COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

FEBRUARY 1972

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F O R E W O R D

The waters of the Colorado River are progressively increasing in salinity. A great concern over this situation and a need to implement a solution has been expressed by those who depend on this great river as a lifeline. This salinity control imperative extends to the Republic of Mexico and has become an important aspect in our international relations with that nation.

This report sets forth a plan of attack in the form of a comprehensive 10-year Water Quality Improvement Program. It identifies potential solutions both short and long range. Investigations are scheduled for control of salinity at point sources, diffuse sources, and irrigation sources. These investigations have been structured and integrated with programs involving desalting, weather modification, geothermal resources and basin-wide water resources management.

The objective of the program is to maintain salinity concentrations at or below levels presently found in the lower main stem of the Colorado River. In implementing this objective, the salinity problem will be treated as a basin-wide problem recognizing that salinity levels may rise until control measures are made effective while the upper basin continues to develop its compact apportioned waters.

The Bureau of Reclamation has statutory responsibility to study all possible means of improving the quality and alleviating the ill effects of water of poor quality in the Colorado River basin. This responsibility is provided for in three separate public laws authorizing the (1) Colorado River Storage Project and participating Projects, (2) Navajo Indian Irrigation Project and San Juan-Chama Project, and (3) Fryingpan-Arkansas Project.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF FIGURES

SUMMARY

The Situation

Waters of the Colorado River are becoming more saline. Great concern and a sense of urgency to halt the rise have been expressed by those who depend upon the river as a lifeline. The salinity control imperative extends to the Republic of Mexico and has become an important aspect in our international relations with that nation.

At the headwaters the average salinity 1/ (concentration of total dissolved solids) in the Colorado River is less than 50 mg/l and progressively increases downstream until, at Imperial Dam, the present modified 2/ condition is 865 mg/l. Projections of future salinity levels without a control program suggest that values of 1,250 mg/l or more will occur at Imperial Dam by the year 2000. One projection used in the Lower Colorado Region Comprehensive Framework Study 3/ foresees such a level being reached by 1980. Should these increases

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1/ Salinity as used in this report refers to the concentration of total dissolved solids and is reported in milligrams per liter (mg/l). This unit of concentration is nearly equivalent to parts per million (ppm) up to concentrations of 7,000 mg/l.
2/ Present modified refers to the historic conditions (1941-1968) modified to reflect all upstream existing projects in operation for the full period.
3/ Water Resources Council.

in salinity levels occur, the agriculture in the Imperial, Coachella, Gila, and Yuma Valleys would be further threatened. Also, a poorer water quality would be diverted to the Metropolitan Water District of Southern California and the Las Vegas Valley Water District, causing further economic losses to the very large block of domestic water users in California and Nevada. Upon completion of the Central Arizona Project, water users in the Phoenix and Tucson areas would be similarly affected.

The Proposed Solution

General Approach and Authority

A comprehensive 10-year Water Quality Improvement Program has been structured and integrated with programs involving weather modification, geothermal resources, desalting, and the Western U.S. Water Plan. These programs, when implemented, could maintain salinity in the lower main stem at or below present levels.

The Water Quality Improvement Program has an investigation and an implementation phase. The authority for the investigation is derived from Public Laws 84-485, 87-483, and 87-590 relating to the Colorado River Storage Project and Participating Projects, Navajo Indian Irrigation Project and San Juan-Chama Project Act, and the Fryingpan-Arkansas Project Act, respectively.

Feasibility studies would be initially performed on a total of 16 irrigation, point, and diffuse salinity sources with related basin-wide planning involving development of a mathematical model of the Colorado River, economic analysis of water quality, analysis of legal and institutional matters, and the investigation of potentials for improving water quality at points of diversion.

Early emphasis is being placed on those activities most likely to achieve water quality improvement at least cost. Construction of a mathematical model may reveal better ways to operate the river system to generate water quality benefits without incurring capital investment costs for structural control measures. Irrigation source control, involving close integration of on-farm irrigation water scheduling and management, with water systems improvement and management, is expected to significantly reduce salt loadings. Some measuring devices may be required to implement the irrigation scheduling and management program which is now being implemented. This can be expected to achieve early benefits at minimal cost.

Following the full operational establishment of the irrigation scheduling activity, water users would be expected to operate the program. This could be contractually tied to water systems improvements and the related cost-sharing arrangements with the irrigation districts or other entities involved. The irrigation scheduling and water systems improvement activities need to move together along with parallel improvements of on-farm irrigation systems, the latter to be done primarily through private investment with technical assistance from the Soil Conservation Service and some financial aid from the Rural Environmental Assistance Program.

Program Elements

The specific Water Quality Improvement Program elements and the fiscal years during which the work is presently scheduled to be accomplished are as follows:

Mathematical simulation submodel, 1972-1973

Economic evaluation of water quality, 1972-1976

Institutional and legal analysis, 1972-1973

Ion exchange process systems, 1972-1974

Irrigation scheduling and management, 1972-1979 (Grand Valley Basin, 1972-1978; Lower Gunnison Basin, 1974-1979; Uintah Basin, 1974-1978; Colorado River Indian Reservation, 1974-1978; Palo Verde Irrigation District, 1974-1978)

Water systems improvement and management, 1972-1976 (Grand Valley Basin, 1972-1975; Lower Gunnison Basin, 1973-1976; Uintah Basin, 1974-1976; Colorado River Indian Reservation, 1972-1974; Palo Verde Irrigation District, 1974-1976)

Point source control projects, 1972-1978 (LaVerkin Springs, 1972-1973; Paradox Valley, 1972-1975; Crystal Geyser, 1972-1973; Glenwood-Dotsero Springs, 1972-1976; Blue Springs, 1973-1978; Littlefield Springs, 1974-1975)

Diffuse source control projects, 1974-1977 (Price River, 1974-1977; San Rafael River, 1975-1977; Dirty Devil River, 1976-1978; McElmo Creek, 1976-1978; Big Sandy River, 1974-1978)

Very little basic data are available regarding the control of diffuse sources. Beginning in fiscal year 1972 basic data will be collected on these sources.

These investigations and the implementation of the irrigation scheduling and management work would cost about $18 million over the 10-year period. Of this amount, $395,000 is currently being used to initiate the program, increasing to $1,005,000 in fiscal year 1973.

Allied Programs

Important allied programs include weather modification, desalting, geothermal resources, research, and the Western U.S. Water Plan. Weather modification research now underway is expected to develop, by 1980, a reliable and workable system for increasing precipitation. The Upper Colorado River Basin will be one of the first areas where region-wide applications could be made. It is estimated that up to 2 million acre-feet of new water could be added to the river system. This would serve to significantly improve the salinity levels.

Desalting will initially involve the installation of a research and development prototype facility using the reverse osmosis process. The prototype plant would have a capacity of 15 mgd and could be expanded to 150 mgd. The facility would be located in the lower reach of the river. If expanded to a capacity of about 150 mgd, the salinity levels in the lower reach would be greatly improved. This would be a cooperative effort between the Office of Saline Water and the Bureau of Reclamation.

Geothermal investigations are now being conducted by the Bureau of Reclamation and the Office of Saline Water. These investigations could ultimately lead to additional sources of water. This water could be fitted into the overall river basin management plan to achieve further improvements in water quality.

Research is underway or scheduled which would provide valuable inputs to the salinity control effort. Included is such work as developing better predictions of irrigation return flow quality, deriving the systems for assessing ecologic impacts of water resource projects, developing procedures for management and use of saline water, testing advanced irrigation systems, and identifying waste-water reclamation opportunities.

It will be the responsibility of the Westwide Study to present the varied and complex alternatives for development, regulation, and use of all waters of the Colorado River Basin, examine tradeoffs between alternatives, prepare plans and cost estimates, and recommend priority of future studies and development. Close coordination and cooperation will be maintained between the Colorado River Water Quality Improvement Program and the Westwide Study to assure the preparation of a sound, well integrated plan of development for the Colorado River Basin.

The Organization

The many activities involved will require close coordination of the work with Federal, State, and local agencies and private and public groups having a mutual concern and interest in the program. Overall responsibility for the program has been assigned to the Bureau of Reclamation. Within this agency, immediate responsibility for direction has been given to the Assistant Commissioner - Resource Planning, with strong coordinative ties with the Assistant Commissioner - Resource Management. Field planning, construction, and operation activities will be handled by the Regional Directors, Regions 3 and 4, with technical assistance as needed being provided by the Engineering and Research Center. A new division is being established at the E&R Center as a focal point for the program to serve the multifaceted coordination and leadership activities involved.

The Implementation

Assuming all projects now under investigation or scheduled to be investigated are implemented, the program is expected to involve capital expenditures in the order of magnitude of $400 to $500 million. These costs are to be shared with the beneficiaries. Therefore, an essential feature of the feasibility studies and the related basin-wide studies will be to develop equitable cost sharing and repayment formulas. New institutional arrangements may be required not only as related to cost sharing and repayment, but also to the operation and maintenance of the constructed facilities. The urgency of the salinity conditions in the lower reach makes it imperative that movement from the study to the construction phase be expedited. This could be done for individual projects within a period of 1 to 2 years following completion of a favorable finding of feasibility. In the interim, as previously stated, some salinity improvements can be anticipated through alteration of river operations using the mathematical model and from the irrigation scheduling and management activities.

Construction of the water system improvement projects would involve periods of 4 to 5 years. Most of this work could be completed by fiscal year 1981. Of the point source control projects, LaVerkin Springs, Crystal Geyser, Littlefield Springs, and Paradox Valley could be constructed in a period of 3 to 4 years. On this basis, construction could be completed during fiscal year 1980. Blue Springs and Glenwood-Dotsero Springs will involve consideration of many complex factors regarding the engineering plan and related environmental and social considerations. Construction, even if found feasible in all respects, could not be started before 1978 on Glenwood-Dotsero Springs and 1980 on Blue Springs. The lack of data on the diffuse source control projects could delay construction starts until fiscal year 1979 or later.

The Effects of Programs

The average annual salinity concentration of the Colorado River at Imperial Dam during the period 1941 to 1968 (most recently published data) was 751 mg/l. The annual salinity concentrations during this same period have ranged from a minimum of 649 mg/l in 1949 to a maximum of 918 mg/l in 1956. The monthly salinity concentrations of the Colorado River at Imperial Dam during the period 1941 to 1968 have experienced an even wider range from a minimum of 551 mg/l in December 1952 to a maximum of 1,000 mg/l in January 1957.

Levels of salinity concentrations presently found in the lower Colorado River vary depending on the type period used to describe the level. As indicated above, the average for a year is greater than the level during the period 1941 to 1968 and the peak monthly concentration is even greater than the level for a year.

To depict effects of the Water Quality Improvement and Allied Programs, Table 1 was developed showing the projected reductions in salinity concentrations for each program and the estimated effects on the synthesized salinity levels at Imperial Dam.

The values in the table are initial estimates based on the average hydrologic conditions for the period of record 1941-1968.

The 1970 average annual value of 865 mg/1 has been derived on the assumption that present developments in the basin were completed and operating during the period of record. In other words, the effects on water quality of all present developments have been extended back to 1941 from the time they became operational.

Similarly, the average annual values for the years 1980, 1990, and 2000 were synthesized to reflect the influence on water quality during the period of record of water resource developments expected to

Table 1

PROJECTED PROGRAM REDUCTIONS - COLORADO RIVER AT IMPERIAL DAM
(Average annual values in mg/l - 1941-1968 period of record)

	1970	1980	1990	2000
Estimated Salinity Level (Full development - no control program)	865	1000	1200	1250
Range	(750-1060)	(860-1220)	(1040-1470)	(1080-1530)
Projected Program Reductions				
Water Quality Improvement Program	(-)	(-60)	(-160)	(-160)
Allied Programs	(-)	(-60)	(-195)	(-245)
Total Program Reduction	-	-120	-355	-405
Estimated Salinity Level (Full development with control programs)	865	880	845	845
Range	(750-1060)	(740-1100)	(685-1115)	(675-1125)

be completed by those dates. These estimates must be regarded as initial approximations. The feasibility and related studies, buttressed by additional research, will improve reliability of the estimates.

It should be recognized that the values in the table are computed average annual values at Imperial Dam under the stated assumptions. The average annual modified value for 1970 of 865 mg/l based on the 1941 to 1968 period would probably have ranged from an annual minimum of 750 mg/l to an annual maximum of 1,060 mg/l. However, with Lakes Powell and Mead regulating the Colorado River, it would require several consecutive low-flow years to produce an annual salinity concentration of 1,000 mg/l, or higher, at Imperial Dam.

Historically, records at Imperial Dam show that the average salinity concentration for January 1957 was 1,000 mg/l and for December 1967 it was 992 mg/l. Six other months in the period 1941-1968 have had average concentrations above 960 mg/l. However, with present development, it is probable that the average monthly concentrations for these 8 months would have exceeded 1,000 mg/l. Furthermore, with present developments, the 1,000 mg/l mean monthly concentration at Imperial Dam would have been exceeded in 40 months during the period 1941-1968.

It is not possible to predict future salinity concentrations for any particular month, nor can it be assumed that past flow and concentration cycles will be repeated in the future.

It is premature to define numerical standards of salinity levels at Imperial Dam now or in the next 2 or 3 years. It is essential that the available technical knowledge of the physical and social factors involved and their interrelationships and the probable consequences of proposed changes be fully understood before applying numerical standards.

Program Appraisals

Appraisal of program progress and direction will be made at intervals of 2 years. The factors to be considered include: (1) kinds of physical control works needed, (2) economic viability of proposed control works, (3) public acceptance and commitment to the proposals, (4) potential impacts of evolving technology, and (5) relationships within the basin-wide management plan.

I INTRODUCTION

The waters of the Colorado River system serve millions of people in many ways. It is a vital link in sustaining cities and farms, mines and industry, recreational space and wildlife, and areas of great aesthetic value to the Nation. The water is used for irrigating crops, producing energy, providing recreation, sustaining cattle and wildlife, supporting industry, and supplying the common daily needs of people for drinking, washing, bathing, cleaning, heating, cooling, watering lawns and gardens, protecting property, and removing wastes. These many uses place varying demands not only on the quantity but also on the quality of water. In the Colorado River, quantity and quality are inseparable. Tomorrow's needs are to be met by augmenting quantity and improving quality. The latter is the concern of this report and is to be regarded as an integrated facet of an overall comprehensive basin management plan for use and development of the water resources.

