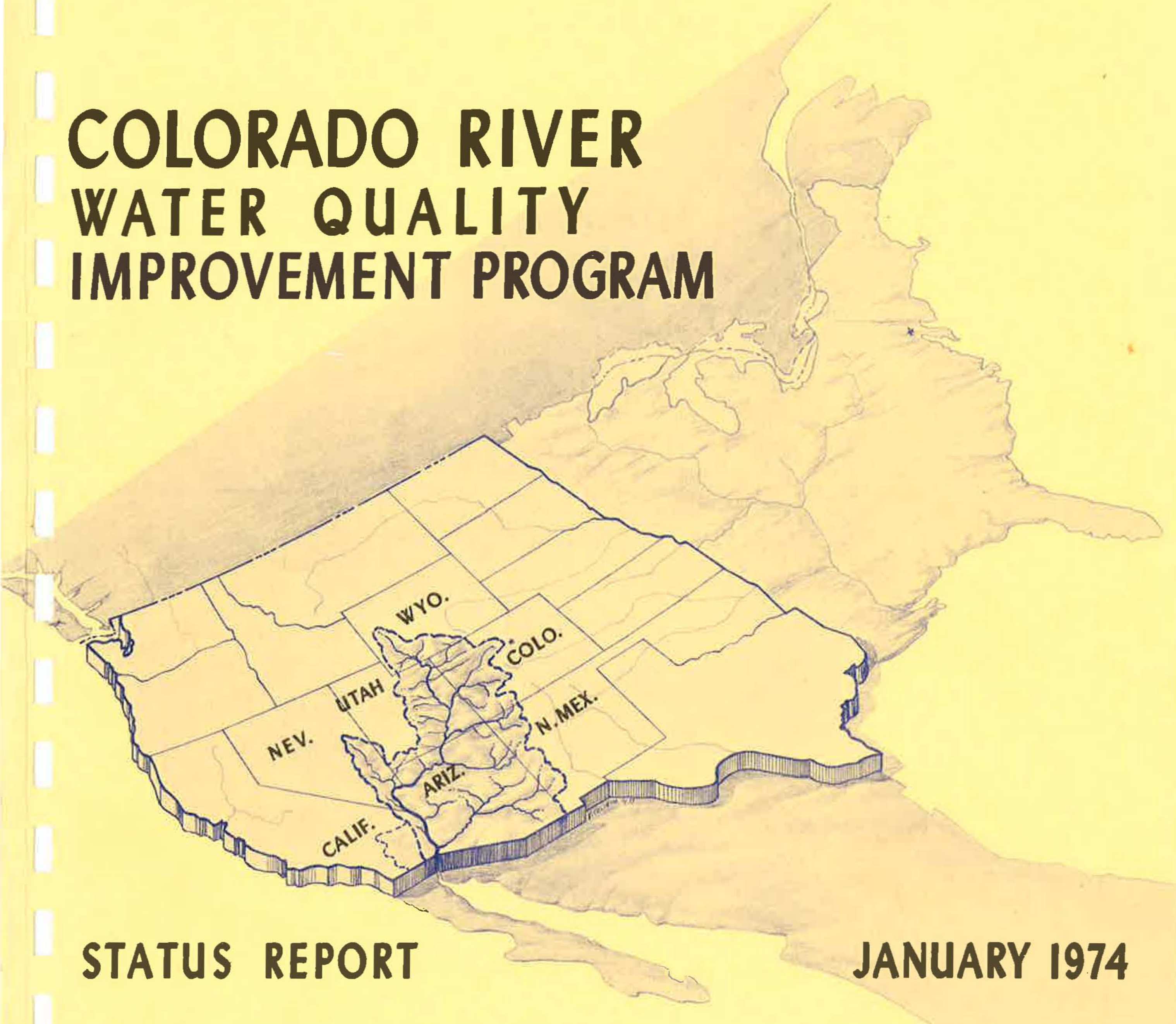
COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM



STATUS REPORT

JANUARY 1974

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

STATUS REPORT

COLORADO RIVER

WATER QUALITY

IMPROVEMENT PROGRAM

UNITED STATES
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Bureau of Reclamation
January 1974

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PREFACE

This status report was prepared by Bureau of Reclamation staff personnel as the biennial program appraisal referred to in the February 1972 report of the Bureau of Reclamation entitled "Colorado River Water Quality Improvement Program" (CRWQIP). That report formed the basis for unanimous recommendations developed by Federal and State conferees at the Seventh Session of the Environmental Protection Agency's 1972 conference on "Matters Relating to the Pollution of the Interstate Waters of the Colorado River and Its Tributaries." The Reclamation report stated that "Appraisal and 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 evaluation of possible control works, (3) public acceptance and commitment to control, (4) potential impacts of evolving technology, and (5) relationships within the basinwide management plan. Moreover, the recommendations of the conference provided that the Bureau of Reclamation report on general program progress annually to the conferees and other interested State agencies.

The results displayed in this status report are based on investigations and research conducted during the past 2 years. Although these studies are largely rooted in prior efforts of the Environmental Protection Agency, the Colorado River Board of California, the U.S. Geological Survey, and the Bureau of Reclamation, they do not as yet unfold a comprehensive basinwide control plan.

These prior studies and the recommendations of the conference were used to structure the program. Consequently, emphasis was placed on determining the effects of salinity levels and on methods of controlling salinity from irrigation, point, and diffuse sources. As the studies progressed, it became evident that within this array, prime considerations should be given to nonstructural or minimal land treatment approaches. Beginning in FY 1974, increased emphasis was placed upon such measures as improving irrigation efficiencies, improving management of the river and water conveyance systems, utilizing saline flows, managing Federal lands for salinity control, reformulating the plans for water resource developments to minimize salt loading, examining salt precipitation phenomena in large reservoirs, and reducing evapotranspiration through treatment and management of vegetation. Some of the measures, such as improving irrigation efficiencies, are being conducted directly within the CRWQIP, while others, such as the research on salt precipitation phenomena in reservoirs and the utilization of saline flows, are being implemented by State or private entities. Other techniques requiring more detailed studies include salt removal at points of diversion to use, and such long-range concepts as dilution through augmentation by weather modification, desalting sea water, and developing geothermal resources.

Salinity control is viewed in these investigations as a related facet of an evolving comprehensive plan for managing the water resources of the Colorado River Basin. No single measure can achieve the goals established by the 1972 Enforcement Conference and the seven basin states of "* * * maintaining salinity at or below present levels in the lower main stem." The CRWQIP has been evaluating and will continue to evaluate alternative ways to meet the salinity problem. Whether or not specific solutions can be recommended depends, in part, on the results of the economic, institutional, and legal studies. Moreover, there has been no commitment by the Federal Government to any specific solutions that may be identified during the evaluations.

Salinity control, particularly as applied to a large river basin, is a novel undertaking. Many physical, social, economic, and legal complexities are involved.

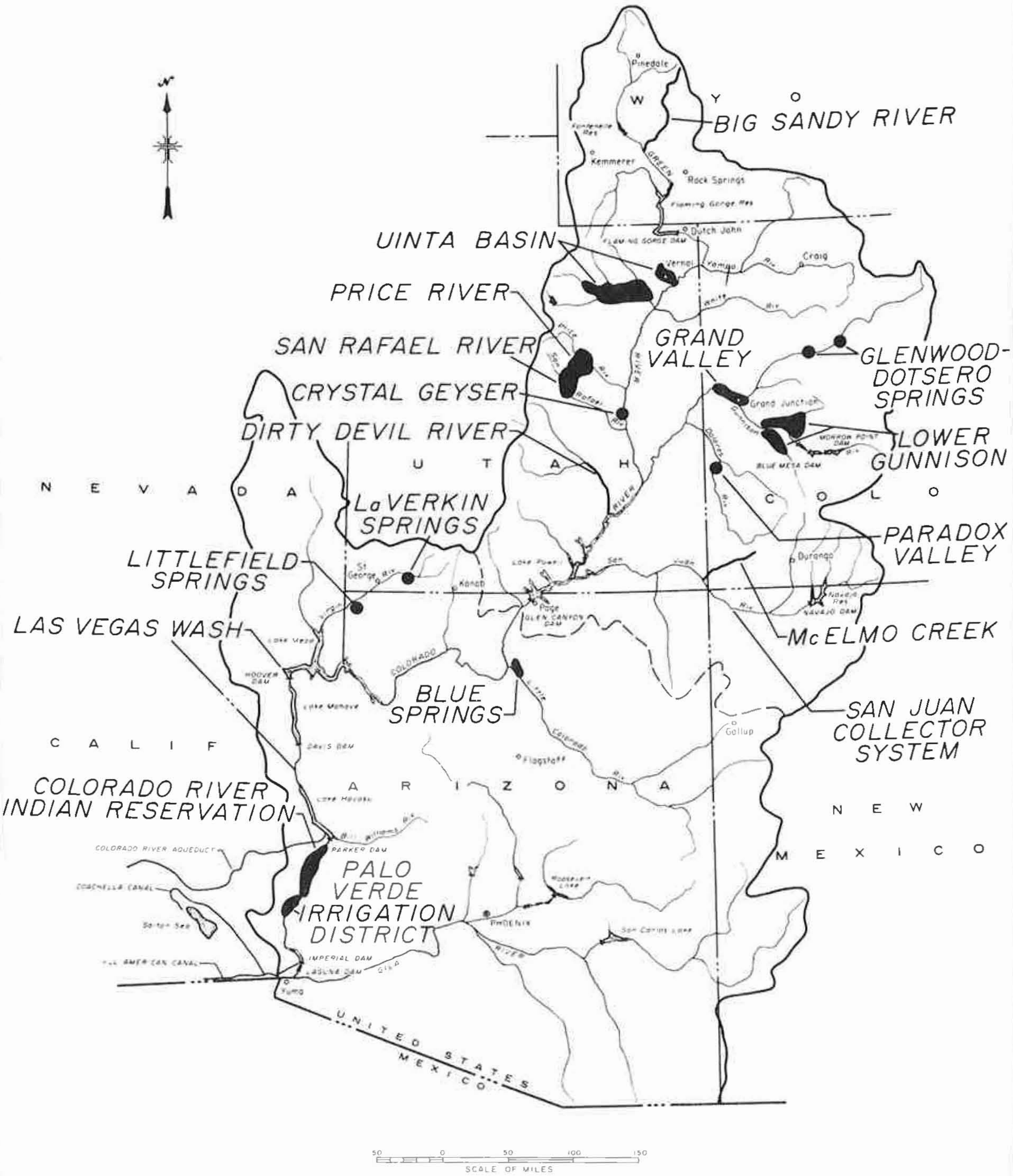
In the physical area, the relative proportion of salinity attributable to various sources such as natural springs, natural solute erosion, irrigation, evaporation, out-of-basin export, and municipal and industrial uses have been identified only in a preliminary manner. For example, all irrigation projects are assumed to participate in salt loading the river system. Recent studies, however, suggest that irrigation under some conditions may actually remove salts from the system. Also, various portions of the basin are remote. Data-gathering in these areas has been difficult and the historic data base has not always been adequate to provide reliable assessments of the impact of various water uses. The program is therefore developing a reliable data base.

Complex social questions arise with respect to value judgments involving salinity goals, environmental impacts of salinity control, accounting for the water losses that would be attributable to salinity control, and cost sharing. The latter is particularly important since most of the entities being impacted by the rising salinity levels are located in or divert from the lower portions of the basin, while most of the salinity originates in the upper portions of the basin.

With respect to the economic dimensions, the damages and benefits have not been fully evaluated. A major study effort in this area is now underway. The data used in determining the benefits in the status report show a wide range in the salinity damage estimates. The value used in evaluating the benefits of the alternatives in this report represents the best single estimate to date but needs verification and/or improvement through continuing analysis. As economically viable alternatives are identified, important legal questions are expected to arise. An evaluation of the institutional and legal setting impacting on salinity control in the Colorado River Basin is nearing completion.

Another major investigative area involves identifying acceptable salinity levels. Under provisions of Public Law 92-500 (1972 Amendments to the Federal Water Pollution Control Act), the Environmental Protection Agency has initiated action toward establishment of salinity standards for the Colorado River System. Salinity standards may well be based upon information on the economic costs of salinity and the economic viability of attaining salinity reduction. As a result of the Enforcement Conference, priority was given to accelerating the investigations at LaVerkin Springs, Paradox Valley, Grand Valley, Las Vegas Wash, and Crystal Geyser. The basin states have stressed that the efficacy of projects such as these in controlling salinity needs to be proved as part of the standard-setting process. More detailed information is thus needed on the sources and behavior of salts in the geochemical cycle of the Basin to help assure meaningful standards.

In summary, this status report is intended to be used for information purposes only, and to indicate the incomplete nature of various alternatives. Considerable work remains to be done over the remaining 8 years of this 10-year program. The investigations are yet to disclose the desirable salinity level, an equitable cost-sharing arrangement, river management and operational procedures, and the feasibility and prioritization of potential salinity control measures. It is hoped that concerned State, local, and Federal entities will analyze findings and provide helpful guidance in the continuing prosecution of the program.



LOCATION OF UNITS - CRWQIP

CHAPTER I. SUMMARY

SCOPE OF PROBLEM

The increase of salinity in the Colorado River is not a new or unique situation in the history of western water resources. Water quality changes in the river were recognized as early as 1903. Today, the salinity problem of the Colorado River is viewed as the forerunner of similar problems of other western rivers such as the Rio Grande, Arkansas, and Platte which are all affected in different degrees by increasing salinity levels.

In geographical terms, the majestic Colorado River is one of the most diverse river basins in the world. The 1,400-mile-long river originates in the Rocky Mountains and flows through scenic canyons and desert vistas to accommodate drainage from parts of seven western states and Mexico.

In its journey to the Gulf of California, the river carries a salinity burden of about 10 million tons annually. About one-half of the salt concentration arises from natural sources, the other half from man's use.

The river water is used and reused several times during its journey, reducing the available water supply and increasing salinity along the way. In overall terms, the high salinity levels in the lower river reaches adversely affect nearly 10,000,000 people and about a million acres of fertile, irrigated farmland. Salinity concentrations are expected to have little adverse impact on instream uses such as recreation, hydroelectric power generation, and fish and wildlife. Serious economic impacts, however, are expected in the municipal, industrial, and agricultural sectors. Recent studies by the Bureau of Reclamation have shown annual economic losses ranging from $194,000 to $395,000 per mg/l increase in salinity at Imperial Dam. Using an annual economic loss value of $230,000 per mg/l increase, the total damages attributable to salinity in the Colorado River system for 1973 are about $53 million. By the year 2000, using the same criteria, these damages to the total regional economy could reach about $124 million per year if water resource development continues and no salinity reduction measures are instituted.

Salinity levels in the Colorado River now range from less than 50 mg/l at the headwaters to average concentrations of about 850 mg/l at Imperial Dam. Projected concentrations of total dissolved solids at Imperial Dam for the year 2000 range from 1,160 mg/l to about 1,300 mg/l if no salinity control measures are undertaken.

The salinity problem in the Colorado River has been the object of several past studies and investigations. Various aspects of the problem and control measures have been pursued by the Bureau of Reclamation, U.S. Geological Survey, Environmental Protection Agency (and its predecessor agencies), Water Resources Council, Colorado River Board of California, and several universities. Studies spanning several years have traced historic salinity levels and flows, sources of salt loading, and the nature and magnitude of damages and potential control measures. The largest portion of the mineral burden and water supply is found to originate in the Upper Basin.

The 1972 EPA Enforcement Conference on the Pollution of Interstate Waters of the Colorado River initiated new efforts to establish an overall salinity control policy for the river. The seven basin state conferees and Federal agency representatives concluded that such a policy would have as its objective the maintenance of salinity concentrations at or below levels presently found in the lower main stem while the Upper Basin continues to develop its compact-apportioned waters.

Another related matter highlighting the need for basinwide salinity controls is a recently executed agreement with Mexico in an effort to find a permanent, definitive, and just solution to the international salinity problem with Mexico. Under the agreement, water delivered to Mexico shall have an average annual salinity of no more than 115 mg/l (plus or minus 30 mg/l) over the average annual salinity of waters arriving at Imperial Dam. This requirement is to become effective upon the authorization of Federal funds to construct works necessary to achieve the limited differential in salinity. Should the river salinity further increase as forecasted, the salinity level of water delivered to Mexico would increase in corresponding amounts.

Another recent institutional consideration in salinity control is recognized in Public Law 92-500. The 1972 "Federal Water Pollution Control Act Amendments" have been interpreted by the EPA to require numerical salinity standards on the Colorado River. Accordingly, the seven basin states have been requested to undertake studies and negotiations to develop such standards and detailed plans of implementation. Moreover, the law provides that by 1977, the "best practicable" water pollution control technology shall be applied to carry out proposed control measures on the river.

In the final analysis, however, the overall salinity problem cannot be divorced from planned future development of the basin's water resources and the resulting water demands that are expected to exceed its dependable supply. Thus, the overriding issue of the Colorado River involves both the interrelated matter of future water depletions and deteriorating water quality. Moreover, the rapid onset of the energy crisis is expected to result in accelerated consumptive use of Colorado River water in order to support oil shale development, electric power generation, and coal development and conversion.

Subsequent energy development in the basin is expected to directly affect water quality and consequently emphasizes the need to implement an effective salinity control program.

In broad context, the salinity problem has a multitude of complex factors ranging from natural hydrologic variations and manmade changes over time to international relations and institutional constraints.

SALINITY ISSUE

There is no single, encompassing solution to the salinity problem. A salinity control program should be regarded as one element of a comprehensive plan of management for the water resources of the Colorado River Basin. Other elements requiring definition and possible implementation to optimize the use of the basin water resources are new management techniques, legal and institutional changes, and the planning and control of interrelated structures.

The Colorado River Water Quality Improvement Program is a 10-year investigational program of the Bureau of Reclamation aimed at evaluating the means by which the salinity control goals can be most efficiently attained from the standpoint of cost effectiveness and time. Current technology and management skills were examined to evaluate the salinity control measures. From this, initial emphasis was placed on evaluating salinity impacts from irrigation, diffuse, and point sources. Within this array, nonstructural measures such as improving irrigation efficiency, river system management, water system management, and utilizing return flows are being given prime consideration. Other techniques such as weather modification, geothermal resources, desalting sea water, land and vegetation management, and wastewater utilization are not as advanced and are undergoing additional research and development to identify their prospects for water quality improvement.

The most promising near-term salinity control measures are improved irrigation efficiencies and water systems management. There are no significant structural requirements associated with these techniques and therefore no large capital investments. The initial costs of training personnel, developing and adapting computer programs to the service areas, and establishing irrigator cooperation are the major costs of the Irrigation Management Services Program. These nonstructural costs are completely covered by the investigational funding of these units. The investigation schedule for these units anticipates that the local water user organizations will assume operation and funding for the IMS activities at the end of the developmental period.

Alternatives have been evaluated in certain areas of the Colorado River Water Quality Improvement Program and have been included in the Status of Investigations grouping. Table 1 summarizes the overall control effects, benefits, and cost effectiveness of the selected alternatives.

The status of other important investigations and research studies are also included in this report. These investigations require additional time and effort to close data gaps and fully evaluate future potential. A brief resume of the analytic studies, the investigations, and research studies based on the best information available follows:

ECONOMIC AND OTHER ANALYTIC STUDIES

ECONOMIC EVALUATION OF WATER QUALITY

Two studies have been made to quantify the impact of salinity increases on the water uses of the Basin. The results are available but they are of a tentative and preliminary nature. Further study and analyses of the findings is continuing. A conclusive evaluation of control measures is dependent on these efforts.

INSTITUTIONAL AND LEGAL REVIEW

An institutional and legal review of Federal law, State laws, power and water contracts, an international treaty, and a U.S. Supreme Court decree has been completed and a report of the findings is being prepared. This analysis will identify the constraints on the program and a legal setting within which salinity control measures can be more effectively pursued.

Table 1

ESTIMATED POTENTIAL EFFECTS AND COSTS–SELECTED INVESTIGATIONS UNITS[1]

Units	Present salt loading (1,000 tons/yr)	Estimated reduction (1,000 tons/yr)	Effect at Imperial Dam (mg/l)	Annual[2] benefits ($1,000,000)	Construction cost ($1,000,000)	Annual OM&R cost ($1,000,000)	Total annual[3] equivalent cost ($1,000,000)	Cost effectiveness	
								(dollars/ ton)	($1,000/ mg/l)
Paradox Valley	200	180	–16	3.1-6.3	16.0	0.4	1.6	9.00	100
Grand Valley	600	200	–19	3.7-7.5	[4] 59.0	[5] 0.0	4.9	24.00	258
Crystal Geyser	3	3	– 0.3	0.06-0.12	0.5	0.003	0.03	10.00	100
Las Vegas Wash									
Desalting Alternative	208	138	–13	2.5-5.1	31.7	2.9	5.3	38.00	408
Evaporation Alternative	208	131	–12	2.3-4.7	49.6	0.2	4.0	30.00	333
LaVerkin Springs	109	103	– 9	1.7-3.6	20.0	1.8	3.2	31.00	356
Total or average	1,120	617-624	–57	11.1-22.5	127-145	2.4-5.1	13.7-15.0		

[1] The potential costs have been shown without implying the source of financing and repayment.
[2] Direct plus indirect benefits.
[3] Includes interest during construction at 6-7/8 percent.
[4] Does not include cost of onfarm improvements which are unknown at this time.
[5] The O&M cost of Irrigation Management Services (estimated $240,000) will be offset by a reduction in distribution system O&M.

COLORADO RIVER MATHEMATICAL MODELS

Two computerized mathematical models have been developed for use in the Colorado River Water Quality Improvement Program. The first of these models is salinity oriented and serves as an accounting system for determining the effect of salt loading at various points on the surface water system. The more comprehensive river basin model will simulate both quantity and quality conditions of the river system including interaction of surface water and ground water.

STATUS OF INVESTIGATIONS

PARADOX VALLEY UNIT, COLORADO

Paradox Valley contributes about 200,000 tons of salt per year to the Dolores River in southwestern Colorado. A control project would reduce this contribution about 180,000 tons per year resulting in a reduction of the salinity concentration at Imperial Dam of about 16 mg/l.

Investigations started in FY 1972 and a feasibility report is scheduled for completion in FY 1975. Ground-water observation wells have been drilled and a resistivity study completed to determine the fresh water/brine interface and the geologic formations of the valley near the river. A pump test well has been drilled and the pump testing was conducted in October through December of 1973.

Based on data developed at this time, one alternative would be to lower the fresh water/brine interface by pumping wells along the Dolores River to prevent the brine from entering the river. The estimated pump discharge of 5-8 cfs would be transmitted via pipeline to an evaporation and salt storage reservoir on the West Fork of Dry Creek about 20 miles to the southeast.

GRAND VALLEY BASIN UNIT, COLORADO

The total quantity of salt contributed by the Grand Valley Basin is about 600,000 tons annually. Alternatives under investigation include irrigation management services and irrigation systems improvement.

There are about 76,000 acres irrigated in the Grand Valley area of western Colorado. Irrigation management services were started in 1972 with about 1,000 acres on 46 separate farms spread throughout the irrigated area. In 1973, the program was expanded to 7,200 acres owned by 120 farmers. Early results indicate that higher efficiencies are being obtained on some sugar beet fields. The planned operations include collection and analysis of yield reports for sugar beets, malting barley, and other crops.

During 1973, salinity data base was increased by adding ground-water wells, and collecting soil and water samples. An intense monitoring of one isolated area will begin in 1974. The irrigation management services are scheduled for continuation through FY 1977 at which time the water users are expected to asuume control of the operation.

An investigation is underway to determine the best methods of increasing water delivery efficiency. The majority of the valley canals were built at an early date and operated by private developers and basic data for these systems such as maps, canal sizes, lengths, acreage served, cropping patterns, and consumptive use and requirements were lacking. Therefore, a good deal of field data had to be collected before an adequate system analysis could be made. Because many different irrigation companies are involved, the valley has been divided into 12 systems. Data have been collected and tabulated on these systems and designs and estimates have been prepared for several of them. Major items that will be pursued are alternate methods of delivery, system water requirements based upon projected land use patterns, a complete hydrogeologic study of the valley, and evaluation of the alternatives for economic benefit to the local area and downstream salinity impacts. The studies are scheduled for culmination in an appraisal report in FY 1975. The combination of water systems improvement and irrigation management services could result in a reduction of about 200,000 tons of total dissolved solids to the Colorado River and a salinity concentration reduction of about 19 mg/l at Imperial Dam.

CRYSTAL GEYSER UNIT, UTAH

The Crystal Geyser, an abandoned oil test well, located 3.5 miles south of Green River, Utah, contributes 200 acre-feet of water and 3,000 tons of salt to the Green River annually. Control of this source would reduce the salinity at Imperial Dam by about 0.3 mg/l. The saline water erupts in the form of a geyser at 5-hour intervals due to carbon dioxide accumulations.

The feasibility investigation of this unit was conducted by Brigham Young University through a contract with the Bureau of Reclamation. A feasibility report and environmental assessment are in the final stages of completion. One alternative would be to build a wall or dike around the points of eruption to collect the discharges and then convey the water by pipeline to an evaporation pond some 3 miles away. Two alternatives will be presented for construction of the retaining dike. The less expensive of the two would use a concrete wall for impounding the water at the geyser site as compared to a more costly but more esthetically pleasing soil-cement dike in the second plan.

LAS VEGAS WASH UNIT, NEVADA

Las Vegas Wash serves as a surface drain for all domestic, municipal, and industrial wastewaters from Las Vegas Valley. The average annual discharge from the Wash to Lake Mead is about 38,000 acre-feet which carries approximately 208,000 tons of dissolved solids. Because of the rapidly increasing population of the valley, the annual discharges of water and salt are expected to increase in the next few decades.

One alternative would collect ground-water flows at a natural "barrier" with a grouted curtain wall and a series of perforated pipes. The collected discharges could be pumped to a nearby reverse osmosis desalting plant. Manmade surface flows in the Wash would be diverted and conveyed around the ground-water collection site. The product water from the desalting plant would be joined with the surface flows for invalley use or release to Lake Mead. The brine residue would be placed in a lined evaporation pond near the project site or pumped to Dry Lake northeast of Las Vegas for evaporation. Other alternatives such as export to Dry Lake for total evaporation are still under investigation.

It is estimated that the Las Vegas Wash Unit would remove 138,000 tons of salt per year from the Colorado River System resulting in salinity reductions of about 13 mg/l at Imperial Dam.

A special report showing possible solutions to the problem was completed in January 1974. Feasibility investigations on the Las Vegas Wash Unit are scheduled through FY 1976.

LaVERKIN SPRINGS UNIT, UTAH

The LaVerkin Springs are located in a 1,800-foot-long reach of the Timpoweap Canyon of the Virgin River in southwestern Utah. The springs discharge about 8,300 acre-feet of water and 109,000 tons of salt each year. A feasibility study has been prepared that shows 103,000 tons of this salt could be removed annually which would reduce total dissolved solids concentrations at Imperial Dam by about 9 mg/l.

A feasibility report on the LaVerkin Springs Unit is undergoing an inhouse review at the present time. One alternative calls for the construction of an upper diversion dam upstream from the springs to divert the normal riverflows around the area of the springs. The lower control dam would be located just below the springs to form a pool from which the springs' flows would be pumped to the LaVerkin Desalting Plant. The average inflow to the reverse osmosis desalting plant would be 11.5 cfs through a 21-inch concrete pressure pipe. It will be necessary to pretreat the feedwater in the form of calcium reduction, cooling, and filtration. A desalting alternative might consist of three stages of vessels containing semipermeable membranes. Since the recovery of some water in each stage would increase the brine concentration passed to the succeeding stage, increasingly higher pressures would be required to effectively recover additional water. A product water of 8.3 cfs would be recovered at a salinity concentration of 500 mg/l. A brine discharge of 2.8 cfs would be at a concentration of 33,000 mg/l.

The product water would be returned to the Virgin River through a 1,600-foot-long pipeline. A 12-inch pipeline almost 19,000 feet long would be used to pump the brine to a 440-acre evaporation pond formed by diking a natural depression about 4 miles north of Hurricane, Utah. The dikes would be rolled earthfill embankments lined with 10-mil polyvinyl chloride. The entire pond would be lined with 10-mil polyvinyl-chloride sheeting covered with 12 inches of earth.

PALO VERDE IRRIGATION DISTRICT UNIT CALIFORNIA

There are about 91,400 acres irrigated in the locally developed district along the Colorado River in California. The irrigation of the district lands results in a salt pickup of about 148,000 tons of salt per year. The irrigation management services and water systems improvement programs should result in a reduction of about 23,000 tons in dissolved solids per year. The corresponding reduction in salinity concentration at Imperial Dam is about 3 mg/l.

Also a private power company is investigating the potential of using return flows from the Palo Verde drain for nuclear power plant cooling. The diversion of such saline flows could result in significant salinity reductions at Imperial Dam.

COLORADO RIVER INDIAN RESERVATION UNIT ARIZONA–CALIFORNIA

The Colorado River Indian Reservation is located on both sides of the Colorado River on the Arizona-California border downstream from Parker Dam. There are about 60,600 acres irrigated at the present time and this is projected to increase to 93,000 acres by 1980. These lands are estimated to contribute 30,000 tons of salt annually to the Colorado River. It is anticipated that this salt load could be reduced by 7,000 tons through the irrigation management services and the water systems improvement programs which would result in a salt concentration reduction of about 1 mg/l at Imperial Dam.

UINTA BASIN UNIT, UTAH

There are about 170,000 irrigated acres in the Uinta Basin of northwestern Utah. The area contributes about 450,000 tons of salt to the Colorado River system each year. It is estimated that the combined irrigation management services and water systems improvement programs would reduce the salt contribution by 100,000 tons per year with a salinity reduction of about 9 mg/l at Imperial Dam. The investigation program is scheduled for completion in fiscal year 1978.

LOWER GUNNISON BASIN UNIT, COLORADO

The lower Gunnison basin in west-central Colorado contributes about 1,100,000 tons of dissolved solids annually. There are about 160,000 irrigated acres in the subbasin. Investigations concerning water systems improvement will be initiated in conjunction with the irrigation management services program in 1974. Some investigations have been conducted and will continue to determine needed improvements on the Uncompahgre Project, a major development in the area.

LITTLEFIELD SPRINGS UNIT, ARIZONA

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 6 cfs and contribute about 17,000 tons of dissolved solids to the river system annually. Feasibility investigations started in 1973 and are scheduled to be completed in FY 1976.

GLENWOOD-DOTSERO SPRINGS UNIT COLORADO

The Glenwood-Dotsero group of springs discharge to the Colorado River at opposite ends of Glenwood Canyon in Colorado. These springs are estimated to contribute 25,000 acre-feet of water and 500,000 tons of salt to the river annually. The removal of 200,000 tons of salt each year would result in the salinity concentration at Imperial Dam being reduced by about 19 mg/l.

Investigation was initiated in April 1972 by locating and identifying 18 separate springs and subsequently measuring the flow and analyzing the quality of them monthly. Several alternatives have been considered to treat or dispose of this highly saline water including deep well injection, plugging springs, evaporative ponds, and several methods of treatment including desalting.

BLUE SPRINGS UNIT, ARIZONA

These springs rise in the Little Colorado River about 13 miles upstream from its confluence with the Colorado River. The springs are the largest point source of salinity in the entire system with an output of 220 cfs and 550,000 tons of salt per year.

Investigations of a control program are not encouraging. The Little Colorado River is entrenched within a steep canyon at a depth of 2,500 feet at this point. The comparatively large flow, the scenic setting, and the special ethnic value to the local Indians are additional complicating factors. Consequently these considerations have led to the termination of investigations.

BIG SANDY RIVER UNIT, WYOMING

The Big Sandy River contributes approximately 180,000 tons of dissolved solids annually to the Green River in Wyoming. Most of this salt enters the Big Sandy from numerous seeps in a reach of the river from Simpson Gulch to Gasson Bridge. It is estimated that about 80,000 tons could be removed by treatment of the more saline flows.

Because of the low winter temperatures, it may be possible to apply natural freezing methods to treat the water. A pilot demonstration of this method in the vicinity of Gasson Bridge is underway through cooperation with the University of Wyoming. This pilot operation will supply needed information regarding the capability of freezing, effectiveness of the sprinkler equipment and configuration for best ice formation, the amount of salt that can be removed, quality of the product water, cost per ton of salt removal, and environmental impact of the process. A feasibility report is scheduled for fiscal year 1978.

McELMO CREEK UNIT, COLORADO

McElmo Creek is tributary to the San Juan River near the Colorado-Utah State line. Although the drainage area is only 350 square miles, the salt loading is estimated to be 130,000 tons per year of which about 40,000 tons could be removed by selective withdrawal and evaporation or desalting. The resulting effect at Imperial Dam is a concentration decrease of about 4 mg/l.

Data collection began in 1972 and includes measurements that will identify the magnitude and effects of return flows from the irrigated areas near Cortez. Recently, consideration of mitigation measures for the Dolores Project has led to the investigation of a possible impoundment and evaporation of Mud Creek, a tributary of McElmo Creek. Feasibility studies for McElmo Creek Unit are to be completed in fiscal year 1978.

PRICE, SAN RAFAEL, AND DIRTY DEVIL RIVER UNITS, UTAH

The Price, San Rafael, and Dirty Devil Rivers originate in the mountains of the Wasatch and Aquarius Plateaus and are tributary to the Green and Colorado Rivers in east-central Utah. Drainage areas contain 1,500, 1,670, and 4,200 square miles for the Price, San Rafael, and Dirty Devil Rivers, respectively. The estimated total dissolved solids contributed by the Price, San Rafael, and Dirty Devil Rivers are 240,000, 210,000, and 200,000 tons, respectively.

The estimated annual removal of salt by proposed control programs are 100,000 tons on the Price River and 80,000 tons each for the San Rafael and Dirty Devil Rivers. Salinity concentrations of the Colorado River at Imperial Dam would be reduced by an estimated 9 mg/l for the Price River and 7 mg/l for each of the San Rafael and Dirty Devil Rivers.

Investigations thus far have included field surveys, data gathering, and tentative formulation of control plans to remove the concentrated flows from these streams.

Feasibility reports are scheduled for fiscal year 1978.

UTILIZING RETURN FLOWS

The potential of treating or converting irrigation return flows to other beneficial consumptive uses such as thermal powerplant cooling and coal gasification within the basin to avoid returning them to the river system is being examined. The San Juan area will be studied in FY 1974 and 1975 to be followed by the Grand Valley area in 1976 and 1977. Utilization of return flows will be investigated in the lower main stem during the fiscal 1974-78 period.

RESEARCH

Research is underway on onfarm irrigation efficiencies, desalting by natural freezing, and modeling for predicting salt and nutrient loading. A cooperative program with the Agricultural Research Service is underway in the Grand Valley area to determine the optimal irrigation water application rates to maintain crop yields while reducing salt-laden return flows.

Considerable other salinity research has been stimulated by the CRWQIP. This research is providing inputs to the program but is being funded through other sources. The Western Directors of the Agricultural Experiment Stations have established a regional research project entitled "Salinity Management in the Colorado River Basin." This will involve cooperation with the USDA. The research is aimed at developing and evaluating methods for understanding and managing salinity from agricultural and diffuse natural sources in the Colorado River Basin.

The Office of Water Resources Research (OWRR) is also sponsoring a regional research project on salinity. Through OWRR, several Colorado River Basin States Water Resources Research Institutes are investigating the economic aspects of salinity control. The research is directed toward evaluating damages caused by salinity. The Bureau of Reclamation is participating and cooperating in the research effort.

A special study has been completed of the potential application of ion exchange desalting to the total flow of the Colorado River System. The intent of this study was to determine the possibilities of controlling salinity at the diversion point from the river rather than at its source. The study was supported by a 6-week operation of an ion exchange pilot plant on the Colorado River below Davis Dam. The 5,000-gpd plant successfully reduced 750 ppm water to 550 ppm product water. Future studies will concentrate on smaller installations having plant capacities similar to the present major diversions. A report covering this study was completed in 1972.

CHAPTER II. THE SALINTY ISSUE

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 esthetic value to the Nation. The water is used for irrigating crops, producing energy, providing recreation, sustaining livestock and wildlife, supporting industry, and supplying the common daily needs of people. It is the source of water for cities within the basin and larger metropolitan areas outside the basin. A large variety of crops, providing a needed diversity to the national diet, are irrigated by its waters both within and outside the basin. But the concentration of dissolved solids in the river, now among the highest of the great rivers of North America, is increasing. The increase will further impair the usefulness of the water.

Rising high in the Rocky Mountains, the Colorado River flows for most of its length through arid and semiarid regions of the United States and Mexico. The great river and its tributaries have cut into mountains and plateaus, formed alluvial valleys, carved magnificent canyons, and produced a highly productive delta. In the process, its waters accumulate the solution products of erosion and weathering—from headwaters to mouth, a distance of nearly 1,400 miles, the salinity progressively increases.

The river drains 242,000 square miles—1/12 the conterminous area of the United States—and 2,000 square miles in Mexico. The basin includes parts of seven states—southwestern Wyoming, western Colorado, parts of Utah, Nevada, New Mexico, nearly all of Arizona, and a small section of California. From this area, it carries a salinity burden of 10 million tons annually. Each square mile above the Grand Canyon contributes an average of about 70 tons of salt to the river each year. The salt loading arises from both natural and manmade sources. The water is used and reused several times along its length causing the volume of available water to decrease while the salinity increases. The potential demands on the river exceed its dependable supply. The major overriding issue on the Colorado River involves the interrelated matter of inadequacy of water supply to meet all proposed uses and deteriorating water quality.

SOURCES OF SALINITY

In any river system, salinity concentrations arise from a salt loading effect and a salt concentrating effect. The salt loading may be regarded as the pickup of salt due to mineral weathering and dissolution of the soluble salts residing in soil and substrata. The salt concentrating is due to the evapotranspiration of the water carrying a finite salt load or the export of high-quality water out of the basin. Generally, the application of irrigation water results in increased salt concentrations because of both loading and concentrating. The evaporated or transpired water is free of salt, hence, the ground-water return flows carry the total salt burden. Under some conditions, however, salts may be precipitated and stored in the soil. These processes operate through the geochemical cycle depicted in Figure 1. As water is evaporated from the ocean or other free water surfaces, alterations in the composition and concentration of the dissolved contituents begin to occur and continue as the concentration progressively increases during movement through the cycle.

While this process adds a large variety of dissolved matter to the water, only 10 elements made up about 99 percent 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 Colorado River water is made up of the cations: calcium, magnesium, and sodium; and the anions: sulface, chloride, and bicarbonate. These, plus minor amounts of other dissolved constituents, are commonly referred to as salinity, "salt," dissolved solids, or dissolved mineral content.

Studies of the operation of the geochemical cycle suggest that about half the salinity concentration in the waters at Hoover Dam is derived from natural sources and the remaining half from manmade uses. The order of magnitude from greatest to least is: natural sources, irrigation, reservoir evaporation, out-of-basin export, and municipal and industrial sources.

SALINITY LEVELS

HISTORIC AND MODIFIED CONDITIONS

The long-term 1941-1970 historic average annual salinity concentration of the Colorado River at its headwaters is less than 50 mg/l. At Imperial Dam, the last major diversion point in the United States, the concentration is 757 mg/l. Modifying this historic condition to reflect all upstream existing projects to be in operation for the full period 1941-1970 would again show a concentration of less than 50 mg/l at headwaters and a value of 851 mg/l at Imperial Dam.

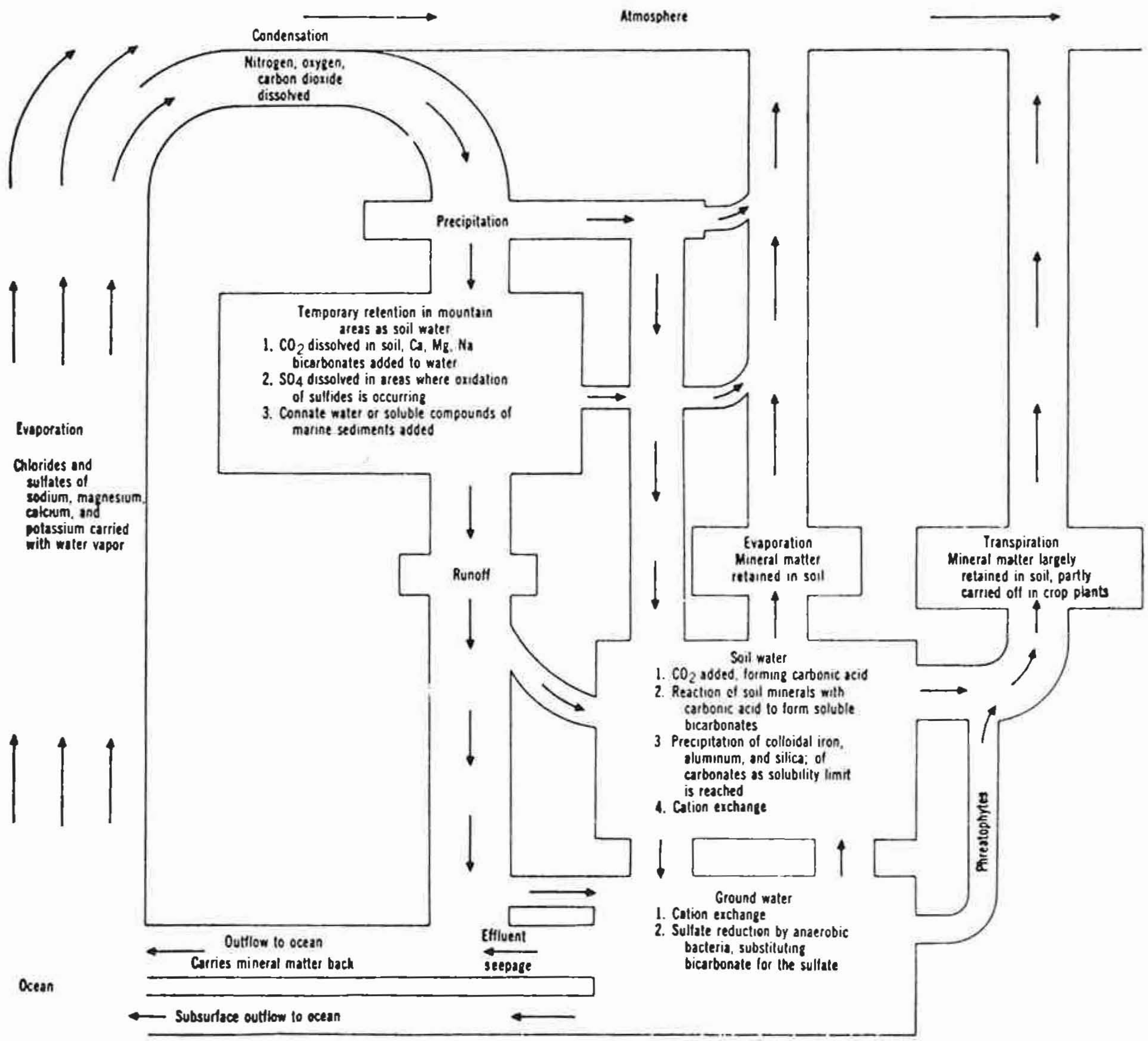


Figure 1. Geochemical cycle of surface and ground waters. (USGS)

Values for intermediate locations in the river are shown in Table 2.

Table 2

HISTORIC AND PRESENT MODIFIED
QUALITY OF WATER
COLORADO RIVER–AVERAGE VALUES
1941-1970

Location	Concentration (mg/l)	
	Historic	Modified
Glenwood Springs, Colorado	271	310
Cameo, Colorado	406	443
Cisco, Utah	613	662
Lees Ferry, Arizona	556	609
Grand Canyon, Arizona	617	669
Hoover Dam, Arizona-Nevada	690	745
Imperial Dam, Arizona-California	757	851

PHYSICAL INTERPRETATION

Current water quality criteria[1] specify that detrimental effects will usually be noted on crops when concentrations in the irrigation water exceed 500 mg/l of total dissolved solids (TDS). The suggested guidelines for salinity in irrigation water are:

Table 3

SUGGESTED GUIDELINES FOR SALINITY
IN IRRIGATION WATER[1]

Crop response	TDS (mg/l)
Water for which no detrimental effects will usually be noticed	0-500
Water which can have detrimental effects on sensitive crops	500-1,000
Water that may have adverse effects on many crops and requiring careful management practices	1,000-2,000
Water that can be used for salt-tolerant plants on permeable soils with careful management practices	2,000-5,000

A very complex relationship is involved in relating salinity of irrigation water to crop yield. Major factors involved are soil conditions, crop type and variety, drainage, climate, and cultural and irrigation practices. Many high-valued crops are grown with Colorado River water. Generally, such crops have a low salt tolerance thus yield is repressed by the salinity.

With respect to criteria for public water supplies, desirable levels are specified as less than 200 mg/l and the recommended level should not exceed 500 mg/l. From Table 2 it is apparent that some present salinity levels exceed these values.

It should be emphasized that when time intervals are reduced to a monthly basis, wide fluctuations can be expected. Under historic conditions at Imperial Dam, the 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 to 1970 have had average concentrations above 960 mg/l. Moreover, under present conditions of depletion, the mean monthly concentration of 1,000 mg/l at Imperial Dam would have been exceeded in 40 months during the period 1941-70. Such monthly salinity values have greater significance than long-term means in relation to impacts on land and crops, water quality standards, and water treatment.

