DISSERTATION

OPTIMIZING SALINITY CONTROL STRATEGIES FOR THE UPPER COLORADO RIVER BASIN

Submitted by

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ABSTRACT

OPTIMIZING SALINITY CONTROL STRATEGIES
FOR THE
UPPER COLORADO RIVER BASIN

Salinity is the most serious water quality problem in the Colorado River Basin. The impact, felt largely in the Lower Basin, is acute because the basin is approaching conditions of full development and utilization of all available water resources. Current estimates indicate that each mg/l increase in concentration at Imperial Dam results in $450,000 annual damages. Therefore, in order to offset salinity caused by the development of the vast energy supplies and to allow the seven Colorado River Basin states to fully utilize their allocation of Colorado River water, it is necessary to implement cost-effective salinity control programs in the basin.

A simple multi-level nonlinear optimization procedure was utilized to formulate the most cost-effective array of salinity control strategies for the Upper Colorado River Basin. The incremental cost-effectiveness methodology qualitatively indicates the location and general type of alternatives to be implemented in a least cost basin-wide salinity control program. The results also qualitatively indicated the anticipated salt load reduction and expected annual costs of each salinity reduction increase for any preselected level of control. The analysis was limited to

projects designated in PL 93-320. Costs and salinity contributions associated with various alternatives were generated using January, 1980, estimated conditions.

Cost-effectiveness functions were developed for each of the major canals and laterals, the aggregate laterals under each canal, and an array of on-farm improvements for each agricultural project area. Similar functions were also developed for point sources such as Paradox Valley, Glenwood-Dotsero Springs and Crystal Geyser. Collection and desalination of agricultural return flows were also considered.

Marginal cost analysis based on current damage estimates indicate that the optimal cost-effective salinity control program in the Upper Basin would cost about $30 million annually and remove about 1.2 million megagrams of salt per year. In addition, it was concluded that maintenance of the 1972 salinity levels at Imperial Dam cannot be cost-effectively achieved and should be allowed to rise by as much as 180 mg/l. Optimal salinity control programs are presented for the individual alternatives, for individual areas or projects, for the states of Colorado and Utah and the Upper Colorado River Basin. Sensitivity analysis showed that very large errors in costs and component salt loading would have to be evident to change the optimal salinity control strategy for the Upper Colorado River Basin.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

CHAPTER 1

INTRODUCTION

The primary water quality problem in the Colorado River Basin (Fig. 1) is salinity. This concern tends to be so dominant that it overshadows most other water quality considerations. Fortunately, the salt pollution of the Colorado River by either man-made or natural depletions and/or discharges is not a general health hazard. Salinity is basically an economic problem in which a progressive build-up in concentration toward the lower reaches causes a reduction of the water's utility to urban and agricultural users.

Salinity increases in the Colorado River are not a recent phenomenon. Salinity has been increasing as a result of all water resource development projects since the 1800's when some degree of salt concentration due to irrigation was tolerated as the price for development (Law and Skogerboe, 1972). Salinity levels also fluctuate with natural weathering and runoff processes. The Colorado River and its tributaries travel more than 2,300 km from the headwaters in the Rocky Mountains to the Gulf of California and drain about 622,000 km^2 in seven states. The drainage area is approximately one-twelfth of the area of the conterminous United States. The annual total salt burden is about 10 million Megagrams (Mgm).

Concentrations of salinity in the Colorado River range from less than 50 mg/l in the high mountain headwaters to

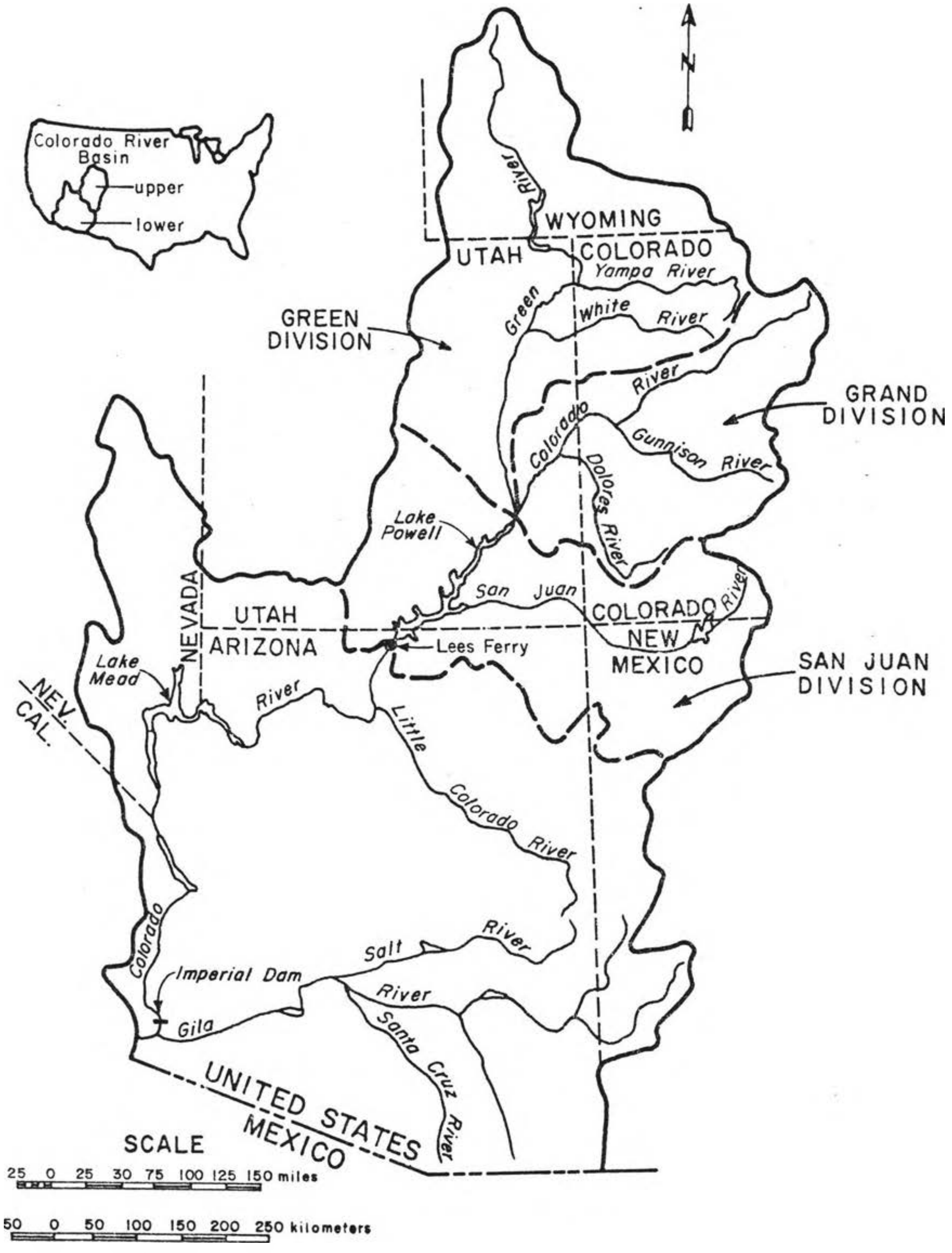


Figure 1. Colorado River Basin.

more than 850 mg/l at Imperial Dam. Further deterioration of Colorado River quality is expected as a result of water and energy resource development. This will occur even if salinity reduction measures are instituted although it would occur at a slower rate. If no salinity control measures are developed, it is anticipated that salinity increases at Imperial Dam will range from 1,150 mg/l (USDI, BR, 1979a) to 1,340 mg/l (Colorado River Board of California, 1970) by the year 2000.

All of the salinity control planning which has been done to date has been oriented toward only reducing the salt load of the Colorado River. The economics of control have not been of overriding concern. Furthermore, development of cost-effective programs or the construction of projects with benefit-cost ratios greater than one has not been high priority even though costs have been compared to estimated annual damages at Imperial Dam. The argument presented in favor of the non-economic approach is that Congress (PL 93-320) mandated certain projects and that these projects would include specific construction items such as canal linings. However, since that legislation was passed the results of numerous investigations have become available which permit the formulation of cost-effective salinity control programs.

The control of salinity on the scale needed in the Colorado River Basin will undoubtedly involve a combination of several individual control measures in each area of salinity contribution. For any specific source of salinity, local conditions will dictate that some measures will be more feasible than others. Furthermore, the measures best suited to an area's conditions change with the level of control scheduled in the area. For example, in an irrigated area contributing 500,000 Mgm to the river system annually, of which 20 percent is to be controlled, lining several miles of the major canals may be the least costly alternative. However, if the desired level of salinity control was increased to 60 percent, the optimal salinity control strategy may involve canal lining as well as several forms of on-farm improvements. Any time more than a single salinity control measure is employed, the relationship between the marginal costs of control and the marginal reductions in salinity will increase with the scale or level of the program (Walker, 1978). Consequently, the most important decision regarding salinity control in the Colorado River Basin is the optimal level and manner of abatement to be achieved at each salinity source.

