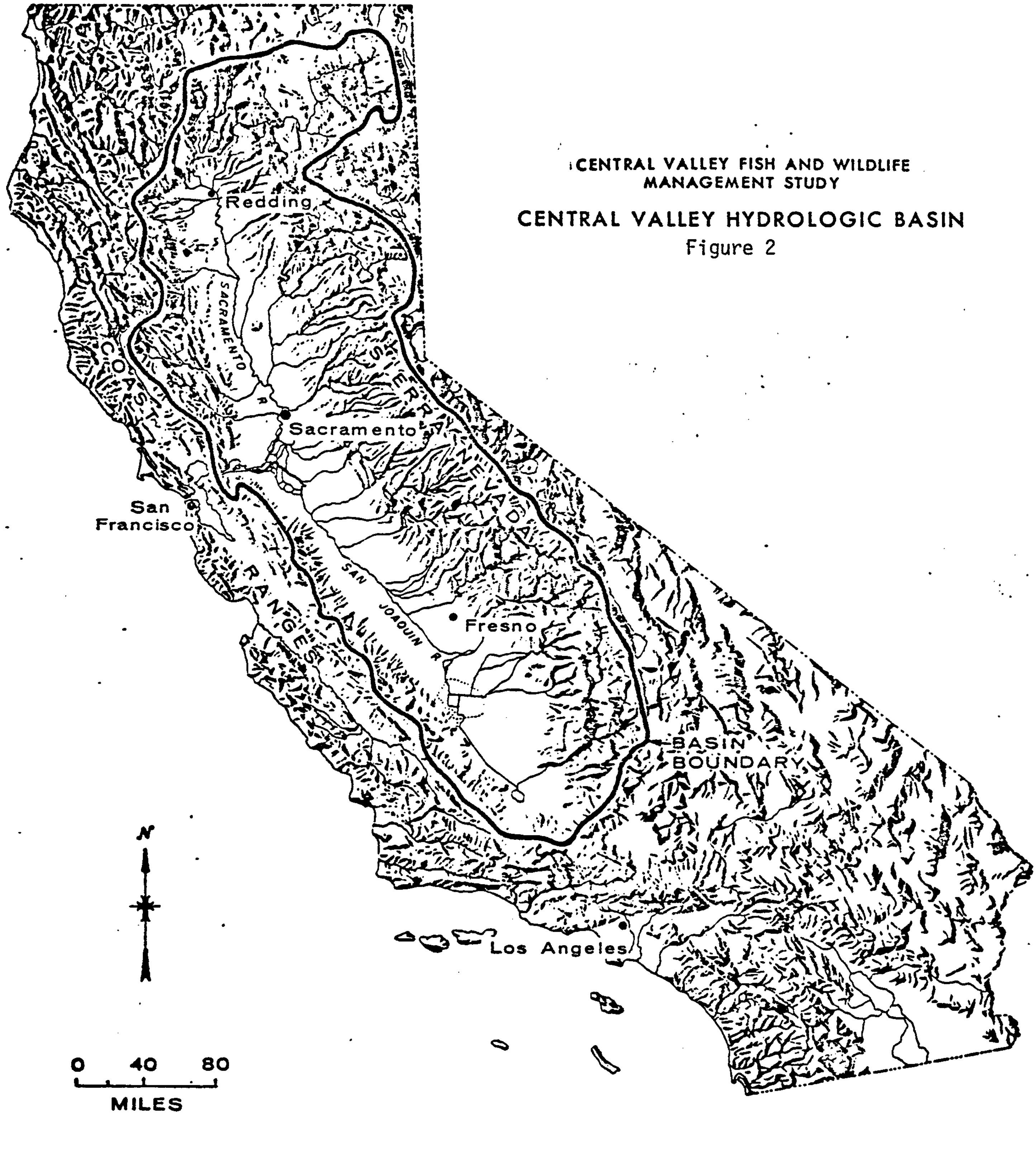
1. To identify fish and wildlife problems and opportunities associated with water resource development, distribution, and utilization in the Central Valley.

2. To provide the basis for formulating and recommending a long-range management framework within which fish and wildlife resources can be protected and enhanced.

CENTRAL VALLEY FISH AND WILDLIFE
MANAGEMENT STUDY

CENTRAL VALLEY HYDROLOGIC BASIN

Figure 2



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The CVF&WMS, initiated in fiscal year 1979, is being made to formulate a comprehensive fish and wildlife management plan for the Central Valley. This plan is essential for the resolution of some of the very complex and controversial water-related fish and wildlife issues.

Water resource development and utilization within the valley are so interrelated that localized modifications of water and land and of fish and wildlife management practices often result in corresponding impacts elsewhere in the valley. Any actions such as modernization of fish hatcheries, streamflow alterations, and modification of control structures cannot be pursued effectively without knowledge of the positive and negative impacts on beneficial uses throughout the system. The comprehensive study of existing basin-wide baseline conditions is being made so that the impacts of proposals for resolving existing fish and wildlife problems or the development of new water supplies can be evaluated adequately.

Three categories of problems and opportunities are being addressed in the CVF&WMS. They are anadromous fish, wildlife, and reservoirs and miscellaneous. This report, is identified as Problem No. C-3 in Table 1, which lists the problems for the Reservoirs and Miscellaneous category.

Basin Description

The area covered by the Central Valley Fish and Wildlife Management Study includes two major river basins, the Sacramento on the north and the

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Table 1. Reservoirs and Miscellaneous problems assigned to Plan Formulation Team C

Problem No.	Description
C-1	Formulate and evaluate alternative solutions to the heavy metal toxicity originating from Spring Creek drainage.
C-2	Evaluate the need and potential of controlling water temperatures in the Sacramento River to optimize production and diversity of salmon.
C-3	Formulate a program to optimize production of resident fish in major reservoirs in the Central Valley.
C-4	Evaluate the impacts of turbidity on fish and sport fishing in the Sacramento River and determine what measures could be taken to resolve any serious problems identified.
C-5	Evaluate the need for additional fishing access at existing major water project facilities and develop appropriate recommendations.
C-8	Evaluate the impacts of copper pollution on resident fisheries in Shasta Lake caused by runoff from Squaw and Backbone Creeks.
C-9	Evaluate the benefits and cost of increased flows in Clear Creek for fish production.

San Joaquin on the south. The combined basin is nearly 500 miles long and about 120 miles wide. It contains 38 million acres of land, or more than one-third of the area of California. Nearly one-third of the basin area is valley floor, where the bulk of the population, industry, and agriculture is located. The foothills and mountains in the remainder of the basin surrounding the valley floor receive most of the precipitation and provide the main source of the water supply for the valley. The summers are hot and usually rainless.

Most of the precipitation occurs in the winter. The water supply of the Central Valley is derived chiefly from snowmelt from the Sierra Nevada to the east, with minor amounts of runoff from the Coast Range mountains to the west, and from precipitation on the valley floor. Runoff varies widely from year to year and from season to season, being highest in the winter and spring, and lowest in the summer and fall months. Many streams in the area are intermittent, flowing only during wet periods of the year.

Water development in the basin has spanned a period of more than 120 years. Basically, it has progressed through four stages. In the first stage, local diversions were made directly from the rivers. The second stage was characterized by the widespread use of ground-water pumping adjacent to rivers. In the third stage, water was stored for use within a river basin. In all of these stages, the water facilities were constructed and operated by individuals, companies, districts, or other water service organizations.

Large-scale federal water development in the Central Valley began in 1935 with the initial phases of construction of the Central Valley Project by the Bureau of Reclamation. This inaugurated the fourth stage and marked the beginning of coordinated interbasin water development in the Central Valley. In 1961, construction began on the California State Water Project, including joint federal and state facilities. The primary source of water for the two projects is the Sacramento River Basin, although some water is derived from the San Joaquin Valley to the south, and some is imported from the Trinity River to the northwest.

The Central Valley Project is a series of storage facilities, conveyance systems, and powerplants (constructed, under construction, or proposed) to make multipurpose use of the water supplies that can be controlled by the facilities. The project reservoirs are coordinated in their operation to make maximum use of the available water supply.

PART II

STATUS OF RESERVOIR FISHERIES RESEARCH

A National Perspective

By 1980, there were 1,613 reservoirs in the United States larger than 500 surface acres in area which, at average water levels, cumulatively comprised over 10 million surface acres (USFWS 1980). This large area of water constitutes 30 percent of all inland fresh waters occurring within the 48 contiguous states.

These large reservoirs or artificial lakes, are estimated to support at least one-fourth of all freshwater fishing in the U.S.. Utilizing expenditure data published in the 1975 National Survey of Hunting and Fishing and Wildlife-Associated Recreation (U.S. Fish and Wildlife Service), reservoir fishing was found to have generated over $2.6 billion in retail expenditures by anglers for the goods and services they required to pursue the sport. Thus, large reservoirs - built principally with federal appropriations and intended primarily for other purposes - have, through multiple purpose management, become a major new resource accommodating a significant part of the demands for new fishing opportunity created by the ever-growing number of anglers.

State fish and wildlife agencies have pursued a variety of programs aimed at successful fisheries management of this vast reservoir resource. The degree to which individual states are able to focus attention on reservoir management programs is constrained more by financial limitations than by the desire to address management issues. Except for the few interstate reservoirs, state resource agencies have not joined together to pursue long-term coordinated research designed to describe conditions which optimize fish populations.

Because most multipurpose reservoirs are built with federal appropriations and impose drastic modification of pre-existing fish and wildlife habitat, there is an inherent federal responsibility to evaluate their impacts and to devise practicable methods of analysis, interpretation, and amelioration of those impacts for the broad public benefit (Fish and Wildlife Coordination Act, 16 U.S.C. 661 et seq.). Methods of amelioration include the development of recreational opportunities such as fishing, as well as mitigation for impacted fish and wildlife resources. The Bureau of Reclamation usually works with the U.S. Fish and Wildlife Service and State agencies, such as the California Department of Fish and Game, to improve the reservoir fishery habitat and management.

Reservoir construction creates significant investigative responsibilities for federal government agencies. The Fish and Wildlife Act of 1956 and the Fish and Wildlife Coordination Act of 1958 focused attention on the importance of developing methods for managing reservoirs and tailwaters so that fishery potentials could be realized. Basic research was deemed fundamental to the development of recommendations designed to protect, enhance, and mitigate negative impacts on fish and wildlife resources in water projects.

In response to evident Congressional interest, the National Reservoir Research Program (NRRP) was initiated by the U.S. Fish and Wildlife Service in 1963. Its purpose was: (1) to provide basic research necessary to describe and quantify factors influencing sport fish production in reservoirs, (2) to synthesize these findings into techniques for improving reservoir sport fish production, and (3) to communicate these findings to state and federal agencies charged with the management of reservoir fishery resources. As of March 1983 the NRRP was discontinued by the Fish and Wildlife Service. Over the 20-year period that the NRRP was operating, its scientists established an international reputation for developing the science of reservoir fishery management through innovative and comprehensive research. The contributions of the NRRP to reservoir fishery management were significant. With the program terminated, there is now no single-agency focus for national reservoir research. Further research will of necessity be conducted at the state level or, when appropriate, by federal water development agencies. The subject material addressed by the program included:

1. Reservoir and tailwater production and ecology.
2. Long-term baseline studies designed to describe fish population composition and structure in various types of reservoirs.
3. Influences of reservoir operational procedures on fish populations.
4. Improvement of sampling and analytical methods.
5. Collection, collation, and analysis of biological information gathered by state fisheries agencies.
6. Evaluation of fish standing crop and harvest based on physiochemical and biological information.

7. Thermal impacts on reservoir fish populations.

8. Physical and ecological simulation modeling of reservoirs and fish populations.

9. Evaluation of research and management practices.

10. Predator-prey relationships.

11. Pumped-storage and hydro-peaking impacts.

12. Habitat evaluation procedures for reservoirs.

Trends in Reservoir Fishing

The history of development of large reservoirs greater than 500 surface acres in area over the past 20 years is presented in Table 2 (USFWS 1980).

Table 2. Reservoir development in the United States for reservoirs averaging greater than 500 surface acres in area1/

Year	Number of reservoirs	Surface area (acres)	Mean annual increase (acres)
1960	1,006	6,450,000	------
1970	1,320	8,844,000	240,000
1976	1,493	9,774,000	155,000
1980	1,613	10,105,000	83,000

1/ USFWS 1980

According to the Outdoor Recreation Resource Review Commission (ORRRC), about 9 million acres of new reservoirs greater in surface area than 500 acres and a doubling of fish harvest per acre would be required between the years 1960 and 2000 to meet angler demands (USFWS 1962). This would require an increase in area from 6.5 million acres in 1960 to about 15.5 million acres at the turn of the century. Projection of the trend in reservoir construction during the past decade (Figure 3) suggests that reservoir area will total about 11.4 million acres in 2000, 4 million acres short of the area required to meet predicted angling needs.

In addition, available data indicate no significant increase in the national average (area-weighted) angler harvest of 15 pounds per acre since 1960 (USFWS 1980). Although many gains in harvest have been attributed to management efforts, these have been offset by the decrease in the construction of large, new reservoirs which afford superb fishing during the early years of impoundment. Although the number of reservoirs has increased steadily since 1960 (Figure 4) and about 600 reservoirs will be added in the next 20 years, the new reservoirs will average only approximately 2,000 acres, which is much smaller than the average size of reservoirs built previously.

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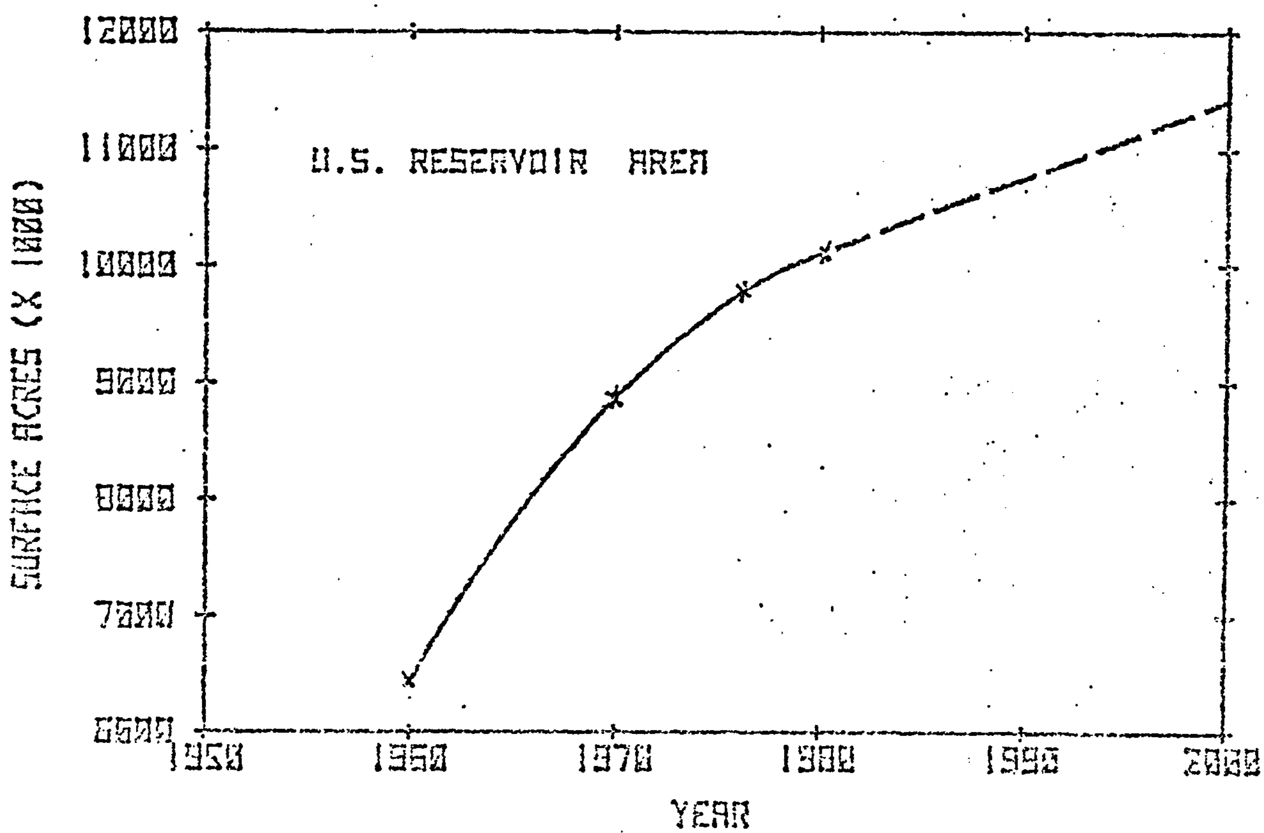

Figure 3. Twenty-year trend in total reservoir area, with a projection to the year 2000 based on the 1976-79 rate of increase (USFWS 1980).