PROJECTED SALINITY LEVELS

The salinity in the Colorado River has been the object of longstanding concern and study. Studies by various agencies converge to one simple fact—salinity will increase with continued use and development of the available water supply unless comprehensive, basinwide water quality management planning is implemented and supported by the installation of structural and nonstructural measures. Projected estimates by various entities are presented in Table 4. These estimates assume that no measures are undertaken to control salinity.

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 at Imperial Dam.

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, many irrigators are resorting to special practices in using the water to grow salt-sensitive crops. Some areas have adverse drainage conditions which would be magnified if higher

[1] "Water Quality Criteria" Report of the National Technical Advisory Committee to the Secretary of the Interior, USDI, April 1968.

Table 4

PROJECTED CONCENTRATIONS OF TOTAL DISSOLVED SOLIDS (mg/l) AT IMPERIAL DAM
(Average annual values)

Source	Year				
	1980	2000	2010	2020	2030
EPA	1,060	–	1,220	–	–
CRBC	1,070	1,340	–	–	1,390
WRC	1,260	1,290	–	1,350	–
USBR	930	1,160	–	–	–

EPA: Environmental Protection Agency, 1972
CRBC: Colorado River Board of California, 1970
WRC: Water Resources Council (Lower Colorado Region Comprehensive Framework Study), 1971
USBR: Bureau of Reclamation, 1973

salinity water were used. Municipal and industrial users are faced with considerable expense due to water quality. Allowing the salinity of the river to increase will result in additional economic impacts.

ECONOMIC IMPACTS

Economic detriments can be computed using the projected increases in salinity, under the assumption that a control program will not be installed. The adverse effects would be expressed primarily in the agricultural, municipal, and industrial uses. Few adverse impacts on instream uses such as recreation, hydroelectric power generation, and propagation of aquatic life are expected. The detriments in agriculture would arise from one or a combination of the following: decreased crop yields, increased leaching requirements, increased management costs, and application of various adaptive practices such as changes in crop patterns, improved drainage systems, and plantings on sloping beds. In the municipal and industrial uses, the detriments arise primarily from increased water treatment costs, accelerated pipe corrosion and appliance wear, increased use of soap and detergents, and decreased palatability of drinking water.

Based on the foregoing kinds of impacts, the total and direct damages now being experienced and those contemplated if no salinity control measures are installed have been determined and the findings are presented in Table 5. These figures are the relevant damages, i.e., those caused by salinity levels in excess of threshold values. The threshold values assumed for M&I and agriculture are 500 and 750 mg/l, respectively.

Table 5

TOTAL AND DIRECT DAMAGES ATTRIBUTABLE TO SALINITY IN THE COLORADO RIVER SYSTEM

Year	Total	Direct
1973	$ 53,000,000	$ 49,000,000
1980	72,000,000	64,000,000
1990	111,000,000	96,000,000
2000	124,000,000	107,000,000
2010	147,000,000	126,000,000

The total damages reflect the impact on the entire regional economy while the direct damages affect only the water users. Damages to water users in Mexico and recreation and fishing uses in the Salton Sea have not been estimated.

Applying present worth factors at 6-7/8 percent to the values from Table 5 indicates the economic magnitude of the salinity problem on the Colorado River. The present value of the future damages amounts to about $1.1 billion for the direct damages and $1.24 billion for the total damages.

PREVIOUS STUDIES AND FINDINGS

The salinity problem in the Colorado River has been the object of many studies and investigations, stemming from the deep concern of the states as expressed during hearings and negotiations with Mexico relating to the 1944 Mexican Water Treaty. California in particular wanted the water quality issue clearly stated to avoid future misunderstanding. This was not accomplished as recent events have shown.

The most relevant studies on salinity in the Colorado River were made 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 concentrate on definition of the salinity problem. 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 report defines the nature and magnitude of the problem and presents a plan for controlling the salinity at or near present levels. The Water Resources Council reports draw heavily on the prior studies, develop estimates of future salinity conditions, and identify potential control measures. Utah State University performed a computer simulation of the hydrologic-salinity flow system in the Upper Colorado River 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 and water supply was found to originate in the Upper Colorado River Basin. The natural sources were thought to be the major contributors to the salinity. Salinity was projected to continually increase 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 No. 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 2.5 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 Environmental Protection Agency), the Bureau of Reclamation in July 1969 completed a report entitled "Upper Colorado River Basin Cooperative Salinity Control Study." The report has been given to the EPA for review and study 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 the 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 annual 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 for water users in California. The report identifies a number of potential salinity control projects which, if constructed, might serve to maintain salinity near present levels. The studies by the Board indicate that unless action is taken to control salinity and with the Upper Basin continuing to develop, the total economic impact in California from salinity increases would be in excess of $40 million a year by the turn of the century.

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 1973. The 1973 report displays the past, present modified, and estimated future quality of the Colorado River at 17 gaging stations for the period of 1941-1970. The future quality condition as used in that 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 745 mg/l and with future known developments, 971 mg/l. At Imperial Dam the comparable estimates are 851 and 1,200 mg/l, respectively, under the same conditions.

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, the university 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 No. 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 Lees Ferry 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 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/l in 1960 and 1970, and 880 and 990 mg/l in 1980 and 2010, respectively. At Imperial Dam, the report estimates 760 and 870 mg/l for 1960 and 1970, and 1,060 and 1,220 mg/l 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 municipal detriments were based on the calculation of additional soap and detergent requirements, only.

The investigation examined three salinity control alternatives: (1) augmentation of basin water supply, (2) basinwide 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/l, and many exceed 1,000 mg/l. The salinity of the supplies affects domestic, industrial, and agricultural uses.

The Colorado River enters the region at concentrations exceeding 500 mg/l, varies between 500 and 900 mg/l at most diversion points, and increases to as high as 1,000 to 1,150 mg/l for very 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)

The 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 should be part of a basinwide 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.

THE EPA ENFORCEMENT CONFERENCE

The Seventh Session of the Conference in the Matter of Pollution of the Interstate Waters of the Colorado River dealt primarily with the salinity issue. The conference was held under the provisions of Section 10 of the Federal Water Pollution Control Act which authorized the EPA Administrator to initiate such a conference when reports or studies show that pollution subject to abatement under the Federal Act is occurring. In this case, the previously described 1971 report by the EPA on "The Mineral Quality Problem in the Colorado River Basin" was used as the backup study. The Conference was held on February 15-17, 1972 and was continued and concluded on April 26-27, 1972.

Conclusions and recommendatons of the enforcement conference were reached unanimously by conferees representing the seven Basin States and the Federal Government. They were:

> "I. It is recommended that: A salinity policy be adopted for the Colorado River System that would have as its objective the maintenance of salinity

concentrations at or below levels presently found in the lower main stem. In implementing the salinity policy objective for the Colorado River System, the salinity problem must be treated as a basinwide problem that needs to be solved to maintain Lower Basin water salinity at or below present levels while the Upper Basin continues to develop its compact-apportioned waters.

"II. The salinity control program as described by the Department of the Interior in their report entitled "Colorado River Quality Improvement Program," dated February 1972, offers the best prospect for implementing the salinity control objective adopted herein. Therefore, it is recommended that:

"(1) to minimize salinity increases in the river, a salinity control program, generally as described in the Interior Department report, be implemented on an accelerated basis;

"(2) the Bureau of Reclamation have the primary responsibility for investigation, planning, and implementing the basinwide salinity, control program in the Colorado River System;

"(3) to accelerate the salinity control program, the Bureau of Reclamation assign a high priority to LaVerkin Springs, Paradox Valley, and Grand Valley water quality improvement projects with the objective of achieving stabilization of salinity levels on the Lower Colorado River at the earliest possible date. The contemplated impact would be to initiate immediate action so as to achieve, by 1977, the removal of 80,000 tons of salt per year from LaVerkin Springs, 180,000 tons per year from Paradox Valley, and 140,000 tons per year from Grand Valley. This would provide a total reduction of 400,000 tons per year and would result in an estimated subsequent reduction of 33 mg/l at Imperial Dam.

"(4) the Office of Saline Water contribute to the program by assisting the Bureau of Reclamation as required to appraise the practicablility of applying desalting techniques; and

"(5) the Environmental Protection Agency continue its support of the program by consulting with and advising the Bureau of Reclamation and accelerating its ongoing data collection and research efforts.

"III. To achieve the salinity policy described herein, the long-range program of the Bureau of Reclamation shall be directed toward achieving reduction of salinity concentrations that would otherwise exist at Imperial Dam to the extent of at least 120 mg/l in 1980, 355 mg/l in 1990, and 405 mg/l in the year 2000.

"The conferees agree that the Bureau of Reclamation's program as submitted in its report "Colorado River Water Quality Improvement Program," dated February 1972, should be considered as an open-ended and flexible program. If alternatives not yet identified prove to be more feasible, they should be included as part of the program, and if elements now included prove not to be feasible, they should be dropped. In addition, it should be recognized that there may be other programs which could reduce the river's salinity. Since present levels are greater than desirable, an effort should be made to develop additional programs that will obtain lower salinity levels.

"The February 1972 report states that the Bureau of Reclamation Mathematical Simulation Model for the Colorado River System will be used to evaluate the Water Quality Improvement Program. This will be an important tool to evalute the program's progress. The results of this evaluation along with the general program progress should be reported annually to the conferees and other interested State agencies."

The recommendations and conclusions of the Enforcement Conference were subsequently approved by the EPA Administrator. On June 9, 1972, Deputy Administrator Robert Fri advised Secretary Morton of the approval in the following letter:

"Honorable Rogers C.B. Morton
Secretary of the Interior
Washington, D.C. 20240

"Dear Mr. Secretary:

"Thank you for the participation of your Department in the seventh session of the conference in the matter of pollution of the interstate waters of the Colorado River and its tributaries (Colorado-Utah-Arizona-Nevada-California New Mexico-Wyoming), held under the provisions of the Federal Water Pollution Control Act on February 15-17, 1972, in Las Vegas, Nevada, and on April 26-27, 1972, in Denver, Colorado. I am enclosing a copy of the summary of the conference which contains the conclusions and recommendations of the conferees.

"The conferees unaminously agreed, and I concur, that the basin-wide salinity control program described by the Department of the Interior in its report, 'Colorado River Quality Improvement Program February 1972,' appears to offer the best prospect for arresting or reducing the salinity increases in the river. This Agency endorses your program for achieving resolution of this salinity problem in furtherance of our mutual goal of water quality improvement. We are prepared to assist to the extent of our available resources.

Sincerely yours,

Sgd/Robert Fri

for William D. Ruckelshaus
Administrator"

Following the conference and in accord with the recommendations, the Bureau of Reclamation began the investigations relating to salinity control.

RELATED MATTERS

The enactment of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) and the conclusion of negotiations with Mexico regarding the control of salinity in waters delivered to Mexico highlight the salinity problems on the river.

AGREEMENT WITH MEXICO

In keeping with President Nixon's objective to find a permanent, definitive, and just solution to the salinity problem with Mexico, accord was reached on August 30, 1973, with the execution of Minute 242 of the International Boundary and Water Commission. The Minute was developed following an intensive study of the problem by former Attorney General Herbert Brownell and a Federal Task Force appointed to assist him. Participation of the Basin States was sought by Mr. Brownell and representatives of the Governors (identified as the Committee of Fourteen), assisted in defining the solution. The key elements of the agreement were:

"1. Referring to the annual volume of the Colorado River waters guaranteed to Mexico under the Treaty of 1944, of 1,500,000 acre-feet (1,850,234,000 cubic meters):

a. The United States shall adopt measures to assure that not earlier than January 1, 1974, and no later than July 1, 1974, the approximately 1,360,000 acre-feet (1,677,545,000 cubic meters) delivered to Mexico upstream of Morelos Dam, have an annual average salinity of no more than 115 ppm plus or minus 30 ppm United States count (121 ppm plus or minus 30 ppm Mexican count) over the annual average salinity of Colorado River waters which arrive at Imperial Dam, with the understanding that any waters that may be delivered to Mexico under the Treaty of 1944 by means of the All American Canal shall be considered as having been delivered upstream of Morelos Dam for the purpose of computing this salinity.

b. The United States will continue to deliver to Mexico on the land boundary at San Luis and in the limitrophe section of the Colorado River downstream from Morelos Dam approximately 140,000 acre-feet (172,689,000 cubic meters) annually with a salinity substantially the same as that of the waters customarily delivered there.

c. Any decrease in deliveries under point 1(b) will be made up by an equal increase in deliveries under point 1(a).

d. Any other substantial changes in the aforementioned volumes of water at the stated locations must be agreed to by the Commission.

e. Implementation of the measures referred to in point 1(a) above is subject to the requirement in point 10 of the authorization of the necessary works.

"2. The life of Minute 241 shall be terminated upon approval of the present Minute. From September 1, 1973, until the provisions of point 1(a) become effective, the United States shall discharge to the Colorado River downstream from Morelos Dam volumes of drainage waters from the Wellton-Mohawk District at the annual rate of 118,000 acre-feet (145,551,000 cubic meters) and substitute therefor an equal volume of other waters to be discharged to the Colorado River above Morelos Dam; and, pursuant to the decision of President Echeverria expressed in the Joint Communique of June 17, 1972, the United States shall discharge to the Colorado River downstream from Morelos Dam the drainage waters of the Wellton-Mohawk District that do not form a part of the volumes of drainage waters referred to above, with the understanding that this remaining volume will not be replaced by substitution waters. The Commission shall continue to account for the drainage waters discharged below Morelos Dam as part of Article 10 of the Water Treaty of February 3, 1944.

"3. As a part of the measures referred to in point 1(a), the United States shall extend in its territory the concrete-lined Wellton-Mohawk bypass drain from Morelos Dam to the Arizona-Sonora international boundary, and operate and maintain the portions of the Wellton-Mohawk bypass drain located in the United States.

"4. To complete the drain referred to in point 3, Mexico, through the Commission and at the expense of the United States, shall construct, operate, and maintain an extension of the concrete-lined bypass drain from the Arizona-Sonora international boundary to the Santa Clara Slough of a capacity of 353 cubic feet (10 cubic meters) per second. Mexico shall permit the United States to discharge through this drain to the Santa Clara Slough all or a portion of the Wellton-Mohawk drainage waters, the volumes of brine from such desalting operations in the United States as are carried out to implement the Resolution of this Minute, and any other volumes of brine which Mexico may agree to accept. It is understood that no radioactive material or nuclear wastes shall be discharged through this drain, and that the United States shall acquire no right to navigation, servitude, or easement by reason of the existence of the drain, nor other legal rights, except as expressly provided in this point.

"5. Pending the conclusion by the Governments of the United States and Mexico of a comprehensive agreement on ground water in the border areas, each country shall limit pumping of ground waters in its territory within 5 miles (8 kilometers) of the Arizona-Sonora boundary near San Luis to 160,000 acre-feet (197,358,000 cubic meters) annually.

"6. With the objective of avoiding future problems, the United States and Mexico shall consult with each other prior to undertaking any new development of either the surface or the ground-water resources, or undertaking substantial modifications of present developments, in its own territory in the border area that might adversely affect the other country.

"7. The United States will support efforts by Mexico to obtain appropriate financing on favorable terms for the improvement and rehabilitation of the Mexicali Valley. The United States will also provide nonreimbursable assistance on a basis mutually acceptable to both countries exclusively for those aspects of the Mexican rehabilitation program of the Mexicali Valley relating to the salinity problem, including tile drainage. In order to comply with the above-mentioned purposes, both countries will undertake negotiations as soon as possible.

"8. The United States and Mexico shall recognize the undertakings and understandings contained in this Resolution as constituting the permanent and definitive solution of the salinity problem referred to in the Joint Communique of President Richard Nixon and President Luis Echeverria dated June 17, 1972.

"9. The measures required to implement this Resolution shall be undertaken and completed at the earliest practical date.

"10. This Minute is subject to the express approval of both Governments by exchange of Notes. It shall enter into force upon such approval; provided, however, that the provisions which are dependent for their implementation on the construction of works or on other measures which require expenditure of funds by the United States, shall become effective upon the notification by the United States to Mexico of the authorization by the United States Congress of said funds, which will be sought promptly."

PUBLIC LAW 92-500

Public Law 92-500 known as the "Federal Water Pollution Control Act Amendments of 1972" has been interpreted by the EPA to mean that numerical standards for salinity on the Colorado River are to be set. Accordingly the seven Basin States have been requested by EPA to undertake studies and negotiations to develop such standards accompanied with a detailed plan of implementation. Moreover the law provides that by July 1, 1977, the "best practicable" water pollution control technology shall be applied followed by the "best available" technology by July 1, 1983. Prosecution of a salinity control program would provide a basis for establishment of numerical standards.

AUTHORIZATION OF INVESTIGATIONS

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 undertake water quality studies and to devise plans for maintenance of suitable salinity levels in the river system. This is provided for in three public laws:

1. Section 15 of the authorizing legislation for the Colorado River Storage Project 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." (P.L. 84-485.)

2. Section 15 of the authorizing legislation of the San Juan-Chama Project and the Navajo Indian Irrigation 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." (P.L. 87-483.)

3. Authorizing legislation for the Fryingpan-Arkansas Project 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. (P.L. 87-590.)

These acts provide authority to the Department of the Interior for basinwide planning of a salinity control program. Implementation of salinity control projects will require congressional authorizations. The responsibility to plan and implement the control program has been entrusted to the Bureau of Reclamation, with the function to be coordinated with other agencies of the Department such as the Office of Saline Water, Office of Water Resources Research, Geological Survey, Bureau of Land Management, Bureau of Indian Affairs, Bureau of Sport Fisheries and Wildlife, Bureau of Outdoor Recreation, and Bureau of Mines. As planning progresses, each of these agencies can be expected to contribute to the comprehensive program for salinity control.

SALINITY INVESTIGATIONS

A salinity control program should be regarded as one facet of a comprehensive plan for management of the total water resources of the Colorado River Basin. Basin water management is the best way to plan and control the interrelated structures and the nonstructural measures to optimize the use and development of the water resources for the good of the people. Under such management, the effects of salinity would be controlled at levels suitable for the many uses to which the water is placed. A program to accomplish this objective would entail evaluation and selection of the salinity control measures that best fit within the basin water management concept.

Potential control measures include control at the source, control at diversion points, altering time pattern of water and salinity discharge, and dilution by augmentation of flow. A 10-year investigation entitled "Colorado River Water Quality Improvement Program" was initiated in 1971 with the specific objective of identifying measures that would maintain salinity concentrations at or below levels presently found in the lower main stem.

The investigation schedule is shown on Figure 2. The investigations are integrated with other programs involving weather modification, geothermal resources, desalting, and the Western U.S. Water Plan. Concurrent feasibility investigations are underway on various irrigation, point, and diffuse sources. The feasibility of collecting saline return flows and converting them to beneficial consumptive use within the basin is also being studied. Related basinwide studies are scheduled to overview relationships between individual control units, assess implications of new technology, and provide guidance to the selection of implementation measures. Cost-sharing and repayment formulas are under study.

The measures currently available for controlling salinity may be categorized as follows:

1. *Point source control* involves salt removal from a localized area contributing an inordinately high salt load to the system.

These sources are generally springs, wells, geysers, or mine drainages. Several techniques are available for control of these sources including desalting,

INVESTIGATION SCHEDULE

COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM

PROGRAM ITEM

POINT SOURCE DIVISION
- LaVerkin Springs Unit
- Paradox Valley Unit
- Las Vegas Wash Unit
- Crystal Geyser Unit
- Glenwood-Dotsero Springs Unit
- Littlefield Springs Unit
- Blue Springs Unit

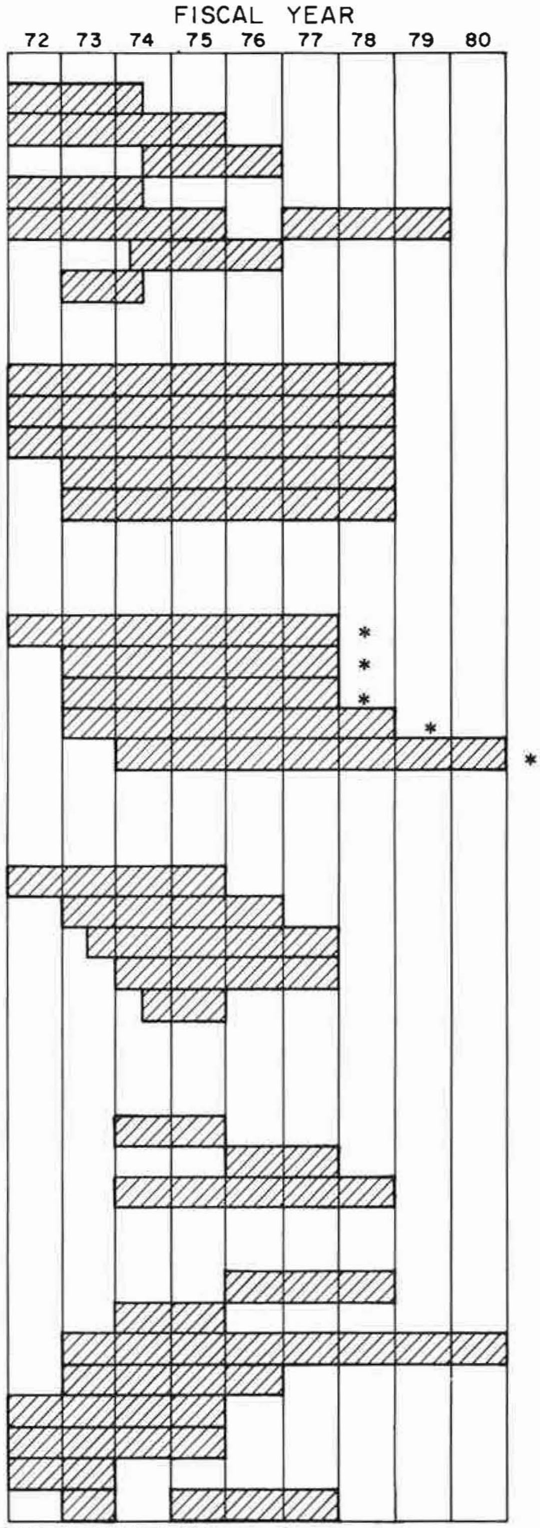
DIFFUSE SOURCE DIVISION
- Big Sandy River
- Price River
- San Rafael River
- Dirty Devil River
- McElmo Creek

IRRIGATION MANAGEMENT SERVICES DIVISION
- Grand Valley Basin Unit
- Palo Verde Irrigation District Unit
- Colo. River Indian Reservation Unit
- Uinta Basin Unit
- Lower Gunnison Basin Unit

WATER SYSTEM IMPROVEMENT DIVISION
- Grand Valley Basin Unit
- Colo. River Indian Reservation Unit
- Uinta Basin Unit
- Lower Gunnison Basin Unit
- Palo Verde Irrigation District Unit

UTILIZATION OF RETURN FLOW DIVISION
- San Juan Collector System Unit
- Grand Valley Collector System Unit
- Palo Verde Powerplant Cooling Unit

SUPPORT STUDIES
- Vegetation Management
- Systems Operations Studies
- Irrigation Efficiency Studies
- Salinity Inflow Studies
- Mathematical Model of the Colo. River
- Economic Evaluation of Water Quality
- Institutional and Legal Analysis
- Desalinization Process Systems



* WATER USER ORGANIZATIONS TAKE OVER PROGRAM OPERATION

Figure 2

diversion and evaporation, diversion for special use, plugging of wells, and deep well injection.

2. *Diffuse source control* involves salt loading and/or concentrating effects that are spread over comparatively large areas such as minor tributary subbasins. A general lack of basic data has limited the studies to tentative plans for control of these sources. The techniques available for control are collection and desalting, collection and evaporation, collection and special use, watershed management, and phreatophyte control.

3. *Irrigation source control* involves reductions in the salt loading and concentrating effect caused by dissolution of salts in the soil and substrata and the consumptive use of water. The techniques applicable to irrigation source control are improved onfarm irrigation water use, improved water conveyance systems, ground-water management, return flow management, and evaporation suppression.

Additional measures such as river system management, watershed management, return flow utilization for other beneficial uses, and dilution by additional water sources are also being developed.

LONG RANGE OUTLOOK

The Colorado River Water Quality Improvement Program is only one facet of an overall basin water management concept which could be implemented to meet the objective of maintaining salinity concentrations at or below their present level. The basin water management concept envisions that existing and proposed structures will be coordinated with the physical features of the basin to optimize the use and development of the water resources for the greatest economic and social benefits of those involved. There are several allied programs which are expected to beneficially affect the Colorado River salinity.

WEATHER MODIFICATION

Weather modification research now in progress is expected to develop by 1980, a reliable and workable system for increasing precipitation. In a limited water area, such as the Colorado River Basin, producing 1 to 2 million acre-feet of usable new water annually might contribute toward salinity improvement. The highly favorable benefit-cost ratios, the flexibility of use, 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.

VEGETATION AND WATERSHED MANAGEMENT

Vegetation and watershed management could also contribute to reductions in salt concentrations of the Colorado River. Phreatophytes are large contributors to the salt concentrating effects in the basin. Research is underway to determine the effect of treating phreatophyte-infested areas with anti-transpirants.

DESALTING

The coast of southern California has been under intensive study to site large-scale sea water desalting plants. Recent reconnaissance studies have evaluated desalting plants at Diablo Canyon (40 million gallons per day [mgd]), Encina-San Diego (40 mgd), San Diego Refuse Incinerator Project (32 mgd), and Orange County Water Factory 21 (3 mgd). Ultimately, large-scale, dual-purpose desalting plants may not only augment local municipal and industrial supplies but also export or exchange water to meet inland demands such as on the Colorado River. As a consequence, desalting is still expected to have a role in providing future water supplies for augmentation purposes. As such, the potential impacts of sea water desalting for exchange water and water quality improvement in the Colorado River should be recognized and monitored.

CONTROL OF EFFLUENT FROM POWERPLANTS

Since 1970, action has been taken with respect to the effect of cooling tower blowdown water from thermal-electric powerplants on the salinity of the Colorado River. Cooling water in the towers evaporates, and salt in the remaining water becomes more and more concentrated. The cooling water must be maintained at or below specific levels of concentration, and this is done by discharging, or "blowing down" a portion of the water, and replacing it with fresh water. At the present time, there are five large coal-fired thermal-electric generating plants either in operation or under construction within the Colorado River Basin, and others are planned, that will be disposing of their blowdown water away from the river, thereby removing dissolved salts from the Colorado River system. Water depletions, however, will cause some increase in salinity downstream.

OTHER INDUSTRIAL USES

Coal gasification plants are being planned for construction in New Mexico on the Navajo Indian Reservation. Indications are that these plants will require about 30,000 acre-feet of water a year, none of which would be returned to the river system. Thus, as with the thermal electric plants, even though dissolved salts would be removed there would be some increase in salinity downstream due to consumptive use of water in the gasification plants.

The nation's increasing demand for oil has caused both industry and Government to proceed with plans for the mining of the tremendous oil shale reserves of the Upper Colorado River Basin and the extraction of oil from the shales. The final Environmental Impact Statement on the Government's oil shale leasing program was recently completed. The statement recommends several measures that would keep dissolved salts in water used in the industry out of the river system.

In the Lower Colorado River Basin, the San Diego Gas and Electric Company has been working on plans to construct a large nuclear powerplant in the Colorado desert near Blythe, California, using the saline Palo Verde Irrigation District drainwater for cooling tower makeup and not returning the cooling tower blowdown water to the Colorado River. The consumed drainwater would be replaced by exchange with a water source outside the Colorado Basin; thus, by consumptively using a saline inflow to the river, this operation will reduce both the total salt load in the Colorado River downstream from the Palo Verde Irrigation District drain and downstream salinity. The reductions will be determined by the difference in salinity between the drainwater, averaging about 1,800-1,900 ppm, and the salinity of the river water, averaging about 750 ppm.

It is estimated that up to 60,000 acre-feet a year would be used in this and similar operations by electrical utilities in southern California.

REAPPRAISAL OF AUTHORIZED WATER DEVELOPMENT PROJECTS

The Office of Management and Budget has directed that a reappraisal be made by the Bureau of Reclamation of presently authorized but unconstructed projects within the Upper Colorado River Basin to identify the salinity impact of such projects. In making this appraisal, the Bureau of Reclamation will be changing some features of the projects so that the salinity impacts of the projects will be minimized. This may be accomplished by careful analysis of lands to receive irrigation water to assure that lands overlying saline formations will be excluded, planning onfarm facilities to reduce excess applications of water by farmers, changes in use of the project water from irrigation to municipal and industrial uses which are expected to add less salt to the system, and other possible alternatives.

INSTALLATION OF TILE DRAINS

In order to combat the high salinity of Colorado River water applied to their lands, farmers in the Imperial and Coachella Valleys have installed thousands of miles of tile drains at depths of 6 and 8 feet under their fields to drain excess water and maintain ground-water levels below the root zones. Through 1972, Imperial Valley farmers installed 17,834 miles of tile drains at a cost of $40.5 million, 1,848 miles of open drains at a cost of $15.9 million, and the Imperial Irrigation District provided master collection drains. A portion of those collection ditches have been lined at a cost of $10.3 million. The farmers are continuing to add more tile drains at a rate of about 1,000 miles a year. Coachella Valley farmers, irrigating about one-seventh of the acreage of Imperial Valley farms, have installed 1,900 miles through 1972 at a comparable cost.

In addition to these substantial investments in facilities to drain off the saline waters percolating through the root zone, the tile drains require regular cleaning on an interval of approximately 5 years, to remove salt deposits and silt. Cleaning costs average about $600/mile.

BLENDING OF COLORADO RIVER WATER TO REDUCE SALINITY

The Metropolitan Water District of Southern California imports over 1 million acre-feet a year of Colorado River water into the Southern California coastal plain, where over 10 million persons reside. Upon the 1972 completion of the first stage of the California State Water Project, the District had available to it added quantities of Northern California water with about one-third the salinity of Colorado River water. In order to reduce the salinity of the water delivered to its service area, the District recently announced a program involving significant expenditures which would allow distribution of a 50-50 blend of the two waters to 75 percent of its service area.

PROJECTED SALINITY REDUCTION

Table 6 summarizes the salinity reductions that are anticipated with implementation of the various proposed salinity control measures outlined herein.

Table 6

ESTIMATED SALINITY REDUCTIONS
Colorado River at Imperial Dam

Mg/l

	1970	1980	1990	2000
Estimated salinity level[a]	865	930	1,115	1,160 [b]
Anticipated range [c]	(795-935)	(855-1,005)	(995-1,235)	(1,035-1,285)
Estimated salinity reductions				
Potential source controls	—	(-39)	(-130)	(-130)
Other possible reductions from practices such as vegetation management, desalting, and weather modification	—	(-26)	(-120)	(-165)
Total estimated reduction	—	(-65)	-250	-295
Estimated salinity level with possible control programs	865	865	865	865
Range	(795-935)	(795-935)	(795-935)	(795-935)

[a]No salinity control programs.
[b]Construction of all Federal and private water resource developments. If Upper Basin develops the full 5.8 million acre-feet estimated to be available, then salinity could increase to 1,260 plus or minus 140 mg/l.
[c]Based on one standard deviation for period of record.

CHAPTER III. ECONOMIC AND OTHER ANALYTIC STUDIES

INTRODUCTION

Special studies, investigations, and analyses have been conducted and are continuing relative to the quality improvement program. These include economic studies of damages, benefits, and costs; project evaluation methodology; cost sharing; and cost allocation, with particular regard to equity considerations.

Investigations are being conducted by using mathematical models to simulate salt loadings at various points in the surface water system and to simulate both water quantity and quality and the interaction of surface and ground water.

Institutional aspects are being examined, including international treaties, interstate compacts, court decisions, State water law, and water and power contracts.

ECONOMIC STUDIES

Increases in salinity levels produce adverse physical effects on some water users. These effects result in direct economic impacts on water users and indirect economic impacts on the regional economy. Salinity is thus an economic problem. In the Colorado River Basin, the economic effects are primarily limited to agricultural, municipal, and industrial uses and include decreased crop yields, increased leaching water requirements and management costs, increased municipal and industrial water treatment costs, accelerated pipe corrosion and appliance wear, and decreased palatability of drinking water.

Large expenditures of funds would be necessary to control the salinity level of the streamflows. Costs and benefits must be ascertained to determine the economic feasibility of salinity controls including individual salinity control projects.

The benefits calculated relate to the economic impact of doing nothing. Whereas the EPA studies related benefits to reduction in salt loading at Hoover Dam, the studies described here relate benefits to reductions in salt loading at Imperial Dam.

CONTRACTED ECONOMIC STUDY

Investigators at Colorado State University performed contractual research in the economics of salinity relative to irrigated agriculture. The report, authored by Drs. R. A. Young, W. T. Franklin, and K. C. Nobe, is titled "Assessing Economic Effects of Salinity on Irrigated Agriculture in the Colorado River Basin: Agronomic and Economic Considerations." (1973)

The overall objective of the research was to derive the most appropriate procedure for evaluating the economic effects on irrigated agriculture of salinity in the flows of the Colorado River. The study included a review of literature and existing data to ascertain the level of accomplishment in measuring adverse effects of salinity.

The investigations revealed that the most comprehensive study of salinity damage estimation for the Colorado River Basin has been that of the Environmental Protection Agency (EPA). The major conclusion drawn was that the EPA estimates significantly understate the damage of salinity increases. Further work is underway on this subject.

PROGRAM STAFF STUDIES

Significant economic studies are being conducted by the program staff and several cooperating universities. The studies involve concepts and methodology related to external project effects, evaluation, cost sharing, cost allocation with particular regard to equity, and more accurate accounting for salinity effects.

Only tentative and preliminary findings on these subjects have been made so far. Various concepts and evaluation techniques are being tested and sharpened. Perhaps the most difficult aspect of the studies involves equity considerations to determine the entities that should provide and pay for controls and to what degree. Traditional cost-sharing policy does not appear adequate for the situation. It is necessary to consider the changing economic conditions of the 1970's, the implications of recent Federal water resource statutes and programs, anticipated new water uses, and the potential energy developments in the area. Also, it is apparent that there must be a much closer accord than in the past among entities and activities imposing salinity costs on the system, the distribution of benefits and beneficiaries of control over time and place, and the assignment of payment responsibility.

ESTIMATES OF ECONOMIC DAMAGES AND BENEFITS

Damages from salinity increases in the Colorado River Basin involve primarily agricultural, municipal, and industrial water users. Damage estimates have been examined by EPA, by a trio of Colorado State University professors, by Dr. Po-Chuan Sun of the University of California, and by other researchers. The reclamation water quality improvement program staff is interpreting and adding to this work. A summary description of the work accomplished to date follows. It must be emphasized that final, conclusive determinations have not yet been made on this subject.

DISCUSSION OF ECONOMIC IMPACT OF SALINITY

As salinity levels rise, the net economic return from agriculture decreases to some extent. Municipal and industrial water users also may incur additional costs of an uncertain magnitude.

As an indication of the magnitude of salinity damages, the EPA estimated (for 1970) total annual economic detriments to be $16 million. If water resource development proceeds as proposed and no salinity controls are implemented, it is estimated that the detriments would increase to $28 million in 1980 and $51 million in 2010. If future water resource development is limited to those projects under construction, estimated annual detriments would increase to $21 million in 1980 and $29 million in 2010. Detriments to recreation and fishery users in the Salton Sea are not included in these EPA estimates but are believed to be substantial. Other studies indicate that these values were extremely low and considerable effort has been expended to update and improve the estimates.

The impacts of changing salinity may include effects on fish and wildlife, recreation, environmental, and others. While recognizing that many other effects of salinity changes exist, the overriding concern addressed here deals with the effects upon direct users of Colorado River water.

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

Because different crops have different tolerances to salts in the root zone, limits are placed on the types of crops that may be grown. When salinity levels in the soil increase above the threshold levels of a crop, progressive impairment of the crop growth and yield results. Irrigation water which has a high percentage of sodium ions may also affect soil structure and cause adverse effects on crop production.

Domestic uses comprise the major utilization of municipal water supplies. Total hardness, a parameter closely related to salinity, is of considerable interest in assessing water quality effects on these uses. Increases in the concentration of salinity and hardness lead to added soap and detergent consumption, corrosion, and scaling of metal water pipes and water heaters, accelerated fabric wear, added water softening costs, and in extreme cases, abandonment of a supply. By most hardness measures, raw water supplies derived from the Colorado River at or below Lake Mead would be classified as very hard.

Boiler feed and cooling water comprise a major portion of water used by industry in the basin. Mineral quality of boiler feed water is an important factor in the rate of scale formation on heating surfaces, degree of corrosion in the system, and quality of produced steam. In cooling water systems, resistance to slime formation and corrosion is affected by mineral quality.

The physical impacts of salinity upon consumptive uses of water were translated into economic values by evaluating how each user might alleviate the effects of salinity increases.

The alternatives available to irrigation water users are influenced by the availability of additional water. The primary means of combating detrimental salinity are to switch to salt tolerant varieties of crops or to apply more irrigation water and leach out excess salts.

(1) If the irrigator does nothing, he will suffer economic loss from decreased crop yields.

(2) If additional water is available, root zone salinity may be reduced by increasing leaching water applications. The irrigator would incur increased costs for purchase of water, for additional labor for water application, and for increased application of fertilizer to replace the fertilizer leached out.

(3) If no additional water is available, the irrigator can increase the leaching of salts from the soil by applying the same amount of water to lesser acreage. This, of course, results in an economic loss since fewer acres of crops can be grown.

(4) By changing the management regime and applying alternative production practices, some salinity effects can be mitigated but only by

incurring additional costs. These alternatives include drain installation, ditch lining, land leveling, deep plowing, planting bed modification, sprinkler and drip irrigation, and increased irrigation frequency.

(5) The last alternative is to plant salt tolerant crops. An economic loss would usually occur since many salt tolerant crops ordinarily produce a lower economic return.

Municipalities could:

(1) Do nothing and the residents would consume more soap and detergents or purchase home softening units or experience accelerated frequency of replacement of water facilities.

(2) Build central water softening plants.

(3) Develop new, less mineralized water supplies.

Industrial users could combine more extensive treatment of their water supply with the purchase of additional makeup water based upon the economics of prevailing conditions. The required mineral quality levels are maintained in boiler and cooling systems by periodically adding an amount of relatively good quality water (makeup water) and discharging from the system an equal volume of the poorer quality water (blowdown).

The cost of applying each of the alternative remedial actions was determined, and the least costly alternative selected for subsequent analyses. For industrial use, an estimate of required makeup water associated with salinity increases was selected to calculate the penalty cost. Municipal damages were estimated by calculating the required additional soap and detergents needed, physical damages to facilities, and the cost of central softening.

Economic studies were intended to provide a basis for assessing the economic impact of a change in salinity levels. Water quality, water use patterns, and economic conditions were projected and appropriate discounts made to arrive at representative values. Direct penalty costs were then aggregated for the entire impact area.

Because of the interdependence of numerous economic activities, there exist indirect effects on the regional economy stemming from the direct economic impact of salinity upon agricultural water users. These effects, termed indirect penalty costs, can be determined if the interdependency of economic activities is known. A simple ratio of direct to indirect impacts was used based on the EPA study wherein an "input-output model" was developed to follow changes affecting any agricultural industry through a chain of transactions in order to identify secondary or indirect effects on the economy stemming from the direct economic costs of salinity.

The economic validity of salinity reduction measures is dependent upon the extent to which damages to water users are reduced or the usefulness of the waters is increased. Similarly, water uses and projects which cause salinity levels to rise must be considered as imposing costs or damages on the system which must be offset by benefits or controls.

An example of economic effects of salinity increases on irrigated crops in the Colorado River Basin is described below.

Po-Chuan Sun's 1972 study[2] provides a means of estimating the direct salinity effect per mg/l. Utilizing a regional economic model for 469,200 acres results in an estimated $16 per acre reduction in net farm income or a penalty effect of 5 cents per mg/l per acre per year.

The Lower Colorado River Basin was divided into three study areas: Southern California, Lower Main Stem, and the Gila area. Within these study areas, irrigation districts or Bureau of Reclamation projects were identified as representative and for which information regarding crop value was available.

A summary of the estimates for each area is given in Table 7. The total direct salinity impacts are $66,900 per mg/l on an annual basis for 1,076,800 acres or an average of $0.0621 per acre per mg/l per year. The indirect effects were estimated to be 62 percent of the direct effects. The total impact of salinity upon the agricultural users of the Lower Basin is estimated to be $108,400 per mg/l per year in 1972 dollars.

Household damages due to salinity have been estimated by a number of researchers. An array of the calculated costs is shown in Table 8. The Orange County and the Black and Veatch studies are the most complete of those available. From these two studies and other information available from various salinity reports, an estimated value for each of the household items was

[2]Sun, Po-Chuan, An Economic Analysis of the Effects of Quantity and Quality of Irrigation Water on Agricultural Production in Imperial Valley, California, an Unpublished Ph. D, Dissertation, University of California, Davis, 1972.

Table 7

SUMMARY OF ESTIMATES OF DIRECT AND INDIRECT SALINITY IMPACTS ON AGRICULTURAL USERS BY AREA

Area	Salinity effects per acre	Cost[1] mg/l per acre	Present modified acres	Total salinity effect cost per mg/l/year
Southern California				
Imperial County	$16	$0.050	526,000	$ 26,300
Coachella Valley[2]	59	0.148	40,000	7,500
MWD (San Diego)[3]	65	0.203	32,500	6,600
Palo Verde	16	0.050	103,800	5,200
Lower Main Stem				
Colorado River Indian Reservation	11	0.034	72,000	2,500
Remainder Yuma County	23	0.072	146,000	10,500
Gila Area				
Salt River Project (CAP area)[4]	9	0.028	50,700	1,400
Gila Project	21	0.066	105,000	6,900
TOTAL			1,076,800	$ 66,900
Indirect effects—0.62 x 66,900				41,500
TOTAL				$108,400

[1] Cost per mg/l per acre was based on Sun's 1972 study which predicted a crop response to change in salinity concentration of 320 mg/l. $\frac{\$16}{320 \text{ mg/l}} = \$0.05$ mg/l/acre.

[2] Twenty percent of the irrigation water comes from wells. The 40,800 acres represent 80 percent of present modified acres.

[3] Represents only that portion of agricultural lands which will not receive a blended water supply.

[4] Based on full service ground-water exchange acre equivalent of the CAP area that can be served with Colorado River water. (5.72 acre-feet per acre at canal side.)

derived. Not all of the household items that might be affected by salinity in other reports were used because of lack of enough evidence that a real detrimental effect occurs. The individual items used were those which were judged to be important and relevant to the average home in the Lower Colorado River area. The damage figures used, which were judged to be representative of full service areas, are given in Table 8.

The Lower Colorado River Basin was analyzed as three separate areas. The areas are (1) the Municipal Water District of California, (2) the Central Arizona Project service area, and (3) the Lower Main Stem municipal service area which includes cities along the Colorado, in the Imperial Valley, and Las Vegas, Nevada, including surrounding cities.

Table 8

ESTIMATED SALINITY IMPACTS

Annual Cost (Dollars) per Household per mg/l of TDS

Cost Item/Report	Orange County	Santa Ana watershed	Black and Veatch	OSW Report 779	Metcalf and Eddy	De Boer and Larson	Orange County corrected by MWD	Values for lower main stem	Values for CAP area	Values for MWD area	Low estimate	High estimate
Purchase of cleaning agents	0.0880		0.0046	0.0600	0.1143	0.0293	–	0.0050	0.0050	0.0050	0.0046	0.0293
Home water softener	.0693			.0500			0.0122	–	–	–	–	–
Bottled water	.0286	0.0100	.0600	.0100	.0091		.0171	.0171	.0171	.0171	.0091	.0286
Water heater	.0423		.0137				.0047	.0137	.0137	.0137	.0047	.0423
Water piping and wastewater	.0693		.0148				.0108	.0108	.0108	.0108	.0108	.0310
Faucets and fixtures	.0100		.0080									
Toilet mechanism	.0020		.0050				.0086	.0086	.0086	.0086	.0086	.0150
Garbage disposal	.0100											
Clothes and dishwasher	.0200		.0080				.0117	.0117	.0117	.0117	.0080	.0200
Water damage	.0030						.0007	–	–	–	–	–
Swimming pool cleaning	.0020						.0018	–	–	–	–	–
Washable fabrics			.0126					–	–	–	–	–
Lawn watering			.0100					–	–	–	–	–
Plumbing and appliances (composite)		.0800						above	above	above	–	–
Water utility system			.0068					–	–	–	–	–
Sewage facilities			.0011					–	–	–	–	–
Meter damage								–	–	–	–	–
Central softening							.0056	.0085	.0085	.0056	.0056	.0085
TOTAL	0.3445	0.0900	0.1446	0.1200	0.1234	0.0293	0.0732	0.0754	0.0754	0.0725	0.0514	0.1747

The Metropolitan Water District water from the Colorado River will be blended with State Water Plan water with the salinity levels eventually falling to about 350 mg/l according to current estimates. The equivalent full-service capability of the portion of the 550,000 acre-feet Colorado River Diversion after 1987 used by households and the larger diversions up to that time amount to about 1,181,000 homes on a present worth basis. It is assumed the 1973-1987 diversion will be about 1,052,000 acre-feet for municipal use. Diversions will be cut back to 550,000 acre-feet in 1987 with 400,000 acre-feet used for municipal purposes. Calculations are based on 0.67 acre-foot per household per year. In order to mitigate the effects of the salt contained in the waters from the Colorado River, it is assumed that central softening will be available to all users at a cost of $0.0056 per mg/l per year with additional homeowner costs of $0.0669 per mg/l per year for a total of $0.0725 per household. The annual detriments for this service area would then total $85,600. Using a range of values given in Table 8 to reveal the uncertainty associated with this estimate, this value could vary from $60,700 to $206,300. A reasonable estimate for the Central Arizona Project is that some 237,400 households on a present worth basis will be serviced with Colorado River water beginning in 1987. It was assumed that 342,000 acre-feet will be delivered to municipal users 100 percent of the time. An additional 176,000 acre-feet was assumed to be delivered to municipal users 49 percent of the time using projected operating criteria. Household use is estimated at 0.76 acre-foot per household per year.