OBJECTIVES OF INVESTIGATION

The principal objective of this research effort is to apply an optimizational analysis to salinity control planning in the Upper Colorado River Basin (UCRB) in order to identify the most cost-effective strategies for alleviating salinity detriments downstream. Intermediate goals of the project may be summarized as follows:

(1) To delineate the regions in which salinity control projects should be implemented to achieve the maximum salinity reductions for various levels of available funding;

(2) To evaluate the best salinity control policies as functions of alternative water development scenarios in the basin, i.e., interbasin transfers, energy industry developments, and expanded agricultural diversions;

(3) To determine the impact of state and federal policies on the costs of Upper Basin salinity management plans; and

(4) To assess the sensitivity of the derived optimal policies to assumptions regarding the physical nature of the salinity system, and costs of alternative control measures, and the effectiveness of salinity control programs.

SCOPE OF INVESTIGATION

The salinity problem in the Colorado River Basin is characteristic of arid and semi-arid river systems approaching conditions of full water resource development. Several years of intensive research and demonstration of alternative salinity control technologies have yielded results which should be applicable throughout the river basins in the western United States as they reach full development. The Colorado River salinity control program, therefore, might be expected to serve as a model for future efforts elsewhere.

One major aspect of the Colorado River Basin salinity problem has not heretofor been addressed. An analysis integrating the existing information concerning alternative salinity control measures into a basin-wide policy for water quality improvement has not been made. It was necessary to take the final step in developing salinity control technology on a large scale. The preliminary basis for this type of analysis has been developed by Walker (1978) and partially tested by Walker et al. (1978).

This project was developed in order to evaluate the alternative strategies for controlling salinity in the Upper Basin, and therefore, identify components of individual salinity programs throughout the Upper Basin in the context of how best to use available funds. At the local scale, only the results reported by Evans et al. (1978a,b), Flug et al. (1977), Walker (1978) and Walker et al. (1978) have been concerned with optimal salinity control strategies. These studies have been completed in only one area, the Grand Valley in western Colorado. Erlenkotter and Scherer (1977) developed an economic optimization model for the entire Colorado River Basin, but stopped short of an ultimate framework for basin-wide salinity management.

This writing delineates a cost-effective salinity control policy for future water resource development in the Upper Colorado River Basin taking into account: (a) salinity control; (b) energy development; and (c) new water demands. The feasibility of maintaining 1972 levels of salinity at Imperial Dam set forth by the U.S. Environmental Protection Agency and the seven basin states has also been evaluated. Under this criterion, it can be expected that approximately 2 to 3 million Mgm of salt must be eliminated from the flows passing into the Lower Basin in order to offset the development of the remaining Upper Basin entitlements. This analysis delineates the regions and expenditures in which salinity control projects should be initiated to achieve these salt reductions at minimum cost. The marginal costs and marginal benefits of control programs are compared with respect to various levels of salinity control.

The results also identify the optimal salinity control policy for various levels of development, and can indicate the best salinity management practices as a function of time or development. Any new project which would be expected to cause an increase in downstream salinity concentration could be identified with the most cost-effective salinity control project to offset its impact.

Conceivably, optimal salinity control strategies could include indirect methods for individual water development projects to offset their salinity detriments to the Colorado River. A new project's salinity impact may be best corrected by a water quality improvement program elsewhere in the Basin. Consequently, a number of important institutional issues can be expected to arise when considering salinity control as a large scale problem. The optimal plan for offsetting the salinity associated with water development in one state may be the treatment of an existing system in another state. If such a policy were to be constrained, by not allowing an interstate or regional view of salinity control, the costs would be higher. Comparison of the optimal strategy with the corresponding constrained strategies indicate the added costs of individual restrictions. Other results evaluate the problems of treating one type of existing use, such as irrigated agriculture, to offset the salinity attributable to new water developments.

There is by no means an absolute certainty in any planning effort. Data must be collected and evaluated during the course of time in order to update and refine earlier conclusions. While this work is no exception, and the strategies developed may be easily modified as new information becomes available or political attitudes alter the importance of salinity, the results illustrate an important and necessary first step. Sensitivity analyses have been used to identify important areas needing special studies and particular data requirements which would most effectively assist accurate determination of future programs and policies.

The scope of this work, in a mathematical sense, is also limited by the choice of optimization criteria. Minimum capital, operation, and maintenance costs expressed as an equivalent annual cost are used to systematically compare salinity control alternatives. While recognizing the much broader economic concepts that operate in the real systems this more restricted indicator is believed to be defensible. Most funding for salinity control projects, as currently authorized, is expected to come from federal sources because the real economic system is unable to return economic detriments to the salinity sources as a means of self-regulation. In addition, legislative action has already set constraints, on allowable Lower Basin salinity levels, so the planning problem is not to solve the problem in an economically optimum fashion, but to meet the standard. Thus, minimizing costs is consistent with the problem structure.

PREVIOUS INVESTIGATIONS

Salinity of the Colorado River and its tributaries has been the subject of many studies and investigations. Various socio-economic, engineering, environmental and other aspects of the salinity problem and potential control measures have been pursued by the U.S. Department of the Interior; Water and Power Resources (formerly the Bureau of Reclamation); the U.S. Geological Survey; the U.S. Environmental Protection Agency and its predecessor agencies; the Water Resources Council, Colorado River Board of California; U.S. Department of Agriculture, Soil Conservation Service, and Science and Education Administration (Agricultural Research); state and local governmental entities; and several universities and consulting engineering firms.

In 1975 Utah State University prepared a comprehensive regional assessment report for the National Commission on Water Quality on the Impacts of PL 92-500 (Federal Water Pollution Control Act and amendments of 1972) on the salinity problem of the Colorado River (Utah State University, 1975).

However, the majority of the conclusions were extrapolated from results of studies on the Green River drainage in Utah. Riley and Jurinak (1979) extended this work and suggest approximate salt loading rates from the various areas in the Upper Basin. A good summary of past and present research and other salinity control programs of the Water and Power Resources Service is contained in the most recent biannual report, Progress Report No. 9, Quality of Water, Colorado River Basin (USDI, BR, 1979a).

Differences among the various studies have been inevitable and have been primarily centered around quantitative historical salinity conditions, salt loadings, concentrating effects and respective magnitude of contribution from the various sources and combinations of sources. These numerical differences have been the result of nonuniformity in data sets, procedures, assumptions, and, sometimes, incorrect extrapolation of events and/or data. However, the general qualitative conclusions and the stated needs for control of most of these studies are basically similar. The major sources of salinity are nonpoint natural sources, irrigation nonpoint sources, natural and man-made point sources, reservoir evaporation, out-of-basin transfers and municipal and industrial uses. These studies will be mentioned in succeeding paragraphs where pertinent. There have also been studies similar to this one and a brief review of these may be helpful in setting forth the contributions of this work.

There are basically three sets of optimization studies in the Upper Colorado River Basin which specifically identify salinity as a goal. These are discussed in the following paragraphs. Other indirect economic input-output studies such as Howe et al. (1972) and Morris (1977) also evaluated salinity effects but did no optimization. Bishop et al. (1975) performed a linear programming analysis of the effects of energy development in the Upper Basin on water resources in Utah.

Erlenkotter and Scherer (1977) developed a fairly comprehensive deterministic investment planning mixed-integer optimization model for salinity control on the Colorado River. They assumed given values of future diversions and associated salt loads and examined the benefit-cost balance between expenditures for salinity reduction, associated with given projects, and the economic damages which would be incurred if the expenditures were not made. The deterministic simulation portion of the model also permitted the projection of when and which projects should be undertaken in a general sense. Scherer (1977) also developed a static net benefit-maximizing model of irrigation related salinity control measures. However, these models only indicated when total aggregate projects should come on-line and did not provide for optimal combinations of individual components from within the various projects for the most cost-effective program. Erlenkotter and Scherer (1977) and Scherer (1975) considered 15 basin-wide Water and Power Resources Service (WPRS) projects including minimal on-farm programs in the Grand Valley and Uncompahgre Valley. Consequently, the majority of the projects were composed of only canal and lateral linings. Desalination was not considered. Much of data used for the Grand Valley and Uncompahgre Valley in Colorado was from a study by Westesen (1975).

Flug et al. (1977) developed a multi-level minimum cost linear programming model to evaluate impacts on the salinity and quantity of flow in the Upper Colorado River Basin by potential energy development. The results of this model indicated that water availability would be the largest constraint to energy development in the Upper Basin. Development policies which utilized high salinity waters could actually result in a net decrease in salinity at Lee's Ferry, Arizona.

Narayanan et al. (1979) developed a uni-level linear program model of the economic effect of water allocation changes and salinity resulting from energy development in the Upper Colorado River Basin. Changes in salinity were predicted by a mass balance approach; and least-cost structural and nonstructural strategies to maintain desired salinity levels were formulated. The "economic" optimal salinity control concentration levels at Lee's Ferry were identified under the objective function of maximizing joint net returns of agriculture and energy outputs. This approach solely utilized data from projects of the WPRS portions of the Colorado Salinity Control Program. The only on-farm structural alternative considered was aggregate sprinkler systems.

