MINERAL QUALITY, COLORADO RIVER—SUMMARY REPORT

THE MINERAL QUALITY PROBLEM IN THE COLORADO RIVER BASIN

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UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
REGIONS VIII and IX

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THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency was established by Reorganization Plan No. 3 of 1970 and became operative on December 2, 1970. The EPA consolidates in one agency Federal control programs involving air and water pollution, solid waste management, pesticides, radiation and noise. This report was prepared over a period of eight years by water program components of EPA and their predecessor agencies--the Federal Water Quality Administration, U.S. Department of Interior, April 1970 to December 1970; the Federal Water Pollution Control Administration, U.S. Department of Interior, October 1965 to April 1970; the Division of Water Supply and Pollution Control, U.S. Public Health Service, prior to October 1965. Throughout the report one or more of these agencies will be mentioned and should be considered as part of a single agency--in evolution.

PREFACE

The Colorado River Basin Water Quality Control Project was established as a result of recommendations made at the first session of a joint Federal-State "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries," held in January of 1960 under the authority of Section 8 of the Federal Water Pollution Control Act (33 U.S.C. 466 et seq.). This conference was called at the request of the States of Arizona, California, Colorado, Nevada, New Mexico, and Utah to consider all types of water pollution in the Colorado River Basin. The Project serves as the technical arm of the conference and provides the conferees with detailed information on water uses, the nature and extent of pollution problems and their effects on water users, and recommended measures for control of pollution in the Colorado River Basin.

The Project has carried out extensive field investigations along with detailed engineering and economic studies to accomplish the following objectives:

(1) Determine the location, magnitude, and causes of interstate pollution of the Colorado River and its tributaries.

(2) Determine and evaluate the nature and magnitude of the damages to water users caused by various types of pollution.

(3) Develop, evaluate, and recommend measures and programs for controlling or minimizing interstate water pollution problems.

In 1963, based upon recommendations of the conferees, the Project began detailed studies of the mineral quality problem in the Colorado River Basin. Mineral quality, commonly known as salinity, is a complex Basinwide problem that is becoming increasingly important to users of Colorado River water. Due to the nature, extent, and impact of the salinity problem, the Project extended certain of its activities over the entire Colorado River Basin and the Southern California water service area.

The more significant findings and data from the Project's salinity studies and related pertinent information are summarized in the report entitled, "The Mineral Quality Problem in the Colorado River Basin." Detailed information pertaining to the methodology and findings of the Project's salinity studies are presented in three appendices to that report--Appendix A, "Natural and Man-Made Conditions Affecting Mineral Quality," Appendix B. "Physical and Economic Impacts," and Appendix C, "Salinity Control and Management Aspects."

TABLE OF CONTENTS

Page

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I. INTRODUCTION

STATEMENT OF PROBLEM

The Colorado River system carries a large salt burden (dissolved solids) contributed by a variety of natural and man-made sources. Depletion of streamflow by natural evapotranspiration and by comsumptive use of water for municipal, industrial, and agricultural uses reduces the volume of water available for dilution of this salt burden. As a result, salinity concentrations in the lower river system exceed desirable levels and are approaching critical levels for some water uses. Future water resource and economic developments will increase streamflow depletions and add salt which in turn will result in higher salinity concentrations.

As salinity concentrations increase, adverse physical effects are produced on some water uses. These effects result in direct economic losses to water users and indirect economic losses to the regional economy. Unless salinity controls are implemented, future increases in salinity concentrations will seriously affect water use patterns and will result in large economic losses.

STUDY OBJECTIVES

The objectives of the salinity investigations summarized in this report were to provide answers to the following questions:

What are the nature and magnitude of the major causes of the salinity build-up in the Colorado River and its tributaries?

What future changes in salinity concentrations may be expected if no controls are implemented?

What are the present physical and economic impacts of salinity on water uses, and how will these change in the future?

What measures may be feasible for control and management of salinity in the Colorado River system?

What are the economic costs and benefits associated with various levels of salinity control?

What is the most practical approach to basinwide control and management of salinity?

What action must be taken to implement a basinwide salinity control and management program?

SCOPE

The Colorado River Basin Water Quality Control Project (hereinafter referred to as the Project) was established in 1960 by the Division of Water Supply and Pollution Control, U. S. Public Health Service (predecessor to the Federal Water Quality Administration). The Project was charged with the responsibility for identifying and evaluating the most critical water pollution problems in the Basin. Initial emphasis was placed upon evaluation and control of pollution resulting from uranium mill operations.

As a result of early Project investigations, salinity was identified as a pressing water quality problem which warranted detailed study. In 1963, the Project initiated salinity investigations directed toward answering the questions outlined above. This report summarizes the results of those investigations.

Salt sources contributing to the salinity problem are located throughout the Colorado River Basin. A large volume of water is exported from the Lower Colorado River to areas of Southern California. For these reasons, the geographical area covered by the Project included the entire Colorado River Basin and the Southern California water service area. Colorado River water is also utilized by Mexico. However, investigation of the effects of salinity on Mexican water uses was not within the scope of this study.

A broad range of studies was carried out which involved an array of scientific disciplines including hydrology, chemistry, mathematics, computer science, soil science, geology, civil, sanitary and agricultural engineering, and economics. The Project studies included intensive, short-term water quality field investigations, long-term water quality monitoring, mathematical simulation of water quality relationships, reconnaissance level evaluation of specific salinity control measures, and detailed economic studies. In addition to the Project's efforts in these areas, much input was provided by other Federal and State agencies and institutions, some of which were financially supported by the Federal Water Quality Administration (FWQA).

The data and recommendations contained herein are specifically related to the Colorado River Basin. However, the basic approach and methodology developed for evaluation of the physical and economic effects of salinity are considered applicable to many other areas of the West. Salinity control measures developed for the Basin may also be applicable to other areas with similar conditions.

It cannot be emphasized too strongly that if this report has erred in regard to estimated projections of salinity increases with the associated economic losses therefore, the errors have been in the direction of minimizing adverse effects. The actual effects are likely to be more severe than these figures indicate.

AUTHORITY

The Federal Water Quality Administration, U. S. Department of the Interior, formerly the Federal Water Pollution Control Administration, has primary responsibility for implementing national policy for enhancement of the quality of the Nation's water resources through the control of pollution. This policy has been spelled out over the past 14 years in a series of legislative acts which are described as the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.). Section 10(d) of this Act authorizes the Secretary of the Interior, ... "whenever requested by any State water pollution control agency..." if such request refers to pollution of waters which is endangering the health or welfare of persons in a State other than in which (the source of pollution) originates, ..."to call a conference..." of the State or States which may be adversely affected by such pollution." Section 10 authorizes the Secretary to recommend "necessary remedial action" and also provides various legal steps that may be taken to abate pollution if remedial action is not taken in a reasonable period of time.

Under the provision of Section 10 of the Act, the initial session of the "Conference in the Matter of Pollution of the Interstate Waters of the Colorado River and Its Tributaries" was held on January 13, 1960. The conference was requested by six of the seven Basin States. Five additional formal sessions of the conference and three technical sessions were held from 1960 to 1967. These sessions provided assignments to the Project for developing recommendations of remedial action to abate pollution.

Added impetus was given to the Project's salinity investigations on October 2, 1965 by passage of the Water Quality Act of 1965 (P.L. 89-234). This Act amended Section 10 of the Federal Water Pollution Control Act to provide that the States establish water quality standards for all interstate waters. Subsequent difficulties, encountered in establishing suitable salinity criteria as a part of these standards, pointed out the need to complete various aspects of the Project's investigations in order to provide the basis for establishing such standards.

CHAPTER II. SUMMARY OF FINDINGS AND RECOMMENDATIONS

SUMMARY OF FINDINGS

1. Salinity (total dissolved solids) is the most serious water quality problem in the Colorado River Basin. Average annual salinity concentrations in the Colorado River presently range from less than 50 mg/l in the high mountain headwaters to about 865 mg/l at Imperial Dam, the last point of major water diversion in the United States. Salinity adversely affects the water supply for a population exceeding 10 million people and for 800,000 irrigated acres located in the Lower Colorado River Basin and the Southern California water service area. Salinity also adversely affects water uses in Mexico and in limited areas of the Upper Colorado River Basin.

2. Salinity concentrations in the Colorado River system are affected by two basic processes: (1) salt loading, the addition of mineral salts from various natural and man-made sources, and (2) salt concentrating, the loss of water from the system through evaporation, transpiration, and out-of-basin export.

3. Salinity and stream flow data for the 1942-1961 period of hydrologic record were used as the basis for estimating average salinity concentrations under various conditions of water development and use. Assuming repetition of this hydrologic record, salinity concentrations at Hoover Dam would average about 700 mg/l and 760 mg/l under 1960 and 1970 conditions. If development and utilization of the Basin's water resources proceed as proposed and if no salinity controls are implemented, average annual salinity concentrations at Hoover Dam would increase to about 880 mg/l in 1980 and 990 mg/l in 2010. Comparable figures at Imperial Dam are 760 mg/l and 870 mg/l under 1960 and 1970 conditions, and 1060 mg/l and 1220 mg/l under 1980 and 2010 conditions. If future water resource development in the Basin were to be limited to completion of projects currently under construction, it is estimated that average annual salinity concentrations for 1980 and subsequent years would increase to only about 800 mg/l at Hoover Dam and 920 mg/l at Imperial Dam.

4. It is estimated that if the 1942-1961 period of hydrologic record were repeated under conditions comparable to when the Colorado River was in its natural state, salinity concentrations at the site of Hoover Dam would average about 330 mg/l. Because of man's influence, average concentrations at this point more than doubled

(697 mg/l) under 1960 conditions and will triple by 2010 (990 mg/l), if presently planned development and utilization of water resources occurs. Reservoir evaporation and irrigation will account for almost three-fourths of the salinity increase between 1960 and 2010.

5. Under 1960 conditions, natural sources accounted for 47% of the salinity concentrations at Hoover Dam. The remainder was accounted for by irrigation (37%), reservoir evaporation (12%), out-of-basin exports (3%), and municipal-industrial uses (1%).

6. As salinity concentrations rise about 500 to 700 mg/l, the net economic return from irrigated agriculture begins to decrease because of increased operating costs and reduced crop yields. At levels above 1,000 mg/l, the types of irrigated crops grown may be limited, and more intensive management of irrigation practices is necessary to maintain crop yields. At levels exceeding 2,000 mg/l, only certain crops can be produced by adopting highly specialized and costly irrigation management practices. Municipal and industrial water users incur increasing costs as salinity levels increase above 500 mg/l, the maximum level recommended in the U. S. Public Health Service Drinking Water Standards.

7. The present annual economic detriments of salinity are estimated to total $16 million. If water resources development proceeds as proposed and no salinity controls are implemented, it is estimated that average annual economic detriments (1970 dollars) would increase to $28 million in 1980 and $51 million in 2010. If future water resources development is limited to those projects now under construction, estimated annual economic detriments would increase to $21 million in 1980 and $29 million in 2010. Detriments to water users in Mexico and to recreation and fishery users in the Salton Sea are not included in the estimates.

8. More than 80 percent of the total future economic detriments caused by salinity will be incurred by irrigated agriculture located in the Lower Basin and the Southern California water service area and by the associated regional economy. About two-thirds of these detriments will be incurred directly by irrigation water users and the remainder will be incurred indirectly by other industries associated with agriculture.

9. Alternatives for salinity control in the Colorado River Basin include:

   a. Augmentation of Basin water supply. This could be achieved by importation of demineralized sea water, importation of fresh water from other basins, or utilization of weather modification techniques to increase precipitation and runoff. This alternative should be considered as a possible long-term solution to the salinity problem.

b. Reduction of salt loads. This could be achieved by impoundment and evaporation of saline water from point sources, diversion of runoff and streams around areas of high salt pickup, improvement of irrigation and drainage practices, improvement of irrigation conveyance facilities, desalination of saline discharges from natural and man-made sources, and desalination of water supplies at points of use with appropriate disposal of the waste brine. A basinwide salt load reduction program has been developed which would reduce the salt load contributed by five large natural sources and twelve irrigated areas totaling 600,000 acres. If fully implemented, it is estimated that this program would reduce average salinity concentrations at Hoover Dam by about 250 mg/l in 1980 and about 275 mg/l in 2010.

c. Limitation of further depletion of Basin water supply. This could be achieved by curtailment of future water resources development. Such action would minimize both future increases in salinity levels and the adverse economic impact of such increases.

10. A basinwide salt load reduction program appears to be the most feasible of the three salinity control alternatives. The scope of such a program will depend upon the desired salinity objectives. Partial implementation of the other two alternatives would increase the effectiveness of the salt load reduction program.

11. A basinwide salt load reduction program designed to minimize total salinity costs (detriments plus control costs) would have an estimated average annual cost of $7 million in 1980 and $13 million in 2010 (1970 dollars). Implementation of this program could limit salinity concentrations at Hoover Dam to approximately 1970 levels while allowing planned water resource development to proceed. The direct salinity control benefits (avoidance or mitigation of expected future salinity detriments) of such a program are estimated to total $11 million in 1980 and $22 million in 2010 (1970 dollars).

RECOMMENDATIONS

It is recommended that:

1. A salinity policy be adopted for the Colorado River system that would have as its objective the maintenance of salinity concentrations at or below levels presently found in the lower main-stem.

2. Specific water quality standards criteria be adopted at key points throughout the basin by the appropriate States, in accordance with the Federal Water Pollution Control Act. Such criteria should be consistent with the salinity policy and should assure the objective of keeping the maximum mean monthly salinity concentrations at Imperial Dam below 1000 mg/l. These criteria should be adopted by January 1, 1973.

3. Implementation of the recommended policy and criteria be accomplished by carrying out a basin-wide salinity control program concurrently with planned future development of the basin's water resources.

CHAPTER III. DESCRIPTION OF AREA

PHYSICAL DESCRIPTION

The Colorado River is situated in the southwestern United States and extends 1,400 miles from the Continental Divide in the Rocky Mountains of north central Colorado to the Gulf of California (Figure 1). Its river basin covers an area of 244,000 square miles, approximately one-twelfth of the continental United States. The Colorado River Basin includes parts of seven states; Arizona, California, Colorado, Nevada, New Mexico, Utah and Wyoming. About one percent of the Basin drains lands in Mexico.

The Colorado River rises on the east slope of Mount Richthofen, a peak on the Continental Divide having an altitude of 13,000 feet, and flows generally southwestward, leaving the United States at an elevation of about 100 feet above sea level. The Colorado River Basin is composed of a complex of rugged mountains, high plateaus, deep canyons, deserts and plains. Principal physical characteristics of the region are its variety of land forms, topography and geology.

The Colorado River Compact of 1922 established a division point on the Colorado River at Lee Ferry, Arizona, to separate the Colorado River Basin into an "Upper Basin" and a "Lower Basin" for legal, political, institutional and hydrologic purposes. Lee Ferry is located about one mile below the confluence of the Paria River and approximately 17 miles downstream from Glen Canyon Dam. The Upper Basin encompasses about 45 percent of the drainage area of the Colorado River Basin.

In addition to the Colorado River Basin, the Project's investigations covered the area of southern California receiving Colorado River water. This area of about 15,400 square miles includes the Imperial and Coachella Valleys which surround the Salton Sea as well as the metropolitan areas of Los Angeles and San Diego.

CLIMATE

Climatic extremes in the Basin range from hot and arid in the desert areas to cold and humid in the mountain ranges. Precipitation is largely controlled by elevation and the orographic effects of mountain ranges. At low elevations or in the rain shadow of coastal mountain ranges, desert areas may receive as little as 6 inches of precipitation annually, while high mountain areas may receive more than 60 inches.