The detriments per household per mg/l per year are estimated at $0.0754 with the water centrally softened for a cost of $0.0085 per mg/l per household per year. The total annual detriment would be $17,900. Using a range of values given in Table III-2 to reveal the uncertainty associated with this estimate, this detriment could vary from $12,200 to $41,500.

Associated with the Lower Main Stem service area of the river are 212,700 households on a present worth value of projected growth. The projections of growth of the towns and cities along the lower main stem of the Colorado River were discounted to the present and put on an annual basis. In addition to service to the Las Vegas Valley full service was assumed to be available to Boulder City, Nevada; Parker, Yuma, Kingman, Havasu City, and Mohave Valley, Arizona; Needles, Blythe, El Centro, Brawley, and Calexico, California; and other smaller communities. The detriments per household per mg/l per year are estimated at $0.0754. The total damage for the lower main stem service area on an annual basis is $16,000. This is a most likely value. Using a range of values given in Table 8, this value could vary from $10,900 to $37,200.

The summary of estimated economic impacts upon municipal users is shown in Table 9. The most likely expected total for the three areas is $119,500 per mg/l per year with a reasonable range of from $83,800 to $285,000.

Table 9

SUMMARY OF ESTIMATED SALINITY IMPACTS ON MUNICIPAL USERS
(Dollars per mg/l per year)

Metropolitan Water District	$ 85,600
Central Arizona Service Area	17,900
Lower Main Stem Service Area	16,000
Total	$119,500

Range—$83,800 to $285,000

The effect of water quality on industrial uses is difficult to generalize because of the varied uses to which industry puts water.

Using data from the EPA study the total industrial detriments per mg/l per year are estimated at $1,500 for the entire Lower Basin area.

The estimated total economic impact of changing salinity levels on the Colorado River is simply a summation of the impacts upon individual users. This summary is given in Table 10.

Table 10

SUMMARY OF ESTIMATED SALINITY IMPACTS ON ALL USERS
(Dollars per mg/l per year)

Agricultural impacts		$108,400
Direct	$ 66,900	
Indirect	41,500	
Municipal impacts		119,500
Low estimate	83,800	
High estimate	285,000	
Industrial impacts		1,500
Total impacts		$229,400
Low estimate	193,700	
High estimate	394,900	
Direct impacts		187,900
Low estimate	152,200	
High estimate	353,400	

The agricultural impacts are divided into direct and indirect with the total estimated at $108,400 per mg/l per year.

No secondary impacts are assumed for municipal damages but a range is given bracketing the most likely value due to the high variability of the estimates of municipal damages. The total impacts expected to be faced by municipalities are $119,500 per mg/l per year.

Industrial impacts are minimal amounting to only $1,500 per mg/l per year for the entire lower basin.

The total impacts are given as $230,000 per mg/l per year with $41,500 of indirect impacts associated with agriculture. The expected direct impacts are $188,000 per mg/l per year with a reasonable range of from $152,000 to $353,000 per mg/l per year.

These figures should be thought of as the best possible estimates at this point in time. Research is continuing to further refine and delineate the economic impact of changing salinity levels on the Colorado River.

FURTHER STUDY IN PROGRESS TO IMPROVE THE ECONOMIC EVALUATION

The research in progress is intended to build on and modify parameters of the EPA work by research, extension, and field specialists' judgments and available unpublished information. Salinity-yield relationships will be further refined by introducing alternative technologies by specialists. Determination of direct economic impacts will be improved by the application of an optimization procedure, linear programing, which internally selects the best acreage, crops, practices, and irrigation in response to salinity changes. Subgroups of farms in various regions will be grouped according to soil types and other important characteristics. Costs of salinity-related irrigation management or other cultural practice modification are being determined. Existing input-output models will be updated and used to quantify the indirect impacts of changing salinity on various regional economies.

The achievement of this research is the responsibility of Bureau personnel using cooperating entities. In cooperation with the Consortium of Water Institutes and Centers comprised of various universities of the Colorado River Basin, the Bureau is involved in a study, "Salinity Management Options for the Colorado River." This work is discussed in the cooperative research section.

The data generated will be used by CRWQIP personnel for optimization programs to derive damage functions to be attached to the Colorado River simulation model in order to ascertain the economic impact of various management alternatives, salinity control schemes, water resource development projects, and selected scenarios of future basin conditions.

PROGRAM ALTERNATIVES AND CONSTRAINTS

Some of the program alternatives that may be affected by legal or institutional restraints include irrigation practices and water management improvements, control of point sources of pollution, control of diffuse sources of pollution, intrabasin importation, and desalting. Other possibilities include supplementary flows from weather modification and the reformulation of authorized projects. Reducing the salt load in streams by evaporation of the more saline flows or with desalting plants results in consumptive use of water. If salinity control by such methods is adopted then means must be found to distribute the water loss. Also, present water laws encourage unnecessary use of water by senior users who think they must do this to protect their priority of right. Other important areas include analyses of cost-sharing proposals and procedures for operating and maintaining salinity control works.

It is expected that the studies will result in conclusions and recommendations related to existing legislation, water-use practices, and contractual arrangements. The most efficient use of Colorado River water may call for a basinwide plan of operation with strict controls on diversion and use, corrective measures provided at critical points in the system, economic incentives to encourage efficient water use, and equitable means of financing the quality enhancement program.

RIVER SYSTEM MODELING

The Colorado River is one of the most highly developed rivers in the world. The complexity of the physical, legal and operational relationships within the basin necessitated mathematical models to develop an improved understanding of the system and to ease computational burdens. Two mathematical models have been developed. One model is identified as the "river network salt routing model" and the other a "system simulation model." The former utilized simplifying assumptions and facilitated early evaluations of salinity impacts from water developments and salinity control works. It provided direction for the development of the more encompassing and complex system simulation model. This latter model involves critical data analysis, simulations, operating criteria, flood control operations, power production, and runoff forecasting.

It is a highly sophisticated representation of the Colorado River system and is set up to analyze impacts of changes in operating criteria, effects of future developments, augmentation and other measures on the flow and salinity levels of the system. Descriptions of the models are given below.

RIVER NETWORK SALT ROUTING MODEL

This model was developed primarily for the Colorado River system to estimate the effects of both water resource developments and salinity control measures. The model is basically an accounting system with limited simulation capabilities. Flows and salinity are routed through the river system including the reservoirs using a time frame of 1 month. Time-dependent interactions of physical processes such as soil-water chemical transformations due to irrigation must be specified. This requirement distinguishes the model from a true simulation model.

Total dissolved solids are used as the quality parameter and the salinity system is treated as a conservative system. Because mass balance concepts are employed, chemical precipitation, dissolution, and reactions of individual constituents are not explicitly considered. While flow is assumed to be independent of quality, quality does depend on flows.

A number of runs involving further conditions were made to assess the ultimate impact of authorized and proposed projects along with salinity control measures. The following conditions were designated and assumptions made:

1. Construction of federally authorized projects and known private developments would be complete.

2. Basin water supply would be fully utilized.

3. Salinity control measures and augmentation from weather modification, desalting, vegetation management, and geothermal development were added to Condition 1 above.

4. Salinity control measures and augmentation were added to Condition 2 above.

Various levels of development corresponding to the years 1980, 1990, and 2000 were used with appropriate conditions. In addition, runs were made to evaluate the impact of the initial salinity control measures and weather modification.

COLORADO RIVER SYSTEMS SIMULATION MODEL

One purpose of Colorado River simulation model is to investigate the effects of future Colorado River Basin depletions on flow and salinity. The model includes data analysis capability along with simulation and it also includes specific Colorado River operating criteria.

A computerized model is needed in order to mathematically describe the behavior of a large water resources system. The physical features and processes can be adequately defined by mathematical formulas which simulate the control and flow of water through the basin.

If the basin operation can be duplicated, the model is accepted as an accurate reflection of the real system. A question then arises as to what hydrologic inflows should be used. Since the basin operation itself is often a rigid set of rules for managing water, the water flow or supply becomes the only variable in the analysis.

Historic records of streamflows can be used, but they suffer serious drawbacks. One of these is that a historic trace will never again repeat itself. The final drawback is that a fixed system operation with a given set of hydrology will always give one number to a quantity which is actually random in nature. With a single historic trace, the question, for example, of what size of reservoir would assure a specified supply has a unique answer. In reality, a more severe drought or "critical period" than historically experienced can occur. Thus, the holdover storage to assure a given flow for a specific period is a random variable. Unfortunately, use of a single historic sequence yields only one estimate and does not lead to probabilistic inferences about the quantity being studied.

To transcend the limited span of historic data, synthetic hydrology can often be used. Synthetic hydrology or data generation is nothing more than a method of manufacturing numbers which have properties similar to the historic data. The technique of data generation which permits the user to create any number of hydrologic sequences is usually used in conjunction with a computer program that has access to an infinite number of random numbers. These sequences are constructed to maintain statistical properties that the historic data have already shown. This assures that the synthetic traces will be acceptable for studying the behavior of a basin operation just as the historic data set was acceptable.

When a synthetic trace is used to estimate a property of the basin's behavior, one measurement is produced. However, each new trace produces another estimate. When a sufficient number of traces are used, the resulting batch of estimates can be ranked and statistically analyzed. The data generation method can then produce enough values to establish probability distributions of quantities that would have had only one value if the historic data were used alone.

Before generation of synthetic hydrologic traces can proceed, the properties and estimates of coefficients used to define them must be obtained from historic data. These data could be either raw measurements or data adjusted to reflect known historic events which have affected it. The data analysis program extracts all the properties needed to determine the structure of a time series and makes estimates of all necessary coefficients. These numbers along with a description of their relative position in the basin are used to generate the synthetic streamflows. These synthetic flows are then used in the basin operation model to produce many estimates of how the water controlling operation performs.

The simulation portion of the model was developed by first developing logic for a general model and then adding specific features necessary to reflect Colorado River operations. The model utilizes an element called the node to represent the relationship between tributaries, diversions, and reservoirs along a reach of the river.

Evaporation, bank storage change, and power production are calculated each time the reservoir is involved in the movement of water through the basin. When the entire basin has been analyzed, dissolved solids are routed through all reaches and reservoirs. Streamflow forecasting has also been added to the model to make it more realistic in simulating basin conditions. Legal constraints which govern the flow of water between the upper and lower basin are incorporated in the model through a special subroutine.

The data analysis program, the synthetic hydrology generation, and the basin simulation model have been put to use analyzing the Colorado River. The data analysis program has been used to estimate coefficients for defining the time series structure of flow and quality at 17 gaging stations in the Colorado River Basin. This information has subsequently been utilized to generate 10 synthetic traces of hydrologic data covering a 30-year span. This application includes operation of all major reservoirs including specific operating criteria for Lake Powell and Lake Mead in conjunction with a representation of the snowmelt forecast procedure.

CHAPTER IV. STATUS OF INVESTIGATIONS

At the initiation of the Colorado River Water Quality Improvement Program, the prior studies of the Environmental Protection Agency, the Colorado River Board of California, and the Bureau of Reclamation were reviewed to select areas for early study. These included Paradox Valley, Colorado; Grand Valley, Colorado; Crystal Geyser, Utah; Las Vegas Wash, Nevada; and LaVerkin Springs, Utah. Currently, investigations on these units are completed, nearing completion, or are highly advanced.

Feasibility reports are nearing completion on the LaVerkin Springs and Crystal Geyser Units. Feasibility investigations are scheduled to be completed on the Grand Valley Systems Improvement Unit and Paradox Valley in fiscal year 1975; and Las Vegas Wash in fiscal year 1976. On each of the latter units, the studies have progressed sufficiently to develop a preliminary cost estimate on a number of alternatives.

The estimated reduction in salt loading of the Colorado River which could be accomplished in the above areas could approach 624,000 tons per year with a corresponding decrease in salinity concentration at Imperial Dam of 57 mg/l.

Table 11 contains a summary of the potential effects, estimated costs, and estimated benefits that can be expected for an alternative for each of the areas. The annual benefits have been calculated on the basis of $230,000 per mg/l salinity improvement at Imperial Dam. Estimated interest during construction is available and is reflected in the Total Annual Equivalent Cost for all units. The Cost Effectiveness column has been divided to show the cost of removing 1 ton of salt from the system and the cost of attaining a 1 mg/l improvement in salinity concentration at Imperial Dam.

PARADOX VALLEY UNIT, COLORADO

DESCRIPTION OF THE AREA

Paradox Valley, a collapsed salt anticline, is a northwest-southeast trending valley 3 to 5 miles wide located in southwestern Colorado. It has a desert climate, dry and hot in the summer and dry and cold in the winter. The Dolores River crosses the valley near its midpoint. Figure 3 is a general location map of the valley. West Paradox Creek heads in the La Sal Mountains and flows southeast through the northwestern half of Paradox Valley to the Dolores River. Water from West Paradox Creek is used to irrigate some lands in northwestern Paradox Valley. East Paradox Creek, an intermittent stream, drains the southeastern half of Paradox Valley before flowing into the Dolores River. In its traverse across the valley, the Dolores River picks up a salt load of 200,000 tons annually. (See Figures 4 and 5.)

Geologic investigations in the Colorado Plateau have established the existence of a series of five major NW-SE trending salt anticlines (elongated swells) about 100 miles long, with the La Sal Mountains, an extrusive mass, perched over the center of the anticline region. Paradox Valley lies along the axis of one of these salt anticlines from which the salt is derived. The valley is essentially the result of erosion of faulted and uplifted sandstone and shale formation from above a residual gypsum cap over about 14,000 feet of pure salt and salt-rich shale. (See Figure 6.) The Dolores River remained in its ancient streambed as the uplift and erosion of the valley developed.

STATUS OF INVESTIGATIONS

Previous estimates of salinity contribution from the Paradox Valley were based on spot measurements of the flow and water quality of the Dolores River as it enters and leaves the valley. Stream gaging stations and a water quality sampling program were established in FY 1972. Two years of records of streamflow and water quality analysis have verified the previous estimate of 200,000 tons per year salinity contribution by Paradox Valley.

In FY 1972, ground control points were established and topography obtained by aerial survey contract with the Forest Service.

To determine the path by which salt was entering the Dolores River, a resistivity survey was conducted along the river and exploratory and observation wells were drilled during the spring and summer of FY 1972 and 1973. The resistivity study estimated contours of the brine interface so that the exploratory and observation wells could be located to better define the subsurface water conditions.

Twelve exploratory wells were drilled located on both sides of the river in unconsolidated riverfill material. Data obtained at the time of drilling included rock and soil samples, drill fluid samples, salinity, conductivity, and hydrogen sulfide gas readings for each 5-foot interval. Perforated casings were installed so that water quality samples could be obtained and the water table

Table 11

ESTIMATED POTENTIAL EFFECTS AND COSTS–SELECTED INVESTIGATIONS UNITS[1]

Units	Present salt loading (1,000 tons/yr)	Estimated reduction (1,000 (tons/yr)	Effect at Imperial Dam (mg/l)	Annual[2] benefits ($1,000,000)	Construction cost ($1,000,000)	Annual OM&R cost ($1,000,000)	Total annual[3] equivalent cost ($1,000,000)	Cost effectiveness	
								(dollars/ ton)	($1,000/ mg/l)
Paradox Valley	200	180	−16	3.1-6.3	16.0	0.4	1.6	9.00	100
Grand Valley	600	200	−19	3.7-7.5	[4]59.0	[5]0.0	4.9	24.00	258
Crystal Geyser	3	3	− 0.3	0.06-0.12	0.5	0.003	0.03	10.00	100
Las Vegas Wash									
Desalting Alternative	208	138	−13	2.5-5.1	31.7	2.9	5.3	38.00	408
Evaporation Alternative	208	131	−12	2.3-4.7	49.6	0.2	4.0	30.00	333
LaVerkin Springs	109	103	− 9	1.7-3.6	20.0	1.8	3.2	31.00	356
Total or average	1,120	617-624	−57	11.1-22.5	127-145	2.4-5.1	13.7-15.0		

[1] The potential costs have been shown without implying the source of financing and repayment.
[2] Direct plus indirect benefits.
[3] Includes interest during construction at 6-7/8 percent.
[4] Does not include cost of onfarm improvements which are unknown at this time.
[5] The O&M cost of Irrigation Management Services (estimated $240,000) will be offset by a reduction in distribution system O&M.

PARADOX VALLEY, COLORADO

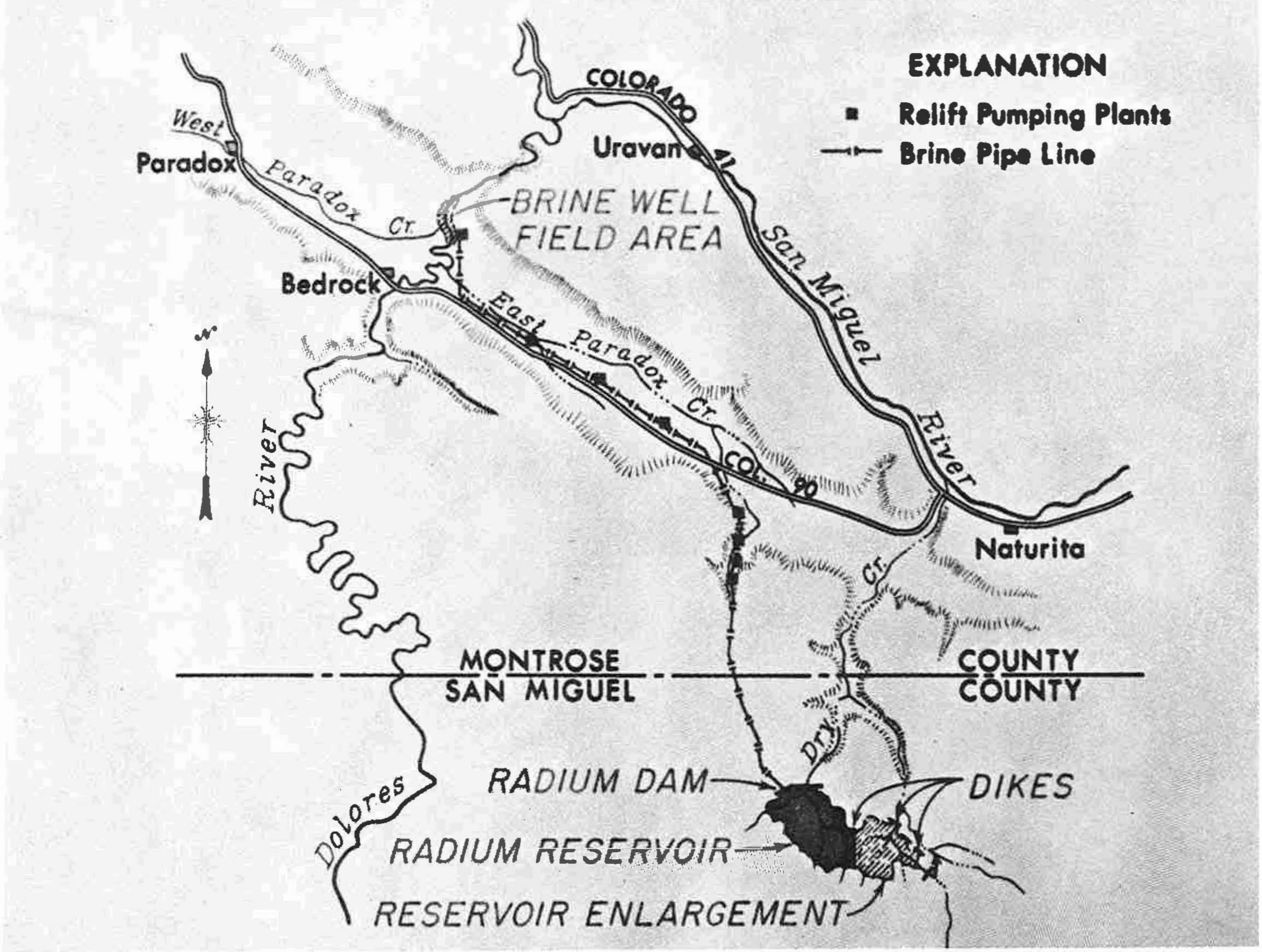


Figure 3

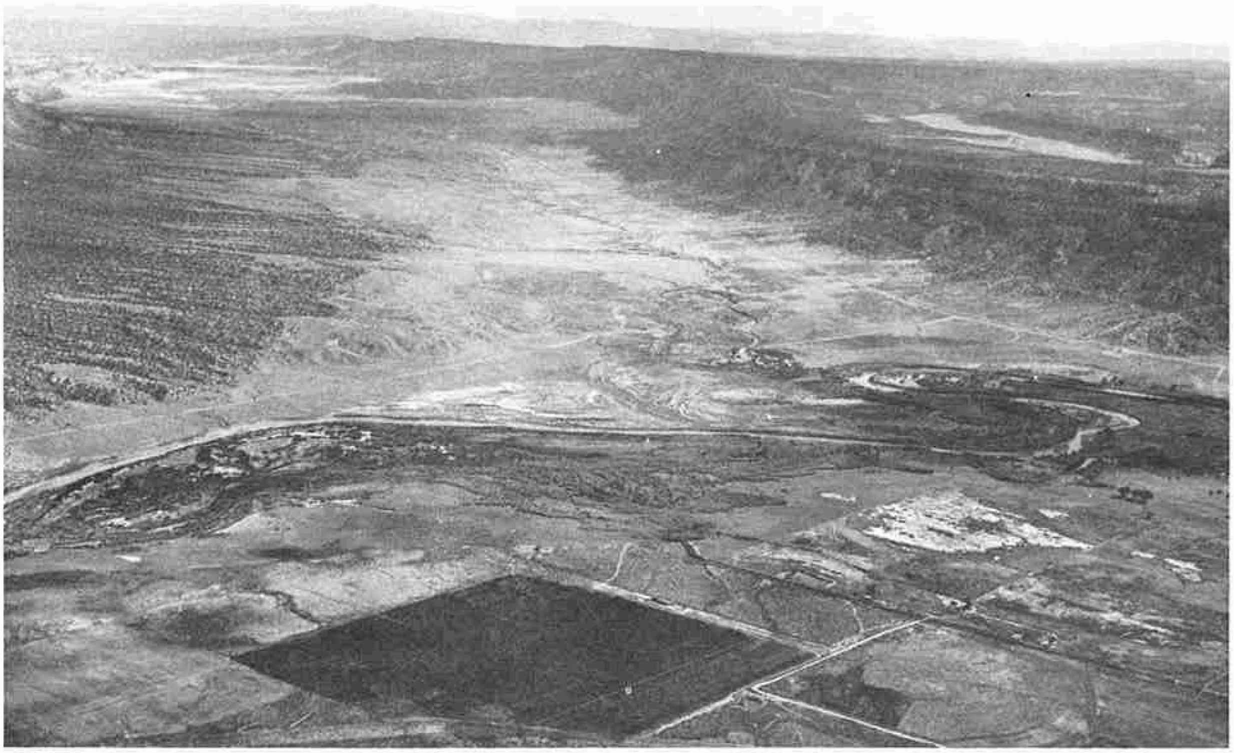


Figure 4. Aerial view looking southeast in the Paradox Valley where the Dolores River crosses. CN520-427-5A

Figure 5. Aerial view looking southwest of the Dolores River in the Paradox Valley. Note alkaline conditions from center of valley toward the foreground. Probability of a salt dome is being investigated at left center of photo. P520-427-2 NA

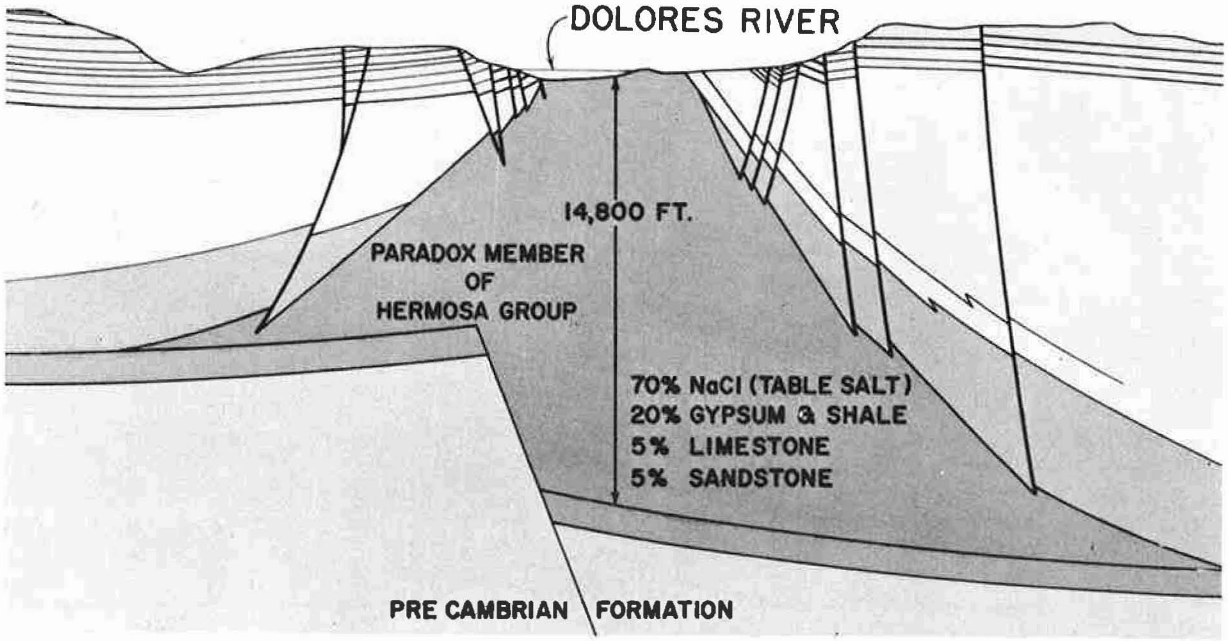


Figure 6. Section across Paradox Valley.

elevation and brine interface observed during the test well pumping program. (See Figure 7.)

Also during FY 1973, five locations on the east side of the river were core drilled into the consolidated formation of the valley floor to depths ranging from 74 to 200 feet. These core holes indicated a shallow unconsolidated overburden of 15 to 30 feet in depth, a very saline ground water, and a brecciated gypsiferous NaCl salt-rich formation. This formation is termed the residual cap of the salt dome.

Data obtained from the resistivity study and the drilling program indicate salt (or brine) within a few feet of the surface along the east side of the river and plunging to a depth of about 150 feet about a mile to the west of the river.

A 100-150-foot-deep pocket of gravels exists in midvalley to the west of the river. This would indicate meandering of the river and deposition of alluvium to replace leaching of the underlying saline formation. This leaching is probably the result of ground water moving along the salt-bearing interface near the base of the gravels, then surfacing to the river.

In the river channel, the brine interface surfaces sharply about midvalley. Upstream from this point, the river is unchanged in its freshness, but within several hundred feet downstream the river has almost reached its maximum salinity condition. This brine contribution results in salt concentrations in the Dolores River ranging from less than 200 mg/l at high flows to 166,000 mg/l during extreme low flows as measured at the outlet of Paradox Valley. The area where the brine is found on the surface is shown in Figure 8. The west or left margin of the brine area is its surfacing line and the area to the right is more or less a stable impoundment or reservoir of the salt brine. (See Figure 9.)

A 16-inch exploratory well has been drilled to penetrate the 100-foot-deep lensatic river deposits and initial testing of this zone has been completed. Deepening of the well to the 300-foot depth into the underlying fractured gypsum cap of the salt anticline has also been accomplished and additional pumping tests were completed. Pump tests in the above two brine yielding zones will provide data on the hydraulic characteristics of these zones to determine the optimum depth and spacing for the production wells.

All indications are that the salt contribution to the Dolores River in this area can be effectively controlled by pumping from the brine zones.

The estimated annual removal of salt is 180,000 tons. Salinity concentrations of the Colorado River at Imperial Dam would be reduced by an estimated 16 mg/l.

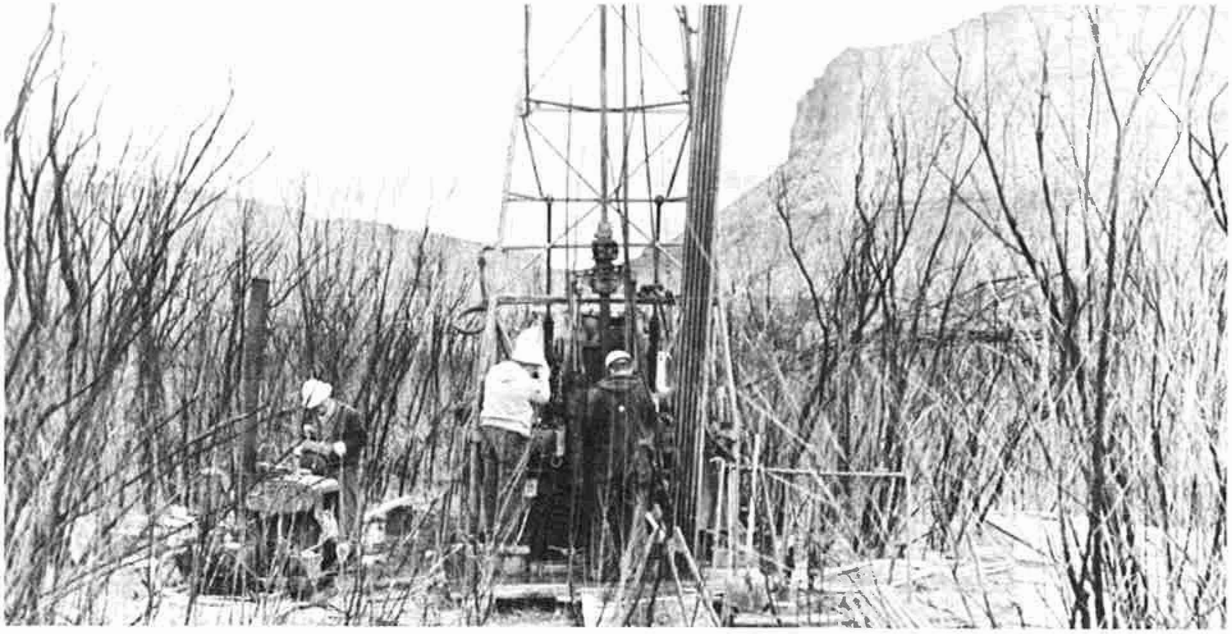


Figure 7. Regional drill crew drilling observation hole 7PX. C-1244-406-15

ALTERNATIVE PLANS

One alternative plan proposed to remove the salt would involve the installation of a field of brine wells to lower the fresh water-brine interface and thus, by pumping, eliminate the natural brine inflow to the river. The brine from the wells could be collected and pumped to a solar evaporation reservoir. (See Figure 3.)

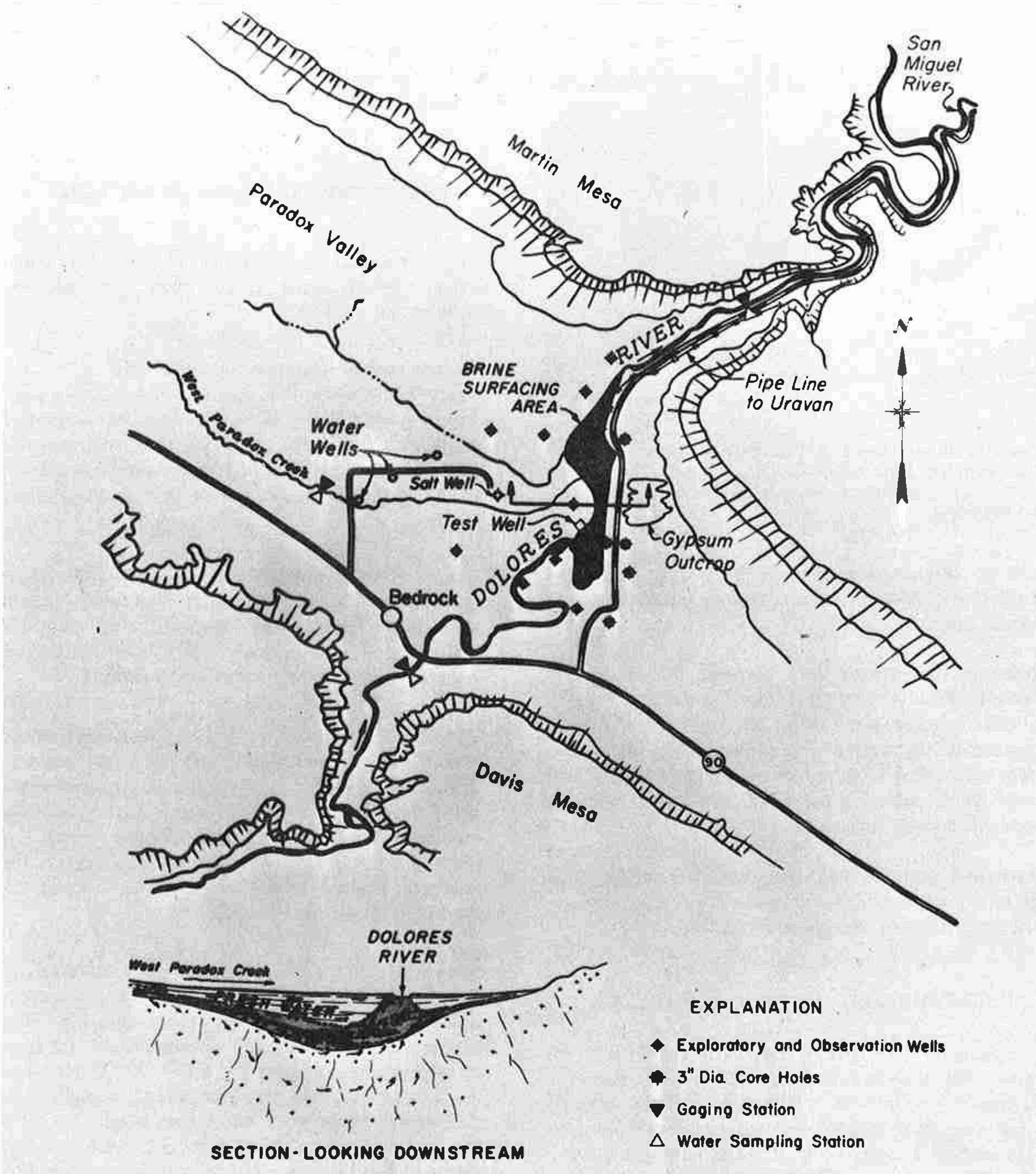
The brine well field could consist of eight or more wells drilled and cased with plastic casing to a depth of approximately 250 feet. The brine flow collected from each of the wells could be transported to a central collection point through pipelines.

It is estimated that at least eight pumping plants might be required to lift the brine from the well field at elevation of 4940 feet to elevation 7000 feet at the top of the divide between Paradox Valley and Dry Creek Basin. Reinforced plastic mortar pipe would be used for the 20.3 miles of pipeline from the well field to the evaporation reservoir.

The potential Radium Reservoir, located in Dry Creek Basin on the West Fork of Dry Creek about 8 miles southwest of Naturita, Colorado, could function as the solar evaporation sited. Mancos shale, an impervious, brackish marine formation, is the surface material of the reservoir site. The reservoir basin is a geologic shallow syncline, a natural collection basin with interior drainage limited to a small watershed area. It is topographically breached along its north side and the damsite is in the breach and founded on firm Dakota sandstone. No leakage is expected from the dam and reservoir. The reservoir would have a total capacity of 70,000 acre-feet and a water surface of 3,375 acres. The average reservoir content allocated to brine inflow would be about 66,000 acre-feet with surface area of 3,200 acres, at a point in time when evaporation equals inflow, based on brine inflow and evaporation rate assumptions. Assuming 4.0 feet per year of pan evaporation with a 0.70 pan factor and 0.71 ratio of saturated salt brine evaporation to fresh water evaporation, the net evaporation from the surface of a brine reservoir would be approximately 2.0 feet per year. Based on brine inflow of 8 cfs and on annual surface runoff estimated to be 660 acre-feet, the theoretical area required for evaporation would be approximately 3,200 acres.

Radium Dam would be a rolled earthfill structure with a height of about 92 feet above streambed. At the crest it would be 30 feet wide and 6,200 feet long. The dam would contain approximately 455,000 cubic yards of material.

A system of three dikes would be required along the east side of Radium Reservoir. They would range up to 71 feet in height, total 4,250 feet in length, and contain approximately 300,000 cubic yards of



PARADOX VALLEY EXPLORATION PROGRAM

Figure 8

Figure 9. Dolores riverbed. View looking north mid-valley near upstream limit of saline inflow. View is looking at section of river just to the east of the pump test site. C-1244-406-6

material. Preliminary geology inspection indicates foundation conditions are satisfactory for construction of these dikes.

No outlet works have been planned. An emergency concrete spillway, would be located at the south end of the dike and the east side of the reservoir. No use is expected to be made of this spillway since the design flood from the 17.8 square miles of drainage area should be contained in the 4,000 acre-feet of reservoir allocated to flood storage.

Alternative reservoir sites were evaluated but from the standpoint of reservoir impermeability only one site (Radium Reservoir site) could be utilized.

ECONOMIC AND FINANCIAL ANALYSIS

The estimated construction cost, as of April 1973, for the alternative of brine wells, pumping plants, pipeline, and reservoir structures is $16 million. The estimated annual operation, maintenance, and replacement costs based on the expected life of equipment and a 6-7/8 percent interest rate are $350,000.

Local benefits would be limited to the effects of decreasing the salinity of the Dolores River in Paradox Valley and downstream. There would be a decrease or elimination of salt encrustations along the river and lowlands adjacent to the river. This could enhance fishery, wildlife, and aesthetic values in the downstream reaches. The annual loss of water by the evaporation of about 5,800 acre-feet would offset some of the expected benefits. Most of the benefits would occur in the lower Colorado River Basin and are estimated to be $3,680,000 annually.

ENVIRONMENTAL CONSIDERATIONS

Construction and operation of the Paradox Valley Salinity Control Unit could have the following environmental impacts:

A noticeable decrease in the low flow salt concentrations in the Dolores River downstream from Paradox Valley with a decrease or elimination of salt encrustations along the river and lowlands adjacent to the river which could enhance fishery, wildlife, and aesthetic values in the downstream reaches.

Construction of one or more well installations along the river with associated pumping plants, powerlines, transformer stations, and pipelines would require removal of some of the brush along the river but with minimal effect on wildlife.

Constructing the pipeline to Dry Creek Basin would create a scar which would require a few years to heal. Booster pumping plants would be constructed along the pipeline at several locations along with the associated transformer stations and powerlines. The plant growth along the pipeline and around the pumping stations would probably be reduced but the effect on animal life should be minor.

The evaporation reservoir in Dry Creek Basin would store the salt removed from Paradox Valley, estimated to be 180,000 tons annually. The reservoir would inundate approximately 3,200 acres of land which would be lost for wildlife habitat and stock grazing. This reservoir would probably be sterile and the existing vegetation would be killed by the saline water. After a few years the reservoir would reach an equilibrium between evaporation and inflow and a salt flat would be exposed around the lake each summer, resulting in a minor amount of windblown salt which may damage the vegetation in the vicinity of the reservoir.

Approximately 4 miles of county road would have to be relocated around the evaporation reservoir.

GRAND VALLEY BASIN UNIT
COLORADO

DESCRIPTION OF THE AREA

The Grand Valley of Colorado is near the western edge of Mesa County. Grand Junction, the largest city in Colorado west of the Continental Divide, is located in the Valley. The Valley covers an area of about 122,000 acres. It is within the Canyon lands section of the Colorado Plateau physiographic province. The Valley was carved in the Mancos Shale formation (a high salt bearing marine shale) by the Colorado River and its tributaries and for the most part is surrounded by steep, rough terrain. Deep canyons flank the valley to the southwest; a sharp escarpment known as the Book Cliffs rises above it to the north and northeast; foot slopes of the Grand Mesa lie to the east; and rough, broken and steep, hilly land that borders high terraces or mesas lies to the south. Within the Valley, the irrigated lands have developed on recent alluvial plains consisting of broad coalescing alluvial fans and on older and higher alluvial fans, terraces, and mesas. Other lands in this arid setting, where rainfall averages only about 9 inches per year, include the stream flood plains and rough broken land occurring as terrace escarpments, high knobs, and remnants of former mesas. A map of the Grand Valley Basin Unit is shown on Figure 10.

Four irrigation entities divert water from the Colorado River. These include the Grand Valley Water Users Association (Bureau of Relamation Project), Grand Valley Irrigation Company, Palisade Irrigation District, and Mesa County Irrigation District. A fifth irrigation company, the Redlands Power and Water Company, diverts water from the Gunnison River. A number of other small companies have carriage agreements with the major canal companies for delivery of water.

First irrigation in the valley began in 1882 with the construction of what is now the Grand Valley Canal (Grand Valley Irrigation Company). Other private systems were built during the period between 1882 and 1908. Construction of the last major system, the Grand Valley Project under the Reclamation Service, began in 1908 with the major construction completed in 1926. This project consists of two divisions, the Garfield Gravity and the Orchard Mesa Divisions, on the north and south sides of the river, respectively.

A total of about 76,000 acres are served water by these irrigation entities with approximately 42,000 acres under Federal projects. Major crops produced in the valley are corn, sugar beets, small grains, alfalfa, and various orchard crops. Figure 11 is an aerial view of the Grand Valley looking to the west.

Bureau of Reclamation data show that in 1972 the value of the crops produced on Grand Valley Project lands (Federal Project) was more than $7 million. This $7 million crop value generated $47 million in increased business for local and state commerce in 1969. The value of crops produced on private projects in the Grand Valley has not been determined but would be nearly equivalent.

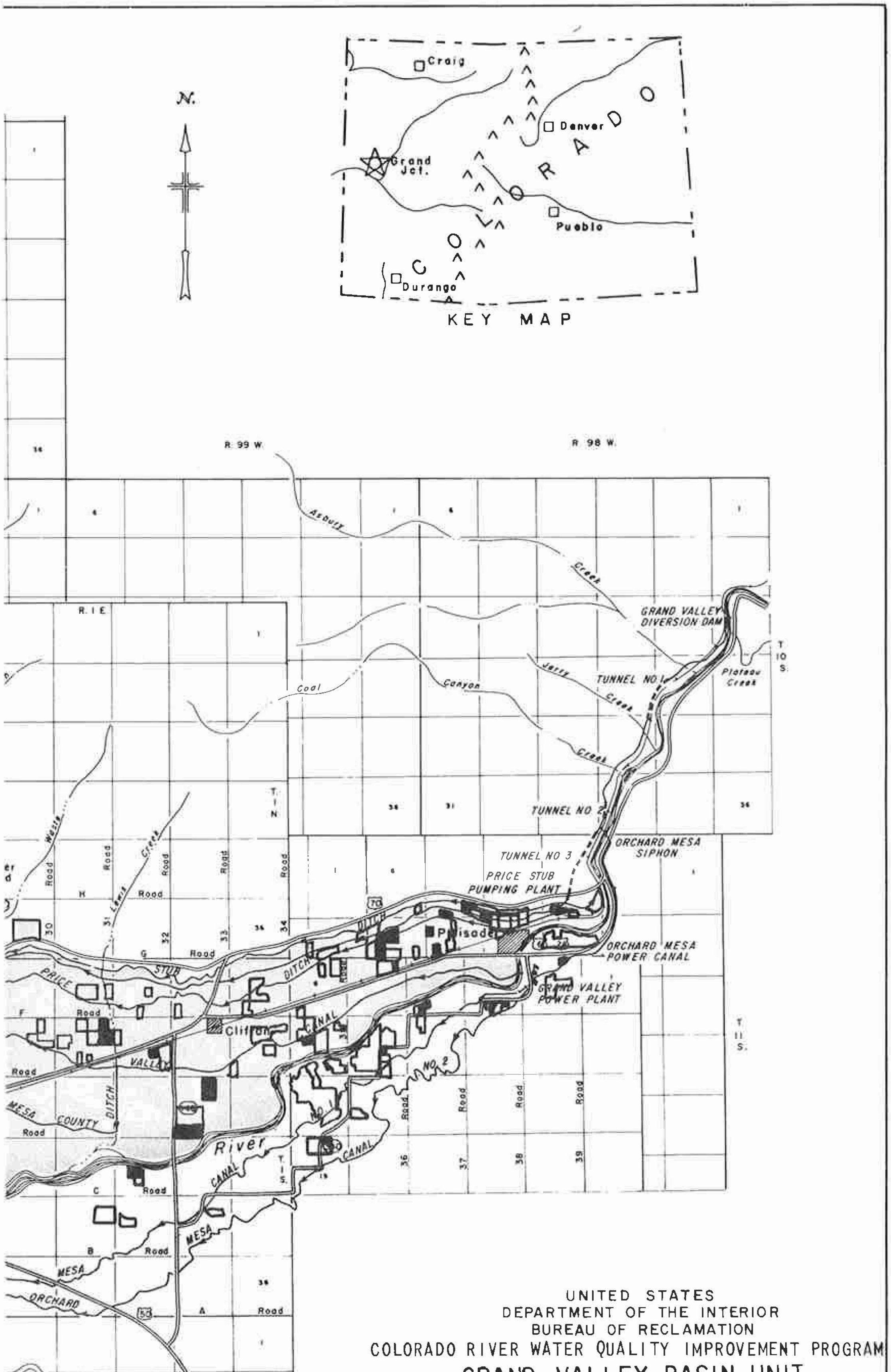
ORIGIN AND AMOUNT OF SALT LOADING

All sources in the Grand Valley are estimated to contribute an average of about 600,000 tons of salt annually to the Colorado River. Most of these salts are thought to be leached from the soil and underlying Mancos Shale and washed into the river by deep percolation and water delivery system losses.