CHAPTER 2

PHYSICAL CONDITIONS IN THE UPPER COLORADO RIVER BASIN

The Upper Colorado River Basin, detailed in Figure 2, is rich in mineral, energy, agricultural and recreational resources. Consideration of salinity control options requires that a number of physical conditions be reviewed. In the following paragraphs a brief review of the basin's geology, water supply, present and future developments of water and energy, and present salinity conditions have been abstracted from the large body of available information. A summary of planned salinity control projects and their anticipated impact will be presented in the next chapter.

GEOLOGY

The geology of the basin is extremely variable since the area has been subjected to glaciation, numerous foldings, severe erosion, uplifts and inland seas; and the high mountain ranges are extremely rugged with many peaks over 4,200 meters. This complex variation is illustrated in Figure 3. Areas which are not mountainous tend to be characterized by spectacular eroded sedimentary rock and desert landscapes of which the Grand Canyon is the most noted example.

The mountains are formed primarily of igneous and very old metamorphic rock. In general, the water leaving the

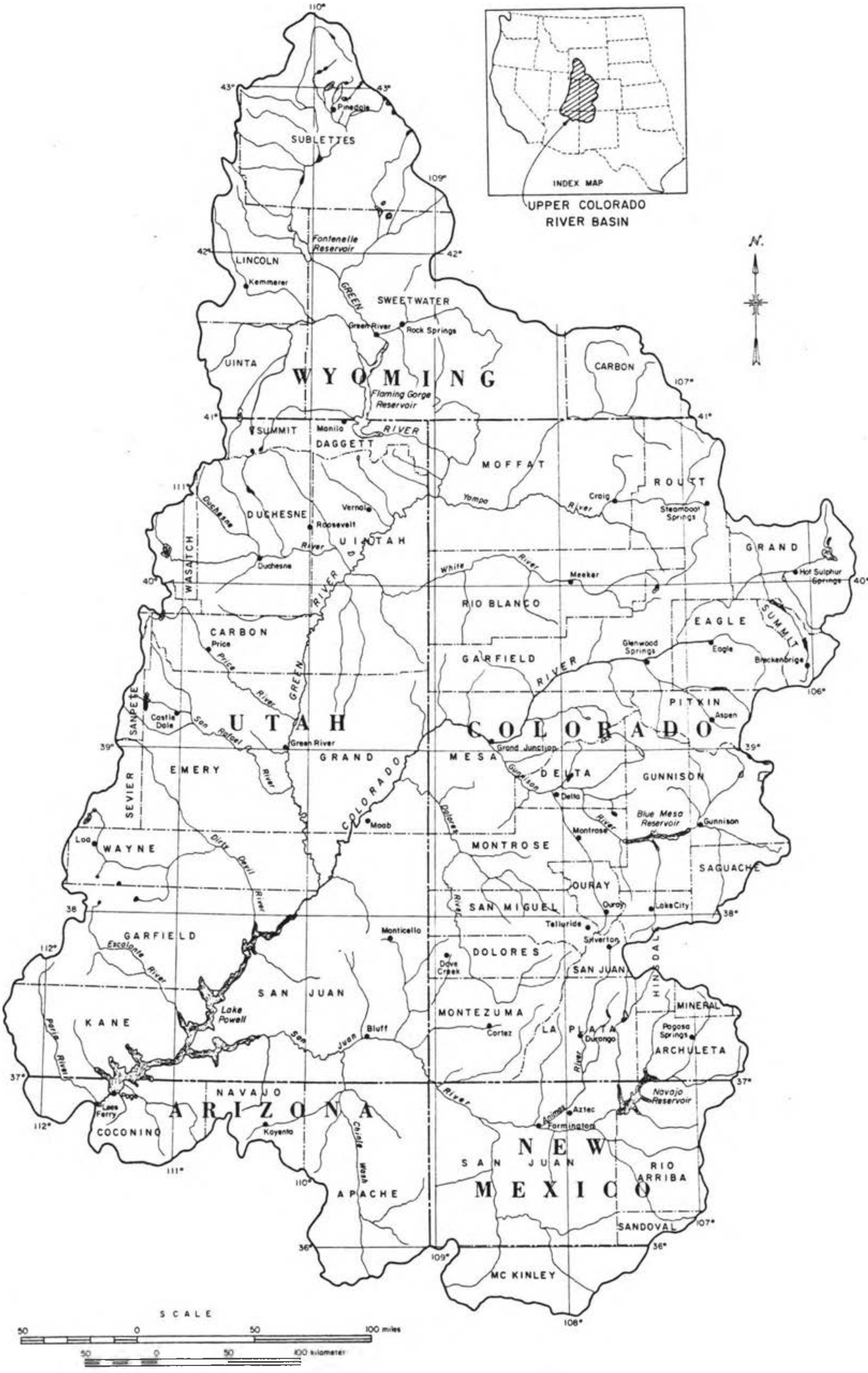


Figure 2. The Upper Colorado River Basin.

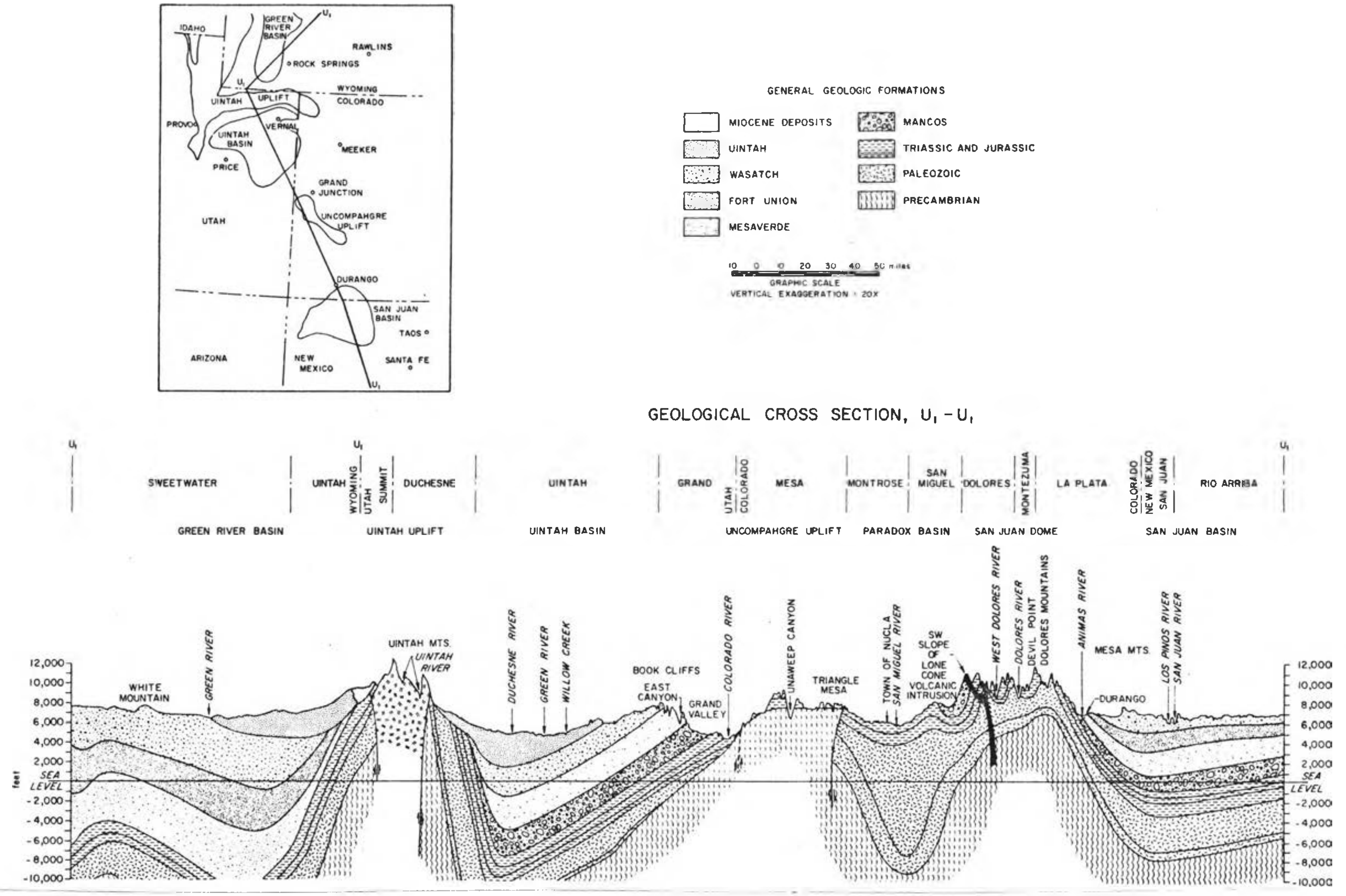


Figure 3. Schematic geologic cross-section through the Upper Colorado River Basin (American Association of Petroleum Geologists, 1967 and 1972).

mountains is of very high quality. The nonmountainous regions of the basin have been subjected to intermittent inundations by great inland seas. Many of the thick sedimentary rock formations underlying the basin were deposited at the bottom of the seas and are consequently high in residual salts. Figure 4 illustrates the areal extent of the main sedimentary deposits. These sedimentary deposits are also the location of the oil, oil shale, coal, uranium, and other large potential energy resources of the basin.