At its headwaters, the Colorado River has a total dissolved solids concentration of 50 mg/l 1/ or less. As the water moves downstream through this vast arid region, there is a gradual increase in salinity

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1/ Refers to milligrams per liter. This unit is nearly equivalent to parts per million (ppm) up to concentrations of 7,000 mg/l.

to the Imperial Dam. Here the present modified 2/ average concentration is 865 mg/l. This increase arises as a result of both natural processes and the activities of man. Wherever rain falls, natural solute erosion occurs. This process embraces the geochemical reactions that take place as water moves through the hydrologic cycle. The pathways and some of the important reactions involved in this cycle are depicted in Figure 1. The process has been active over geologic time. Even with the extensive developments by man, the natural processes are still the principal source of salinity in the Colorado River.

While the geochemical processes add a large variety of dissolved matter to the water, only 10 elements make up 99 percent or so of the dissolved constituents. These are hydrogen, sodium, magnesium, potassium, calcium, silicon, chlorine, oxygen, carbon, and sulfur. The elements occur in solution as various ions, molecules, or radicals. The major part of the dissolved constituents in the Colorado River are made up of the cations calcium, magnesium, and sodium, and the anions sulfate, chloride, and bicarbonate. These, plus minor amounts of other dissolved constituents, are commonly referred to as salinity.

2/ Present modified refers to the historic conditions (1941-1968) modified to reflect all upstream existing projects in operation for the full period.

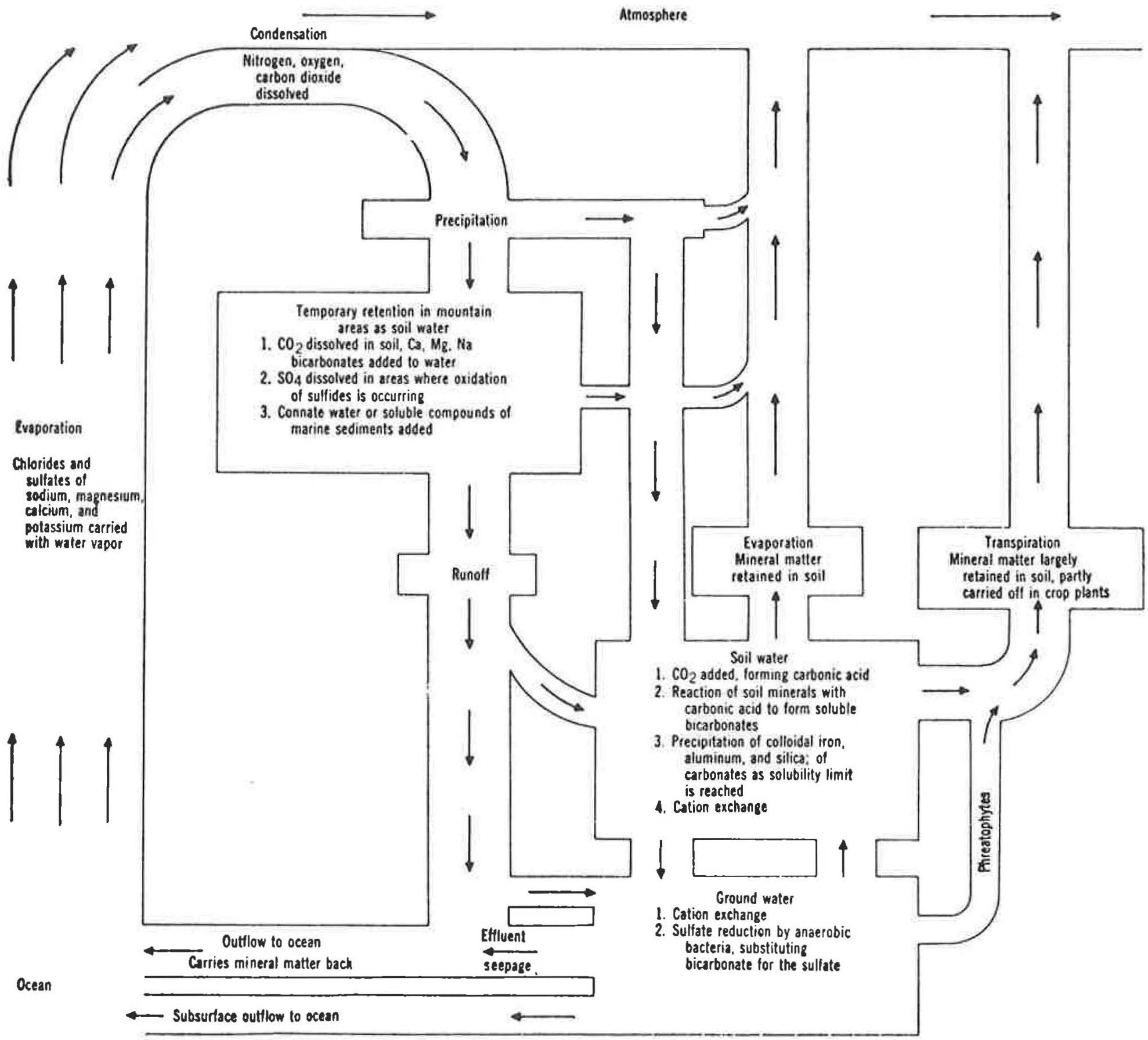


FIGURE 1.—Geochemical cycle of surface and ground waters.

Development of the water resources in the Colorado River Basin took place gradually from the beginning of settlement around 1860 and has been continuing. In the Upper Basin, 1.4 million acres were irrigated by 1920. The pace of development slowed thereafter with the result that in 1965, 1.6 million acres were under irrigation. In addition, the water exported from the Upper Basin amounted to about 500,000 acre-feet per year and consumptive use of water for municipal and industrial purposes depleted about 30,000 acre-feet per year.

Initial development in the Lower Basin was slow because of difficult diversions from the Colorado River and its widely fluctuating flow. However, with the completion of the Boulder Canyon Project in the 1930's, the development accelerated and about 1.3 million acres are now under irrigation. In this regard, the Colorado River now provides 75 percent of the water to southern California where more than half of that State's 20 million people live.

The importance of salinity in water supplies was recognized as early as 1903. At that time, the initial work was done to identify desirable salinity levels for maintenance of crop production under irrigation. A limited amount of water sampling and analysis of the river was being performed, primarily by the Geological Survey. The main purpose of these early tests was to evaluate the suitability of the water supply for irrigation and other uses. In time, it became clear that a gradual rise in the salinity of the river was occurring as the water resources were developed.

Salt-concentrating effects were produced by evaporation, transpiration, and diversion of high quality water out of the basin. Also, salt-loading effects occurred through the addition of dissolved solids to the river system from both natural and manmade sources. Because of the wide fluctuations in concentration from natural causes, the developments on the river, particularly the large reservoirs, produced offsetting beneficial effects by minimizing these fluctuations.

Prior to their authorization, it was known that the Colorado River Storage and Participating Projects, Navajo Indian Irrigation Project, San Juan-Chama Project, and the Fryingpan-Arkansas Project would cause significant increases in salinity levels. This was expected to arise primarily from the increased consumptive use of water and transport of high quality water out of the basin. Recognizing the concern of the Colorado River water users, Congress stipulated that studies be made of the water quality in the basin and that control plans be developed. The stipulation was expressed in the authorizing legislation for the projects.

As a result of the legislative requirements, a basic network of water quality stations was established at principal points throughout the Colorado River Basin. Analyses and studies were begun for the entire basin, biennial reports were started in 1963 and have continued since that time. These reports cover the basic studies and evaluations of salinity conditions, the anticipated effects of additional developments, the effect of salinity on water use, the potentials for salinity control, and other related water quality aspects.

The Colorado River Basin Water Quality Control Project was established in 1960 by the U.S. Public Health Service. These functions were later transferred to the Federal Water Quality Administration within the Department of the Interior and, subsequently, transferred to the Environmental Protection Agency. The early project investigations assisted in better defining the water quality conditions of the basin. In 1963, efforts were directed towards evaluating various salinity problems.

In 1968, the FWQA and the Bureau of Reclamation initiated a joint reconnaissance salinity control study in the Upper Basin to identify potential controllable sources of salinity, make preliminary assessments of the technical feasibility of the control measures, and derive initial cost estimates for installation and operation of such measures. The first year of the study was financed by the FWQA, which transferred funds to the Bureau of Reclamation, and the second year of work was financed by the Bureau. Upon completion of the reconnaissance studies, FWQA proposed to finance feasibility studies; however, budget restrictions in fiscal year 1970 prevented funding the studies.

Also in 1968, the two agencies cooperated to develop a proposed salinity control plan of study for the Colorado River Basin. This initial program had an investigation phase spread over a 6-year period, with costs averaging about $1.75 million annually. The second phase was to involve implementation of a basin-wide salinity control plan. During the Federal reorganization activities which transferred the responsibilities of FWQA of the Department to the newly established Environmental Protection Agency, the program became inactive.

Subsequently, the Colorado River Board of California prepared and issued a report in 1970 entitled "Need for Controlling the Salinity of the Colorado River." The EPA also completed a report on the mineral water quality. The report, entitled "The Mineral Quality Problems in the Colorado River Basin," was completed in 1971 and pulled together the studies made during the period 1963-1970.

Under the direction of the Water Resources Council, a State-Federal interagency group prepared a framework program for the development and management of the water and related land resources of the Upper and Lower Colorado Region. These reports, abstracted in the next section of this report, recommended continuing studies of the Region's increasingly complex water quality issues and suggested various salinity control measures. Concurrently, the Bureau of Reclamation, with the assistance of the several States involved, developed the program described herein for controlling the salinity of the river. The recommendations contained in the reports of the various organizations were considered in developing this program.

The progress reports by the Bureau of Reclamation, the salinity report by the Colorado River Board of California, the Upper and Lower Colorado Region Comprehensive Framework Studies of the Water Resources Council, and the EPA report, have served to identify and better define the issues involved. The important fact emerging is that salinity is projected to increase unless a comprehensive, basin-wide water quality management plan is implemented and supported by the installation of structural and nonstructural measures to control salinity increases. Projected estimates of salinity levels at Imperial Dam are presented in Table 2. The projected salinity levels in all studies are considerably above the present modified average concentration of 865 mg/l.

TABLE 2

Projected Concentrations of Total Dissolved Solids

(mg/1) at Imperial Dam

(Average values)

Source	Year 1980	1990	2000	2010	2020	2030
EPA	1,060	-	-	1,220	-	-
CRBC	1,070	-	1,340	-	-	1,390
WRC	1,260	-	1,290	-	1,350	-
USBR	1,000	1,200	1,250	-	-	-

EPA: Environmental Protection Agency

CRBC: Colorado River Board of California

WRC: Lower Colorado Region Comprehensive Framework Study (Water Resources Council)

USBR: Bureau of Reclamation

The differences in the values reported by the various agencies arise from assumptions made regarding completion dates for water development projects, estimates of the amount of salt loading or concentration effects produced by these projects, the period of analysis used, and estimates of the time involved for the effects to emerge in the lower reach. The USBR projection is based on progressive accomplishment of the projects listed in Table 3 with completion assumed to occur by the year 2000.

It is significant that all studies by the various agencies predicted that proposed developments will cause a considerable increase in the future salinity of the river. Even under current salinity conditions, some irrigators are resorting to special practices in using the water to grow salt-sensitive crops. Some areas have drainage conditions which could be magnified if higher salinity water were used. Municipal and industrial users are faced with considerable expense in treating water. It is clear that allowing the salinity of the river to increase will result in considerable additional economic injury.

Table 3

Projects depleting Colorado River water

Project and state	New depletion (ac.-ft.)	New irrigation land (acres)
Above the gage Green River at Green River, Wyoming		
Seedskadee, Wyoming	145,000	58,000
Westvaco and others, Wyoming	86,000	1/
Between the above gage and the gage Green River near Greendale, Utah		
Lyman, Wyoming	10,000	0
Utah Power & Light and others, Wyoming	8,000	1/
Above the gage Duchesne River near Randlett, Utah		
Central Utah Project, Utah		
Bonneville Unit	166,000	2/
Upalco Unit	10,000	0
Uintah Unit	30,000	7,800
Between the gages Green River near Greendale, Utah, and Duchesne River near Randlett, Utah, and the gage Green River at Green River, Utah		
Four County, Colorado	40,000	2/
Hayden Steamplant, Colorado	12,000	1/
Cheyenne-Laramie, Wyoming	24,000	2/
Savery-Pot Hook, Colorado-Wyoming	27,000	17,920
Central Utah Project		
Jensen Unit	15,000	440
Above the gage San Rafael near Green River, Utah		
Utah Power & Light, Emery County, Utah	5,000	1/
Above the gage Colorado River near Glenwood Springs, Colorado		
Denver-Englewood, Colorado	216,000	2/
Green Mountain M&I, Colorado	12,000	1/
Homestake Project, Colorado	49,000	2/
Between the above gage and gage Colorado River near Cameo, Colorado		
Independence Pass Expansion, Colorado	14,000	2/
Fryingpan-Arkansas, Colorado	70,000	2/
Ruedi M&I, Colorado	38,000	1/
West Divide, Colorado	76,000	19,000
Above the gage Gunnison River near Grand Junction, Colorado		
Fruitland Mesa, Colorado	28,000	15,870
Bostwick Park, Colorado	4,000	1,610
Dallas Creek, Colorado	37,000	15,000
Between the gages Colorado River near Cameo, Colorado, and Gunnison River near Grand Junction, Colorado, and the gage Colorado River near Cisco, Utah		
Dolores, Colorado	3/140,000	32,000
San Miguel, Colorado	85,000	26,000
Above the gage San Juan River near Archuleta, New Mexico		
San Juan-Chama, New Mexico	110,000	2/
Navajo Indian Irrigation, New Mexico	4/508,000	110,000
Between the above gage and the gage San Juan River near Bluff, Utah		
Animas-La Plata, Colorado-New Mexico	146,000	46,500
Expansion Hogback, New Mexico	10,000	0
Utah Construction Co., New Mexico	25,000	1/
Return flow--Dolores and Navajo Indian Irrigation, Colorado and New Mexico	-311,000	3/ 4/
Between the gages Green River at Green River, Utah; San Rafael River near Green River, Utah; Colorado River near Cisco, Utah; and San Juan River near Bluff, Utah; and the gage Colorado River at Lees Ferry, Arizona		
Resources, Inc., Utah	102,000	1/
Arizona M&I, Arizona	35,000	1/
Salvage	-80,000	
Subtotal Upper Basin	1,892,000	350,140
Between the above gage and the gage Colorado River near Grand Canyon, Arizona	0	0
Above the gage Virgin River at Littlefield, Arizona		
Dixie Project, Utah	5/48,000	6,900
Between the gages Colorado River near Grand Canyon, Arizona, and Virgin River at Littlefield, Arizona, and the gage Colorado River below Hoover Dam, Arizona-Nevada		
Southern Nevada Water Project, Nevada	6/240,000	1/
Between the above gage and the gage Colorado River below Parker Dam, Arizona-California		
Fort Mohave and Chemehuevi Indian, Arizona, California, and Nevada	83,000	20,900
Central Arizona, Arizona 7/	433,000	
Reduced Metropolitan Water District Diversions 7/	-433,000	
Kingman, Arizona	18,000	1/
Mohave Valley I&D District, Arizona	6,000	1/
Lake Havasu I&D District, Arizona	7,000	1/
Salvage	-87,000	
Reduced Metropolitan Water District Diversions 7/	-199,000	
Between the above gage and the gage Colorado River at Imperial Dam, Arizona-Colorado		
Colorado River Indian, Arizona-California	243,000	60,840
Salvage	-104,000	
Subtotal Lower Basin	255,000	88,640
Total Colorado River	2,147,000	438,780

1/ In-basin depletion without irrigated lands.