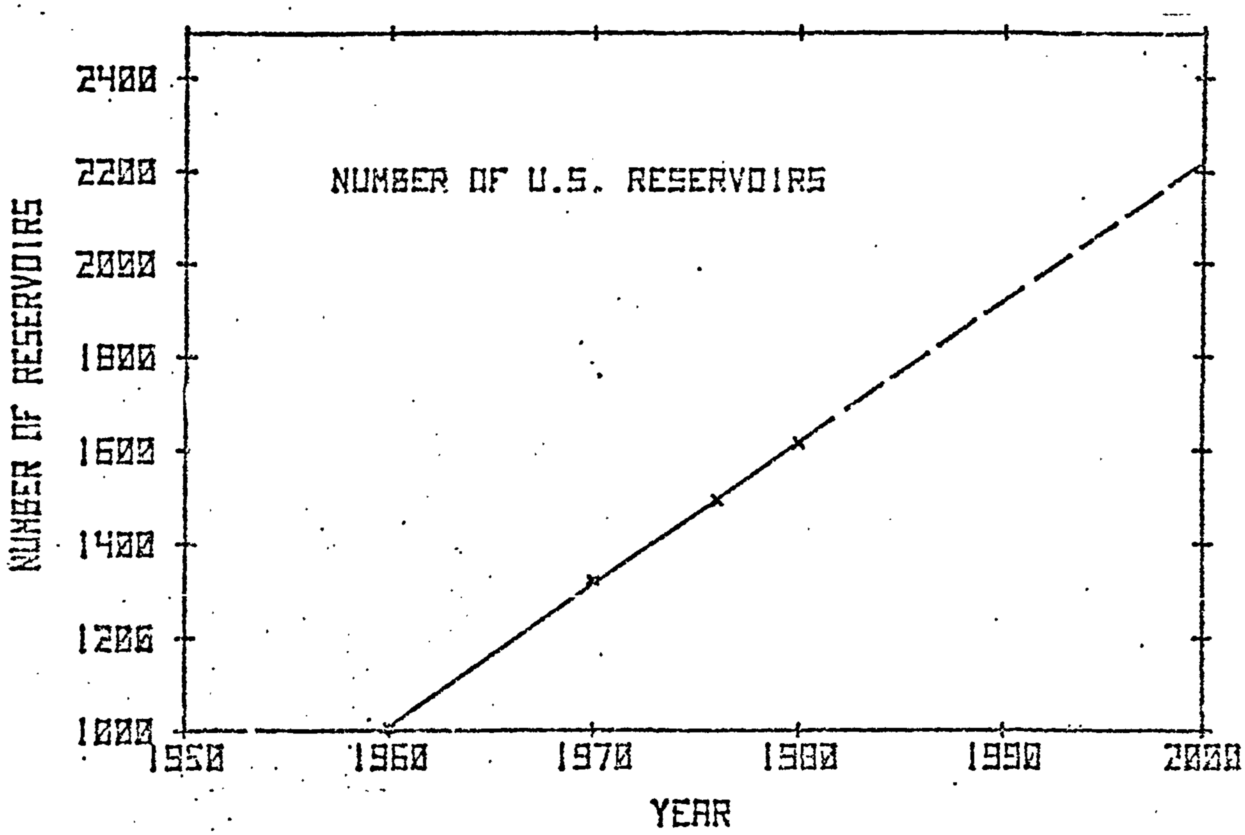

Figure 4. Twenty-year trend in number of U.S. reservoirs, with a projection to the year 2000 based on the 1960-79 rate of increase (USFWS 1980).

The NRRP's 1980 estimate of fishing pressure on reservoirs is 200 million angler-days. The ORRRC predicted a demand of about 400 million angler-days in the year 2000. If the total reservoir area is going to increase only 10 percent in that time, doubling current angler harvest rate will be a challenge for fishery managers and researchers. Accelerated efforts to improve current techniques are urgently needed.

Reservoir Research in California

California ranks second in the nation in the total number of reservoirs having greater than 500 acres average surface area. In total area of large reservoirs, California ranks tenth (Table 3). The 23 Central Valley reservoirs selected for investigation in this report collectively total 109,700 acres at average surface area. Thus, this report will address fishery problems at reservoirs comprising about 30 percent of the total reservoir area of California.

Widespread construction of reservoirs in California has resulted in greatly increased game fish production. However, angling in these reservoirs is generally not outstanding. Most reservoirs are relatively artificial ecosystems which rarely meet all the needs of all the fish species present. Consequently, large, self-sustaining game fish populations are uncommon.

Table 3. Number and area of reservoirs in the 50 states greater than 500 acres at average surface area 1/

Ranked by total area at mean annual pool levels. Interstate reservoir areas are apportioned to the respective states.

Rank	State	Number of Reservoirs	Total area in acres
1	Texas	197	1,576,600
2	Oklahoma	67	557,300
3	North Dakota	17	522,400
4	Tennessee	32	486,100
5	Alabama	41	457,600
6	South Dakota	15	453,800
7	Montana	48	429,200
8	Washington	46	394,800
9	Arkansas	69	364,900
10	California	146	362,200
11	South Carolina	17	362,500
12	Georgia	29	281,700
13	Missouri	31	261,100
14	Idaho	42	247,800
15	Louisiana	34	244,900
16	Utah	19	219,600
17	Wisconsin	85	211,500
18	Oregon	53	203,700
19	Kentucky	19	201,800
20	Maine	21	179,700
21	North Carolina	38	170,400
22	Kansas	28	154,300
23	Wyoming	30	135,800
24	Mississippi	15	131,000
25	Illinois	41	129,900
26	New York	49	129,400
27	Arizona	22	128,200
28	Virginia	23	112,200
29	Colorado	74	108,300
30	Nevada	10	107,500
31	Ohio	44	97,000
32	Pennsylvania	43	87,600
33	Michigan	42	83,500
34	Nebraska	20	83,100
35	New Mexico	17	66,800
36	Minnesota	12	62,300
37	Indiana	24	57,100
38	Iowa	9	51,300
39	Florida	7	39,200
40	Massachusetts	5	31,900
41	New Hampshire	18	30,000
42	Connecticut	13	17,300
43	Maryland	8	16,100
44	West Virginia	11	14,700
45	New Jersey	11	13,800
46	Vermont	9	7,600
47	Alaska	2	4,100
48	Rhode Island	2	4,100
49	Delaware	0	0
50	Hawaii	0	0
		1,655	10,104,900
		-42 Interstate duplications	
		1,613	

1/ USFWS 1980

The California Department of Fish and Game estimated in 1958 that increasing the yield of game fish from all California reservoirs by 5 pounds per acre would add about 2,750,000 pounds of fish annually to the sport fish catch (CDFG 1958). That report recommended experimental management studies on representative reservoirs to discover ways to increase game fish production. The Department initiated these studies soon thereafter primarily using Federal Aid to Fish Restoration Funds (better known as D-J, or Dingell-Johnson funds). Much of the research undertaken by the Department of Fish and Game over the intervening years has been supported by D-J funds. The approach followed by the Department has been to use basic research on the dynamics of reservoir ecosystems whenever possible and, when necessary, test experimental management practices (CDFG 1971).

The Department of Fish and Game has focused its research efforts on three distinctively different types of reservoirs: those supporting coldwater fisheries only, those supporting warmwater fisheries only, and those supporting both cold and warmwater fisheries. The fishery management issues associated with each reservoir type vary widely. Among the important research subjects pursued by the Department from 1958 to 1983 have been investigations assessing:

1. Control of nongame fishes that compete with game fishes.
2. Mortality and survival studies of various fish species or strains of species.

3. Impacts of new introductions of sport and forage fishes.
4. Life histories of various reservoir fish species.
5. Habitat manipulation as a method for improving reservoir fish productivity.
6. Fish stocking as a management tool.
7. Impacts of restrictive harvest regulations on fish survival and production.
8. Analysis of angler harvest data.

Research results have been applied to field operations as they became available, and have been documented in various technical reports and scientific journals.

The development of knowledge about reservoir fisheries management is a continuing process. Many experimental studies are long-term in nature. Often biological systems must be evaluated for many years if meaningful data are to be acquired. Thus, resource agencies must pursue institutional mechanisms that allow for such long-term commitments of agency resources. The Department of Fish and Game has met with mixed success in pursuing long-term commitments to reservoir research. All other resource agencies have faced similar problems in developing long-term programs. In this time of significantly reduced agency budgets, the California Department of Fish and Game has continued to allocate funds to selective reservoir research projects. Federal agency assistance and Dingell-Johnson funds have aided these research efforts.

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PART III

ANALYSIS OF CENTRAL VALLEY RESERVOIR PROBLEMS

Introduction

Twenty-three Central Valley reservoirs were investigated to identify specific problems faced by fishery managers in their efforts to improve reservoir fish populations for the angling public. This part of the report identifies and defines each of the 16 problem categories that were evaluated, based on the results of the individual reservoir investigations. These problem categories and the individual reservoirs to which each problem is applicable, are presented in Table 4. The problems are listed in natural groupings (i.e., institutional problems, harvest related problems, habitat related problems) and not necessarily by priority.

Specific fishery management problems of each reservoir and potential solutions to each problem were identified. Because most identified problems are common to several reservoirs the management solutions are also similar. Solutions to the problems are discussed in detail in Part IV.

Table 4. Comparison of fishery management problems at 23 selected Central Valley reservoirs

Reservoir Name	Identified Problem Categories																No. Problems Identified Per Reservoir
	No Fishery Management Plan	Limited Fisheries Data	Water Level Fluctua-tion	Excessive Harvest	Under-harvest	Limited Cover Habitat	Limited Spawning Habitat	Limited Littoral Habitat	Low Water Fertility	Water Quality Problems	Limited Fishery	Forage Fish Related Problems	Undesirable Species	Shoreline Erosion	Multiple Use Conflict	Angler Access	
Black Butte Lake	x	x	x		x	x					x		x	x			8
East Park Reservoir	x	x	x			x							x	x	x		7
Englebright Reservoir	x	x				x			x			x				x	6
Folsom Lake	x	x	x	x	x	x	x		x								8
H. V. Eastman Lake	x	x	x	x													4
Hensley Lake	x	x								x	x						4
Jenkinson Lake	x	x				x				x				x	x		6
Keswick Reservoir	x	x								x							3
Lake Berryessa			x			x									x		3
Lake Isabella		x	x			x	x						x	x			6
Lake Kaweah	x	x	x			x							x	x	x		7
Lake Natoma	x	x	x					x	x							x	6
Lake Oroville	x	x	x			x		x			x	x					7
Lake Red Bluff	x	x															2
Millerton Lake	x		x	x		x											5
New Hogan Lake	x	x	x		x	x				x							6
O'Neill Forebay	x	x	x		x											x	5
Pine Flat Lake	x	x	x		x	x			x					x	x		8
San Luis Reservoir	x	x	x			x					x						5
Shasta Lake	x		x	x		x				x	x	x	x				8
Stony Gorge Reservoir	x	x	x			x							x	x	x		7
Success Lake	x	x	x	x		x				x	x						7
Whiskeytown Lake	x	x							x			x	x				5
No. reservoirs with identified problem	21	20	17	5	5	16	2	2	5	6	6	4	7	7	6	3	

Identified Problem Categories

1. Absence of a Management Plan

Management plans are tools used to guide the fishery manager so that tasks are performed effectively and efficiently. Of the 23 reservoirs reviewed in this study only two reservoirs had a detailed written fishery management plan (Table 4). This circumstance was unfortunate because it made problem identification difficult. The team could not always determine if identified problems were, in fact, problems in relation to a specific management objective. For example, lack of fish cover habitat was often identified as a major reservoir fishery management problem. This is a correct identification if the reservoir lacks sufficient cover and the management objective is increased survival of juvenile largemouth bass. It is an incorrect problem identification if the management objective is only to maintain a put-and-take catchable trout program. For those reservoirs without specific fishery mangement plans, the investigators relied heavily on knowledgable fishery biologists from the California Department of Fish and Game for the identification of specific management problems.

Most reservoirs would benefit greatly from a written management plan. A few reservoirs which are severely restricted by operational constraints would benefit less from a formalized plan but the management policy of these reservoirs should still be clearly stated in a written document.

Specific written reservoir fishery management plans should result in:

a. Clear management goals and objectives.

b. Efficient use of available resources (i.e., time, materials, and funding).

c. Implementation of justified fishery management practices.

d. Identification and implementation of appropriate research or monitoring programs necessary to effectively manage the resources of concern.

e. Continuity in management programs.

f. Effective communication with decision makers and other fishery managers with similar management goals.

2. Limited Fisheries Data

Of the 23 Central Valley reservoirs investigated, 20 had historical fisheries data limitations which restricted the evaluation of fisheries management problems (Table 4). This statement does not imply that the knowledge of the individual reservoir fisheries is marginal in all respects or that research should be given highest priority in all 20 reservoirs. The quantity and quality of information needed by a fishery manager will vary depending on the specific problem that is being addressed or the management objective that is

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being pursued. Some of the reservoirs have been heavily studied. However, for the 20 reservoirs, one or more of the following data limitations applied:

a. Identified fishery management problems could not be assessed adequately with existing fisheries data.

b. Available information was out of date.

c. No monitoring programs were implemented to follow-up on applied management practices, thus information on the success of specific applications is unknown or speculative.

d. Fisheries data known to have been collected were lost or were not locatable.

e. Data quality was marginal to poor, and consequently, of little value in management evaluations.

f. Data was scattered in various locations and often in a format that limited its usefulness in problem assessment.

For most of the reservoirs with limited fisheries data, the type of data that were available were a potpourri of miscellaneous bits of information with little coherence. Lack of continuity in the subject, quality, and timing of data collected for some reservoirs suggested a lack of management goals and objectives which seems to have led to a more-or-less random system of data collection without a clear focus.

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When data were incomplete or lacking, professional judgement on the part of the biologists assessing each reservoir, rather than factual evidence, was required to address management problems.

3. Water-Level Fluctuation

Extreme water-level fluctuation in reservoirs is perhaps the most significant environmental factor influencing reservoir fish population productivity. The direct and indirect effects of fluctuating water levels are responsible to a large degree for other fishery management problems, e.g., limited cover habitat, limited littoral habitat, and shoreline erosion. Seventeen of the 23 Central Valley reservoirs investigated faced fishery management problems directly related to water-level fluctuation (Table 4).

In the Central Valley of California, rainfall is highly seasonal, with about 90 percent falling between the months from November to April (Brouha and von Geldern 1978). Water project reservoirs in the Central Valley operate to store water during the winter and spring months with subsequent releases in the summer and fall. This pattern of storage and withdrawal results in variable seasonal availability of water in reservoirs. Surface water fluctuations in some Central Valley reservoirs may exceed 100 feet annually.

The major constraints on limiting reservoir pool fluctuations are the resulting losses of operating flexibility for water supply, irrigation, power production, and flood control (Nelson et al. 1978). These constraints impose a serious limitation on the types of management options available to the fishery manager.

Much has been written about the biological impacts of fluctuating water levels in reservoirs (Ploskey 1982, 1983). The purpose of this report is not to review this literature. However, a summary of key impacts resulting from water level fluctuations is provided, followed in Part IV by a discussion of fishery management options designed to address this problem.

Water-level fluctuation can affect reservoir productivity directly in a number of ways. Physical, chemical, and biological parameters are all affected by water-level changes which, in turn, either directly or indirectly impact fish populations. The following is a summary of the most significant impacts to reservoir productivity related to water-level fluctuation as compiled by Haase (1978):

a. Changes in surface area.
   Most primary production occurs near the surface. A greater surface area will yield higher total primary production.

b. Changes in mean depth.
   Depth may influence the degree of stratification, and consequently temperature, oxygen, and total dissolved solids profiles. Additionally, the extent of littoral areas may be

altered. Littoral areas are more biologically productive than the limnetic zone of the reservoir.

c. Changes in reservoir volume.

In some reservoirs, greater volume results in greater species diversity as well as greater total biomass and abundance of plankton and fish.

d. Changes in storage ratio (flushing rate).

A high flushing rate may continually draw plankton and fish out of the reservoir, resulting in lower total productivity (e.g., review Lake Natoma and Lake Red Bluff reports).

e. Changes in shoreline development.

Shoreline development is a measure of how much littoral area is available. The greater the shoreline development is, the higher the total littoral production is likely to be. Shoreline characteristics may affect temperature and reservoir water currents.

f. Change in outlet depth.

Epilimnial outlets tend to draw off the most productive layer of water in the reservoir. Hypolimnial outlets may break down temperature stratification and effect mineral and dissolved gas distributions.

g. Magnitude of water-level fluctuation.

The degree of depth change directly impacts the quantity of littoral area exposed. The greater the magnitude of fluctuation the greater the reservoir physical and chemical changes which organisms are subjected to.

h. Rate of drawdown.

Benthic organisms, macrophytes, and fishes may be able to adjust to a slow, gradual drawdown, but not to a sudden, rapid decline in water levels.

i. Timing of drawdown.

The timing of drawdown may affect reproductive success of littoral spawning fishes by impacting their physical and chemical environment as well as influencing reproductive behavior (e.g., guarding of nests). The presence of habitat suitable for reproduction may be affected. Plants providing shoreline cover habitat for fishes may be either enhanced or depleated depending on drawdown timing. Finally, reservoir turnover may depend on pool levels during turnover seasons. The timing of reservoir drawdown has been a key concern of fishery biologists managing Central Valley reservoirs.

j. Annual changes in fluctuation pattern.

Long-range or annual changes in water-level fluctuation may be reflected in changes in reservoir flora and fauna composition.