The most significant formations in terms of salinity contribution from irrigated areas are the Mancos Shales of the Cretaceous Age. These shale, sandstone and mudstone deposits form a thick formation that lies between the underlying Dakota sandstones and the overlying Mesa Verde formations. The thickness of the Mancos Shale usually varies from between 900 to 1,500 meters. Due to its great thickness and its ability to be easily eroded, this shale forms many of the large irrigated valleys of western Colorado and eastern Utah.

The effect of these shales is illustrated by Bently et al. (1978). They report that sampling runoff from Spring Creek in the Price River drainages above and below a Mancos Shale outcrop resulted in a threefold increase in dissolved solids concentrations. Irrigation return flows on Mancos Shales in the Huntington Creek in the San Rafael and Muddy Creek in the Dirty Devil River drainages result in as much as a tenfold increase in dissolved solids concentrations.

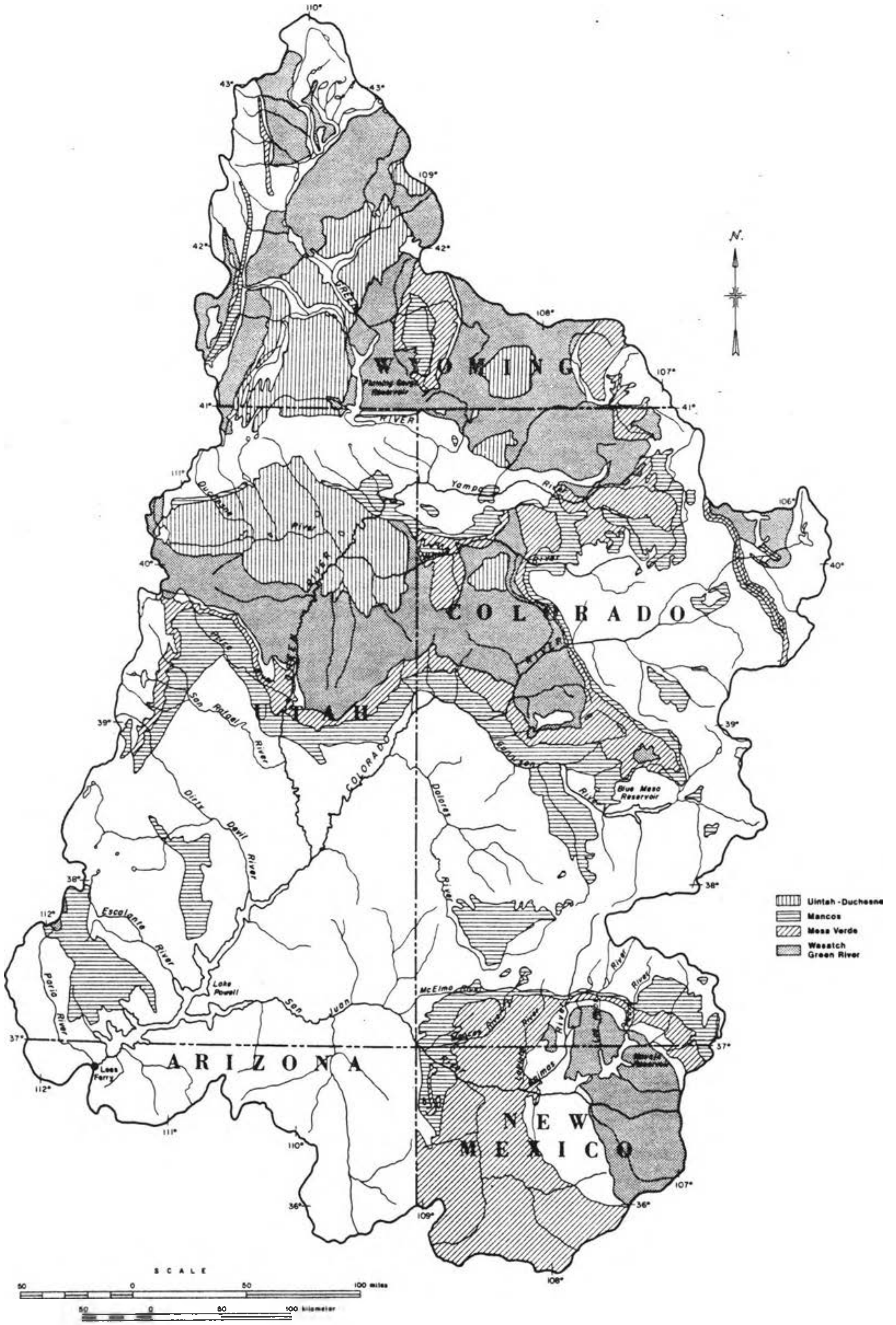


Figure 4. Areal extent of the primary sedimentary marine shales and sandstone in the Upper Colorado River Basin (American Association of Petroleum Geologists, 1967, 1972).

This increase is typical of many of the marine shales although generally not as pronounced. Other marine formations which contribute significant amounts of salt are the Wasatch and Green River formations and the Uintah-Duchesne formation which underlies the irrigated areas in the Uintah and Big Sandy drainages.

The saline Paradox formation of Pennsylvania Age underlies a large area of western Colorado and eastern Utah, but has few surface exposures. The most notable salt contribution from this formation is the Paradox Valley on the Dolores River in western Colorado.

Natural point salinity sources like the Glenwood-Dotsero and the Steamboat Springs are also the result of geologic conditions. Water moving downward into the earth along fractures and bedding planes increases in temperature and in the ability of the water to dissolve mineral constituents. When the saline waters eventually return to the surface, their salt content is usually very high. Hagan (1971) reports that the salt discharge of major thermal springs in the Colorado River Basin exceeds 500,000 Mgm per year.

Geologic investigations have been made in many parts of the basin in connection with coal, uranium, oil and gas and other minerals. Although the vast majority of these investigations are not hydrologically oriented, the results can still be useful in the interpretation of data on the quality of surface and shallow groundwaters. The geology of the basin is the dominant factor in the chemical quality of the basin's waters. Figure 5 depicts the surface water quality concentrations associated with the various areas in the Upper Colorado River Basin. Comparing Figures 4 and 5 will indicate the geologic importance to water quality.

WATER SUPPLY OF THE UPPER COLORADO RIVER

The largest and most prominent constraints to the water supply in the Upper Basin are the various treaty and compact rights. The 1922 Colorado River Compact guarantees a total of 9.25×10^6 ha-m over each consecutive ten-year period to the Lower Basin for an annual average of about 9.25×10^5 ha-m. The 1944 Mexican Water Treaty effectively raised this annual average amount to 1.02×10^6 ha-m, assuming that one-half of the water promised to Mexico comes from the UCRB allocation (Holburt, 1977). In addition, several other legal, legislative and international obligations have tied the salinity concentrations and control to the water supply. Mann et al. (1974) produced an interesting legal-political history of the Upper Basin which is helpful in understanding the development of the Colorado River.

Precipitation

The majority of the water supply in the Colorado River Basin comes from high mountain snowpacks. Flow duration tables and curves describing the seasonal and annual water supply variability of the Upper Colorado River and its major tributaries are presented by Iorns et al. (1965). Extreme