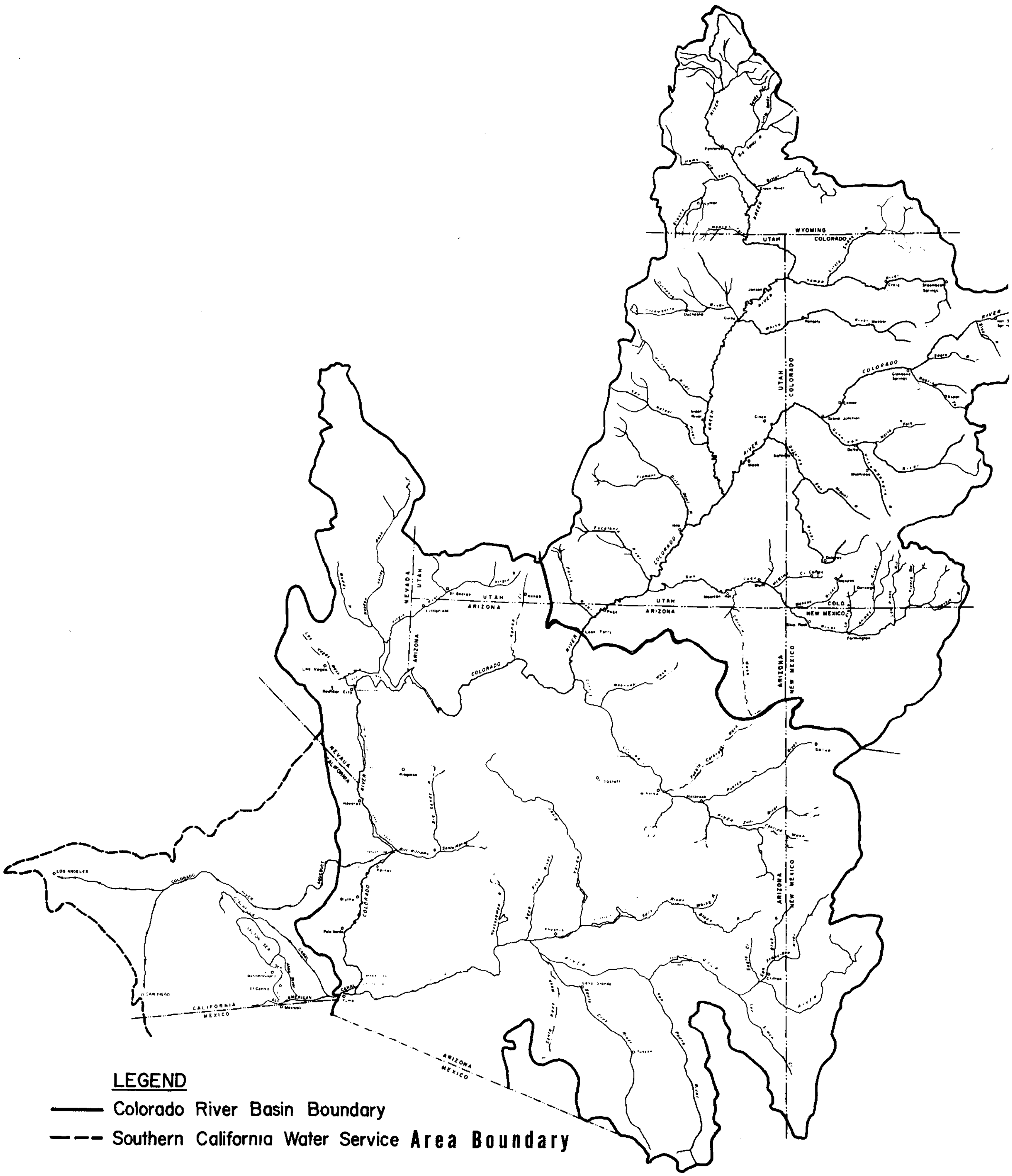


Figure 1 Colorado River Basin and Southern California Water Service Area

Basin temperatures range from temperate, affording only a 90-day growing season in the mountain meadows of Colorado and Wyoming, to semi-tropical with year-round cropping in the Yuma-Phoenix area. On a given day, both the high and low temperature extremes for the continental United States frequently occur within the Basin.

In the southern California water service area, the climate of the area surrounding the Salton Sea is hot and arid, while the climate of the coastal metropolitan areas is moderated by proximity to the Pacific Ocean.

POPULATION AND ECONOMY

The Colorado River Basin is sparsely populated. In 1965 the estimated population was nearly 2.25 million. The average density was about nine persons per square mile compared with a national average of 64. Eighty-five percent of the population lived in the Lower Basin. About 70 percent of the Lower Basin population resided in the metropolitan areas of Las Vegas, Nevada, and Phoenix and Tucson, Arizona. The population of the Colorado River Basin is estimated to triple by 2010.

The southern California water service area contained an estimated eleven million people in 1965. Most of the population was concentrated in the highly urbanized Los Angeles-San Diego metropolitan area.

The economy of the Basin is based on manufacturing, irrigated agriculture, mining, forestry, oil and gas production, livestock and tourism.

The present economy of the Upper Basin is largely resource oriented. This orientation is not restricted entirely to agriculture, forestry and mining, but includes the region's recreational endowment and the associated contribution to basic income. The mineral industry overshadows activities of the agricultural and forestry sectors. The major effects of outdoor recreation and tourism are reflected in the tertiary or non-commodity producing industries which as a group contribute the greatest share to total Upper Basin economic activity.

In the last two decades, the economy of the Lower Basin has experienced a significant transition from an agricultural-mining base to a manufacturing-service base. Growth in the manufacturing sectors has been one of the major factors in the overall economic growth of the Lower Basin. Important manufacturing categories are electrical equipment, aircraft and parts, primary metals industries, food and kindred products, printing and publishing, and chemicals.

Agriculture continues to play an important role in the southern California economy amidst the fast-growing industrial and commercial activity. Manufacturing is the most important industrial activity and principally includes production of transportation equipment (largely aircraft and parts), machinery, food and kindred products, and apparel. Agriculture accounts for about three percent of the total employment, manufacturing for an estimated 30 percent, and trades and services for approximately 42 percent.

WATER RESOURCES

An average of about 200 million acre-feet of water a year is provided by precipitation in the Colorado River Basin. All but about 18 million acre-feet of this is returned to the atmosphere by evapotranspiration. Most of the streamflows originate in the high forest areas where heavy snowpacks accumulate and evapotranspiration is low. A small amount of runoff originates at the lower altitudes, primarily from infrequent storms. Approximately two-thirds of the runoff is produced from about six percent of the Basin area.

Streamflows fluctuate widely from year to year and season to season because of variations in precipitation, and numerous reservoirs have been constructed to make water available for local needs, exports and downstream obligations. The usable capacity of the Basin reservoirs is about 62 million acre-feet.

WATER COMPACTS

In addition to State laws which provide for intrastate control of water, use of water in the Colorado River system is governed principally by four documents--the Colorado River Compact signed in 1922, the Mexican Water Treaty signed in 1944, the Upper Colorado River Basin Compact signed in 1948 and by the Supreme Court Decree of 1964 in Arizona vs. California.

Among other provisions, the Colorado River Compact apportions to each the Upper and Lower Basin in perpetuity the exclusive beneficial consumptive use of 7,500,000 acre-feet of water of the Colorado River system per annum. It further establishes the obligation of Colorado, New Mexico, Utah, and Wyoming, designated States of the Upper Division, not to cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 million acre-feet for any period of 10 consecutive years.

The Mexican Water Treaty defines the rights of Mexico to the use of water from the Colorado River system. It guarantees the delivery of 1,500,000 acre-feet of Colorado

River water annually from the United States to Mexico.

In accordance with the Upper Colorado River Basin Compact, Arizona is granted the consumptive use of 50,000 acre-feet of water a year and the other Upper Basin States are each apportioned a percentage of the remaining consumptive use as follows: Colorado 51.75 percent, New Mexico 11.25 percent, Utah 23 percent, and Wyoming 14 percent. Of the first 7,500,000 acre-feet annually of Colorado River water entering the Lower Basin, the States of Arizona and Nevada are apportioned 2,800,000 acre-feet and 300,000 acre-feet respectively. The Lower Division apportionment was divided among the Lower Basin States--Arizona, California, and Nevada--by the decree of the United States Supreme Court in 1964 which states that apportionment was accomplished by the Boulder Canyon Project Act of 1929. If Colorado River mainstem water is available in sufficient quantity to satisfy 7,500,000 acre-feet of annual consumptive use in the three Lower Basin states, Arizona, Nevada, and California are apportioned 2,800,000, 300,000 and 4,400,000 acre-feet, respectively.

WATER USE

There is essentially no outflow from the Basin beyond that required to meet the Mexican Treaty obligation. In 1965, one-half million acre-feet of water was exported out of the Upper Basin for use in other parts of the Upper Basin States. Gross diversions from the Lower Colorado River for use in the southern California service area and the Lower Colorado area in California totaled 5.35 million acre-feet in 1965.

The major use of water within the Basin is for agricultural, municipal, and industrial purposes. At present, over 90 percent of the total Basin withdrawal from ground-water and surface-water sources serves irrigated agriculture within the basin. The remaining portion is used principally for municipal and industrial uses. Approximately three-fourths or 7.0 million acre feet of the water consumptively used in the Basin each year is depleted by agricultural uses. Minor quantities of water are consumed by hydroelectric and thermal power production, recreation, fish and wildlife, rural-domestic needs, and livestock uses. In the urban areas of the Basin, municipal and industrial uses are increasing significantly due to the rapid rate of population growth.

One of the largest causes of streamflow depletions in the Basin is surface evaportation from storage reservoirs. Over 2.0 million acre-feet are estimated to evaporate annually from the lakes and reservoirs of the Basin. Most of this evaporates from major storage reservoirs on the main stem of the Colorado River.

CHAPTER IV. MINERAL QUALITY EVALUATIONS

At the outset of the Project only limited information was available on the causes and sources of salinity in the Colorado River Basin. Little was known about the economic impact of salinity on water uses. No comprehensive evaluation of projected future mineral quality had been made. A major Project effort, therefore, was directed toward improving knowledge in these specific areas. Results of these investigations are summarized in the following sections.

CAUSES OF SALINITY INCREASES

Salinity concentrations progressively increase from the headwaters to the mouth of the Colorado River. This increase results from two basic processes - salt loading and salt concentrating. Salt loading, the addition of mineral salts from various natural and man-made sources, increases salinity by increasing the total salt burden carried by the river. In contrast, salt concentrating effects are produced by streamflow depletions and increase salinity by concentrating the salt burden in a lesser volume of water.

Salt loads are contributed to the river system by natural and man-made sources. Natural sources include diffuse sources such as surface runoff and diffuse ground water discharges, and discrete sources such as mineral springs, seeps, and other identifiable point discharges of saline waters. Man-made sources include municipal and industrial waste discharges and return flows from irrigated lands.

Streamflow depletions contribute significantly to salinity increases. Consumptive use of water for irrigation is responsible for the largest depletions. Consumptive use of water for municipal and industrial purposes accounts for a much smaller depletion. Evaporation from reservoir and stream surfaces also produces large depletions. Phreatophytes, too, cause significant water losses by evapotranspiration, especially in the Lower Basin below Hoover Dam.

Out-of-basin diversions from the Upper Basin contribute significantly to streamflow depletions and produce a salt concentrating effect similar to consumptive use. The water diverted is high in quality and low in salt content. Thus, while these diversions remove substantial quantities of water from the Basin, they remove only a small portion of the salt load.

The relative effects of the various salt loading and salt concentrating factors on salinity concentrations of the Colorado River at Hoover Dam are summarized in Table 1. This evaluation indicates that about 74 percent of average

Table 1. Effect of Various Factors on Salt Concentration of Colorado River at Hoover Dam (1942-61 period of record adjusted to 1960 conditions)a/

Factor	Flow (1,000 AF/Yr)	Cumulative Flow (1,000 AF/Yr)	Salt Load (1,000 Tons/Yr)	Cumulative Salt Load (1,000 Tons/Yr	Cumulative Concentration Tons/AF	Cumulative Concentration mg/l	Change[b/] in Concentration mg/l	% of Total Concentration
Natural Diffuse Sources	14,471	14,471	5,408	5,408	0.374	275	275	39
Natural Point Sources	229	14,700	1,283	6,691	0.455	334	59	8
Irrigation (Salt Contribution)	0	14,700	3,536	10,227	0.696	512	178	26
Irrigation (Consumptive Use)	-1,883	12,817	0	10 227	0.798	587	75	11
Municipal & Industrial Sources	-42	12,775	146	10,373	0.812	597	10	1
Exports Out of Basin	-465	12,310	-37	10,336	0.840	617	20	3
Evaporation & Phreatohytes	-1,409	10,901	0	10,336	0.948	697	80	12

Storage Release from Hoover	412	11,313	391	10,727	0.948	697	0	0
Total		11,313		10,727		697		100

a/ Based on data from:
(1) USGS, Prof. Paper 441, "Water Resources of the Upper Colorado River Basin, Technical Report," 1965.
(2) USDI, Progress Report No. 3, "Quality of Water, Colorado River Basin," January 1967.
(3) FWQA unpublished Records.

b/ Concentrations in this column will vary depending upon the order in which they are calculated.

salinity concentrations for the 20-year period 1942-1961 were attributable to salt loading factors. The remaining 26 percent were attributable to salt concentrating factors. The relative effects of natural and man-made factors are also summarized in Table 1. Only about 47 percent of average salinity concentrations for the 20-year period were attributed to natural factors. This evaluation indicates that salinity concentrations would have averaged only 334 mg/l at the Hoover Dam location under natural conditions for the 1942-1961 period.

A more detailed discussion of the various factors affecting salt concentrations is contained in Appendix A.

SOURCES OF SALT LOADS

Natural sources, including both diffuse and discrete sources, are the most important sources of salt loads in the Colorado River Basin. They contribute about two-thirds of the average annual salt load passing Hoover Dam. Natural diffuse pickup of mineral salts by surface runoff and groundwater inflow takes place throughout the Colorado River Basin; however, the areas responsible for the greatest salt loads are located in the Upper Basin. Several relatively small areas, such as Paradox Valley, have very high rates of pickup and contribute large salt loads. Diffuse sources contribute about half of the Basin salt burden.

Discrete or point salinity sources also occur throughout the Basin. In the Lower Basin, mineral springs add more salt to the Colorado River than any other type of salinity source. Blue Springs, located near the mouth of the Little Colorado River, contributes a salt load of about 547,000 tons per year, or approximately five percent of the annual salt burden at Hoover Dam. Blue Springs is the largest point source of salinity in the entire Colorado River Basin. In the Upper Basin, some 30 significant mineral springs have been identified. Dotsero and Glenwood Springs, two major point sources of salinity, contribute a salt load of about 518,000 tons per year.

Man's use of water for irrigation, municipal, and industrial purposes contributes to salt loading effects. Irrigation is the major man-made source of salinity throughout the Basin. The annual salt pickup from all irrigation above Hoover Dam averages about two tons per acre. For some areas, especially those underlain by shales and saline lake-bed formations, salt pickup is much higher, with average annual loads ranging between four and eight tons per acre. Below Hoover Dam, the average annual salt pickup from irrigation is about 0.5 ton per acre after the initial leaching period.

Municipal and industrial salinity sources located within the drainage area of Lake Mead contribute only about one percent of the average annual salt load at Hoover Dam. Below Hoover Dam, these sources are responsible for less than one percent of the average annual salt load.

The sources and amounts of salt loads for the Upper Basin, the Lower Basin, and the drainage area of Lake Mead above Hoover Dam are summarized in Table 2. Data presented in Table is based on salinity conditions existing in the period 1963-1966 and should not be confused with data in Table 1 which is based on period 1942-61. The Upper Basin sources contribute approximately 77 percent of the salt load at Hoover Dam, about three-fourths of total Basin salt load.