Random fluctuations in water-level over time may inhibit stabilization of the fish community of the reservoir.

k. Changes in temperature stratification.

Fluctuating water levels may affect temperature stratification which, in turn, may influence the extent of water mixing, oxygen content of epilimnion and hypolimnion, and distribution of incoming nutrients. The temperature regime will affect biological production in the reservoir as well as the distribution of plankton and fish.

l. Changes in dissolved oxygen content.

Low reservoir volumes due to water level fluctuations coupled with high water temperatures and/or organic decay of benthic materials may produce anoxic conditions lethal to fishes. Low hypolimnial oxygen levels due to limited mixing may restrict fish and plankton distribution to the epilimnion.

The physical and chemical changes brought about by water-level fluctuations impact reservoir populations of bacteria, phytoplankton, zooplankton, macrophytes, and fishes by influencing biomass, production, species composition, distribution, and yield. No single component of the reservoir aquatic ecosystem can be changed without resultant impacts to other ecosystem components (Johnson 1981; Leidy and Jenkins 1977; Leidy and Ploskey 1980; Lorenzen et al. 1981). Fishery managers over

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the years have always assumed that management measures that are good for fish will also be good for the balance of the reservoir biota as well. Further research will be required to determine if this assumption is valid.

The principal concerns of fishery biologists managing Central Valley reservoirs with water-level fluctuation problems are:

(1) Adverse impacts to spawning sport fishes.

(2) Reductions in cover habitat for fishes.

(3) Maintenance of minimum reservoir pools.

Adverse impacts to spawning sport fishes, usually centrarchids such as the largemouth bass, occur when water levels increase or decrease in littoral spawning areas during the spawning, incubation, or rearing periods (Mitchell 1982). Water-level fluctuations at spawning sites alter the physical and chemical characteristics of these areas. The results may range from nest abandonment by spawning or brooding adult fish to direct mortality of eggs or fry.

Declining water levels often eliminate desirable littoral habitat that provides structural cover for juvenile fishes (e.g., riparian and rooted aquatic vegetation and rocks). Fish forced out of these protected areas may suffer higher mortality rates from increased predation by larger fish.

Three Central Valley reservoirs - Black Butte Lake, East Park Reservoir, and Stony Gorge Reservoir - have no guaranteed minimum pools for the maintenance of fishes during low water periods. In cases of drought or extreme water-level fluctuations, these reservoirs may be completely drained, thereby eliminating the fish populations.

4. Excessive Harvest

Excessive harvest means the overharvesting by anglers of certain species or sizes of fish, resulting in adverse impacts to the fish population. In the long-run, excessive angler harvest acts to restrict the availability of fish to the angler. Five of the 23 Central Valley reservoirs investigated had identified excessive fish harvest problems (Table 4). All five of these reservoirs reported overharvesting of black basses (largemouth and smallmouth bass).

Excessive harvest of bass results in a smaller average size of bass as the largest fish are removed from the population. The larger fish are mature adults that comprise much of the reproductive potential of the population. Removing these fish may reduce bass reproduction significantly. It has also been suggested that such overharvest results in a shift in the population to smaller though mature fish. The fishery becomes dominated by the progeny of small largemouth bass rather than by the progeny of large, early spawning, fast growing largemouth bass. This may have genetic effects induced by strong selection for slow growth.

In one reservoir, Shasta Lake, overharvest of hatchery-reared rainbow trout was reported. Hatchery-reared rainbow trout are planted as part of the trophy trout program at the reservoir. Creel surveys revealed that many of these fish were being caught by anglers immediately, before the trout had the opportunity to contribute to the trophy fishery. This has hampered the success of the trophy trout program, and reduced the quality of angling in the fall, winter, and early spring months.

5. Underharvest

Five of the 23 Central Valley reservoirs investigated reported that anglers were underharvesting catfish populations (Table 4). Catfishes were the only group of sport fishes that were not utilized by anglers to the degree that they could be. Two reasons have been identified for the limited angler interest in fishing for catfishes. These reasons are (a) lack of angler access to the catfish resource, and (b) lack of knowledge by anglers about how to fish for catfishes.

6. Limited Cover Habitat

The lack of adequate quantity or quality of cover habitat in California's Central Valley reservoirs is a significant factor limiting production of warmwater fishery resources. Sixteen of the 23 reservoirs investigated had serious cover habitat problems (Table 4). Fishery managers reported in all cases that the lack of cover restricted development of centrarchid fish populations (black basses, sunfishes, and crappies). Cover provides shelter for these fishes for spawning and rearing. Cover habitat is also related to improved food availablility.

Cover for fish may take many forms but, as a rule, reservoir cover implies structural relief which fish can use for various purposes (e.g., shelter and feeding). During the construction of many of the Central Valley reservoirs that were investigated, trees and brush, were cleared from all or most of the reservoir basin. In clearing vegetation, critical cover habitat was removed. Thus, in many of these reservoirs, the only cover remaining was rocks and boulders. This limited type of cover, coupled with extreme water level fluctuation has severely limited the productivity of reservoir fish populations dependent on cover.

The lack of established rooted aquatic vegetation is another problem common to Central Valley reservoirs. A variety of factors, including fluctuating water levels, shoreline erosion, and cattle grazing, all prevent vegetation from becoming established. Studies have shown that a positive correlation exists between flooded vegetation during the spring spawning period and highly successful reproduction. Sheltered areas during the spring and summer drawdown are essential for providing escape cover for juvenile fish.

The problem presently facing fishery biologists responsible for managing centrarchid fish populations in Central Valley reservoirs is how to restore cover habitat with techniques that are efficient in the utilization of manpower and money, effective in meeting management objectives, and which work properly over a long time-horizon. This is not simple task. Remedial fish habitat restoration measures for an entire reservoir are resource intensive.

Because most of the Central Valley reservoirs are large in size, comprehensive habitat improvements, if implemented, may take many years, even decades, to complete.

7. Limited Spawning Habitat

Limited spawning habitat has been identified as a fishery management problem at two Central Valley reservoirs (Table 4). Water fluctuations during the centrarchid spawning period at both Lake Isabella and Folsom Lake significantly reduce recruitment of young largemouth bass at these two Central Valley reservoirs. Centrarchid spawning habitat in reservoirs is known to be degraded by sedimentation resulting from shoreline erosion and from exposure and desiccation due to fluctuating water levels. Reductions in the quantity and quality of spawning habitat will result in poor reproductive success and small year classes of fish. Spawning habitat for largemouth bass and survival of juveniles is poor in both Lake Isabella and Folsom Lake because of the interaction of several complex factors. A review of these problems as they relate to fisheries management in Central Valley reservoirs is presented in discussions of water-level fluctuations, shoreline erosion, and limited cover habitat elsewhere in this section.

8. Limited Littoral Habitat

The quality and amount of littoral habitat available to fishes has been identified as a fishery management problem at two Central Valley reservoirs (Table 4). Littoral habitat as defined in this analysis is that portion of a reservoir extending from the shoreline lakeward to the limit of occurrence of rooted plants. In the shallower coves of many Central Valley reservoirs this zone extends well across the basin, especially during the spring and summer growing season. However, in deeper reservoirs well-developed littoral habitat may be limited in area or virtually nonexistent. Factors limiting plant growth which directly influence the development of littoral habitat include water depth, vertical extent of effective light transmission (affected by turbidity), movement of water (particularly wave action), nutrient supply, texture of the substrate, and fluctuations in water level (Reid 1961).

Extensive and well developed littoral habitats are a critical factor in determining the primary and secondary productivity in all Central Valley reservoirs. It is within this zone that the greatest variety of fish species are found, largely as the result of greater plant and animal productivity which is available to fishes as food. In general, reservoirs with large areas of littoral habitat have higher fish productivity than reservoirs with small areas of littoral habitat.

In two Central Valley reservoirs, Lake Natoma and Lake Oroville, decreased productivity of several important game fishes has been attributed in part to limited available littoral habitat. In Lake Natoma the development of littoral habitat has been limited by low water fertility (total dissolved solids = 41 mg/l), a fast flushing rate (hydraulic retention time is about 2 days) limited shallow-water habitat, and large daily water-level fluctuations (Table 10). Fluctuating water-levels are known to reduce the establishment of shoreline aquatic vegetation, and Central Valley reservoirs subject to such fluctuations generally exhibit poorly developed littoral habitat which is of limited value to fish populations.

The large size and great depth of Lake Oroville presents problems unique to this reservoir. It has a mean depth of 213 feet, indicating that extensive areas of productive littoral zone do not exist. As in the case with Lake Natoma, the development of littoral habitat in Lake Oroville is also limited by low fertility (total dissolved solids = 52 mg/l). In addition, extensive development of littoral habitat in the few existing shallow, inshore areas in Lake Oroville is not possible because of seasonal surface water-level fluctuations. Water-level fluctuations (averaging 75 feet/year) have had a particularly negative effect on centrarchid production, with fall drawdown reducing the already limited littoral habitat preferred by these fishes. Finally, wave action generated by boat wakes and wind reduces the establishment of aquatic vegetation in shallow inshore littoral habitats.

The development of littoral habitat in reservoirs is dependent on, and related to, a number of physical and chemical factors that change within and between reservoirs. There will be further discussion of these factors as they relate to fishery management in several of the other problem categories in this part of the report.

9. Low Water Fertility

Five of the 23 Central Valley reservoirs investigated were found to have low water fertility, which was indirectly related to limited fish

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production (Table 4). Water fertility is defined to mean the combination of dissolved and particulate inorganic and organic material in the water that is required by aquatic organisms to reproduce and grow. Water fertility is a function of the geochemical nature of the watershed plus the impacts of human related activities such as land use which may increase fertility over what would be found under natural conditions. There is no single measure of water fertility. We have used the measurement of total dissolved solids (TDS) as an index to overall water fertility. The total concentration of dissolved substances or minerals in natural waters reflects edaphic relationships that contribute to productivity within a body of water (Reid 1961).

The quantity and quality of dissolved solids often determine the variety and abundance of plants and animals in a given aquatic environment. Many researchers have related total dissolved solids concentrations to productivity of many aquatic organisms, particularly algae, but also to fish (Benson 1973; Jenkins 1970; Jenkins and Morais 1971; Rawson 1958). The NRRP of the USFWS has developed a series of multiple regression formulas for estimating fish standing crop based on the concentration of total dissolved solids of reservoir water (USFWS 1977). The regression formula for hydropower storage reservoirs (e.g., Shasta Lake, Lake Oroville, Whiskeytown Lake) has a coefficient of determination (R^2) of 0.81, suggesting high predictability.

Table 10 (contained in Part IV) of this report lists the mean TDS concentration of the Central Valley reservoirs investigated. TDS values less than 100 mg/l are generally considered indicative of low productivity and occurred at ten of the reservoirs. Fishery managers at five of the ten reservoirs identified low fertility as a problem (Table 4). Low fertility was not identified as a problem limiting fish productivity in the other five reservoirs apparently due to other limiting factors.

10. Water Quality Problems

Water quality problems affecting fish production occurred at six of the 23 Central Valley reservoirs investigated (Table 4). Table 5 lists these water quality problems by reservoir for comparison.

Low dissolved oxygen levels during the summer months at Hensley Lake, New Hogan Lake, and Success Lake adversely impact the fish population, particularly salmonids. Directly linked with low dissolved oxygen problems is production of hydrogen sulfide gas. This gas is a byproduct of the decomposition of decaying vegetation on the reservoir bottom. The decomposition process consumes oxygen and produces hydrogen sulfide which is highly toxic to fish.

Under anaerobic conditions, as in the hypolimnion in the summer, both iron and manganese are soluble in water. In Jenkinson Lake, iron and manganese content is a water quality problem only to the extent that lake water is used as a domestic water source. Iron and manganese when, in solution, often give an unacceptable taste to the drinking water but will not harm fish. However, these elements in solution are indicative of anaerobic conditions. Low dissolved oxygen may be an as yet unidentified problem in Jenkinson Lake during the periods of spring and fall turnover each year. Further review of this potential problem may be necessary.

Table 5. Comparison of water quality problems at six Central Valley reservoirs[1/]

Reservoir Name	Water Temperature Too High	Water Temperature Too Low	Dissolved Oxygen	Hydrogen Sulfide	Iron and Manganese	Heavy Metal Pollution
Hensley Lake			X	X		
Jenkinson Lake					X	
Keswick Reservoir		X				X
New Hogan Lake	X		X			
Shasta Lake						X
Success Lake	X		X	X		

1/ California Department of Fish and Game files

High water temperatures during the summer months at New Hogan Lake and Success Lake limit development of the salmonid fisheries. Low water temperatures at Keswick Reservoir limit the overall productivity of aquatic resources, which is reflected in limited fish production.

Finally, both Keswick Reservoir and Shasta Lake suffer from heavy metal pollution. High concentrations of copper, zinc, and cadmium have been identified as causative factors for fish kills in these adjacent reservoirs. These metals also precipitate out of solution to the bottom of the reservoirs and may further limit benthic productivity. Benthic organisms are an important food source for fish, particularly in Keswick Reservoir.

11. Limited Fishery

The category of limited fishery problems contains a miscellaneous group of issues related to the availability of desirable species and sizes of fish to the angler. This problem category unavoidably overlaps the categories of excessive harvest, underharvest, and angler access. Six of the 23 Central Valley Reservoirs investigated had limited fishery problems (Table 4). These problems can be listed as:

a. Insufficient numbers and size of largemouth bass available to the angler (Black Butte, Hensley, Shasta).

b. Declining striped bass populations (San Luis).

c. Difficulty in harvesting salmonids in the trophy trout program (Oroville).

d. Limited species variety in the fishery (Success).

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The limited availability of adequate numbers of large largemouth bass in Black Butte and Hensley Lakes is not well understood. Neither of these reservoirs have an excessive harvest problem (Table 4). In Black Butte Lake, bass survival and growth may be limited by water level fluctuation, limited cover habitat, and undesirable fish species. In Hensley Lake, the limited bass fishery may be related to water quality problems, although in most years the water quality is adequate. The bass availability problem in Shasta Lake is principally one of too few young-of-the-year (YOY) fish surviving long enough to enter the fishery. Bass survival is related to water-level fluctuation, limited cover habitat, water quality problems (in specific areas of the reservoir), and undesirable species (Table 4).

The declining striped bass population in San Luis Reservoir is probably a reflection of the general decline of this species in the Sacramento-San Joaquin River Delta. Stripers enter San Luis in water pumped from the Delta. The California Department of Fish and Game has expended considerable effort in studying the striped bass fishery of the Delta. To date, research continues on the reasons for the decline of this fish species.

Lake Oroville supports a trophy trout program. In this program salmonids (for example chinook and silver salmon) are planted in the fall to provide large fish for anglers during the winter and spring months. These fish remain deep during the summer months and, consequently, are inaccessible to the average angler. Thus, this fish resource is probably underutilized at Lake Oroville. The enormous volume of water in Lake Oroville coupled with low water fertility makes it difficult to maintain the numbers of sport fish necessary to provide a high return to the angler.

Finally, the Success Lake sport fishery is principally supported by largemouth bass and bluegill, while the available catfishes go unharvested to a large extent. The result has been excessive angling pressure on the bass population. Opportunities for resolving both of these problems (i.e., excessive harvest and underharvest) exist.

12. Forage Fish Related Problems

Forage fishes are defined as those species providing an important food source for larger piscivorous game fishes sought by anglers. Four of the 23 Central Valley reservoirs investigated had problems associated with forage fishes (Table 4). These problems are identified as:

a. Little or no forage fish resources available as a food source for game fish (Englebright, Whiskeytown).

b. Underutilized forage fish resource (Oroville).

c. Widely fluctuating forage fish abundance adversely affecting the game fish food base (Shasta).

d. Suspected forage fish competition with game fishes (Oroville).

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Fisheries data for Englebright Reservoir are extremely limited. The reservoir does not support a limnetic forage fish species. Consequently, no sport fishes have been introduced to utilize this open-water habitat type in the reservoir. It has been suggested that if forage fish were available, then a game fish such as lake trout might be introduced to utilize the food and space in the hypolimnion. Virtually nothing is known about the abundance of zooplankton and benthos in the reservoir which might be used as a food source for forage fish. Until baseline studies are undertaken it will not be possible to accurately assess the potential for successful introductions of forage and game fishes in this reservoir.

The forage fish problem in Whiskeytown Lake, on the other hand, has been investigated thoroughly and the results reported by Healey (1977). The primary productivity of Whiskeytown Lake appears to be limited by the coldwater inflow from the Trinity River and by the high flushing rate. Cold temperatures prevent full utilization of nutrients while the high flushing rate many dilute the standing crop of plankton. Consequently, conditions remain unsuitable for developing an adequate forage food source for game fishes. Attempts to develop forage resources in Whiskeytown have been attempted by introducing threadfin shad (1964), opossum shrimp (1967), and scuds (1971). None of these introductions have been successful.

Apparent underutilization of forage fish resources occurs in Lake Oroville. Both threadfin shad and pond smelt provide a forage resource in Oroville. The shad is a surface foraging species and the smelt a pelagic forager.