Mancos Shale is a very thick sequence of drab gray fissile shale that lies between the underlying Dakota sandstone and the overlying Mesa Verde Formation. The thickness of the shale usually varies between 3,000 and 5,000 feet. Due to this great thickness and its easy erodibility, the shale forms most of the large valleys of western Colorado and eastern Utah.

It is of marine origin and contains marine fossils at many locations. Geologic studies suggest that the shale was deposited as mud in the shallow water of a very extensive Late Cretaceous sea and that the region was gradually subsiding which explains the great thickness of the formation. Because of its marine origin the shale contains a high percentage of salts; the high salt content is borne out by the many white patches of alkali on both irrigated and nonirrigated surfaces. The type of salts present in the shale are mostly calcium sulfate with smaller amounts of sodium chloride, sodium sulfate, and magnesium sulfate. The evidence that calcium sulfate is the most common salt is verified by the existence of the mineral gypsum commonly found in crystal form in open joints and fractures of the Mancos Shale.

Due to the compactness of the clay and silt particles making up the shale, the formation is not considered as water bearing at depth. However, the weathered zone near the surface does transmit small quantities of water along joints, fractures, and open bedding planes. This zone is the area from which percolating water, often originating from irrigation of croplands, dissolves out salts present in the shale.



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM
GRAND VALLEY BASIN UNIT
DECEMBER 1973

Figure 10

Figure 11. Aerial view looking west over the project lands. Palisade, Colorado, is visible at lower center and Grand Junction is in the distant background. P8-427-42 NA

Most of the soils forming the irrigated lands have been derived from Mancos Shale. As a result, the soils are also a source of salinity.

A gravel and cobble layer also has been found under some of the irrigated areas in the Grand Valley and is believed to serve as an aquifer for ground water. Previous studies have identified areas where the ground water has an upward pressure gradient in the cobble aquifer due to the confining effect of the Mancos Shale beneath and the tight clay soil above. This situation is believed to be responsible for some areas of high water tables. Further studies of the cobble aquifer will be necessary to determine its extent and its influence on the ground water. The gravel and cobble layer may be ancient stream deposits from the Colorado River and may not be continuous throughout the valley.

A "Use of Water on Federal Irrigation Projects Study" was conducted in the Grand Valley between 1964 and 1968. From that study the irrigation efficiency was computed at about 33 percent. Of the water lost, only a small portion is collected for reuse. Surface runoff accounts for approximately one-half of all farm losses. The remaining one-half is made up of deep percolation and farm system losses.

SALT REMOVAL EFFECTS DOWNSTREAM

The programs underway in the Grand Valley are a combination of irrigation management services (IMS) and investigation of water system improvements (WSI). The IMS phase is being implemented. The WSI, if implemented, in combination with the IMS program is expected to reduce the contribution of dissolved minerals by an estimated 200,000 tons/year. This is equivalent to a reduction of approximately 19 mg/l at Imperial Dam.

IRRIGATION MANAGEMENT SERVICES

Program Description

The purpose of the irrigation management services (IMS) program is to optimize water management to attain one or more specific goals of maximizing yields, net returns, water use efficiency, or minimizing indirect adverse effects. In the Grand Valley, IMS is expected to improve the efficiency of water use and thereby reduce the salt loading from the irrigated lands.

Under the IMS program, irrigators are provided professionsl services relating to the scheduling of irrigation. Research has shown that imprecision regarding the timing and amount of irrigation water applied is one of the major causes of low irrigation efficiencies. In the Grand Valley area, irrigation efficiencies were measured during the 1964 through 1968 period and found to average about 33 percent. Through cooperation with the irrigators in the IMS program, it is hoped that efficiencies could be increased to average about 55 percent. Concurrently, improvement of onfarm irrigation systems through the Soil Conservation District programs of the USDA should result in even higher irrigation efficiencies. These improvements would involve such measures as landforming, lining ditches, automation of delivery system, use of sprinklers, and installation of pumpback systems.

The IMS program focuses on advising the irrigator when and how much water to apply. In what is identified as the "Field by Field" method, the irrigator is provided with the daily soil moisture status of each of his fields in the program. He is provided with a recommended optimum date and amount for his next irrigation event. This is done by computer, utilizing a mathematical technique that simulates and predicts moisture use by the crops. Crop, weather, and soil data are used as inputs to make the predictions. The computer printouts are given to irrigators and they then follow the predictions as closely as their workloads permit.

The salinity control effort in the Grand Valley as structured around the IMS and onfarm system improvements involves considerable cooperation. Most farmers in the Grand Valley are interested in saving water and improving irrigation efficiencies. Participants in the IMS program were readily obtained on a voluntary basis. Also considerable cooperation in the effort has been and is being provided by the Colorado Water Conservation Board, Colorado River Water Conservation District, Grand Junction Drainage District, Grand Valley Water Users Association, Grand Junction Chamber of Commerce-Agricultural Subcommittee, Grand Valley Irrigation Company, Irrigators of the Grand Valley, Inc., Western Colorado Agricultural Advisory Council, Agricultural Stabilization and Conservation Committee, Mesa Soil Conservation District, Rifle Production Credit Association, Agricultural Research Service, Soil Conservation Service, U.S. Geological Survey, Environmental Protection Agency, Colorado State University Cooperative Extension Service, and Colorado State University Department of Agricultural Engineering. The work of these local, state, and Federal agencies is coordinated through the "Grand Valley Salinity Coordinating Committee." They also keep the public informed of the work and investigation being done.

Status of IMS Program

Through cooperation with the irrigation entities and other interested groups, 45 irrigators initiated the Grand Valley Irrigation Management Services Program in 1972. Eighty-seven fields totaling 1,050 acres were scheduled the first year. A good area and crop distribution was obtained.

One hundred twenty farms were scheduled during the 1973 irrigation season. These included 43 participants carried over from the 1972 season. All returning participants increased the acreage to be scheduled, with some including their entire farming operation in the program. During the 1973 season, 580 fields representing 7,200 acres were scheduled, comprising approximately 10 percent of the Grand Valley area.

With planned modifications to the field operation, it is believed that the IMS program can reach 14,000 acres during the 1974 irrigation season. In subsequent years, the irrigation districts and perhaps other entities will furnish personnel as the initial step to complete operation of the program by the local entities. An important goal is to have the program continued and financed by suitable local entities. Federal participation is scheduled to be concluded in FY 1977 at which time it is hoped that most of the irrigable land in Grand Valley will be covered by the IMS program.

Field Operations

The initiation of the irrigation scheduling activities required the assembly of considerable input data and the adjustment of the computer program to fit Grand Valley conditions. Emphasis was placed on proper characterization of the soil properties related to moisture retention and movement. Climatic data were obtained from available records . . . records obtained at the Grand Junction airport which are not representative of conditions in irrigated fields. Thus a complete weather station was established within the irrigated area to be representative of the irrigated environment for scheduling purposes. (See Figures 12 and 13.)

During the 1972 and 1973 seasons a CDC 3100 computer at the Atomic Energy Commission Compound at Grand Junction was used. Each field was visited weekly by one of the five field representatives to compare the computer printout with the actual field conditions. Crop status data stored on memory filed by the computer were then corrected as required.

Each field representative was assigned farms in four different general geographic locations to give them experience in a variety of locations and crops. Fieldwork in the Grand Valley Basin Unit is difficult and time consuming because the average field size is small (12.5 acres). The field representatives devote the same amount of time to each field regardless of size. During a farm visit they check such items as crop condition, root zone, water table, soil moisture, irrigation applications, and efficiencies. Any assistance requested by the participant on ways to improve efficiencies or calculate applicable rates was given.

Few fields, especially under the private companies, have water measurement devices, and most water measurement was done by the field representatives. During the 1973 season the participants were urged to report irrigation events and estimated applications by letter or telephone answering service.

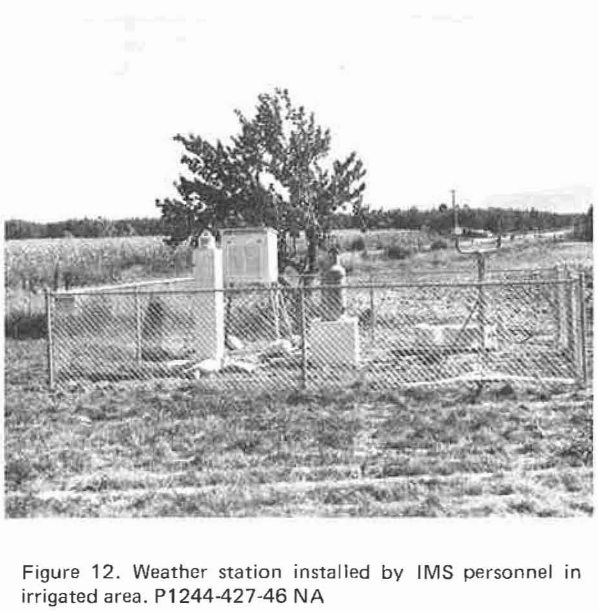


Figure 12. Weather station installed by IMS personnel in irrigated area. P1244-427-46 NA

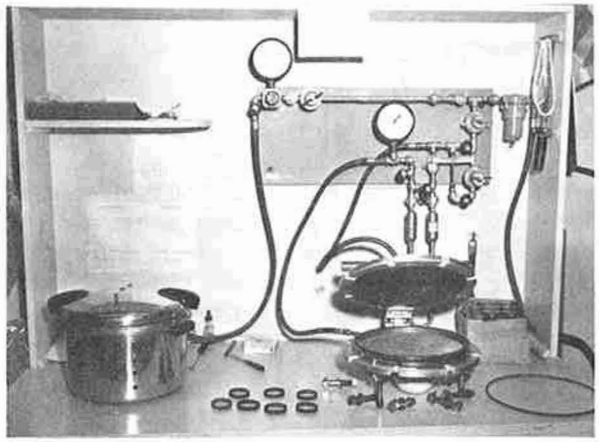


Figure 13. Soil moisture retention apparatus used to determine soil water holding capacities. P1244-427-47 NA

Ground-water observation wells have been installed in many fields to determine the effects of high water tables on crop consumptive use.

It has not been determined yet if the high water tables are caused by overirrigation or canal seepage. Additional wells were installed in the fall of 1973. More wells will be jointly installed for the Irrigation Management Services and System Improvement Programs. At the initiation of collecting water samples from these wells, additional soil samples were taken at the well site. Correlations will be sought between the ground-water salinity and soil salinity at various depths and times. Such data are required to evaluate the success of the IMS and Water Systems Improvement Program.

In the Grand Valley it will be a number of years before the total effects of scheduling will be realized. For this reason preliminary work was done in the fall of 1973 to evaluate isolated areas within the Grand Valley where a detailed hydrologic study could be made. With a joint program, a study of this type would be used to evaluate the effects of both the Irrigation Scheduling and Systems Improvement Programs in a shorter period.

WATER SYSTEMS IMPROVEMENT (WSI)

Plan of Development

A feasibility study in the Grand Valley area was begun in FY 1972 with the purpose of improving efficiency of the water conveyance systems and reducing the seepage losses. Such improvements are expected to further assist in reduction of the salt loading emanating from the irrigated areas of the valley.

Four irrigation entities divert water from the Colorado River. These include the Grand Valley Water Users Association (Bureau of Reclamation Project) and three private companies—The Grand Valley Irrigation Company, The Palisade Irrigation District, and The Mesa County Irrigation District. A fifth irrigation company, The Redlands Power and Water Company, diverts water from the Gunnison River. A number of other small companies have carriage agreements with the major canal companies for delivery of water. There are a total of approximately 210 miles of canals and 500 miles of laterals in the valley, with a few of the laterals and parts of some canals presently being concrete or gunite lined. Figures 14 and 15 are views of a lateral and a canal which is typical of the present condition of some of the systems.

Studies underway on water systems improvement include computation of irrigated acreages, lateral and canal sizing studies, locations and capacities of canal and lateral structures, canal and lateral lining studies, and computations of quantities for feasibility cost estimates to improve the entire system.

Studies were made on the conveyance systems capacities based on crop consumptive use employing the Jensen-Haise formula, cropping patterns, increased efficiency, and climatic data for the valley. Irrigation efficiencies were determined on study farms in conjunction with the study of Use of Water on Federal Irrigation Projects during the period 1964 to 1968. In 1969 the Agricultural Engineering Department, Colorado State University, collected field data for an agricultural land use survey of the entire Grand Valley. This survey included a breakdown of the various agricultural crops, municipal and industrial uses, open water surfaces, phreatophytes, and areas receiving only precipitation. This breakdown is essential in establishing the potential consumptive use for the hydrologic area. In 1973 the Bureau of Reclamation conducted a land use survey to compute consumptive use and losses in the Grand Valley. This survey was an update of the Colorado State University's 1969 survey. With the land use pattern thus defined, the capacities arrived at by the Jensen-Haise formula were close to the existing capacities, so the cost estimates were based on the present capacities.

Figure 14. View looking downstream at an unlined lateral from the Government Highline Canal. The measuring device shown in the foreground is typical of the few that are on the laterals. P1244-427-43 NA

Figure 15. Typical section of an unlined canal in the Grand Valley area. P1244-427-44 NA

For purposes of evaluation it is assumed that all canals and laterals would be concrete lined, with some pipe sections being used in areas in and around cities and towns, and other highly developed areas. Figure 16 is a view of a lateral which has recently been concrete lined. This construction would be similar to future construction.

Fencing would be installed along both sides of open concrete-lined sections where there is a safety hazard, and safety features are included for structures on canals and large laterals.

Figure 16. View looking downstream at a small concrete-lined lateral with a Parshall flume in the foreground. The lateral is paralled by private concrete ditches which are typical of onfarm improvements. P1244-427-45 NA

In areas where two or more laterals parallel each other very closely, consideration will be given to combining these laterals into a single lateral. Other than this type of combining laterals, the various irrigation companies will not consider any combination of their systems.

An alternative method of delivery of water through laterals by using an underground pipe system was studied for an area comprising about 6,700 acres in the lower Grand Valley. This study showed that the cost of this type system would be much greater than for a concrete-lined lateral system, therefore, a concrete-lined lateral system is described in this report. Should further study indicate that an underground pressure system would be more beneficial to areas of the valley, then consideration would be given to use of this type of system.

Water quality samples and flow measurement stations have been established on 10 drainages which carry return flow to the Colorado River. Data collected at these stations will assist in evaluating the present conditions and any salinity reductions resulting from irrigation scheduling and water systems improvements.

A study area has been selected in the valley to acquire detailed information on surface and ground-water quality and sources. A system of observation wells is planned to adequately define the water table, and as a means of sampling the ground water for quality determinations. Piezometers will monitor vertical gradients of water pressure through the soil profile, and gaging stations will measure inflow and outflow from the area. Parshall flumes will be installed on canals and laterals in the area to adequately determine seepage losses. After any irrigation scheduling or systems improvement is initiated, conditions would be monitored to ascertain the change in salinity levels due to scheduling and/or improvements. The method of determining changes in salinity levels would be a control area in which neither scheduling nor systems improvement would be done. Monitoring of this area would take place concurrently with the work in the project area, and comparisons made of the data collected from both areas. These results would be used to determine the downstream effects of irrigation management services and water systems improvements.

This feasibility study and related cost estimates include delivery of water to the individual farm property line. Estimates of onfarm improvements, such as concrete lining of farm ditches, installation of automated irrigation systems, land leveling, ditch structures, etc., will be prepared by the Soil Conservation Service. The Bureau will work very closely with the Soil Conservation Service on these estimates.

Modifications are being considered for the drains in the area. As of the present time, sufficient information has not been obtained to arrive at any definite drainage rehabilitation plans. The Grand Junction Drainage District is a member of the Grand Valley Salinity Coordinating Committee, and is kept advised on drainage plans. A large number of ground-water observation wells have been installed in the valley and are being monitored to obtain information which might be used for future drainage design. In addition, Colorado State University is conducting several experiments in the valley, one of which is a detailed study of drain spacing requirements.

A number of other programs and activities have begun in the valley, all of which have a direct bearing on the Water Systems Improvement Program. These include research on increasing irrigation efficiency and determination of mineral weathering and salt precipitation as a function of irrigation management being done by the Agricultural Research Service under contract with the Bureau of Reclamation, research on automated systems by the Colorado Water Conservation Board, initiation of conservation practices by the Agricultural Stabilization and Conservation Service in cooperation with the Soil Conservation Service.

The Agricultural Engineering Department, Colorado State University (CSU), is conducting salinity research for the Environmental Protection Agency. They are currently monitoring the salinity of water before and after its use for irrigation. They are monitoring approximately 12 square miles between Grand Junction and Clifton where they are attempting to accurately establish the salt contribution from irrigation on various types of soil and subsurface material. Canals, laterals, and drains throughout this area are frequently sampled and measured to establish salt loading and irrigation efficiency.

A number of fields within this area are actually being irrigated by CSU to insure maximum control and measurement of water. Recorders are employed to check water on and off of the field and salinity measurements are made. The Bureau is scheduling 16 of these fields.

The Colorado Water Conservation Board is conducting a pilot demonstration project for automated irrigation systems in the Grand Valley. Their primary objective is to test various modern onfarm irrigation systems and develop them for use in this area. They are currently engaged in work on three systems; an automated border irrigation system, an automated pump-back system, and a drip irrigation system.

The automated border system is established on one of the Bureau's scheduled farms and serves one field of alfalfa and two fields devoted to Jose' wheatgrass seed production. By use of a system of clock-controlled and float-controlled gates in the level concrete head ditch, it is possible for the operator to make several consecutive irrigation sets at one time. Irrigation across the field progresses, whether or not the operator is present, and a controlled head of water is delivered to each border.

The automated pump-back system was not operational in 1973 but will be in use in 1974. This system will collect tailwater from irrigated pastures for use on the subject field. Tailwater from this field will be reused on the field and complete records will be maintained on the quantity and quality of water. The Bureau expects to schedule this field as they are currently scheduling other fields on this farm.

The drip irrigation system was installed in a 10-acre peach orchard south of Palisade, Colorado, in the spring of 1973. This system delivers water through plastic pipe with drip emitters spaced along the pipe. The application is sufficiently slow to allow all of the water to move through the soil by capillarity. By trickling water to the root zones, it is believed that surface runoff can be eliminated, evaporation losses can be minimized, and no water will be wasted on weeds.

The Soil Conservation Service has since the middle 1940's been concerned with drainage, reclamation of salted areas and restoration of productivity. In recent years, their activities have been oriented toward increased irrigation efficiency and reduction of salt contribution to the river from irrigated land. The Agricultural Stabilization and Conservation Service in cooperation with SCS has been involved in cost sharing of conservation practicies such as ditch lining, pipelines, land leveling, drainage, and water control structures. Improvements that have been accomplished up to June 30, 1973, in the Grand Valley area include the following:

Concrete lining of lateral and onfarm ditches, 241 miles.
Construction of onfarm pipelines, 86 miles.
Construction of irrigation water control structures, which includes 8,099 structures such as division boxes, turnouts, measuring devices, and check structures.
Landforming on 24,392 acres, which consists of grading to a definite slope to increase irrigation efficiency.
Land smoothing on 3,599 acres, which consists of rough grading not to be a definite slope.
Water management on 56,000 acres. The farms that qualify must have an improved irrigation system, and must conform to irrigation practices outlined in the SCS irrigation guide.

The results of all of the above research studies where applicable are being used as input data for the system improvement study.

Investigation Schedule

Investigation work leading to a feasibility report began in FY 1972. Basic data such as maps showing canal and lateral locations, canal and lateral sizes, acreages served, cropping patterns, and structure locations were not available. Such information was thus compiled early in the program. At the present time, base maps and location maps have been prepared, conveyance capacities determined, acreages tabulated, and feasibility designs, and cost estimates prepared for all laterals. Also, ground-water studies have been progressing, including regular sampling of water quality and quantity at about 90 points in the valley. Studies are in progress and designs and cost estimates are being made for all canals in the valley.

Future work will consist of preparation of a cost estimate to place all laterals to the individual farm headgate in an underground pipe system. Concentrated studies will be made in a study area for the evaluation of surface and ground-water quality and sources and drainage requirements. Further studies will be made concerning benefits and beneficiaries, and a feasibility report prepared by the end of FY 1975.

COSTS

IMS Program

The average cost of the IMS program in the Grand Valley during 1973 was $1 per acre per month during the irrigation season. Because of the technical requirements needed to start such a program in the Grand Valley, highly qualified personnel have been required. Considerable technical and analytical work is done during the nonirrigation season. This work is needed to both establish the program and evaluate its success. As the program progresses and adjustments are made for the increased acreages in the program the costs will decline. When the program is taken over by the local entities it is anticipated that the costs will be between $1 and $2 per acre per year.

WSI Program

For purposes of preparing a feasibility cost estimate, the Grand Valley Unit was divided into 12 subareas. Each subarea includes a major canal or section of major canal and all laterals under that canal. A map of the Grand Valley Basin Unit is shown on Figure 10 and shows the irrigated area and all major canals in the valley.

Table 12 shows the initial capacities, lengths, and number of structures for each of the 12 subareas, including the major canals and laterals.

The estimates include costs for lining and structures for all canals and laterals except those presently concrete lined for delivery to each farm property line. Cost estimates of onfarm improvements including lining of ditches, leveling, constructing automated systems, etc., will be made by the Soil Conservation Service.

All canal deliveries are proposed to be at the same locations and at the same water surface elevations as the present deliveries. A study was made to compare the cost of lining the existing canal sections to the cost of partially filling in the existing canals and constructing a standard USBR concrete section. This analysis indicated that it would be more economical and also more practical to construct a standard USBR concrete section. Cost curves were developed for estimating earthwork and concrete quantities for various canal flows and slopes. As the existing canal cross sections are much larger than required for a typical USBR concrete canal, very little excavation will be required, and compacted backfill will be needed in all canals.

Nearly all structures along the canals could be replaced to present USBR standards. All canal turnouts could be replaced, and Parshall flume-measuring devices would be provided for all lateral and farm turnouts.

All laterals could be constructed using standard USBR concrete-lined sections and standard structures. Curves were also developed for estimating lateral earthwork and concrete quantities for the various sized laterals.

Costs at the feasibility level have not been completed at this time for all systems in the valley. However, with the studies completed to date, the estimated cost of the systems improvements, based on a July 1973 price level, is shown in Table 13.

BENEFITS

In addition to a reduction in salt loading of the Colorado River a multiplicity of corollary benefits would be generated by the IMS and WSI programs. Under the IMS program the irrigator can expect: (1) increased yield and quality of crops, (2) better use and savings of labor, (3) better use and savings of water, (4) reduced leaching of fertilizers and other agricultural chemicals, and (5) under some conditions, reduced drainage requirements. A survey following the 1972 program revealed that most participants felt they had increased crop yields as a result of the program. Crop census data further suggests that in 1972 the yield of row crops was increased about 5 percent on farms that were either fully or partially under irrigation scheduling. Because of the short period of record available no attempt has been made to impute monetary values to benefits other than the reduction in salt loading.

The IMS and WSI programs would also benefit the water users organizations. Expected benefits include reduction of operation, maintenance and management costs, improved control of drainage and ground water, and better control of water deliveries. Should the present water delivery systems in the valley be improved as described there will be a net savings in annual operation, maintenance, and replacement costs. Present annual operation, maintenance, and

Table 12

CANAL AND LATERAL DATA—GRAND VALLEY BASIN UNIT

System name	Initial capacity cfs	Length (miles)	Road crossings	Concrete canal bridges	Turnouts[2]	Parshall flumes	Drops	Checks	Pipe	Irrigation pipe flume crossings
Canals										
Government Highline	715	53		25	33					34
Grand Valley	650	12		} 24	} 256					10
Grand Valley Mainline	300	14								11
Grand Valley Highline	350	39		54	309					25
Mesa County	40	4		1	29					4
Independent Ranchmans	60	12		17	85					7
Price	80	9		21	139					15
Stubb	25	10		12	96					1
Orchard Mesa Power Canal	830	3		3	18					2
Orchard Mesa No. 1	80	16		} 48	} 238					12
Orchard Mesa No. 2	60	17								13
Redlands[1]	750	23								
TOTAL		212		205	1,203					134
Laterals										
Government Highline	1-30	160	494		1,028	99	662	277	0	48
Grand Valley	1- 8	29	130		187	196	0	91	18,900	3
Grand Valley Mainline	1-30	62	166		178	342	20	54	3,750	10
Grand Valley Highline	1-20	98	219		623	621	2	235	0	3
Mesa County	1- 8	14	94		99	99	0	45	0	0
Independent Ranchmans	1- 8	28	55		109	130	0	41	33,700	0
Price	1- 8	40	190		322	333	0	123	2,175	0
Stubb	1- 6	7	20		83	64	0	15	0	0
Orchard Mesa Power Canal	1- 4	} 29	} 82		} 121	} 121	0	0	0	0
Orchard Mesa No. 1	1-30						3	25	52,000	0
Orchard Mesa No. 2	1- 6	18	19		47	47	0	3	0	0
Redlands[1]		18								
TOTAL		503	1,469		2,797	2,052	687	909	111,525	64

[1] Most canals and laterals are presently lined or in pipe section.
[2] For (canals = constant head orifice—CHO)
(laterals = stemgate).

Table 13

ESTIMATED COST DATA–POTENTIAL WATER SYSTEMS IMPROVEMENT–
GRAND VALLEY BASIN UNIT

Subarea	Canal: Concrete lining ($)	Canal: Canal structures ($)	Laterals under canal ($)	Field cost ($)
Government Highline	6,000,000	1,138,000	6,976,000	14,114,000
Grand Valley Private Grand Valley Mainline	3,900,000	1,219,000	2,420,000	7,539,000
Grand Valley Highline	4,150,000	2,040,000	2,803,000	8,993,000
Mesa County	250,000	106,000	559,000	915,000
Independent Ranchmans	800,000	661,000	1,068,000	2,529,000
Price Ditch	450,000	884,000	1,351,000	2,685,000
Stubb Ditch	250,000	484,000	162,000	896,000
Orchard Mesa Power Canal	600,000	130,000		730,000
Orchard Mesa No. 1 Orchard Mesa No. 2	1,050,000	1,677,000	1,207,000	3,934,000
Redlands	800,000	55,000		855,000
Total field cost				43,190,000
Engineering and general expense				15,810,000
Total construction cost				59,000,000

The cost of the Redlands system includes only the power canal as nearly all of the other canals and nearly all the laterals are presently concrete lined or are in pipe sections.

replacement costs at the July 1973 price level are about $8 per acre, or about $570,000 per year. With water systems improvements, it is estimated that there will be a savings of about 33 percent in operation, maintenance, and replacement costs, which would be a savings of about $200,000 per year. Other beneficiaries would be downstream Colorado River water users in the lower Colorado Basin and Mexico, and the State of Colorado in the savings in water that could be used elsewhere in the state under Colorado's compact allotment. The benefits in the lower Colorado River Basin are estimated to be $4,370,000 annually for the Irrigation Management Services and Water System Improvements programs.

ECONOMIC AND FINANCIAL ANALYSIS

Based on the Reclamation report "Economic Impacts of Changes in Salinity Levels of the Colorado River" (1973), total benefits for irrigation, municipal, and industrial water have been estimated at $230,000 annually for each mg/l reduction with direct benefits amounting to $188,000 annually. Over a 100-year period of analysis at 6.875 percent interest, the total annual equivalent benefits for the Water Systems Improvement program and the Irrigation Management Services would be $4,370,000 and the direct annual equivalent benefits would be $3,570,000.

The costs of the construction of the alternatives cited are estimated at $59,000,000 with a reduction in the net operation, maintenance, and replacement costs of $200,000 annually. The costs associated with the Irrigation Management Services would be borne by the water users. At 6.875 percent, interest over a 100-year period, the total annual equivalent cost including interest during construction would be $4,735,000.

ENVIRONMENTAL CONSIDERATIONS

The IMS and WSI programs would enhance environmental values within the Grand Valley area and assist in improving water quality conditions downstream. With regard to the former, erosion along drains and washes would be expected to decrease due to reduction in return flows. Water tables would drop and some seep areas would disappear thus reducing vector problems. The esthetic appearance of the landscape would be improved with the concrete lining and pipe system.

Safety features incorporated into the designs would provide greater protection for humans, wildlife, and livestock.

With water deliveries controlled, opportunities would be created to develop special areas for wildlife. This would be needed to offset the impact of lower water tables and reduce drainage returns on phreatophytes and hydrophytes. Such vegetation provides habitat for game and nongame animals. Significant changes could, therefore, have an adverse affect on wildlife populations.

The phreatophytes include such high water use plants as salt cedar, greasewood, willows, and cottonwood. They occupy an area of 18,000 acres in the Grand Valley area.[3] The hydrophytes, including cattails and bulrushes, are also widespread in the valley. About 1,000 acres of seeped land occurs in the valley.[3] The IMS and WSI programs can be expected to affect such land areas, therefore, plans for protecting wildlife need to be evaluated. The studies would need to attempt quantification of the impacts on wildlife.

Currently, other factors are reducing wildlife habitat. These include ditch burning, spraying, mowing, and urbanization. The ongoing studies will need to determine what percent of habitat loss is due to IMS and WSI and what percent to other factors.

The reduction in return flow would reduce siltation in the Colorado River, conserve soil, and reduce salt loading. The improved water quality would be a long-term benefit to downstream users. As with other water quality improvement measures, the broad environmental influences include:

1. Protecting the highly diversified agriculture of the lower basin and thus supporting the economy of small communities dependent upon such production.

2. Sustaining the quality of life by assisting an agriculture that provides an important diversity to the United States diet . . . such agricultural resources are limited in the United States.

3. Conserving water that could become available for energy production, recreation, and other nonagricultural uses.

4. Using less water for crop production since higher quality water reduces the leaching requirement and enhances reusability.

5. Conserving resources since water treatment requirements for municipal and industrial uses would be reduced and plumbing and appliance replacement times would be increased.

As the studies progress, environmental impact analysis is being fitted into the plan formulation process. Important data collection activities are underway and evaluation of alternatives and their impacts are being determined.

CRYSTAL GEYSER UNIT, UTAH

INTRODUCTION

The Crystal Geyser, a privately owned abandoned oil test well, located 3.5 miles south of the town of Green River, Utah, on the east bank of the Green River contributes about 3,000 tons of salt annually to the Colorado River system. (See Figure 17.) The saline water located some 700 feet deep in the Navajo Sandstone Formation erupts in the form of a geyser at about 5-hour intervals due to carbon dioxide accumulations. (See Figures 18, 19, and 20.) The concentration of the water ranges from 11,000 to 14,000 mg/l and the annual flow amounts to about 150 acre-feet. The climate at the geyser is a desert type with an average annual temperature of 52° F and an average annual precipitation of 6 inches. The vegetation in the geyser area is sparse with tamarisk and scattered cottonwood trees along the edges of the river and cactus, Brigham tea, greasewood, and shadscale elsewhere.

The estimated annual removal of salt by the alternative plans is about 3,000 tons, a relatively minor amount. Salinity concentrations of the Colorado River at Imperial Dam would be reduced by an estimated 0.3 mg/l.

STATUS OF INVESTIGATIONS

A feasibility report for control of the geyser and environmental assessment is now being reviewed. This report is based primarily on an investigation conducted by the Brigham Young University through contract with the Bureau of Reclamation.

[3]Anonymous. 1965. Water and Related Land Resources: Colorado River Basin in Colorado, Colorado Water Conservation Board and United States Department of Agriculture.

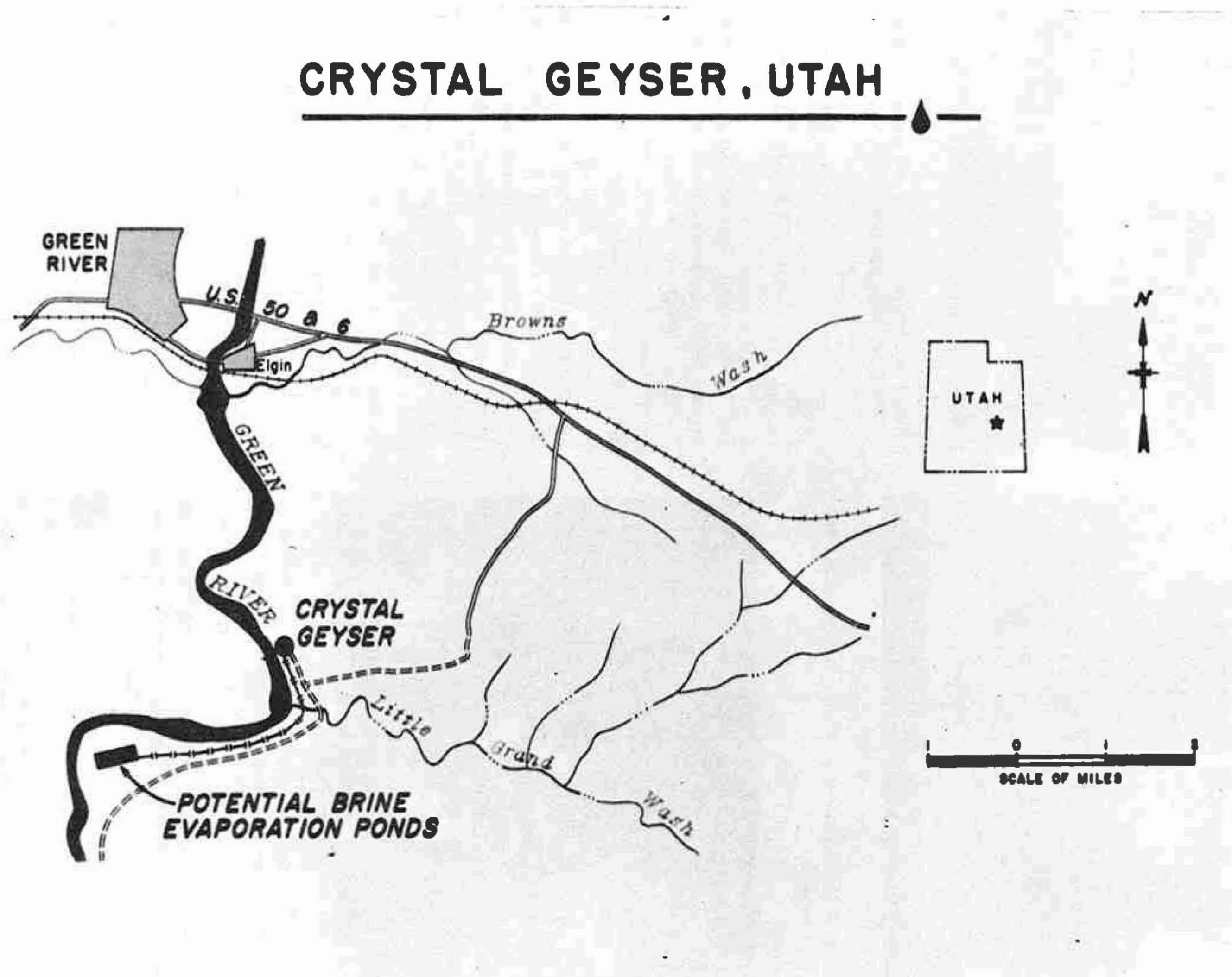

CRYSTAL GEYSER, UTAH
GREEN RIVER
U.S. 50 & 6
Elgin
Browns
Wash
GREEN
RIVER
CRYSTAL GEYSER
Little
Grand
Wash
POTENTIAL BRINE EVAPORATION PONDS
UTAH
N
0 1 2
SCALE OF MILES

Figure 17

Figure 18. Eruptions occur at 5-hour intervals from this abandoned oil well.

Figure 19. Water from an eruption flowing into the Green River. The annual water contribution is about 150 acre-feet.

Serious consideration was given to plugging the geyser. Important geological facts, however, were brought out in the course of the investigation that discouraged this as a means of control: (1) The well was drilled in an area of eruptive activity already in existence; (2) The well penetrates the Little Grand Wash Fault and provides a ready outlet for the carbon dioxide buildup at this location; and (3) Any plugging of the well would, in all likelihood, cause an eruption to occur at some other location along the fault, possibly in the river channel. For these reasons this means for control of the geyser is not considered desirable.

Figure 20. Measurement of the water during an eruption. Green River in the background.

ALTERNATIVE PLANS

Two plans, both of them to collect the flows and convey them to evaporating ponds within a distance of 3 miles, appear to be most feasible although other alternatives of eliminating the salt have not entirely been abandoned. These two plans have been designated at Alternate A and Alternate B. Alternate A would have as a first stage a concrete wall with a spillway surrounding the erupting points to temporarily store and regulate flows before delivery to the evaporation ponds. Alternate B would have as a first stage a layered soil-cement dike with a spillway constructed around the erupting points replacing the concrete wall and be designed to blend with the exposed sandstone formations, making it a more esthetic sight.

After a year's operation of the regulatory pond at the geyser with spills recorded through a 12-month cycle the second stage would be constructed with a pipeline large enough to convey the maximum recorded spills to the evaporating ponds.

ECONOMIC AND FINANCIAL ANALYSIS

The estimated construction costs for each of the alternates are:

	Construction cost
Alternate A	$460,000
Alternate B	$490,000

Estimated annual operation, maintenance and replacement cost is $3,000.

The geyser is presently a minor tourist attraction being located 6 miles from U.S. Highway No. 50. Local benefits would include improved access to the geyser which might possibly entice some tourists to use Green River, Utah, as a stopping point. There would be an annual loss of water by evaporation of about 150 acre-feet. The benefits in the lower Colorado River Basin are estimated to be $69,000 annually.

ENVIRONMENTAL CONSIDERATIONS

Control of the salt loading from this point source could have the following environmental impacts.

Negligible change on the macroinvertebrate populations of the Green River below Crystal Geyser because of the insignificant effect on the large volumes of water in the Green River.

With the surrounding dike or concrete wall, erupted water will be ponded over the geyser openings causing an immediate pressure buildup in the well and resulting in eruptions every 2 to 3 hours rather than every 5 to 6 hours. This could increase the potential for tourism and visitors. Also, depending upon the plan, some benefits may be derived from increased recreation through camping and picnicking in the area. The added influx of people would have an adverse impact on the sparse vegetation. This effect would be minimized by restricting foot traffic to marked trails. The economy of the Green River area, however, would be increased due to tourism.

The pipeline for delivery of water from the geyser to the evaporation pond would have only a minimal environmental impact. About one-third of the pipeline would be buried and the other two-thirds would traverse flood plains of the Green River and Little Grand Wash.

Less than an acre of ground would be disturbed in the borrow pit excavation for the dike surrounding the geyser. The evaporation ponds would require 20 to 40 acres of land. Possibilities of wind scattering the salt or of rupture of the ponds would exist. These could cause some damage to vegetation in surrounding areas or enter the Green River. The appearance of the area would be changed by the unnatural white salt flats in the evaporation ponds that could be observed from nearby roads.

LAS VEGAS WASH UNIT, NEVADA

INTRODUCTION

The Las Vegas Wash is a natural drainage channel which drains the Las Vegas Valley watershed area of 2,200 square miles into the Colorado River (see Figure 21). Approximately 50 miles long and varying in width from 5 to 25 miles, the valley contains the major population center of the State of Nevada and has experienced one of the fastest population growth rates in the United States (approximately 10 percent per year) since 1940. The Las Vegas Wash flows through the valley in a general southeast direction and terminates at the Las Vegas Bay arm of Lake Mead in southern Clark County, Nevada.

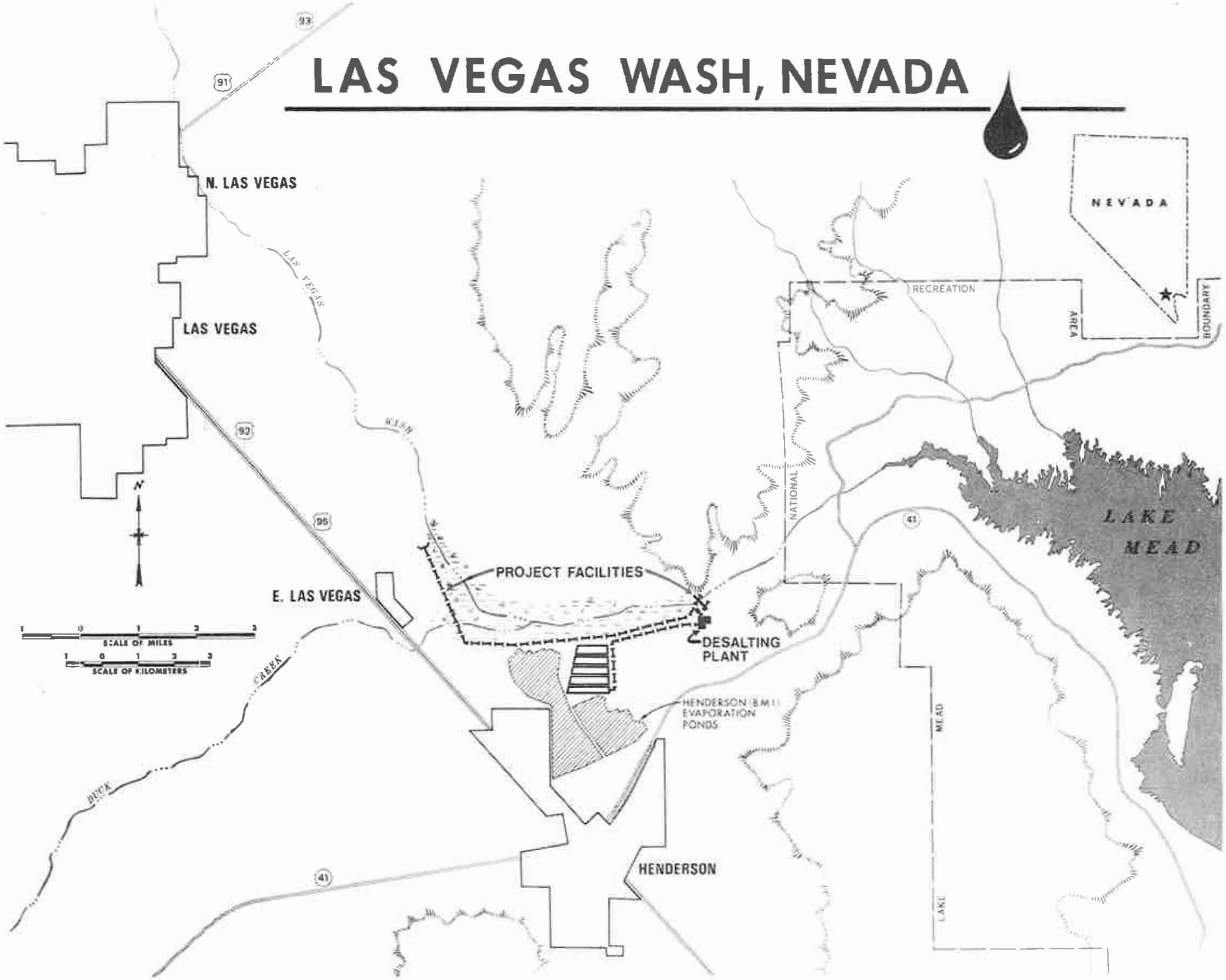
Historically, Las Vegas Wash was an intermittent stream discharging only during periods of high rainfall and runoff. Around the turn of the century the valley was developed as a railroad community with limited farming and mining. With increasing development, the use of the ground water in the valley continually increased. Eventually, municipal and industrial wastewaters were discharged to Las Vegas Wash and these, along with return flows and seepage from the near surface aquifers, have created a perennial flow into the lake (see Figure 22). These wastewaters are polluting Lake Mead and the Colorado River downstream.

THE LAS VEGAS WASH AREA

For purposes of the study, the wash is considered as being the lower 11-mile portion of the drainage between Las Vegas and Lake Mead, consisting of about 1,800 acres of dense marsh and phreatophyte vegetation in a strip about one-half mile wide in the upper portion and decreasing to a narrow gorge in the lower portion.

The topography of the valley consists of smooth, gentle alluvial slopes bounded by relatively high steeply sloping mountain ranges which trend north-south. The area can be classified in three physiographic units: mountains, alluvial aprons, and basin lowlands.

The arid climate of the area is characterized by low humidity, high evaporation, abundant sunshine, mild winters, hot dry summers, and a wide range of temperatures, both daily and seasonally. The mean annual temperature is around 66°, with extremes ranging from 8° to 117°. The average annual precipitation is less than 4 inches, and the relative



LAS VEGAS WASH, NEVADA
N. LAS VEGAS
LAS VEGAS
E. LAS VEGAS
HENDERSON
PROJECT FACILITIES
DESALTING PLANT
HENDERSON (B.M.I.) EVAPORATION PONDS
LAKE MEAD
NEVADA
RECREATION
AREA
BOUNDARY
NATIONAL
LAKE
MEAD
LAS VEGAS WASH
DUCK CREEK
N
SCALE OF MILES
SCALE OF KILOMETERS

Figure 21

Figure 22. Las Vegas Wash looking downstream from North Shore Road toward Lake Mead. Vegetation in the wash consists of tules and salt cedar. P45-300-7275

humidity averages about 28 percent. The frost-free growing season approximates 241 days.