2/ Transmountain diversion.

3/ In-basin transfer from Dolores River drainage to the San Juan River drainage--estimated 53,000-acre-foot return flow to the San Juan River.

4/ Diversions at Navajo Reservoir, estimated 258,000-acre-foot return flow to the San Juan River below the gage near Archuleta, New Mexico.

5/ Includes a transmountain diversion to Great Basin.

6/ Pending full development, the Mohave Thermal Plant will use part of this water which will be diverted below Hoover Dam.

7/ The Central Arizona Project diversions will vary, depending on the depletions by other projects on the river. Under present modified conditions maximum diversions to Central Arizona could be 2,172,000 acre-feet but with full depletions by the projects tabulated, the maximum diversions would be 433,000 acre-feet. Also with full depletions by the projects tabulated, the diversions to the Metropolitan Water District of Southern California would be reduced to an annual 550,000 acre-feet from its present diversions of 1,182,000 acre-feet. This will provide 199,000 acre-feet needed to develop the other tabulated projects in the Lower Basin in addition to the 433,000 acre-feet delivered to the Central Arizona Project.

II PREVIOUS STUDIES AND FINDINGS

The program for controlling salinity in the Colorado River has evolved from prior studies. Those of most relevance to the program were performed by the U.S. Geological Survey, Bureau of Reclamation, Environmental Protection Agency (and its predecessor agencies), Water Resources Council, Colorado River Board of California, and Utah State University.

The USGS studies were of the definition type. They trace historic salinity levels, estimate salt loading from specific sources, and identify salt contribution from various river reaches. The Bureau of Reclamation studies report on the past, present modified, and future water quality conditions in the basin. The effects of salinity on water uses and potentials for salinity control are discussed. The EPA study describes salinity conditions in the basin, evaluates the nature and magnitude of damages to water users, examines alternative salinity control measures, and provides recommended measures and programs for control of the salinity levels. The Colorado River Board of California also defined the nature and magnitude of the problem and presented a plan for controlling the salinity at or near present levels. The Water Resources Council Task Forces drew heavily on the prior studies and developed estimates of future salinity conditions and identified potential control measures. Utah State University performed a computer simulation of the hydrologic-salinity flow system in the Upper Basin.

Differences in findings among the various studies occurred, particularly as related to quantitative displays of historic salinity conditions, salt loading, concentrating effects, contributions from various sources, and economic impacts. Because there was nonuniformity in assumptions, data sets, and procedures, the quantitative findings should be expected to differ. On the other hand, the conclusions derived are generally similar. The major sources of salinity were identified as arising from natural point and diffuse sources, irrigation, evaporation, out-of-basin transfers, and municipal and industrial uses. The largest portion of the mineral burden was found to originate in the Upper Basin. The natural sources were thought to be the major contributors to the salt loading. Salinity was projected to continually increase in the lower reaches unless control programs are implemented. The impact of the increasing salinity levels was found to be primarily economic. While salinity levels increased over time, the composition of the water with respect to individual ions remained relatively stable.

Water Resources of the Upper Colorado Basin-Basic Data (USGS)

In 1964, the U.S. Geological Survey published its report entitled "Water Resources of the Upper Colorado Basin-Basic Data" as

Professional Paper 442. This report is based on data for the 1941-1957 period. In summary, the report states that if the developments of 1957 had not been in existence then: (1) the hypothetical average yearly water yield at Lees Ferry would have been about 15.2 million acre-feet rather than the 12.7 million measured, (2) the hypothetical average concentration would have been about 250 mg/l rather than observed values of about 500 mg/l, and (3) the hypothetical dissolved solids discharge would have been about 5.2 rather than observed amounts of about 8.7 million tons annually. Substantially all the increase in dissolved solids discharge was construed by the investigators to be an effect of irrigation on 1.4 million acres of land. They estimated the average increase to be 2.4 tons per irrigated acre per year. From one part of the area to another, this average was said to range from about 0.1 to 5.6 tons. The report did not indicate which portion of this increase was due specifically to irrigation and which to natural sources.

Upper Colorado River Basin Cooperative Salinity Control Study (USBR)

In cooperation with the Federal Water Pollution Control Administration (now the Office of Water Programs, Environmental Protection Agency), the Bureau of Reclamation in July 1969 completed a report entitled "Upper Colorado River Basin Cooperative Salinity Control

Study." The report is currently under review by EPA and has not yet been released. It deals with the control of salinity from specific identified sources, appraises potential salt-load reduction values, and evaluates status of the economic feasibility of salinity control. The need for a coordinated salinity control program for the entire Colorado River is stressed.

Need for Controlling Salinity of the Colorado River (CRBC)

The Colorado River Board of California published a report entitled "Need for Controlling Salinity of the Colorado River" in August 1970. Using available data, the report traces the average salinity principally at Hoover, Parker, and Imperial Dams and makes projections for the years 1980, 2000, and 2030. The historical average is based on the years 1963-1967 and shows values below Hoover Dam to be 730 mg/l and at Imperial Dam 850 mg/l. Below Hoover Dam, values of 830 and 1,090 mg/l are projected for the years 1980 and 2030, respectively. Comparable projections for Imperial Dam suggest 1,070 mg/l in 1980 and 1,390 mg/l in 2030. The salinity is estimated to cause $8 to $10 million damage annually for each salinity increase of 100 mg/l. The report identifies a number of potential salinity control projects which, if constructed, might serve to maintain salinity near present levels.

Quality of Water - Colorado River Basin (USDI)

Biennial Progress Reports on the "Quality of Water - Colorado River Basin" are prepared by the Department of the Interior. The initial report was issued in 1963 and the latest report is dated 1971. The report displays the past, present modified, and estimated future quality of the Colorado River at 17 gaging stations for the period of 1941-1968. The future quality condition as used in this report is an estimate of the situation after the presently authorized developments, projects proposed for authorization, and private developments are placed in operation. The report estimates the present modified average concentration below Hoover Dam to be 760 mg/l and with future known developments, 1,010 mg/l. At Imperial Dam the comparable projections are 865 and 1,250 mg/l, respectively, under the same conditions. No time period is specified in the report to identify when the projected concentrations would be reached.

Computer Simulation of the Hydrologic-Salinity Flow System Within the Upper Colorado River Basin (USU)

Salinity conditions were investigated by Utah State University. In 1970, they issued a report entitled "Computer Simulation of the Hydrologic-Salinity Flow System Within the Upper Colorado River Basin." This study employed an electronic analog computer in developing a simulation model of the hydrologic and salinity flow systems of the Upper Colorado River Basin. Estimates were derived based on the 1931-1960 period and reflect cropping and riverflow regulation conditions as of 1960. The estimated salt load at Lees Ferry was 8.6 million tons per year of which approximately 4.3 million tons originated from natural sources, 1.5 million tons from within the agricultural system, and 2.8 million tons from other inputs to the system; thus, natural sources are thought to contribute 50 percent of the salt load, agricultural sources 17 percent, and unidentified sources 33 percent. The report states that the agricultural salt load and cropland consumptive use increase the total dissolved solids concentration within the Upper Basin by 104 and 113 mg/l, respectively. The model was designed to predict the effects of various possible water resource management alternatives.

Salinity of Surface Water in the Lower Colorado River-Salton Sea Area (USGS)

U.S. Geological Survey Professional Paper 486-E, entitled "Salinity of Surface Water in the Lower Colorado River-Salton Sea Area," was published in 1971. The report shows that during the period 1926-1962, the chemical regimen of the Colorado River at Grand Canyon and upstream, although probably somewhat different from the virgin regimen, was relatively stable. There may, however, have been small increases in average mineral concentrations, particularly toward the end of the period, caused by construction of reservoirs, increased irrigation, and out-of-basin diversions. The research also found that most of the mineral burden of the Colorado River, like most of its flow, originates in the Upper Basin. The largest individual increment to the mineral burden of the Colorado River below the compact point and above Imperial Dam was found to be the Blue Springs located near the mouth of the Little Colorado River. The report further shows that a principal increase in salinity in the lower reach is derived from irrigated land in the Parker and Palo Verde valleys. The increasing out-of-basin diversions are also reported as contributing to the rising salinity concentration levels.

The Mineral Quality Problem in the Colorado River Basin (EPA)

In 1971, the EPA released its report entitled "The Mineral Quality Problem in the Colorado River Basin." In this report, salinity and streamflow data for the 1942-1961 period of record were used as a basis for estimating average salinity concentrations under various conditions of water development and use. Under these conditions, concentrations at Hoover Dam were estimated to average about 700 and 760 mg/1 in 1960 and 1970, and 880 and 990 mg/1 in 1980 and 2010, respectively. At Imperial Dam, the report estimates 760 and 870 mg/1 for 1960 and 1970, and 1,060 and 1,220 mg/1 for 1980 and 2010 conditions. The findings of the study with respect to salinity sources were that natural sources accounted for 47 percent of the salinity concentrations at Hoover Dam. The remainder was accounted for by irrigation (37 percent), reservoir evaporation (12 percent), out-of-basin exports (3 percent), and M&I uses (1 percent).

The present annual economic detriments of salinity were estimated to total $16 million. The report further advises that if no salinity controls are implemented, it is estimated that average annual economic detriments would increase to $28 million in 1980 and $51 million in 2010. More than 80 percent of these detriments would be incurred by irrigated agriculture and the associated regional economy located in the Lower Basin and the southern California water service area.

The investigation examined three salinity control alternatives: (1) augmentation of basin water supply, (2) basin-wide salt load reduction program, and (3) limitation on further depletion of basin water supply. The study concluded that the salt load reduction program appeared to be the most feasible of the three alternatives. It then proceeded to develop a broad conceptual plan and related costs for such a program.

Lower Colorado Region Comprehensive Framework Study (WRC)

The report by the Water Resources Council dated June 1971 states that high levels of dissolved mineral salts in surface and ground waters are the major water quality problem in the region. With few exceptions, most surface and ground-water supplies have mineral concentrations exceeding 500 mg/1, and many exceed 1,000 mg/1. The salinity of the supplies affects domestic, industrial, and agricultural uses.

The Colorado River enters the region at concentrations exceeding 500 mg/1, varies between 500 and 900 mg/1 at most diversion points, and increases to as high as 1,100 to 1,150 mg/1 for short periods of time at Imperial Dam. Salinity increases in the Colorado River from Lees Ferry, Arizona, to Imperial Dam are due principally to inputs from saline springs and the concentrating effects of consumptive use and reservoir evaporation.

Dissolved solids concentrations in the Colorado River are estimated to increase about 55 to 75 percent between 1965 and 2020, with the exception of Imperial Dam where the concentration is estimated to double. These results are based on the assumptions that the Central Arizona Project is in operation and no salinity controls are incorporated in future developments.

Upper Colorado Region Comprehensive Framework Study (WRC)

This report by the Water Resources Council dated June 1971 states that salinity is the most serious water quality problem in the Colorado River Basin. Salt-loading and salt-concentrating effects of consumptive use or depletion are the primary causes of salinity increases. Salt loading principally results from salts contributed from diffuse and point sources of geologic origin and from salts carried in irrigation return flows.

Future dissolved solids concentrations were estimated for 1980, 2000, and 2020. The TDS concentration at Lees Ferry, Arizona, assuming no salinity improvement program, is projected at 820 mg/l for the year 2020, or 40 percent greater than the 1965 concentration. The major cause of the projected salinity increase is continued development of the region. It includes the additional stream depletions for irrigation, thermal power production and export, and the additional salt leached from newly irrigated lands.

State and Federal representatives in both the upper and lower Colorado regions agreed that the salinity improvement programs outlined in the Upper and Lower Colorado Framework Study documents would be part of a basin-wide approach to salinity management. The salinity improvement program consists of a salt-loading reduction program which maintains concentrations at Lees Ferry at about 600 mg/l through the year 2020.

III PROGRAM OBJECTIVE

Building on the prior investigations of the salinity conditions in the Basin, The Bureau of Reclamation initiated a Water Quality Improvement Program in early 1971. The objective of the program is to maintain salinity concentrations at or below levels presently found in the lower main stem of the Colorado River. In implementing this objective, the salinity problem will be treated as a basin-wide problem, recognizing that salinity levels may rise until control measures are made effective while the upper basin continues to develop its compact-apportioned waters.

In moving toward this objective, corollary activities will, to the extent found feasible, encompass:

1. Stimulating improvements in management of water supplies in water systems,

2. Coordinating and integrating implementation of salinity control measures with basin-wide water resource management plans,

3. Recommending institutional and legal arrangements essential for efficient and equitable accomplishment of salinity control,

4. Removing salinity or otherwise controlling the concentration levels economically, safely, and without adverse side effects to the ecology and the environment,

5. Providing the requisite means for public participation in the choice of and commitment to water quality improvement measures, and

6. Initiating the needed installation of structural and non-structural measures for salinity control to achieve substantial salt load reductions in this decade and early in the subsequent decade.

IV PROGRAM STRUCTURE

The program is structured within the framework of existing Departmental responsibilities and legislative requirements. These provide the basis for a basin-wide planning approach to salinity control. The program places early emphasis upon salinity control procedures whose implementation does not involve structural measures. Thus the least costly measures will be undertaken first. Concurrent feasibility investigations are scheduled on various irrigation, point, and diffuse sources. Related basin-wide studies are scheduled to over-view individual control projects, assess implications of new technology, and provide guidance to the selection of implementation measures. The program will be closely integrated with ongoing activities involving development of the Western U.S. Water Plan, weather modification, desalting, geothermal resources and research. The activities will be closely coordinated with other Federal, State, and local agencies, and public and private groups interested in the program. Cost-sharing and repayment formulas would be developed and recommended prior to implementation of the structural measures. Special organizational arrangements are being made within the Bureau of Reclamation to enable close liaison with affected entities and to enable efficient prosecution of the work.