Consequently, it is difficult to determine the most appropriate game fish to stock to fully utilize these resources. The trophy salmonid program at the reservoir generally shows poor angler returns from limnetic areas and it is, consequently, concluded that the two forage species are poorly utilized.

Widely fluctuating population levels of threadfin shad from year to year are believed to adversely impact game fish food availability in Shasta Lake. The causes for these fluctuations are not completely clear, however, the availablility of food (plankton) for shad is thought to be one reason for the erratic population fluctuations. The trophy salmonid program in Shasta Lake is the most seriously affected fishery.

Circumstantial evidence from Lake Oroville suggests that pond smelt may be competing with young-of-the-year (YOY) largemouth bass for food and space. In 1976, it was first noted that pond smelt were established in Lake Oroville. The smelt came down the Feather River from Lake Almanor. Before the smelt's establishment, threadfin shad were the most abundant forage fish. With the change in the forage base, a change in the resident fish populations was also noted.

Young-of-the-year largemouth bass numbers per mile of shoreline were 65 percent lower in 1980 than the mean number prior to 1975. It was found that one of the two major spawning periods for pond smelt coincided spatially and temporally with largemouth bass spawning. Smallmouth bass and spotted bass spawned 4-5 weeks earlier and no reduction in their numbers was observed. In fact, smallmouth bass were 25 percent more abundant in 1978 and

1979 than prior to 1976. Young centrarchids which were spawned before the pond smelt were able to utilize YOY pond smelt for forage. Young-of-the-year largemouth bass spawned at the same time as the pond smelt may have been in direct competition with the smelt for food and habitat (CDFG files).

Another change which occurred after the pond smelt became established was a reduction in threadfin shad and kokanee populations. Threadfin shad ceased to be an important forage fish and occurred in less than 5 percent of the game fish stomachs observed. It appears that pond smelt and threadfin shad have a dynamic interaction, with the pond smelt being more abundant some years and threadfin shad being more abundant in others. The kokanee fishery was essentially eliminated. Other fish, including rainbow trout, brown trout, chinook salmon, and smallmouth bass, benefited from the availability of pond smelt and demonstrated growth rates as much as 30 percent higher than those seen prior to the pond smelt introduction (CDFG files).

13. Undesirable Species

The presence of undesirable species has been identified as a fishery management problem at seven Central Valley reservoirs (Table 4). As defined in this analysis, undesirable species are organisms that either indirectly or directly, limit or reduce, the productivity of desirable game fishes. Productivity of game fishes may be limited or reduced by undesirable species through competition for food, cover, or spawning habitat, as well as through predation, disease, and habitat alteration.

A summary of problems associated with undesirable species and suggested solutions for the seven identified problem reservoirs is presented in Table 6.

In five Central Valley reservoirs overabundant populations of nongame fishes have been identified as factors reducing the productivity of game fishes. Undesirable nongame fishes may be either native or introduced species. However, within Central Valley reservoirs the majority of fishes that have been identified as undesirable have been native nongame species, primarily Sacramento sucker, hardhead, and Sacramento squawfish (CDFG files). It must be emphasized, however, that the extent to which native nongame species have a detrimental effect on game fishes in Central Valley reservoirs has not been adequately documented. Research on the interaction between native nongame species associations and, primarily, introduced game fishes in Central Valley reservoirs has not been done.

Nongame fishes within Shasta Lake such as carp, blackfish, squawfish, suckers, and hardheads are abundant and are thought to be competing with game fish. The carp and blackfish are lake spawners. Squawfish, suckers, and hardheads are primarily tributary spawners. It is thought by California Department of Fish and Game personnel that these species reduce game fish production in the reservoir and in the tributaries. However, studies to examine interactions between nongame species and game fishes in Shasta Lake and its tributaries have not been undertaken to date.

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Table 6. Problems associated with undesirable species and suggested solutions for seven Central Valley reservoirs 1/

Reservoir Name	Undesirable Species Problem	Solutions Proposed
Whiskeytown Lake	Overabundant nongame fishes	Stream barriers
Black Butte Lake	Overabundant nongame fishes	Poisoning
East Park Reservoir	Overabundant nongame fishes	Poisoning
Lake Isabella	Introduced mollusk _Corbicula_	None proposed
Lake Kaweah	Introduction of white bass	Poisoning
Shasta Lake	Overabundant nongame fishes	Stream barriers, Poisoning
Stony Gorge Reservoir	Overabundant nongame fishes	Introduce predator

1/ California Department of Fish and Game files

In Lake Kaweah the white bass, a game fish, was identified as an undesirable species. Sometime before or during 1977 white bass became established in the reservoir by an unauthorized introduction. The California Department of Fish and Game decided not to chemically treat the reservoir to eradicate the white bass but was very concerned about the possibility of this fish spreading to new waters and eventually to the Sacramento-San Joaquin River Delta. Once established in the Delta, the white bass might have an adverse effect on the populations of salmon, striped bass, and American shad.

At Lake Isabella there is speculation that the abundant Asiatic clam (Corbicula sp.) may significantly reduce plankton populations by grazing. Plankton populations are, in turn, used by juvenile fishes as a food resource. Thus, fish may compete with the clam for food. It has been suggested that this competition for food may affect survival and growth of centrarchids such as white crappie.

14. Shoreline Erosion

Shoreline erosion has been identified as a fishery management problem at seven of the 23 Central Valley reservoirs investigated. A summary of the causes of shoreline erosion at the seven reservoirs is presented in Table 7. Causes of shoreline erosion identified as fishery management problems include excessive cattle grazing and trampling, wave action associated with wind, recreational boating, and seasonal water-level fluctuations.

Excessive cattle grazing and trampling of shoreline habitat has been identified as a fishery management problem at Pine Flat Reservoir and Lake Kaweah. Excessive grazing along reservoir shorelines results in erosion and a concomitant increase in turbidity in the littoral zone. Heavy grazing on the banks around the shoreline of both Pine Flat Reservoir and Lake Kaweah has denuded the soil of protective cover, decreased the survival of aquatic and riparian vegetation (especially willows through browsing and trampling) and eliminated grasses which,

Table 7. Causes of shoreline erosion at seven Central Valley reservoirs[1/]

	Reservoir Name	Identified Cause of Shoreline Erosion
1.	Black Butte Reservoir	Wave action associated with wind and recreational boating
2.	Stony Gorge Reservoir	Wave action associated with wind and recreational boating
3.	East Park Reservoir	Wave action associated with wind; Seasonal water-level fluctuations
4.	Pine Flat Lake	Excessive cattle grazing and trampling
5.	Jenkinson Lake	Wave action associated with wind and recreational boating
6.	Lake Kaweah	Excessive cattle grazing and trampling
7.	Isabella Lake	Seasonal water-level fluctuations

1/ California Department of Fish and Game files when inundated, could provide cover for juvenile fish. Increases in the turbidity of affected littoral habitats is a noticeable consequence of excessive cattle grazing and trampling. The loss of littoral habitat caused by excessive cattle grazing and subsequent erosion will result in a decrease in productivity of this habitat for fishes through:

a. The elimination of spawning habitat of some fishes, especially centrarchids.

b. The loss of juvenile rearing habitat.

c. The loss of cover habitat.

d. A reduction in primary and secondary food production.

The reader is referred to the review of limited littoral habitat within this Part (Problem 8) for a detailed discussion on the importance of littoral habitat in determining the productivity of Central Valley reservoirs.

Water-level fluctuations, as a cause of erosion, have been identified as fishery management problems at Lake Isabella and East Park Reservoir. In general, fluctuating water levels:

a) Preclude the long-term establishment of vegetation in the littoral zone through extended periods of desiccation and inundation.

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2) Allow wave wash to affect a larger areal extent of shoreline.

The importance of vegetation in reducing shoreline erosion has already been discussed. Wave wash, especially on exposed (unvegetated) shoreline, is an important cause of erosion in Central Valley reservoirs. A detailed discussion on the effects of fluctuating water levels on fishery management in Central Valley reservoirs is included in this Part (Problem 3).

Erosion resulting from wave wash generated by wind and recreational boating has been identified as a fishery management problem at Black Butte Reservoir, Stony Gorge Reservoir, East Park Reservoir, and Jenkinson Lake. The physical force exerted by waves against the shoreline is increased by wind and motorboats, thus exacerbating the effects of moving water on exposed shoreline. The cumulative negative effects of cattle grazing, water level fluctuations, and wave action on reservoir shorelines may be great. In many instances, shoreline erosion is the consequence of all of these factors working in combination to reduce the establishment of vegetation which is necessary to stabilize shoreline habitats.

15. Multiple Use Conflicts

Multiple use conflicts with optimum sport fishery management were identified at six of 23 Central Valley reservoirs investigated (Table 4). Multiple use activities affecting fishery management are presented in Table 8.

Table 8. Central Valley reservoirs which have multipe use conflicts with optimum fishery management[1/]

Reservoir Name	Type of Conflict: Power Boat Use	Livestock Grazing
East Park Reservoir	X	
Jenkinson Lake	X	
Lake Berryessa	X	X
Lake Kaweah		X
Pine Flat Lake		X
Stony Gorge Reservoir	X	

1/ California Department of Fish and Game files

In each of four reservoirs adversely impacted by water oriented recreation activities, the problem was consistently identified as conflicts with power boat uses (e.g., water skiing and boat racing). Boating activities resulted in:

a. Disturbance to anglers (East Park, Berryessa).

b. Loss of centrarchid fish production from boat-generated wave action (Berryessa).

c. Aggravated shoreline erosion affecting fish survival and aesthetics (Jenkinson, Stony Gorge).

The second multiple use conflict with optimum fishery management practices was from livestock grazing along reservoir shorelines resulting in:

a. Increased soil erosion and water turbidity.

b. Trampling and removal of vegetation used as cover habitat by fish.

16. Angler Access

Plan Formulation Team C Problem No. C-5 focuses on a detailed evaluation of angler access to Central Valley reservoirs. The reader is referred to that Special Report for a complete analysis. This investigation found that three of the 23 Central Valley reservoirs had access problems (Table 4). Two distinct access problems were noted. The first problem involves physical access to the reservoir, and the second problem involves access to fish concentrations at the reservoir. This latter problem overlaps the problem categories of underharvest (see Black Butte Lake and O'Neill Forebay), and limited fishery (see Lake Oroville). Access to fish once the angler has reached the reservoir is not discussed further in this problem category.

Both Englebright Reservoir and Lake Natoma have severe physical access problems. In the case of Englebright Reservoir, most of the reservoir can only be reached by boat. About 40 percent of the stocked salmonids are caught from the upstream end of the lake near Rice's Crossing. Vehicular access to this point is difficult and normally limited to off-road vehicles. Additionally, there are few angler access trails leading to the lakeshore. Lake Natoma has very steep banks on the north shoreline that prevent angler access. Additionally, the reservoir area near Folsom State Prison is closed to entry.

PART IV

POTENTIAL SOLUTIONS TO CENTRAL VALLEY RESERVOIR FISHERY MANAGEMENT PROBLEMS

Introduction

Part III of this report defined 16 fishery management problem categories that were identified based on the results of the 23 individual reservoir investigations. Many of the problems common to several reservoirs also have common solutions. This part of the report reviews and discusses potential problem solutions in detail and, where appropriate, relates the solutions to specific reservoirs. The solutions are presented in the same order as the problem headings listed in Table 4. The order of presentation is not necessarily related to importance or priority.

The case histories of management practices at selected Central Valley reservoirs are used as necessary to illustrate solution applications. A detailed account of each reservoir (including solution to problems specific for each) is presented in the Appendix to this report. A descriptive summary of each of the 23 reservoirs is provided in Tables 9 and 10.

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Table 9. Descriptive information for 23 selected Central Valley reservoirs.

Reservoir Name	County	Stream Impounded	Owner	Recreation Manager	Reservoir Purpose*	Drainage Area (mi.^{2})	Year Storage Began
Black Butte Lake	Tehama	Stony Creek	CE	CE	FC IR	738	1963
East Park Reservoir	Colusa	Little Stony Creek	USBR	USBR	IR	98	1910
Englebright Reservoir	Nevada Yuba	Yuba River	CE	CE	DC	1108	1941
Folsom Lake	Sacramento Placer El Dorado	American River	USBR	CDPR	FC IR HP WS	1861	1955
H.V. Eastman Lake	Madera	Chowchilla River	CE	CE	FC IR RC	236	1975
Hensley Lake	Madera	Fresno River	CE	CE	FC IR RC	237	1975
Jenkinson Lake	El Dorado	Sly Park Creek	USBR	El Dorado - Irrig. Dist.	IR WS	16	1954
Keswick Reservoir	Shasta	Sacramento River	USBR	Shasta Co.	HP	6468	1948
Lake Berryessa	Napa	Putah Creek	USBR	USBR	FC IR WS	566	1956
Lake Isabella	Kern	Kern River	CE	CE	FC IR	7074	1954
Lake Kaweah	Tulae	Kaweah River	CE	CE	FC IR	560	1962
Lake Natoma	Sacramento	American River	USBR	CDPR	HP RR	1887	1955
Lake Oroville	Butte	Feather River	St. of CA	DWR	FC HP IR RC WS	3607	1967
Lake Red Bluff	Tehama	Sacramento River	USBR	USBR	FC IR	8900	1964
Millerton Lake	Fresno	San Joaquin River	USBR	CDPR	FC IR	1638	1944
New Hogan Lake	Calaveras	Calaveras River	CE	CE	FC IR	362	1963
O'Neil Forebay	Merced	San Luis Creek	USBR St. of CA	CDPR	IR	0	1966
Pine Flat Lake	Fresno	Kings River	CE	CE	FC IR	1545	1951
San Luis Reservoir	Merced	San Luis Creek	USBR St. of CA	CDPR	HP IR	83	1967
Shasta Lake	Shasta	Sacramento River	USBR	USFS	FC HP IR NV WS WQ	6400	1944
Stony Gorge Reservoir	Glenn	Stony Creek	USBR	USBR	IR	301	1928
Success Lake	Tulare	Tule River	CE	CE	IR FC	393	1961
Whiskeytown Lake	Shasta	Clear Creek	USBR	USNPS	HP	200	1963

*DC - debris control
FC - flood control
HP - hydropower
IR - irrigation
NV - navigation
RC - recreation
RR - reregulation
WS - water supply
WQ - water quality

Table 10. Physical description of 23 selected Central Valley reservoirs
Mean annual parameter values are presented for the period
1970-1979 unless otherwise noted.

Reservoir Name	Surface Elevation (feet mean sea level)	Surface Area (acres)	Volume (acre - feet)	Total Annual Discharge (acre - feet)	Storage Ratio	Mean Depth (feet)	Maximum Depth (feet)	Thermocline Depth (feet)	Water Level Fluctuation (feet)	Shoreline Length (miles)	Shore Development	Total Dissolved Solids (mg/l)	Total Phosphorus (mg/l as P)
Black Butte Lake	448	2,449	52,600	433,000	0.12	21	73	0	35	23	3.3	234 2/	0.09 2/
East Park Reservoir	1,177	986	19,100	54,600	0.40	19	65	30	33	21	4.8	430	0.1
Englebright Reservoir	520	765	64,500	704,200	0.09	84	230	NA	21	20	4.3	68	0.01
Folsom Lake	435	10,000	713,000	2,970,800	0.24	71	238	30	66	72	5.2	46	0.02
H.V. Eastman Lake 3/	506	975	39,700	44,600	0.89	41	96	22	37	12	2.7	202	0.08
Hensley Lake	483	767	22,800	70,700	0.32	30	78	36	35	15	3.9	105	0.06
Jenkinson Lake	3,448	518	27,500	4,500	6.11	53	137	NA	31	7	2.0	32	NA
Keswick Reservoir	585	625	22,300	5,177,400	0.004	36	105	0	3	19	5.4	103	0.03
Lake Berryessa	424	17,731	1,299,000	342,100	3.80	73	232	17	16	136	7.3	181	0.03
Lake Isabella	2,560	5,800	163,000	465,700	0.35	28	113	0 6/	23	31	2.9	67 2/	0.06 2/
Lake Kaweah	616	855	31,100	373,200	0.08	36	106	40 2/	101	13	3.0	68 2/	0.02 2/
Lake Natoma 1/	124	500	8,300	201,500	0.04	17	54	0	3	19	6.1	41	0.02
Lake Oroville	861	13,866	2,954,500	411,700	7.17	213	708	37	75	140	8.5	52 7/	0.02 7/
Lake Red Bluff	252	499	3,674	9,505,000	0.0004	7	51	0	2	19	5.9	100	0.04
Millerton Lake	524	3,676	294,100	1,600,000	0.18	80	224	NA	59	45	5.3	36	NA
New Hogan Lake	664	2,800	146,100	1,400,000	1.06	53	130	28	30	35	4.7	114 2/	0.06 2/
O'Neill Forebay	221	2,159	46,300	251,400	0.18	21	46	0	5	14	1.9	225	0.08
Pine Flat Lake	877	4,526	613,100	2,083,800	0.29	135	314	50 2/	96	57	6.1	30 2/	0.04 2/
San Luis Reservoir	508	11,700	1,595,700	763,000	2.09	136	238	25	64	47	3.1	370	0.06
Shasta Lake	1,065	29,500	4,500,000	6,396,947 4/	0.89	152	490	30	55	365	14.8	102	NA
Stony Gorge Reservoir	818	825	25,300	18,700	1.35	31	88	14	42	10	2.8	281	0.01
Success Lake	615	917	24,300	107,900	0.22	27	57	18 2/	43	11	2.5	191 2/	0.03 2/
Whiskeytown Lake	1,204	3,081	221,600	396,900	0.56	72	239	20	15	37	4.8	52	NA

NA - Not Available
1/ All values for the period 1968-1977
2/ 1974-1979 data
3/ All Values for the period 1976-1979
4/ 1968-1969 data
5/ 1976-1975 data
6/ 1974-1975 data
7/ 1974-1978 data

Potential Solutions by Problem Categories

1. Absence of a Fishery Management Plan

Twenty-one of the 23 Central Valley reservoirs investigated did not have specific written fishery management plans applicable to current reservoir conditions (Table 4). Management problems related to the absence of a management plan were discussed in Part III of this report. The solution to this problem is to write a comprehensive fishery management plan for each reservoir not now having one.