The largest economic factors in the area are tourism and recreation, which are aided by legal gambling, natural scenic wonders, top-rated shows and entertainment, an excellent climate, outdoor recreation (golfing, fishing, boating, water skiing, sightseeing, etc.), convention facilities, and excellent transportation.

The 1973 population as estimated by the Regional Planning Council is as follows: Las Vegas, 259,170; North Las Vegas, 55,629; Henderson, 17,477; unincorporated areas, 9,257; for a total in the valley of 341,533.

The water supply for the valley comes from wells and from Lake Mead through the Southern Nevada Water System.

LAS VEGAS WASH FLOWS

Based on an average rate of flow of about 50 cfs and a weighted average salinity of 4,228 mg/l, the wash has been contributing an average of 208,000 tons of salt per year to Lake Mead and the Colorado River.

The flows of the wash come from several sources: secondary treated effluent from the city of Las Vegas sewage treatment plant; secondary effluent from the Clark County Sanitation District sewage treatment plant; highly saline cooling water from two powerplants; highly saline industrial wastes from the Basic Management Incorporated (BMI) industries in Henderson; secondary effluent from the city of Henderson and BMI sewage treatment plants; and return flows from agricultural irrigation, domestic irrigation, and septic tanks.

Wastes entering Lake Mead, contribute to algae growth during some periods, forming unsightly and odorous blooms in the bay. The dissolved solids in the water mix in the lake and eventually flow downstream to water users in Arizona, California, and Mexico. (See Figures 23 and 24.)

LEGAL AND INSTITUTIONAL FACTORS

In December 1971, the Environmental Protection Agency (EPA) instituted a 180-day enforcement action against the major polluting Governmental agencies and industries in Las Vegas Valley. Since the termination of the 180-day period, the various industries at BMI and the two Nevada Power Company powerplants have been granted permits under the National Pollution Discharge Elimination System and are responsible for developing plans in the immediate future in compliance with the EPA action to prevent further pollution of the wash.

Recognizing that proper planning was required to accomplish a solution, the enforcement action requires that a workable solution be scheduled and submitted to EPA for approval.

In 1973, the Nevada legislature empowered Clark County to assume the responsibility for the collection, disposal, and treatment of sewage and wastewater in the valley. This legislative act also assigned to the county the responsibility for the development and implementation of a pollution abatement plan for the Las Vegas Wash area. To meet the EPA standards the office in charge of the program (Clark County Pollution Abatement Project) is planning an advanced wastewater treatment plant (AWT) for the sewage flows from Las Vegas and the county system to meet the EPA standards. The city of Henderson will treat its own sewage to EPA standards.

Figure 23. View showing conditions of the shoreline at the swimming area on Las Vegas Bay, Lake Mead. P45-300-7269

Figure 24. Aerial view of Las Vegas Wash Bay showing the mouth of Las Vegas Wash in the upper right as it enters Lake Mead. P1244-300-01046

The remaining flows in the wash derive from surfacing ground-water returns and fall under the category of point sources of salinity within the definition of the Colorado River Water Quality Improvement Program. These saline ground-water flows lend themselves to salinity control activities which are consistent with proposed Federal legislation and the activities of the Bureau of Reclamation. Both the Colorado River Commission of Nevada and the Board of Clark County Commissioners passed resolutions in August 1973 urging the Bureau of Reclamation to immediately initiate reviews and studies to produce an early report leading to construction of a Federal salinity control project in Las Vegas Wash.

ALTERNATIVE PLANS

One alternative plan for reducing the salinity contributions of Las Vegas Wash ground water consists of an interception facility, a delivery system, a treatment plant, a brine discharge and evaporation system, and a surface flow bypass system.

This alternative could remove about 138,000 tons of salt per year by desalting the ground-water component. It would reduce the salinity of the river by about 13 mg/l at Imperial Dam.

In normal operations, ground-water flows which presently surface above a narrow point in the wash formed by a so-called natural "barrier" would be collected at that point by a system composed of a grouted and backfilled cutoff wall and a series of perforated pipes (french drains) surrounded by pervious materials. The collected flows would be directed by the drains to a main sump box where they would be pumped by a small pumping plant to a nearby reverse osmosis desalting plant. Manmade surface flows in the wash (mainly AWT treated effluent) would be diverted above the ground-water collection site and conveyed by pipeline around the site.

The product water from the desalting plant could be combined with the effluent from the AWT plant for invalley use or released to Lake Mead for credit to Nevada's 300,000 acre-foot depletion allotment from the Colorado River. The brine residue would be conveyed to a lined evaporation pond near the site or pumped to Dry Lake northeast of Las Vegas for evaporation. The county presently has plans for a pipeline to the Dry Lake vicinity for delivery of AWT effluent to Nevada Power Company's proposed Arrow Canyon Powerplant for cooling purposes. If built, this same pipeline could be used by the "slug-flow" method to handle the brine wastes.

During periods of floodflow conditions in the wash, the flows in excess of the diversion and bypass capacity would pass over the diversion facility crest and follow the natural wash channel to the lake. Project operations would be temporarily suspended during such periods.

An alternative plan was also considered which would utilize the same collection and bypass facilities but would have a pumping system and evaporation ponds for total invalley evaporation of the ground water in lieu of a desalting plant. Such a scheme would require an area of about 2,300 acres of land for lined evaporation ponds. This alternative would have a higher investment cost than the one evaluated above, but the OM&R costs would be less; consequently, the total annual equivalent costs would be lower. The salt removal would amount to about 131,000 tons per year in such a plan. Up to 15,400 acre-feet per year of a critical water supply would be sacrificed to evaporation.

Other alternatives, such as export to Dry Lake and other areas, are also under investigation.

Economic and Financial Analysis

A comparison of costs for a desalting alternative versus an invalley evaporation scheme is as follows:

	Alternatives	
	Desalting plant	Total evaporation of ground water
Total estimated cost	$31,667,000	$49,590,000
Annual equivalent investment cost	2,397,000	3,764,000
Annual OM&R	2,878,000	200,000
Total annual equivalent costs	5,275,000	3,964,000
Cost effectiveness	$38/ton	$30/ton

Annual equivalent total benefits for the alternatives to irrigation, municipal, and industrial Colorado River water users in the United States are estimated to be $2,990,000 for the desalting plan and $2,760,000 for the evaporation plan, respectively. Other benefits would accrue to recreation and fish and wildlife in the Lower Basin.

STATUS OF INVESTIGATIONS

A special report which lists possible approaches for a solution to the problem has been prepared and is under review process. Included in the report will be the costs and benefits of the alternatives studied. More detailed studies will be necessary to select the most viable alternative for a salt reduction system.

ENVIRONMENTAL CONSIDERATIONS

The environmental impacts would be dependent upon the alternative selected for controlling the flow of Las Vegas Wash. In general, the implementation of the control measures for the wash would reduce the pollution of Lake Mead and the salt concentration of the Colorado River. The wastewater would be reclaimed for beneficial use, and the unpleasant odors caused by algal growth would be reduced. It would enable continued growth in the area and create construction and maintenance employment.

The Las Vegas Wash area is of great concern and is highly valued by a substantial segment of the community for its recreational advantages, as was evidenced by the report "Environmental Assessment, Pollution Abatement Project, Las Vegas Wash and Bay," by VTN Nevada & Jones and Stokes Associates, Inc., November 1972.

The main Las Vegas Wash channel supports an area of dense vegetation extending over about 1,800 acres (see Figure 25). This growth is composed mainly of cattails, reeds, and other aquatic plants. Along most of the wash, a dense growth of salt cedars also borders the marsh. The wash supports two species of fish as well as numerous species of birds, mammals, and reptiles. It would be highly desirable to release controlled amounts of water so as to maintain a permanent green belt.

Construction of the desalting alternative would have an adverse effect on the environment within the construction area. The esthetic value of the immediate area would be altered during construction. Noise, dust, inconvenience, erosion, and loss of a small amount of vegetation and wildlife could result from the proposed action. The operation of a desalting plant would require a significant amount of electrical power, necessitating the construction of additional generating facilities in the area and in an increased demand upon fossil fuels. Product brine residue or saline residue would require disposal facilities. Areas may be committed to evaporation ponds causing loss of present use of such areas.

Figure 25. Rank tule and salt cedar growth in the vicinity of the Geological Survey gage on Las Vegas Wash. Water shown is effluent from Clark County and Las Vegas sewage disposal plants. P45-300-7276

LaVERKIN SPRINGS UNIT, UTAH

INTRODUCTION

LaVerkin Springs, located in the southwestern corner of Utah, are highly saline discharges which contribute an average salt load of 109,000 tons per year to the Virgin River, a tributary of the lower Colorado River. Feasibility studies on this point source of salinity were started in fiscal year 1972 and are scheduled to be completed in fiscal year 1974. The Regional Director's Proposed Report was completed in July 1973 and is currently under administrative review in the Office of the Commissioner. One of the alternatives evaluated in this report consists of potential desalting of the spring flows to remove approximately 103,000 tons of salt per year. A draft environmental statement is scheduled for completion in early 1974.

THE LaVERKIN SPRINGS AREA

The immediate project area includes the reach of the Virgin River from the Hurricane Diversion Dam upstream from the springs to the St. George-Washington Diversion Dam 15 river miles downstream from the springs (see Figure 26). The principal communities in the general vicinity are St. George, approximately 17 miles to the west of the springs, and Cedar City, approximately 40 miles to the north.

LaVerkin Springs, sometimes referred to as "Dixie Hot Springs," are located on the intersection of the river and the Hurricane Fault Ridge near the lower end of Timpoweap Canyon. Of deep-seated origin and probably under high heads, the hot flows (ranging from 100^{o} to 109^{o} F) issue from a number of vents in the riverbed and both banks along a 2,000-foot reach. During the late summer and fall, they constitute nearly all of the riverflow downstream from the discharge points.

The physiography of the area is spectacular and colorful. The predominant topographic and geologic feature is the Hurricane Fault escarpment. This westward facing escarpment is the boundary between the Colorado Plateau physiographic province to the east and the Basin and Range physiographic province to the west. The escarpment is 800 feet high and is characterized by steep limestone cliffs indented with canyons. The Virgin River flows in the deepest canyon, which is known as Timpoweap Canyon. The topography east of the escarpment is characterized by high plateaus, flat-topped buttes, and deep gorges; all

LA VERKIN SPRINGS, UTAH

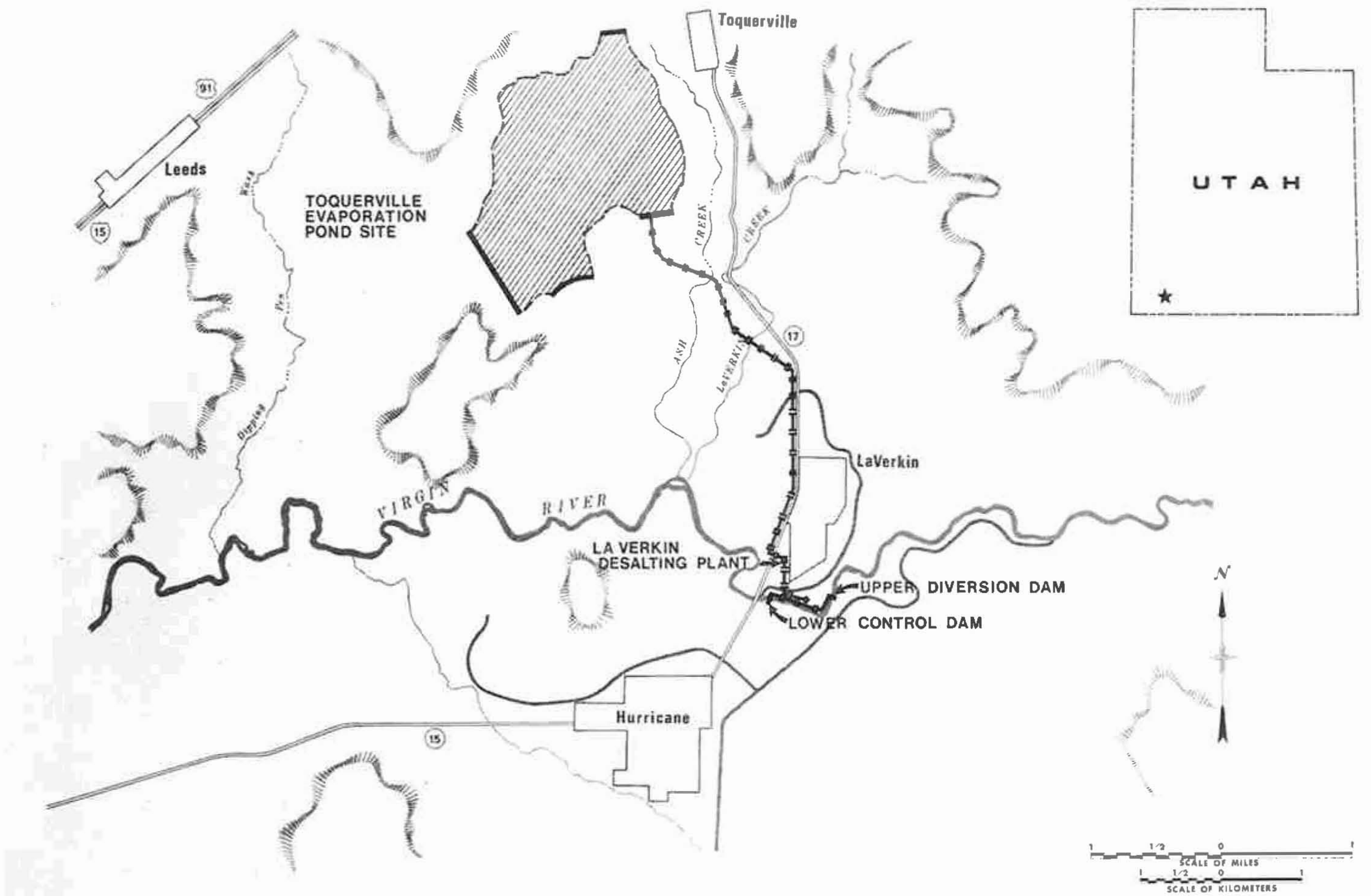


Figure 26

of which expose multicolored, essentially flat-lying strata.

The topography west of the escarpment is more subdued and characterized by low mountain ranges and wide valleys eroded in folded and faulted strata.

The climate is arid to semiarid, with hot summers, mild winters, and wide daily extremes in temperature. The mean annual temperature is 61° F, and the annual frost-free period averages 213 days. Nearly half of the precipitation in the area occurs during the winter months of December through March.

Although the area has remained basically agricultural since its settlement in about 1852, there has been a steady growth in tourist businesses, service industries, and urban developments. The favorable climatic conditions, in combination with the colorful and frequently spectacular geologic formations, have created an increasing tourist and recreational use of the land.

WATER SUPPLY

LaVerkin Springs

Because of the large number of spring outlets and the location of some of them in the bed of the river, direct measurements of the discharges are not practical. Estimates have been made, however, by measuring the riverflows above and below the spring area. On the basis of these measurements, a maximum spring flow of 12 cfs was selected for the purpose of designing the control facilities, and an average flow of 11.5 cfs was adopted for evaluating the effects of the project on water quantity and quality.

From January through November 1972, water samples were collected from 13 springs, 2 drill holes, and 2 points in the river (1 above and 1 below the springs). Chemical analyses indicated a maximum salinity of 10,000 mg/l for designing the project and an average value of 9,650 mg/l for estimating the effect of the project. Based on an average flow of 11.5 cfs at 9,650 mg/l, the salt contribution to the Virgin River averages 109,000 tons per year. The Environmental Protection Agency has indicated that the spring flows contain, in addition to the salts, the radiactive element radium-226 in average concentrations of about 37 picocuries per liter.

The Virgin River

From April 1909 to September 1971 the Geological Survey operated a gaging station on the river at Virgin, Utah, about 5 miles upstream from LaVerkin Springs. The records prior to 1926 are fragmentary. Although the average flow for the entire period of record was 145,000 acre-feet per year, the average during the period of October 1939 through September 1971 as used in the feasibility study was 123,700 acre-feet per year.

Chemical analyses conducted at the Virgin River gage by the Geological Survey from October 1950 to September 1956 showed an average weighted salinity of 489 mg/l, with average annual values varying from 390 mg/l to 588 mg/l. Using the relationship of total dissolved solids to discharge, the water quality records were extended to cover the 1940-1970 study period. This resulted in an estimated average salinity of 493 mg/l, which is good for agricultural use and satisfactory for most municipal and industrial uses. This represents the average quality of water diverted for irrigation from the Hurricane and LaVerkin Diversion Dams in Timpoweap Canyon.

The average flow and salinity of the river below the springs were computed from the records of the gaging station at Virgin, the diversions at the Hurricane and LaVerkin Diversion Dams, and the inflow from the springs. This yielded an estimated average flow of 115,000 acre-feet per year at 1,153 mg/l, for an average annual salt load of about 180,400 tons. Samples collected from the river below the springs during the feasibility studies ranged from 1,357 mg/l to 8,622 mg/l, with the wide variation reflecting the fluctuating amount of riverflow available to dilute the spring discharges. Water of this quality has historically been diverted at the St. George-Washington Diversion Dam for agricultural use, but has limited the range of crops and necessitated a considerable amount of leaching during periods of high flow.

LEGAL AND INSTITUTIONAL FACTORS

Within the immediate project area all but the extreme floodflows of the Virgin River, including tributary inflows, irrigation return flows, and spring discharges, have been completely appropriated under existing water rights. During much of the irrigation season, no flows are allowed to pass the St. George-Washington Diversion Dam. The allocations are interrelated and dependent upon the available riverflows, and a depletion of water by a desalting alternative could consequently affect the water rights of many users.

The removal of dissolved salts from LaVerkin Springs would involve an incidental consumptive use of water, creating a situation which has not previously been specifically recognized in interpretations of Utah State Law. While this depletion could clearly conform to the State requirements of a "useful and beneficial purpose," such a use has never been included in decisions rendered by the Utah Supreme Court. In addition, the alternative would require continuous operation for maximum benefits and would at times be in direct conflict with the legal priorities of domestic and agricultural use during times of scarcity. Consequently, the implementation of this alternative would entail a legal recognition regarding the priorities of water use.

ALTERNATIVE PLANS

Facilities

In order to effectively treat the discharges of LaVerkins Springs, the flows of the Virgin River could be diverted around the spring area and the spring flows collected to the riverbed. The ponded water could subsequently be pumped to a potential reverse osmosis desalting plant for treatment, with the resulting product water returned to the river system and the brine waste transported to an evaporation pond for disposal. Figure 27 shows how this alternative could be located with the exception of the evaporation pond.

A concrete upper diversion dam, consisting of an overflow spillway and abutments, could be located above the uppermost spring outlet and would divert the riverflows around the area by means of a buried reinforced concrete bypass pipeline. The latter would be about 2,100 feet long and 96 inches in diameter and would have a maximum capacity of 1,275 cfs, although floodwater would top the spillway crest when diverted flows exceeded 950 cfs. Flow duration studies indicate that the entire riverflow would be diverted approximately 98 percent of the time. The bypassed

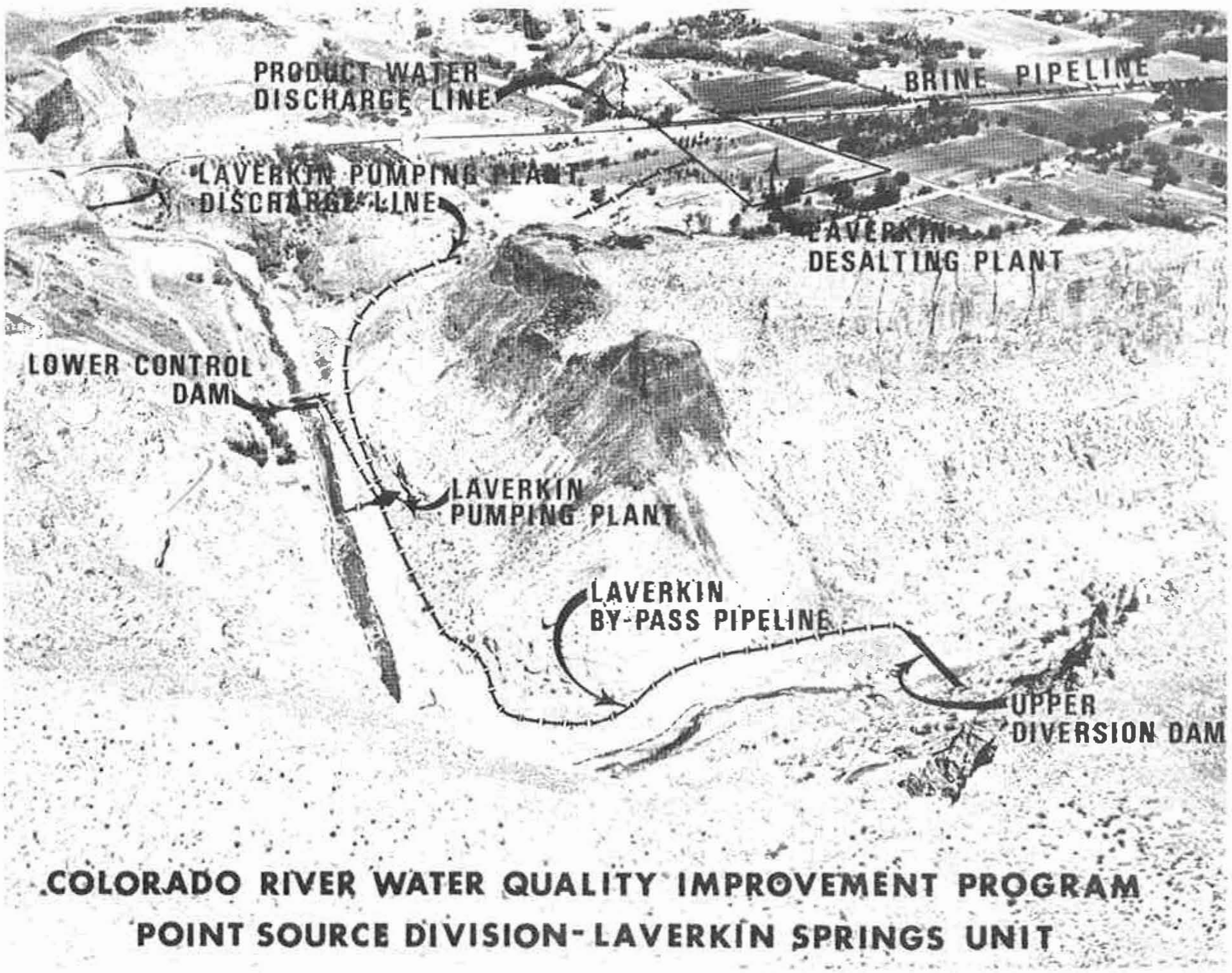


Figure 27

flows would be discharged into the river channel immediately downstream from the lower control dam, which would be constructed to collect the spring flows.

The control dam could consist of an inflatable fiber-fabric tube affixed to an embedded concrete apron, with a cutoff wall and grout preventing seepage beneath the structure. When inflated with product water, the dam would provide a depth of about 6 feet for impounding the spring discharges. The tube would be deflated whenever riverflows were too great to be completely diverted, allowing the floodwaters to pass unhindered down the river channel and clear the ponded area of sediment and debris. During such an event, the water level between the dams would not be higher than under existing natural conditions.

The spring flows ponded by a lower control dam would be pumped through a total lift of about 160 feet to a potential desalting facility located on an 8-acre plot on a low plateau above the river near the town of LaVerkin. Here, the flows would be softened to remove calcium, cooled to about 75° F, filtered to remove suspended particles, and desalted in a three-stage reverse osmosis process. From a maximum design feed water of 12 cfs at a salinity of 10,000 mg/l, the plant would yield a product water of 8.3 cfs at a salinity of approximately 500 mg/l and a brine waste of 2.8 cfs at a salinity of about 33,000 parts per million. The remaining flow would be lost through evaporation or in the form of a chemical sludge from the softening process.

The product water could be returned to the Virgin River through an 18-inch-diameter, 1,600-foot-long pipeline, while the brine waste and chemical sludge would be conveyed to an evaporation pond located 4 miles north of Hurricane. The brine pipeline would consist of 18,120 feet of buried reinforced concrete pressure pipe and 800 feet of steel pipe for two creek crossings. The total required lift of about 300 feet would be achieved with the residual pressure from the desalting plant.

Formed by constructing several dikes around a natural depression, the 440-acre evaporation pond would be lined with a PVC sheeting in order to prevent any seepage of brine into the local ground-water systems. The size would be sufficient to retain inflows from precipitation and storm runoff and would provide enough capacity to store over a 200-year accumulation of salt deposits.

By treating 98 percent of the average spring flows, the desalting alternative could remove about 103,000 tons of salt per year which have historically entered the Colorado River, thus reducing the salinity of Lake Mead and of the Colorado River below Hoover Dam. Under present modified conditions, salinity levels could be lowered by about 9 mg/l at Imperial Dam. In achieving these results, the project would decrease the flow of the lower Colorado River by about 2,470 acre-feet per year.

The potential operation of the pumping plant and the desalting plant could require electrical power of about 30,327 megawatt-hours per year. This could be obtained from the California Pacific Utilities Company, which supplies three-phase power in the general area. As an alternative, however, the potential to develop geothermal energy as a source of power is being considered. The Geological Survey has classified the springs as a prospective area for geothermal development, and preliminary geochemical analyses indicate maximum temperatures in excess of 360° F. While generally marginal for power production, temperatures in this range could provide sufficient energy to desalt the spring flows, possibly by a distillation process.

Economic and Financial Analysis

Based on the report "Economic Impacts of Changes in Salinity Levels of the Colorado River" (1973), total benefits for irrigation, municipal, and industrial water have been estimated at $230,000 annually for each mg/l reduction with direct benefits amounting to $188,000 annually for each mg/l. Over a 100-year period of analysis at 6.875 percent interest, the total annual equivalent benefits would be $2,070,000 and the direct annual equivalent benefits would be $1,692,000. There would also be unmeasured benefits to recreation and fish and wildlife in the lower basin and to 7,600 irrigated acres on the Virgin River below LaVerkin Springs.

The costs of one alternative is estimated at $20,028,000, including $300,000 for obtaining water rights and excluding $425,000 for nonreimbursable investigation costs. At 6.875 percent, interest during the 3-1/2-year preconstruction and construction period would amount to $1,432,000. The following tabulation illustrates the derivation of the total annual equivalent costs for the project, which would be $3,229,000.

	Estimated costs
Total Estimated Cost	$20,453,000
Less: Investigation Cost	425,000
	$20,028,000
Plus Interest During Construction	1,432,000
Investment Cost	$21,460,000
Annual Equivalent Investment Cost	1,477,000
Annual Equivalent OM&R Cost	1,752,000
Total Annual Equivalent Cost	$ 3,229,000

ENVIRONMENTAL CONSIDERATIONS

The LaVerkin Springs area is located in the Lower Sonoran Desert of southwestern Utah, and the native vegetation is characteristic of much of the arid southwestern United States. Among the more common species in the area are creosote bush, blackbrush, shadscale, mesquite, and 4-wing saltbush. Willows, salt cedars, and cottonwood trees grow along streams and ditches; and salt grass, greasewood, and inkweed are found in areas of poor drainage or high salinity.

There are various upland game species, primarily on irrigated croplands and along stream channels. Ducks and Canadian geese utilize the agricultural lands for winter feeding stops. Indigenous small mammals include bobcats, coyotes, foxes, badgers, skunks, weasels, rabbits, and several species of squirrels and mice. There are a number of reptiles in the general vicinity.

The Virgin River from LaVerkin Springs to Lake Mead, a distance of about 134 river miles, is the only known habitat of the endangered woundfin *(Plagopterus argentissimus)*. Other fish species with small populations and limited ranges include the Virgin River spinedace *(Lepidomeda m. mollispinis)*, the Virgin River bonytail *(Gila elegans)*, the bluehead mountain sucker *(Pantosteus clarki delphenus)*, and the flannelmouth sucker *(Catostomus latipinnis)*.

The features of the desalting alternative, which would require about 680 acres of Federal, State, and private land for rights-of-way, would be located primarily on sparsely vegetated habitat. Consequently, impacts on wildlife should be minimal. There could, however, be a long-term adverse impact on some of the unique fish in the project area, particularly the woundfin and the Virgin River spinedace.

Esthetically, the area would be permanently changed at the sites of the various potential features, although adverse effects would be ameliorated by the restoration of areas temporarily disturbed by construction activities. The potential structures would generally be small and visible for only short distances.

In addition to land and water uses, the desalting alternative would require commitments of electric power, construction materials, chemicals, and public funds. Power requirements could be obtained from a local utility or from an alternative development of geothermal energy to operate the desalting facilities.

The desalting alternative would provide considerable direct and indirect employment during construction and a lesser amount of permanent employment for the operation and maintenance of the desalting plant. Generally, the economic impact in and around the immediate area should be beneficial.

The following investigations are under continuing study and field evaluation efforts to examine other alternatives for salinity control. Most of the studies are not sufficiently advanced to identify specific salt removal prospects and environmental impacts, but show significant control potential from initial appraisals.

The investigations in this category are focused on both the structural and nonstructural controls or techniques applicable to irrigation, point, and diffuse sources of salinity. The basic strategies applied to these studies include improving irrigation efficiencies, containment, control, or treatment of salinity sources, and utilization of saline return flows.

The continuing investigations directed at irrigation salinity sources include Palo Verde Irrigation District, Colorado River Indian Reservation, Uinta Basin irrigation, and Lower Gunnison Basin irrigation. Point source studies include Littlefield Springs, Glenwood-Dotsero Springs, and Blue Springs. Studies on diffuse sources include the Big Sandy River, Wyoming, the Price, San Rafael, and Dirty Devil Rivers in Utah, and McElmo Creek in Colorado. Finally, the potential use of agricultural wastewater to support energy development and other beneficial consumptive uses is examined by studies on the Palo Verde Drain System, Grand Valley collection system, and the San Juan collection system.

IRRIGATION SOURCES

Major program emphasis for control of irrigation sources is placed on improved irrigation management and improved control of waterflow in canals, laterals, and drainage systems. Both the Irrigation Management Services (IMS) and Water Systems Improvement (WSI) portions of this program have been recently expanded by the Bureau of Reclamation into seven western states covering over 118,000 acres of irrigated land. Included in this total are four major irrigation districts within the Colorado River Basin which serve as key demonstration projects.

The IMS program is a nonstructural management technique to increase onfarm irrigation water efficiency. Major benefits derived from irrigation management services include increased crop yields, water savings, reduced leaching of soils, and reduced drainage requirements.

The WSI program, on the other hand, involves a structural water management tool to improve water delivery conveyances in order to reduce drainage and seepage salinity pickup. The lining of canals and laterals as well as installation of field drainage systems can result in decreased losses and percolation, reducing water contact with high saline soils, shales, and ground-water aquifers. Recent EPA estimates indicate that a 50 percent reduction in seepage flow may result in 30 to 70 percent reduction in salt load.

For efficient salinity control, particularly to meet a wide range of local conditions, both the IMS and WSI programs must be considered under an integrated program. At present, based on available data, it is difficult to separate the relative effects of each program. Consequently, both programs are considered as operating together for field evaluation and feasibility studies.

Aside from expected salinity control benefits, firm economic returns to the farmer have been reported in terms of increased crop yields. Recent evaluation of IMS benefits in Idaho show increased crop yields of 12 to 32 percent representing increased farm incomes of $12 to $85 per acre. Although there are many differences in crops, soils, climates, etc., these basic economic incentives are also expected to occur in the Colorado River Basin.

Of the two programs considered, however, IMS is likely to be among the least expensive methods of achieving salinity reductions. There are no significant structural measures associated with IMS and therefore no future large capital investments. Initial funding is needed for training personnel, developing and adapting computer programs to the service area, and establishing the cooperation of local irrigators. It is anticipated that the local water user organizations will assume operation of the irrigation management services upon completion of the scheduled investigation period for each unit.

The major constraint on the use of IMS is found in the institutional structure of western water laws. Present laws actually serve as a deterrent to any more efficient water use that results in water savings. Such a savings over historical use patterns could cause a loss of a portion of a water right, considered very valuable to irrigated agriculture. However, with the proven potential of increased crop yields and demonstration of economic gains from more efficient use of water, IMS is considered to have significant potential for salinity control.

The pertinent data for the four investigation units under both IMS and WSI application are shown in the following summary Table 14. The scheduled field evaluations will yield estimates of total costs and identification of more definitive control effects.

Table 14

COMBINED PROGRAM

Irrigation Management Services—Potential Water Systems Improvement

Investigation unit	Present irrigated land—1,000 acres	Salt load Tons/Year	Estimated control effect		Annual estimated benefits—$1,000[1]
			Tons/Year	mg/l Reduction at Imperial Dam	
Palo Verde	91	148,000	23,000	3	690
Colorado River Indian Reservation	60	30,000	7,000	1	230
Unita Basin	170	450,000	100,000	9	2,070
Lower Gunnison	160	1,110,000	300,000	27	6,210

[1]Based on Gross Benefits of $230,000 per mg/l.

PALO VERDE IRRIGATION DISTRICT UNIT CALIFORNIA

The Palo Verde Irrigation District is a privately developed district located in Riverside and Imperial Counties, California, as shown in Figure 28. Water for irrigation is diverted from the Colorado River at the Palo Verde Diversion Dam and is conveyed through 295 miles of main canals and laterals to serve approximately 91,400 acres of irrigated land within the District. The irrigation return flows are collected in a 153-mile drainage system and returned to the Colorado River. It is estimated that these return flows contribute about 148,000 tons of salt annually to the river.

Irrigation Management Services Program

The irrigation management services program in the Lower Colorado Region was implemented on the Palo Verde Irrigation District during calendar year 1973. Through improved irrigation management, a reduction can be achieved in the volume of irrigation return flows and an overall reduction in the amount of salt loading attributed to these flows. The primary technique employed by this program is the development and dissemination of information on the timing of irrigation and the applied amount. A computer program developed by the Bureau of Reclamation is utilized in the process.

A contract was executed by the Bureau of Reclamation and the Palo Verde Irrigation District on April 27, 1973. As provided for in the contract, the Bureau and the District will cooperatively conduct an Irrigation Management Services Program using climate, crop, and soil data to provide a method that is expected to improve crop quality and yields and more effectively utilize irrigation water. The demonstration phase of this cooperative program began in 1973 and is scheduled to be completed in June 1978. The District has assigned an employee to work directly with Bureau personnel assigned to the program. The employee will at all times remain under the direction and control of the District. The District's representative will be trained in irrigation scheduling by Bureau personnel, so that at the end of the demonstration period he will be capable of assuming full responsibility for the operation of the program. The District is expected to assign additional employees to the program when benefits are demonstrated to the District and to farm owners and operators. The District personnel will be given increased reponsibilities in operation of the program until such time as it is mutually agreed that the District personnel are capable of operating the program by themselves. At this time, the Bureau personnel will be withdrawn from the program on the District level and the District will assume full control. Technical liaison will be maintained thereafter by agreement between the Bureau and the District in order that the District will have access to the computerized program and technical assistance as needed. Development of the program is scheduled for a maximum of 5 years; 1973-1978. After this period, the District has agreed to assume operation of the program provided the program's value has been demonstrated.

Water Systems Improvement Program

These studies will identify the improvement works needed in the irrigation systems and determine the reduction in salt loading that can be obtained by an improved irrigation system. Improvements such as lined canals and buried pipe are expected to reduce return flows, and this in turn will reduce the salt load that is now returned to the river.

Over 886,000 acre-feet of Colorado River water were diverted to irrigate 91,400 acres in 1972, and over 443,000 acre-feet with an average salinity of 1,757 mg/l were returned to the river by the drainage system (see Figures 29 and 30).

The investigation for the unit will evaluate the condition of the existing distribution system and determine the potential for reducing losses from the system. The program is closely tied to the irrigation and management services program, and figures quoted in regard to potential salt loading reductions assume an integrated application of both programs. Feasibility investigations were initiated in fiscal year 1974 and are scheduled to be completed in fiscal year 1975. A feasibility report is scheduled in June 1975.

Costs and Benefits

The total Federal investment, during the IMS demonstration phase of this program will amount to about $400,000. The total WSI investigation costs are estimated to be $35,000. Costs estimates for rehabilitating the irrigation distribution system have not yet been made.

The benefits of both programs will accrue to the farmer, the irrigation district, and to the lower Colorado River water users. The farmer will benefit by increased crop yields, improved crop quality, reduced labor costs, reduced water changes, and reduced fertilizer costs. The irrigation district will benefit by requiring less water diverted through a more efficient distribution system along with improved scheduling capability and fewer drainage structures. The combined effect of both programs will benefit the lower

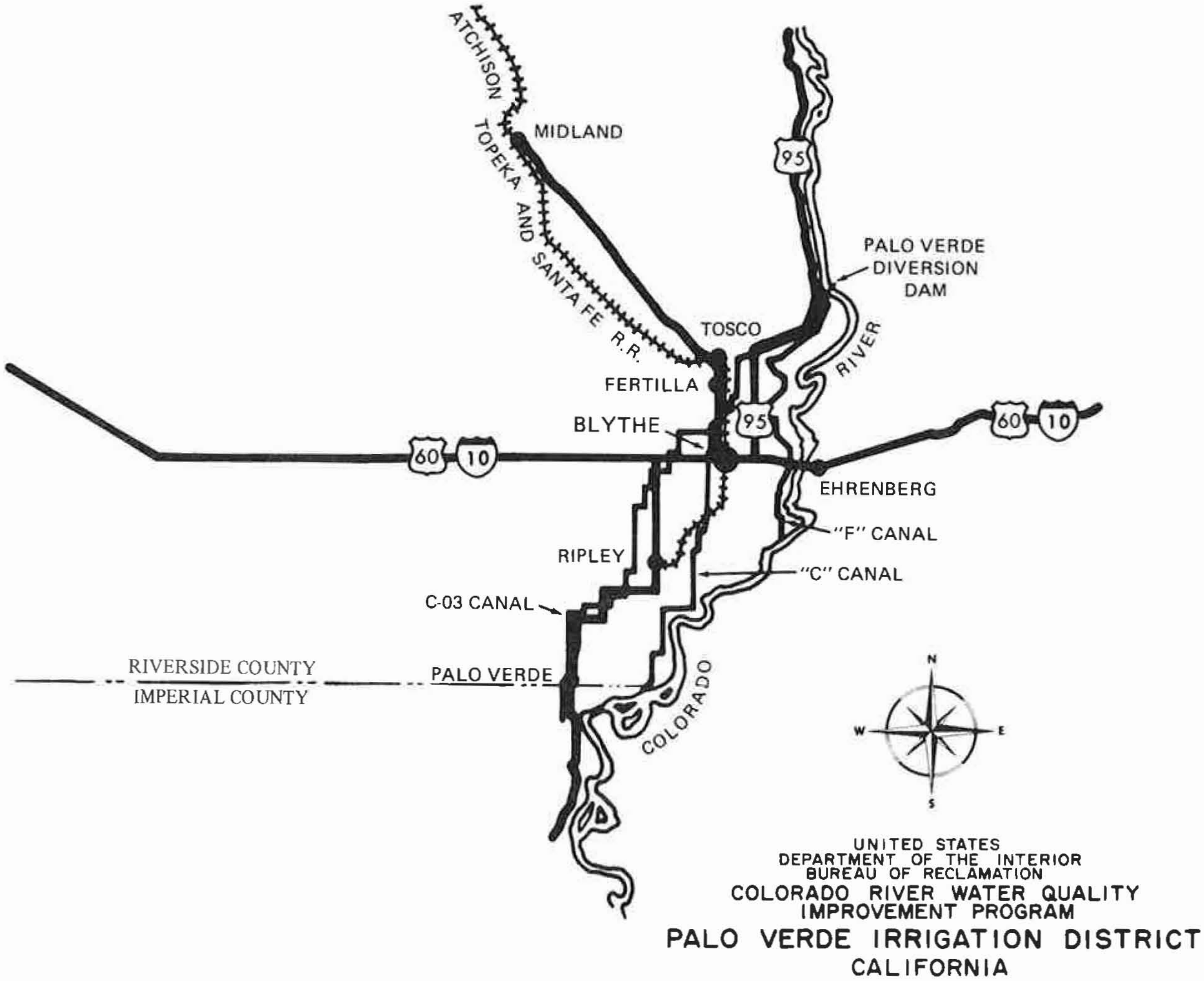


Figure 28

Colorado River water users by reducing the salt load in the river by 23,000 tons of salt annually, thus lowering the salinity at Imperial Dam by 3 mg/l. However, most of the direct economic benefits can be attributed to the IMS portion of the program.

Environmental Considerations

The improvement of the water conveyance systems to reduce losses and increase operational efficiency, matched with the improved efficiency of onfarm irrigation water use, will have beneficial environmental impacts resulting from the reduced salt load of the Colorado River and the reduced salinity at Imperial Dam. Small wildlife may be adversely affected as a result of the reduced seepage, the lowered water table, and less waste of water from the lined canals or buried pipeline. The energy required for this action will be minimal and will primarily occur during the construction period.

Some improvement would result in the esthetic appearance of lined canals and buried pipes over those unlined with weeds and grass growing on the banks and in the bottom of the canal. If some canals are converted to a pipe system, hazards toward loss of animal or human life would be reduced.

The lining of the canals could have an adverse effect on small animals and wild birds that may use the bank vegetation for cover or nesting. Moreover, the amount of open water in drains and washes would probably be reduced to the detriment of species such as ducks, muskrats, and various amphibians.

Figure 29. View showing the Palo Verde Diversion Dam on the Colorado River and the headworks of the District's main canal. P385-300-5769 NA

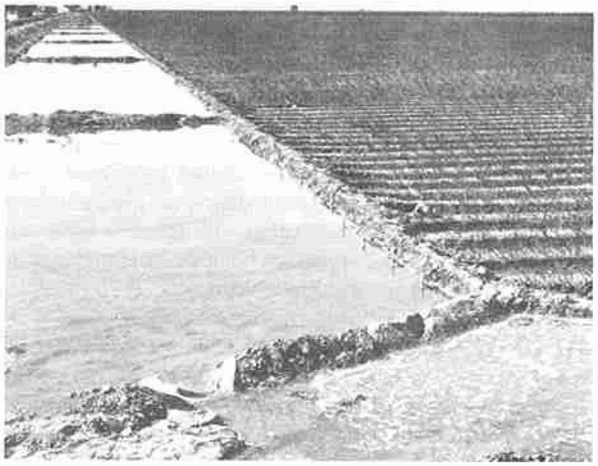


Figure 30. Irrigation in the Palo Verde Irrigation District. P178-300-11388

Reduction of wasted water to drains and low areas including slough and pastures may also reduce the vegetative growth for supplying cover and nesting areas for game birds. It could also reduce subirrigation water supplies to pasture lands. It would, however, reduce mosquito breeding areas and decrease consumptive use by such plants as greasewood, salt cedar, willows, cottonwoods, and cattails.

COLORADO RIVER INDIAN RESERVATION UNIT, ARIZONA

The Colorado River Indian Reservation is located along the Colorado River below Parker Dam (see Figures 31 and 32).