A detailed discussion of the nature, location, and magnitude of salt sources in the Basin is contained in Appendix A.

Table 2. Summary of Salt Load Distributions

	Salt Load (1,000) T/Yr.			Percent of Total Load		
Source	Upper Basin	Lower Basin	Above Hoover Dam	Upper Basin	Lower Basin	Above Hoover Dam
Natural Diffuse Sources	4,400	1,400	5,760	52.2	52.1	53.7
Natural Point Sources	510	770	1,280	6.1	28.6	11.9
Irrigation	3,460	420	3,540	41.1	15.6	33.0
Municipal and Industrial	50	100	150	0.6	3.7	1.4
Total	8,420	2,690	10,730	100.0	100.0	100.0

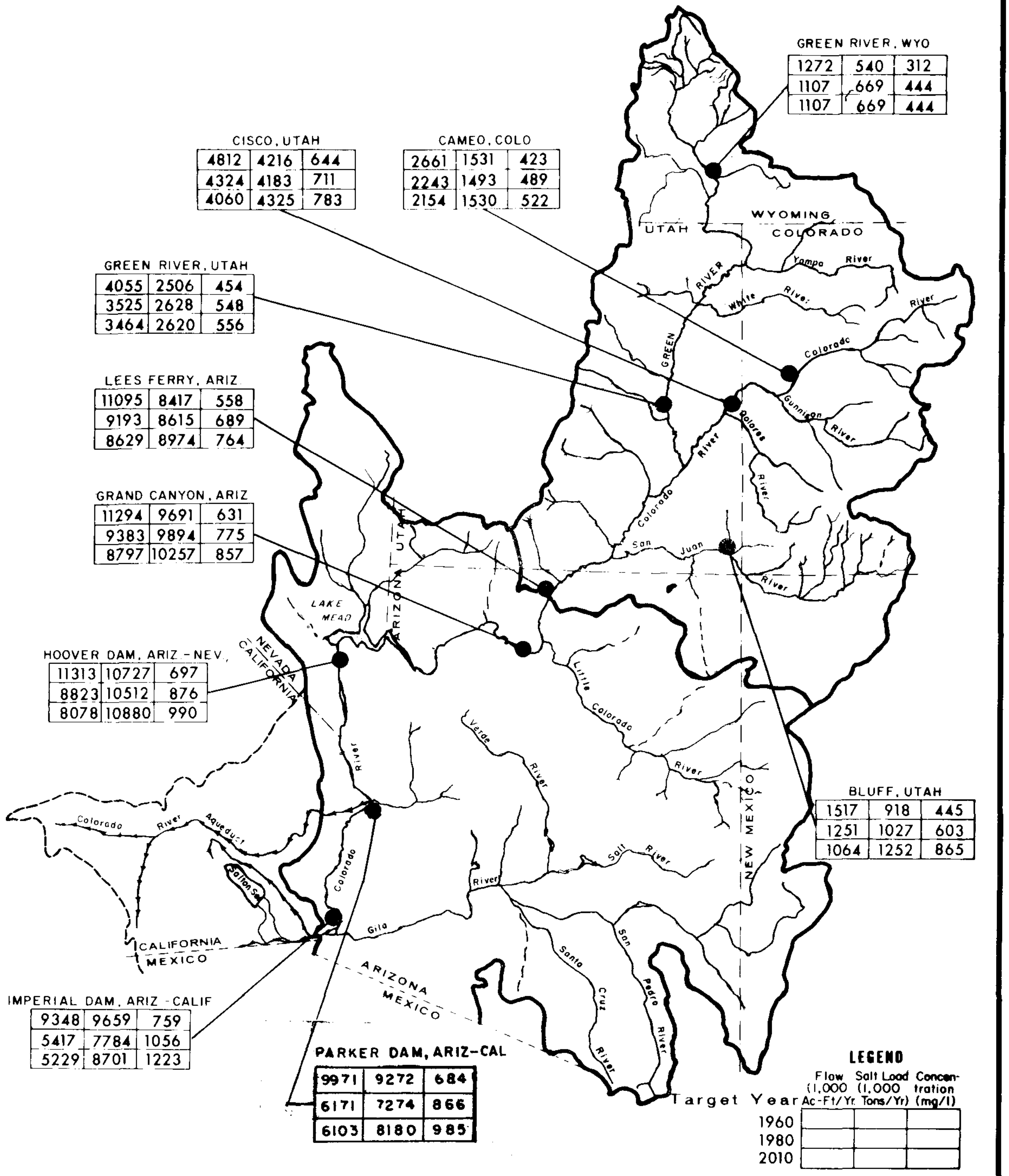
PRESENT AND FUTURE SALINITY CONCENTRATIONS

Long-term average salinity levels have progressively increased in the Colorado River system as the Basin's water resources have been developed and consumptive use of water for various purposes has increased. This trend is expected to continue with future water resource development and to bring about serious water quality implications. As the economic impact of salinity is closely related to the rate at which salinity levels rise in the future, an evaluation was made of present and future salinity concentrations in the Basin to provide the basis for the economic evaluation discussed in the following section. Historical salinity and stream flow data for the 1942-1961 period of hydrologic record were used as the basis for estimating average salinity concentrations under various conditions of water development and use. This historical data was modified to reflect the effects that water uses existing in 1960 would have had on average salinity levels if these uses had existed during the full 20-year period. Average salinity concentrations obtained from this modified data were designated as 1960 base conditions. These concentrations are shown at key Basin locations in Figure 2.

Predicted future conditions of water use, based on Federal, State and local development plans available in 1967, were utilized to develop detailed projections of 1980 and 2010 salinity levels. These projections based on the assumptions that water resource development would proceed as planned in 1967 and that the 1942-1961 hydrologic record would be repeated, are shown at key Basin locations in Figure 2. These projections are for long-term average salinity concentrations; actual concentrations can be expected to fluctuate about these averages as a result of seasonal changes in streamflow and other hydrological factors. Sensitivity of future salinity projections to the period of record utilized and the assumptions concerning the rate of water resource development are discussed in Appendix C.

To provide the degree of refinement necessary to allow evaluation of the small incremental changes in salinity levels produced by a given water resource development, salinity concentrations were computed to the nearest mg/l in making the projections shown in Figure 2. It was not intended that a high degree of accuracy by implied as salinity projections are dependent upon a number of factors which are not known with certainty.

The detailed salinity projections presented in Figure 2 were made on the basis that no limits would be placed on future water resource developments other than those limits imposed by availability of a water supply under applicable water laws. In evaluating potential means of managing salinity on a basinwide basis as discussed in Chapter VII, it became apparent that one possible approach to management of future salinity levels would be to limit further water resource development in the Basin. A second set of salinity projections was made to evaluate the results of limiting such development. A comparison of future salinity levels at four key locations on the Lower Colorado River for unlimited and limited development conditions is shown in Table 3.



NOTE : Values shown are based on 1942 – 1961 period of record modified to 1960 conditions.

Figure 2. Flow, Loads, & Salinity Concentrations in Streams in the Colorado River Basin

Table 3. Comparison of Salinity Projections

Location	Unlimited Development Conditions: 1960 Base	1980	2010	Limited Development Conditions: 1970	1980 & 2010
Hoover Dam	697	876	990	760	800
Parker Dam	684	866	985	760	800
Palo Verde Dam	713	940	1082	800	850
Imperial Dam	759	1056	1223	865	920

Salinity projections for 1970 conditions of limited development were made on the basis that water resource developments currently in operation and present water use patterns would hold for a repetition of the 1942-1961 hydrological record. The 1970 projections reflect the effects of evaporation losses from Lake Powell operated at normal levels. Since Lake Powell has not yet reached normal storage levels, evaporation losses are less than expected average losses and present average salinity levels at downstream points are correspondingly lower than projected.

For 1980 conditions of limited development, it was assumed that no new water resource developments would be placed in operation but that those projects currently under construction would be completed as planned. It was assumed that all such construction could be completed by 1980 and that 2010 conditions of water use would remain the same as for 1980.

In the past, salt loading was the dominant factor affecting salinity concentrations, contributing about three-fourths of average salinity concentrations at Hoover Dam under 1960 conditions. In contrast, future increases in salinity levels will result primarily from flow depletions caused by out-of-basin exports, reservoir evaporation and consumptive use of water for municipal, industrial and agricultural purposes. The relative effects of these factors on future salinity concentrations at Hoover Dam are summarized in Table 4.

Projections for Hoover Dam indicate a relatively constant, average salt load over the next 40 years, but a substantial drop in water flow. Over 80 percent of the future increase in salinity concentrations at Hoover Dam will be the result of increases in flow depletions. Over three-fourths of the projected salinity increase between 1960 and 2010 will be the result of increases in reservoir evaporation brought about by the filling of major storage reservoirs completed since 1960 and of increases in consumptive use brought about by the expansion of irrigated agriculture.

Table 4 Effect of Various Factors on Future Salt Concentration of Colorado River at Hoover Dam (1942-61 period of record adjusted to 2010 conditions)[a]

Factor	Flow (1,000 AF/Yr)	Cumulative Flow (1,000 AF/Yr)	Salt Load (1,000 Tons/Yr)	Cumulative Salt Load (1,000 Tons/Yr	Cumulative Concentration Tons/AF	Cumulative Concentration mg/l	Change[b] in Concentration mg/l	% of Total Concentration
Natural Diffuse Sources	14,471	14,471	5,408	5,408	0.374	275	275	28
Natural Point Sources	229	14,700	1,283	6,691	0.455	334	59	6
Irrigation (Salt Contribution)	--	14,700	4,225	10,916	0.743	546	212	21
Irrigation (Consumptive Use)	-2,905	11,795	--	10,916	0.925	680	134	14
Municipal & Industrial Sources	-427	11,368	165	11,081	0.975	717	37	4
Exports Out of Basin	-1,174	10,194	-140	10,941	1.073	789	72	7

Reservoir Evaporation	-2,041	8,153	0	10,941	1.342	986	197	20
Model Adjustments	-75	8,078	-61	10,880	1.347	990	4	--
Total		8,078		10,880		990		100

a/ Based on data from:
(1) USGS, Prof. Paper 441, "Water Resources of the Upper Colorado River Basin, Technical Report," 1965
(2) USDI, Progress Report No. 3, "Quality of Water, Colorado River Basin," January 1967.
(3) FWPCA unpublished records.

b/ Concentrations in this column will vary depending upon the order in which they are calculated.

PHYSICAL AND ECONOMIC IMPACT OF SALINITY

Water uses exhibit an increasing sensitivity to rising salinity concentrations. As concentrations of salinity rise water use is progressively impaired, and at some critical level, defined as a threshold level, utilization of the supply is no longer possible. In the Colorado River Basin, future salinity concentrations will be below threshold levels for in stream uses such as recreation, hydroelectric power generation, and propagation of aquatic life. Only marginal impairment of these uses is anticipated.

In the Lower Colorado River present salinity concentrations are above threshold limits for municipal, industrial and agricultural uses. Some impairment of these uses is now occurring and future increases in salinity will increase this adverse impact. The Projects investigated this progressive impairment of water uses and developed methods to quantify the resulting economic impact on both water users and the regional economy. It should be emphasized that the methodology employed by the Project staff was intentionally conservative; all costs developed by this report to describe the impact of salinity must be considered minimal values.

Initial investigations conducted on the potential impact of future salinity levels revealed that only small effects on water uses could be anticipated in the Upper Basin. Subsequent investigations, therefore, were limited to three main study areas: the Lower Main Stem and Gila areas in the Lower Basin, and the Southern California area encompassing the southern California water service area. The boundaries of these study areas follow political rather than hydrological boundaries and are shown in Figure 3. Although significant economic effects are known to occur in Mexico, lack of data precluded their inclusion.

Effects of Salinity on Beneficial Uses of Water

Initial evaluations of possible salinity effects on Basin water uses indicated that adverse physical effects would essentially be limited to municipal, industrial, and agricultural uses. Major effects on these uses are discussed briefly in this section.

Domestic uses comprise the major utilization of municipal water supplies. Total hardness, a parameter closely related to salinity, is of primary interest in assessing water quality effects on these uses. Increases in the concentration of hardness lead to added soap and detergent

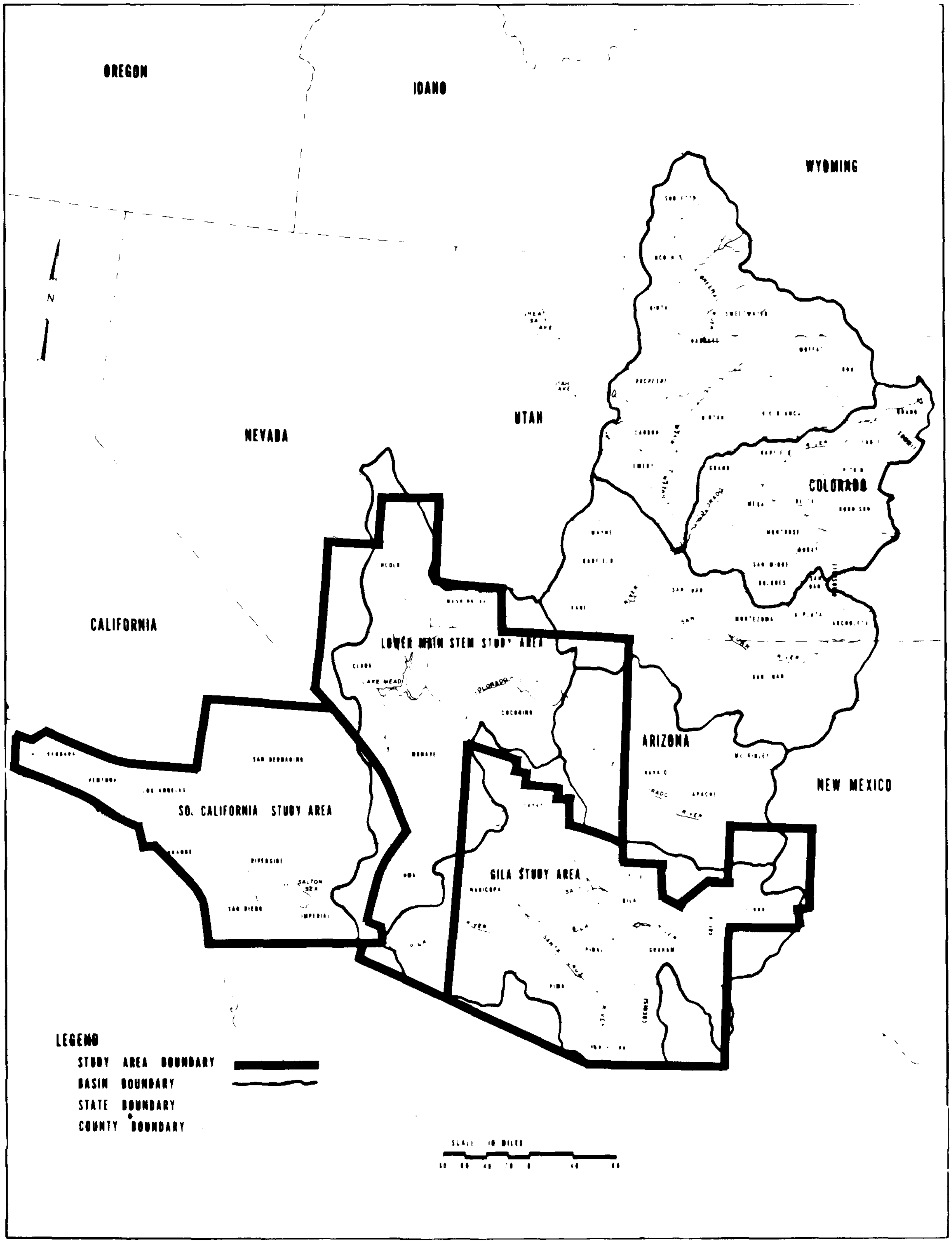


Figure 3. Location of Salinity Impact Study Areas

consumption, corrosion and scaling of metal water pipes and water heaters, accelerated fabric wear, added water softening costs, and in extreme cases, abandonment of a supply. By most hardness measures, raw water supplies derived from the Colorado River at or below Lake Mead would be classified as very hard.