The development of reservoir-specific fishery management plans should be the responsibility of the California Department of Fish and Game. Other resource agencies directly involved with the operation and management of each reservoir (e.g., the Army Corps of Engineers, Bureau of Reclamation, and California Department of Water Resources) should be prepared to assist in the planning process by providing reservoir operational data, as determined necessary by CDFG, for the preparation of the management plans. Such data might include, but would not necessarily be limited to, the results of operations studies, water delivery schedules, water storage allocations, water rights restrictions, and operational constraints.

The purpose of the individual fishery management plans should be to set management goals and objectives for each reservoir for a specified time frame. The plans should include as a minimum the following elements:

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1. A clear and concise statement of the fishery management goals for the reservoir.

2. A clear and concise statement of the fishery management objectives to be pursued in achieving the management goals.

3. An identification of the fish species of management interest.

4. An identification of the data needs required to meet stated objectives.

5. A detailed summary of the historical fishery management practices applied to the reservoir, and an assessment of their impact or value in relation to present goals and objectives.

6. A detailed appendix of all data available on the reservoir fishery of relevance to present goals and objectives.

7. The identification of a specific reservoir management program directed by the management plan. The program should involve a period of years sufficient to allow management goals and objectives to be achieved (or revised in the face of new factual evidence).

8. A provision for revision or updating of the fishery management plan and its elements, based on new circumstances and factual information.

Implementation of this problem solution should be initiated for each of the 21 reservoirs presently lacking reservoir fishery management plans. The benefits of developing reservoir-specific plans will, at the minimum, include the following:

1. Improved direction to fishery management activities.

2. Continuity of management and research programs.

3. Improved information transfer.

4. Better allocation of limited management resources.

2. Limited Fisheries Data

Limited fishery data was identified at 20 of 23 reservoirs investigated (Table 4). The data that a fishery manager will need for a given reservoir are directly related to the management goals and objectives that are identified in the reservor's fishery management plan. A management plan should be developed prior to data collection. When this approach is followed, the fishery manager can proceed systematically to efficiently collect the needed data by priority.

The benefit of using the fishery management plan as a guideline to data collection is that the data needed are explicitly stated with respect to specific management objectives. Consequently, the fishery manager will not direct limited resources to collecting irrelevant or low priority information. Also, the data collected will meet specific management needs required to achieve the goals and objectives.

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The importance of using a fishery management plan as a tool for directing data collection efforts cannot be overemphasized. Only in the cases of Lake Berryessa and Lake Isabella did the investigators conclude that adequate fishery management plans were available to guide and direct data collection. Shasta Lake was in the unique position of having an abundance of fisheries data on a wide variety of subjects, yet no specific management plan had been formulated.

This report can not list the types of data required to adequately assess the fishery needs and problems of the 20 reservoirs with limited information. The exact type and quality of these data will depend on the fishery management plans that are eventually developed for these reservoirs.

The solution to the problem of limited fisheries data is to focus future data collection and research programs on the goals and objectives of the reservoir fishery management plans.

3. Water-Level Fluctuation

Water-level fluctuation was the most frequently noted environmental problem and was identified in 17 Central Valley reservoirs (Table 4). Part III of this report discussed the range of impacts to reservoir biota resulting from water-level fluctuations. This section of the report discusses potential solutions to these issues. The appropriate solution for each reservoir will depend on:

a. The goals and objectives of the fishery management plan.

b. Reservoir operational constraints.

c. Adequate biological knowledge about the fish species to be managed.

This discussion assumes that the reservoir operating agency has some operational flexibility to control water levels, at least in some years. If there is no operational flexability, then there is no solution to the water-level fluctuation problem. Such a situation does not preclude initiating actions which will mitigate, in whole or in part, some of the effects of water-level fluctuation. As was noted in Part III of this report, the major constraints on limiting pool fluctuations are the resulting losses of reservoir operating flexibility for water supply, irrigation, power production, and flood control.

The general goal of fishery managers seeking limitations on the timing and magnitude of water-level fluctuations is to provide habitat for fishes of management concern during critical life history stages, or to guarantee survival of the population during stressful seasons. Habitat maintenance in the 17 Central Valley reservoirs facing severe water-level fluctuation problems is directly related to maintenance of spawning, incubation, and brooding habitat for specific periods of the year, and maintenance of escape cover habitat for juvenile fishes. Maintenance of these habitat types can be achieved by fluctuation control usually on a seasonal basis.

Fluctuation Control. This management technique involves stabilization of water levels for specified periods. Repetition of the process may occur annually or at longer intervals, depending on the management objectives. For example, in many Central Valley reservoirs being managed for largemouth bass, it is desirable to stabilize water levels during the bass spawning and brooding period, usually May-June.

Unique plans for individual reservoirs are necessary. The individual plans should consider the species of management concern, timing of various life stages, and the operational requirements of the specific reservoir.

Water stabilization may not be achievable nor necessary every year. The joint operation of two or more reservoirs may offer management options not achievable by changing the operation of one reservoir alone. For example, the crappie fisheries at both Black Butte Lake and Stony Gorge Reservoir have been successfully managed by operating the reservoirs together. The reservoir management agencies have agreed to stabilize Black Butte Reservoir water levels during the crappie spawning period every other year. In years when Black Butte is stabilized, Stony Gorge Reservoir fluctuates in response to project demands. In alternate years Stony Gorge is stabilized and Black Butte Lake fluctuates. The result of this joint operational scheme has been successful crappie spawning resulting in good fisheries for both reservoirs. It is unlikely that this result would have been achievable if the reservoirs had been operated seperately.

Staged Fluctuations. In reservoirs where it is not possible to maintain stable water levels over protracted periods of time, it may be possible to fluctuate the water in stages. Mitchell (1982) discusses this management alternative with respect to the largemouth bass fishery of Millerton Lake. For bass, he recommends at least three weeks between major periods of fluctuation. While this management strategy may not guarantee the degree of success achieved with completely stabilized water levels, it does offer a viable option to the alternative of uncontrolled fluctuations, which pose significantly greater adverse impacts to the fishery.

Minimum Pools. As was noted in Part III of this report, extreme fluctuation may result in the drawdown of the reservoir to the point that fish die from adverse environmental conditions (e.g., high water temperature, low dissolved oxygen levels, disease). To prevent this condition from occurring, minimum pool guarantees should be developed at all Central Valley reservoirs not having them now. Maintenance of a minimum reservoir pool reduces fish losses and thereby reduces the need for annual restocking to maintain adequate populations. Minimum pools improve the holdover capacity of a reservoir, which will result in increased yield because smaller fish can be stocked (Nelson et al. 1978).

The major constraints on the sizes of the pools reserved for fish are the resulting loss of water storage capacity for irrigation and power production and the decrease in reservoir capacity for flood control. The size of minimum pools allows only for survival of the fish populations. If the reservoir is held at this low level for extended periods, loss of year-classes and other population degradation may result. An additional constraint concerns trade-offs between maintaining a minimum pool for habitat and population protection and for providing sufficient reservoir releases to maintain the downstream fishery. The compromises made will depend on the comparative resource values downstream and in the reservoir (Nelson et al. 1978).

Reallocation of Storage. A concept that is too rarely considered in addressing the problem of water level fluctuations is that of reallocation of storage for fishery management purposes. The goal of any major reallocation of storage is to increase overall project net benefits (Johnson 1980). Information on storage allocations and uncommitted storage at Central Valley reservoirs could not be obtained. Therefore, we were unable to determine the specific applicability of this management technique.

Reallocation of reservoir storage for fish and wildlife purposes would require that fish and wildlife maintenance and enhancement be identified as a project purpose. If fish and wildlife is not already a project purpose, then legislation is required to make it so.

Johnson (1980) has identified constraints on reallocation efforts:

1. Existing water compacts and water rights.

2. Existing long-term contracts for water supply, hydroelectric power, etc.

3. Existing and continuing required levels of flood control.

4. Possible need for reauthorization by Congress.

5. Arousing public concerns.

6. Cost sharing features and sponsors.

7. Limited benefits attributed to fish and wildlife resources.

The degree to which fishery managers resolve water-level fluctuation problems will influence to a great extent their success in dealing with many of the other 15 fishery management problems associated with Central Valley reservoirs.

4. Excessive Harvest

Excessive fish harvest can be controlled by restrictive fishing regulations and by manipulation of the fish population to make them less susceptible to angler harvest.

Restrictive Fishing Regulations. The most straightforward tool for restricting fish harvest is to impose restrictive fishing regulations. Attempts to reduce black bass harvest by regulation have focused on limiting bag limits (e.g., five-fish limit), and by limiting the size of fish that may be kept by the angler. Of the five Central Valley reservoirs investigated with an identified excessive harvest problem, all had five-fish limits and four reservoirs had 12-inch minimum length limits.

The objectives of length limit regulations have been identified by Keith (1978):

1. Increase the fisherman's effectiveness (catch rate). This is the number of fish caught per unit of effort, e.g., number of fish caught per hour of fishing. This does not mean that a fisherman's harvest (number of fish taken home) will increase.

2. Increase the quality of fishing. Quality fishing is a relative term and perhaps every fisherman has a different definition of a quality fishing trip. Some fish managers define the term as increased catch rate and the catching of larger size fish. This again, however, does not necessarily mean that the fish kept are larger or that the number kept is greater.

3. Protect predatory fishes so that they will remain in the population to help control the prey (forage) fishes. It is

important that the forage fish population be prevented from overpopulating. Predatory fishes such as bass, crappie, and catfishes control forage fish populations naturally and should be protected.

The effectiveness of black bass size limits is still a hotly debated issue among knowledgeable fishery biologists. While this question can only be resolved on the basis of carefully documented long-term studies, the preliminary evidence from California indicates that size limits may achieve the objective of increasing the quality of the fishing.

The slot-limit is in effect at Hensley Lake to reduce the harvest of bass. Fish less than 12 inches or greater than 15 inches are the only ones which may be kept. It is felt that under the former 12-inch size limit, slower growing fish are selected for by anglers because the faster growing fish are removed by anglers as soon as they reach 12 inches and before they have a chance to spawn. Slower growing fish are in the lake longer and have the opportunity to spawn. Concern has been expressed that angler pressure may act as a selection mechanism for genetically slower growing fish, thus altering over time the genetic make-up of the population. The effects of slot-limits are currently under investigation by the California Department of Fish and Game.

In the case of the Shasta Lake rainbow trout fishery, the mechanism for reducing angler harvest of planted fish might consist of setting a size limit on rainbow trout to prevent excessive harvest of small fish before they contribute to the trophy trout fishery. Drawbacks to a trout size limit are discussed in the Shasta Lake report.

Manipulation of Fish Populations. Manipulating species populations to reduce the susceptibility of fish to angling has been attempted in recent years in a number of California reservoirs. The Florida strain of the largemouth bass was introduced to the four reservoirs facing excessive harvest problems as follows: Shasta Lake - 1982; Folsom Lake - 1972; Success Lake - 1981; H. V. Eastman Lake - 1982. To date, the Florida strain has not been introduced to Millerton Lake. The Florida largemouth bass is thought to be less susceptible to angling than the northern strain largemouth bass (the predominant largemouth strain in Central Valley reservoirs). Additionally, the Florida bass is a longer-lived fish. It is hoped that by hybridizing the two strains of largemouth bass, a fish population will develop that is 1) less susceptible to angling, 2) longer-lived, and 3) attains a larger size by the time of harvest.

The introduction of the Florida largemouth to Central Valley reservoirs is too recent a management technique to know if it will achieve the anticipated results. Careful population monitoring studies must be continued over time to determine the validity of this technique. If proven successful, manipulation of fish populations by introducing Florida largemouth bass may be an acceptable management tool in other California reservoirs.

At the present time, implementation of carefully considered fishing regulation restrictions, coupled with adequate monitoring programs, appears to be the best fishery management tool for addressing the excessive harvest problem in Central Valley reservoirs.

5. Underharvest

Underharvest of catfishes by anglers was identified as a fishery management problem at five of the 23 Central Valley reservoirs investigated (Table 4). Angler access to the fish resource and knowledge of how to fish for catfishes were identified as factors influencing harvest.

To solve the problem anglers must be educated (through signs or pamphlets) about the various species of catfish available at each reservoir and how best to go about fishing for them. For example, signs might tell anglers what species are present, the best areas to fish, and what to use for bait. This solution is applicable to all five of the reservoirs supporting underutilized catfish resources.

Two solutions are available to the fishery manager in dealing with the angler access problem. The first solution involves providing physical access to the resource. The second solution focuses on regulatory access. Fish population sampling results at several of the five reservoirs under consideration reveal that the greatest densities of catfishes in the reservoirs can be found at depths ranging from 25 to 50 feet. Most anglers fishing from shore cannot readily reach these depths. The most practical technique for solving this problem is to construct floating fishing piers at appropriate locations to allow shore anglers access to deeper water. Floating piers would need to be constructed to fluctuate with the reservoir water level. For additional discussion of fishing access issues, the reader may wish to refer to the

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Special Report on Problem C-5, dealing with fishing access at Central Valley reservoirs.

Regulatory access means implementing fishing regulations designed to encourage angler utilization of catfish resources. These regulations will probably be reservoir specific. Within the concepts of scientific fishery management, possible regulatory changes designed to encourage greater harvest of catfishes might include:

1. Increasing the allowable bag limit on catfishes.
2. Opening reservoirs or selected areas of reservoirs to night fishing.
3. Allowing new types of fishing methods to be used such as trotlines.

These solutions to the underharvest problem, if implemented, should stimulate increased fishing pressure on catfishes, thus providing additional fishing opportunity and angler harvest using existing fishery resources at each of the five Central Valley reservoirs.

6. Limited Cover Habitat

The development of cover habitat involves either revegetation of reservoir shoreline areas or construction and placement of artificial structures in the reservoir. Table 11 presents a summary of the types of habitat improvement measures that have been attempted to date on 16 Central Valley reservoirs.

Revegetation of Shoreline Areas. Considerable effort has been expended in efforts to determine which species of terrestrial plants are capable of withstanding periodic inundation in the fluctuation zone of Central Valley reservoirs (Harris et al. 1975). A summary of these efforts and a discussion of several case histories at California reservoirs is presented by Brouha and von Geldern (1978).

Not only is the selection of species to be planted critical, but so are the method and timing of planting. In the Central Valley, plants are normally set out in the fall and winter months and watered for one or more years during the dry summer season. Those plants subject to browsing by deer and other animals must be protected until well established.

To date, attempts to establish shoreline vegetation for cover habitat have met with mixed success (Table 11). Failures to establish plants were attributed to:

1. Poor site selection (e.g., soils, aspect, slope).

2. Planting at the wrong time of the year.

3. Improper planting techniques.

4. Desiccation due to lack of water.

Table 11. Comparison of cover habitat improvement's projects for warmwater fishes at 16 Central Valley reservoirs 1/

Reservoir Name	Year Implemented	Type of Habitat Improvement	Was the Project Monitored & Documented?	Did the Project Succeed or Fail? 2/
Black Butte Lake	1977	tire reefs	no	?
	1978	willows planted	yes	F
	1980	willows planted	yes	F
East Park Reservoir	----	none known	----	-
Englebright Reservoir	1981	willows planted	yes	S
	1982	brush shelters	no	?
	1982	concrete reefs	no	?
	late 1970's	artificial kelp clumps	no	?
Folsom Lake	1977	artificial kelp clumps	no	?
	1978	willow planting	yes	F
Jenkinson Lake	1978	artificial kelp clumps	no	?
Lake Berryessa	1978	willow planting	yes	S
	1978	brush shelters	yes	S
Lake Isabella	1976	tire reef	no	?
	1976	buttonbush planted	yes	F
	1979	willows planted	no	?
	1979	brush shelters	no	?
Lake Kaweah	1978	buttonbush planted	no	?
	1981	willows planted	no	?
	1981	winter wheat planted	no	?
Lake Oroville	1973	willows planted	yes	S
	1973-1975	artificial kelp clumps	yes	S
	1974	willows planted	yes	?
	1974	buttonbush planted	yes	F
	1975	willows planted	yes	S
	1975	buttonbush planted	yes	S
	1976	willows planted	yes	S
	1976	buttonbush planted	yes	S
	1976	lady's thumb planted	yes	F
	1977	willows planted	yes	S
	1977	buttonbush planted	yes	F
	1978	willows planted	yes	? 3/
	1978	buttonbush planted	yes	? 3/
	1978	cottonwoods planted	yes	? 3/
	?	bermuda grass planted	yes	S
	1979-1980	barley planted	yes	S
	1979-1980	rose clover planted	yes	S
	1979-1980	lan vetch planted	yes	S
	1979-1980	ryegrass planted	yes	S
	1982	annual grasses	yes	F
Millerton Lake	1958	floating brush shelters	yes	S
	1976	willows planted	no	?
	1977	willows planted	no	?
	1977	lady's thumb planted	no	?
	1978	buttonbush planted	yes	? 3/
	1978	willows planted	yes	?
New Hogan Lake	1982	willows planted	yes	S
	1982	grasses planted	yes	F
	1982	tire/brush shelters	no	?
Pine Flat Lake	1976-1977	willows planted	yes	F
	1976-1977	buttonbush planted	yes	F
	1976-1977	mule fat planted	yes	F
	1978	buttonbush planted	yes	F
	1981	buttonbush planted	yes	F
	1982	buttonbush planted	?	?
San Luis Reservoir	----	none known	--	-
Shasta Lake	1974	brush shelters	yes	S
	1975	trees planted	yes	F
	1976	brush shelters	?	?
	1977	willows planted	yes	F
	1978-1979	willows planted	yes	F
	1978-1979	buttonbush planted	?	?
	1978-1979	lady's thumb planted	?	?
	1978	trees planted	yes	F
	1979	willows planted	yes	
Stony Gorge Reservoir	----	none known	---	-
Success Lake	1977-1978	willows planted	?	?
	1980-1981	willows planted	yes	F
	?	brush shelters	?	?