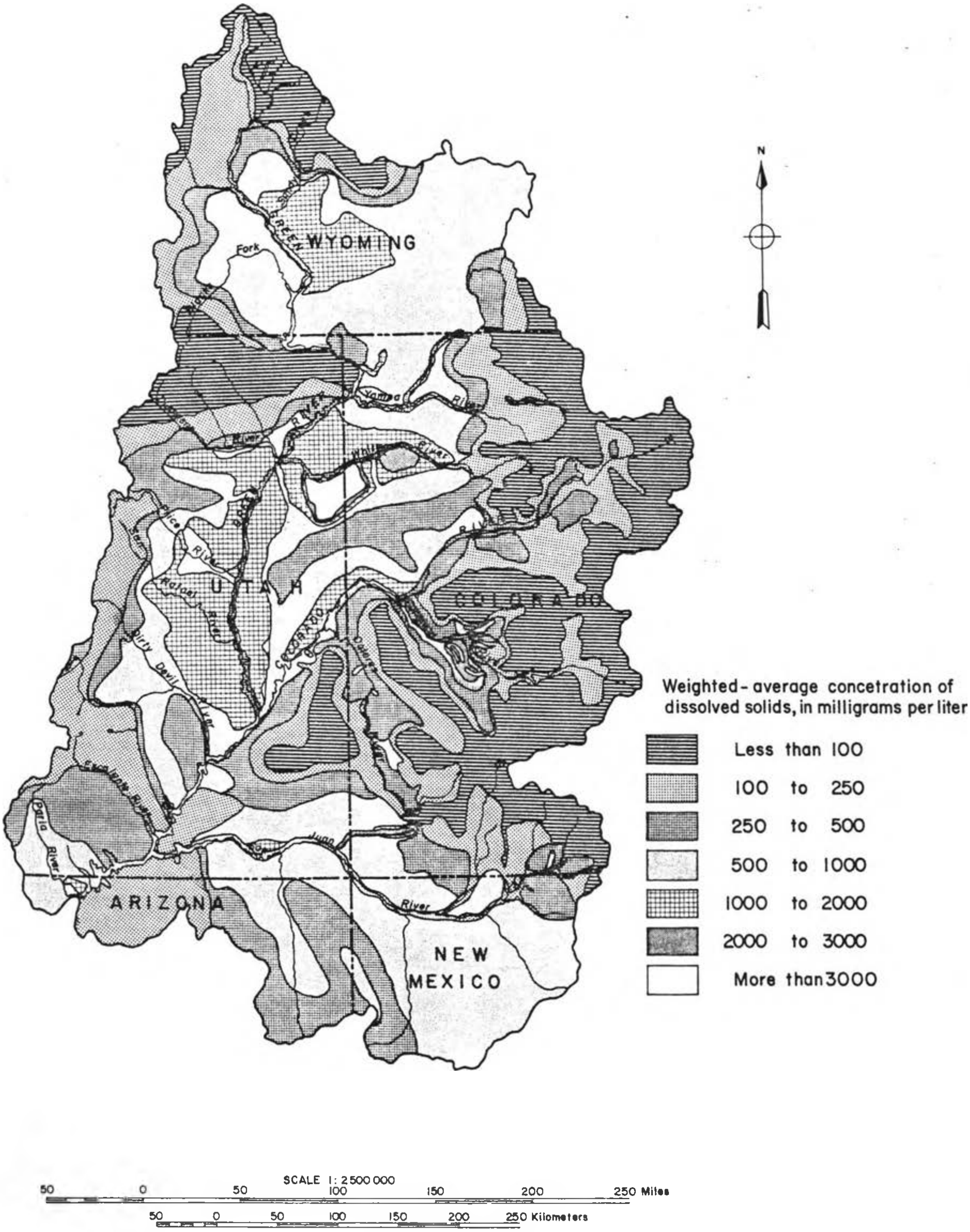


Figure 5. Surface water salinity concentrations in the Upper Colorado River Basin (Price and Waddell, 1973).

precipitation events are discussed and analyzed by Hansen et al. (1977). The extreme cyclic nature of the stream flows typical to the Basin have necessitated large amounts of surface storage facilities.

Forty-two percent of the area of the Basin receives less than 300 mm of precipitation per year. These internal deserts contribute very little water to the Colorado River Basin. Figure 6 is an isoheytal map of the average annual precipitation in the Upper Colorado River Basin indicating that approximately 10 percent of the land area contributes about 85 percent of the total water supply.

Streamflow

The average annual recorded flow of the Upper Colorado River Basin at Lee's Ferry has ranged from a low of 690,500 ha-m in 1934 to a high of 2,960,700 ha-m in 1917. Figure 7 presents a map showing the relative stream volumes and their respective salt load as a percentage of the average annual Lee's Ferry conditions.

The 1922 Colorado River Compact divided water rights between the Upper and Lower Basin based on an optimistic average annual virgin flow of 1.997×10^6 ha-m/yr. However, a part of the Lake Powell Research Project (Stockton and Jacoby, 1976) estimated the "long-term annual virgin runoff" of the Colorado River at Lee's Ferry to be 1,664,550 ha-m/yr based on the analysis of tree-ring data. From the analysis of existing hydrologic data, Tipton and Kalmback, Inc. (1965) estimated the annual virgin flow at Lee's Ferry at

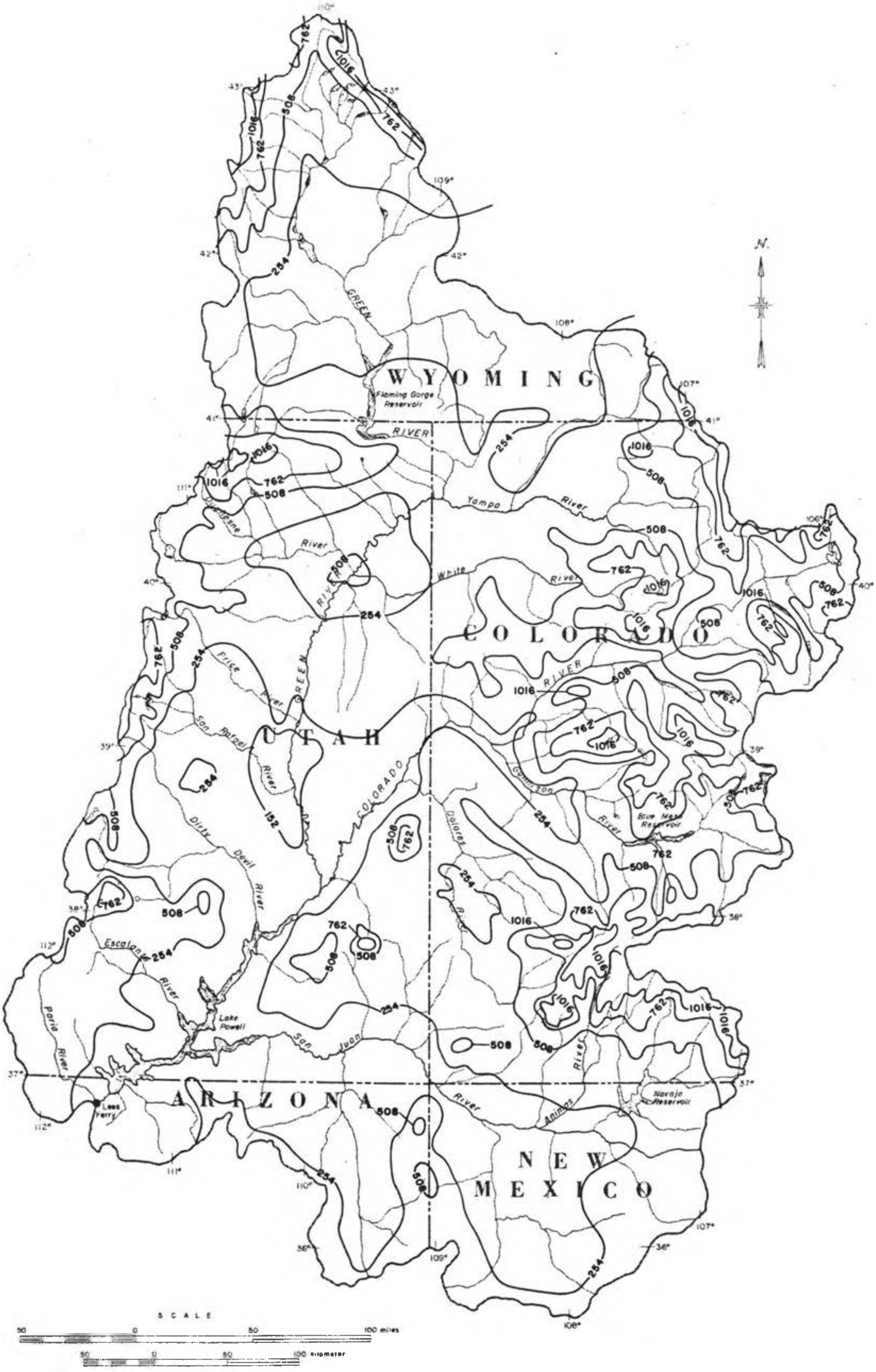


Figure 6. Isoheytal map of average annual precipitation in the Upper Colorado River Basin (Flug et al. 1977).