The U.S. Supreme Court allocated water to irrigate 107,588 acres, of which 99,375 acres are in Arizona

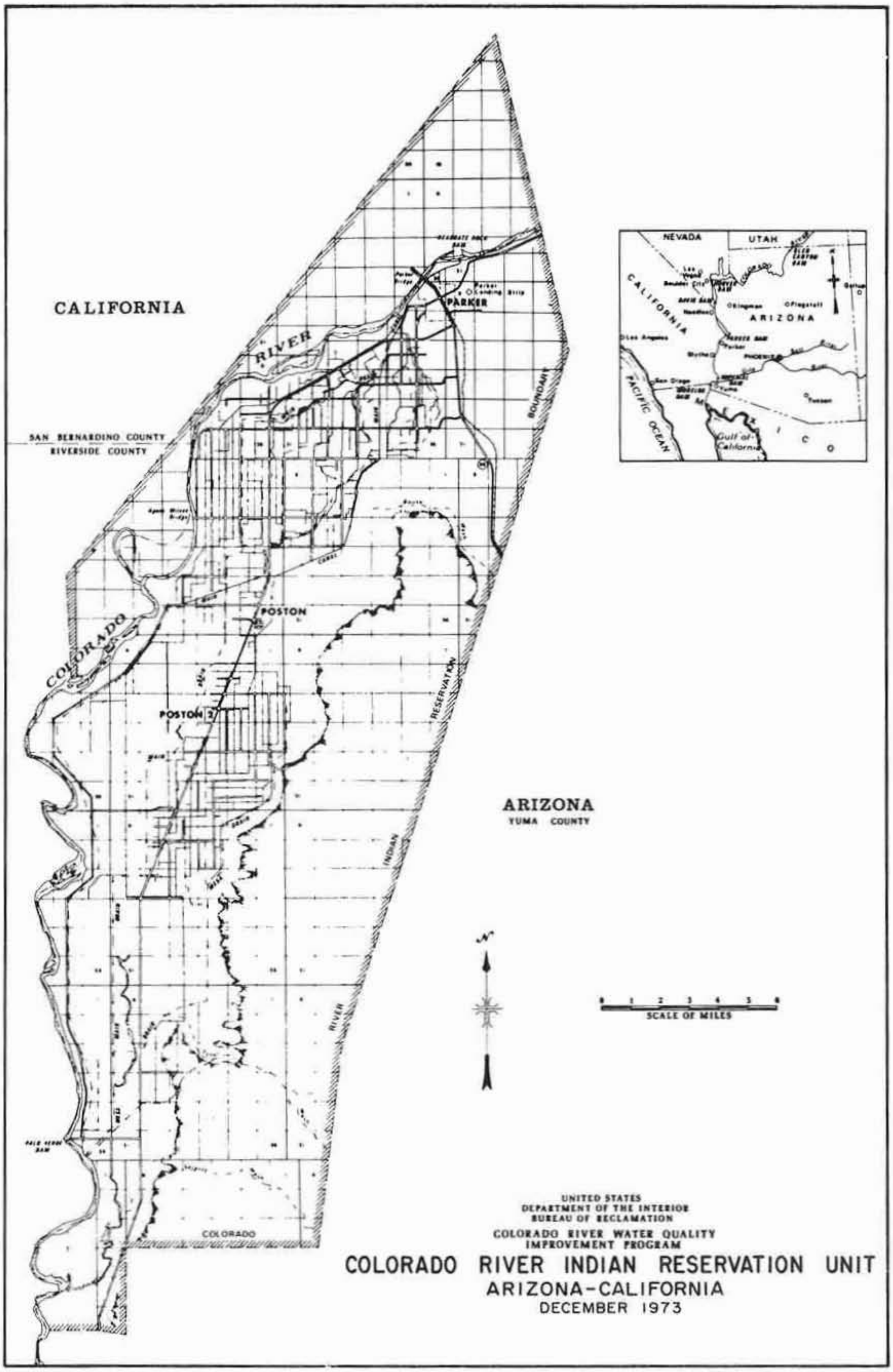

CALIFORNIA
SAN BERNARDINO COUNTY
RIVERSIDE COUNTY
RIVER
COLORADO
PARKER
POSTON
POSTON 2
ARIZONA
YUMA COUNTY
BOUNDARY
RESERVATION
INDIAN
RIVER
COLORADO
NEVADA
UTAH
CALIFORNIA
ARIZONA
PACIFIC OCEAN
Gulf of California
SCALE OF MILES
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER WATER QUALITY
IMPROVEMENT PROGRAM
COLORADO RIVER INDIAN RESERVATION UNIT
ARIZONA-CALIFORNIA
DECEMBER 1973

Figure 31

Figure 32. View showing the Colorado River and irrigated land on the Reservation. P423-300-8911

and 8,213 acres are in California. The court's allocation also provided for a maximum diversion of 717,148 acre-feet per year. In 1972 there were 60,000 acres irrigated with Colorado River water diverted at Headgate Rock Dam. About 200 miles of canals and laterals delivered water to irrigate this acreage. The irrigation system will be expanded to supply water to irrigate about 93,000 acres in Arizona by 1980. Irrigation return flows are collected in a 100-mile drainage system and returned to the river just below the Palo Verde Diversion Dam. It is estimated that under present conditions these return flows contribute about 30,000 tons of salt annually to the Colorado River and this will significantly increase as the irrigated acreage increases.

Irrigation Management Services Program

The IMS Program was initiated on the Colorado River Indian Irrigation Project during calendar year 1973. By a letter of agreement dated October 1, 1973, the Bureau of Reclamation, the Bureau of Indian Affairs (BIA), and the Colorado River Indian Tribal Council for the Colorado River Indian Irrigation Project entered into an agreement for developing an IMS program within the Colorado River Indian Irrigation Project. Under the agreement the BIA was assigned one employee to work directly with the Bureau of Reclamation personnel. The BIA employee will at all times remain under the direction and control of the BIA. This representative is being trained in the science of irrigation scheduling by the Bureau of Reclamation personnel, so that at the end of the demonstration period he will be capable of assuming responsibility for the operation of the program. The BIA is expected to assign additional employees to the program as benefits are demonstrated to the Colorado River Indian Irrigation Project and to farm owners and operators. The BIA personnel will be assigned increasing responsibilities in operation of the program until such time as it is mutually agreed that these personnel are capable of operating the program. At that time, the Bureau of Reclamation personnel will be withdrawn from the Colorado River Indian Irrigation Project and the Council and/or the BIA will assume full operation of the program. Technical liaison will be maintained thereafter by agreement between the Bureau of Reclamation and the Council and/or the BIA in order that the Colorado River Indian Irrigation Project will have access to the computerized program and technical assistance as needed.

A demonstration period of about 4 years is planned, during which time the water users will become proficient with the operation and apprised of the benefits of the program. This period will not extend beyond June 30, 1978. At the conclusion of the demonstration stage, the BIA and the Colorado River Tribal Council will continue the program, provided that it has a demonstrated benefit.

Water Systems Improvement Program

Studies will be made to identify the improvement works needed in the irrigation system and to determine the amount of reduction in the salt loading of the river that can be obtained by an improved irrigation system. Concrete-lined distribution systems are presently being installed to serve newly irrigated lands, but there is a need to rehabilitate portions of the old distribution system in order to reduce losses. In 1972, 676,828 acre-feet were diverted to lands in Arizona from the Colorado River and from wells along the river.

These investigations were initiated in fiscal year 1973 and are expected to be completed in fiscal year 1976. A feasibility report and an environmental impact statement are scheduled to be completed in June 1976.

Costs and Benefits

The total Federal investment during the IMS demonstration phase of the program (through fiscal year 1978) will be about $400,000.

Investigation costs of the WSI program are estimated to be $225,000. Construction costs are not yet available. These costs will be developed during progress of the investigation.

The combined programs are anticipated to reduce the present salt load of 30,000 tons by 7,000 tons. This will lower the salt concentration at Imperial Dam by 1 mg/l. The studies now underway will firm up these estimates and develop recommendations for reducing the salt load returned to the stream. As further acreages are developed, a substantial increase in the effect at Imperial Dam is anticipated.

Environmental Considerations

The general considerations discussed earlier for the Palo Verde Irrigation District also apply to the Colorado River Indian Reservation. Specific effects on local wildlife species have not yet been determined.

UINTA BASIN UNIT, UTAH

The Uinta Basin lies between the Uinta Mountains on the north and the Tavaputs Plateau on the south in northeastern Utah. The climate in the basin is extremely variable. The summers are normally hot, with low humidity, and the winters are relatively severe. Extreme fluctuations in precipitation and temperature occur over the area. Average annual precipitation is about 7.5 inches in Roosevelt, Utah, and about 8.5 inches in Altamont, Utah, near the areas where irrigation scheduling has been started. The average annual temperature is 47° F ranging from minus 32° F to 105° F. Irrigated lands in the Uinta Basin totaling 170,000 acres are located (Figure 33) primarily on alluvial materials adjacent to rivers and on benches and mesas. The Uinta Mountains, several peaks of which exceed 13,000 feet, are the main source of water for the Basin. The mountain front stream above the irrigated lands produce high-quality water with total dissolved solids ranging from 30 to 350 mg/l. Water quality in the basin deteriorates as return flow from irrigated areas enter the Duchesne River and its tributaries. Concentrations in the Duchesne River below most irrigated land range from 200 to 3,400 mg/l with an average of 680 mg/l.

The Uinta Basin contributes about 450,000 tons of salt annually to the Colorado River—much of it from irrigated areas. IMS and WSI programs are proposed to control the salt pickup from the irrigated lands.

Irrigation Management Services Program

Irrigation scheduling was begun in the Uinta Basin in the spring of 1973, when Bureau of Reclamation personnel met with the Moon Lake Water Users Association and explained the proposal. From initial contacts with 26 farmers, 16 agreed to participate in the program. These irrigators owned 81 fields with a total of 1,312 acres. Soil samples were taken from the fields of the participants and tested for bulk density

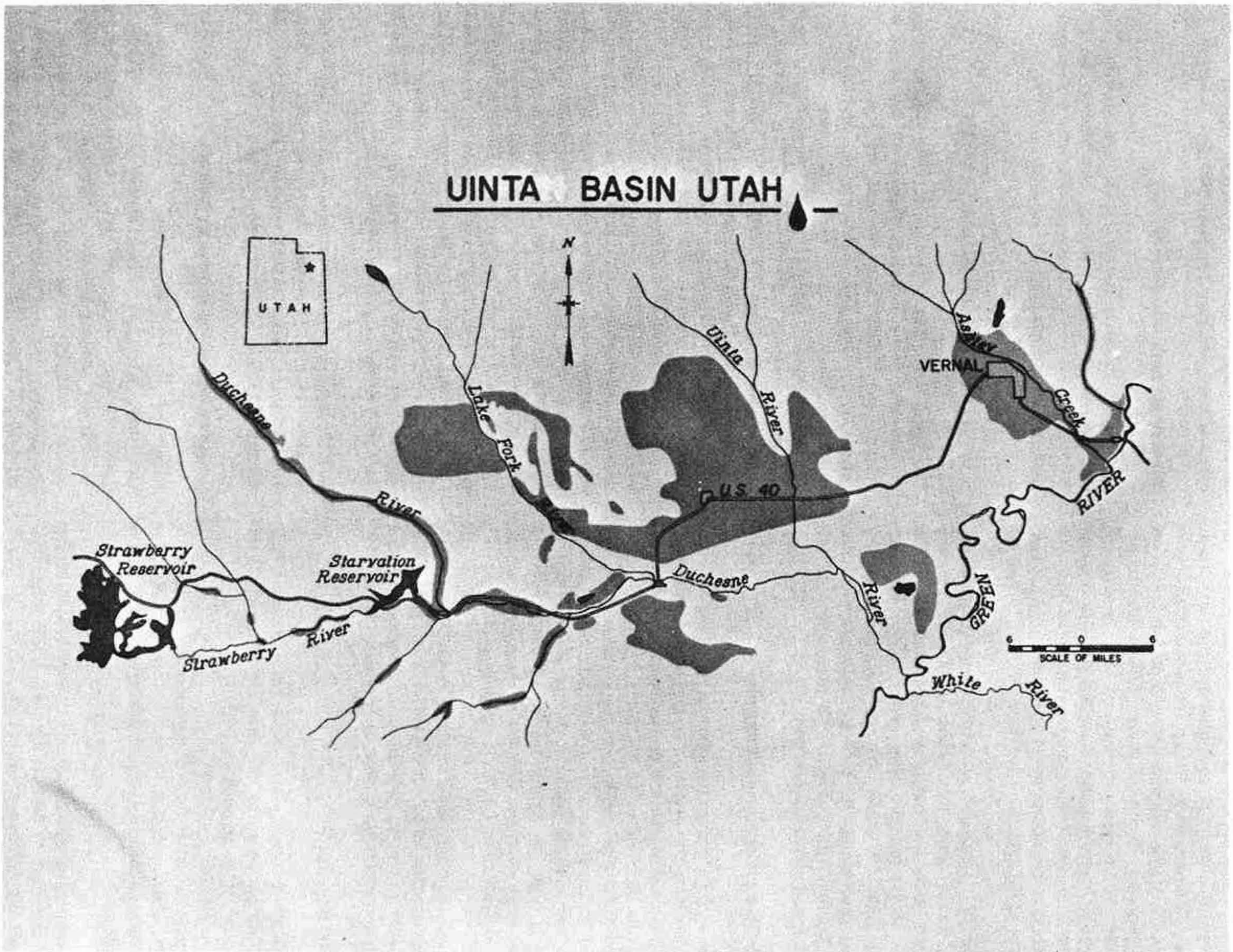

UINTA BASIN UTAH
N
UTAH
Duchesne
River
Lake
Fork
Uinta
River
Ashley
Creek
VERNAL
U.S. 40
RIVER
GREEN
Duchesne
River
Strawberry
Reservoir
Starvation
Reservoir
Strawberry
River
White
River
SCALE OF MILES
6
0
6

Figure 33

and moisture-holding capacity. Two weather stations were established in the area to obtain the required climatological data (see Figure 34).

The scheduling computation program was adapted to the Univac 1108 computer, available at the University of Utah in Salt Lake City. The first computations were made on June 19, 1973, and an update was run every week thereafter. Each field was visited every week. Field conditions were compared with computer results and scheduling information was given to the participating farmers.

Initial Bureau activities have been geared to a small cross section of the Uinta Basin and a large amount of testing and experimentation has taken place in order to find what type of service can be economically provided and gain wide acceptance. The Bureau plans to expand the Uinta Basin IMS program in 1974 to include at least 5,000 acres. To date, 4,500 acres have been signed up and no difficulty is anticipated in recruiting additional acreage.

Some probelms were encountered the first year. The canal systems and head ditches were in poor condition which made it very difficult to estimate the amount of water being applied to the field (see photograph on next page). Rotation irrigation scheduling made it difficult for the farmer to schedule water when the computer program called for it, and he would often only irrigate one-half of the field before losing his turn. The field would then be finished 2 or 3 weeks later. Ground water was also a serious problem, because often only a part of the field was affected.

The fields averaged about 15 acres each and required much more time to visit the entire area than if

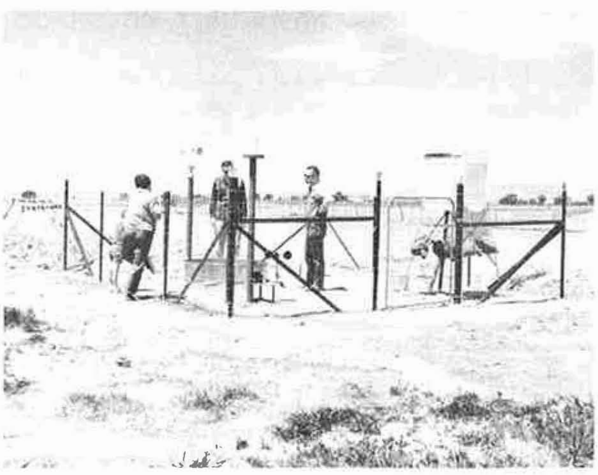


Figure 34. Weather station for irrigation scheduling.

scheduling were performed only on large fields. Field checks showed the computer results to be fairly accurate, except where a serious ground-water problem existed. A water quality sampling program has been initiated to establish how much scheduling improves the quality of irrigation return flow; but until the program advances further, few results can be realized.

The Bureau will continue to develop the program so that it can eventually be administered by trained personnel working for the water users. Under the present schedule, the water users will assume the full cost of the program by FY 1978. The ultimate goal is to schedule not only irrigation applications, but water deliveries throughout the distribution systems.

Water Systems Improvement Program

Systems improvement possibilities consist principally of the improvement of irrigation conveyance systems such as lining canals, use of pipe systems, and upgrading diversion and measurement structures.

A study to determine the seepage losses and salt loading of Uintah Indian Irrigation Project canals was begun in June 1973. This study is being conducted with the cooperation of the Bureau of Indian Affairs on canals located near Roosevelt, Fort Duchesne, and Myton, Utah. The field data collected during the 1973 irrigation season consists of seepage loss measurements on Dry Gulch, South Fork Dry Gulch, and Myton Townsite Canals; and quality of water sampling at 17 stations located on canals and natural drains in the study area.

On Dry Gulch Canal, seepage losses in 3.5 miles of canal have been measured at three continuous streamflow recording stations. Recorders have also been installed at four turnouts within the study reach to monitor water released from the canal (see Figures 35, 36, and 37). Seepage losses in 2.6 miles of South Fork Dry Gulch Canal and 2.7 miles of Myton Townsite Canal will be determined from flow records measured at two stations on each canal. The 1973 field data is presently being analyzed.

Collection of field data will continue for FY 1974, 1975, and 1976. Additional canals will be measured for seepage losses with the emphasis on canals which have not been previously studied. A feasibility report of the alternative systems improvements is scheduled to be completed by the end of FY 1977.

Costs and Benefits

Construction costs are not applicable to the IMS activity. The program has not been developed

Figure 35. Showing gaging station used to determine loss in a canal. Notice also the growth of weeds along the canal.

Figure 36. Diversion structure showing how ditches are infested with weeds and difficulty in obtaining measurement of water application.

sufficiently to determine the operational per acre costs for the program. A total of $480,000 has been scheduled through FY 1978 to continue to develop and implement the program in the Uinta Basin.

Based on economic studies and unit costs of canal rehabilitation taken from definite plan studies for the Upalco, Uintah, and Bonneville Units of the Central Utah Project, the estimated total cost of the water systems improvements that may offer possibilities under the Colorado River Water Quality Improvement Program is $40,000,000 for the main canals and laterals. Annual operation, maintenance, and replacement cost is estimated to be $200,000.

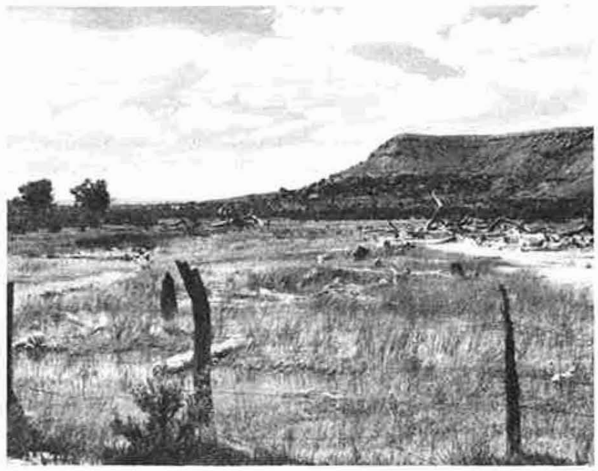


Figure 37. Showing seeped area below one of the canals.

The benefits in the lower Colorado River Basin resulting from both the Irrigation Management Services and Water Systems Improvement Programs are estimated at $2,070,000 annually.

It is estimated that the combined IMS and WSI programs could annually remove 100,000 tons of salt. Salinity concentration of the Colorado River at Imperial Dam would be reduced by an estimated 9 mg/l.

Environmental Considerations

The general considerations discussed earlier for the Palo Verde Irrigation District also apply to the Uinta Basin. Specific effects on local wildlife species have not yet been determined.

LOWER GUNNISON BASIN UNIT, COLORADO

The Lower Gunnison Basin Unit encompasses the Gunnison River drainage area below the Curecanti Unit, a feature of the Colorado River Storage Project. Within this area, there a number of private and Federal projects presently irrigating approximately 160,000 acres. Also included in the area is an additional 17,000 acres of presently nonirrigated land that would be irrigated under authorized projects. Figure 38 is a location map of the unit and Table 15 shows the breakdown by projects of the separate acreages.

The Uncompahgre Project is the largest single irrigated area in the basin. This project was authorized in 1903, and was one of the first five projects authorized for construction following passage of the Reclamation Act

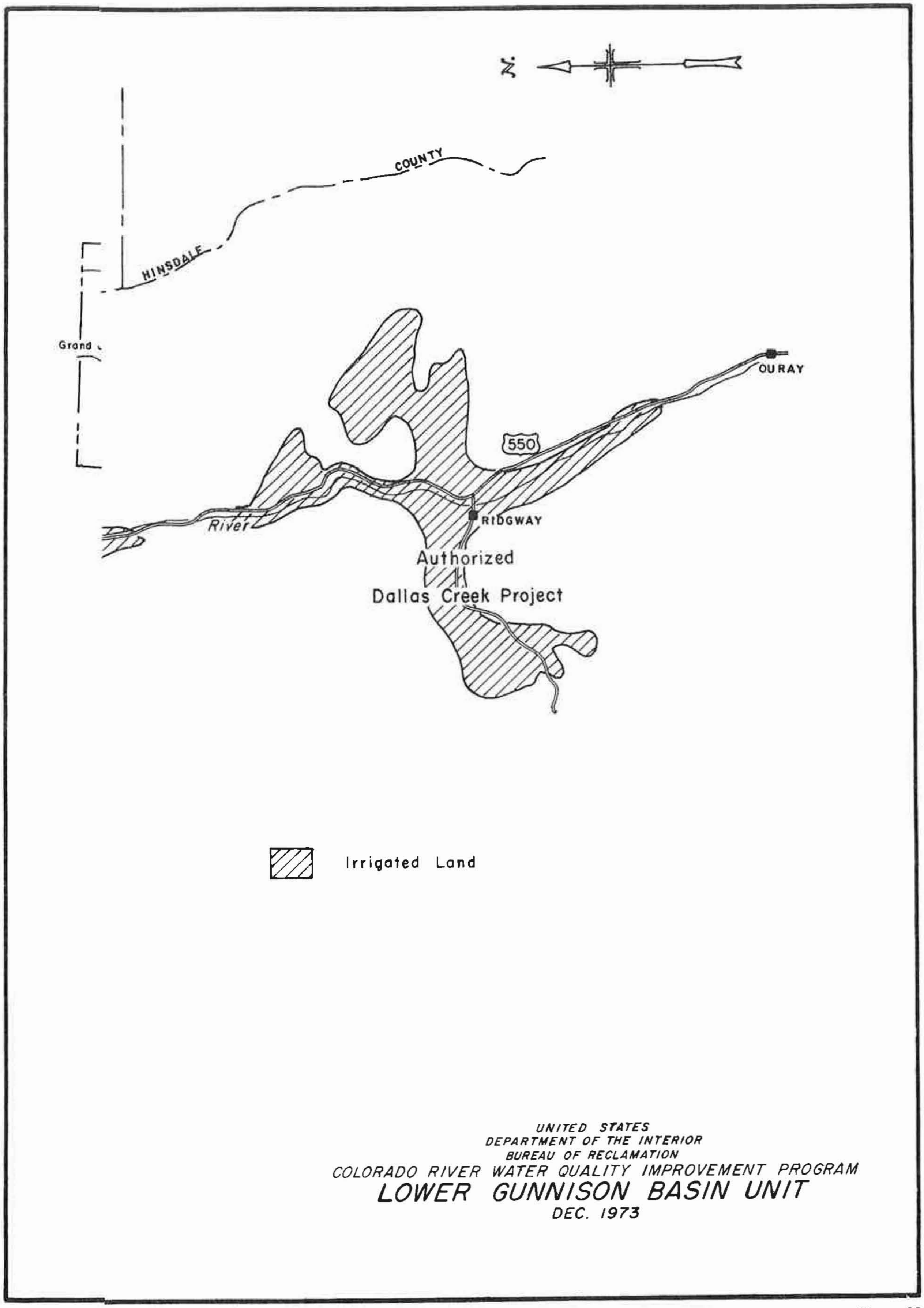

N
HINSDALE
COUNTY
Grand
OURAY
550
RIDGWAY
River
Authorized
Dallas Creek Project
Irrigated Land
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM
LOWER GUNNISON BASIN UNIT
DEC. 1973

Figure 38

Table 15

PARTICIPATING PROJECTS AND ACREAGES
Lower Gunnison Basin Unit

Project	Acres presently irrigated	Acres presently nonirrigated	Total acres
Uncompahgre Project (Government)	83,800		83,800
Fruitgrowers Dam Project (Government)	2,662		2,662
Paonia Project (Government)	15,300		15,300
Smith Fork Project (Government)	8,240		8,240
Grand Mesa Project (potential)	20,840		20,840
Dallas Creek Project (authorized)	3,470	3,880	7,350
Fruitland Mesa Project (authorized)	6,679	11,995	18,674
Bostwick Park Project (authorized)	4,500	1,610	6,110
Other private lands	13,260		13,260
Total	158,751	17,485	176,236

of 1902. Figure 39 is a view of the Uncompahgre Valley.

The average gross crop value on lands served by Government facilities in 1971 was $136 per irrigated acre.[4] This value applied to the total basin would be approximately $21.5 million.

This area contributes an estimated 1,100,000 tons of salt to the Colorado River. As in the Grand Valley area, it is believed that salts are washed from the area by excessive irrigation applications and system losses.

The valleys in the Lower Gunnison area are generally eroded from the upper Cretaceous Mancos Shale which

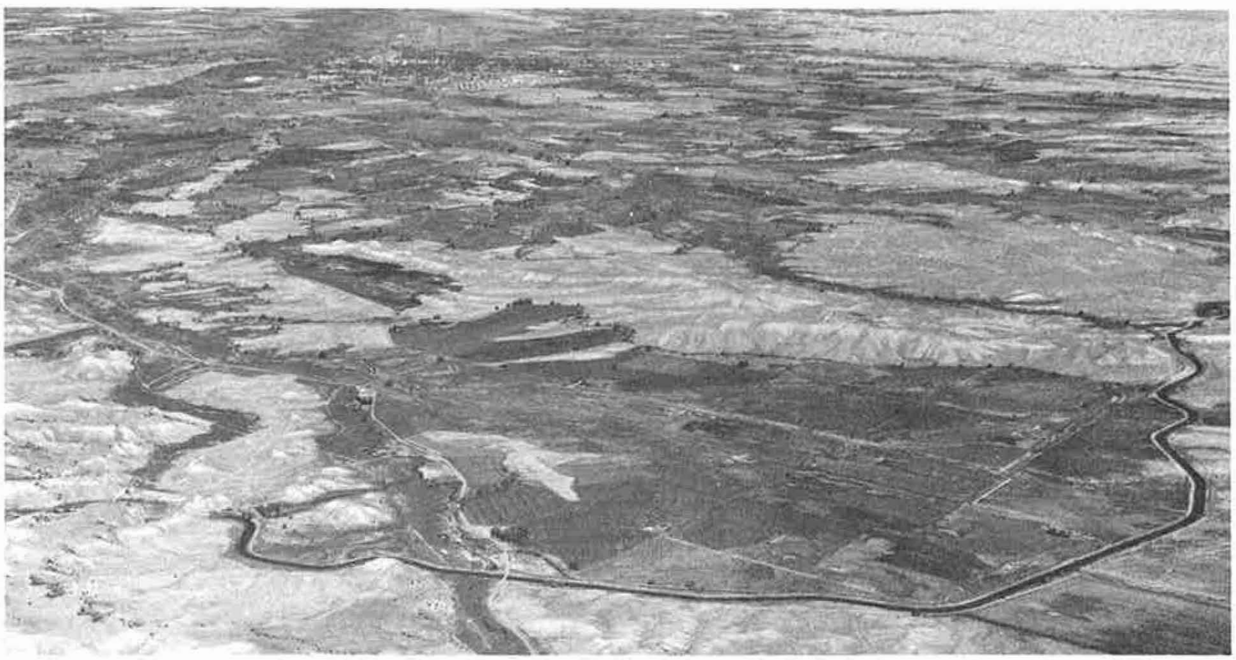


Figure 39. View looking north across project lands from an area southeast of Montrose, Colorado. The south canal is in the lower portion of the photo and Montrose is in the background. P31-427-412 NA

[4]Water and Land Resource Accomplishments, Statistical Appendix, 1971, Bureau of Reclamation.

is a thick sequence of gray fissile shale. The thickness of the formation usually varies from 3,000 to 5,000 feet. Further descriptions of the Mancos Shale Formation are found in the discussion of the Grand Valley investigation unit.

Water percolating through the weathered shale or soils derived from the Mancos Shale leaches out the soluble salts. Figure 40 shows some Uncompahgre Project lands with the Mancos Shale hills in the background.

Irrigation Management Services Program

The Irrigation Management Services Program, conducted by the Bureau of Reclamation, Grand Junction Projects Office, will begin in the Lower Gunnison Basin Unit early in the calendar year 1974. This program will be conducted in conjunction with the program already in operation in the Grand Valley Unit.

The program is scheduled to begin with approximately 1,000 acres in FY 1974. At present, all irrigation scheduling will be concentrated within the Uncompahgre Project. Not only is it in close proximity to the Grand Junction Office, but it is also the largest project in the basin.

Initial contacts will be made with the various state and local agencies in the Uncompahgre Project to insure a maximum of interagency cooperation. At that time, a few select farms will be chosen to participate in the irrigation scheduling program. It is hoped that a small isolated basin can be found in which to begin the scheduling program. Within this small basin, the effects of scheduling can quickly be determined.

Though the program has been developed initially in the Grand Valley area, it can be adjusted to fit the conditions in the Uncompahgre Project. New climatic conditions exist as well as changes in soil conditions.

Figure 40. View showing project lands southeast of Montrose, Colorado, surrounded by decomposed shale hills. The south canal is visible at bottom of photo. P3I-427-4II A

After the initial contacts with various entities and proposed participants, soil samples will be collected and a strategically located weather station will be established. In addition, all possible historic climatological data will be obtained from local sources. This will be needed in determining coefficients required for the computer calculations of irrigation schedules.

Water Systems Improvement Program

A feasibility study to determine the best method of increasing water delivery efficiency in the Lower Gunnison area began in FY 1973 with the purpose of eliminating a part of the return flow containing high concentrations of salt, and thereby reduce the salinity of the Colorado River.

A little over one-half of the 160,000 irrigated acres are under the Government projects, with the remainder being under systems constructed and operated by private enterprise. Figure 38 shows the location of the irrigated area in the Lower Gunnison unit.

All canals and laterals which lie in areas of highly saline soils could be concrete lined or replaced by pipe sections. Rehabilitation of structures on the canals and laterals will be investigated, surface and ground-water sources and quality, and drainage requirements will be studied.

The Bureau will work very closely with the Soil Conservation Service to obtain estimates of onfarm improvements.

Investigation work leading to a feasibility report began during 1973 on a limited scale.

Studies are to include computation of acreages, lateral and canal sizing studies based on crop consumptive use, cropping patterns and local climatic data, determination of locations and capacities of all laterals and canals, economic studies, ground-water quality and sources, drainage requirements, preparation of feasibility designs and cost estimates. A feasibility report is scheduled for completion by the end of FY 1977.

Cost and Benefits

Costs for either the IMS or WSI programs cannot be determined at this time. Because of the installation of a weather station, personnel training costs, and limited acreage, initial cost per acre could be relatively high. As the program progresses, cost per acre will be gradually reduced.

The Uncompahgre Project furnished crop yield data to the Bureau of Reclamation annually. With this information available, some indication of increased yield can be determined. As on any project, it will be a number of years before a trend of increased yield can be related to irrigation scheduling.

With the hopes of starting in the Lower Gunnison Basin Unit with an isolated area, hydrologic studies will begin immediately. From these studies, the water savings and reduced salinity should be easily determined. Benefits in the lower Colorado River Basin are estimated to be $6,210,000 annually for both Irrigation Management Services and Water System Improvement Programs.

The Irrigation Management Services and Water Systems Improvement Programs could result in the reduction in dissolved solids of approximately 300,000 tons per year. This is equivalent to approximately 27 mg/l improvement in concentration at Imperial Dam.

Environmental Considerations

The general considerations discussed earlier for the Palo Verde Irrigation District also apply to the Lower Gunnison Basin Unit.

The extent of the detrimental effects cannot be determined until more data are available on the overall effects of the IMS and WSI programs. There are several important factors that determine wildlife habitat quality in the Lower Gunnison that are independent of salinity control measure. Studies should be conducted to determine what changes are due to IMS and WSI programs and what changes are due to other factors.

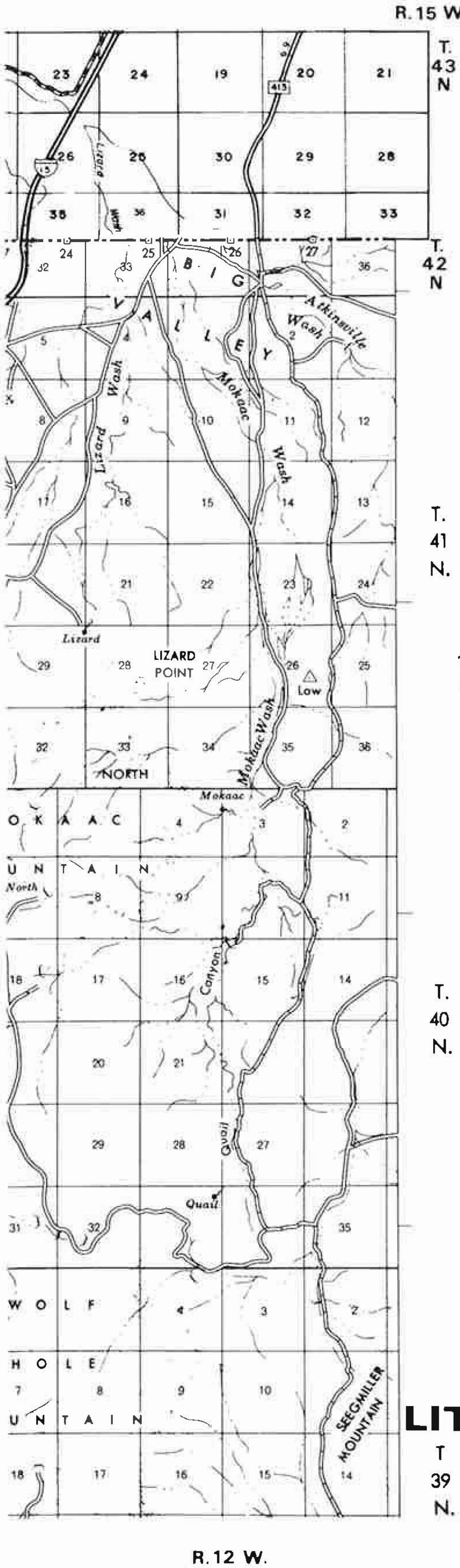
POINT SOURCE CONTROL

This control technique involves structural measures to contain localized sources contributing an inordinately high salt load to the river system. These sources are generally springs, wells, geysers, or mine drainage.

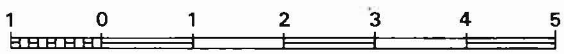
LITTLEFIELD SPRINGS UNIT, ARIZONA

Introduction

Littlefield Springs are a widely scattered group of springs located along the south side of the Virgin River about 1 mile upstream from Littlefield, Arizona (location map is Figure 41). A typical spring is shown in Figure 42. Littlefield is in the extreme northwestern part of Mohave County, about 3 miles east of the



KEY MAP



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM

POINT SOURCE DIVISION

LITTLEFIELD SPRINGS UNIT

ARIZONA

MAP NO. 1244-300-44

NOVEMBER 1973

Figure 41

Figure 42. View of typical saline springs. P1244-300-01036

Nevada State line and 5 miles south of the Utah State line. Feasibility studies on the Unit were started in fiscal year 1974 and are scheduled to be completed in fiscal year 1976. In the report on the Colorado River Water Quality Improvement Program, dated February 1972, the springs were classified as a point source of salinity contributing 30,000 tons of salt per year to the Virgin and lower Colorado Rivers. Measurements and water samples taken of the springflows during the period of August to October 1973, however, show that the salt contribution is only about 16,700 tons per year. Additional measurements will be made as the feasibility studies continue.

The area being studied includes the reach of the Virgin River from where it enters the "First Narrows" canyon above the Arizona-Utah State line to the vicinity of Littlefield (see Figure 43). The principal communities in the vicinity are Littlefield, Arizona, and Mesquite and Bunkerville, Nevada. St. George, Utah, the largest community in the area, is located about 28 miles upstream from the springs.

The Virgin River disappears during low flow periods after it enters the rugged canyon known as the "First Narrows" near the state boundary between Utah and Arizona. It emerges again near the mouth of the canyon about 6 miles upstream from Littlefield Springs and then flows through the broad, sloping Virgin Valley and discharges into Lake Mead. The river in the area of Littlefield Springs is flanked on the southeast by the Virgin Mountains, on the northwest by the Mormon Mountains, and on the north by the Beaver Dam Mountains.

Beaver Dam Wash, a tributary of the Virgin River, begins in Nevada and flows about 50 miles on a southerly course to its confluence with the Virgin River 1 mile above Littlefield. The stream is intermittent throughout most of its length, with certain reaches fed by perennial springs. Ranchers along the wash use these springs, which are of good quality, for domestic and irrigation purposes. Most of the irrigated land along the wash lies upstream about 2 miles from the Virgin River. Several fresh water springs are found near the mouth of the wash and across the river from the Littlefield Springs.

Water Supply

A program of sampling the spring flows was started in August 1973. Water samples and measurements indicate an average combined flow of 5.7 cfs and an average salinity of 2,960 mg/l. Based on this, the salt contribution to the river averages 16,700 tons per year. The mineral salts in the spring discharges are chiefly carbonates, sulfates, and chlorides of calcium and sodium. The springs are unsatisfactory for domestic use, but they are used to irrigate salt tolerant crops near Littlefield.

During periods of low flow, from May to October, the Virgin River flows underground through the upper part of "The Narrows." Surface flow begins to reappear about 2 miles above the mouth of "The Narrows" in the form of springs discharging from the riverbed and from the adjacent banks. Flows of 20 cfs at an average salinity of 2,915 mg/l were measured at the mouth of the canyon in 1973. At a point 2 miles downstream, the flow increased to 43 cfs with an average salinity of 2,900 mg/l. The stream continues to gain, and at the Geological Survey's gaging station at Littlefield the flow was 70 cfs and the salinity decreased to 2,470 mg/l. The salinity improvement is attributed, in part, to an inflow of about 3 cfs of good quality water from Beaver Dam Wash and from springs on the north bank of the river above the gage.

Alternative Plans

Alternative methods for collecting and disposing of the spring discharges are currently under study. One alternative is to collect the spring flows in a ditch, desalt the water, and return the product water to the river. The brine fluids would be transported to a lined evaporation pond. Studies will be made of the hydrology of the Virgin River through "The Narrows" to support the estimates of the effect of desalting LaVerkin Springs upon the quality of the water in the river above Littlefield. These studies will also aid in determining the source of the springs. Alternative plans will be further defined in the future, and a recommended plan of action will be developed. Feasibility designs and estimates, environmental quality studies, and economic and financial analyses

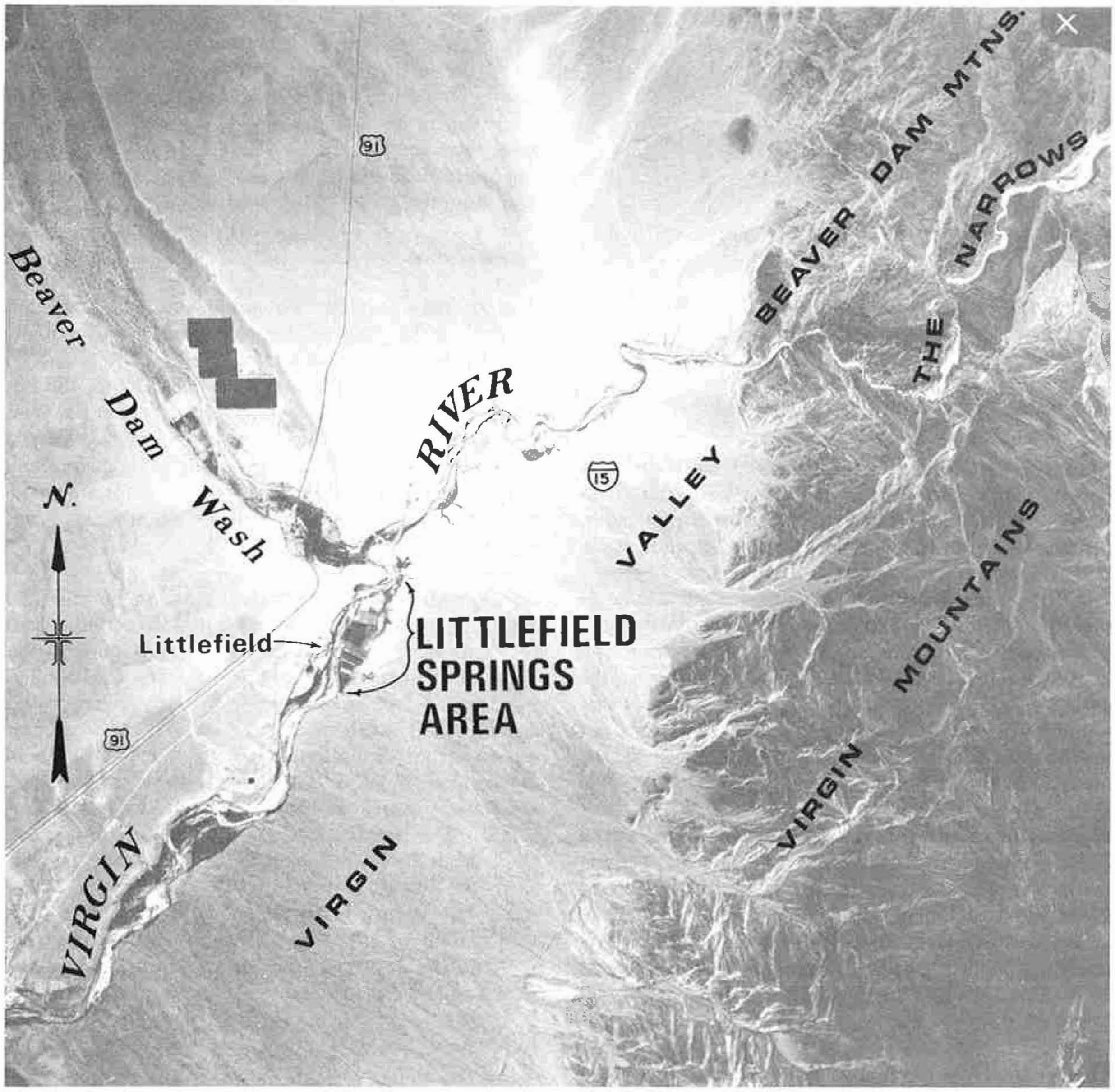


Figure 43. Aerial view of the Littlefield Springs area showing the Virgin River from near the mouth of "The Narrows" canyon.

will be made to determine if the construction and operation of the unit would be justified. The results of these investigations will be compiled in a feasibility report and an environmental statement scheduled for completion in June of 1976.

Collecting and desalting the spring discharges could remove about 16,000 tons of salt annually. This could reduce the salinity concentration by about 2 mg/l at Imperial Dam.

Environmental Considerations

The vegetation and wildlife in the area are characteristic of much of the arid southwestern United States. The vegetation consists primarily of the creosote bush-bur sage plant community. Willows, salt cedars, and cottonwood trees grow along the Virgin River and Beaver Dam Wash. Salt grass, greasewood, and inkweed are found in areas of poor drainage and high salinity.

The most important game birds in the area are Gambel's quail, mourning dove, and ringnecked pheasants. Ducks and Canadian geese visit the area for winter feeding stops. Bobcats, coyotes, foxes, badgers, skunks, weasels, rabbits, several species of squirrels, and mice inhabit the area.

The endangered woundfin *(Plagopterus argentissimus)* lives in this reach of the river but complete studies of the biota have not been made. These studies, as well as archeological and historical surveys, will be conducted in the future for inclusion in the feasibility report and the environmental statement.

Construction of the desalting alternative could have some social and economic benefits. Economic activity would be generated during the construction and operation phase. Reduction of the salinity in the Virgin River would enhance the environment of the water users. A new source of electrical energy would be required for operating the desalting plant and other features of the unit.

There would be an esthetic impact in the areas in which the treatment plant and evaporation pond would be located. The size of the evaporation pond needed would depend on the amount of water treated and the type of treatment used. Some land would be removed from its present use by the construction. Although no studies have been conducted, the environmental impact on the flora and fauna of the area would probably be small.

GLENWOOD-DOTSERO SPRINGS UNIT COLORADO

Introduction

The largest point source contributors of dissolved solids to the Upper Colorado River are in the river between the mouth of the Roaring Fork River at Glenwood Springs and the mouth of the Eagle River near Dotsero. These contributions are from thermal springs rising in or near the bed of the river and from ground water entering this reach of the river (see Figure 44). Inflow-outflow measurements indicate this reach of the river contributes approximately 25,000 acre-feet of water containing over 500,000 tons of dissolved solids annually.[5] Based on a 1-year period of data collection, the springs that could be identified and measured have a combined flow of about 16 cfs and an average dissolved mineral content of approximately 14,200 mg/l. These flows would carry about 225,000 tons of dissolved solids into the Colorado River annually. Table 16 shows the summary of point source salinity data.

The thermal springs and the ground-water inflows to the Colorado River between the mouth of the Roaring Fork River and the Eagle River are widely scattered (see Figures 45 and 46). The located springs whose flows are considered collectible by conventional methods for desalination treatment are clustered in the vicinity of Glenwood Springs around a point approximately 2.5 miles downstream from the mouth of the Eagle River called Dotsero. Geologically speaking, the area is located at the southeastern edge of the extensive White River uplift. The Glenwood and Dotsero Springs are situated at opposite ends of Glenwood Canyon which has been created by the Colorado River eroding through very resistant rocks of the uplift. Many faults have been mapped in the area and may be related to the springs.