Departmental Responsibilities

The Secretary has broad as well as specific responsibilities under applicable laws to manage the water resources of the Colorado River Basin to (1) apportion the waterflows according to the Colorado River Compact of 1922, (2) meet commitments to Mexico under the International Water Treaty of 1944 with that nation, (3) conform to the requirements of the Supreme Court Decree of 1964, (4) meet specific contractual obligations with water users in the United States, (5) develop and manage water resources in accordance with specific authorizing legislation and in the public interest, (6) protect the recreation, fish and wildlife, and environmental values, and (7) assist in implementing the provisions of the Water Quality Act of 1965 and amendments relating thereto.

There are many documents that river operations must conform to, including the Colorado River Basin Project Act, September 30, 1968. Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs, June 10, 1970, were developed in accordance with this act.

Within the context of these responsibilities and legal requirements certain considerations are paramount: (1) There can be wide fluctuations in the concentration of dissolved solids above Lake Powell as a result of annual variations in precipitation and the management of the available water resources, (2) the total available water resources of the river are allocated by interbasin and interstate compacts and the international treaty, (3) the treaties and decrees have apportioned water quantity but are silent on water quality, and (4) studies made by this Department, the Environmental Protection Agency, the Colorado River Board of California, and the Water Resources Council project increases in salinity unless control measures are taken concurrent with development for use of presently allocated water.

In recognition of the effects of the proposed developments on the salinity of the river, the Congress specifically directed the Secretary of the Interior to make water quality studies and to devise plans for improvement. This is provided for in three public laws:

1. Section 15 of the authorizing legislation for the Colorado River Storage and Participating Projects states: "The Secretary of the Interior is directed to continue studies and make reports to the Congress and to the States of the Colorado River Basin on the quality of water of the Colorado River."

2. Section 15 of the authorizing legislation of the Navajo Indian Irrigation Project and San Juan-Chama Project states: "The Secretary of the Interior is directed to continue his

studies of the quality of the water of the Colorado River system, to appraise its suitability for municipal, domestic, and industrial use, and for irrigation in various areas of the United States in which it is proposed to be used, to estimate the effect of additional developments involving its storage and use (whether heretofore authorized or contemplated for authorization) on the remaining water available for use in the United States, to study all possible means of improving the quality of such water, and of alleviating the ill effects of water of poor quality, and to report the results of his studies and estimates to the 87th Congress and every 2 years thereafter."

3. Authorizing legislation for the Fryingpan-Arkansas Project, Colorado, contains similar language pertaining to water quality reports and stipulated that the first report should be provided by January 3, 1963, to be followed by submission of reports every 2 years thereafter.

These acts provide authority to this Department for basin-wide planning of a salinity control program. Feasible salinity control projects involving construction will require congressional authorizations. The responsibility to plan and implement the control programs has been entrusted to the Bureau of Reclamation, with the function to be coordinated with other agencies of this Department such as the Office of Saline Water, the Office of Water Resources Research, the Geological Survey, Bureau of Land Management, the Bureau of Indian Affairs, Bureau of Sport Fisheries and Wildlife, Bureau of Outdoor Recreation, and the Bureau of Mines. As planning and implementation progress, it is expected that particular contributions can be made by each of these agencies to the successful conduct of the comprehensive program for salinity control.

Organization

The immediate responsibility for direction of the Colorado River Water Quality Improvement Program has been assigned to the Assistant Commissioner - Resource Planning with strong coordinative ties with the Assistant Commissioner - Resource Management. The field planning, construction, and operation activities will be handled by the Regional Directors, Regions 3 and 4, with assistance as needed being provided by the Engineering and Research Center. A new division to be entitled "Division of Colorado River Water Quality" will be established within the Engineering and Research Center in Denver to serve as the focal point for the program. The Division Chief will report directly to the Assistant Commissioner - Resource Planning. Leadership responsibilities of this Division will cover such activities as coordinating, developing, and expediting the program; closely working with and integrating elements of the program with other governmental entities; and developing coordinative ties with Federal, State, and local agencies and public and private groups having a mutual concern and interest in the salinity control program. Program progress will be monitored, policy positions analyzed, and recommendations developed for consideration by the appropriate decisionmaking levels within the Department of the Interior. The Division will maintain close liaison with the Westwide management team to insure compatibility and integration of its program with the Western U.S. Water Plan. Work involving the allied programs will continue to be planned and implemented according to current procedures that will be closely observed to insure timely application of results to the salinity control program.

Program Elements

The program is structured to investigate the feasibility of constructing point, diffuse and irrigation source control projects; initiating immediate nonstructural control measures in the field of irrigation scheduling and management; and conducting essential supporting studies of basin-wide applicability. The latter involve institutional and legal matters, mathematical modeling of the river system to measure impacts and guide choices, economic analysis of water quality costs and benefits, and prospects of adopting alternative conceptual bases for the program such as controlling salinity on a large scale at diversions to points of use rather than control of sources (or combinations thereof).

Figure 2 identifies the specific elements of the program and indicates the period during which the work is proposed to be accomplished and Figure 3 shows the location of the various projects.

Program Costs

Currently the program is funded at a level of $455,000, with a proposed expansion of the program to $1,005,000 in fiscal year 1973. The planning activities as scheduled in fiscal years 1972 through 1981 total approximately $18 million. Construction activities which may be required within this time frame could involve costs in the order of magnitude of $400 to $500 million. Such funding would be determined by congressional authorization and appropriate non-Federal cost sharing and repayment. The most promising prospects for achieving salinity control have been screened and, therefore, effort will be concentrated on feasibility investigations to expedite movement of salinity control projects through the congressional authorization processes.

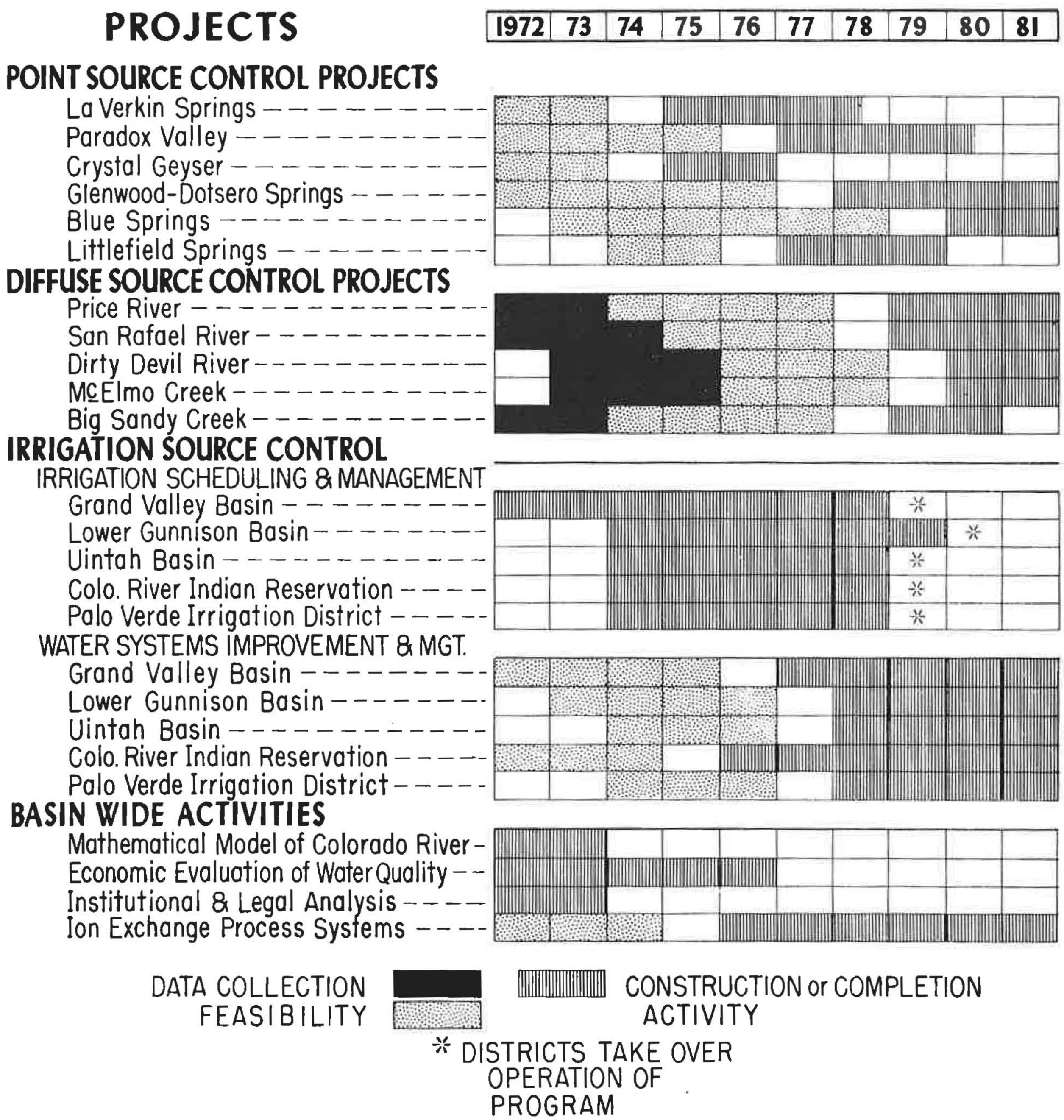
Program Financing and Repayment

The investigation program would be financed by the Federal Government under the authority of laws previously cited herein. As feasibility of specific control projects is demonstrated, beneficiaries

Figure 2

COLORADO RIVER

WATER QUALITY IMPROVEMENT PROGRAM



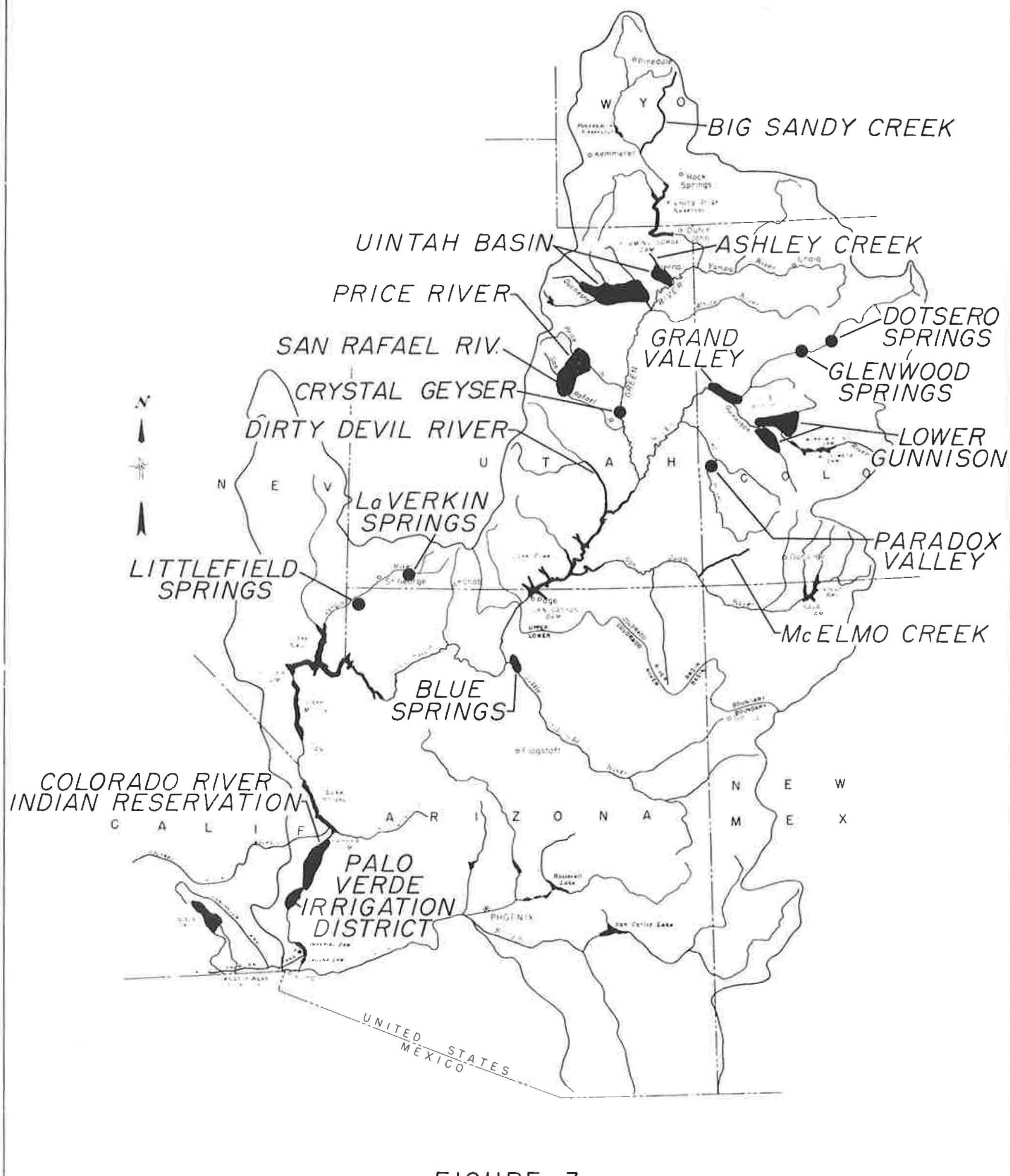


FIGURE 3

LOCATION OF SALINITY IMPROVEMENT PROJECTS-COLO. RIVER BASIN will be identified and cost-sharing and repayment formulas will be developed. Through such cost sharing, it is anticipated that direct non-Federal financial support would be forthcoming to implement the construction phase of the program. This may require new institutional arrangements not only as related to repayment but also to operation and maintenance of constructed facilities.

As indicated under the corollary principles guiding the program, every effort would be made to move the feasible projects into the construction phase within a period of 1 to 2 years following a favorable finding of feasibility.

Related Program Features

Provision is built into the program to undertake other supporting and feasibility investigations. As now developed, the program draws heavily on precedent studies. The more detailed investigations to be done under this program may reveal that some of the projects should not be implemented because of economic, physical, or environmental considerations. Accordingly, concurrent analysis of other alternatives will need to be conducted. The kind of work contemplated here would involve a careful analysis of the salinity sources in the Lower Basin. Previous studies have failed to adequately investigate the lower reach from Parker to Imperial Dam. Such work will, therefore, be fitted into the program and would be accompanied with other items such as prospects for desalting return flows from the Palo Verde Irrigation District and a general study of brine disposal possibilities in the lower reach of the river. Should findings of the supporting studies involving the use of the ion exchange processes prove attractive, then an analysis would be needed to identify the best ways to use the process in the overall program.