Boiler feed and cooling water comprise a major portion of water used by industry in the Basin. Mineral quality of boiler feed water is an important factor in the rate of scale formation on heating surfaces, degree of corrosion in the system, and quality of produced steam. In cooling water systems, resistance to slime formation and corrosion are effected by mineral quality. The required mineral quality levels are maintained in boiler and cooling systems by periodically adding an amount of relatively good quality water (make-up water) and discharging from the system an equal volume of the poorer quality water (blowdown).

Salinity effects on agricultural uses are manifested primarily by limitations on the types of crops that may be irrigated with a given water supply and by reductions of crop yields as salinity levels increase. Other conditions being equal, as salinity levels increase in applied irrigation water, salinity levels in the root zone of the soil also increase.

Because different crops have different tolerances to salts in the root zone, limits are placed on the types of crops that may be grown. When salinity levels in the soil increase above the threshold levels of a crop, progressive impairment of the crop yield results. Irrigation water which has a high percentage of sodium ions may also affect soil structure and cause adverse effects on crop production. The primary means of combating detrimental salinity concentrations in the soil are to switch to salt tolerant crops or to apply more irrigation water and leach out excess salts from the soil.

Direct Economic Effects Upon Water Users

The previously described physical impacts of salinity upon consumptive uses of water were translated into economic values by evaluating how each user might alleviate the effects of salinity increases. Municipalities could (1) do nothing and the residents would consume more soap and detergents or purchase home softening units; (2) build central water softening plants; or (3) develop new, less mineralized water supplies. Industrial users could combine more extensive treatment of their water supply with the purchase of additional make-up water based upon the economics of prevailing conditions. The alternatives available to irrigation water users are governed by the availability of additional water. (1) If the irrigator does nothing, he will suffer economic loss from decreased crop yields. (2) If additional water is available, root zone salinity may be reduced by increasing leaching water applications. The irrigator would incur increased costs for purchase of water, for additional labor for water application, and for increased application of fertilizer to replace the fertilizer leached out. (3) If no additional water is available, the irrigator can increase the leaching of salts from the soil by applying the same amount of water to lesser acreage. This, of course, results in an economic loss since fewer crops can be grown. (4) The last alternative is to plant salt tolerant crops. An economic loss would usually occur since salt tolerant crops primarily produce a lower economic return.

The cost of applying each of the alternative remedial actions was determined, and the least costly alternative selected for subsequent analyses. The yield-decrement method, which measures reductions in crop yield resulting from salinity increases, was selected to evaluate the economic impact on irrigated agriculture. For industrial use, an estimate of required make-up water associated with salinity increases was selected to calculate the penalty cost. Municipal damages were estimated by calculating the required additional soap and detergents needed. Details of the methodology employed and a discussion of the assumptions required to complete the analysis are presented in Chapter IV of Appendix B.

The direct economic costs of mineral quality degradation may be summarized in two basic forms, total direct costs and penalty costs. Total direct costs incurred for a given salinity level result from increases in salinity concentrations above the threshold levels of water uses. Penalty costs are the differences between total direct costs for a given salinity level and for a specified base level. They represent the marginal costs of increases in salinity concentrations above base conditions.

Detailed economic studies were aimed at evaluating penalty costs in order to provide a basis for assessing the economic impact of predicted future increases in salinity. Water quality, water use patterns, and economic conditions existing in 1960 were selected as base conditions. Water use and economic conditions projected for the target years 1980 and 2010 and predictions of future salinity concentrations were utilized to estimate total direct costs in the future. Direct penalty costs were then computed from differences in total direct costs. These direct penalty costs are summarized by type of water use and by study area in Table 5. The indirect and total penalty costs, also presented in the table, are discussed below.

Indirect Economic Effects

Because of the interdependence of numerous economic activities, there are indirect effects on the regional economy stemming from the direct economic impact of salinity upon water users. These effects, termed indirect penalty costs, can be determined if the interdependency of economic activities are known.

The Project's economic base study investigated the interdependence of various categories of economic activity or sectors. These interdependent relationships, in the form of transactions tables, were quantified for 1960 conditions, and were projected for the target years 1980 and 2010. A digital computer program known as an "input-output model" was developed to follow changes affecting any given industry through a chain of transactions in order to identify secondary or indirect effects on the economy stemming from the direct economic costs of salinity. Application of the model to evaluate indirect penalty costs is discussed in Appendix B, Chapter V. The indirect penalty costs predicted by the model are summarized in Table 5.

Total Penalty Costs

Total penalty costs represent the total marginal costs of increases in salinity concentrations above base conditions. They are the sum of direct penalty costs incurred by water users and indirect penalty costs suffered by the regional economy. Total penalty costs are also summarized in Table 5.

Several conclusions can be drawn from Table 5.

1. The majority of the penalty costs (an average of 82 percent) will result from water use for irrigated agriculture. This fact may be attributed to the heavy utilization of Colorado River water for irrigation along the Lower Colorado River and in the southern California area.

2. Over three-fourths of the penalty costs will be incurred in the southern California water service area. These costs will result primarily from agricultural use in the Imperial and Coachella Valleys, and municipal and industrial uses in the coastal metropolitan areas.

Table 5 Summary of Penalty Costs

Location and Water Use	1980 Direct Penalty Cost	1980 Indirect Penalty Cost	1980 Total Penalty Cost	2010 Direct Penalty Cost	2010 Indirect Penalty Cost	2010 Total Penalty Cost
	($1,000 Annually)*			($1,000 Annually)*		
Lower Main Stem Study Area						
Irrigation Agriculture	1,096	765	1,861	2,424	2,237	4,661
Industrial	107	4	111	410	15	425
Municipal	275	14	289	779	39	818
Sub-Total	1,478	783	2,261	3,613	2,291	5,904
Southern California Study Area						
Irrigated Agriculture	4,617	2,447	7,064	10,072	6,195	16,267
Industrial	56	3	59	103	5	108
Municipal	1,347	305	1,652	2,239	507	2,746
Sub-Total	6,020	2,755	8,775	12,414	6,707	19,121
Gila Study Area						
Irrigated Agriculture	---	---	---	246	125	371
Industrial	---	---	---	---	---	---
Municipal	---	---	---	---	---	---
Sub-Total	---	---	---	246	125	371
Total	7,498	3,538	11,036	16,273	9,123	25,396

* - 1960 Dollars

3. Penalty costs in the Gila study area will be minor and will not occur until after 1980 when water deliveries to the Central Arizona Project begin. (It was assumed that all Central Arizona Project water would be utilized for agricultural purposes.)

It should be noted that the penalty costs summarized in Table 3 do not represent the total economic impact of salinity, but only the incremental increases in salinity detriments resulting from rising salinity levels. There are economic costs known as salinity detriments that were being incurred by water users in 1960 as a result of salinity levels exceeding threshold levels for certain water uses. These costs would continue in the future if salinity levels remained at the 1960 base conditions. Total salinity detriments are discussed below.

Total Salinity Detriments

The detailed economic analysis outlined in previous sections and discussed in detail in Appendix B forms a basis for evaluating the distribution of the total economic impact of future salinity increases. Penalty costs are not practical, however, for evaluation of the economic impact of basinwide salinity control, especially when reductions in salinity concentrations below 1960 base levels were considered. For this reason, estimates of total salinity detriments were prepared utilizing the basic information developed for peanlty cost evaluations. These estimates, in the form of empirical relationships between salinity levels at Hoover Dam and salinity detriments, are shown graphically for various target years in Figure 4.

Hoover Dam is a key point on the Colorado River system. Water quality at most points of use in the Lower Basin and Southern California water service area may be directly related to salinity levels at Hoover Dam. Modifications of salt loads contributed by sources located upstream from Hoover Dam also directly affect salinity levels at this location. Salinity concentrations at Hoover Dam were, therefore, utilized as a water quality index to which all economic evaluations were keyed.

Total salinity detriments are the sum of direct costs to water users (including direct penalty costs) and indirect penalty costs. A discussion of the methodology used to develop the detriment relationships is contained in Appendix C. It should be noted that the salinity detriments are expressed in terms of 1970 dollars. It was necessary to modify the basic data utilized in evaluating penalty costs (expressed in terms of 1960 dollars) in order to make the

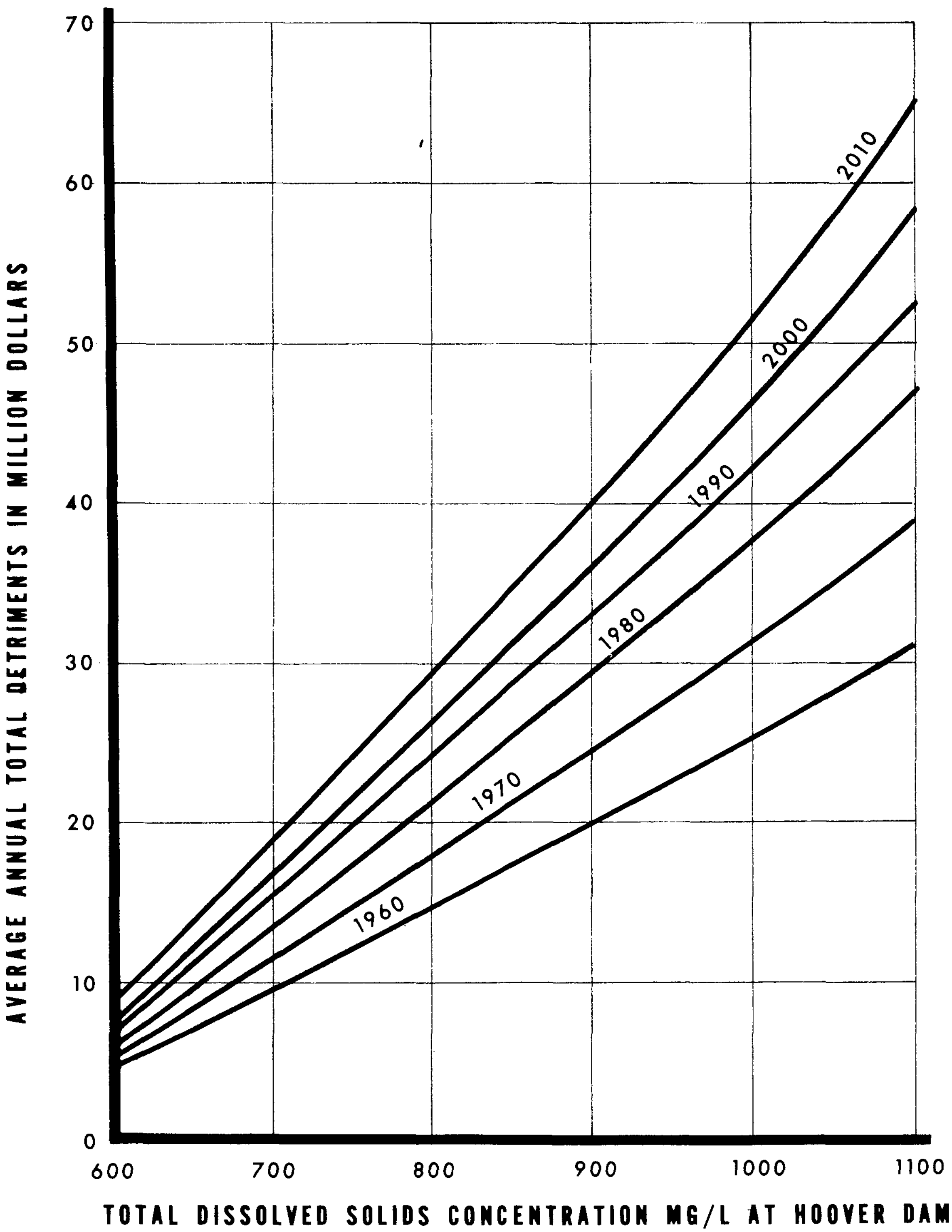


Figure 4. Salinity Detriments

salinity detriments compatible with current estimates of salinity management costs discussed in Chapter VII.

Using the projected salinity levels for Hoover Dam shown in Table 3 and the salinity detriment functions of Figure 4, it is possible to compare the total economic detriments of salinity under various conditions of water use and resource development. Under 1960 conditions, the annual economic impact of salinity was estimated to total $9.5 million. It is estimated that present salinity detriments have increased to an annual total of $15.5 million. If water resources development proceeds as proposed and no salinity controls are implemented, it is estimated that average annual economic detriments (1970 dollars) would increase to $27.7 million in 1980 and $50.5 million in 2010. If future water resources development is limited to those projects now under construction, estimated annual economic detriments would increase to $21 million in 1980 and $29 million in 2010.

CHAPTER V. TECHNICAL POSSIBILITIES FOR SALINITY CONTROL

Technical possibilities for minimizing and controlling salinity in the Colorado River Basin may be divided into two categories: water-phase and salt-phase control measures. Water-phase measures seek to reduce salinity concentrations by augmenting the water supply, while salt-phase measures seek to reduce salt input into the river system. Specific control measures are listed in Table 6 and are discussed at length in Appendix C, Chapter III.

Various factors, such as economic feasibility, lack of research and legal and institutional constraints limit the present application of some water-phase and salt-phase control measures. The most practical means of augmenting the Basin water supply include importing water from other basins, importing demineralized sea water, and utilizing weather modification techniques to increase precipitation and runoff within the Basin. Practical means of reducing salt loads include: impoundment and evaporation of point source discharges, diversion of runoff and streams around areas of salt pickup, improvement of irrigation and drainage practices, improvement of irrigation conveyance facilities, desalination of saline discharges from natural and man-made sources, and desalination of water supplies at points of use. These measures could be implemented in a variety of locations and in several different combinations.

Table 6. <u>Technical Possibilities for Salinity Control</u>

I. Measures for Increasing Water Supply

   A. Water Conservation Measures

      1. Increased Watershed Runoff
      2. Suppression of Evaporation
      3. Phreatophyte Control
      4. Optimized Water Utilization for Irrigation
         a. Reduced Consumptive Use
         b. Improved Irrigation Efficiency
      5. Water Reuse

   B. Water Augmentation Measures

      1. Weather Modification
      2. Water Importation
         a. Fresh Water Sources
         b. Demineralized Sea Water

Table 6. Technical Possiblities for Salinity Control (con't)

II. Measures for Reducing Salt Loading

A. Control of Natural Sources

1. Natural Discrete Sources
   a. Evaporation of Discharge
   b. Injection into Deep Geological Formations
   c. Desalination
   d. Suppression of Discharge
   e. Reduction of Recharge
2. Natural Diffuse Sources
   a. Surface Diversions
   b. Reduced Groundwater Recharge
   c. Reduced Sediment Production

B. Control of Man-Made Sources

1. Municipal and Industrial Sources
   a. Evaporation
   b. Injection into Deep Geological Formations
   c. Desalination
2. Irrigation Return Flows
   a. Proper Land Selection
   b. Canal Lining
   c. Improved Irrigation Efficiency
   d. Proper Drainage
   e. Treatment or Disposal of Return Flows

CHAPTER VI. SALINITY CONTROL ACTIVITIES

Activities related to the control and management of salinity have been carried out over the years by a variety of agencies and institutions and have contributed to the overall knowledge of salinity control technology. In the past four years, several activities have been specifically directed toward the application of salinity control technology to the Colorado River Basin. The current status of these activities is discussed in the following sections.