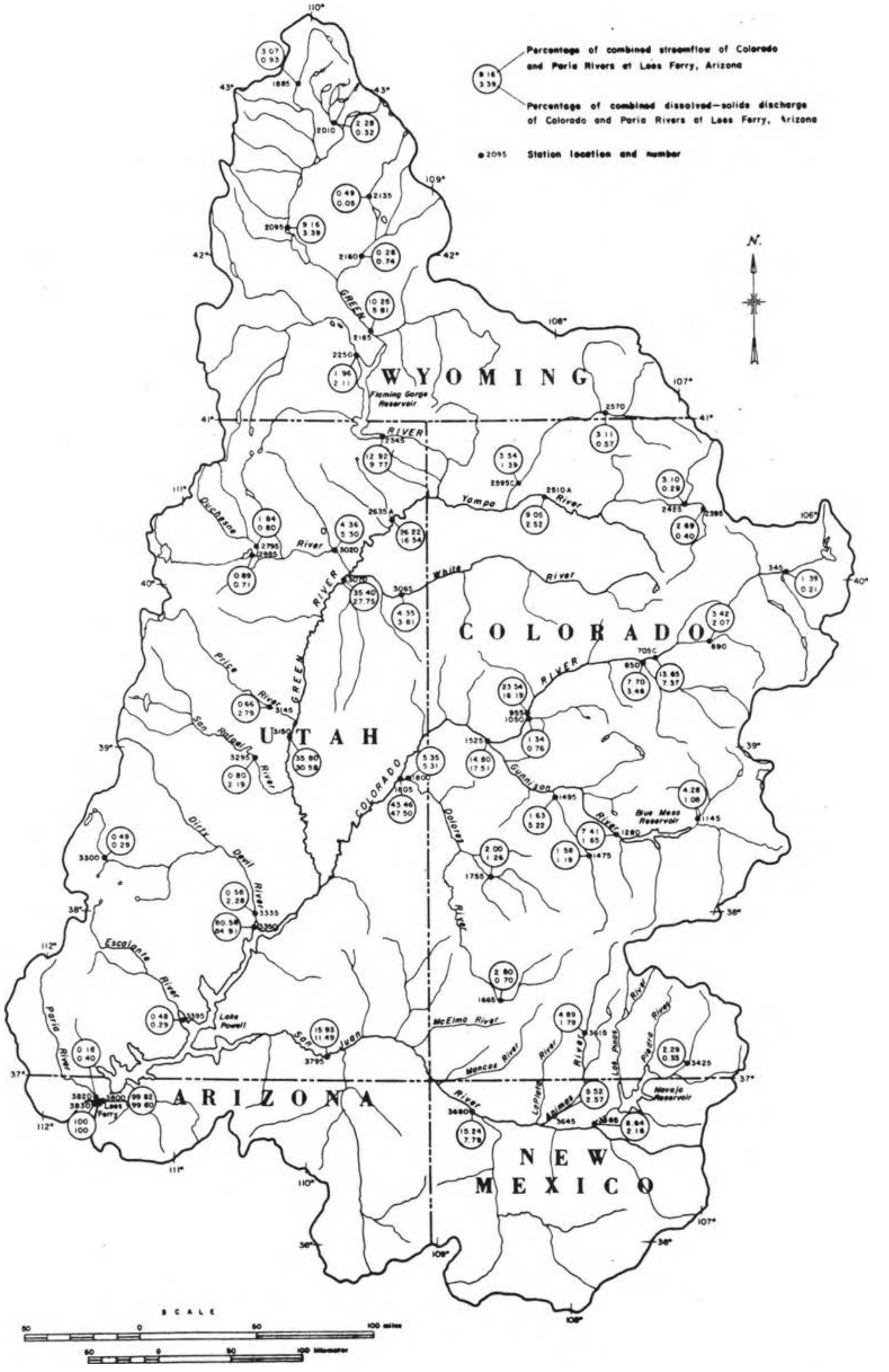


Figure 7. Map of average stream volume and total dissolved solids concentration of the Colorado River at Lee's Ferry, Arizona (Iorns et al. 1965).

1,071,540 ha-m/yr. In comparison, data published by the U.S. Department of the Interior (USDI, BR, 1979a) indicate an actual observed average flow of 1.27 x 10^6 ha-m at Lee's Ferry for the period of 1941-1978.

The difference between virgin and observed flows should ideally represent the consumptive use in the Upper Basin. Estimates of consumptive use and water availability vary widely. The USDI (1974) estimated the present depletion to be about 4,562 x 10^5 ha-m/yr, and using different assumptions, the Westwide Study (USDI, BR, 1975b) estimated the 1975 total consumptive use to be about 3,946 x 10^5 ha-m/yr. The USDI estimated that an average of 7.15 x 10^5 ha-m of water is the total available water supply in the Basin, leaving about 260,000 ha-m for future development.

The most obvious conclusion which can be derived from the above data is that there is little water for new development without conflicting with present use. The USDI (1974) calculated that 1.85 x 10^5 to 2.28 x 10^5 ha-m/yr of additional water would be consumed for nonenergy uses by the year 2000. Plotkin et al. (1979) presented data which indicates that just energy development consumption by the year 2000 could be between 74,000 and 136,000 ha-m/yr.

The WPRS developed the "1976-Modified Base (1)" which states that 1,158,030 ha-m/yr water with a concentration of 1,100 mg/l at Imperial Dam depicts conditions expected by 1900 (USDI, BR, 1979a). This "base" includes existing observed conditions in 1976 plus effects of projects under construction, those authorized for construction or those with an approved environmental impact statement (EIS) as of 1976. The expected depletions and expected salinity contributions from various Water and Power Resources Service projects are summarized in Table 1.

Weather modification programs will potentially augment Upper Basin water supplies by an estimated 62,000 ha-m or more per year (USDI, BR, 1979a). Groundwater supplies can also be utilized as an interim or conjunctive supply source although the constraints of water quality and streamflow depletion effects must be considered. Most of the future demands and further use of Upper Basin Compact allocations will require substantial additional surface storage facilities.

Through the proper selection of energy extraction technologies, low water consuming cooling alternatives, careful attention to all potential water reuse opportunities, and site selection, it would be possible to affect substantial reductions in individual energy plant water demands. Opportunities to reduce agricultural water use are much more limited. Changing to more efficient irrigation practices and lining canals may not change the agricultural consumptive use. Proposals to "conserve" agricultural water must include reducing consumptive use by crops or reducing evaporation. Where the water is not tied to the land, water transfers in the UCRB are limited by state laws to only the amount of existing crop water use and effectively removes

Table 1. Estimated 1980 depletions and salt loads of CRSP and salinity control projects which are constructed and/or authorized for construction (USDI, BR, 1979a, 1979d).

	Actual or estimated completion date	Anticipated Annual Depletion ha-m	Anticipated Annual Salinity Increase at Imperial Dam		Irrigated Land		Irrigated Supply ha-m
			Estimated Mg/l	Mgm/y	Full Service hectares	Supplemental hectares	
CRSP developments or under construction							
Storage Units--Act of April 11, 1956							
Curecanti, Colorado[1]		1,233.00	1.2[5]				
Blue Mesa Dam, Reservoir, and Powerplant	1966						
Morrow Point Dam, Reservoir, and Powerplant	1970						
Crystal Dam, Reservoir, and Powerplant	1977						
Flaming Gorge, Wyoming[1]	1963	6,165.00	5.9[5]				
Glen Canyon, Utah and Arizona[1]	1965	56,718	57.0[5]				
Navajo, New Mexico[1]	1963	3,205.8	3.0[5]				
Participating projects							
Act of April 11, 1956							
Florida, Colorado[1]	1963	1,726.2	2.8	9,979.2	2,318.36	5,551.11	3,205.8
Paonia, Colorado[1]	1962	1,233	1.2[5]	--	902.26	5,288.12	2,466.0
Silt, Colorado[1]	1966	739.8	1.1	3,628.8	857.75	1,812.61	1,602.9
Smith Fork, Colorado[1]	1963	739.8	1.0	2,721.6	574.53	3,261.08	1,233.0
Hammond, New Mexico[1]	1975	616.5	1.4	7,257.6	1,577.94	--	2,342.7
Central Utah, Utah							
Bonneville Unit, Collection System[1,3]	1988	20,467.8	17.0	-24,494.4[3]	--	--	--
Jensen Unit[1]	1986	1,849.5	1.8	907.2	178.02	1,472.74	616.5
Vernal Unit[1]	1961	1,479.6	1.4	--	--	5,980.39	2,219.4
Emery County, Utah[1]	1965	2,096.1	2.2	1,814.4	311.54	6,963.17	2,712.6
Lyman, Wyoming[1]	1980	1,233	1.2[5]	--	--	18,882.68	6,041.7
Seedskadee, Wyoming (Fontenelle Dam and Powerplant)[1]	1964	2,712.6	2.6[5]	--	--	--	--
Act of June 13, 1962							
Navajo Indian, New Mexico[1]	1987	31,318.2	54.3	19,584.0	44,506.0	--	40,689.0
San Juan-Chama, Colorado and New Mexico[1]	1983	13,563	11.4	-14,515.2[3]	--	34,140.15	7,558.29
Act of September 2, 1964							
Bostwick Park, Colorado[1]	1971	493.2	0.8	2,721.6	534.07	1,735.73	1,356.3
Act of September 30, 1968							
Dallas Creek, Colorado[1]	1981	2,096.1	2.9	8,164.8	--	8,435.91	1,380.96
Developments scheduled for construction since 1976							
Act of April 11, 1956							
Upalco Unit, Central Utah Project, Utah (CRSP)	1985	1,294.65	1.3	14,160	--	17,240.01	2,207.07
Bonneville Unit, Central Utah Project, Utah (CRSP) M&I System	1991	0	--	--	--	9,200.6	1,738.53
Act of September 30, 1968							
Dolores, Colorado (CRSP)	1988	9,974.97	11.1	9,072.0	14,306.66	10,640.98	11,207.97
Uintah Unit, Central Utah Project, Utah (CRSP)	1986	3,477.06	5.1	14,152.32	3,163.16	23,997.64	5,770.44
Animas-La Plata Project, Colorado and New Mexico (CRSP)	1990	19,086.84	17.8	-5,869.58	2,870.76	3,491.70	14,561.73
Act of June 24, 1974							
Grand Valley Unit, Colorado (Colorado River Basin Salinity Control Project)	1987	493.2	-43	-371,952.0	--	--	--
Paradox Valley Unit, Colorado (Colorado River Basin Salinity Control Project) Radium Evaporation Pond	1984	480.87	-18.2	-163,296.0			

[1] included in 1976 modified base uses a salinity level of 1,100 mg/l and includes the effects of CRSP projects constructed or under construction for a total depletion of AF and 147 mg/l increase at Imperial Dam

[2] negative value due to transmountain diversion of salt

[3] total stream depletions and salinity associated with the Bonneville Unit

[4] Rio Grande River Basin

[5] concentration effects due to evaporation losses

these lands from crop production. Private sector land retirement through water transfers reduces the agricultural consumptive use although the net consumptive use of the river system is only slightly affected. An added benefit for salinity control is that these "retired" lands are usually marginal and the most inefficiently irrigated.