The program will be faced with uncertainties with respect to potential advances in technology not only in the field of desalting but also in other areas such as development of antitranspirants, evaporation suppression, enhancement of salt precipitation reactions in large reservoirs, and development of lower cost energy sources (breeder reactors and fusion).

In consideration of the foregoing, decision points will be utilized in the program to determine direction as the feasibility and related studies are completed. Salinity control on the scale contemplated represents a pioneering effort in which alternative solutions will need to be assessed for effectiveness, environmental consequences, economic impact, and equitability of the measures to the States involved. An appraisal of program direction and a description of program accomplishments will be made to Congress at 2-year intervals as part of the biennial report on continuing studies of the quality of water of the Colorado River Basin. The directive for preparing the biennial report is contained in three separate public laws which authorized the (1) Colorado River Storage Project and participating projects, (2) Navajo Indian Irrigation Project and San Juan-Chama Project, and (3) Fryingpan-Arkansas Project.

Allied Programs

Allied programs of the Bureau of Reclamation and other agencies will be coordinated with this salinity control effort. The allied programs, particularly those involving augmentation of water supply, can be expected to have important impacts on the concentration of dissolved constituents in the river system. Accordingly, as these plans emerge, their impacts will be assessed and measured for effectiveness along with the specific control projects identified in the water quality improvement program. A discussion of the allied program is provided in a subsequent section of this report.

V EFFECT OF PROGRAM

The amount of salt load reduction that can be achieved through control of point sources, diffuse sources, and irrigation sources cannot, at this time, be estimated with a high degree of accuracy. Good data exist on the annual salt tonnage output from the point and diffuse sources but detailed engineering plans are needed to determine the amount of salt load reduction possible, the cost, and the feasibility of the plan. Also, the ongoing research by Colorado State University now being financed by EPA, and the research underway by the Bureau of Reclamation will need to be completed to derive reliable estimates of salt load reduction and concentrating effects generated by the irrigation scheduling and water systems improvement programs.

Recognizing the foregoing limitation, the Water Quality Improvement Program as now scheduled is estimated to achieve a reduction of about 140 mg/l at Hoover Dam and 160 mg/l at Imperial Dam including Blue Springs. This assumes that all point and diffuse source projects, irrigation scheduling and management activities, and the water system improvement and management projects now included in the program are implemented.

The total capital costs for the point and diffuse source control projects are in the order of magnitude of $150 to $200 million excluding Blue Springs. Insufficient data preclude making an order of magnitude estimate for this point source. The irrigation scheduling and management costs would total $4 to $5 million within the program period. Subsequently, this program would be continued by the water users. Order of magnitude costs for improvement of the water systems have been made and these range from $240 to $300 million. Summation of the capital costs for the point and diffuse source control projects exclusive of Blue Springs, the water systems improvement projects, and the irrigation scheduling and management activities indicates an order of magnitude of $400 to $500 million.

Relating the program accomplishments to time periods, it is estimated that the program if implemented according to the proposed schedule could achieve a reduction of 60 and 160 mg/l at Imperial Dam by 1980 and 1990, respectively. The control measures included for the 1980 reduction include LaVerkin and Littlefield Springs under the point source control program and the irrigation source control programs in the Grand Valley and Lower Gunnison Basins plus the Colorado River Indian Reservation and the Palo Verde Irrigation District. The reduction by 1990 would be achieved through control of the remaining point, diffuse, and irrigation sources.

To provide requisite initial guidance to the selection of projects to be studied at the feasibility level, a ranking based on cost effectiveness has been prepared. This along with other factors such as quantities of potential salt load reduction, reliability of currently available data regarding the projects, knowledge of the kind and capacity of physical works required, prospects for achieving early effects through salt load reductions and potential economic viability of the projects were considered. The cost effectiveness is based on dollars per ton per year amortized over a 50-year period. The data are shown in Table 4, Potential Effects and Costs - Point and Diffuse Source Control Projects, and Table 5, Potential Effects and Costs - Irrigation Scheduling and Management and Water Systems Improvement Projects.

The irrigation scheduling and water systems improvement programs are to be closely integrated. Both programs contemplate heavy participation of the water users. The irrigation system improvement program would provide direct benefits to the water user organizations. This would include such factors as labor savings, more efficient water deliveries, reduced operational costs, and providing a basis for more efficient layouts of irrigated fields. Accordingly, in compiling the cost effectiveness, it was assumed that one-half of the capital costs of the water systems would be paid for by the water users as a benefit to the irrigation system of the project. The remainder of the cost is assumed to be allocated to salinity control and would be subject to cost sharing.

Table 4

Potential Effects and Costs - Point and Diffuse Source Control Projects

Projects	Present salt loading (1,000's ton/yr)	Estimated reduction (1,000's ton/yr)	Effect at Hoover Dam (mg/l)	Effect at Imperial Dam (mg/l)	Construction cost ($1,000,000's)	Construction period (FY)	Cost effectiveness (dollars/ton/yr)
LaVerkin Springs	100	80	-6	-8	8-10	1975-78	2.00-2.50
San Rafael River	190	90	-7	-8	10-15	1979-81	2.20-3.30
Paradox Valley	200	180	-14	-15	25-35	1977-80	2.80-3.90
Price River	240	100	-8	-9	15-20	1979-81	3.00-4.00
Dirty Devil River	200	80	-7	-8	15-20	1980-82	3.80-5.00
Littlefield Springs	30	30	-2	-2	6-8	1977-79	4.00-5.30
Glenwood-Dotsero Springs	500	200	-15	-17	40-60	1978-81	4.00-6.00
Big Sandy River	180	80	-7	-8	20-25	1979-80	5.00-6.30
McElmo Creek	115	40	-3	-4	10-15	1980-82	5.00-7.50
Crystal Geyser	4	4	1	1	1-2	1975-76	5.00-10.00
Blue Springs*	550	250	-16	-19	-	-	-
Total**	2310	1130	-90	-100	150-200	-	-

* Insufficient data to estimate cost
** Total values are rounded

Table 5

Potential Effects and Costs
Irrigation Scheduling and Management and Water Systems Improvement Projects

Areas	Present Salt Loading (1000's tons/yr)	Estimated Reduction (1000's tons/yr)	Effect at Hoover Dam (mg/l)	Effect at Imperial Dam (mg/l)	Irrigation Scheduling Costs ($1,000,000)	Water Systems Improvements		Cost Effectiveness (dollars/ton/yr)
						Total Cost ($1,000,000)	Assumed Federal Cost ($1,000,000)	
Lower Gunnison Basin	1,100	300	-23	-26	1-1.5	80-100	40-50	2.70 - 3.30
Uintah Basin	450	150	-12	-14	1-1.5	40-50	20-25	2.70 - 3.30
Grand Valley Basin	700	200	-15	-17	0.8-1.0	70-80	35-40	3.50 - 4.00
Palo Verde Irrigation District	90	23	0	-5	0.4-0.5	30-40	15-20	13.00 - 17.00
Colorado River Indian Reservation	30	7	0	-2	0.3-0.5	20-30	10-15	28.00 - 43.00
Totals*	2,370	680	-50	-60	4-5	240-300	120-150	---

*Values shown are rounded

At this time, the separation of effects between irrigation scheduling and water system improvements cannot be made. The effects will vary between areas depending upon soil, geologic, drainage, and topographic conditions, as well as the condition of present irrigation systems and the irrigation efficiencies now being attained by the water users. It is reasonable, however, to assume that irrigation scheduling and management will have a significant effect and for this reason early implementation would be a desirable feature of the program.

The total reduction of 160 mg/l at Imperial Dam as now estimated cannot maintain the salinity levels at or below present levels. Other measures involving combinations of desalting, weather modification, vegetation management, and channelization are required.

Vegetation management and channelization measures could be installed in accordance with the Colorado River Basin Project Act. Through these measures, there could be a water recovery of perhaps 200,000 acre-feet during the period 1980 to 1990 in the vicinity of Imperial Dam. This would achieve a substantial reduction in concentration at Imperial Dam at a cost less than some of the other control measures. Difficulties of implementing such a program are recognized. The program would need to protect the fauna and achieve environmental enhancement. Research into these areas is needed.

Increased confidence in weather modification leads to the assumption that 1 million acre-feet of additional flow could be expected by 1980 and possibly 2 million acre-feet by 1990. The additional water would be a significant advantage of this method.

Desalting will also be an important function in maintaining salinity at the present level. A specific desalting process can be designed to maintain the flow and quality desired at a given location permitting wide flexibility. It is estimated that desalting 500,000 acre-feet from a concentration of 1,000 to 735 mg/l would result in a 20 mg/l reduction in the concentration at Imperial Dam by 1980. Increased desalting by 1990 and the year 2000 could bring about reductions of 75 and 125 mg/l, respectively.

The interactions of the various control measures are physically related to one another and hence the order and time of accomplishment are important in assessing the overall effect.

The average annual salinity concentration of the Colorado River at Imperial Dam during the period 1941 to 1968 (most recently published data) was 751 mg/l. The annual salinity concentrations during this same period have ranged from a minimum of 649 mg/l in 1949 to a maximum of 918 mg/l in 1956. The monthly salinity concentrations of the Colorado River at Imperial Dam during the period

1941 to 1968 have experienced an even wider range from a minimum of 551 mg/l in December 1952 to a maximum of 1,000 mg/l in January 1957.

Levels of salinity concentrations presently found in the lower Colorado River vary depending on the time period used to describe the level. As indicated above, the average for a year is greater than the level during the period 1941 to 1968 and the peak monthly concentration is even greater than the level for a year.

In order to depict the effects of the Water Quality Improvement and Allied Programs, Table 6 was developed showing the projected reductions in salinity concentrations for each program and the estimated effects on the synthesized salinity levels at Imperial Dam.

Table 6

PROJECTED PROGRAM REDUCTIONS - COLORADO RIVER AT IMPERIAL DAM

(Average annual values in mg/l - 1941-68 period of record)

	1970	1980	1990	2000
Estimated salinity level (Full development - no control program)	865	1,000	1,200	1,250
Range	(750-1,060)	(860-1,220)	(1,040-1,470)	(1,080-1,530)
Projected program reductions				
Point, diffuse, and irrigation source control	(-)	(-60)	(-160)	(-160)
Vegetation management and channelization	(-)	(-)	(-50)	(-50)
Desalting	(-)	(-20)	(-75)	(-125)
Weather modification	(-)	(-40)	(-70)	(-70)
Total program reduction	-	-120	-355	-405
Estimated salinity level (Full development with control programs)	865	880	845	845
Range	(750-1,060)	(740-1,100)	(685-1,115)	(675-1,125)

The values in the table are initial estimates based on the average hydrologic conditions for the period of record 1941-1968.

The 1970 average annual value of 865 mg/l has been derived on the assumption that present developments in the basin were completed and operating during the period of record. In other words, the effects of water quality of all present developments have been extended back to 1941 from the time they became operational.

Similarly, the average annual values for the years 1980, 1990, and 2000 were synthesized to reflect the influence on water quality during the period of record of water resource developments expected to be completed by those dates. These estimates must be regarded as initial approximations. The feasibility and related studies, buttressed by additional research, will improve reliability of the estimates.

It should be recognized that the values in the table are computed average annual values at Imperial Dam under the stated assumptions. The average annual modified value for 1970 of 865 mg/l based on the 1941 to 1968 period would probably have ranged from an annual minimum of 750 mg/l to an annual maximum of 1,060 mg/l. However, with Lakes Powell and Mead regulating the Colorado River, it would require several consecutive low-flow years to produce an annual salinity concentration of 1,000 mg/l, or higher, at Imperial Dam.

Historically, records at Imperial Dam show that the average salinity concentration for January 1957 was 1,000 mg/l and for December 1967 it was 992 mg/l. Six other months in the period 1941-1968 have had average concentrations above 960 mg/l. However, with present development, it is probable that the average monthly concentrations for these 8 months would have exceeded, 1,000 mg/l. Furthermore, with present developments, the 1,000 mg/l mean monthly concentration at Imperial Dam would have been exceeded in 40 months during the period 1941-1968.

It is not possible to predict future salinity concentrations for any particular month, nor can it be assumed that past flow and concentration cycles will be repeated in the future.

In view of the foregoing, it is essential that feasibility studies be pursued on point, diffuse, and irrigation sources to disclose the maximum improvement in water quality that can be achieved. These must be coordinated with allied programs and fitted into a basin-wide water resources management plan. The studies must develop the full costs involved, identify the control means, assess benefits, identify beneficiaries, present financial plans, display the tradeoffs, and specify the time required to achieve specific degrees of water quality improvement for particular reaches of the river. The comprehensive plan for water quality improvement must be engineeringly feasible, politically acceptable, and administratively viable through appropriate institutions. This then would permit the salinity levels to be maintained at an average annual level of about 845 mg/l while the Upper Basin States continued to develop up to their apportionment under terms of the Colorado River Compact.

It is premature to define numerical standards of salinity levels at Imperial Dam now or in the next 2 or 3 years. It is essential that the available technical knowledge of the physical and social factors involved and their interrelationships and the probable consequences of proposed changes be fully understood before applying numerical standards.

VI DESCRIPTION OF WATER QUALITY IMPROVEMENT PROGRAM

The prior studies of water quality in the Colorado River by the Bureau of Reclamation, the EPA, and the Colorado River Board of California have served to define the problems and outline potential control measures. They are not, however, sufficient to undertake immediate construction of control measures. Cost effectiveness analyses have been prepared on the basis of reconnaissance studies.

For example, point sources of salinity have been geographically identified, salinity concentrations have been measured, and output of salt load estimated. Neither the feasibility of capturing these flows has been verified by requisite field geological explorations nor the consequence of such proposed actions assessed. Similarly, diffuse sources of salinity have been located but reliable measurement of salt loading cannot be made because adequate records are not available. Moreover, practical methods for controlling the salt loading from such sources still need to be developed.

With respect to irrigated lands, it is anticipated that improvement in management and use of water on the irrigated farms will result in reduced salt loading thereby improving the quality of the receiving stream. Such action, buttressed by improvements in water conveyance systems, involving seepage reduction through canal lining and improvement in operational techniques, also is expected to contribute toward reduced salt loadings in the river. Complex interrelationships of human activities and physical field conditions must be analyzed to determine the amount of salt load reduction that could be achieved.