TECHNICAL INVESTIGATIONS

Limited investigations of several potential salinity control projects and control measures were made by the Project. These investigations evaluated a number of technical possibilities for salinity control discussed in Chapter V. Salinity control research needs were also identified; these provided the basis for support by the FWQA of several research efforts discussed below.

Early in FY 1968, the FWQA and the Bureau of Reclamation initiated a cooperative salinity control reconnaissance study in the Upper Basin. Study objectives were to identify controllable sources of salinity and to determine technically feasible control measures and estimate their costs. A shortage of funds resulted in discontinuance of the study during FY 1970. A report entitled "Cooperative Salinity Control Reconnaissance Study, Upper Colorado River Basin," presenting the results of the study to date, is scheduled for release during 1970.

During the course of the study, preliminary plans were developed for two salinity control projects, and cost estimates were prepared for a number of control measures. (1) A project was formulated to eliminate the heavy pickup of salt by the Dolores River as it crosses a salt anticline in the Paradox Valley of western Colorado. Control of this salt source could be achieved by constructing both a floodwater retarding dam and a lined channel to convey the river across the valley and prevent recharge of an aquifer in contact with salt formations. (2) A project was also formulated to control the salt load from Crystal Geyser, an abandoned oil test well which periodically discharges highly mineralized water. Control could be achieved by collecting the discharge and pumping it to a lined impoundment for evaporation. If suitable land area for an evaporation pond could be found and evaporation rates were high enough, a project of this type could be potentially applicable for control of some of the more concentrated mineral springs.

Cost estimates were prepared for several types of salinity control measures, but preliminary plans were not developed for specific sites. For control of irrigation return flows, the costs of impounding and evaporating the flows at two topographically different sites were estimated. The costs of deep well injection of relatively small quantities of the more concentrated return flows were also evaluated. The cost of lining canals and distribution systems in several existing irrigation projects was investigated.

Following discontinuance of the cooperative study, the project conducted a preliminary study of a project to control the salt load from several large mineral spring areas in the vicinity of Glenwood Springs, Colorado.

A similar preliminary study of control measures for LaVerkin Springs, a large thermal spring discharging significant quantities of radium-226 and mineral salts into the Virgin River of southern Utah, is currently underway.

RESEARCH AND DEMONSTRATION ACTIVITIES

A number of research and demonstration projects presently underway are expected to contribute significantly to the development and/or evaluation of various salinity control measures.

(1) Under an FWQA research grant, a project entitled "Quality of Irrigation Return Flow" was initiated during FY 1969 by Utah State University at Logan, Utah. This project is directed toward the dual objectives of increasing the store of knowledge of basic processes controlling the movement of salts in soils, and applying this knowledge to development of salinity control measures. Research to date has primarily been conducted on a small scale in the laboratory and in greenhouse lysimeters. A digital simulation model is being developed to accurately predict the movement of salts and the changes in quality of applied irrigation water within the soil and root zone. This model will be utilized to design on-farm irrigation practices, such as the rate and timing of irrigation applications, which will minimize the salt load contributed by irrigation activities.

The University has established a 40-acre test farm in Ashley Valley near Vernal, Utah, and will conduct full scale field testing of theoretical results during 1970 and 1971. Establishment of a test farm at this location will provide a demonstration of salinity control measures under conditions similar to those found in many irrigated areas of the Upper Basin.

(2) In response to a request from the FWQA, a large scale research project entitled "Prediction of Mineral Quality of Return Flow Water from Irrigated Land" was initiated by the Bureau of Reclamation in late FY 1969, with financial support provided by the FWQA. The primary objective of this project is to develop a digital simulation model that will accurately predict the quantity and quality of irrigation return flows from an entire irrigation project with known soil, groundwater, and geologic and hydrologic characteristics. Such a model would have several applications. The water quality impact of a proposed irrigation development could be more accurately assessed. More importantly, the model could be utilized to evaluate the water quality effects of alternative project designs and, therefore, allow selection of the optimal design of features in order to minimize any adverse effects on water quality. Another application would be to evaluate improvements of irrigation facilities and practices in established irrigated areas aimed at reducing presently high salt contributions.

Field studies will be conducted in several locations with various soil and geologic conditions in order to verify prediction techniques under a wide range of conditions. Ashley Valley, surrounding Vernal, Utah, was selected as the initial study area. Characterization studies of this area are currently underway. Using present data, initial runs of an elementary simulation model will be made during 1970. The model will be refined; additional data will be collected during the next three years; and field studies at other locations will be initiated.

(3) The "Grand Valley Salinity Control Demonstration Project" at Grand Junction, Colorado, was initiated in FY 1969 under a FWQA demonstration grant. Its objective is to demonstrate the salinity control potential of lining irrigation canals and laterals. The Grand Valley is underlain by an aquifer containing highly saline groundwater. Seepage from canals and laterals contributes to recharge of this aquifer and displaces the saline groundwater into the Colorado River, thereby increasing its salt load. Reduction of such recharge by reducing seepage from conveyance systems, is therefore, expected to reduce the salt load discharged to the river.

A major portion of the canals and some of the laterals serving a study area of about 4,600 acres have been lined and additional lining will be completed during the 1970-1971 winter season. A simulation model is being developed which will evaluate the effects of changes in irrigation efficiency on salt load contributions, as well as changes in seepage losses from the conveyance system. Upon completion this model will not only allow the results of the demonstration project to be projected valley-wide, but also form the basis for future salinity control activities in Grand Valley. Completion of the demonstration project, including all post-construction studies, is scheduled for mid-1972.

(4) Only limited research efforts are presently directed toward defining processes to control salt loading from natural sources. The FWQA provided financial support to Utah State University for one such effort, "The Electric Analog Simulation of the Salinity Flow System within the Upper Colorado River Basin." Results from this research provided new information concerning the distribution of salt sources in the Upper Basin and will serve as a potential analytical tool for evaluating the water quality effects of various salinity control measures. The final research report is scheduled for publication during 1970.

(5) In late 1969 a research project entitled "Effect of Water Management on Quality of Groundwater and Surface Recharge in Las Vegas Valley," was initiated by Desert Research Institute, Las Vegas, Nevada, under a FWQA research grant. Among other things this project will evaluate the movement of salts in the groundwater system and the exchange of salts between the groundwater and surface waters of Las Vegas Wash. Research results will help define the optimum approach for control of this salt source. Completion of the research effort is scheduled for mid-1973.

(6) A cooperative regional research effort, "Project W-107, Management of Salt Load in Irrigation Agriculture," was initiated in 1969 by seven western universities and the U. S. Salinity Laboratory of the Agricultural Research Service. Work currently underway or planned, covers a wide range of salinity management aspects and should provide a number of results which can be applied to Basin salinity problems. The FWQA is participating in the coordination of this research effort.

SALINITY CONTROL PROJECTS

During the latter part of FY 1968, the FWQA made funds available and requested the Bureau of Reclamation to select a pilot project to test and demonstrate control methods for reducing salinity concentrations and salt loads in the Colorado River system. The plugging of two flowing wells, the Meeker and Piceance Creek wells near Meeker, Colorado, was selected as the pilot demonstration project. Completion of the well plugging in August, 1968 reduced the salinity load of the White River and the Colorado River system by about 62,500 tons annually. This is approximately 19 percent of the average annual salinity load in the White River near Watson, Utah. Plugging the Meeker and Piceance Creek wells initially decreased the annual flow of the White River by about 2,380 acre-feet. In the opinion of the Bureau's regional geologist, however, this flow will reappear through natural springs nearer the recharge area at an improved quality, and plugging the wells will not decrease the annual flow of the White River. Costs for plugging the two wells totaled about $40,000.

Another flowing well near Rock Springs, Wyoming, which contributed approximately 5,000 tons of salt annually, was plugged in November 1968, under the direction of the Wyoming State Engineer. The effects of eliminating this salt source have not been evaluated.

In late 1969, the Utah Oil and Gas Commission plugged seven abandoned oil test wells near Moab, Utah, including two flowing wells which formerly contributed a salt load of approximately 33,000 tons per year to the Colorado River. Costs of plugging the wells totaled about $35,000.

It is estimated that plugging the five flowing wells in Colorado, Wyoming, and Utah will reduce the average annual salt load passing Hoover Dam by 100,000 tons or 0.93 percent. Under present conditions this salt load reduction would reduce average salinity concentrations by about 6 mg/l. Although this change in salinity concentrations is small when compared to present salinity levels, the resulting economic benefits are significant. These benefits are estimated to range annually from $0.4 million in 1970 to $1.0 million in 2010 and have a present worth of more than $10 million.

CHAPTER VII. ALTERNATIVES FOR MANAGEMENT AND CONTROL OF SALINTIY

Three basic approaches, or a combination of these approaches might be used to achieve a solution to the salinity problem: do nothing, limit development or implement salinity controls. The first approach would achieve no management of salinity. Water resource development would be allowed to proceed with no constraints applied because of water quality degradation and with no implementation of salinity control works. This approach, in effect, ignores the problem and allows unrestrained economic development at the expense of an increased adverse economic impact resulting from rising salinity concentrations. The increases in future salinity levels and economic impact associated with this approach have been discussed in Chapter IV.

The second approach would limit economic or water resource development that is expected to produce an increase in salt loads or streamflow depletions. Such an approach would minimize future increases in the economic impact of salinity and possibly eliminate the need for salinity control facilities. However, it has the obvious disadvantage of possibly stagnating growth of the regional economy. Projections of future salinity levels and associated salinity detriments for this approach have been discussed in Chapter IV.

The third approach, calling for the construction of salinity control works, would allow water resource development to proceed. At least three possible management objectives could be considered: (1) salinity controls could be implemented to maintain specific salinity levels; (2) salinity could be maintained at a level which would minimize its total economic impact; and (3) salinity could be maintained at some low level for which the total economic impact of salinity would be equal to the impact that would be produced if no action were taken at all.

The following sections discuss an evaluation of the costs and benefits of various levels of salinity control and a comparison of the relative economics of the three basic salinity management approaches discussed above. This comparison forms the basis for the determination that the implementation of a basinwide salt load reduction program is the most feasible approach to achieving basinwide management of salinity.

POTENTIAL ALTERNATIVE BASINWIDE SALINITY CONTROL PROGRAMS

The potential measures for managing and controlling salinity concentrations presented in Chapter V were evaluated, and those which appeared most practical were selected for further investigation. Eight potential alternative salinity control programs incorporating a variety of control measures were formulated as a means of evaluating the magnitude, scope, and economic feasibility of a potential basinwide control program. These alternatives include three salt-load reduction programs, four flow augmentation programs, and one program to demineralize water supplies at the point of use.

The three salt load reduction programs utilized control measures such as desalination or impoundment and evaporation of mineral spring discharges, irrigation return flows and saline tributary flows, diversion of streams, and improvement of irrigation practices and facilities. These programs would acheive estimated salt load reductions of up to three million tons annually and would reduce average annual salinity concentrations at Hoover Dam by about 200 to 300 mg/l.

The four flow augmentation programs evaluated were based on three potential sources of water: increased precipitation through weather modification, interbasin transfer of water, and importation of demineralized sea water. The volume of flow augmentation provided by these programs would range from 1.7 to 5.9 million acre-feet annually. Resulting reductions in annual salinity concentrations at Hoover Dam would range from 100 to 300 mg/l.

The last alternative program evaluated would utilize desalination of the water supplies diverted to southern California as a means to minimize the adverse impact of salinity on the southern California water service area.

Average annual costs including amortized construction costs, operation costs, and maintenance costs, were estimated for each alternative program and ranged from $3 million to $177 million annually. The present worth of total program costs for each alternative from 1975 to 2010 would range from $30 million to $1,570 million. Estimated costs and resulting salinity concentrations are shown by program in Table 7. If no control or augmentation program were undertaken, comparable average salinity concentrations at Hoover Dam would be 876 mg/l and 990 mg/l in 1980 and 2010 respectively. Specific details used to compare and evaluate each alternative program are discussed in Appendix C, Chapter V.

The eight alternative programs evaluated were not directly comparable due to differences in the level of salinity control achieved, the multi-purpose aspects of some programs versus the singular salinity control natures of others, and the time required for implementation. Based on evaluation of a number of factors including total program costs, practicality, the implementation time period, salinity control benefits, and other benefits such as increased water supply, the phased implementation of a salt load reduction program

Table 7 Comparison of Alternative Salinity Control Programs

No.	Alternative Salinity Control Programs	Average Salinity Concentrations at Hoover Dam 1980 (mg/l)	2010 (mg/l)	Average Annual Program 1980 ($ Million/Yr)	2010 ($ Million/Yr)	Present Worth ($ Million)
1.	Salt Load Reduction (Full scale implementation)	620	720	47	47	510
2.	Salt Load Reduction (Phased Implementation)	700	700	23	52	350
3.	Flow Augmentation (Weather Modification) (1.7 MAF/Yr)	780	870	3	3	30
4.	Flow Augmentation (Interbasin Transfer) (2.5 MAF/Yr)	750	830	75	75	800
5.	Flow Augmentation (Interbasin Transfer) (3.9-5.9 MAF/Yr)	700	700	118	177	1,470
6.	Desalination (Source Control)	700	700	41	62	510
7.	Desalination (Supply Treatment)	--	--	140	160	1,570
8.	Desalination (Flow Augmentation) (2.0 MAF/Yr)	710	740	131	131	1,400

was selected as the least cost alternative for achieving basinwide management and control of salinity. Should the practicality of flow augmentation by weather modification be demonstrated by current pilot studies, however, the combination of such flow augmentation with a salt load reduction program would be a more optimal approach.

SALINITY MANAGEMENT COSTS

If salinity concentrations are reduced by the implementation of control measures, certain costs known as salinity management costs will be incurred. The form and magnitude of these costs depend upon a number of factors including the control measures utilized and the degree of salinity control achieved. Estimates of the probable costs and effects of the salt load reduction program, were utilized to evaluate the magnitude of salinity management costs for various levels of salinity control.

The major features of the salt load reduction program are presented in Table 8. This program was designed to reduce the salt load contributed by five large natural sources and twelve irrigated areas totaling 600,000 acres. Together, the five natural sources contribute about 14 percent of the Basin salt load. All of the irrigated areas selected exhibit high salt pick-up by return flows of about three to six tons per acre per year. Although this acreage comprises only about 20 percent of the Basin's irrigated load from irrigation sources above Hoover Dam. The specific control measures for the 17 component projects are listed in Table 8 along with project locations (also shown in Figure 5).

Average annual costs, including operation, maintenance, and amortized construction costs, were estimated for each of the 17 projects. For the five single-purpose salt load reduction projects, all costs were assigned to salinity control. The irrigation improvement projects would be multi-purpose. It is estimated they would produce various economic benefits of about the same magnitude as salinity control benefits and for this reason, only half of the costs of irrigation improvement were allocated to salinity control.