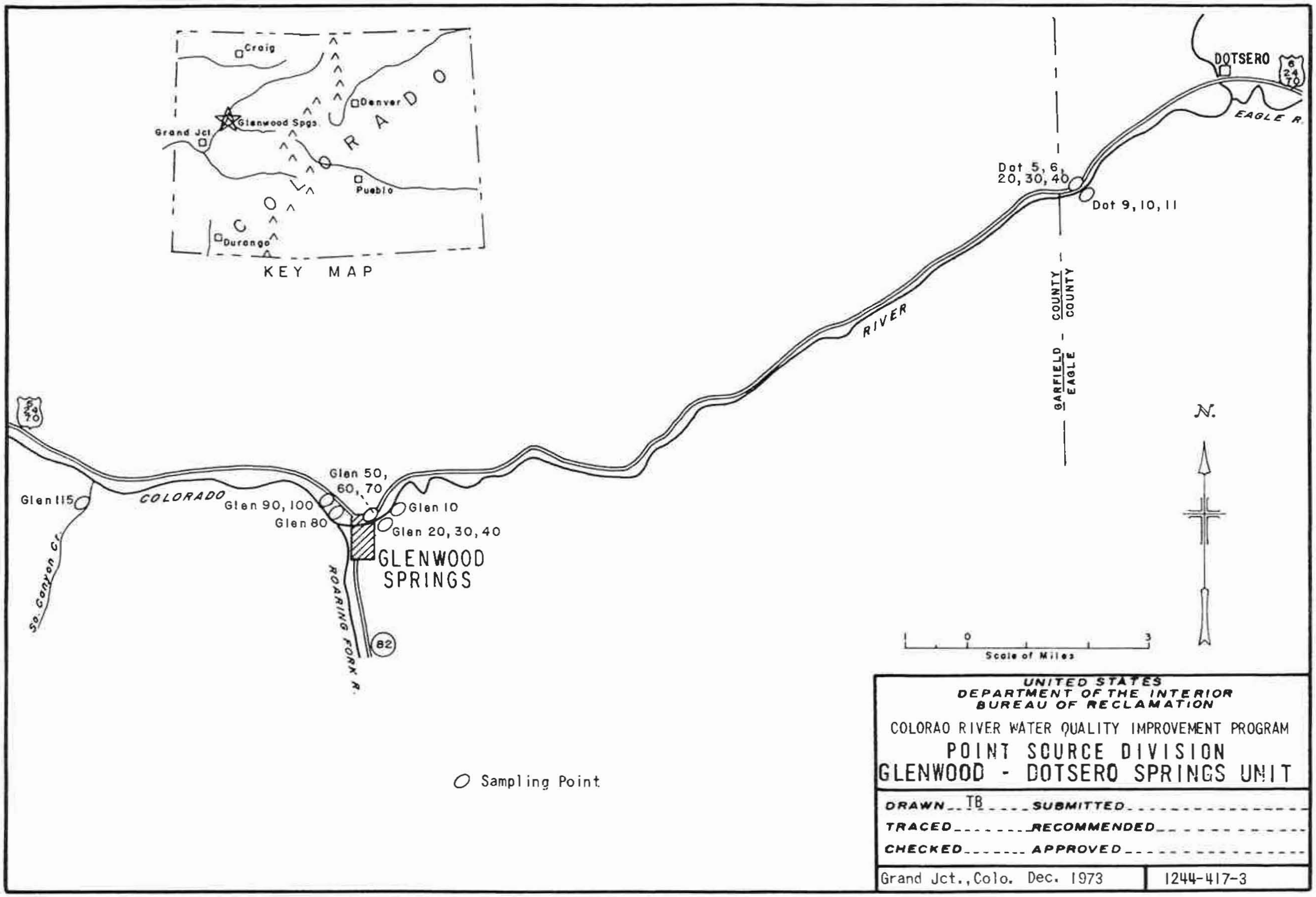
The thermal springs generally issue from gravels along the river but this water is traveling to the surface through the underlying bedrock. Generally the springs seem to be found in areas where the cavernous Leadville limestone crops out but other formations are also involved. It is also of significance that the Paradox Formation is found in the general vicinity of both spring areas. Chemical analyses of the water from the springs show large amounts of both sodium chloride and calcium sulfate, and the Paradox contains beds of these minerals in the form of halite and gypsum.

Evidence of volcanism as recent as Pleistocene in age occurs in the area and suggests the possibility that hot intrusive bodies may be present in the subsurface. A cinder cone and lava flow are found about 5 miles east of the Dotsero Springs and other similar evidence exists.

In summary, only very generalized geologic data are available on the Glenwood and Dotsero Springs and an extensive exploration program would be necessary to delineate the geology and hydrology.

It is possible, however, to hypothesize that ground water in the area travels along faults or related fracture zones, dissolves out salts principally from the Paradox Formation, becomes heated by deep-lying intrusive bodies, and returns to the surface as warm, saline springs.

[5]The Mineral Quality Problem in the Colorado River Basin, Appendix A, Environmental Protection Agency, 1971.


Craig
Denver
Grand Jct.
Glenwood Spgs.
Pueblo
Durango
C O L O R A D O
KEY MAP
DOTSERO
6
24
70
EAGLE R.
Dot 5, 6,
20, 30, 40
Dot 9, 10, 11
RIVER
GARFIELD COUNTY
EAGLE COUNTY
N.
COLORADO
Glen 115
So. Canyon Cr.
Glen 50,
60, 70
Glen 90, 100
Glen 80
Glen 10
Glen 20, 30, 40
GLENWOOD
SPRINGS
ROARING FORK R.
82
0
3
Scale of Miles
Sampling Point
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORAO RIVER WATER QUALITY IMPROVEMENT PROGRAM
POINT SOURCE DIVISION
GLENWOOD - DOTSERO SPRINGS UNIT
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CHECKED APPROVED
Grand Jct., Colo. Dec. 1973
1244-417-3

Figure 44

Table 16

GLENWOOD–DOTSERO SPRINGS UNIT
Summary of Point Source Salinity Data

Date	Q (cfs)	tds (ppm)[1]	Load (tons) Daily	Load (tons) Annual
		Dotsero Area		
4/25 & 26-1972	3.0[2]	9,533		
7/11 & 12	2.3[2]	9,738		
8/2 & 3	2.2[2]	9,369		
8/30 & 31	6.1	9,088	150	54,750
10/4 & 5	6.7	8,926	161	58,765
11/8 & 9	6.7	9,346	169	61,685
12/4 & 5	6.2	9,217	154	56,210
1/15 & 16-1973	5.8	9,128	143	52,195
2/13 & 14	6.7	9,339	169	61,685
3/12 & 13	7.4	9,255	185	67,525
Average	6.5	9,174	161	58,974
		Glenwood Springs Area		
4/25 & 26-1972	12.0	17,961	582	212,430
7/11 & 12	7.5	18,070	366	133,590
8/2 & 3	11.6	15,391	482	175,930
8/30 & 31	8.5	19,153	440	160,600
10/4 & 5	8.2	17,508	388	141,620
11/8 & 9	9.3	18,749	471	171,915
12/4 & 5	8.2	18,153	402	146,730
1/15 & 16-1973	9.0	18,926	460	167,900
2/13 & 14	9.0	18,662	453	165,345
3/12 & 13	9.8	18,641	493	179,945
Average	9.3	18,080	454	165,600
		South Canyon Creek Area		
4/25 & 26-1972	0.1	2,492	0.7	256
7/11 & 12	0.3	1,728	1.4	511
8/2 & 3	0.3	1,297	1.1	402
8/30 & 31	0.4	775	0.8	292
10/4 & 5	0.4	784	0.8	292
11/8 & 9	0.3	784	0.6	219
12/4 & 5	0.3	783	0.6	219
1/15 & 16-1973	0.4	771	0.8	292
2/13 & 14	0.3	772	0.6	219
3/12 & 13	0.3	762	0.6	219
Average	0.3	988	0.8	292
Totals	16.1	14,166	615.8	224,767

[1] Weighted average.
[2] These values do not reflect the total flow of all the Dotsero Springs.

Figure 45. View of one of the hot saline springs issuing on the south edge of the Colorado River near Dotsero, Colorado. The flow is about 1.5 cfs and the temperature of the spring is about 89° F. P1244-427-7 NA

Figure 46. View of hot saline water flowing from river cobbles cemented together by mineral deposition; the site is in the center of the Colorado River near Glenwood Springs. One of the bathhouses which use the spring water can be seen in the background. P1244-427-23 NA

Salt Removal Effects Downstream

Based on the preliminary studies to date, it appears that a desalting treatment plant or plants utilizing the multistage flash distillation process could remove approximately 200,000 tons of salt annually, and the salinity could be reduced about 19 mg/l at Imperial Dam.

Alternative Plans

During the preliminary studies to date, several methods of disposing or treating the saline water have been considered. Methods that could be used to control or eliminate point source flows include evaporative ponds, deep-well injection, plugging or grouting off the springs, diversion for industrial use, or various types of treatment plants. After cursory evaluation of each of the alternatives, some type of treatment plant to remove the bulk of the salts is being evaluated in more detail. In addition, this would be the only solution that could salvage the fresh water for return to the Colorado River.

Brief consideration was given to collecting the flows of each spring and conveying the water to evaporative ponds. However, there are several factors that would seem to reduce the effectiveness of this alternative. Since rather large flows are involved (16 cfs total), ponds with a large surface area would be necessary. Also, since the topography at both Glenwood Springs and Dotsero is dominated by narrow canyons, it might be necessary to convey the saline water downstream 30 miles or more, possibly to the Rifle, Colorado area to obtain a suitable site. Moreover, the elevation at Glenwood Springs of about 5700 feet and the latitude result in a cool climate and a moderate winter snowfall which would further restrict the effectiveness of evaporative ponds.

Deep-well injection has been used in various circumstances to dispose of industrial wastes and has been studied by the Office of Saline Water as a technique for disposal of brine solutions. After a brief review of the geologic conditions at the Glenwood and Dotsero Springs areas, it seems very unlikely that a subsurface formation exists into which the saline water could be injected due to the existence of faults and well-developed joint systems in the vicinity. It might be practical to convey the concentrated brine effluent from a desalting plant several miles downstream for evaporation or deep injection if satisfactory geologic conditions can be found.

Serious consideration was not given to plugging or grouting off the springs since the mode of their occurrence and the complex geology seem to preclude the practicality of this alternative. Also the Glenwood Springs are commercially developed for recreation and these springs supplying the resort areas could not be plugged off without adverse social and economic impacts (see Figure 47).

Several types of desalting plants are available and preliminary studies indicated that the multistage flash distillation process is the most thoroughly proven method of treating water similar to the Glenwood-Dotsero Springs. Geothermal heat sources could be a source of desalting energy. Some very approximate cost estimates for treatment plants and

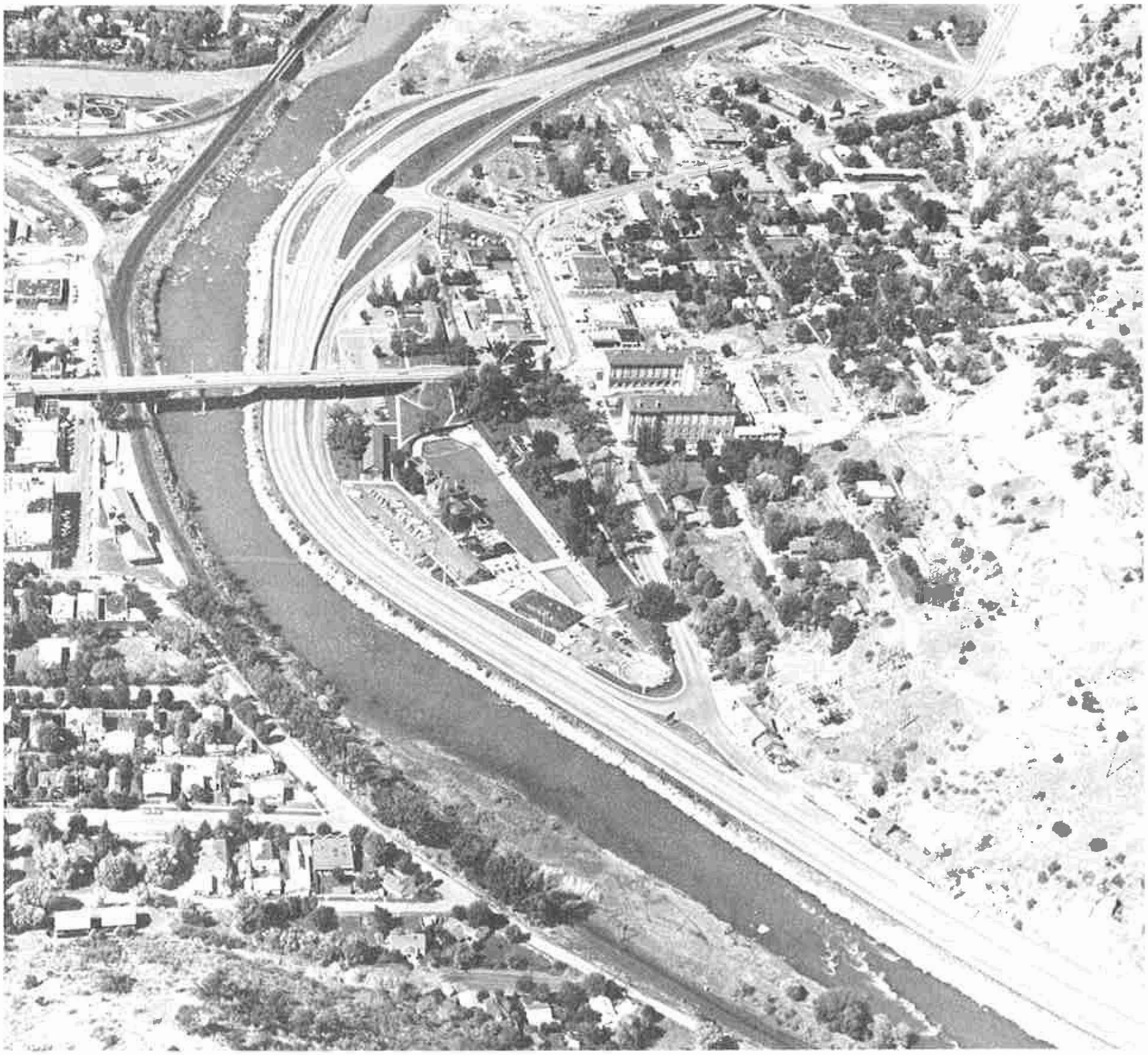


Figure 47. Aerial view looking downstream along the Colorado River showing a portion of the town of Glenwood Springs. Hot saline springs are found intermittently along the edges of the river. Note the large swimming pool near the center of the photograph which uses from one of the springs for year-round recreation. P8-427-40 NA

associated features were prepared considering an individual plant located near each of the sources or a combined plant to treat both sources.

Investigation Schedule

Work was begun on this segment of the Colorado River Water Quality Improvement Program in April 1972. An on-the-ground appraisal of the area located the various springs and 1 year's measurement of the flow from each spring was obtained on a monthly basis. Total dissolved solids and chemical analyses were determined on all samples.

In April 1973, geophysical studies were conducted in the Dotsero Springs area to determine if it might be feasible to collect the saline water by drill holes. If this were possible, water that now reaches the river through the stream gravels might be collected. The limited amount of geophysical work indicated that the flows may be along open fractures in the underlying bedrock. Future core drilling is proposed to determine if the flows can be intercepted at depth. Any control plan must preserve the existing highly developed recreation facilities in the Glenwood Springs area.

As previously stated, preliminary studies indicate that a treatment plant or plants could eliminate the salt load contributed to the Colorado River by the Dotsero and Glenwood Springs.

Substantial work remains to be accomplished to meet the programed goal of a feasibility report to be completed in fiscal year 1979 under current funding projections. This work includes preliminary design, economics, geology, and many other aspects including environmental considerations. Further subsurface work including drilling and geophysical surveying is planned especially in the Dotsero area. Economic studies to determine the benefits of desalting will be conducted. More detailed studies of other methods of treating the saline water are planned. Other uses of the water will also be considered.

The pertinent data collected at Dotsero and Glenwood Springs indicate the average total dissolved solids contained in the discharges from these two areas to be approximately 9,300 and 18,000 parts per million (ppm), respectively. The combined weighted average of both areas is about 14,200 ppm. The discharge of the springs at Dotsero has been measured to be about 7 cfs and at Glenwood Springs to be approximately 9 cfs.

Costs and Benefits

Because of the nearly 16 miles separating the two springs areas, a cost estimate was prepared for individual desalting plants at Dotsero and Glenwood Springs. In addition, a cost estimate was made of a single plant to treat the combined discharges of both areas. A schematic outline of these plans is presented in Figure 48 and a summary of the preliminary cost estimates is shown in Tables 17, 18, and 19.

A review of the available data indicated that the multistage flash distallation process best met the overall requirements for desalting discharges from the Dotsero and Glenwood Springs areas. A reconnaissance cost estimate was made of the plans considered for treating the saline discharges. The costs of these plans, indexed to July 1973 are as follows.

As indicated, the estimated cost of treating the discharge of the two areas separately would cost approximately 14 percent more than the cost of combining the discharges for treatment at one desalting facility.

The previous estimates have been based on 1 year's collections of quantity and quality data, U.S. Geological Quadrangle Sheets for topographic and distance estimates, current Bureau of Reclamation planning costs, and the Desalting Handbook for

Table 17

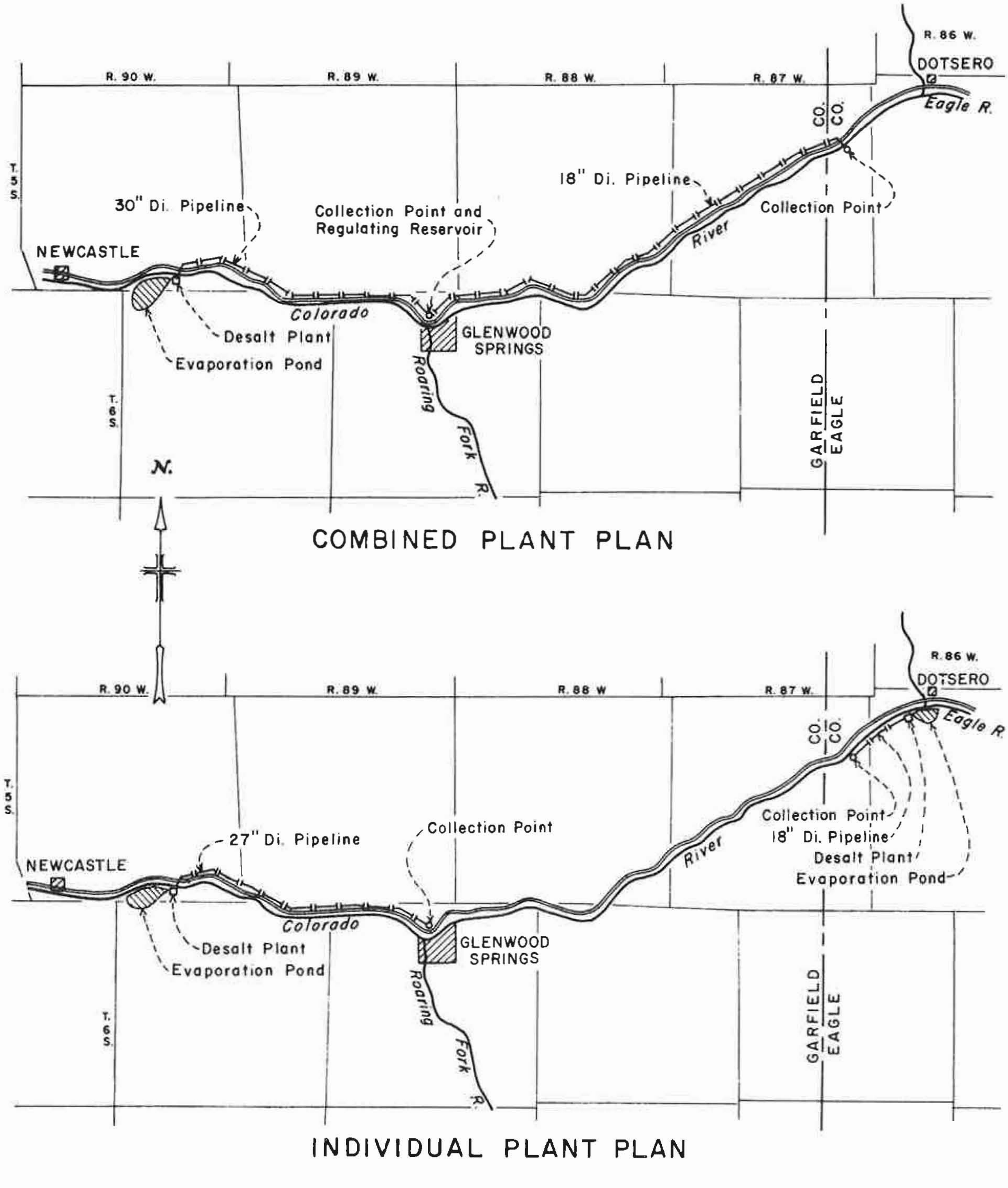
ESTIMATED COSTS (ROUNDED)
Alternative of Desalting the
Dotsero Springs Discharges (7 cfs)

Item	Cost
Multistage flash process plant	$10,150,000
Intake and discharge lines	470,000
Steam generators	1,080,000
Cooling tower	105,000
Evaporation pond	1,130,000
Site development	390,000
Collection system	120,000
Pipelines	350,000
Cooling pond	140,000
Land	145,000
Total	$14,100,000
Annual operation, maintenance, and replacement costs	$ 2,500,000

Table 18

ESTIMATED COSTS (ROUNDED)
Alternative of Desalting the
Glenwood Springs Discharges (9 cfs)

Item	Cost
Multistage flash process plant	$15,450,000
Intake and discharge lines	740,000
Steam generators	1,610,000
Cooling tower	160,000
Evaporation pond	1,810,000
Site development	550,000
Collection system	440,000
Pipelines	2,360,000
Cooling pond	165,000
Land	270,000
Total	$23,600,000
Annual operation, maintenance, and replacement costs	$ 4,000,000



COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM

GLENWOOD-DOTSERO SPRINGS UNIT
RECONNAISSANCE DESALINATION PLANS

Figure 48

Table 19

ESTIMATED COSTS (ROUNDED)
Alternative of Desalting the Combined
Dotsero and Glenwood Springs Discharges (16 cfs)

Item	Cost
Multistage flash process plant	$18,730,000
Intake and discharge lines	1,130,000
Steam generators	2,300,000
Cooling tower	220,000
Evaporation pond	2,900,000
Site development	660,000
Collection system	550,000
Pipelines	5,660,000
Cooling pond	160,000
Regulating reservoir and valves	30,000
Land	480,000
Total	$32,800,000
Annual operation, maintenance, and replacement costs	$ 5,850,000

Planners. The estimates should therefore be recognized as very preliminary and subject to change.

Benefits from the control measures to the Colorado River Basin are estimated to be $4,370,000 annually.

Environmental Considerations

Environmental studies, other than collection of physical data from the study area, have not been initiated at this time. Such studies should be carried out as an integral part of feasibility studies and should be completed prior to construction funding. At this time, however, potential environmental effects—both beneficial and adverse—can be outlined.

A reduction in the concentration of total dissolved solids in the river downstream would provide higher quality waters for municipal, industrial, and agricultural uses. Some impairment of these uses now occurs. There is also a potential for utilizing spring waters for recreation and waterfowl purposes under the project.

Construction of a treatment plant or plants, brine ponds, pipelines, pumping stations, or other potential features would have potential temporary adverse effects on air and water quality and long-term effects on the landscape. If the combined plant plan were selected, a pipeline would be necessary through scenic Glenwood Canyon which is presently involved in a controversy regarding the location of the proposed route of Interstate Highway No. 70. Construction of a pipeline to carry the Glenwood-Dotsero Springs flow through the canyon, if coordinated with the interstate highway construction or the existing railroad right-of-way, should have little adverse impact.

Studies have not been undertaken to determine if unique or possibly rare plant or animal species have become established in the Glenwood or Dotsero Springs.

An evaporation pond or lake would be needed to evaporate the brine from the desalting plant, industrial uses, or for evaporating the untreated flow of the springs and to store the salt removed from the spring water. These ponds would become sterile within a few years with a salt flat exposed at the upper end during part of the year. Some plants such as willows and tamarisk could possibly become established before the pond became sterile. The dead vegetation would be unsightly. It is also likely that strong winds would pick up the dry salt from the salt flats and carry it to surrounding areas with some damage to the vegetation growing there. Salt would accumulate at the rate of a million tons every 5 years, so continued protection would be needed to stabilize the storage ponds.

BLUE SPRINGS UNIT, ARIZONA

Area Description

Blue Springs are located on the lower portion of the Little Colorado River within the Navajo Indian Reservation of north-central Arizona, as shown in Figure 49. This stream joins the Colorado River at the northeastern corner of Grand Canyon National Park and constitutes the principal inflow to the river from Arizona, with an average historic discharge of about 310,000 acre-feet per year at the confluence. Approximately half of this flow, or an average of 160,000 acre-feet per year, is contributed by a series of springs which have a collective salinity of 2,500 mg/l and a total salt load of about 550,000 tons per year. These are the largest point sources of salinity in the Colorado River Basin and increase the salinity of the river at Imperial Dam by an estimated 47 mg/l.

The Blue Springs Area

The Little Colorado River drains approximately 26,900 square miles of semiarid to semihumid land in western New Mexico and northeastern Arizona, all of which lie within the Colorado Plateau Uplands geographic

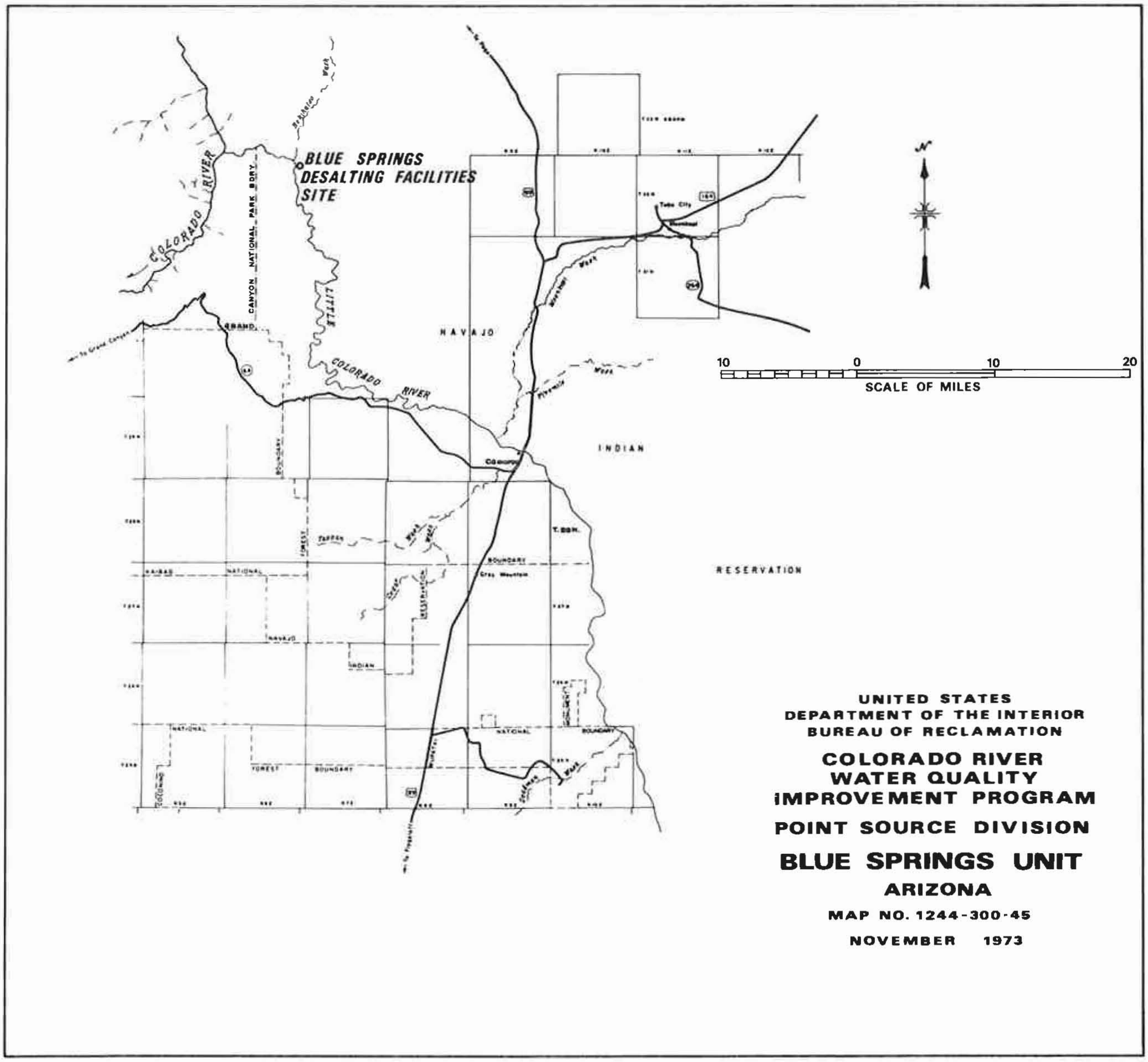


Figure 49

province. The streamflow is characteristically erratic, sediment laden, and of only moderately good quality. According to the records of the Geological Survey's gage near Cameron (about 32 miles upstream from Blue Springs), the flow is 10 cfs or less approximately 60 percent of the time, and there has been no flow approximately 40 percent of the time. Sediment concentrations frequently exceed 50,000 mg/l and have occasionally been higher than 150,000 mg/l.

The lower portion of the river flows through a meandering canyon of about a mile in width and half mile in depth. The walls of this rugged gorge are a series of nearly vertical cliffs of massive limestone and sandstone separated by steep slopes or benches of shale, siltstone, or thin-bedded sandstone, with a narrow inner gorge where the Redwall limestone forms the lower walls. The bottom can be reached near Blue Spring only by a rugged foot trail from the rim or by helicopter (see Figures 50 and 51).

The springs originate from ground water which moves into the area from the east and south and emerges as springflows where the canyon has penetrated the

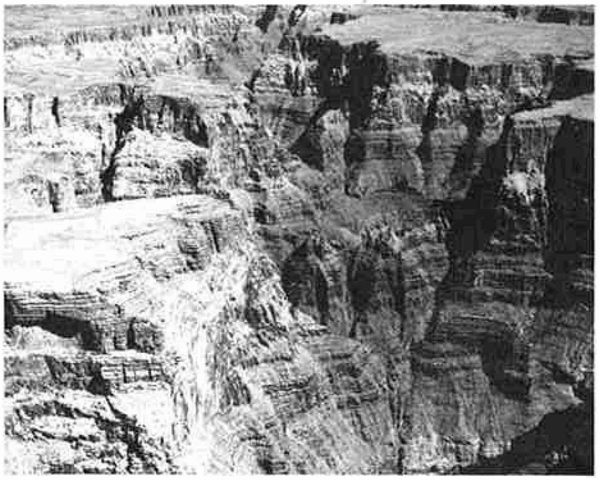


Figure 50. Canyon area—Vicinity of Gold Hill above Blue Spring. P57-300-9843

Figure 51. Blue Springs area—Confluence of Little Colorado River and the Colorado River. CN788-300-1006

Redwall and Mauv limestones below the regional water table. There are many spring openings along two relatively well-defined reaches; a primary zone from Mile 11.5 to Mile 15 and a secondary zone from Mile 3 to Mile 7, as measured from the mouth of the river. The upper zone begins where the canyon first penetrates the Redwall formation and contains the largest springs, including Blue Spring. The lower zone is located on the bottom of the Mauv limestone and the top of the Bright Angel shale.

The springflows are clear, salty, slightly acidic, and from 65^{o} to 70^{o} F. In the winter, the temperature drops below 50^{o} F. Chemically, they are typically sodium chloride water, with secondary concentrations of calcium bicarbonate. Between the outlets and the mouth of the river, carbon dioxide evidently escapes from solution, and the pH increases to 7.5 or higher. Large amounts of calcium carbonate precipitate to form a fine white mud on the bottom of the stream.

Alternative Plans

Because of the physical confinement of the deep canyon and the large number of spring openings, it would be economically infeasible to separate the flows of the springs from those of the Little Colorado River. Consequently, reconnaissance studies considered several plans to divert flows from the river at a point where most of the springflows could be collected and convey them to a desalting plant. Electrodialysis, reverse osmosis, and vertical tube evaporator-multistage flash (VTE-MSF) plants were considered. One of the alternative plans included the development of a pump-back power storage facility in conjunction with a desalting plant. The pump-back storage features were delineated in the report entitled "Memorandum Report, Little Colorado River Basin, Arizona" (September 1971). The possibility of conveying water to the Navajo thermal generation facility and using heat from the powerplant exchanges in a VTE-MSF plant was also evaluated.

Preliminary estimates indicate that a 125-million-gallon-per-day (mgd) electrodialysis plant could remove about 270,000 tons of salt annually from the flow contributed by the Little Colorado River. This would result in improving the salinity by 23 mg/l at Imperial Dam. Disposing of brine from a desalting plant is a difficult problem because of the quantity of brine and the difficulty in finding a suitable disposal site.

Full-scale feasibility studies for this project are not planned due to the high expected capital cost of the project and environmental problems resulting from the significant historical and religious value of the area to the Hopi Indians.

DIFFUSE SOURCE CONTROL

This method of control deals with salt loading or concentrating effects that occur over comparatively large areas such as the tributary subbasins. The techniques available for control include collection, desalting, evaporation, special use, watershed management, and vegetative control.

BIG SANDY RIVER UNIT, WYOMING

Area Description

The Big Sandy River originates in the Wind River Mountains of northwestern Wyoming and flows southerly to the Big Sandy Reservoir and Dam where most of the flow is diverted to irrigate the Eden Project (Figure 52). From Big Sandy Dam, it flows southwesterly to the Green River. Near the mountains, the water is of high quality containing less than 50 mg/l of dissolved solids. After flowing across several miles of desert, the dissolved solids increase to 70-120 mg/l at Big Sandy Reservoir. Below Big Sandy Dam, it picks up the irrigation return flows from the Eden Project and many saline seeps along the river channel. No single point source contributes a large amount of salt. However, the Big Sandy River annually discharges approximately 180,000 tons of dissolved solids at concentrations ranging from 300 to 3,900 mg/l to the Green River. It is estimated that about 80,000 tons per year might be removed by treatment which would reduce salinity concentrations of the Colorado River at Imperial Dam by an estimated 7 mg/l. The climate is cold and dry in the winter with minimum temperature often 40^{o} F below zero. The average temperature for December is 13.8^{o} F, January is 9.2^{o} F, and February is 14.5^{o} F. The summers are dry and mild with maximum temperatures only occasionally getting above 90^{o} F.

Because of low winter temperatures, it may be possible to apply natural freezing methods to desalt the water. Small-scale experiments have been conducted by Professor D. L. Stinson of the University of Wyoming in which sprinklers were used to spray water into the air where it freezes and falls forming an ice pile. The ice crystals which separate out are almost pure water and the unfrozen brine contains nearly all the salt. The experiments were successful in producing a very low salinity concentration in the effluent.

A research contract has been negotiated with the University of Wyoming for Professor Stinson to conduct a pilot demonstration of this method during the winter of 1973-74 in the vicinity of Gasson Bridge which is halfway between Farson and Fontenelle and 36 miles northwest of Rock Springs, Wyoming. The necessary ponds and pipelines for conducting the test have been constructed and it is expected that the natural freezing test will begin in early 1974. Water will be pumped from the Big Sandy River, sprinkled to produce ice piles, and then the brine and product water separated by natural aging and thawing. A schematic layout of the system is shown on Figure 53. The pilot operation should provide needed information regarding (1) the capability of freezing, (2) effectiveness of the sprinkler equipment, (3) configuration for the best ice formation, (4) the amount of salt that can be removed, (5) cost per ton of salt removed, (6) quality of the product water, and (7) environmental impact of the process. A report on the pilot test is due in June 1974. If the pilot test indicates that natural freezing is a promising method of desalting, this alternative will be included in the evaluation of the other alternative methods to reduce salt load.

Investigations have not advanced sufficiently to prepare an estimate of cost. The pilot study will provide much of the needed data.

The quantity and quality of the water presently available from the Green River will satisfy industrial requirements in the area. A detriment would occur from evaporation of at least 2,000 acre-feet of remaining brine water. The principal benefits will accrue in the lower Colorado River Basin which are estimated to be $1,610,000 annually.

Environmental Considerations

Environmental considerations include: (a) Some degradation of natural scenery will result from the construction of a diversion structure, ice field, and evaporating ponds. The salts accumulating in the evaporating ponds may be scattered by wind action. It is expected that construction and operation of these facilities will have negligible effect on animal life and only minor effect on the plant life in the area. The pilot test could give better indications of the effect of the ice piles on plant life. (b) Special consideration in design of the evaporating pond will be required to prevent concentrated dissolved salts from spilling back into the stream system. (c) The diversion of the low flows during the winter may have some effect on plant and animal life on the lower reach of the Big Sandy River. Also, the return of low salinity water to the stream during part of the summer may affect the kind of animal and plant life that live in the stream and on banks of the lower reach.

PRICE, SAN RAFAEL, AND DIRTY DEVIL RIVER UNITS, UTAH

The Price, San Rafael, and Dirty Devil Rivers originate in the mountains of the Wasatch and Aquarius Plateaus and provide tributary flows to the Green and Colorado Rivers in east-central Utah (Figure 54). Elevations in these river systems range from about 4000 feet above sea level on the Colorado River to over 11,000 feet above sea level in the mountain ranges and high

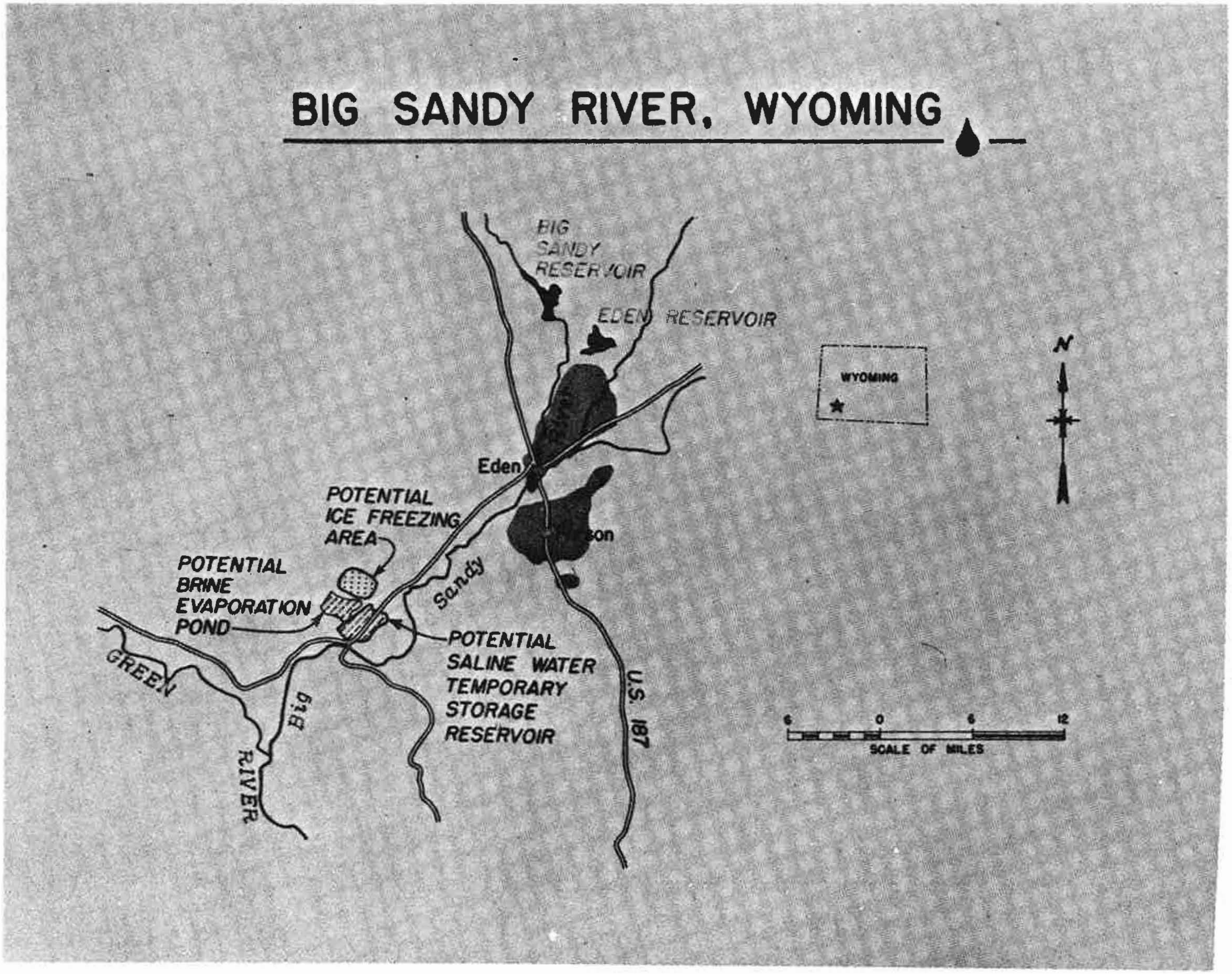
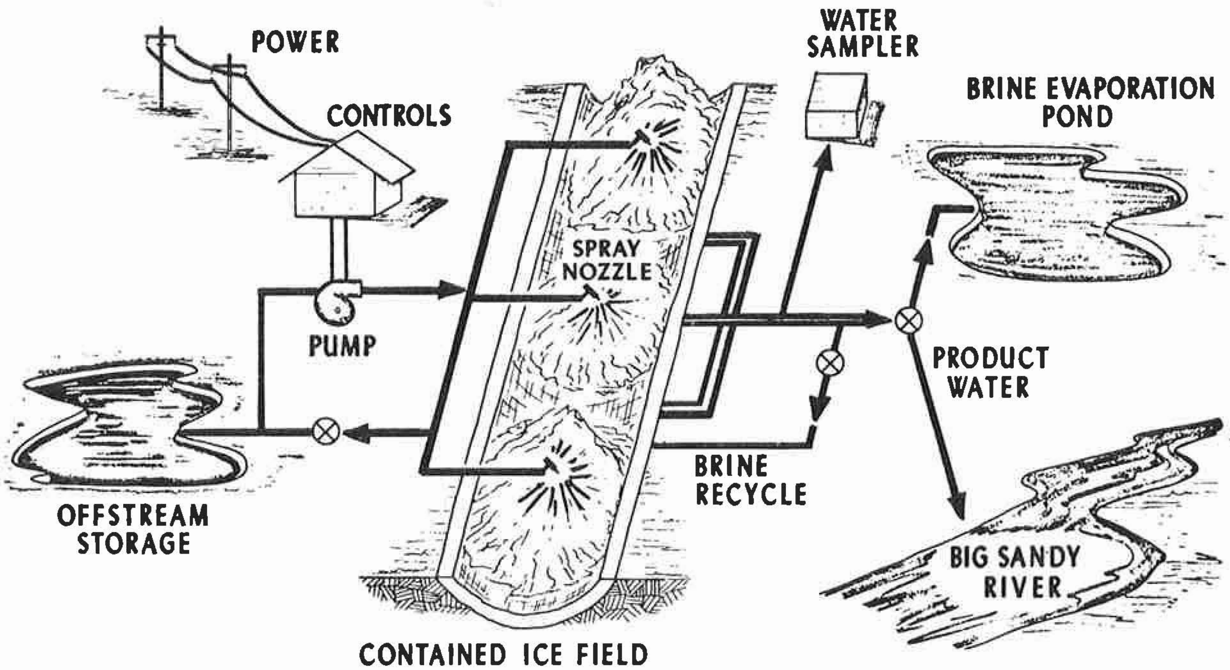

BIG SANDY RIVER, WYOMING
BIG SANDY RESERVOIR
EDEN RESERVOIR
WYOMING
N
Eden
POTENTIAL ICE FREEZING AREA
POTENTIAL BRINE EVAPORATION POND
POTENTIAL SALINE WATER TEMPORARY STORAGE RESERVOIR
Sandy
GREEN
Big
RIVER
U.S. 187
6 0 6 12
SCALE OF MILES

Figure 52



BIG SANDY
NATURAL FREEZING DESALTING-SCHEMATIC LAYOUT

Figure 53

plateaus to the west. Drainage areas contain 1,500, 1,670, and 4,200 square miles for the Price, San Rafael, and Dirty Devil Rivers, respectively. These study areas are principally desert, with an arid to semiarid climate. The summers are hot and dry and the winters are usually dry and cold. Temperatures range from over 100° F in summer to well below zero in the winter. For example, Hanksville, Utah, has recorded a high temperature of 112° F and a low of minus 35° F. Snowfall is generally light and amounts to only a few inches during the winter season, except at the higher elevations, where substantial amounts accumulate on the ground.

The geological formations in these river basins consist primarily of sedimentary rock. About 60 percent of the Dirty Devil drainage and 75 percent of the Price and San Rafael drainages are composed of mudstones, claystones, and shales which are the main source of salt loading in these rivers (see Figures 55 and 56). Much of the irrigated lands are located on salt-producing formations particularly in the upper portions of the Price and San Rafael drainages.

The estimated total dissolved solids contributed by the Price, San Rafael, and Dirty Devil Rivers are 240,000, 190,000, and 200,000 tons, respectively.

The estimated annual removal of salt by potential control programs are 100,000 tons on the Price River and 80,000 tons each for the San Rafael and Dirty Devil Rivers. Salinity concentrations of the Colorado River at Imperial Dam would be reduced by an estimated 9 mg/l for the Price River and 7 mg/l for each of the San Rafael and Dirty Devil Rivers.

Investigations thus far have included field surveys and data gathering. Streamflow and water quality data are being obtained at several locations on each of the rivers. These data and future investigations will locate areas of greatest salt loading. Further studies will be made to determine if other methods such as water systems improvement, irrigation scheduling, and farm management could be used along with selective withdrawal.

Additional sampling stations will be established as needed in conjunction with geologic investigations of each drainage basin.

Data gathering will continue in FY 1974-75 and feasibility reports are scheduled for FY 1978. Investigations have not progressed sufficiently to provide an estimate of costs.