This chapter describes the details of the various elements of the program. Details of some of the projects are lacking due to the scarcity of knowledge and basic data for making judgments prior to undertaking the studies. The studies and activities are described in the approximate order in which they are expected to yield the greatest returns for the least investment of funds. These activities are described in the following sequence: the mathematical model for the Colorado River, other basin-wide activities which will have a bearing to some degree on all the investigations, irrigation source control, point source control, and diffuse source control.

Basin-wide Activities

These activities will include the development of a mathematical simulation model of the Colorado River system, further development of economic evaluation methods for water quality as an adjunct to the model, an in-depth study of the legal and institutional aspects involved, and the potential application of salinity reduction processes which have not been previously investigated.

Mathematical Model for Colorado River

To aid in evaluating the Water Quality Improvement Program, a mathematical simulation model for the Colorado River System is being developed. The model employs various aspects of systems analysis, probability theory, mathematical statistics, and operational research. In addition, computer science, engineering mathematics, and numerical analyses are utilized. The model would simulate the river system for both water quantity and water quality. Quality will be displayed in terms of the total dissolved constituents and the major anions and cations. Models already in existence will be used to the maximum extent possible.

In concept, the model incorporates the use of deterministic and/or probabilistic inputs and demands to measure system response or yield under specific operational criteria. The model consists of five fundamental computational blocks which are primarily submodels of the overall system. Each primary submodel can be used independently for a particular system objective. Initially the model will be developed with the first two submodels. Subsequently, the remaining three submodels will be incorporated.

The five computational blocks or submodels are as follows:

1. Data analysis submodel. This block is utilized to analyze and evaluate the basic time series data. The block is used to

develop builder functions to relate quantity and quality and transfer information from one point to another in the system. Statistical information and equations are developed to allow the synthetic generation of a longer time series from a shorter series while preserving the statistical characteristics of the shorter series.

2. Simulation submodel. Provides an operational simulation of the basin based on a series of nodes with five system objectives utilized in each node, handles surface and ground-water flows, and specifies the operating constraints or conditions of flow, storage, and quality that must be met.

3. Sensitivity and impact analysis submodel. Identifies effects of factors such as changes in frequency distribution curves and ranks the impacts of operational influences; e.g., how do irrigation demands effect power production.

4. Linear optimization submodel. Identifies the optimal economic operating conditions required to achieve specified system objectives.

5. Dynamic system submodel. With operational rules specified, this submodel provides a dynamic optimization of the system for specified objectives such as water quantity and quality at each node point moving either up or downstream.

The model will make it possible to evaluate the quality changes under various flow regimes so time changes of quality can be presented on a probability basis. The effects of salinity control projects, weather modification, vegetation management and channelization, desalting and augmentation by import, and water resource development could be analyzed through use of the model. The model will be of great value in developing alternative plans of water use and regulation. It could be used to optimize plans, define changes in present operating criteria for salinity control, and evaluate impacts of salinity control projects and new water resource developments on the salinity of the system.

Economics of Water Quality Management

Proposals for salinity management actions will be evaluated to identify potential benefits and costs. Because the proposed salinity control measures are expected to be costly, sensitivity analysis will be made on various components. Alternative remedial actions will be analyzed along with associated impacts, both beneficial and adverse. Beneficial effects from reductions in salinity concentration in the river include the avoidance of decreased crop yields, maintenance of higher quality municipal and industrial water, and savings in water treatment costs. The estimation of secondary and indirect effects on the economy resulting under conditions with and without alternative salinity control measures will also be considered.

Equally important but not as easily quantified are the intangible detriments, such as possible environmental effects and the international relationship with Mexico.

The economic appraisal will utilize the simulation model of the entire Colorado River Basin. The structure and inputs for optimization submodels will be developed. The comprehensive work done by the EPA will be reviewed to determine modifications and additions of the most value to program needs. This definition-type study is currently underway. It will bring together all the past research efforts and outline a plan of action for subsequent years. New economic evaluation procedures will be explored. Data gaps will be filled and optimization submodels formulated to test the economics of alternative salinity management projects. This would be followed by economic evaluations of individual projects and the overall proposed system of salinity control.

Institutional and Legal Analysis

Operations of the Colorado River are controlled to a large degree by compacts, Federal laws, State laws, power and water contracts, an international treaty, and a U.S. Supreme Court decree. These legal and institutional arrangements place constraints on a water quality improvement program. It is therefore important that every potential corrective action includes consideration of institutional and legal aspects along with engineering and economic feasibility. New legislation or special interbasin agreements may be necessary before certain programs can be accomplished. This analysis will document and identify the operational constraints and establish the legal framework that may be required to pursue implementation of salinity control measures.

Some of the controlling documents are:

Colorado River Compact - November 24, 1922

Boulder Canyon Project Act - December 21, 1928

California Limitation Act - March 4, 1929

Seven-Party Water Agreement - August 18, 1931

Boulder Canyon Project Water Contracts - February 21, 1930, through the present

Boulder Canyon Project Power Contracts - April 26, 1930, through the present

Boulder Canyon Project Adjustment Act - July 19, 1940

Mexican Water Treaty, 1944

Upper Colorado River Basin Compact - October 11, 1948

Colorado River Storage Project Act - April 11, 1956

Supreme Court Decree in Arizona v. California - March 9, 1964

Lake Mead Flood Control Regulations - July 29, 1968

Colorado River Basin Project Act (Public Law 90-537, 90th Congress, approved September 30, 1968)

Criteria for Coordinated Long-Range Operation of Colorado River Reservoirs - June 10, 1970

State Water Laws

Winters Doctrine

Eagle County Case

Contracts for Sale of Water from Boulder Canyon Project and Colorado River Storage Project Reservoirs

Other Contracts Related to Thermal Powerplants

Water Quality Act of 1965 and Amendments

Environmental Protection Act

Executive Orders of the President

Ion Exchange Desalting

The Office of Saline Water is conducting a parametric study of the preliminary feasibility and cost of utilizing large-scale ion exchange systems to control salinity levels on the Colorado River at various points such as Parker or Davis Dam. This study would determine the plant boundary costs of reducing the salinity in 100 mg/l increments down to a lower limit of 500 mg/l.

The study is considering the various costs of regeneration, possible costs of resins if billion gallons per day plants were built, and various salinities of feed water from 750 up to 1,000 mg/1. Feed-water flows to be considered in the study will range from 500 to 5,000 cfs.

A small ion-exchange pilot plant is being installed at a selected site on the Colorado River to verify the theoretical results of the parametric study. Housing for the pilot plant and power for operation would be furnished by the Bureau of Reclamation. Verification runs are expected to take 90 days.

Ion exchange was selected for special study because it may hold better prospects for most economically reducing the salinity of water having concentrations of 700 to 1,300 mg/1 by 200 to 500 mg/1 than other desalting processes. This study will provide an opportunity to analyze alternative concepts of salinity control not heretofore critically studied. Involved would be control of the salinity at levels required for a particular use, with the water being treated within the delivery system to the use areas. Should the initial studies show favorable economical relationships, feasibility studies of large-scale installations could be made and integrated into a system analysis of the river using the ion-exchange process at or in key water-delivery systems.

Irrigation Source Control

The principal irrigated areas contributing to the salinity of the Colorado River system are the Grand Valley and Lower Gunnison Basins in Colorado; the Uintah Basin in Utah; and the Colorado River Indian Reservation in Arizona and the Palo Verde Irrigation District lands in California. To alleviate this source of salt loading and the concentrating effect caused by the consumptive use of water, on-farm irrigation scheduling and water management will be undertaken. This program will be coordinated with water systems improvement and management programs within each of the areas. Completed research indicates that improved on-farm irrigation scheduling and water management is likely to be among the least expensive methods of reducing salinity levels.

Irrigation Scheduling and Farm Management

Objectives. The principal objective of this program as related to the Colorado River Water Quality Improvement Program is to reduce the salt loading of the Colorado River contributed by irrigation return flows. By minimizing irrigation water's contribution to the ground-water regime that is in contact with saline geological formations, a substantial reduction in the total volume of salt being yielded to Colorado River is expected. Some water would be salvaged through a reduction of nonbeneficial consumptive use in seeped and shallow water table areas. The salvaged water and the reduced diversions would be available for further uses such as increasing water available for other withdrawals, increasing streamflows in some river reaches, or increasing reservoir storage for multipurpose uses.

The principal objectives of this program as related to the irrigators include an increased net return through greater yields and improved crop quality with lower production costs. Irrigation scheduling and a farm management program will help assure the efficacy of irrigation for agricultural production and reduce its overall environmental impact on the water and land resource. A desirable feature of this program is that the benefits will be sufficient to support an initial level of irrigation improvement.

Three levels of obtainable irrigation efficiencies can be realized on an operating irrigation project. The first is realized by the irrigator when making proper and timely irrigation applications without an increased labor input. The second level of improved irrigation efficiency will be realized through additional labor involvement in the on-farm operation.

The third increment of irrigation efficiency is associated with improved on-farm irrigation systems and improvement of the total distribution system. This final level can only be realized with a substantial investment. Improvement of the on-farm irrigation systems could be accomplished through private investment with some assistance from the U.S. Department of Agriculture, Rural Environmental Assistance Program.

The primary technique employed by this program is the development and dissemination of information on timing of irrigations and their applied amounts with a computer program. By developing an accurate and timely water budget and giving operational considerations to the root zone reservoir, the basis for high irrigation efficiencies can be maintained and the first increment of improved irrigation efficiency realized. Through employment of other good management tools, proper operational techniques along with the right irrigation system, these improved irrigation efficiencies can be further optimized within the physical constraints of an irrigated area. Through interaction with irrigators and improved education and communication with the involved organizations, these criteria can be developed and implemented.

Program Evaluation. The very essence of the effectiveness of this program is motivation at all levels, but most important at the farmer/irrigator level of involvement. With a program of this nature, motivation can best be developed by evaluating the program and identifying its benefits and the beneficiaries. By showing a farmer real benefits associated with this program, he will be stimulated to respond to a suggested irrigation schedule and become motivated to make an effort to improve his irrigation operation. His level of response will directly affect his level of returns. When these benefits are large enough, the farmer or another direct beneficiary will be expected to finance a portion of this program's operation and provide the capital investment needed. Measurements of the present and future conditions with regard to such items as crop yields, crop quality, water use, fertilizer use, production costs, and ground-water levels will need to be documented. This documentation of the effects of this program on the initial areas will thus allow easier implementation on subsequent areas.

Proposed Areas. It is believed that the earliest and most dynamic results on quality will be obtained through irrigation scheduling in the Upper Basin. This program will, therefore, be initiated immediately in the Grand Valley area of the Upper Basin. In fiscal year 1974, this program is scheduled to be expanded into other areas in the Upper Basin and introduced into two areas in the Lower Colorado River Basin. The initial areas to be considered for irrigation scheduling under this program are:

1. Grand Valley Area (Presently there are 76,000 acres being served by private districts and the Grand Valley Project in this area.)

2. Lower Gunnison Basin (Present irrigated acreage is 160,000 acres). Projects under construction will add 17,000 acres to this area.

3. Uintah Basin (170,000 acres are located in this area).

4. Colorado River Indian Reservation (The present irrigated area here is 55,600 and projected to increase to 99,400.)

5. Palo Verde Irrigation District (There are 91,500 acres of land irrigated in this area.)

Water Systems Improvements and Management

An important adjunct to on-farm management of water involves improvement of the water conveyance systems to reduce losses and increase operational efficiency. Such activities, when meshed with improvements in on-farm irrigation water use efficiencies are important water conservation measures. Reductions in the amount of deep percolation losses from farms and conveyance systems can be expected to reduce salt loadings. The effect on salinity reductions will vary according to many factors. Involved would be the nature of the soil and substrata, present water management practices, conditions of the conveyance system, and the natural and artificial drainage conditions.

The studies scheduled will identify the improvement works needed in irrigation systems throughout the Grand Valley, Lower Gunnison and Uintah Basins, the Colorado River Indian Reservation, and the Palo Verde Irrigation District.

Grand Valley. The Grand Valley in Colorado contributes an average of over 700,000 tons of salt annually to the Colorado River. About 76,000 acres are irrigated in Grand Valley. The amount of salt contributed by the irrigated area is unknown, but has been estimated in various studies as being 300,000 to 700,000 tons annually. It has been estimated that an irrigation scheduling and water systems improvement program will reduce the salt contribution by 30,000 to 200,000 tons annually - a potential reduction of 2 to 15 mg/l in concentration at Hoover Dam.

Lower Gunnison. The Lower Gunnison subbasin in Colorado contributes an average of about 1,100,000 tons of salt annually to the Colorado River. About 160,000 acres are irrigated in the subbasin. An irrigation scheduling and water systems improvement program could reduce the salt contribution. The amount of reduction needs to be determined by the feasibility investigation.

Uintah Basin. Drainage from the Uintah Basin contributes an average of 450,000 tons of salt annually. About 170,000 acres are irrigated in the Uintah Basin. Lining the canals and laterals could reduce the salt contribution. The amount of reduction needs to be determined by the feasibility investigation.

Colorado River Indian Reservation. The irrigated lands of the Colorado River Indian Reservation are not yet in salt balance. These lands contribute an average of about 30,000 tons of salt annually to the Colorado River. About 55,600 acres are now irrigated, and this is projected to increase to 99,400 acres by 1980.

Palo Verde Irrigation District. The Palo Verde Irrigation District, a locally developed district, has irrigated about 90,000 acres for many years. In 1970, the irrigated acreage was 91,500 acres which is thought to be near the maximum that will be irrigated in the district. This irrigated land is the major source of return flow to the river between Parker and Imperial Dams. These lands contribute an average of about 90,000 tons of salt annually to the Colorado River.

Point Source Control

Point source control involves salt removal from a localized area contributing an inordinately high salt load to the river system. The principal point source control projects in the program include: LaVerkin Springs, Littlefield Springs, Blue Springs, Paradox Valley, Crystal Geyser, and Glenwood-Dotsero Springs. Within the basin, 28 point sources have been identified and these 6 held the most favorable prospects for achieving the control desired. Among those rejected at this time, based principally on flow-concentration relationships, were Warm Kendall Springs, Steamboat Springs, Jones Hole Creek-Whirlpool Canyon, Pagosa Hot Springs, Havasu Springs, and 17 other small salt load contributing wells, springs, and mine drainages.

Feasibility studies have been scheduled for the six major sources listed. The studies will be carried only as far as is necessary to make a decision regarding the desirability of recommending construction.

The estimated cost for these studies in the 10-year program is approximately $2.5 million. With appropriate authorization and funding, all projects found feasible could be under construction within the 10-year period with several scheduled for construction as early as fiscal year 1975. This presumes that legal and institutional problems of water rights and the Colorado River Compacts are worked out and arrangements made for repayment.