1/ California Department of Fish and Game and U.S. Army Corps of Engineers files
2/ For vegetation, failure is less than 20% survival
3/ Quantitative results unavailable

5. Excessive inundation.

6. Browsing and trampling by grazing animals.

7. Vandalism.

Careful consideration to these seven items prior to implementation of a planting program should eliminate most problems.

Most of the revegetation programs listed in Table 11 were monitored to see what percentage of the plants survived. Unfortunately, few of these programs were evaluated to determine the effect establishing vegetation had on fish populations. Presumably, surviving vegetation provided limited cover habitat for the species of management concern.

Sufficient experience has been gained now in shoreline revegetation to confirm this technique as a valuable fishery management tool. Perhaps the greatest drawback to revegetation of large reservoirs is the time and resources needed to establish vegetation in sufficient quantities to produce a significant improvement in fish population productivity. Revegetation to provide cover can be successful if it is combined with a plan for seasonal manipulation of reservoir water level and with long-term committments of resources to the program. The principal advantage of revegetation in drawdown zones is that the plants, once established, provide a large amount of self-perpetuating cover that requires no maintenance.

Carefully conceived planting programs may offer significant fishery benefits for many Central Valley reservoirs. These programs, if implemented, should be carefully monitored and documented in order to determine if the expected fishery benefits have been realized.

Placement of Artificial Structures. A second method of providing cover for centrarchid fishes is through the placement of artificial structures, often called reefs or shelters. For some large reservoirs without suitable locations for the establishment of vegetation, structures may be the only practical means of increasing cover habitat.

Prince et al. (1978) reviewed the history of artificial structures as a fishery management technique. Brouha and von Geldern (1978) offered the following summary:

> "In general, reefs [structures] are installed on firm substrates in the littoral zones of lakes and reservoirs. Extreme water level fluctuations in western reservoirs, however, generally make such installations inappropriate. As reservoirs are drawn down annually, reefs get progressively closer to the water surface, and finally become exposed. Such occurrences create navigational hazards, aesthetics problems, and result in reduced utility of the structures for fish. If reef structures are installed below the normal low water elevation, these problems are not often encountered; however, at full pool the structures may be in the hypolimnion and receive reduced utilization because of cold temperatures and lack of dissolved oxygen.
>
> Floating reefs (originally conceived as breakwaters) constructed of scrap tires (Kowalaski and Ross, 1975) can be used to create additional structures that will rise and fall with the water level. These structures when clearly buoyed and securely anchored, offer year-long utility as well as providing wave attenuation between the structure and the reservoir shoreline. As with conventional reef installation, floating reefs create navigational hazards and problems of aesthetics.
>
> Suggested floating reef applications for western reservoirs are in remote coves or as breakwaters around marina areas. Allen and Romero (1975) found that receding water levels and extreme wind

conditions caused excessive bank erosion and/or suffocation of centrarchid nests at Lake Mead, Nevada. Such conditions are common in reservoirs throughout the west. In addition to providing shelter, the wave attenuating characteristics of floating reefs may act to improve centrarchid spawning conditions through reduced turbulence and turbidity in shoreline areas protected by such structures.

Mid-water reefs have been successful in attracting fish in both marine (Wickham et al., 1973) and freshwater environments (Reeves et al., 1977). J. I. Hiscox's (California Fish and Game, personal communication) observations of mid-water structures placed in Lake Oroville, California, confirm the attractiveness of these structures to fish. He found artificial spawning platforms concentrated several species of centrarchids and that adult largemouth bass exhibited territorial defense behavior. On several occasions he observed one bass defending more than one platform.

These types of structures have appeal for use in western reservoirs because they may be combined with existing floating structures (fishing piers, breakwaters, floating docks, buoys, etc.) or may be constructed independently and also because they will rise and fall with the water level. They are inexpensive to build when compared to conventional reefs, easy to transport, and present few navigation hazards (Ogren, 1974). As Reeves et al. (1977) note, in fluctuating reservoirs mid-water structures may provide added structure without adversely affecting aesthetics of the exposed shoreline. Several incidents of vandalism encountered during the Lake Oroville tests suggest, however, that these devices, unless combined with existing floating structures, would work best in areas with limited public use."

Brouha and von Geldern (1978) also describe research by the California Department of Fish and Game on kelp clumps at Lake Oroville.

"The California Department of Fish and Game (Anon., undated) has developed specifications for construction of "kelp clumps" which feature strips of black polyethylene plastic cut two inches wide and 8-12 feet long. The strips, which are buoyant (no density data presented), are held together in bundles and attached to a weight. Several of these weighted bundles are then spaced along a cable to facilitate maintenance or recovery if desired. When a series of clumps was installed in Lake Oroville, J.I. Hiscox (California Department of Fish and Game, personal communication) found 200-400% increases in yearling centrarchids as compared to control areas during electrofishing surveys. The strips, however, soon started to sag because of sediment deposition and after two years were completely flattened out and attractive only to catfish species. Despite vandalism and an observed lack of longevity in Lake Oroville, a less dense artificial seaweed may have practical application because maintenance costs are low, the entire system is movable, and individual strips collapse and provide a low profile when exposed. These features result in little aesthetic impact and minimal navigation hazards. A possible strategy for using artificial seaweed in western reservoirs would be installation below the normal low water mark to provide cover where aquatic or flood-tolerant terrestrial plants cannot be established. Such strategy might result in increased longevity of the seaweed because colder water temperatures, less light penetration, and lower dissolved oxygen at these water depths might increase longevity of plastics and reduce periphyton growth."

Artificial kelp clumps have also been tried with unknown results at three other Central Valley reservoirs (Table 11).

The most commonly attempted artificial structure (by number) in Central Valley reservoirs is the brush shelter. While floating shelters have been placed in Millerton Lake with success, most brush shelters are firmly fixed to the reservoir bottom in or just below the normal fluctuation zone. As with other types of artificial structures, brush shelters provide cover and feeding habitat for centrarchids. The shelters serve as substrate and cover for periphyton and zooplankton which, in turn, attract fish.

The primary constraint on the use of brush shelters is their effect on restricting boat traffic or other uses of the reservoir. For this reason, the shelters must be anchored securely in deep water or in shallow coves and other seldom-used areas. Brush shelters should be placed above zones of summer and winter stagnation, but should not be subjected to repeated wetting and drying because of resulting increased rates of decomposition. These requirements may make the shelters of limited use in reservoirs with widely varying surface levels. Excessive siltation in and around brush shelters also can limit their effectiveness (Nelson et al. 1978).

Tire shelters or reefs also have been used in Central Valley reservoirs (Table 11). Tire shelters, like brush shelters, provide additional habitat for many types of fish. Tire shelters serve as substrate for periphyton and provide cover and feeding habitat for zooplankton and fish. The shelters are constructed by binding tires together in various designs which then are sunk to form a reef or other structure on the reservoir bottom. Concrete or other ballast can be used to weight the structures and the tires are usually slashed so that air is not trapped (Nelson et al. 1978).

It has been suggested that tire shelters have the most potential among the possibilities for fish shelters. Used tires are generally available and do not deteriorate rapidly when used in underwater shelters (Prince and Maughan 1978). As with brush shelters, excessive siltation and water-level fluctuations may limit that effectiveness. Aside from the previously noted hazards to navigation or other recreational activities from any fixed structure, tire reefs have two potential drawbacks. One, when exposed above the surface they are not aesthetically pleasing to view. This may detract from the recreational experience if tire shelters are placed in certain areas where visual aesthetics are of concern. Two, tire shelters may not be appropriate in reservoirs supplying municipal drinking water (e.g., Jenkinson Lake). Pollutants from the tires may contaminate water supplies.

A variety of materials other than brush and tires can be used to construct fixed fish shelters. Among the materials used to date have been rocks, cement blocks, car bodies, building rubble, and concrete pipe (Stone 1978). Car bodies are expensive and difficult to handle. Building rubble, cement blocks, and rock all have been more or less unsuccessful. When used alone, they tend to sink into the bottom and do not create much habitat diversity (Stone 1978; Nelson et al. 1978).

Another technique noted by Nelson et al. (1978) is the construction of stake beds for fish shelters. Stake beds are built by driving four-to six-foot-long wooden slats about one to two feet apart into a reservoir bottom. The slats are usually about one inch by two inches in cross section, though sawmill strips and pipes also have been used. Authorities do not agree on the effectiveness of stake bed shelters. In some cases, they have been successful in attracting crappie, but the shelters are relatively expensive and also are difficult to build and handle.

Brouha and von Geldern (1978) summarize the application of artificial structures as cover habitat in California by stating:

> "In general, application of reef technology has been limited in California because of problems associated with fluctuating water levels and because of concerns that structures may serve primarily as attractors which would increase vulnerability to angling of species already cropped at very high levels. Annual exploitation rates exceeding 50% for centrarchid bass, for example, have regularly been recorded from a number of California waters (Rawstron and Hashagan, 1972; Van Woert). While problems relating to the increased exploitation cannot be ignored, the authors argue that reefs increase cover and firm substrate which in turn improve primary and invertebrate productivity (Prince et al., 1978; Cowell and Hudson, 1968). These factors result in improved condition for fish (Swingle, 1968; Prince, 1976) increased growth (R. O. Anderson, pers. comm.; Prince, pers. comm.) and probably increased survival (Aggus and Elliot, 1975). Increased recruitment on reef areas should result. Other areas of the lake remain as potential habitat which should continue to be occupied if production of young centrarchids is maintained at normal levels.

In summary, reefs provide life requirements through all life phases; they do not just serve simply as attractors to increase exploitation of mature adults."

As with revegetation programs, carefully conceived programs to place artificial structures in reservoirs may offer significant fishery benefits for many Central Valley reservoirs. Once again, monitoring of these programs to determine the effects on the fishery is essential if meaningful reservoir management is to occur.

To date, well conceived habitat improvement plans have been developed for Lake Berryessa, Lake Isabella, and Shasta Lake. Additional planning is required for the remaining 20 Central Valley reservoirs investigated before a comprehensive program to address the problem of limited cover habitat can be implemented.

7. Limited Spawning Habitat

Water fluctuation during the centrarchid spawning period is a significant problem at Lake Isabella. Largemouth bass in particular are adversely affected by this fluctuation. It was suggested in the Isabella Lake Management Plan (CDFG 1978) that the water level not fall more than two vertical feet or rise more than five vertical feet during the 2-3 week spawning period. It is suggested that an agreement limiting water fluctuations be finalized with the Army Corps of Engineers, which owns and operates Lake Isabella.

Water-level fluctuations, shoreline wave action, and cattle grazing reduce and limit vegetation in the fluctuation and littoral zone. Vegetation provides protective cover for juvenile fish, substrate

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for aquatic insects, and recycles nutrients tied up in sediments. Grazing in the fluctuation zone is the easiest of these problems to address. Grazing has been eliminated from some critical areas, but further reduction or elimination of grazing has been recommended by personnel of the Department of Fish and Game. Planned and completed habitat improvement through vegetative planting is discussed in detail in the individual reservoir report for Lake Isabella.

Reservoir fluctuation during spawning season limits the reproductive success for centrarchids in Folsom Lake also. An agreement between the Department of Fish and Game and the U.S. Bureau of Reclamation (owner and operator of Folsom Lake), similar to the proposal suggested for Lake Isabella, would reduce the detrimental effects of water-level fluctuations on spawning centrarchids in Folsom Lake. It is essential that priority be given to the formulation of a specific written habitat improvement and management plan for Folsom Lake, similar to that which exists for Lake Isabella. In the interim, habitat improvement practices developed for Lake Isabella to improve the centrarchid fishery in general, and the largemouth bass fishery in particular, should be adopted for Folsom Lake.

In addition, improvement of spawning conditions in the tributaries to the lake would enhance salmonid recruitment. Upstream hydroelectric projects on the South Fork of the American River release irregular quantities of water which can vary from 100-2,000 cubic feet per second daily. If an adequate uniform flow of water could be guaranteed during spawning periods (April-May) and when the eggs are in the stream gravel, natural recruitment would be improved.

8. Limited Littoral Habitat

The quality and amount of littoral habitat available to fishes in Central Valley reservoirs is dependent on, and related to several physical and chemical factors previously identified in Part III. The depth component is the most important factor in determining the potential area available for littoral habitat development in Lake Natoma and Lake Oroville. The costs associated with increasing the area of shallow-water littoral habitat available to game fishes along the predominately deep shoreline areas existing in these two reservoirs would be excessive. For this reason, solutions for the improvement of littoral habitat, in order to increase fish production, should be implemented on existing limited shallow-water habitats. Potential solutions for improving the quality and increasing the quantity of existing shallow-water littoral habitats with particular reference to Lake Natoma and Lake Oroville are as follows:

a. Scheduling of reservoir releases in order to reduce diel and seasonal surface elevation fluctuations when target game fishes are using shallow littoral habitat for spawning and rearing of young. Ideally, water-level fluctuations should be kept at a minimum throughout the year in order to maintain species diversity and population stability of the littoral zone community. For example, annual drawdown in Lake Oroville (averaging 75 feet), especially during the fall, displaces centrarchids from mostly shallow, productive littoral habitats into the deeper areas of the reservoir. Recolonization of these littoral areas in the spring requires energy and may reduce reproductive success of the fishes.

b. <u>Revegetation of the fluctuation zone with terrestrial plant species capable of withstanding periodic inundation</u>. Beginning in 1973 and continuing through 1978, a program was initiated by the California Department of Fish and Game to increase cover within the fluctuation zone of Lake Oroville (Brouha and von Geldern 1978). A detailed discussion of this program is presented in the individual reservoir report for Lake Oroville (see Appendix). Discussion of other potential solutions for improving littoral habitat in Central Valley reservoirs in relation to cover and spawning habitat is presented in the evaluation of limited spawning habitat and limited cover habitat previously presented in this Part.

c. <u>Reduction of wave action from boat wakes</u>. This will decrease the loss of aquatic vegetation and reduce erosion in shallow inshore littoral habitats. Implementation and enforcement of "no wake" zones within a certain distance of the shoreline would reduce wave action. Discussion of other potential solutions for improving littoral habitat in Central Valley reservoirs in relation to shoreline erosion is presented in the review of that topic presented later in this Part.

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9. Low Water Fertility

Because low water fertility is a function of geochemical conditions in the watershed and human activities influencing the amount of nutrients entering the reservoir (e.g., land use, water pollution), there is little that can be done to directly improve the fertility of reservoir water. While it is conceivable that the five reservoirs with this problem listed in Table 4 could be fertilized by the addition of nutrients to the water to stimulate production, this is not the recommended solution. Fertilization of lakes to stimulate phytoplankton production, which, in turn, is eventually manifest in fish production, has been attempted on a small scale for experimental purposes. It has never been attempted on large reservoirs. The reasons for not pursuing reservoir fertilization as a fishery management tool are:

a. Water quality constraints, i.e., many reservoirs are sources for domestic water supplies.

b. Recreational constraints, i.e., water sports and other types of recreation might be impaired.

c. Cost, i.e., a sustained fertilization program on a large reservoir would be prohibitively expensive.

d. It is not a proven management technique for large impoundments.

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e. Other limiting factors, for example, water-level fluctuations or cover habitat, which may mask the results of the program.

If the objective of the fishery manager is to increase sport fish harvest to the angler, then his/her efforts would be more profitably directed toward improving survival and growth of the fish that are produced in the reservoir under existing conditions of water fertility. By similar argument, fish stocking on a put-and-take basis may be a management technique that circumvents the problem of low water fertility.