In the case of energy development and in many other industries, the transferred water is generally totally consumed on-site, therefore, the salinity detriments are limited to concentrating effects due to the reduced amount of water available for dilution. The high salt loading component from the irrigated lands is eliminated.

Storage

There is more than 5.2×10^5 ha-m of storage available in the Upper Colorado River Basin. Table 1-3 in Appendix 1 lists the major irrigation and power reservoirs. However, there are a great many livestock water retention, recreational and municipal reservoirs, which are not listed. Most of the unlisted reservoirs and lakes are very small, although some, such as Dillon Reservoir (Denver, Colorado, municipal water supply) are quite large. As of 1965, Shafer (1971) indicated a total of 208 reservoirs with an active capacity of 403,540 ha-m had been constructed. Since then the amount of storage capacity has been increased by more than 100,000 ha-m through the completion of Navajo, Curecanti and other projects.

Groundwater

The small role of groundwater in the Upper Colorado River Basin has primarily been one of furnishing domestic and livestock needs. Groundwater occurs under almost all of the area. However, many of the wells are small and/or water quality is poor. The alluvial valley-fill aquifers generally have the highest potential capacity for wells, although most are hydraulically connected to the streams. Most of the valleys are narrow, consequently the water withdrawn from the wells affect the streams in relatively short time periods. Because of the low volumes involved, this is not expected to be a significant problem in the basin for many years.

Shallow groundwater is generally of very poor water quality and not suitable for agricultural or municipal uses in the Upper Basin. In much of the basin, wells capable of producing 60 lps (1,000 gpm) or more can be developed provided that the wells are drilled to sufficient depths. The most productive aquifers are in sandstone formations in the southern portion of the basin and in the Green River formation in the Piceance Creek Basin. In most other areas, the wells must be drilled thousands of meters deep to tap all of the available aquifers.

Groundwater is considered as a potential short-term supplemental water supply to energy development. The USDI (1974) estimated that the "average annual replenishment" of the groundwater supply in the Upper Colorado River Basin is about 500,000 ha-m. This is an estimate of the sum of stream base flows, phreatophyte evapotranspiration, well pumpage, and subsurface water movement out of the basin. This quantity does not represent a sustained yield since eventual adverse effects on streamflow and phreatophyte vegetation will result from long-term continued depletions. Thus, the long-term reduction of groundwater inflows to the streams would probably have a beneficial impact on total salt loading although recreational uses and fisheries may be damaged.

Transbasin Diversions

The more than 10 transmountain diversions to the eastern slope of Colorado amounting to about 70,000 ha-m/yr represents the largest aggregate transbasin diversion from the UCRB. The Bonneville Unit of the Central Utah Project follows with an expected volume of 20,500 ha-m/yr. There is only one small diversion (320 ha-m/yr) into the basin from the Paria River near Tropic, Utah (Hedland, 1971). The total out-of-basin water exports are approximately 110,000 ha-m/yr.

At the present time, there is a diversion of 900 ha-m/yr wich is expected to increase to 3,000 ha-m into Douglas Creek from Wyoming tributaries of the Green River. These diversions are part of the Laramie-Cheyenne water supply system (USDI, BR, 1979a).

The Sevier River in Utah receives water from several small transmountain diversions from the Colorado River

System. There is one diversion from Gooseberry Creek in the Price drainage (USDI, BR, 1964), and there are 13 diversions from the San Rafael headwater to the San Pitch Basin (USDA, SCS, 1979d) of the Sevier River. These diversions are high in the mountains, of very high quality water and individually rarely exceed 300 ha-m/yr.

DEVELOPMENT OF THE COLORADO RIVER BASIN

Irrigation Development

The earliest known irrigation development in the Colorado River Basin was apparently practices by the Hohokam Indians in the Salt River Valley near Phoenix, Arizona, where canal remnants can still be found today (Keys and Strand, 1979). The more modern irrigation systems started in the 1850's. This development was primarily in the alluvial valleys directly bordering the streams and was limited by great quantitative and temporal fluctuations in the water supply. With the development of storage facilities and more intricate distribution systems, the irrigated areas greatly expanded. For the interested reader, Goslin (1978) presents an excellent review of the history of water resources development in the Colorado River Basin.

The amount of irrigated land in the UCRB is presently estimated at about 656,000 ha or 2 percent of the total land area. Much more land could be irrigated if water were available. The Soil Conservation Service has classified a total of 2,855,900 ha of land as "suitable" for irrigation in the UCRB (Gardner and Stewart, 1978). About 99 percent of the irrigated land is served entirely by surface water supplies. Figure 8 indicates the extent of irrigation development in the basin.

Energy Development

USDI (1974) states that, although salinity is presently the most serious water quality problem in the Upper Colorado River Basin, energy development also presents some potentially serious problems. Additional municipal and industrial wastes, sediment, heavy metals, toxic materials, and undesirable bacteria, temperature and dissolved oxygen content levels in the streams and rivers pose future concerns for the basin. Without strict monitoring and enforcement of existing water quality laws, localized problems, in addition to salinity, such as sediment production, can be expected to occur on the minor tributaries.

Because of the present energy shortage, the slow development of solar power, and the long delays in nuclear power plant construction, the use of the large coal (Fig. 9) and oil shale (Fig. 10) deposits in the Upper Colorado River Basin appear critical to the nation's energy needs. Other significant energy resources are uranium (Fig. 11) and tar sands deposits (Fig. 12).

Corsentino (1976) presented a listing of known planned and proposed energy developments in the western United States (Table 2), including 125 areas located in the Colorado River Basin. There have been other projects proposed and

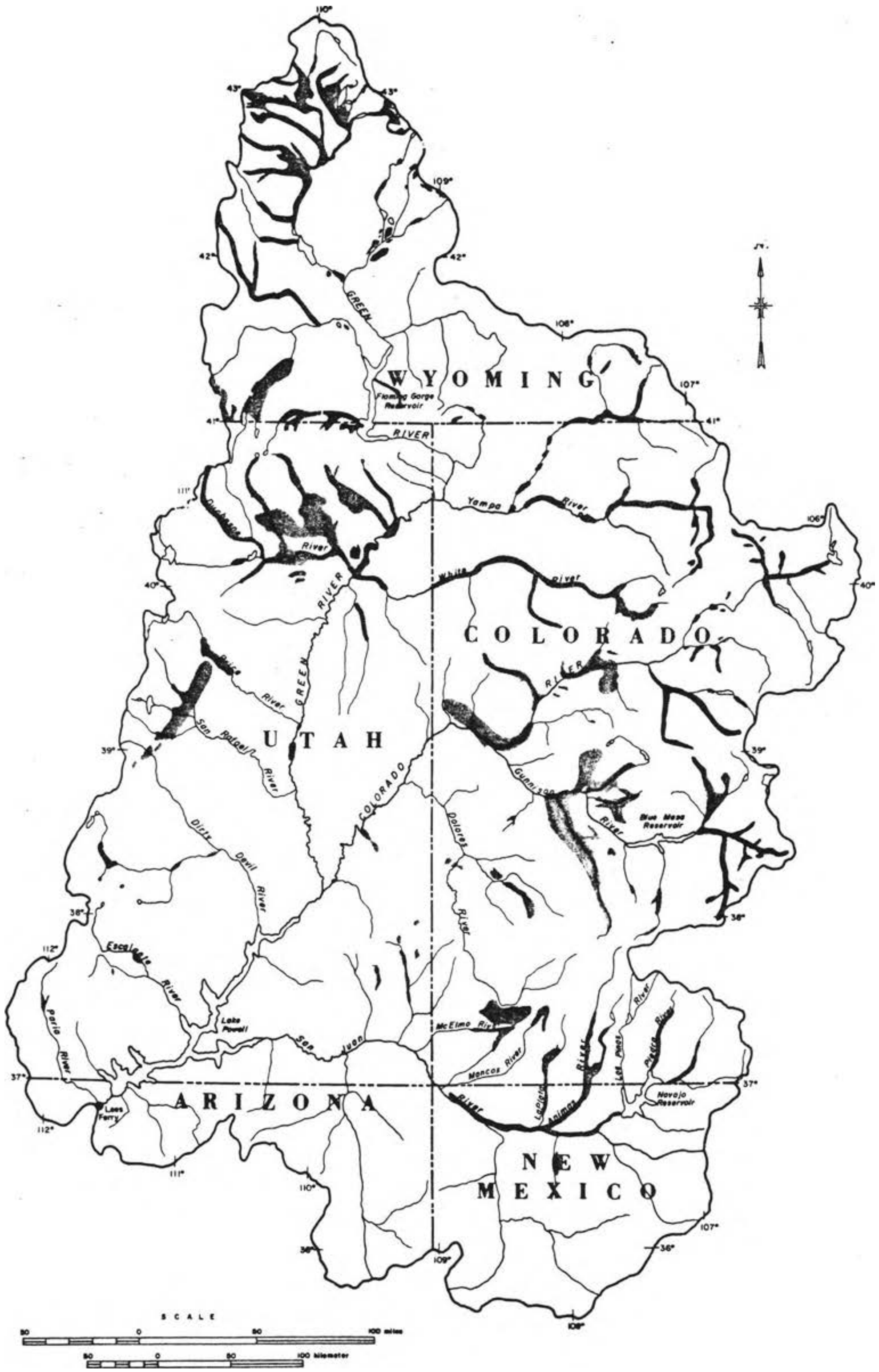


Figure 8. Areas of irrigation development in the Upper Colorado River Basin.