Estimates of the changes in streamflow depletions and salt load reductions were also prepared for each project. The five salt load reduction projects would remove an average of 172,000 acre-feet per year from the river system above Hoover Dam; of this amount, 140,000 acre-feet of demineralized water from the Blue Springs project would be available for use in central Arizona. The irrigation improvement projects would reduce non-beneficial consumptive water use by an estimated average of 299,000 acre-feet per year. The

Table 8. Salinity Management Data For Potential Projects

PROJECT DESCRIPTION			AVERAGE ANNUAL COSTS		EFFECTS AT HOOVER DAM				
No.	Location	Features	Total Proj. Cost ($1000)	Salinity Control Costs ($1000)	Flow Change (1000 AF/Yr)	Salt Load Reduction (1000 T/Yr)	TDS Reduction in mg/l 1980	TDS Reduction in mg/l 2010	Cost Index ($/T)
1	Paradox Valley, Colorado	Stream Diversion	700	700	0	180	15	16	3.89
2	Grand Valley, Colorado	Irrigation Improvement	3,140	1,570	38	312	29	33	5.04
3	Lower Stem Gunnison River, Colorado	Irrigation Improvement	3,600	1,800	45	334	32	35	5.40
4	Price River, Utah	Irrigation Improvement	1,000	500	13	89	9	9	5.65
5	Las Vegas Wash, Nevada	Export & Evaporation	600	600	- 10	100	7	8	6.00
6	Uncompahgre River, Colo.	Irrigation Improvement	4,000	2,000	50	320	31	35	6.25
7	Big Sandy Creek, Wyoming	Irrigation Improvement	490	245	7	39	4	4	6.28
8	La Verkin Springs, Utah	Impoundment & Evap.	600	600	- 7	80	6	6	7.50
9	Roaring Fork River, Colo.	Irrigation Improvement	880	440	13	52	6	6	8.47
10	Upper Stem Colorado River, Colorado	Irrigation Improvement	1,420	710	20	80	9	9	8.88
11	Henry's Fork River, Utah	Irrigation Improvement	710	355	10	40	4	5	8.88
12	Dirty Devil River, Utah	Irrigation Improvement	710	355	10	40	4	5	8.88
13	Duchesne River, Utah	Irrigation Improvement	5,660	2,830	65	273	29	32	10.37
14	San Rafael River, Utah	Irrigation Improvement	1,360	680	18	65	7	8	10.48
15	Ashley Creek, Utah	Irrigation Improvement	830	415	10	36	4	4	11.55
16	Glenwood Springs, Colo.	Desalination	5,000	5,000	- 5	370	30	33	13.50
17	Blue Springs, Arizona	Export & Desalination	16,000	16,000	- 150	500	27	27	32.00
	Totals		46,700	34,800	127	2,910	253	275	--

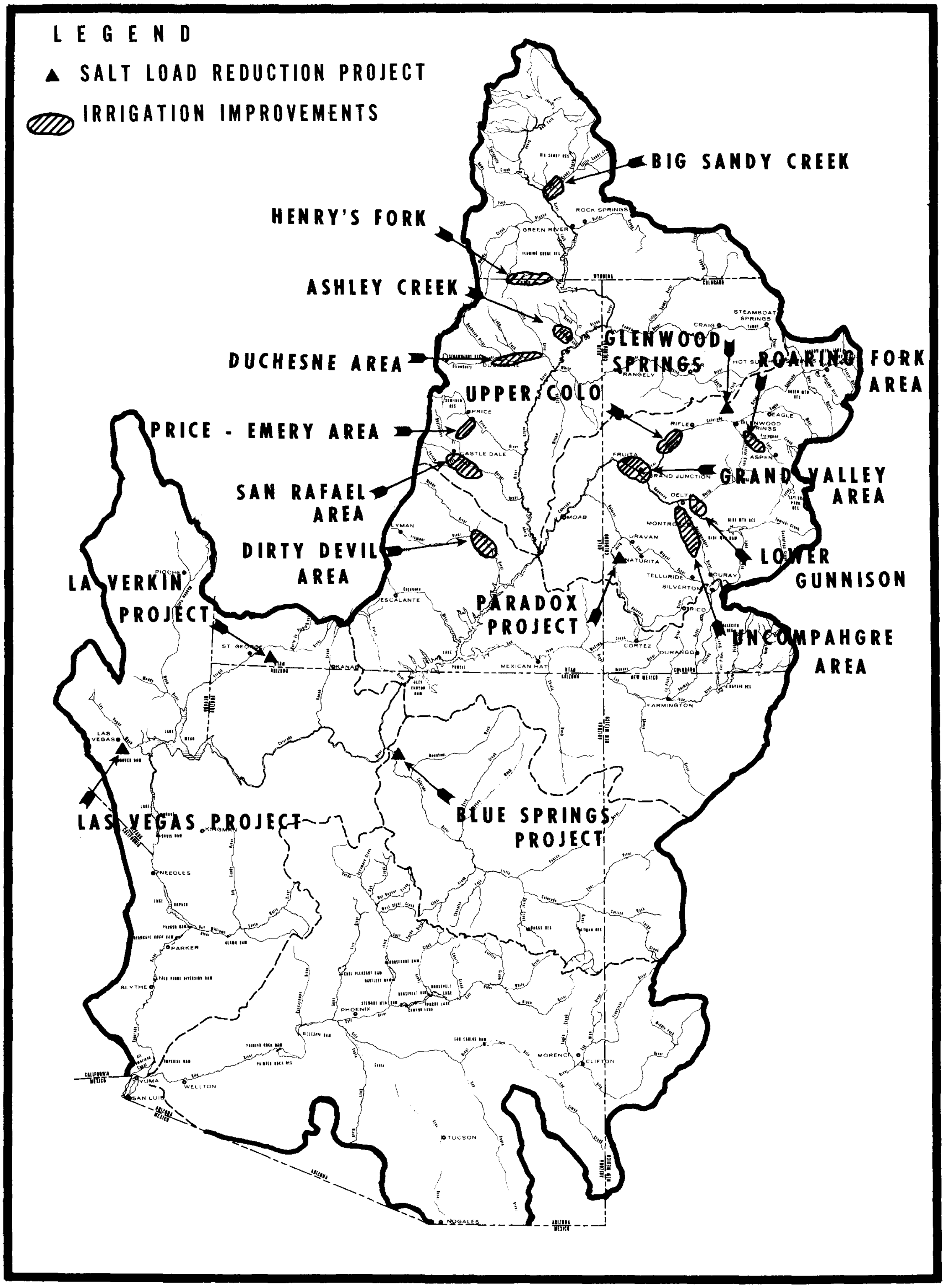


Figure 5. Location of Potential Salt Load Reduction Projects

salinity control program would thus result in a net increase in available basin water supply of more than 250,000 acre-feet per year.

The incremental reductions in average salinity concentrations at Hoover Dam were estimated for each control project for the years 1980 and 2010 by utilizing predicted changes in flow and salt load. These incremental changes are shown in Table 8. Note that the salinity reduction for each project is greater in the year 2010 than in 1980. This factor results from decreases in average streamflow predicted to occur between 1980 and 2010.

A cost index utilizing estimated costs and salt load reductions was computed for each project. This index was then used to rank the projects in order of increasing unit cost of salt removal.

By utilizing the data in Table 8, salinity management cost functions relating cumulative salinity management costs to salinity reductions were prepared. These cost functions are also shown in Figure 6.

TOTAL SALINITY COSTS

For a given salinity level, there is an economic cost associated with water use (salinity detriments) and a second economic cost associated with maintaining salinity concentrations at that level (salinity management costs). The sum of these costs, defined as total salinity costs, can be determined for any time period and salinity level by the proper manipulation of three factors: the salinity detriment functions presented in Chapter IV, (Figure 4); the salinity management cost functions, (Figure 6); and the predicted future salinity concentrations with no control implemented, (Figure 2). Total salinity cost functions for various time periods are presented in Figure 7. The methodology utilized to develop these functions is discussed in Appendix C, Chapter V.

ECONOMIC AND WATER QUALITY EFFECTS

Salinity controls could be implemented to meet a variety of salinity management objectives which include both water quality and economic objectives. Since salinity levels and total salinity costs are interrelated, the selection of a water quality objective will result in the indirect selection of associated economic effects; conversely, the selection of an economic objective will result in the selection of associated salinity levels. A knowledge of the interrelationships between economic and water quality effects is thus

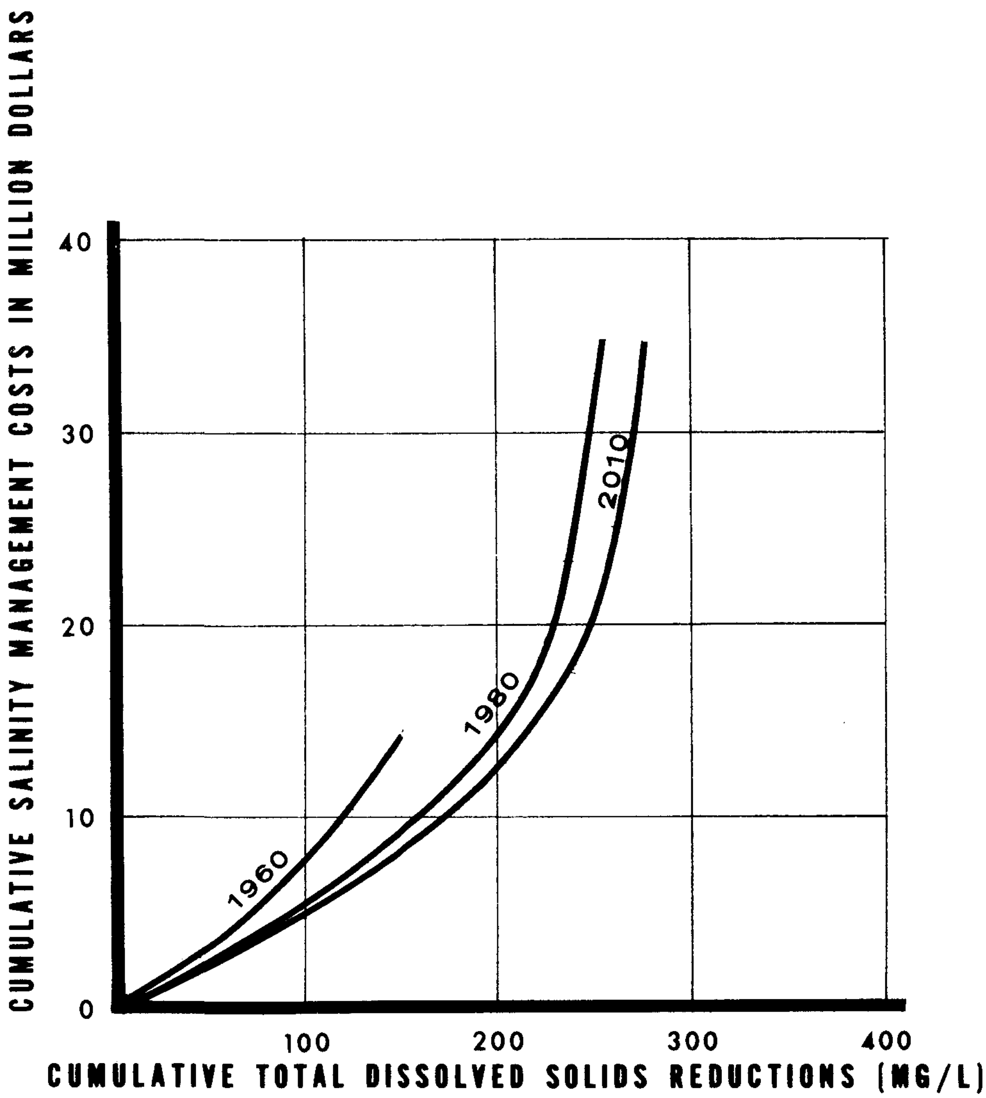


Figure 6. Salinity Management Costs

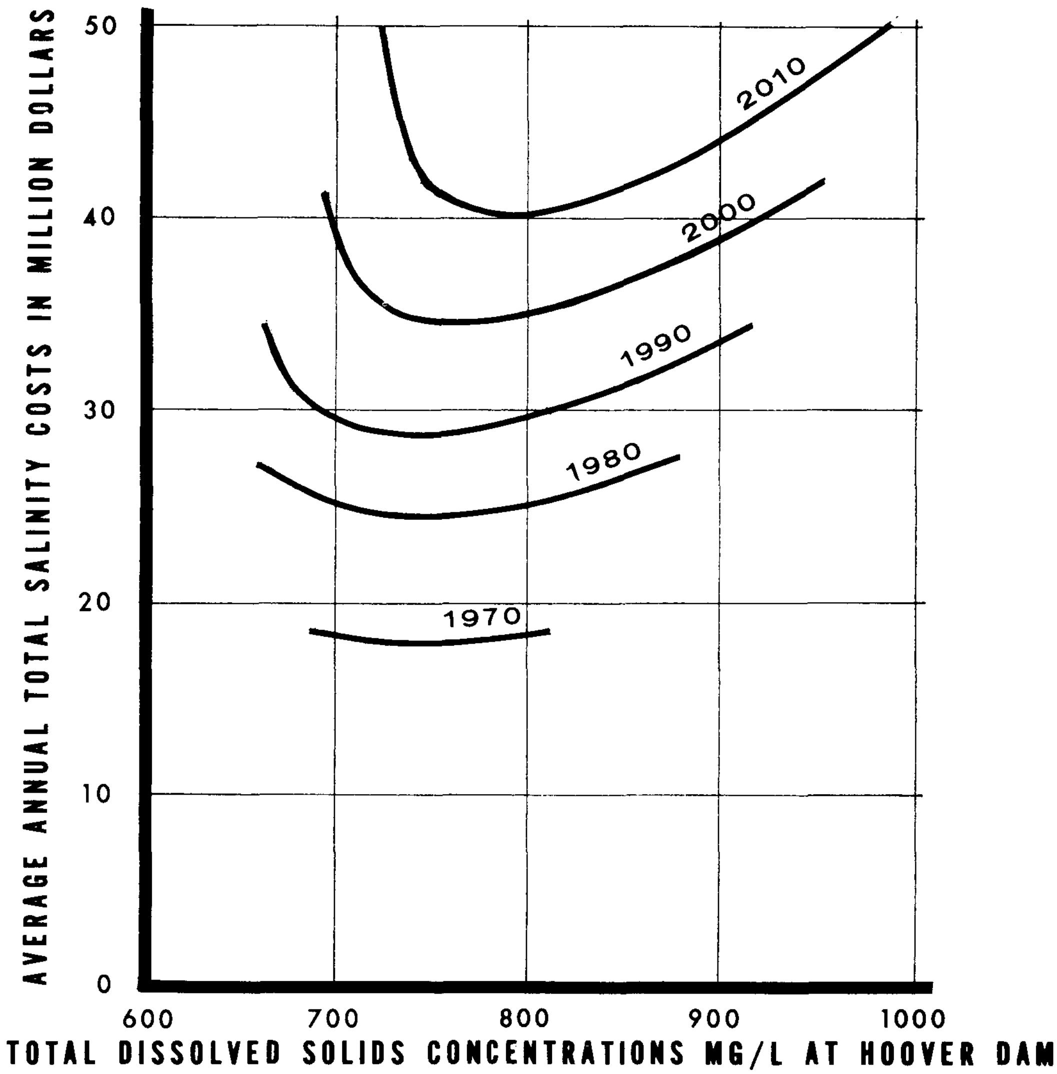


Figure 7. Total Salinity Costs

useful in the rational selection of salinity management objectives.

By utilizing the total cost functions shown in Figure 7, the economic and water quality effects associated with the three salinity management objectives were determined: (1) Maintain salinity at a level which would minimize its total economic impact and achieve economic efficiency (minimum cost objective); (2) Maintain salinity concentrations at some specified level (constant salinity objective); and (3) Maintain salinity at some low level for which the total economic impact would be equal to the economic impact that would be produced if no action were taken at all (equal cost objective). A comparison of the economic effects associated with these three objectives, in the form of variations in salinity costs with time, are shown in Figure 8. The economic effects associated with allowing unlimited water resource development in the absence of salinity control works (no control approach) and associated with the limited development approach are also shown in Figure 8.

Total salinity costs would be minimized by the limited development alternative. This approach might not be the most economical, however, when all effects on the regional economy are measured. Water resource developments are not constructed unless it has been demonstrated that such development will return economic benefits which exceed all costs of the development. A project which is economically feasible will thus produce a net improvement in the regional economy. If the project is not built, the net benefits of the project would be foregone representing an economic cost. A determination of the net economic benefits foregone if the limited development approach were utilized was beyond the scope of the Project's investigations. It is apparent from Figure 8, however, that if the annual benefits foregone exceed $3 million in 1980 and $11 million in 2010, the total economic impact of limited development would exceed the impact of the minimum cost alternative.