This investigation found no reasonable and proven fishery management technique directly applicable to improving the productivity of reservoir water itself. It is likely that low fertility will be a permanent constraint on fish production in the five Central Valley reservoirs experiencing this problem.

10. Water Quality Problems

Water temperatures, low dissolved oxygen levels, hydrogen sulfide, iron and manganese, and heavy metals pollution were identified as water quality problems in one or more of six Central Valley reservoirs (Tables 4 and 5). Potential solutions to each of these water quality problems are presented in this section.

Water Temperatures. High water temperatures are often associated with low dissolved oxygen levels and production of hydrogen sulfide gas. Solving the temperature problem also may solve problems with oxygen and sulfide. Unfortunately, the only practical method of reducing high water temperatures at New Hogan Lake and Success Lake is to significantly increase the volume of the minimum reservoir pool for fish to the extent these reservoirs stratify in the summer, producing a cool hypolimnion. The success of this approach rests on the condition that the minimum pool can be increased, and, that if it were increased, the hypolimnion would not continue to have a low dissolved oxygen problem. The first assumption may be incorrect and can be validated only by reviewing the reservoir operations schedule or by performing an operations study to determine if water can be reallocated. It appears that without reallocation of reservoir storage in both New Hogan and Success Lakes, opportunities for increasing the minimum pool do not exist. On that basis, there is no solution to the temperature problem. Consequently, the Department of Fish and Game's present management program of providing a put-and-take trout fishery in these two reservoirs is reasonable if it meets the goals and objectives of the fishery management plans (specific written plans are not yet written for these two reservoirs).

Keswick Reservoir faces the opposite problem of cold water temperatures originating from below the hypolimnion in Shasta Lake. Aquatic productivity and fish growth has apparently been limited by very low temperatures. The only feasible solution to cold water temperatures is to release warmer epilimnetic water from Shasta Lake in a mixture that optimizes the water temperature for fish production. It may be possible to modify water intake structures at Shasta Dam to provide some control of the temperature of released water. An operations study may be necessary to determine the effects of altered Shasta Lake releases on Keswick Reservoir temperatures. It is important to note that Keswick Reservoir has an extremely high flushing rate of less than two days (Table 10). Under this condition, aquatic productivity is limited by the rapid cycling of nutrients through the reservoir and reduced productivity associated with short flushing times. Thus, the benefits of improved water temperatures to aquatic resources may be masked by the consequences of a high flushing rate.

Low Dissolved Oxygen Content. Three reservoirs suffer from low dissolved oxygen levels (DO) seasonally during the summer months. Low DO in Hensley Lake and Success Lake is directly related to the decomposition of decaying vegetation in the hypolimnion. Dissolved oxygen levels of less than 5 mg/l have been reported (CDFG files). The problem in Hensley Lake originates from vegetation still decaying from the time of inundation in 1975. It is anticipated that the problem will eventually correct itself over time as the decomposition process comes to an end. Success Lake, however, faces a continuing problem which appears to be related to high levels of organic material loading from inflowing water to the reservoir which promotes anaerobic decay.

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In both of these reservoirs the hydrogen sulfide problem is directly linked to decay and low DO levels. The low dissolved oxygen problem and the hydrogen sulfide problem can be solved simultaneously by artificial aeration-destratification of the reservoirs. The aeration-destratification process is summarized succinctly by Nelson et al. (1978) as follows:

> "Aeration can be described as a process by which oxygen is added to or assimilated by water. Destratification is a process by which the density layering of a body of water is disrupted. By forcing the colder, denser water from the bottom of a reservoir to circulate with water from the surface, temperature and density differences are decreased, allowing wind and convection currents to further mix the impoundment. The processes of aeration and destratification are usually interdependent, i.e., when one occurs, the other does also. The extent of this, however, depends on the method used to effect aeration or destratification.
>
> Several objectives may be met by aerating and destratifying a reservoir. Destratification will lower surface water temperatures during the summer, which can reduce evaporation losses and control algae growth. Aeration can reduce the effects of eutrophication by providing critical oxygen to the water for metabolism and decomposition. Lake productivity can be increased by circulating nutrient-rich water from the bottom strata. In addition, the quality of discharge water can be improved by aeration and destratification in the reservoir.
>
> Many types of equipment and methods have been used for aerating and destratifying. A more complete review can be found in King (1970) and Toetz et al. (1972). The injection of compressed air is one technique which has been used. The air can be released using a diffuser such as perforated pipe anchored to the bottom of the reservoir. Some immediate aeration results from the air bubbles, but the primary function is the "chimney effect" by which water from the bottom is raised in a current established by the rising bubbles. This produces destratification and additional aeration when the water comes in contact with the atmosphere at the surface.
>
> Liquid oxygen can be used as a means of reservoir aeration. Molecular oxygen is released through a diffuser, such as a perforated pipe or ceramic plate, which breaks the flow into small bubbles. As the bubbles rise through the water, the oxygen is absorbed directly. Stratification in the reservoir is maintained because only small amounts of gas are released."

"Other techniques for aeration and destratification include surface spraying, cascade weirs in inflow streams, submerged weirs, mechanical agitators, and "U-tubes". The reports mentioned above (King; Toetz, et al) provide reviews of these techniques as well as bibliographic references.

Aeration and destratification have usually been successful towards increasing dissolved oxygen concentrations, decreasing levels of carbon dioxide, hydrogen sulfide and ammonia, and increasing survival and production of zooplankton and fish. Additional habitat has been provided by the prevention or reduction of anoxic conditions in some reservoirs. A more indepth analysis of physical and biological reactions to aeration and destratification is provided in Toetz, et al. Constraints on these procedures include the costs for equipment, materials, and operation. The labor necessary to maintain some of the devices such as pumps and compressors may be a limiting factor. Costs for aeration and destratification may be offset by reduction in the need for annual stocking due to summer or winter fish kills; the increased yield of the fishery because smaller fish can be stocked without fear of seasonal kills; and the reduced need for extensive filtering and chlorination for an adequate drinking water supply.

Additional constraints include the possibility of promoting anoxic conditions by the resuspension of decomposing sediments. This is particularly critical during the first year of operation, though the possibility of anoxia should decrease as seasons of aeration continue. Also, by destratifying a reservoir, overall water temperature or the heat budget will fall below normal during the winter and climb above normal during the summer. This may reduce or eliminate some of the resident biota of the reservoir. A solution to this problem may lie in hypolimnetic aeration. With this technique, only the hypolimnion is aerated while the temperature regime and stratification pattern are not altered significantly. Thus it may be possible to maintain a "two-story" fishery, i.e., a warmwater fishery in the epilimnion and a coldwater fishery in the hypolimnion. Again, Toetz, et al provide further discussion."

Hydrogen Sulfide Problems. See the previous discussion on Low Dissolved Oxygen Content.

Iron and Manganese Problems. This problem is unique to Jenkinson Lake and does not appear to be solely a fisheries issue (see Part III of this report). Iron and manganese in solution can be eliminated by

1) aeration of the water (see discussion on Low Dissolved Oxygen Content), or by 2) filtering the water supply. This latter solution is irrelevant to fishery management concerns. The degree to which iron and manganese are seasonal fishery problems at Jenkinson Lake is unknown. Further study of this issue at the reservoir is necessary to determine if the identified problem is of management concern. Only after a study is concluded can appropriate solutions to the problem be discussed in a constructive manner.

Heavy Metals Pollution. Chronic water quality problems associated with heavy metal pollution occur in both Keswick Reservoir and locally in Shasta Lake. Keswick Reservoir receives water contaminated with the heavy metals copper, zinc, and cadmium primarily from Spring Creek. The Spring Creek arm of the reservoir is polluted with heavy metals from mining activities in the Spring Creek drainage. The optimum solution to the heavy metal pollution problem would be to eliminate all point sources of effluent outflow. Non-point sources would be more difficult to control. Installing fish barriers to prevent fish from entering the dilution zone also should be considered.

In Shasta Lake, chronic heavy metals problems occur in the Little Squaw Creek and Backbone Creek arms of the lake. Fish kills regularly occur in these areas. Smaller concentrations of metals enter Shasta Lake from the Bully Hill Mine on the Big Squaw Creek arm of the reservoir. Solutions to the heavy metals pollution problem in Shasta Lake must focus on eliminating the problem at its source.

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This report does not discuss solutions to the heavy metals problems further. Two Special Reports of the Central Valley Fish and Wildlife Management Study focusing on Problems C-1 and C-8 address the heavy metals pollution problems at Keswick Reservoir and Shasta Lake, respectively, in detail.

11. Limited Fishery

The specific issues identified in the limited fishery problem category are discussed in Part III of this report. A discussion of potential solutions follows.

The problem of insufficient numbers and size of largemouth bass in Black Butte Lake and Hensley Lake is not well understood. The implementation of a voluntary 12-inch size limit on bass at Black Butte, and a 12 to 15-inch slot-limit at Hensley Lake, are being tried in attempts to produce larger fish for the creel and to stimulate improved juvenile recruitment. These are reasonable fishery management measures. However, it should be noted that factors other than harvest rate (e.g., water-level fluctuation, limited cover habitat for juvenile bass, undesirable fish species competition, and poor water quality), may influence the population structure of largemouth bass to a large degree. Insufficient fishery data are available to fully assess all of the causative factors restricting bass population development. The ultimate solution to this problem at Black Butte and Hensley requires specific research on the dynamics of the bass fish populations before definitive fishery management practices can be implemented.

In the case of Shasta Lake, the survival of young-of-the-year bass can be addressed by focusing on improving cover habitat and by insuring that adequate numbers of adult fish are available to reproduce. This latter issue has been addressed at Shasta Lake by implementation of a 12-inch size limit on bass in 1982. This report fully discusses improvement of cover habitat in the review of that problem. The reader is referred to that section.

The declining striped bass harvest in San Luis Reservoir is probably related to similar declines in striper abundance in the Sacramento-San Joaquin River Delta. It is unlikely that, outside of stocking additional stripers in the reservoir, any management technique can be successfully applied to solve this problem. Successful fishery management rests on understanding the causative factors of the decline. To date, these factors are not understood.

The difficulty in harvesting trophy salmonids at Lake Oroville cannot be overcome readily. Fishing for these species is a specialized type of fishing requiring access to deep water during the summer. Thus, a boat is required. Shore anglers will not have the opportunity to fish for trophy salmonids except during the fall through spring period when the reservoir destratifies and these fish are near the surface and closer to shore. Replacing the trophy salmonid fishery with a striped bass fishery has been proposed. This concept, if successful, would produce a fishery more accessible to boat anglers year-round, but not necessarily more accesible to shore anglers. It appears likely that the forage fish resource of Lake Oroville (threadfin shad and pond smelt) might be better utilized by striped bass than by salmonids. If so, then a more productive fishery for the angler might be developed by introducing striped bass.

The limited fishery at Success Lake can be improved by reducing excess harvest of largemouth bass to encourage better juvenile recruitment and by educating anglers to the availability of the apparently underutilized catfish resource. A 12-inch bass size limit is at present in effect at Success Lake. Hopefully, this management tool will address the bass overharvest problem. Discussions of excessive harvest and underharvest were presented previously in this report. The reader is referred to these sections for a full analysis.

12. Forage Fish Related Problems

Forage fish related problems were defined and discussed in Part III of this report. A discussion of potential solutions for each reservoir follows.

Englebright Reservoir apparently has available limnetic habitat that could potentially support a productive sport fishery but does not do so now because no forage fish resource is available. Unfortunately, not enough information is known about the limnology or aquatic ecology of Englebright Reservoir for the proposal of specific fishery management practices. A potential management option may be to introduce both a limnetic forage fish species, and a sport fish that will utilize this food resource. Implementation of this option is not recommended

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until carefully conducted baseline studies are concluded at Englebright and it is determined, based on sound fishery management principles, that the reservoir can support new fishery resources successfully.

Increasing the forage fish resource at Whiskeytown Lake may not be possible without significant changes in the operation of the reservoir. Cold water temperatures and high flushing rates limit forage resource productivity. These conditions are inherent in the operation of the lake and will undoubtedly continue to retard the fishery potential. Additional efforts to locate a new forage resource adaptable to the environmental conditions in Whiskeytown may be profitable. New introductions must not be attempted without careful study of the potential impact to the entire reservoir fishery resource.

The apparent underutilization of threadfin shad and pond smelt at Lake Oroville may be addressed by evaluating the introduction of a new sport fish capable of using these resources. Striped bass has been proposed as a species capable of pelagic foraging for both shad and smelt. Striped bass may have the advantage of also being more accessible to anglers than are the presently stocked salmonids. Caution must be exercised in evaluating a potential introduction such as that of striped bass. Potential impacts from introduced species to other desirable sport fishes in the reservoir must be assessed fully.

There is no clear-cut solution to the problem of fluctuating population abundance of threadfin shad in Shasta Lake. A full understanding of the problem based on well documented research is required before solutions can be implemented. Additional forage species have been considered for introduction. However, without adequate knowledge of the problem, this is a hazardous trial-and-error approach to problem solving. Further assessment of the problem and its causative factors is necessary before sound fishery management practices can be implemented.

The apparent problem of pond smelt competition with juvenile largemouth bass in Lake Oroville is not readily resolvable. While pond smelt may restrict bass survival by competing for food and space, they have been an apparent benefit to various salmonids and smallmouth bass populations. Resource trade-offs may be involved in addressing this problem. The introduction of a predatory game fish that utilizes smelt may reduce bass/smelt competition to an unknown degree. A more careful evaluation of bass/smelt interactions designed to address the degree of the problem is necessary prior to the development and implementation of a management program. Other factors, or combinations of factors, (such as, water-level fluctuation, limited cover habitat, and limited littoral habitat (Table 4)), may be more constraining on the largemouth bass population than competition with pond smelt.

13. Undesirable Species

The control of undesirable species is an important fisheries management tool. The following discussion addressing the control of undesirable fishes relies on excellent reviews of the problems by Meyer (1963) and Nelson et al. (1978). These reviews are freely quoted.

Barrier Dams. Stream barriers, or barrier dams, have been proposed as methods for restricting the stream spawning habitat available to undesirable species within a reservoir and for preventing competition between undesirable species and game fishes in spawning habitat at two Central Valley reservoirs (Shasta Lake and Whiskeytown Lake - see Table 6). Barrier dams restrict the movement of fish populations by creating turbulence, high water velocities, and shallow water depth. According to Nelson et al. (1978) the

> "primary constraints on using barrier dams concern high construction costs and difficult site selection. Ideal stable site conditions are nearly impossible to find and very expensive to create. The wider the stream or river the more difficult it becomes to establish the necessary head differential. In addition, many streams where barriers are needed are subject to periodic high water and flooding which can wash out all but very stable structures. Maintenance and replacement costs also may be limiting factors."

It should be noted that barrier dams have been used successfully on Hat Creek, California. In this case, nongame fish are prevented from moving into Hat Creek from Lake Britton and the Pit River.

Fish Eradication. According to Nelson et al. (1978):

> "Fish eradication is a drastic control measure deemed necessary when too much of the total fish productivity of a stream or impoundment has favored undesirable fish species. This measure is used to provide desirable sport fish with a short-term advantage over competitive rough fish. Generally, a complete elimination of all fish species is sought and sport fish are restocked following treatment. However, in most cases only a partial eradication is obtainable. The most frequent targets of eradication programs include several species of suckers, chubs, and carp. In addition to competing with game fish for food and habitat, some species such as carp can interfere with aquatic plant production and subsequent waterfowl use.
>
> The most common method of fish eradication is the introduction of a toxicant such as rotenone to the water. To improve the economy

and effectiveness of this measure, toxicants usually are applied to whole watersheds above dams before final closure. McKnight (1975) provides an excellent review of this and other fish toxicants.

Other methods include the use of explosives (Tabe, et al, 1973), drawdown, introduction of non-native predators such as striped bass and northern pike, and commercial harvest where a market exists or can be established.

A major constraint on eradication programs is their temporary nature. Complete eradication of undesirable fish species is an almost impossible task because of the great difficulty in reaching all unfiltered water and potholes existing within a reservoir site. Even when the initial eradication is highly successful, conditions can be expected to return to pre-treatment levels in three to ten years. To prevent rapid degradation following treatment, a barrier dam or other control device may be necessary although installation may be too costly or technically infeasible."

The eradication of nongame fishes from reservoirs is not always warranted. According to Meyer (1963), the damage attributed to these undesirable species

"must be balanced against their benefit as forage, especially in large lakes. In Eagle Lake [California], for example, where tui chubs (Siphateles) act as forage for a unique game fish population, treatment would not be desirable. Native species of fish with restricted distributon must always be given careful consideration before a treatment program is carried out. There can be no excuse for risking extermination of any native species. The Department [of Fish and Game] is obligated to protect them as unique natural resources."

All five Central Valley reservoirs identified in Table 4 as having excessive nongame fish populations have at one time been treated with fish toxicants to remove undesirable fishes. Four of the five reservoirs carried out toxicant eradication of fishes prior to filling. Dates of treatments for these Central Valley reservoirs are presented in Table 12.