LaVerkin Springs

The LaVerkin Springs study is underway and is scheduled to be completed in fiscal year 1973. Construction could begin in fiscal year 1975 and be completed in fiscal year 1978. These warm springs discharge about 10 cfs into the Virgin River in a reach of about 1,800 feet located 1 mile northeast of Hurricane, Utah. They add a salt load of about 100,000 tons per year to the Colorado River. The spring water contains significant amounts (37 picograms per liter) of radioactivity in the form of radium 226. However, the concentration in the Virgin River at Littlefield, Arizona, in October 1966 was only 0.45 picograms per liter which is lower than the standards set by the Public Health Service for a public water supply. The control could be achieved either by evaporation of the collected waters or by the use of desalting. The evaporation plan might involve the use of from 4 to 10 wells to tap the springs' water source, then conveying the water via a lined channel to an evaporation pond.

An important consideration in these studies will be the loss in water associated with the selected control method. This loss will vary from a total loss of about 8,000 acre-feet per year in the case of the evaporation plan to perhaps as small as 400 acre-feet with some desalting processes. Very preliminary review of the evaporation plan suggests that construction costs could be from $8 to $10 million. The alternative cost of desalting is under study, but cost estimates have not yet been made. Removal of 80 percent of the salt load is expected to reduce the salinity concentration of the river below Hoover Dam by about 6 mg/l and 8 mg/l at Imperial Dam.

Littlefield Springs

The Littlefield Springs discharge along the south side of the Virgin River about a mile upstream from Littlefield, Arizona. These springs have a combined outflow of about 10 cfs with an average salinity of about 2,900 mg/1, and contribute an annual salt load of about 30,000 tons to the river system. The disposal of these springs presents a special problem as the outflow is presently collected and used for irrigation in the Littlefield area. This problem, coupled with a general lack of data concerning these springs, dictates the need to approach the study by critically examining the limiting factors to determine the degree of investigative effort required.

Initiation of the feasibility study is scheduled to begin in fiscal year 1974. Removal of the salt load from this source is expected to reduce the salinity concentration by about 2 mg/1 at both Hoover and Imperial Dams.

Blue Springs

The Blue Springs area is located on the Navajo Indian Reservation, Coconino County, Arizona, about 25 miles northwest of Cameron. Spring flow originating from an 11.6-mile reach of the river between miles 3.0 and 14.6 amounts to between 155,000 and 170,000 acre-feet per year with an average annual flow of 161,000 acre-feet or 222 cfs. This is about half the average annual flow of the Little Colorado River. The salt content of the springs averages 2,500 mg/l and adds an annual salt load of 550,000 tons to the river. It is the largest point source in the basin.

The high canyon walls and the inaccessibility of the area cause major difficulties in collecting the spring discharge, desalting, and disposing of the brine. The loss of water associated with desalting would be very important, even with a process that has minimum losses. Exceedingly difficult and costly solutions appear to be involved. Controlling the springs will have a considerable impact on the environment. The Blue Springs are a part of the local Indian folklore. Matters with the Indians and the environment must therefore be evaluated. These engineering, ethnic, and environmental factors will be appraised early in the study. The need for progressing with the study will be continually assessed.

Paradox Valley

It is estimated that Paradox Valley, a collapsed salt anticline, contributes about 200,000 tons of salt per year to the Dolores River. A control project might reduce this salt contribution about 180,000 tons per year. The removal of 180,000 tons per year could reduce the salinity concentration at Hoover Dam about 14 mg/l and 15 mg/l at Imperial Dam.

Previous studies suggest that the control works may include a regulatory reservoir on the Dolores River above Bedrock, Colorado; an evaporating reservoir on the Dolores River in Paradox Valley to evaporate the saline flows from Paradox Valley; a bypass canal to convey the regulated flows of the Dolores River through the valley and around the evaporating reservoir; a West Paradox Creek Diversion Dam; and a West Paradox Creek Diversion Canal to carry the flows of West Paradox Creek around the evaporating reservoir. An estimate of the construction cost would be in the range of $25 to $35 million.

The first year (fiscal year 1972) of investigations will include data gathering, installing gaging stations and ground-water observation wells, and other preliminary fieldwork. The second year (fiscal year 1973) would continue data gathering; map the reservoirs, damsites, and canal alinements; and conduct other fieldwork. In subsequent years (fiscal years 1974 and 1975) the data would be analyzed, a plan formulated, feasibility design and cost estimates made, and a feasibility report prepared. Data gathering would continue through the last 2 years to verify the analysis of the data collected in the first 2 years. The construction period might be from fiscal year 1977 through fiscal year 1980.

Crystal Geyser

The Crystal Geyser results from a gas (carbon dioxide) accumulation blowing water out of an abandoned oil test well at about 4-hour intervals. This geyser spouts about 200 acre-feet of water and 4,000 tons of salt per year which flows west a few hundred feet into the Green River.

The discharge could be collected and pumped to a nearby evaporating reservoir to dispose of most of the 4,000 tons of salt. Removal of 4,000 tons of salt per year would reduce the salinity concentration at Hoover Dam by less than 1 mg/l. During the first year (fiscal year 1972), fieldwork will be accomplished. Designs and estimates would be made and a feasibility report prepared in the second year (fiscal year 1973).

Preliminary appraisals indicate that the control works could include an equalizing reservoir, pumping plant, evaporating reservoir, and a discharge line from the equalizing reservoir to the evaporating reservoir. Estimated construction costs are in a range of $1 to $1.5 million. The project would be scheduled for construction during fiscal years 1975 and 1976.

Glenwood-Dotsero Springs

The Glenwood and Dotsero Springs, located in Colorado, are estimated to discharge about 25,000 acre-feet of water and over 500,000 tons of salt per year. It is the second largest point source in the basin. It is estimated that about 200,000 tons could be removed by collection of the larger flows and desalting or evaporating them. Removal of this salt load per year could reduce the salinity concentration at Hoover Dam about 15 mg/l and 17 mg/l at Imperial Dam.

Investigations are underway for the collection of data. Collection and analysis of data, mapping of the conveyance route and treatment area, other fieldwork, preparation of feasibility designs and estimates would be accomplished in subsequent years with the completion of a report scheduled in fiscal year 1976 or earlier if insurmountable physical or economic problems are encountered.

As now perceived from very preliminary studies, it is anticipated that control works might include a collection system for the saline springs, a conveyance system, and a desalting system or evaporating system to dispose of saline water. Order or magnitude estimates suggest costs in a range of $40 to $60 million. Construction would be scheduled during the period fiscal year 1978-1983.

Diffuse Source Control

Diffuse source control involves salt loading and/or concentration effects that are spread over comparatively large areas such as a minor subbasin. The diffuse source control projects have not as yet been sufficiently studied to formulate more than tentative plans for which rough approximations of costs have been estimated. The tentative plan for diffuse source control projects is to selectively remove the more saline - over 1,500 mg/l - flows and desalting and/or evaporating them. The irrigated areas on these streams would also be investigated to determine if a water systems improvement and management program or an irrigation scheduling and farm management program might reduce the salt load.

Data gathering for the diffuse source control studies are underway. Feasibility studies are scheduled to begin in FY 1974 and continue through FY 1978. Descriptions of these projects are given in the following section.

Price River

The Price River at Woodside, Utah, drains about 1,500 square miles. The flow averages about 74,000 acre-feet per year and contains about 240,000 tons of dissolved solids with concentrations up to 8,200 mg/l.

Selective removal of 50 cubic feet per second during low flow periods could remove about 100,000 tons of salt per year. Removal of this amount of salt may require the desalting or evaporation of about 25,000 acre-feet per year. Removal of 100,000 tons of salt from the river is estimated to reduce the salinity concentration at Hoover Dam about 8 mg/l and 9 mg/l at Imperial Dam.

Data gathering on the Price River is underway and will continue into subsequent years. The feasibility study could begin in FY 1974 and be completed in FY 1977.

San Rafael River

The San Rafael River near Green River, Utah, drains about 1,670 square miles. The flow averages about 95,000 acre-feet per year and contains about 190,000 tons of dissolved solids with concentrations up to 6,400 mg/l. Selective removal of 75 cubic feet per second during low flow periods could remove about 90,000 tons of salt per year. Removal of this amount of salt could require the desalting or evaporation of about 30,000 acre-feet per year. Removal of 90,000 tons of salt from the river is estimated to reduce the salinity concentration at Hoover Dam by about 7 mg/l and 8 mg/l at Imperial Dam.

Data gathering on the San Rafael River is underway and will continue in subsequent years. The feasibility study could begin in FY 1974 and be completed in FY 1977.

Dirty Devil River

The Dirty Devil River near Hite, Utah, drains about 4,170 square miles. The flow averages about 72,000 acre-feet per year and contains an estimated 200,000 tons of dissolved solids with concentrations up to 2,500 mg/l. It is estimated that about 80,000 tons of this salt could be removed which could drecrease the salinity concentration at Hoover Dam by about 7 mg/l and 8 mg/l at Imperial Dam.

Data gathering on the Dirty Devil River is scheduled to begin in FY 1973 and continue in subsequent years. The feasibility study could begin in FY 1976 and be completed in FY 1978.

McElmo Creek

McElmo Creek near Colorado-Utah State Line drains about 350 square miles. However, McElmo Creek also receives return flows from lands irrigated with water from the Dolores River. The flow of McElmo Creek averages about 31,000 acre-feet per year and contains an estimated 115,000 tons of dissolved solids with concentrations up to 3,000 mg/l. It is estimated that about 40,000 tons of this salt could be removed which could decrease the salinity concentration at Hoover Dam about 3 mg/l and 4 mg/l at Imperial Dam.

Data gathering on McElmo Creek is scheduled to begin in FY 1973 and continue in subsequent years. The feasibility study could begin in FY 1976 and be completed in FY 1978.

Big Sandy River

Big Sandy River at the gaging station below Eden, Wyoming, drains about 1,610 square miles. The flow averages about 30,000 acre-feet per year with salinity concentrations up to 2,800 mg/l. However, the flow of Big Sandy River at its mouth is estimated to be considerably larger and also to have a higher salinity concentration. It is estimated the Big Sandy River discharges 180,000 tons of dissolved solids into the Green River. It is also estimated that 80,000 tons of this salt could be removed which could reduce the salinity concentration at Hoover Dam about 7 mg/l and 8 mg/l at Imperial Dam.

Data gathering on Big Sandy River is underway and will continue in subsequent years. The feasibility study could begin in FY 1974 and be completed in FY 1977.

Other Diffuse Sources Considered

Other diffuse sources were considered for inclusion in the program. Blacks Fork and Henrys Fork in Wyoming were considered, but not included as a diffuse source for selective withdrawal because the salinity concentrations exceeded 1,500 mg/l only for short periods each year. Blacks Fork and Henrys Fork will be investigated as a part of the other feasibility studies to determine other methods to reduce their salinity contributions.

Irrigated areas along Upper Colorado River and Roaring Fork have been listed as contributing heavy salinity loads to the Colorado River. Insufficient data are available to determine a method of reducing these contributions. These areas will also be investigated as a part of the other feasibility studies.

VII ALLIED PROGRAMS

The water quality improvement program as described previously may be regarded as one facet of an overall water resource management program of the basin. Water resource development and salinity control are inseparable elements in fostering continued economic growth and development of the resources of the Colorado River Basin.

Salinity control adds another dimension to the preparation of the Western U.S. Water Plan and must be viewed in context with other investigations for augmentation such as weather modification, geothermal resources, and desalting. From such studies, a basin-wide management plan for optimum use of the water resources will evolve.

Western U.S. Water Plan

The Western U.S. Water Plan, referred to as the Westwide Study, is a Level B study of water resource development for the 11 Western States. It was authorized by Public Law 90-537 and includes the specific requirement for providing a plan for the further comprehensive development of the water resources of the Colorado River Basin. As a part of the preparation of that program, augmentation potentials from the fields of weather modification, geothermal resources, and desalting will be evaluated and integrated into the plan. Additional water supplies available through better operational management, conservation, and salvage will be considered. The satisfaction of the international obligations to the Republic of Mexico will also be an integral part of the study.

The augmentation studies are underway and are being scheduled and coordinated through the Westwide Study to provide the most reliable degree of information attainable by 1977 which is the completion date of the study. The Westwide Study would analyze the varied and complex alternatives for development, regulation, and use of all waters of the Colorado River Basin, examine trade offs among alternatives, and recommend priority of future studies and development. Close coordination and cooperation will be maintained between the Colorado River Water Quality Improvement Program and the Westwide Study to assure the preparation of a sound, well integrated plan of development for the Colorado River Basin.

Desalting

To demonstrate the application of reverse osmosis technology to the reduction of salinity at point sources in the Colorado River drainage basin, it is planned to design, construct, and operate a multimodular plant at a site to be determined by investigations now being initiated for completion in fiscal year 1973. The design of this prototype plant would be based on the best reverse osmosis desalting technology available. Design and construction of the prototype plant is scheduled to be undertaken in fiscal years 1974 and 1975. In subsequent years, studies would be made of the application of the technology to specific point source salinity and return flow locations within the Colorado River Basin.

The initial prototype plant would be sized for 15 million gallons per day (mgd). Total capacity needs are estimated at 150 to 200 mgd for installations at specific locations to be established by the investigations. The initial prototype 15-mgd plant is scheduled to be on stream in fiscal year 1975, with the balance of the capacity scheduled to be built in the time period fiscal year 1976 through fiscal year 1979. The initial project would demonstrate the feasibility of desalting high salinity flows in the Colorado River system from a representative source. The acquisition of this technology and experience could then be extended to apply to major point sources of high salinity flows in the system. This program will be a joint endeavor of the Office of Saline Water and the Bureau of Reclamation. Its total cost is estimated at $110 million. To initiate the studies, $200,000 will be available to OSW and $400,000 to the Bureau of Reclamation for work to be undertaken in fiscal year 1973.