If unrestricted water resource development is permitted, implementing salinity controls to achieve the minimum cost objective would minimize total salinity costs. The no control and equal cost alternatives produce the identical highest average costs and most rapid increase with time of all the alternatives evaluated. Total costs associated with a constant salinity objective will fall somewhere between the extremes established by the other alternatives with the exact cost dependent upon the target salinity level. For a target level of 700 mg/l, total costs approximate minimum costs until 1990, then increase rapidly, eventually exceeding the no control costs. Beyond the year 2000, the rapidly increasing cost reduce the practicality of maintaining this salinity level. Selection of a higher target salinity concentration for the years 2000 and 2010 would reduce the total cost of this alternative.

One important observation can be made from Figure 8. Regardless of the alternative selected, the future economic impact of salinity will be great. Although implementing salinity controls will result in the availability of better quality water for various uses and some of the economic impact will be shifted from salinity detriments to salinity management costs, the total economic impact of salinity will not be substantially reduced. As a minimum, average annual total salinity costs will increase threefold between 1960 and 2010. Selection of the limited development alternative would reduce total annual costs by only about 40 percent below the no control alternative in the year 2010.

Variations with time of the predicted salinity levels associated with the five alternatives evaluated are shown in Figure 9. With no controls implemented, average annual salinity concentrations at Hoover Dam are predicted to increase between 1960 and 2010 by about 42 percent or 293 mg/l. Selection of any of the other alternatives evaluated would substantially reduce future salinity concentrations below the no control levels. Except for the limited development alternative, these reductions would result in the maintenance of average salinity concentrations at or below present (1970) levels for more than 25 years. Resulting water quality therefore would be consistent with non-degradation provisions of the water quality standards adopted by the seven Basin States. The limited development alternative would result in slight increases in average salinity concentrations.

COST DISTRIBUTIONS AND EQUITY CONSIDERATIONS

Although the total economic impact of salinity associated with each of the alternatives evaluated varies over a limited range, the distribution of salinity costs related to each alternative differs greatly. Distribution of costs may therefore be an important factor in the selection of alternatives. Associated with cost distribution are various equity considerations. These, too, influence the selection of alternatives. Salinity cost distributions for the five alternatives evaluated for both 1980 and 2010 conditions of water use are compared in Table 9. A further breakdown of salinity management costs, by individual projects, is shown in Table 8.

The no control and equal cost alternatives produced the extremes in the range of cost distributions evaluated. Total

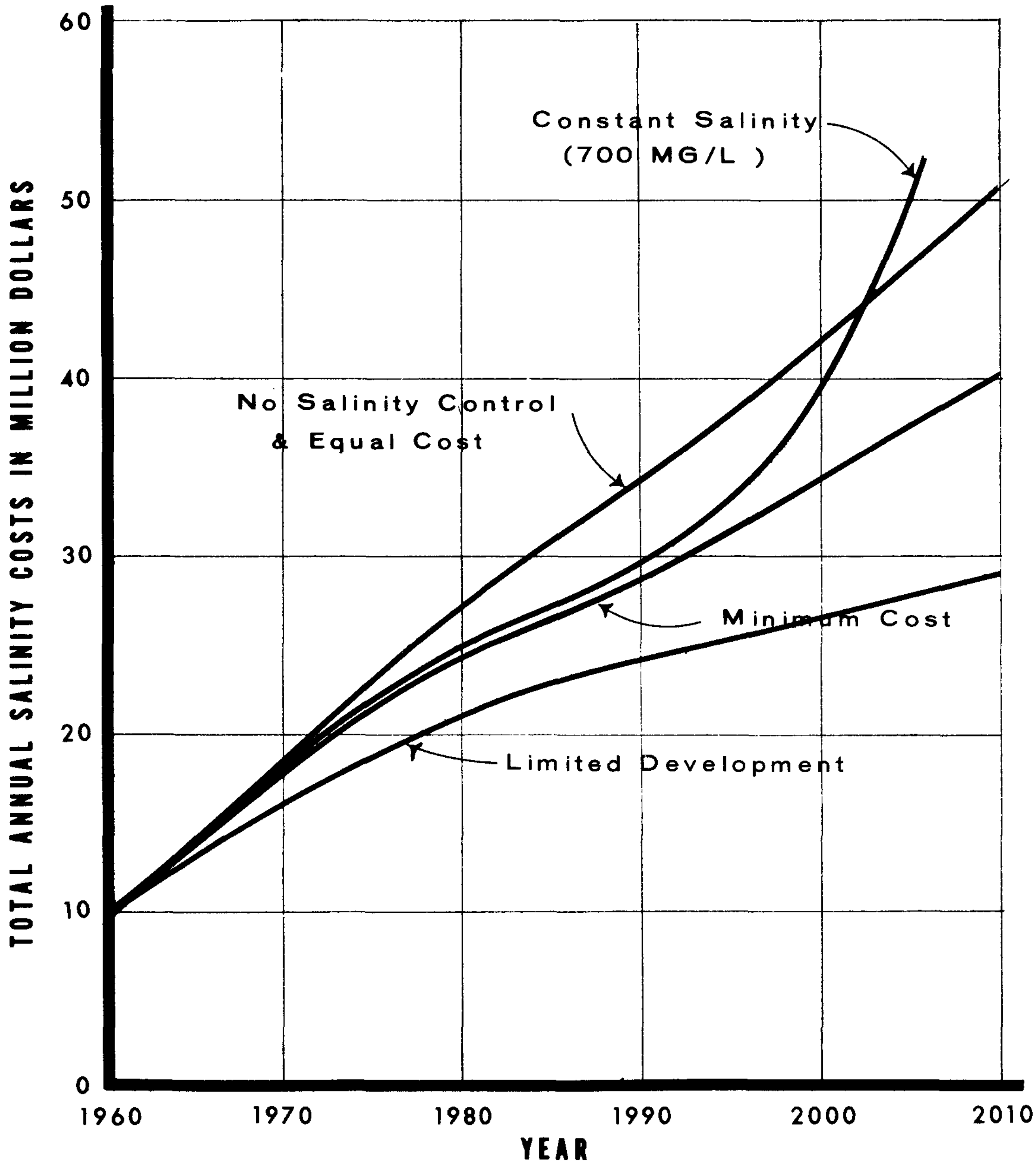


Figure 8. Salinity Costs vs Time

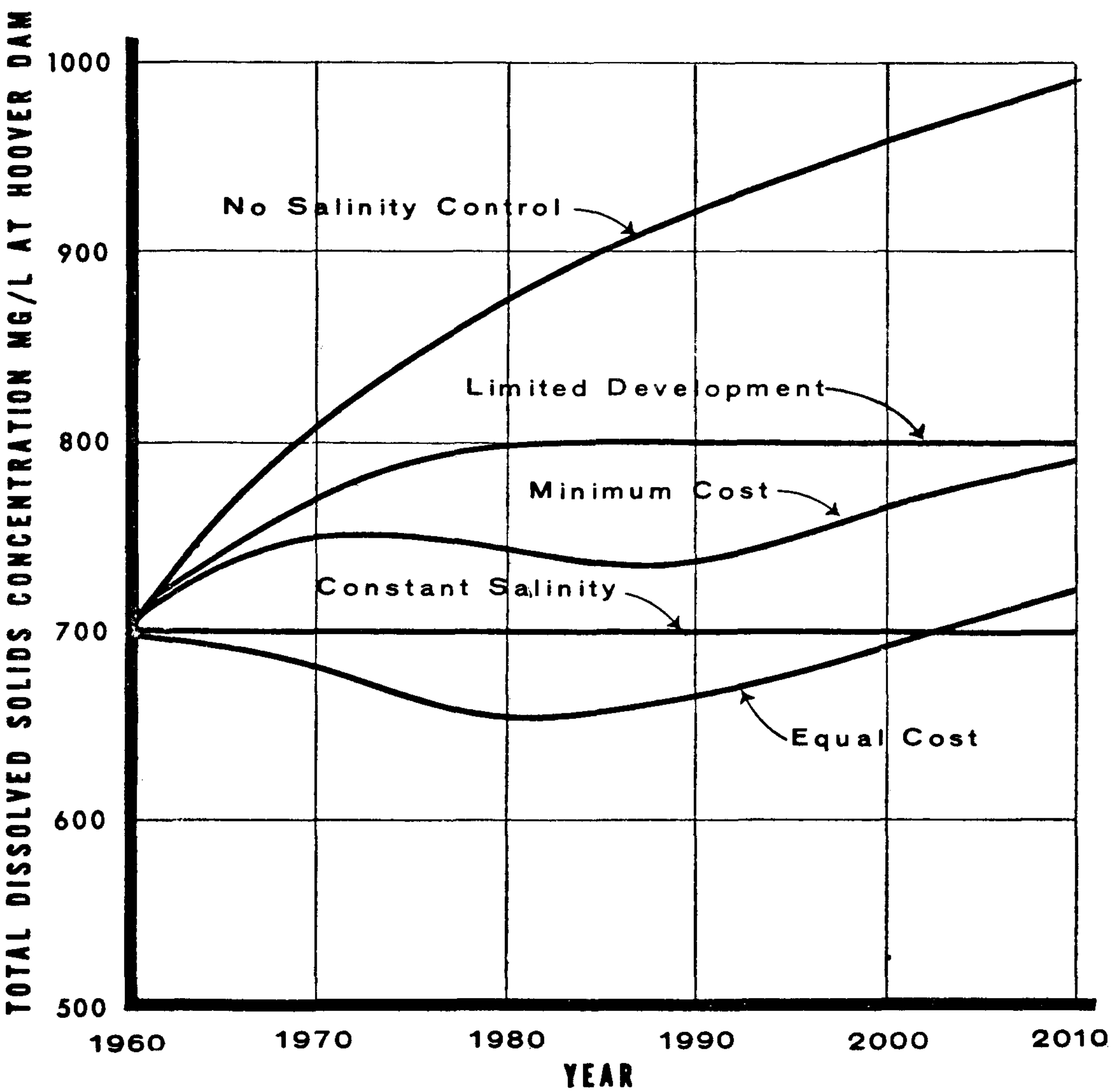


Figure 9. Salinity Concentration vs Time

costs for these two alternatives, by definition, are equal but the distributions of costs are vastly different. For the no control alternative, all costs are in the form of detriments. For the equal cost alternative, however, salinity detriments are reduced by an average of 60 percent. This cost reduction is offset by a corresponding increase in salinity management costs.

The extremes in the range of cost distribution point out the basis for equity considerations which may enter into the selection of management objectives. If the no control alternative is selected, all salinity costs would essentially be borne by water users and by the regional economy in the Lower Basin and southern California water service area. In contrast, selection of the equal cost alternative would redistribute a majority of the costs to investments in salinity control facilities in the drainage area upstream from Hoover Dam. Much of this investment would be for irrigation improvements in the Upper Basin, improvements that would produce substantial economic benefits in addition to salinity control benefits. The equity of these two extremes in cost distributions is vastly different.

Salinity detriments for the other three alternatives evaluated fall between the extremes extablished by the no control and equal cost alternatives. Salinity management costs are less than for the equal cost alternative. The equity of these cost distributions may also be an important factor in selection of the most desirable alternative. The cost distribution shown in Table 9 can be used to evaluate the relative costs and benefits of a given alternative. For example, a salinity control program designed to meet the minimum cost objective would have an estimated average annual cost of $7.2 million in 1980 and $12.7 million in 2010. The benefits associated with a given alternative would be the difference between salinity detriments expected if no controls are implemented and if the control program associated with that alternative is implemented. For the minimum cost alternative, average annual salinity control benefits would total $10.7 million in 1980 and $22.0 million in 2010.

LEGAL AND INSTITUTIONAL CONSTRAINTS

Implementation of a basinwide salinity control program based on salt load reduction projects would face a number of legal and institutional constraints. Perhaps one of the most formidable constraints would be imposed by existing State water laws and their requirements concerning water rights and beneficial use. These laws do not recognize utilization of water for quality control purposes as a beneficial use, yet several of the salt load reduction projects formulated would result in some minor depletion of water. Modification

Table 9 Comparison of Salinity Cost Distribution

Alternative Objective	Date	Salinity Detriments ($1,000/Yr)	Salinity Management Costs			Total Salinity Costs ($1,000/Yr
			Salt Load Reduction Projects ($1,000/Yr)	Salinity Control Costs ($1,000/Yr)	Total Salinity Management Costs ($1,000/Yr)	
No Control	1980	27,700	0	0	0	27,700
	2010	50,500	0	0	0	50,500
Limited	1980	21,000	0	0	0	21,000
Development	2010	29,000	0	0	0	29,000
Minimum Cost	1980	17,000	1,300	5,900	7,200	24,200
	2010	28,500	1,900	10,800	12,700	41,200
Constant Salinity	1980	13,500	1,900	10,000	11,900	25,300
(700 mg/l)	2010	19,000	25,000	13,500	38,500	57,500
Equal Cost	1980	9,200	6,900	11,600	18,500	27,700
	2010	21,000	17,600	11,900	29,500	50,500

of existing constraints would therefore be required to allow operation of these project facilities.

Improvement of irrigation efficiencies would reduce the amount of water required for diversion to a given farm or irrigation project. The effect of such a reduction in water use on perfected water rights is unclear and could cause legal problems. Such legal factors may affect the selection of control measures to be incorporated in a basinwide salinity management program.

The Water Quality Act of 1965 provided that the States establish water quality standards for all interstate streams. Subsequently, the seven Basin States developed water quality standards for the Colorado River. The standards established by the States did not include numerical salinity standards, primarily due to a lack of adequate salinity control information on which an implementation plan could be based. The Secretary of the Interior approved the water quality standards for the Colorado River, with the provision that numerical salinity standards would be established at such a future time when sufficient information had been developed to provide the basis for workable, equitable, and enforceable salinity standards. The states are thus still faced with the task of establishing suitable salinity standards in compliance with the Water Quality Act of 1965. The lack of numerical salinity standards may be a constraint to the rational planning of water resources development and implementation of salinity controls.

An important institutional factor for consideration is the lack of a single entity with basinwide jurisdiction to direct and implement a salinity control program. In addition, water quality and water quantity considerations are generally under the jurisdiction of different agencies at both the State and Federal level. This split jurisdiction poses coordination problems to all interests affected by a salinity control program.

Existing legal and institutional arrangements would also place constraints upon the means available to finance a salinity control program. In addition, a detailed analysis has not yet been made of the potential means for financing such a program. A cursory review of programs available for financing facilities similar to those contemplated indicated that existing financing schemes are not fully adequate to meet salinity control program needs. This is due either to an insufficient magnitude of available funds or a lack of legal authorization.

OTHER CONSIDERATIONS

The least cost alternative program, utilized as the basis for the evaluation of the economic feasibility of salinity control, was directed toward the objective of minimizing salinity concentrations on a basinwide basis. This objective was achieved by reducing the average salt load passing Hoover Dam, a control point for the quality of water delivered to most Lower Basin and all Southern California water users. It is important to note that salinity concentrations increase substantially between Hoover Dam and Imperial Dam due to water use in the Lower Basin and exports of water to the Metropolitan Water District of Southern California. Implementation of salinity control measures along the Lower Colorado River could offset or minimize these salinity increases. Such measures have a higher unit cost for salinity reductions at Imperial Dam than those measures selected for the least cost program and were omitted from consideration for this reason. Salinity control below Hoover Dam, however, is a possible, practical approach toward minimizing the economic impact of salinity and should receive further consideration in the formulation of a basinwide salinity control program.