Table 12. Central Valley reservoirs treated with fish toxicants to eliminate undesirable fishes[1/]

Reservoir Name[2/]	Year of Treatment	Degree of Success
East Park Reservoir	1959, 1977	Limited, short-term
Lake Kaweah	1961	Limited, short-term
Stony Gorge Reservoir	1963	Limited, short-term
Black Butte Lake	1963	Limited, short-term
Whiskeytown Lake	1962	Limited, short-term

1/ California Department of Fish and Game files

2/ Includes only those reservoirs identified as having problems with undesirable fishes (See Table 4)

The fact that all five reservoirs are identified today as having nongame fish management problems demonstrates the limited and short-term success of fish toxicants in controlling or eradicating undesirable fishes in large reservoirs. In addition, the political and environmental constraints that are inherent in the use of fish toxicants in public reservoirs are increasingly evident, given current State water quality standards.

At Lake Kaweah, white bass pose both a political problem and a biological one. The white bass population is apparently increasing and it provides sport fishing to local anglers. Measures to eliminate the bass have met with strong public opposition. The California Department of Fish and Game had the opportunity to eliminate white bass from Lake Kaweah in 1977 through the use of fish toxicants, but did not proceed because of public pressure against the plan. A second plan to introduce striped bass to control white bass was also strongly opposed by local anglers. White bass have now spread to Tulare Lake downstream of Lake Kaweah and threaten expansion to the San Joaquin River.

Further political opposition to control or eradication of white bass from Lake Kaweah may only insure its eventual spread into the Sacramento-San Joaquin River Delta. To date, an acceptable solution to the white bass problem has not been found.

Densities and biomass of Asiatic clams (Corbicula sp.) found in Lake Isabella, vary with food supply (phytoplankton), substrate, and location (CDFG 1978). Even if it can be determined that the Asiatic clam is significantly decreasing phytoplankton concentrations, resulting in limitations of the food web leading to the more desirable game fish species, control of this species may be unfruitful. Mechanical control is largely ineffective. Biological control may be possible through the introduction of additional predator species such as redear sunfish or channel catfish. The best alternative is probably through water level manipulation. Occasional extreme drawdowns may be effective in reducing Asiatic clam populations in the littoral areas. Unfortunately, extreme drawdowns may also adversely affect desirable fishes as well.

In order to more fully understand the significance of the Asiatic clam and its function in the lake ecosystem the Isabella Lake Management Plan (CDFG 1978) states that it will be necessary to:

" 1. Initiate investigations directed towards evaluating Asiatic clam biomass and densities, and their relationship to plankton in the aquatic media.

2. Evaluate the potential for introducing redear sunfish and channel catfish into Isabella Lake as a biological control of Asiatic clam.

3. Determine what lake level manipulations or other measures would be necessary to reduce the Asiatic clam population in the littoral areas."

Until further research identifies specific nongame fishes of concern and the degree to which nongame fishes (and the Asiatic clam in the case of Lake Isabella) affect the sport fisheries of Central Valley reservoirs, it is not possible to speculate as to which management practices are most suited to addressing the problem. The development of specific written management goals for dealing with the problem of undesirable species at each reservoir is a necessary first step.

14. Shoreline Erosion

Shoreline erosion has been identified as being caused by a combination of physical and biological factors, often working together to exacerbate the problem. Excessive cattle grazing, wave erosion from recreational boating, and fluctuating water levels all reduce the establishment and maintenance of shoreline vegetation. Shoreline vegetation is an extremely important factor in reducing shoreline erosion.

Heavy grazing on the banks around a reservoir eliminates protective soil cover, decreases the survival of vegetation (through browsing and trampling), and eliminates grasses which could provide cover for fish when inundated. A solution to reduce the impact of excessive cattle grazing, and subsequent erosion, on shoreline habitats is to implement grazing leases that specify the time of grazing and specific location of grazing allotments, as well as establish the stocking rates and animal unit capacities. The stocking rate is the number of acres per animal unit permitted for grazing on various range sites under various conditions. An animal unit is the amount of forage necessary to feed a

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certain-weight animal for a specified grazing period. For each range site, the stocking rate and time of grazing must be set independently each year to avoid overgrazing and shoreline habitat degradation. This flexibility in grazing rates is especially needed to allow for reduced rates during drought years. It has been suggested that rates be set so as to remove only one-half or less of the current year's vegetation growth. Furthermore, these rates should allow only for the use of excess forage over fishery needs.

According to Nelson et al. (1978), if terms for grazing allotments are fixed for more than one year for an established number of animal units, overgrazing will likely occur. Even if animal units are not exceeded, overgrazing will occur in drought years. The optimum rate of grazing cannot be predicted several years in advance. In addition, grazing control is further limited by noncompliance with lease conditions. For these reasons, grazing leases bordering reservoirs should be scheduled for short periods of time and for intervals that will not conflict with the use of spawning and rearing habitats by fishes. Enforcement of grazing leases is necessary.

Cattle should be excluded entirely from shoreline and littoral habitats that contain important spawning and rearing areas for fishes. In addition, habitats with extensive aquatic and riparian vegetation should be fenced to exclude cattle. Fencing used in conjunction with leases to control grazing and exclude livestock from shoreline habitats is essential for the protection of productive littoral habitats of reservoirs. Fencing along reservoir shoreline should be set back a

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sufficient distance from the water to ensure protection for riparian vegetation. This important vegetation provides cover for fish and helps protect against sedimentation, turbidity, and bank erosion (Nelson et al. 1978). Fencing may not be an appropriate measure for some reservoirs. Inundated fences are a boating hazard, and periodic inundation increases the cost of fence repair and replacement.

Other proposed solutions to the shoreline erosion problem include:

a. Exclusion of motorboat use and waterskiing from areas of a reservoir containing important spawning and rearing habitat for fishes. This includes habitats with extensive amounts of aquatic and riparian vegetation. Designation of restricted areas for boats and water skiing can be accomplished with signs posted on buoys. Patrolling of restricted areas would be necessary. Low speed limits should be set for motorboats within a certain distance to shoreline in order to reduce erosion from waves.

b. Reduction of the extent and duration of water-level fluctuations on all Central Valley reservoirs. The reader is referred to the review of water-level fluctuations within this Part for a detailed discussion of potential solutions in relation to fishery management practices.

c. Initiation of programs to revegetate eroded shoreline habitats with aquatic and riparian vegetation. The reader is referred to the review of limited cover habitat within this Part for a detailed discussion of potential solutions in relation to fishery management practices.

It should be stressed that the proposed solutions to the problem of shoreline erosion in Central Valley reservoirs must be initiated as a single management strategy. Shoreline erosion is caused by a combination of physical and biological factors, often working together to exacerbate the problem. Thus, solutions to the erosion problem must be comprehensive, in order to develop an effective fishery management program.

15. Multiple Use Conflicts

Power boat recreation uses were identified as adversely affecting optimum sport fishery management at four Central Valley reservoirs (Table 4). Disturbance to anglers, loss of fish production, and shoreline erosion were the impacts noted. All three of these adverse impacts may be addressed simultaneously for each reservoir by implementation of speed zoning at specific locations or times of the year. Before speed zoning is implemented, it is essential that the zoning proposals be designed to achieve specific objectives as identified in the fishery management plan for the reservoir. This has been accomplished at Lake Berryessa but not at the remaining three reservoirs which have no specific written management plans. The reader is referred to the individual reservoir report for Lake Berryessa (contained in the Appendix) for examples of specific speed zoning proposals included in a fish habitat improvement plan. Speed zoning, by regulating reduced boat speeds in specific areas of the reservoir, is an effective fishery management tool for addressing the three adverse impacts previously cited.

Solutions to the problems generated by livestock grazing may be achieved in several ways related to prudent land use management and consideration of the needs of fishery resources. Because livestock grazing is directly related to erosion control issues, the reader is referred to the previous section which discusses in detail solutions to the grazing problem.

16. Angler Access

As noted in Part III of this report, the problem of angler access is evaluated as part of Problem C-5 of the Central Valley Fish and Wildlife Management Study. The reader is referred to the Special Report on "Fishing Access at Major Project Facilities" for solutions to this problem.

In general, angler access is not a major fishery management issue at most of the Central Valley reservoirs investigated. At two reservoirs, Englebright and Natoma, physical access was severely restricted, thus preventing full angler use of the reservoir fishery available. The solution is to provide improved angler access at appropriate locations at each of these two reservoirs.

PART V

FISHERY BENEFITS

Assessment of Fishery Benefits

The fourth objective of this investigation is to evaluate the expected recreational fishery benefits (as measured by fish returned to the angler) resulting from improved fishery management. This objective has proved to be elusive for two reasons. First, without specific reservoir fishery management plans to use as guidelines for 21 of the 23 reservoirs investigated, it is difficult, if not impossible, to determine what the long-term fishery management goals and objectives are. Consequently, reservoir-specific management options could not be identified with certainty. This made it impossible to evaluate the expected benefits to the fishery of implementing these options.

Second, there is no developed quantitative methodology for relating the costs of resources (e.g., time and material) applied to improve fish populations or their management, to the resultant benefit to the recreational angler. The state of the art of fishery management science has not developed sufficiently to allow this type of assessment to be made. Many years of further research will be required before managers can reliably predict the biological outputs resulting from the application of specific management techniques. The fundamental reason for this gap in the ability to predict the consequences of management measures originates in the nature of biological systems.

Fish populations in reservoirs are components of a larger complex ecosystem. Ecosystems, while understood on a conceptual basis, have been inherently difficult to model. Only in recent years has significant effort been expended to describe and predict how reservoir ecosystems will function in response to environmental changes (Johnson 1981; Leidy and Jenkins 1977; Leidy and Ploskey 1980; Lorenzen et al. 1981). At the present time, the understanding of cause and effect relationships between reservoir fishes and various factors in their environment is limited.

Reservoir fishery managers can state confidently that specific types of management techniques will generally benefit fish populations (e.g., placement of artificial cover habitat or reducing water-level fluctuations). However, the fishery manager's ability to determine what type, quantity, and quality of measures must be implemented to produce the desired product to the angler is extremely limited. In fact, this determination rests solely on informed professional judgment - not quantitative analysis.

During the investigation of fishery management problems at individual reservoirs, fishery managers from the California Department of Fish and Game were asked to use their professional judgment and speculate as to the magnitude of fishery benefits resulting from implementation of a comprehensive fishery management plan. While some managers did not wish to make such estimates, those that did believed that fishery benefits, expressed as fish harvested by anglers, could be improved by two to four

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times current levels. Of course, these estimates are not estimates of net economic benefits over costs, since no estimates of the costs to implement management plans were developed.

It should be noted that the economic costs of implementing specific fishery management measures can be calculated with reasonable accuracy. For example, the cost of constructing and placing 100 tire reefs in a reservoir or of planting 1000 willow sprigs is a straightforward calculation based on material and manpower costs. The difficulty in completing the benefit/cost analysis lies in the estimation of economic benefits attributable to management practices. Assuming fishery managers could accurately predict the increase in numbers of fish harvested by anglers resulting directly from management practices (which they cannot), a monetary value could be assigned to the fish harvested and a benefit/cost assessment could be derived. Thus it is clear that the key to developing useful benefit/cost forecasts depends on the fishery manager's ability to link management practices to a quantifiable product produced, i.e., fish harvested by anglers.

While this report cannot address with confidence the issue of economic benefits and costs attributable to fishery management planning, for the reasons previously discussed, it can offer a strategy for developing this information.

Strategy for Evaluating the Benefit/Cost Concept in Reservoir Fishery Management Planning

As has been discussed in the preceding paragraphs, the problem of developing sound benefit/cost estimates lies in the fishery manager's ability to bridge the gap between specific management measures implemented and estimating the product produced (fish) which can be directly attributable to those measures. Bridging this knowledge gap will require the development of new quantitative methodologies for the fishery manager to use. These new methodologies can only be developed based on a carefully planned research program that focuses on the evaluation of specific management practices (i.e., habitat improvements, reservoir operational modifications, land use restrictions). Such a research program is feasible with current knowledge, provided there is adequate organizational and financial support for such a program over an extended time period.

This report concludes that a logical strategy for developing the much-needed information linking management practices to angler harvest of fish could be implemented as a pilot research program at one or more of the 23 Central Valley reservoirs investigated. Such a research program should be undertaken by the California Department of Fish and Game with the cooperation and support of the reservoir operating agency.

The duration of a pilot research program of the type described would depend on the specific program objectives as defined at the planning stage. A reasonable estimate for such a research program might be ten years. The cost of implementing a research program would also depend on the objectives of the program. The total cost of a research program for one reservoir might be from $400,000 to $1,000,000 over a 10-year period.

The results of the specific studies undertaken during the program would be used to develop the assessment methodologies previously described. The results of the research program could then be applied to the management of other Central Valley reservoirs, and perhaps to reservoirs elsewhere in the United States.

Although Central Valley reservoir managers agree that the reservoirs have additional fishery potential, it will not be possible to confidently forecast the economic benefits of improved reservoir management until the results of a research program of the type described are available.

PART VI

FINDINGS AND CONCLUSIONS

Findings

Based on the results of the investigations made for this report, the analysis of fishery management problems at 23 reservoirs revealed 16 problem categories as follows:

1. Absence of a fishery management plan
2. Limited fisheries data
3. Water-level fluctuation
4. Excessive harvest
5. Underharvest
6. Limited cover habitat
7. Limited spawning habitat
8. Limited littoral area
9. Low water fertility
10. Water quality problems
11. Limited fishery
12. Forage fish related problems
13. Undesirable species
14. Shoreline erosion
15. Multiple use conflicts
16. Angler access

Each of these problem categories was defined and analyzed in Parts III and IV of this report.

Each reservoir had from three to eight problems identified as being of management concern. While some fishery management problems were limited to only a few reservoirs, many were generic and occurred widely (Table 4). The most important institutional constraint on efficient and effective fishery management of the Central Valley reservoirs was the lack of detailed fishery management plans for 21 of the reservoirs investigated. Without the benefit of identified management goals and objectives that are reservoir-specific, it is unlikely that coherent and comprehensive reservoir management will occur. Management plans provide direction and continuity to management decisions. These plans ensure the efficient use of limited resources to meet specific needs.

Limited data on the fisheries of Central Valley reservoirs handicaps the fishery scientists responsible for making the management decisions. While new data are being collected each year as the result of ongoing research and management programs, most of the existing data are not released in a medium or format suitable for review or use by other fishery workers. Some of the data available were fragmented, reflecting the lack of continuity in research programs.

The data requirements should address clearly the goals and objectives of the reservoir-specific management plans. Until such plans are developed it will not be possible to ensure that research efforts focus not only on collecting the right data, but also on collecting the highest priority data first.

Of the 14 environmental conditions identified as management problems, the most prevalent and severe problem was water-level fluctuation. The problem is widespread and affects other problems such as limited cover habitat, limited littoral habitat, and shoreline erosion. The solution to fluctuating water levels hinges on whether there are opportunities for revising reservoir operations consistent with meeting water supplies and flood control needs. Because most Central Valley reservoirs are operated for flood control and irrigation purposes, and because these two project purposes inevitably result in extreme water-level fluctuations, it is unlikely that full resolution of this problem will be possible for each reservoir. Water-level fluctuation will be a permanent management problem for fishery biologists.

The second important environmental problem identified for Central Valley reservoirs is the limited nature of cover habitat for warmwater sport fishes. Cover habitat can be created by implementing corrective management measures. However, on large reservoirs, cover habitat development is a long-term process requiring the commitment of large amounts of limited resources. Careful assessment of the expected benefits to the fishery from large-scale habitat-development projects must be completed prior to the long-term commitment of resources.

The remaining 12 fishery management problems identified in this investigation are more reservoir-specific than those just discussed and are reviewed in Part III of this report.

A quantitative benefit/cost analysis of the expected recreational fishery benefits which could be realized with optimum fishery management is beyond the present state of the art of reservoir fisheries science. Informed professional judgment suggests that angler use and harvest could be improved. The degree of improvement and the amount of money required to achieve target benefit levels cannot be reliably determined without the benefit of new assessment methodologies, based on the results of carefully planned research studies.

Conclusions

The conclusions in this report are based on a review of existing data. No new data were developed specifically for this report. The conclusions follow.

1. All Central Valley reservoirs should have a written fishery management plan developed cooperatively by the California Department of Fish and Game and the agency operating the reservoir.

2. The agencies which operate each reservoir should provide reservoir operational data (i.e., operational constraints, water delivery schedules, water storage allocations, water rights) to aid CDFG in the development of fishery management plans.

3. Reservoir-specific programs to address the fishery management problems identified in this report should be developed, based on the goals and objectives of the fishery management plan.

4. The California Department of Fish and Game and the agency that operates the reservoir should explore the options for jointly financing long-term research programs.

5. A long-term reservoir research program should be initiated to address high priority fishery problems common to many Central Valley reservoirs.

6. The California Department of Fish and Game with the assistance of the reservoir operating agency should commence a long-term program designed to implement specific fishery management improvements that have been determined to be effective in meeting the goals and objectives of the fishery management plan.

7. In order to reliably predict and evaluate the benefits and costs attributable to improved recreational fishery management, a pilot research program, independent of but complementary to the program identified in Conclusion 5, should be undertaken by the California Department of Fish and Game with the cooperation and support of the reservoir operating agencies.

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