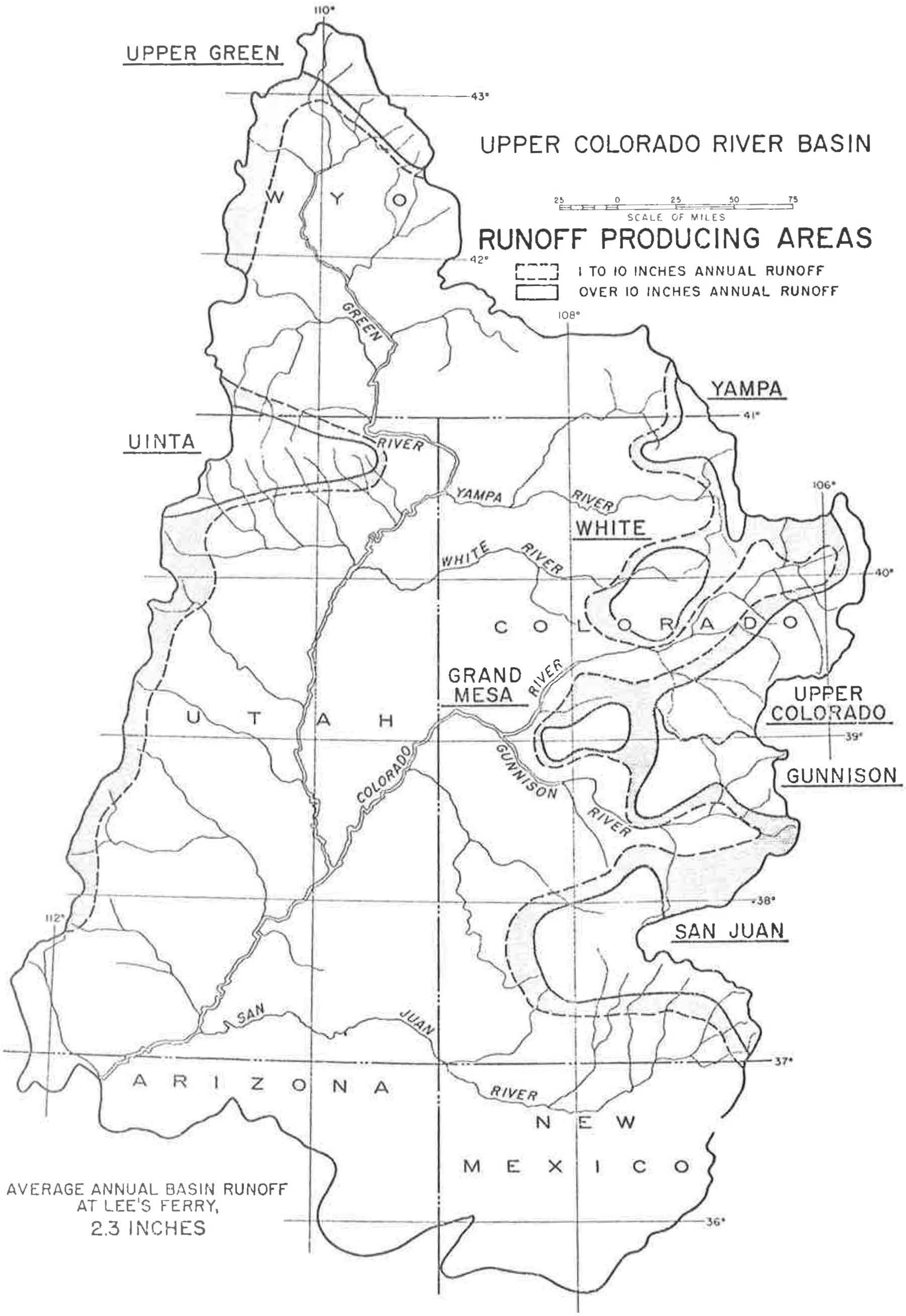
Very significant salt load reduction can be achieved by such a plant particularly if highly saline flows are desalted. Assume, for example, that the feed water has a concentration of 4,000 mg/l and the product water 400 mg/l. Under these conditions, a 150-mgd plant with a 90 percent plant factor would desalt 150,000 acre-ft/year resulting in the removal of 735,000 tons of salt.

Weather Modification

The weather modification program considers only what can be done by 1980. This restriction limits estimates of water supply increases to the scope of reliable capability that can reasonably be developed and feasibly be used within the next 10 years. Given an applied research and engineering effort to refine and confirm present cloud seeding techniques and provide analysis of parameters in storms pertinent to a more fully identified seeding criteria, a justifiable continuous operation could be initated in the Upper Colorado River Basin within 10 years involving: (1) seeding within well-defined and localized target areas by remote-controlled, ground-based generators using silver iodide, and (2) seeding susceptible winter storms at high elevations to increase winter snowpack. There are eight major runoff-producing areas as shown on Figure 4.

Not considered are modification of winter precipitation in the lower and mid-elevations of the basin and summer precipitation throughout the region. Feasible development of these water augmentation potentials will probably require more sophisticated techniques and resolution of more complex environmental aspects than are involved with

Figure 4



UPPER COLORADO RIVER BASIN
SCALE OF MILES
RUNOFF PRODUCING AREAS
1 TO 10 INCHES ANNUAL RUNOFF
OVER 10 INCHES ANNUAL RUNOFF
UPPER GREEN
UINTA
YAMPA
WHITE
GRAND MESA
UPPER COLORADO
GUNNISON
SAN JUAN
W Y O
U T A H
C O L O R A D O
A R I Z O N A
N E W
M E X I C O
GREEN
RIVER
YAMPA RIVER
WHITE RIVER
COLORADO RIVER
GUNNISON RIVER
SAN JUAN RIVER
AVERAGE ANNUAL BASIN RUNOFF
AT LEE'S FERRY,
2.3 INCHES

high elevation winter seeding. Continued improvement of the techniques assumed available by the mid-1970's and development of completely new methods represent speculative possibilities for further enhancing basin water supplies through weather modification.

In a limited water area, such as the Colorado River Basin, producing about 2 million acre-feet of usable new water annually could be a significant contribution toward salinity improvement. The highly favorable benefit-cost ratios; the flexibility of use, largely with existing water and power systems; and the opportunity for obtaining even greater new water yields with advanced techniques point to weather modification as a very desirable tool for water resources management. The Upper Colorado River Basin will be one of the first regions where a reliable, optimized capability to increase precipitation could be developed on a region-wide basis. It is believed that firm, acceptable answers and workable systems can be successfully achieved within 10 years.

Geothermal Resources

The potential of geothermal resources for water production is currently under investigation by the Bureau of Reclamation and the Office of Saline Water. Successful development could provide an additional source of water. The geothermal water could be meshed into the overall water management system to assist in achieving salinity control, particularly in the lower reaches of the system.

The Bureau of Reclamation and Office of Saline Water are actively engaged in a joint geothermal resource investigation program in the Imperial Valley, California. Following more than 3 years of geophysical investigations, coupled with shallow exploratory drilling (to 1,500 feet), the first deep well capable of producing hot steam and brine will be drilled late in fiscal year 1972. The well will be located in the East Mesa area of Imperial Valley and drilled to a depth of 4,000 to 8,000 feet. A portable pilot desalting plant will be moved to the well site and test operations for desalting geothermal brines will start. Also, a test disposal well will be drilled in July 1972 to determine the feasibility of reinjecting the byproduct fluids from geothermal development.

Preliminary studies indicate the Imperial Valley geothermal resources might be capable of producing up to 2,500,000 acre-feet of fresh water per year on a sustained basis as well as large quantities of electric energy with possible mineral byproduct recovery.

Operation and Maintenance Activities

Various facets of the Bureau of Reclamation's operation and maintenance activities deal directly with salinity problems in the

Colorado River. Water quality studies are continuing in the basin as required under various public laws, and biennial reports are made to Congress. These reports are prepared in cooperation with the Geological Survey, and include data regarding historical, present modified, and anticipated future chemical quality of water conditions at 17 key stations in the Colorado River Basin. Also presented are discussions of State water quality standards, quality control, sources of salinity, sources of other forms of pollution, and other aspects of water quality in the basin. In fiscal year 1972, $90,000 will be used in prosecution of this program.

Consumptive use studies are being undertaken as required by Section 601 of the Colorado River Basin Project Act. These studies will provide useful input to prosecution of the salinity control program. In fiscal year 1972, $100,000 is being expended for this activity.

Water Quality Prediction Investigations

A cooperative study is underway between the Bureau and EPA to develop a technique for predicting more precisely than now possible the mineral quality of irrigation return flow. The means for accomplishing this will be through the use of mathematical models and high-speed computers. The mathematical model is primarily a mathematical formula or expression attempting to duplicate conditions encountered on an irrigation project. The study utilizes data from existing irrigation projects in order to verify the technique.

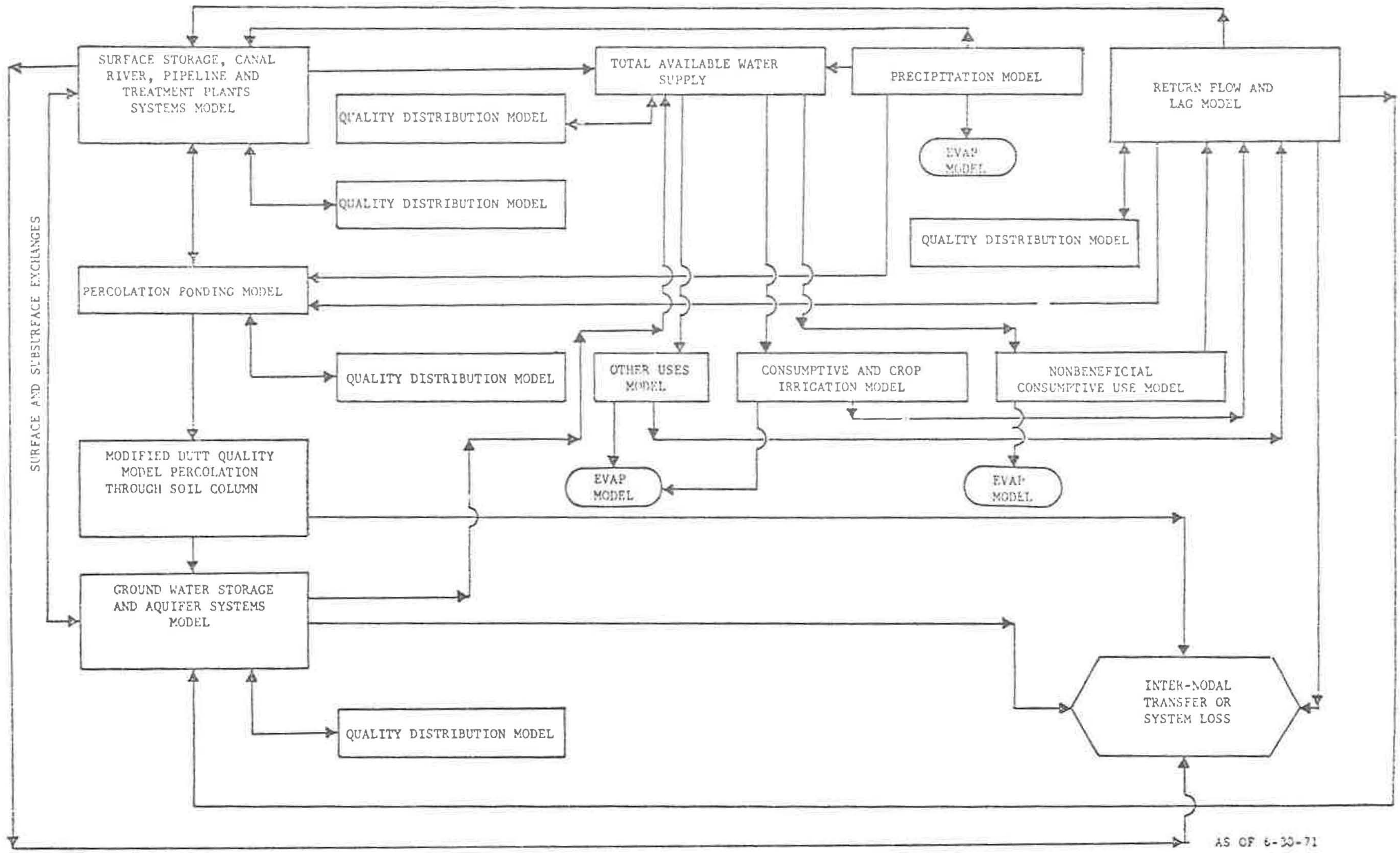
The objective of the study is to use a model in predicting changes in capacity and the associated water quality distribution of the aquifer and also the quality distribution of the water as surface effluents from the system. The prediction of the system responses was compared with the historical data, both quantity and quality distributions as a measure of the reliability of the model. Data from the Vernal Unit of the Central Utah Project have been used for designing and testing the model. Further tests will be made using data from the Grand Valley area in Colorado and the Cedar Bluff Unit in Kansas.

Although model testing and development of all the mathematical submodels is not complete, it appears at this point that a satisfactory model has been designed to predict the mineral quality of return flow from irrigation projects. Completion of the submodels will extend capability to impact analysis, optimization, and best plan selection. The simulation submodel is depicted in Figure 5.

The implication for water resource projects is that farm operation could be designed to use the least amount of water, return the smallest amount of salt to the river and permit the farmer to

Figure 5

HYDROLOGIC SYSTEM FOR SIMULATION SUBMODEL



obtain the greatest possible return from his farm. Using this model, the salt load reductions expected from irrigation scheduling and management will be verified on the Vernal Unit in the Uintah Basin.

Research

Considerable research will be required to support the water quality improvement program in the basin. Ongoing and scheduled research which is expected to find application in the salinity control effort now underway or scheduled by the Bureau of Reclamation includes: (1) prediction of the quality of return flows (in cooperation with EPA), (2) mathematical model for predicting nutrient and salt loadings, (3) ecological considerations in project planning, (4) wastewater reclamation opportunities, (5) case studies of desalting for salinity control, (6) management of saline waters, and (7) testing advanced irrigation systems.

In addition to the foregoing research, considerable additional research ought to be performed to assist in implementing a viable salinity control program. The Office of Water Resources Research is supporting activities in this area, and it is anticipated that the Environmental Protection Agency will join in financing such research efforts. The land grant universities and the Agricultural Research Service of the Department of Agriculture should also have important inputs.

Some of the kinds of work needed are field trials of water harvesting techniques, developing special uses for water of inferior quality; reducing costs of achieving high irrigation efficiencies; identifying field relationships of irrigation efficiency to return flow quality under specific soil and geologic conditions; studies of water flow through large impoundments including the chemical reactions and velocity of throughput of the dissolved constituents; vegetative management techniques particularly as related to phreatophytes with the aim of reducing water use and protecting the breeding areas of birds and other wildlife; identification of watershed management and salinity output relationships; further studies into the economics of water quality; and ecologic considerations involving salinity effects on aquatic life and other biological systems; recovery and extraction of minerals from brines; development of better inland brine disposal techniques; identifying opportunities for using reclaimed waste water to satisfy outdoor recreation needs; and identifying opportunities for using heated water from desalting installations to extend the recreation season for swimming and other activities.

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