Fluctuations in salinity concentrations resulting from factors such as seasonal changes in streamflow and water use occur throughout the Basin. Peak concentrations reached during such fluctuation may exert adverse effects on water use far exceeding the effects predicted on the basis of average salinity concentrations. By reducing average salinity concentrations, a salt load reduction program would provide a moderating effect on peak concentrations. The possible magnitude of such fluctuations and their adverse impact, however, would indicate the need for more positive means of minimizing peak concentrations. Possible control measures would include the manipulation of reservoir storage and releases, close control of water deliveries to minimize stream fluctuations, and seasonal storage of salts in irrigated areas. The water quality simulation model utilized to predict future salinity concentrations only determines long term average concentrations and does not have the capability to predict the magnitude of short term fluctuations. Water quality simulation capabilities therefore will need to be refined before the effectiveness of control measures can be evaluated.

CHAPTER VIII. ACTION PLAN FOR SALINITY CONTROL AND MANAGEMENT

The preceding chapters defined the present and expected future magnitude of the physical and economic impacts of salinity. Possible technical solutions to minimize these impacts including alternative approaches to management of salinity and associated water quality and economic effects were also discussed. The range of possible problem solutions point out the need for rational selection by the Basin states of objectives for future water quality and uses and the formulation of a basinwide salinity control plan to meet these objectives. This Chapter outlines a recommended plan of action to achieve an early solution to the salinity problem in the Colorado River Basin.

BASIC WATER QUALITY OBJECTIVE

In the past, the development of the Basin's water resources was primarily guided by two basic objectives: (1) full development of the water supply allocated to each State by applicable water laws and compacts, and (2) expansion of the regional economy. A number of legal, institutional and political factors have supported these basic objectives. The lack of consideration given to the water quality impact of such development has resulted in the creation of a serious water quality problem which has basinwide economic significance. There is thus the urgent need for a water quality objective to supplement these basic objectives and provide guidance in the optimal development of remaining water resources.

The Project's investigations have demonstrated that basinwide control and management of salinity is possible, practical and economically feasible. In addition, the feasibility of maintaining salinity concentrations at or below present levels in the Colorado River below Hoover Dam has been shown. The enhancement of water quality in the lower river would alleviate much of the future economic impact of salinity. Enhancement of the quality of the Nation's water resources has been declared a national policy. It is therefore recommended that a broad water quality objective be adopted by Basin interests which would require salinity concentrations to be maintained at or below present levels in the Lower Colorado River. This objective would become part of the basic policy guiding the comprehensive planning and development of the Basin's remaining water resources.

Salinity Standards

The present lack of numerical limits on salinity concentrations is a serious deficiency in the water quality standards established by the seven Basin States for the Colorado River and interstate tributaries. Salinity affects a number of water uses which are designated as uses to be protected by the standards. Suitable limits should be established to provide adequate protection for these designated uses.

In the initial process of establishing water quality standards pursuant to the Water Quality Act of 1965, salinity standards were not established, primarily due to a lack of information. Salinity levels which could be maintained by implementing controls were not known. More significantly, the economic effects of maintaining any given salinity level were also unknown. The Project's investigations have provided much of the needed information. Although additional effort will be required to establish detailed basinwide criteria which are equitable, workable and enforceable, present information is considered adequate to form the basis for the establishment of a salinity objective which will set an upper limit on salinity increases in the Lower Colorado River.

It is recommended that appropriate Colorado River Basin States take the steps necessary to establish a numerical objective for salinity concentration. Based on the factors discussed below, it is recommended that, as a minimum, this objective require the average concentrations of total dissolved solids for any given month to be maintained below 1000 mg/l at Imperial Dam. This would apply until such time as detailed basinwide criteria can be established as discussed in the following section.

Evaluation of the water quality effects of various salinity control alternatives has shown that by either implementing a basinwide salinity control program or limiting water resource development, future salinity levels at Hoover Dam could be maintained at or below an average annual concentration of 800 mg/l. A corresponding limit of 1000 mg/l at Imperial Dam could be achieved. A maximum limit based on average annual salinity concentrations would not provide water uses with adequate protection against potentially damaging short-term salinity fluctuations. A limit on average monthly concentrations is considered necessary to provide a more acceptable level of protection.

To achieve compliance with the basic policy objective to enhance water quality in the Lower Colorado River will require that detailed salinity criteria be established at a number of key locations throughout the Basin. These criteria will serve two purposes. By maintaining salinity levels at upstream locations below assigned limits, compliance with downstream criteria will be assured. Secondly, the criteria will provide a basis for optimal development of the water resources of a given tributary, sub-basin or State.

Complete Basinwide salinity criteria should be established after careful consideration by the Basin interests of such factors as existing salinity levels, proposed water resources development, the feasibility of salinity control, water quality requirements for water uses, and the economic impact of salinity. Such criteria should be consistent with the salinity policy and with the numerical objective outlined above, and should be adopted by January 1, 1973.

It is recommended that a State/Federal task group be established immediately to carry out the necessary activities to develop detailed salinity criteria for key control points in the Basin. Following completion of the Task Group's activities, the salinity criteria should be adopted by the appropriate Basin States in accordance with the Federal Water Pollution Control Act, as amended.

Task groups have been utilized in a similar manner in the Basin in the past. A task group was assembled to develop guidelines for establishing the initial water quality standards in the Basin. More recently, a task group was utilized to develop operating criteria for the large main-stem reservoirs.

To provide adequate consideration of all interests affected by salinity, the Task Group should include representation from Federal, State and local agencies. It would be desirable for state representation to include the State water pollution control agency and the State water resource agency. In view of Federal involvement in water resource development, water quality management, and the basinwide nature of the salinity problem Federal representation should include the Environmental Protection Agency, the Bureau of Reclamation, the Geological Survey, the Office of Saline Water, the Soil Conservation Service, the Agricultural Research Service and the International Boundary and Water Commission. Representation from other groups such as the Upper Colorado River Commission, Colorado River Commission of Nevada, Colorado River Board of California, and the Colorado River Water Users Association would be desirable.

SALINITY CONTROL AGENCY

One major constraint that must be overcome before basinwide management and control of salinity can be achieved is the lack of a single institutional entity with basinwide jurisdiction which could be responsible for planning and implementing a control program. There are various agencies with jurisdictions over parts or all of the Basin. In the case of the States, no suitable basinwide organizations exist. Several Federal agencies have basinwide responsibilities but no single agency has legislative authority to carry out all program elements. It would therefore appear necessary to create a new institution with the necessary authority to plan and implement a control program.

Three possible means of creating a salinity control agency are available. The Task Group assembled to formulate salinity criteria could continue to function and could be utilized to develop policy and plan a basinwide salinity control program. It would be heavily dependent upon member agencies to carry out the necessary program planning activities. A Task Group would be severly limited in its authority to require the States or Federal agencies to proceed with specific courses of action and would not have the necessary powers to fully implement a control program. No new legislative authority would be required to create this somewhat limited salinity control agency.

A second possible approach would be to extend the authority of an existing agency or commission to provide the necessary powers to carry out all the phases of a basinwide salinity control program. This approach would require changes in the authorizing legislation for the particular institutional entity selected for expansion of its functions.

Perhaps the most desirable approach would be to create a new permanent State/Federal agency or river basin commission with the authority to carry out all activities necessary to the basinwide management and control of salinity. Such an agency would have the advantages of concentrating all necessary powers in one agency and of being a single purpose institution with no conflict with other assigned functions. New legislation would be required to create the agency.

In view of the magnitude and scope of the salinity problem and possible solutions, it is recommended that the third approach be taken and that legislation be sought to establish a permanent State/Federal agency or river basin commission with the authority to plan, formulate policy, direct, and implement a basinwide salinity control program. Consideration should also be given to the possibility of extending the authority of existing agencies or commissions to assume this responsibility.

BASINWIDE SALINITY CONTROL PROGRAM

A large-scale salt load reduction program was identified in

Chapter VII as the least cost alternative means of achieving basinwide control of salinity. The steps which must be taken to authorize, fund, plan and implement such a program are outlined in the following paragraphs.

<u>Legislative Authorization</u>

Existing legal and institutional arrangements are not adequate to provide the basis for implementing a large-scale salinity control program. It is therefore recommended that the necessary congressional authorization and funding be sought at an early date so that the implementation of the salinity control program can proceed.

Due to the scale and types of control projects included in the salt load reduction program an approach similar to that utilized for the authorization and funding of water resources developments is recommended. Water resource projects normally move through three basic steps before they are placed in operation. A project is first authorized by Congress on the basis of preliminary plans developed by limited studies known as reconnaissance studies. Following authorization, funds may be appropriated for more detailed planning investigations known as feasibility studies, a feasibility report is submitted to Congress, and construction funds are requested. The third step begins when funds are appropriated for construction. Completion of construction then places the project in operation.

Frequently, a number of related projects are authorized by a single legislative act. This was the case for the Colorado River Storage Project Act which authorized several large reservoir projects at one time. It is recommended that legislation be introduced in the near future to authorize the entire basinwide salt load reduction program and to appropriate funds for the necessary planning studies.

<u>Planning Phase</u>

In line with the three steps outlined above for authorizing and funding a water resource project, once authorized, the basinwide salinity control program should be conducted in two phases, a planning phase and an implementation phase. This section outlines the activities which make up the planning phase.

The planning phase of the basinwide program should be directed toward the objectives of providing sufficient information for developing an implementation plan, and of providing the feasibility reports on which requests for construction funds for necessary control works can be based, and of identifying construction, operation and related costs which should be properly assigned to the Basin States and other beneficiaries. To achieve these objectives will require substantial efforts to be expended in five types of activity: systems analyses, research and demonstration activities, reconnaissance investigations, feasibility studies and legal, institutional and financial evaluations.

System Analyses. A systematic evaluation of the quality and economic aspects of the salinity problem provided a key element in the Project's determination of the potential feasibility and practicality of a basinwide salinity control program. Systems analysis capability similar to the methodology developed for this evaluation will be required for the planning phase. Refinement and updating of the analytical tools will be required, however, to provide adequate capability for the improved information developed by other planning activities. Specifically, a refined water quality simulation model and updated economic evaluation models will be required.

The Project's water quality simulation model is basically a water and salt budget model with the capability to predict long term averages for streamflow, salt loads and salinity concentrations at various points in the basin and to evaluate the long term effects of modifications in water use and salt loading at any point in the river system. This model is not capable of predicting fluctuations in salinity concentrations or of evaluating the short term effects of various control measures. The model should be refined to provide for simulation of water quality on a monthly basis including the routing of salt loads through irrigated areas and large reservoirs. This improved model would have the capability to evaluate the water quality effects of proposed annual operating plans for the major reservoirs of the basin, to optimize reservoir operations to minimize salinity fluctuations, to provide an improved degres of evaluation of the salinity impacts of proposed water resource development projects and to assist in the formulation of suitable numerical salinity standards in addition to its utilization for evaluation of alternative salinity control measures and facilities.

The Project's economic evaluations and models were largely based on 1960 economic data. The economic impact of salinity increases in specific areas in the Upper Basin and Mexican water users was not evaluated. The effects of rising salinity levels in the Colorado River supply on the feasibility of controlling the salinity of the Salton Sea was not considered. Economic effects were based on average salinity concentrations and fluctuations in concentrations were not evaluated.

Updating the economic models on the basis of 1970 economic data which should be available by 1972 would provide a better estimate of the current detrimental effects of salinity and would improve predictions of future effects since historical trends from 1960 to 1970 would be available. In view of the probable economic impact of salinity on Mexican water users, on water use in certain areas of the Upper Basin and on control of salinity in the Salton Sea, the economic models should have the capability for handling such areas. In addition, the capability to evaluate the economic impact of salinity fluctuations should be developed.

Research and Demonstration Activities. A number of research and demonstration activities discussed in Chapter V are currently directed toward improvement of salinity control technology. Completion of these activities will not provide the technology needed for control of all types of salinity sources. Additional research will be required if certain types of salinity sources are to be controlled.

The greatest lack of available technology is in the area of natural diffuse sources. Control of salt contributed by surface runoff and diffuse groundwater sources, although the major sources of salt-loading in the Basin, is presently not technically feasible. The Soil Conservation Service, the Bureau of Reclamation, the Geological Survey, the Bureau of Land Management and various State agencies are all concerned with various aspects of water and land utilization which may have an impact on diffuse salt contributions. It may be possible to conduct research or demonstration efforts through these agencies programs to develop means of minimizing diffuse salt contributions.

Control measures applicable to natural point sources are limited, especially in areas with low evaporation rates. The Geological Survey has an extensive reserach program in the field of groundwater quality and movement. Directing some of this research effort toward mineral springs could result in the development of additional control measures.

Another area for which present control technology is limited is irrigated agriculture. Research concerning various irrigation practices and facilities, crop yields, and land characteristics being carried out by various State institutions, the Bureau of Reclamation, the Soil Conservation Service and the Agricultural Research Service may be expanded to include salinity control aspects.

Reduction of salt loads from irrigated agriculture utilizing present technology as contemplated for the salt load reduction program previously discussed will require the education of irrigators with regard to improved practices and will require a substantial investment by irrigators for improved facilities. Demonstrations of the economic benefits associated with proposed improvements will be required to provide the incentive for irrigators to make the necessary changes. Such demonstrations would also show the technical feasibility of such control measures with regard to water quality improvements. The Bureau of Reclamation, the Soil Conservation Service, the Agricultural Stabilization and Conservation Service, the Extension Service, various water user's associations and other state agencies conduct programs which could assist in such education and demonstration efforts.

Completion of reconnaissance and feasibility studies discussed in the following sections will be dependent upon completion of research and demonstration activities in some cases. This fact coupled with the time span required for completion of most research efforts would indicate the need for early initiation of desired additional research and demonstration efforts.

Reconnaissance Investigations. Preliminary, limited scope investigations known as reconnaissance investigations were completed in sufficient detail to provide the basis for seeking appropriations of funds for feasibility studies for only two of the seventeen projects included in the salt load reduction program. Reconnaissance investigations would thus be required for the other 15 projects. In addition, similar investigations should be made of control measures along the Lower Colorado River below Hoover Dam, in the Yuma Valley area with respect to the salinity of Mexican water deliveries and in the Salton Sea area where such controls might alleviate rising salinity levels in the Sea. Such investigations could best be performed by the water resource development agencies at both the State and Federal level. The Bureau of Reclamation is currently conducting a planning study for rehabilitation of irrigation facilities for the Uncompahgre Project, Colorado, which could be expanded to include the desired salinity control reconnaissance investigation.

An evaluation of the results of the reconnaissance investigations would provide the basis for initiation of feasibility studies for those control projects showning economic feasibility at the reconnaissance level.

Feasibility Studies

Feasibility studies are planning studies which go into much greater detail than reconnaissance investigations and frequently require extensive and costly field investigations. For this reason, such studies should be conducted for only those control projects which could reasonably be constructed to meet salinity management objectives. Such studies would provide the basis for seeking appropriations for actual project construction.

Legal and Institutional Evaluation

Constraints imposed by legal and institutional factors may significantly alter the range of available salinity control measures. Detailed evaluations of existing legal and institutional constraints which may affect the basinwide salinity control program should be conducted. Where modifications of existing legislation or institutional arrangements are needed to allow a rational approach to management of salinity, such modifications should be identified. Emphasis should be placed on evaluations of the various water laws controlling use and distribution of Colorado River water.

Implementation Phase

The final or implementation phase of the basinwide control program would include the appropriation of construction funds, the actual construction of projects, and the actual management of salinity through operation of control works.

As feasibility studies are completed, a final implementation plan should be developed which would be directed toward meeting the established numerical salinity standards. Feasibility reports for the control projects included in the final plan should then be submitted to Congress and construction funds requested. Funds should be made available according to the construction schedule established by the implementation plan. Since the implementation of control works will be dependent to some extent upon the rate at which water resources development proceeds, the actual construction of control projects could extend over a lengthy period.

Once control measures are implemented, provision will need to be made for funding for continued operation and maintenance as most facilities will be need continuously for the foreseeable future.

☆ GPO 790-485