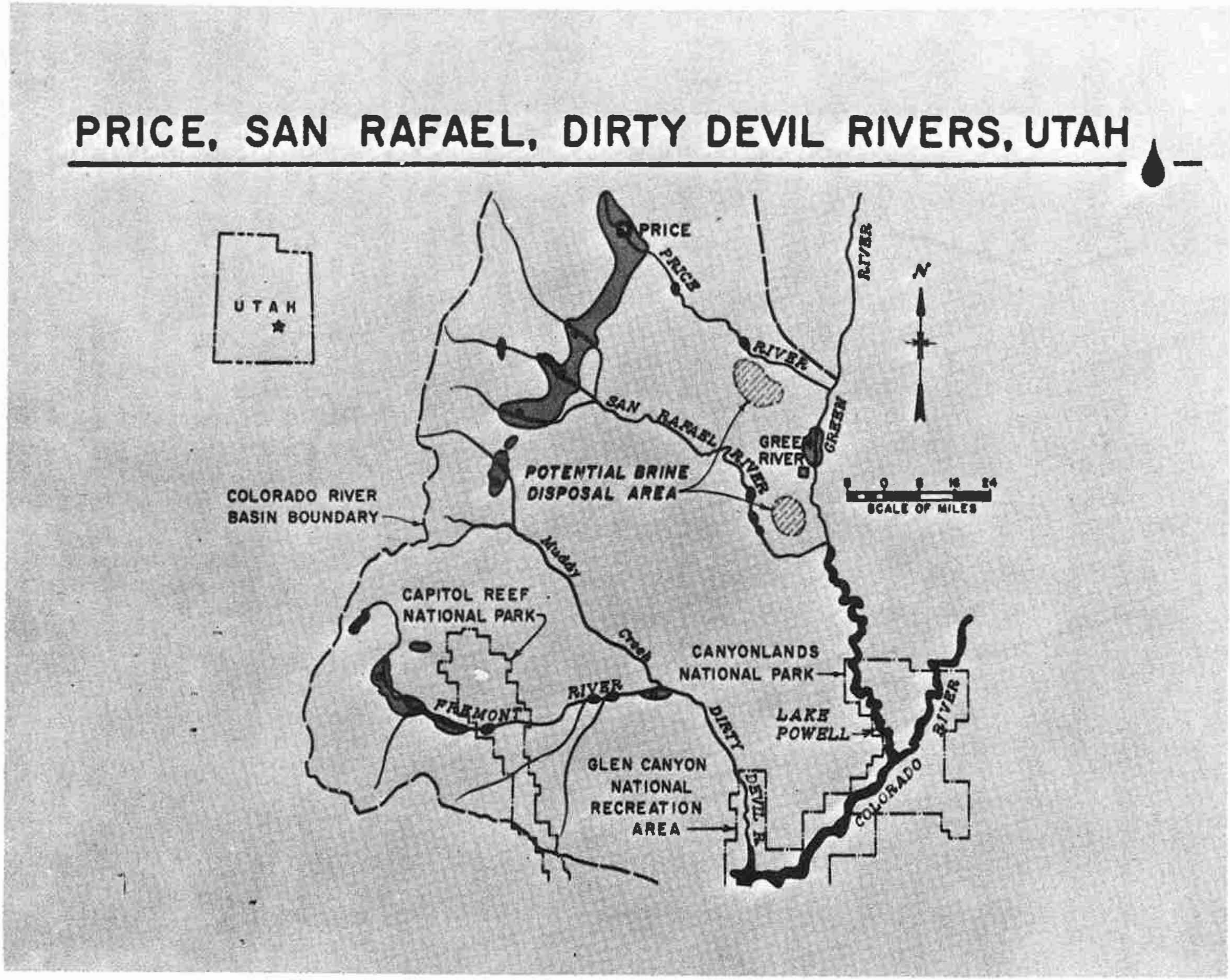

PRICE, SAN RAFAEL, DIRTY DEVIL RIVERS, UTAH
UTAH
PRICE
PRICE
RIVER
RIVER
SAN RAFAEL RIVER
GREEN RIVER
GREEN
N
POTENTIAL BRINE DISPOSAL AREA
SCALE OF MILES
COLORADO RIVER BASIN BOUNDARY
Muddy Creek
CAPITOL REEF NATIONAL PARK
CANYONLANDS NATIONAL PARK
FREMONT RIVER
DIRTY DEVIL R.
LAKE POWELL
GLEN CANYON NATIONAL RECREATION AREA
COLORADO RIVER

Figure 54

Figure 55. Dirty Devil River near Poison Spring Wash showing typical canyon as it exists between Hanksville, Utah, and the mouth.

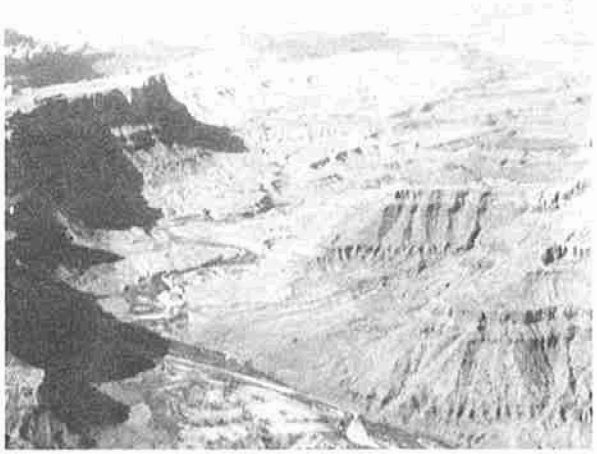


Figure 56. Showing typical topography through the San Rafael Swell.

Local benefits of the control programs have not been determined at this time. There would be an annual loss of water by evaporation estimated at 5,000 to 30,000 acre-feet for each river. It will be necessary to evolve procedure for accounting for such losses. The benefits in the lower Colorado River Basin are estimated to be $2,070,000, $1,610,000, and $1,610,000 for the Price, San Rafael, and Dirty Devil Rivers, respectively.

Control of the salt loading from these diffuse sources could have the following environmental impacts: Some degradation of natural scenery would result from construction of diversion dams and evaporating ponds or desalting plants. The accumulation of salts in the evaporating ponds may become scattered by wind or may be accidentally discharged into the Colorado River system. Water diverted out at low flows may result in some adverse effects downstream to plant and animal life.

McELMO CREEK UNIT, COLORADO

McElmo Creek drains 350 square miles which includes the irrigated area in Montezuma Vallèy in southwestern Colorado and flows into the San Juan River a few miles below the Colorado-Utah State line (Figure 57). The lands in Montezuma Valley are irrigated with water diverted from the Dolores River.

Based on 1 year's data, upper McElmo Creek and Mud Creek, a tributary of McElmo Creek which drains the south portion of Montezuma Valley, contribute approximately 85,000 tons of salt annually. Upper McElmo Creek and Mud Creek collect return flows from the major portion of the irrigated lands in South Montezuma Valley. These lands are derived from and are underlain by the Mancos Shale Formation.

Based on 3-1/2 years of data, McElmo Creek near the Colorado-Utah State line contributes an average of 130,000 tons of salt annually. Concentrations of McElmo Creek near the Colorado-Utah State line vary from 1,500 to 3,700 mg/l with an average of 2,650 mg/l.

The estimated annual removal of salt by the proposed program is 40,000 tons. Salinity concentration of the Colorado River at Imperial Dam would be reduced by an estimated 4 mg/l.

Various methods are being considered to remove salts from the flows of McElmo Creek. One method would be to selectively withdraw and evaporate the saline flows of upper McElmo Creek and Mud Creek. A second method would be to desalt the same saline flows. A reservoir site on Mud Creek is being investigated to evaporate either these saline flows or brine discharge from a desalting plant (see Figure 58). Upper McElmo Creek and Mud Creek capture most of the return flows from the irrigated lands in Montezuma Valley.

Gaging stations were installed and water sampling began in FY 1972 for collection of data. Continued data collection is scheduled for FY 1974 and FY 1975. A feasibility report is scheduled for FY 1978.

Investigations have not progressed far enough at this time to determine costs or local benefits. If a desalting plant were used to remove the salt, the product water

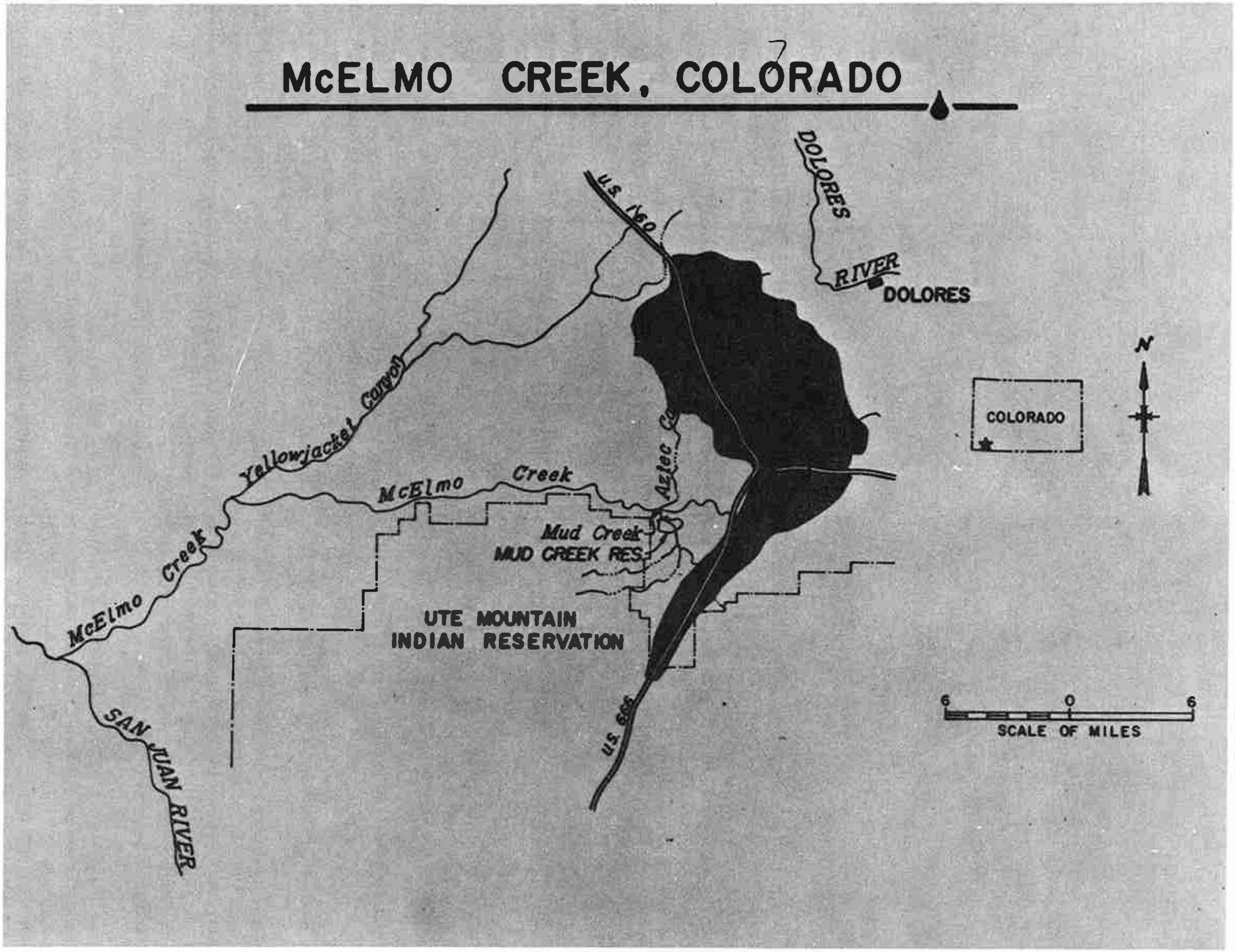

McELMO CREEK, COLORADO
DOLORES RIVER
DOLORES
U.S. 160
COLORADO
N
Yellowjacket Canyon
McElmo Creek
Aztec Cr.
Mud Creek
MUD CREEK RES.
UTE MOUNTAIN INDIAN RESERVATION
McElmo Creek
SAN JUAN RIVER
U.S. 666
6 0 6
SCALE OF MILES

Figure 57

Figure 58. Mud Creek Damsite. View looking upstream at Mud Creek Damsite. Dam location is just downstream from building in center of photo. C-1244-406-16

could be used for municipal or industrial purposes. There would be an annual loss of water by evaporation of up to 10,000 acre-feet. Most of the benefits would occur in the Lower Colorado River Basin and are estimated to be $920,000 annually.

Environmental Considerations

Control of this source of salinity could have the following environmental impacts: (a) a reduction in the salinity concentrations downstream, (b) reduction of the stream discharge during low flow periods, (c) some degradation of the natural scenery would result from the construction of the works necessary for evaporating or desalting the water. The evaporating ponds would be sterile within a few years and surrounded with dead plant life. At times, part of the ponds would be salt flats and the wind could transport the dry salts to the surrounding areas which may damage local vegetation.

RETURN FLOW UTILIZATION

The energy crisis has focused new attention on western water supplies to meet projected cooling water requirements for energy conversion and power production. Projected water consumption for power generation, coal conversion, and oil shale development could remove as much as 1.0 million acre-feet of fresh water from the Colorado River Basin by 1985. Water of high quality will not be available in sufficient quantity to supply all needs as envisioned. However, most energy uses of water for cooling and production processes will not require water of high quality and indeed may use flows that have a high mineral content without significant detrimental results.

Projected Western Systems Coordinating Council (WSCC) water requirements for thermal electric powerplants show a substantial amount of agricultural wastewater (over 300,000 acre-feet per year in the Colorado River Basin to the year 2000) allocated for cooling purposes. In view of the potential use of agricultural wastewater for cooling, expanded efforts to evaluate sites and sources for wastewater utilization are expected in order to conserve remaining fresh-water supplies.

In California, inland powerplant sites in key areas such as the Southeast Desert are under investigation in light of recent legislation restricting use of coastal sites. As a consequence of accelerated energy demands and availability of wastewater at inland sites, the potential use of agricultural return flows for salinity control should be recognized.

GRAND VALLEY COLLECTOR SYSTEM
COLORADO

Investigations are to commence in FY 1976 to evaluate systems for collecting the highly saline flows from irrigation return water prior to their entry into the Colorado River and to utilize the water for some beneficial purpose.

One of the most promising uses of saline wastewater in the area could be in connection with oil shale development. This could be accomplished by direct use or exchange. The richest oil shale deposit in Colorado lies in the Piceance Creek basin located between the Colorado River and White River in Western Colorado. Recent projections[6] of oil shale development on both public and private lands range from 300,000 to 1,000,000 barrels per day by 1985. Matching consumptive water requirements for these levels of production and expected technology mix range from 30,000 to 155,000 acre-feet per year. Current oil shortages sharp increases in foreign oil prices, and "Project Independence"[7] may accelerate oil shale development and supporting reuse of water resources.

The drainages leading to the Colorado River presently carry surface runoff, canal wastewater, and water from subsurface drainage. The flows from ground water are highly saline, while the other flows contain much less dissolved solids. Studies may show that selective collection of the water may be desirable with the saline water being processed and reused and the less saline flows being returned directly to the river.

One method of selective collection of water could be to construct tile drains in the bottom of present open drainages to collect the saline water, with an open concrete-lined channel near the ground surface to collect the surface runoff and wastewater. Another method of collection would be to pump the saline ground water.

The saline water could be stored at a site in the lower end of the valley, be partially desalted, or possibly used without any treatment in a thermal generation plant, coal conversion plant, oil shale plant, or other industrial use.

SAN JUAN COLLECTOR SYSTEM
COLORADO AND NEW MEXICO

This investigation unit was programed to evaluate the concept of collection of water of impaired quality and delivery to suitable location for use in coal gasification power production or other industrial processes. Possible sources in the San Juan Basin include natural waters and irrigation return flows (see Figure 59). The latter wastewater source will be of large magnitude (estimated to be about 250,000 acre-feet per year) when the Navajo Indian Irrigation Project is completed. This study will also have to evaluate means to satisfy the various legal and institutional constraints involved. Investigations for the San Juan Collector System will begin in FY 1974 and a report will be prepared in FY 1975.

PALO VERDE IRRIGATION DISTRICT
CALIFORNIA

The Palo Verde Irrigation District is located downstream from Parker Dam on the Colorado River in California and irrigates 91,400 acres. The 1972 records indicate a return flow of about 450,000 acre-feet and a salt pickup of nearly 148,000 tons annually. The discharge of the outflow drain varied from 147 cfs to 648 cfs with the concentration averaging 1,827 mg/l (see Figure 60). For every 20,000 acre-feet of water used for powerplant cooling, the salt load at Imperial Dam would be reduced by 31,000 tons per year, assuming the evaporated water is replaced by water from Hoover Dam with an average salinity of 690 mg/l. This would lower the concentration of Colorado River water at Imperial Dam by 4 mg/l.

COLORADO RIVER INDIAN RESERVATION
ARIZONA-CALIFORNIA

The situation on the Colorado River Indian Reservation is similar to that in the Palo Verde Irrigation District. A large acreage adjacent to the Colorado River is irrigated with direct diversions and the return flows have a salt concentration much greater than the river thereby increasing the concentration

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[6] Final Environmental Statement for the Proposed Prototype Oil Shale Leasing Program, U.S. Department of the Interior, August 1973.

[7] Recently announced by President Nixon as national policy to encourage the United States to be independent of foreign energy resources by 1980.

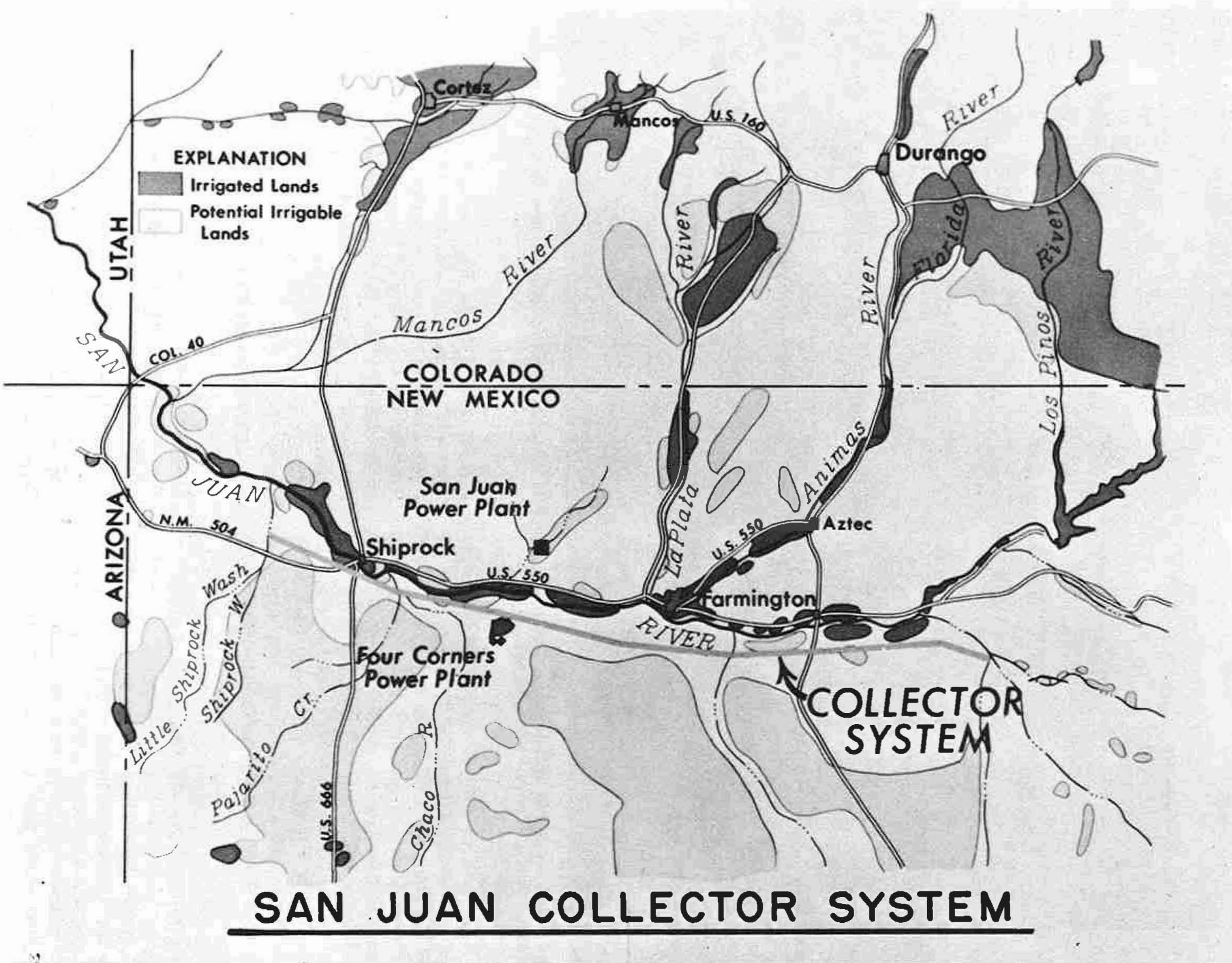
EXPLANATION
Irrigated Lands
Potential Irrigable Lands
UTAH
ARIZONA
COLORADO
NEW MEXICO
Cortez
Mancos
U.S. 160
Durango
Aztec
Farmington
Shiprock
San Juan Power Plant
Four Corners Power Plant
COL. 40
N.M. 504
U.S. 550
U.S. 666
SAN JUAN RIVER
Mancos River
La Plata River
Animas River
Florida River
Los Pinos River
Chaco R.
Pajarito Cr.
Shiprock Wash
Little Shiprock W.
COLLECTOR SYSTEM
SAN JUAN COLLECTOR SYSTEM

Figure 59

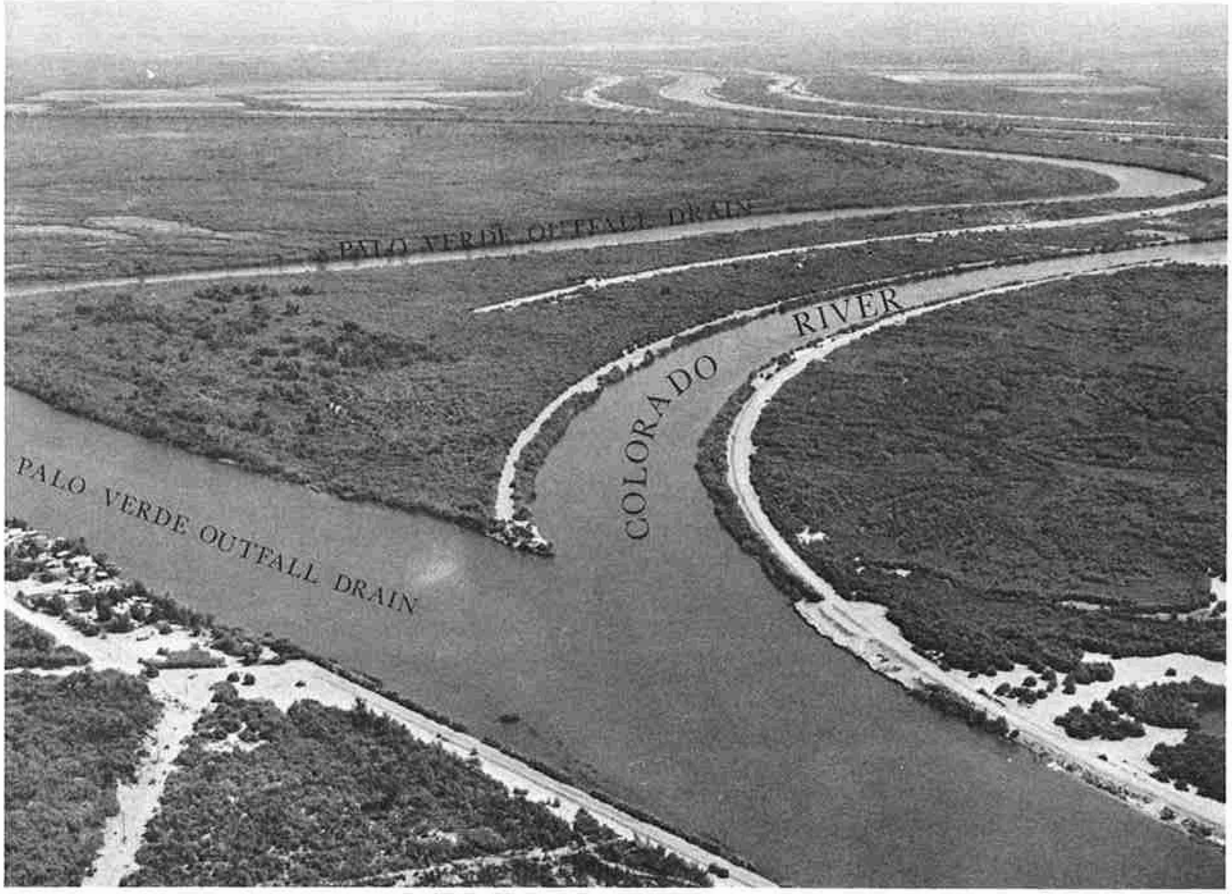

Figure 60. Palo Verde Powerplant cooling view showing the Palo Verde Outfall Drain and its confluence with the Colorado River below Blythe, California. P423-300-01037

downstream. About 60,000 acres are presently irrigated but almost another 50,000 acres could be irrigated according to the Supreme Court decree. The present concentration of salt in the return flow water is somewhat less than occurs in the Palo Verde drain but by the time the full acreage is developed and the lands are adequately drained it is expected that the concentration will increase. This would be another source of powerplant cooling water but would be subject to the same legal and institutional constraints.

OTHER SOURCES OF COOLING WATER

Future return flows from irrigation on the Fort Mohave and Chemehuevi Indian reservations may also present opportunities for using higher salinity water for powerplant cooling. The planned irrigation of about 21,000 acres along the Lower Colorado River will provide return flows high in salinity that would otherwise increase the concentration in the river. These sources will be the object of a general study that will examine the possibility of using water with a higher concentration of salt to accomplish two purposes, (1) the reduction of salt in the river system and (2) powerplant cooling.

ENVIRONMENTAL CONSIDERATIONS

The principal adverse impact of using more saline water for powerplant cooling would be the slightly greater storage ponds required for evaporation of the brine on the desert.

The positive environmental effect would be Colorado River water containing less salt.

CHAPTER V. RESEARCH

ION EXCHANGE

One alternative to controlling the salinity in the Colorado River would be desalting to the water users' specifications at the points of diversion. For irrigation purposes, this would involve large desalting plants. For other purposes, however, smaller capacity plants might be required to reduce the salinity concentrations by only a few hundred mg/l. Ion exchange would be well suited for such applications.

In a cooperative effort with the Office of Saline Water, a preliminary study of the feasibility of applying ion exchange technology was completed in 1972. This report indicated that with the development of the technology it might be possible to achieve very large scale river quality control at the 500-mg/l level. Product water recovery will be expected to vary between 89 and 95 percent.

The study was supported by a 6-week ion exchange desalting pilot plant operation on the Colorado River below Davis Dam. A 5,000-gallon-per-day pilot plant successfully operated on 750 mg/l water to yield a product water of 500 mg/l. The pilot plant tests examined several resins and process configurations. For the various processes, recommended regenerate chemicals are sulphuric acid and ammonia.

These chemicals are the most important single cost element in the economic structure of the entire process. It is conceivable that these costs could be reduced considerably by using industrial waste products in the basin from thermal power generating facilities and other sources.

Considerable problems can be foreseen for applying ion exchange processes on a very large scale. Therefore, future attention will be directed toward developing conceptual designs for handling water volumes more closely alined with the major diversions anticipated in future years.

ARS–BR IRRIGATION EFFICIENCY STUDY

An agreement was executed on April 24, 1973, between the Bureau of Reclamation, Department of the Interior, and the Agricultural Research Service (ARS), Department of Agriculture, to conduct research on irrigation application rates in relation to salinity output, from lands in the Grand Valley, Colorado. The research program will continue to June 30, 1975, at an estimated total cost of $903,000. The Bureau of Reclamation agreed to fund the program to a total of $380,000 with the Agricultural Research Service funding the balance of $523,000.

This research is aimed at evaluating the potential of increasing irrigation efficiency through use of high-frequency, low-volume irrigation sprinkler applications and advance gravity application methods and relating the results to the salinity output from the irrigated areas. This will involve quantitative studies of the mineral weathering and salt precipitation as a function of irrigation management on the soils of the Grand Valley area with waters of the Colorado River. The research will also attempt to determine procedures needed for predicting mineral weathering and salt precipitation for representative soils and waters in other locations of the Colorado River Basin.

Work was started in the spring of 1973. It was decided that work should proceed only on a well-drained site during 1973 due to the late spring season in the Grand Valley area and the limited amount of funds available for site preparation and instrumentation. Requirements included a fairly deep water table throughout the growing season, preferably 8-10 feet below the surface; field topography suitable for both surface and sprinkler irrigation; intake characteristics on which a center pivot sprinkler irrigation system could be expected to operate satisfactorily; and an area of 50-60 acres in order to include adequate size field plots for both types of irrigation systems. Details of the experimental procedure for a well-drained site were finalized and a 55-acre field owned by Mr. E. L. Barbee was selected for the initial experimental studies. Soil on the site is a Ravola loam with one small corner being Ravola clay loam, and it affords opportunity for surface irrigation runs of approximately 600 and 1,200 feet and operation of a center pivot sprinkler system with 605-foot radius. The site is supplied by surface water from the Government Highline Canal through excellent water control facilities. An agreement was negotiated with Mr. Barbee whereby ARS would lease the experimental site annually on a renewable basis for a period of up to 5 years. ARS agreed to furnish fertilizer, herbicides, and experimental irrigation equipment and irrigate the site throughout each season. Mr. Barbee agreed to till, plant, fertilize, cultivate, and harvest the corn crop and to provide water.

Soil samples were obtained for chemical and physical analysis at approximately 70 locations on the experimental site (see photographs on next page).

Instrumentation for experimental work was installed and included (1) sensors to measure salinity levels, in situ, in various portions of the field, (2) one large weighing lysimeter to provide precise measurement of water use through the season, (3) vacuum extractors to determine both weight and quality of waterflow beneath the undisturbed soil profile, and (4) additional tanks to determine water balance through the disturbed profile. (Figures 61, 62, 63, 64, and 65 show the instrumentation used.)

A center pivot self-propelled sprinkler was installed with sufficient control equipment to apply precise amounts of water on different portions of the circular field. A gated pipe system was used for the furrow irrigation plots.

Figure 61. Obtaining soil samples on experimental farm for physical and chemical analyses.

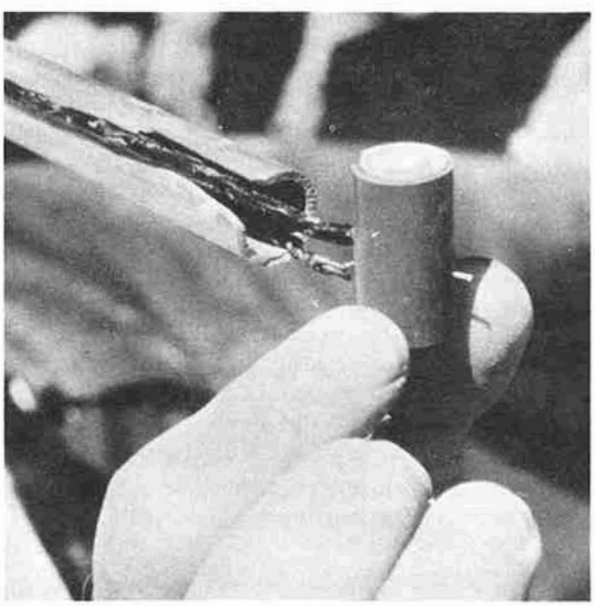

Figure 62. Sensor that measures salinity levels in place.

The experimental plots were planted in corn crop and excellent harvests were obtained, considering that the planting was delayed due to installation of equipment. The harvest of corn ensilage averaged 24.7 and 19.5 tons per acre, respectively, for the sprinkled and furrow irrigated plots. Experimental results from 1973 are now being analyzed to provide additional guidance for the 1974 planting season.

Preliminary review of the experimental procedure by Bureau and ARS personnel resulted in agreement to conduct additional priority investigations to locate major gaps in the knowledge of salt return flow processes in Grand Valley and to determine the volumes of water entering the ground-water system as deep percolation from fields irrigated under prevailing methods. Other studies would be undertaken to estimate rates and salt concentration of water exchanged between ground-water bodies and open drainages and to determine if aquifer characteristics are amenable to pumping sufficient saline water from them so as to intercept a significant amount of water now flowing to the Colorado River.

A public information brochure is now being prepared explaining the research.

CONSORTIUM OF WATER INSTITUTES AND CENTERS

In cooperation with the Consortium of Water Institutes and Centers comprised of various universities of the

Figure 63. Weighing lysimeter planted to corn. Lysimeter provides precise measurement of water use.

Figure 64. Vacuum extractor in place below root zone under undisturbed soil profile.

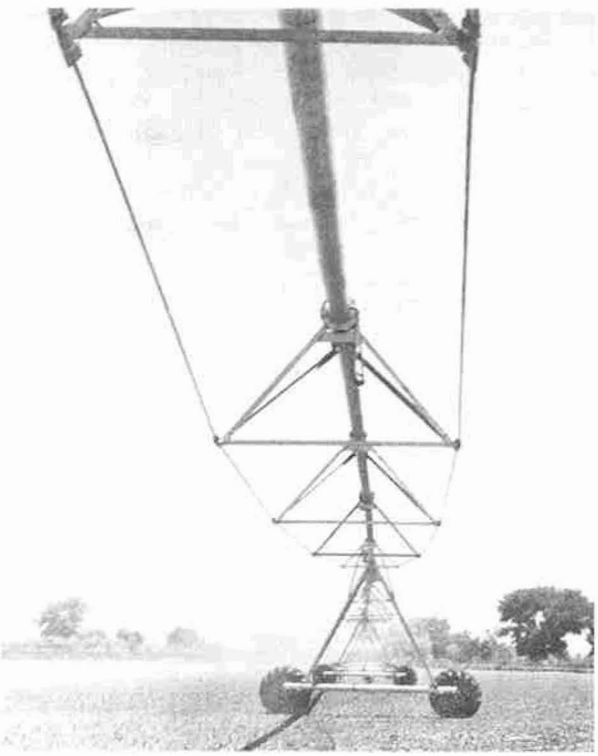

Figure 65. Center pivot, self-propelled sprinkler used on experimental farm.

Colorado River Basin, the CRWQIP is involved in a study "Salinity Management Options for the Colorado River." This work is supported by the Office of Water Resources Research (OWRR) as a matching fund grant. OWRR has made available $80,000 which will be matched by the universities. In addition, the CRWQIP will be supporting personnel and other inputs valued at about $75,000 making the total funding $235,000 over a 2-year period ending June 30, 1975.

The objectives of the study are:

1. Estimate the direct economic damages associated with changing levels of salt concentration in agriculture.

2. Estimate direct economic damages associated with changing levels of salt concentration for municipal and industrial uses in the basin.

3. Estimate direct economic impacts of possible salinity control measures on upper basin water users.

4. Estimate indirect economic impacts associated with changing salt concentration levels as used in Objectives 1, 2, and 3.

Data gathered will define production activities and production functions for agriculture. These activities become the basis for parametric linear programing used to generate the economic relationships between farm-firm crop production and farm income with respect to the quality of irrigation water. From this, regional functions can be derived with associated economic impacts resulting from changing water quality.

Linear programing analysis is a normative approach based upon the theory of the firm. The results provide information to decisionmakers as to what they ought to do if they have given objectives. In most cases, a farm firm may produce a number of crops within the framework of a bundle of relatively fixed resources and other production restraints. A manager may be able to combine his resources in a number of ways. The choice of a particular combination will be made after considering all the economic implications of the different alternatives.

The use of the field data and programing models will define the best that a farmer could do in the face of increasing salinity. This optimum condition defines a conservative economic impact of salinity.

This most important phase, analysis of data and specifications of assumptions, will be carried out by Bureau of Reclamation personnel. The fieldwork performed by the contractors is essentially a data gathering and microanalysis activity. The more sophisticated analysis will be handled by scientists completely familiar with the entire salinity program. Dr. Alan P. Kleinmen of the Bureau staff will serve as coprincipal investigator of the project so that the CRWQIP will have close control on the performance of the research.

The data provided will be used by CRWQIP personnel for optimization programs to derive damage functions to be attached to the Colorado River simulation model in order to ascertain the economic impact of various management alternatives, salinity control works, water resource development projects, and selected scenarios of future basin conditions.

AGRICULTURAL EXPERIMENT STATIONS–USDA COOPERATIVE RESEARCH

The Western Experiment Station Directors in cooperation with the USDA have established a regional research project entitled "Salinity Management in the Colorado River Basin." The stated objectives of the project are to develop and evaluate methods for understanding and managing salinity in the Colorado River Basin from agricultural and diffuse natural sources. Specifically it is intended to:

1. Develop and field test irrigation management methods and determine their physical and chemical consequences in terms of crop production, salt storage, and discharge.

2. Evaluate irrigation and land management methods in terms of resource requirements, economic returns, and institutional requirements.

3. Determine and evaluate the consequences of vegetative management and land surface treatment on the output of salts in surface and ground waters.

4. Determine natural sources of salts within watershed areas and to develop and assess methods for eliminating or reducing salt loading from these sources.

5. Analyze water allocation, water delivery, and water removal in selected representative areas to determine optimal methods of managing the salt load.

6. Develop and verify a hydraulic-salinity river simulation model capable of:

   a. Predicting effects of salinity control within the basin at specified response points.

   b. Evaluating management possibilities to improve salinity conditions within the basin.

7. Determine operation effects on salinity of:

   a. Evaporation.

   b. Bank storage.

   c. Mixing phenomena.

   d. Potential salt sink.

LAKE POWELL STUDIES–NATIONAL SCIENCE FOUNDATION

The Lake Powell Research Project (LPRP), officially entitled "Collaborative Research on Assessment of Man's Activities in the Lake Powell Region," is being conducted by a consortium of academic institutions under the sponsorship of the Research Applied to National Needs (RANN) program of the National Science Foundation. The Project formally came into existence in 1971. The Bureau of Reclamation has cooperated with the Project by a complete interchange of data, assistance in fieldwork, and limited financial support for those subprojects that have direct application to operational programs of the reservoir. (See Figure 66.) The LPRP consists of 16 subprojects, covering a wide range of disciplines. Four of the subprojects deal with some aspect of the water quality of Lake Powell. These are (1) Cultural Eutrophication, (2) Heavy Metals, (3) Geochemistry, and (4) Physical Limnology.

The goals of the *Cultural Eutrophication* subproject are to develop indices of eutrophication, measures of primary productivity, and to understand the impact of man on reservoir aquatic ecology. Using analyses of lake water samples, parameters are being evaluated which will provide measures of phytoplankton, zooplankton, biomass, rate of carbon fixation, and coliform and other intestinal bacteria. The investigators have tentatively concluded that Lake Powell is "mildly" eutrophic.

The general goal of the *Heavy Metals* subproject is to establish baseline levels of concentration for certain cations in a variety of kinds of material of the aquatic ecosystem including water, soils, sediments, plants, and fish. The analysis program includes iron, calcium, lead, copper, zinc, chromium, magnesium, cadmium, and mercury.

Figure 66. Lake Powell showing typical cliffs at the water's edge.

The *Geochemistry* subproject is directed toward (1) examining the time-dependent distribution of chemical elements in the lake and (2) quantifying the ions added to the lake by solution and/or chemical precipitation. Activities have included (1) sample and analysis of main channel and bay waters, (2) a recent implementation of the sampling program to include input and output waters of the lake system, (3) the development of a hypsometric computer model of the lake, and (4) laboratory studies of calcium carbonate precipitation in Lake Powell water samples.

Field and laboratory studies of Lake Powell by the Project investigators suggest that precipitation of calcium carbonate is the most quantitatively important chemical process that alters water quality as a result of impoundment. The principal investigators estimate that the total reduction of salinity in the lake due to this process could reach a level of 7 to 8 percent at full reservoir capacity.

The goals of the *Physical Limnology* subproject are (1) to find and understand the chemical and physical matrix provided by the lake and its subsequent effect on water quality and biological potential and (2) to provide baseline data on circulation and currents within the lake as it approaches full volume. Samples are being obtained to determine the synoptic distribution of temperature, conductivity (salinity), oxygen, chemistry, and turbidity.

CHAPTER VI. COOPERATING ENTITIES

The investigations involved in the Colorado River Water Quality Improvement have been aided by the support of all of the basin states and most water user organizations. Several other agencies of the Federal government, particularly the EPA, have contributed effectively to the program in addition to the research efforts already discussed.

BUREAU OF LAND MANAGEMENT

The Assistant Secretary—Land and Water Resources has directed the Bureau of Land Management and the Bureau of Reclamation to establish a working relationship to integrate Reclamation and public land programs as they relate to improvement of the water quality in the Colorado River Basin. Currently, a task force is being established with representatives from the Bureau of Land Management and the Bureau of Reclamation whose responsibility will include:

1. Review research on various methods of water quality improvement applicable to the Colorado River Basin natural resource lands.

2. Recommend implementation of those methods suitable for application and identify specific treatments needing further research.

3. Determine the need for on-the-ground review on specific sites.

4. Develop guidelines for use by field personnel to identify potential areas for study (i.e., physical data on salinity concentrations, quantity of flow, geographic location, control measures, and associated cost). The guidelines are to be on areas of mutual concern rather than on those that are solely within the responsibility of one organization (i.e., salinity associated with irrigation projects will not be considered).

5. Identify potential areas for study.

6. Identify types of programs or treatments that should be considered for improvement of water quality.

7. Recommend areas of responsibility between Bureaus in relation to the application of remedial treatment practices in specific geographic areas.

Following completion of these tasks, specific programs will be identified to implement measures of reducing salinity in the Colorado River system.

DEPARTMENT OF AGRICULTURE

In addition to the research underway by the Department of Agriculture, it has also undertaken the examination of the magnitude of program inputs needed to provide definitive appraisals of present and potential contributions to the reduction of the salt load of the Colorado River system. The Department of Agriculture has been working with farmers and ranchers for many years to improve onfarm water management techniques. These onfarm activities significantly compliment the Colorado River Water Quality Improvement Program.

Evaluations proposed or underway by the Department of Agriculture include:

1. Showing relationships of erosion and sediment production to salt loading.

2. Identifying land areas having the highest potential to affect salt loading through erosion and sedimentation.

3. Identifying watershed areas where management and treatment practices will reduce salt loading.

4. Identifying areas where improved irrigation system and management practices can be utilized.

5. Showing relationships between such practices and salt loading.

6. Quantifying effects which can be achieved through technical or financial assistance programs of the Department.

7. Identifying the impacts of alternative salt load reduction programs on the agriculture, livestock, and forest industries.

In particular, the Soil Conservation Service is actively participating in salinity control activities in the Grand Valley area. Through its Rural Environmental Assistance Programs, it has installed 14 miles of ditch lining at a cost of about $300,000. Moreover, it is cooperating with the Bureau in the conduct of the Irrigation Management Services program. It has had a task force appraise required improvements in onfarm irrigation systems. Its role in further improving farm irrigation efficiencies can be highly significant.

STATE PARTICIPATION

The seven basin states all participated in structuring the Colorado River Water Quality Improvement Program. They have monitored progress of the investigations and have provided helpful assistance and suggestions as the program progresses. For example, in the Grand Valley area, the State of Colorado has assigned personnel to work toward the goal of improving water use efficiency in the Valley. It has financed field trials of advanced onfarm automated irrigation systems including a drip irrigation system in an orchard. The State of Wyoming is participating in a pilot study of the natural freezing process for salt removal in the Big Sandy River. The State of California has accomplished background studies of the salinity problem and has been most helpful in providing results of independent studies relating to economic impacts of saline water use. Nevada has arranged for and provided considerable technical data and background relating to Las Vegas Wash. Such continuing cooperation is essential to successful completion and evaluation of the various salinity control units involved in the program.

DEFINITION OF TERMS

ACRE-FOOT—The volume of water that would cover 1 acre to a depth of 1 foot (325,850 gallons). One acre-foot per day is approximately equal to 0.5 cubic foot per second (cfs).

BRINE—In general, any water containing more total dissolved solids than sea water.

CFS—CUBIC FEET PER SECOND—Standard terminology to express flow rate, interchangeable with acre-foot per unit time (year, month, day). One cfs is equal to approximately 724 acre-feet per year.

CONCENTRATION—TDS—TOTAL DISSOLVED SOLIDS—SALT—SALINITY—DISSOLVED MINERALS—All synonymous terms referring to quantity of dissolved mineral salts in solution. Almost all dissolved salts in water may be considered to be salts of three metals; calcium, magnesium, and sodium, or nonmetallic elements such as bicarbonates, sulfates, and chlorides.

CONCENTRATION, UNITS OF—MILLIGRAMS PER LITER (MG/L), PARTS PER MILLION (PPM)—For mildly saline waters, the weight of salts per unit volume of solution (mg/l) corresponds to weight per unit weight of solution (ppm) and is used interchangeably up to about 7,000 mg/l.

CONCENTRATION REDUCTION—In this report, mg/l reduction benefits are reported as time-weighted averages.

DESALTING PROCESS NOMENCLATURE—Reverse Osmosis (RO), Ion Exchange (IX), Multistage Flash Distillation (MSF), Electrodialysis (ED), Vertical Tube Evaporator (VTE).

EVAPOTRANSPIRATION—The consumptive use of water from the soil. Water lost as vapor from a given area through the combined processes of evaporation from the soil surface and transpiration from plants plus water stored in plant tissues.

IRRIGATION EFFICIENCY—Refers to ratio of irrigation water actually used in crop evapotranspiration to the amount of water delivered to the farm.

IRRIGATION MANAGEMENT SERVICES (IMS)—A Bureau of Reclamation program established to improve irrigation water efficiency by management techniques applied to irrigation scheduling, timing, and mode of water application.

IRRIGATION RETURN FLOW—Any water diverted for irrigation purposes that finds its way back into a source of supply (surface stream or ground water). This includes bypass water, percolation losses, runoff, and seepage.

GPO 832-520