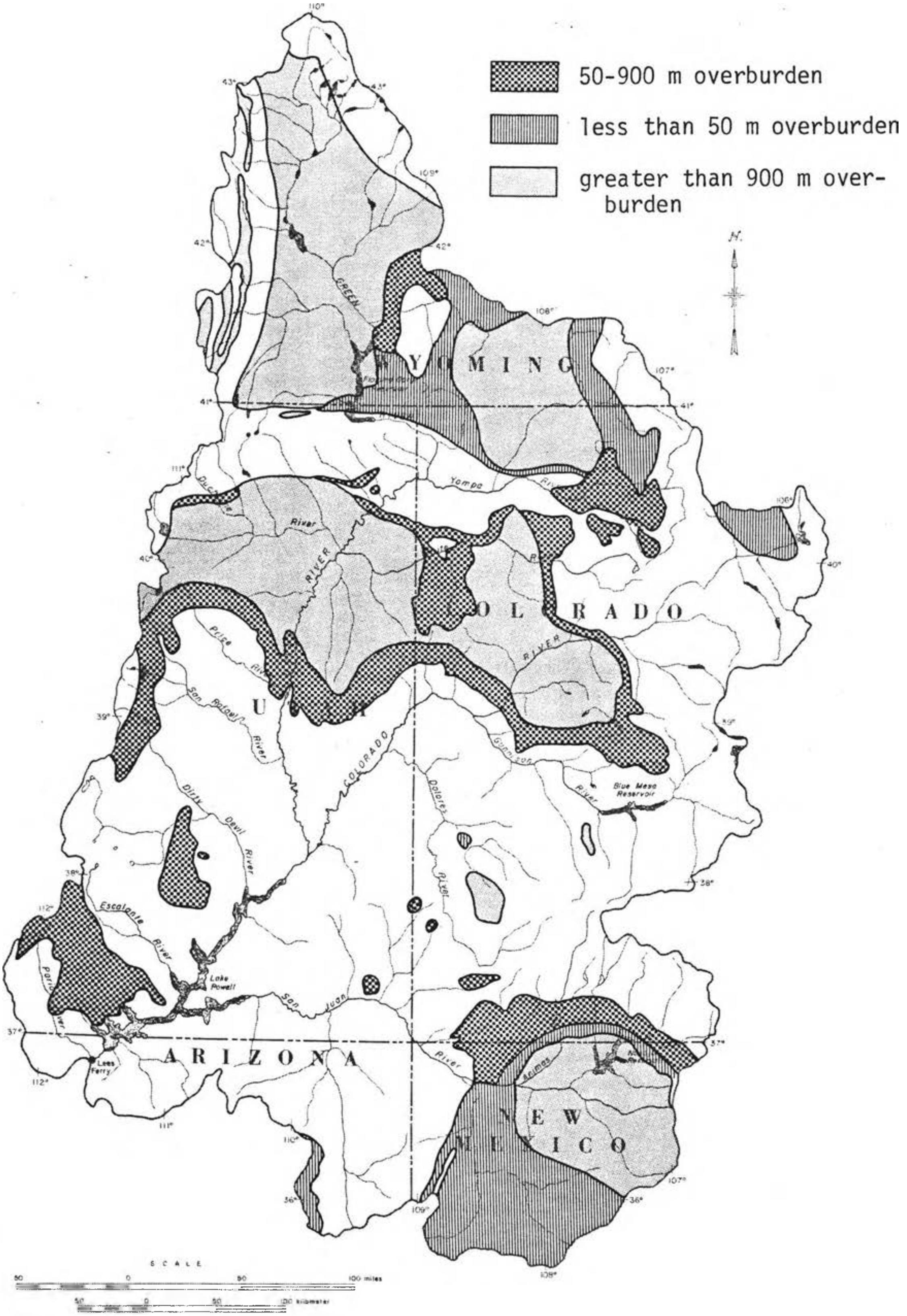


Figure 9. Coal deposits in the Upper Colorado River Basin (Flug et al. 1977).

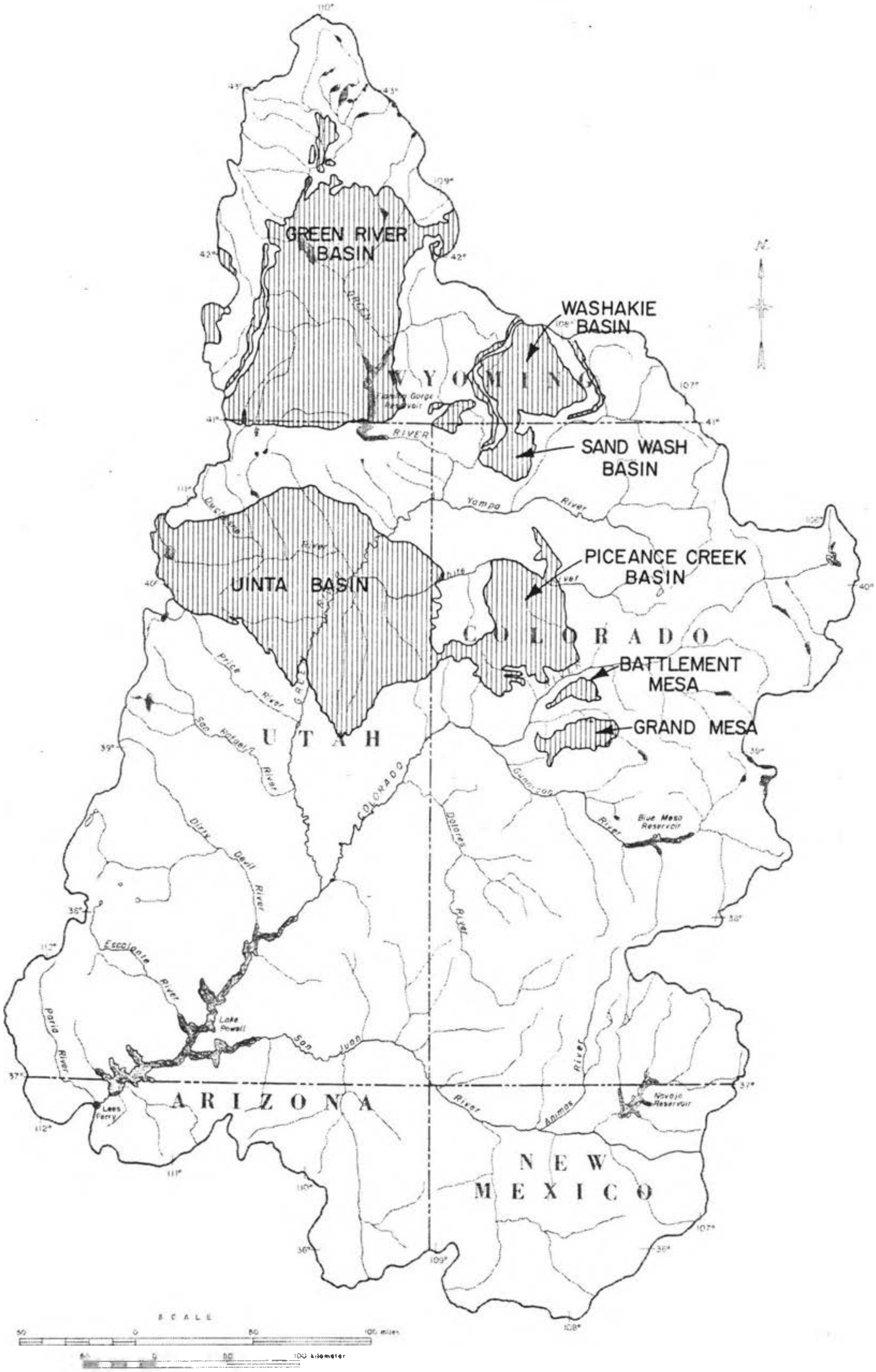


Figure 10. Oil shale deposits in the Upper Colorado River Basin (Flug et al. 1977).

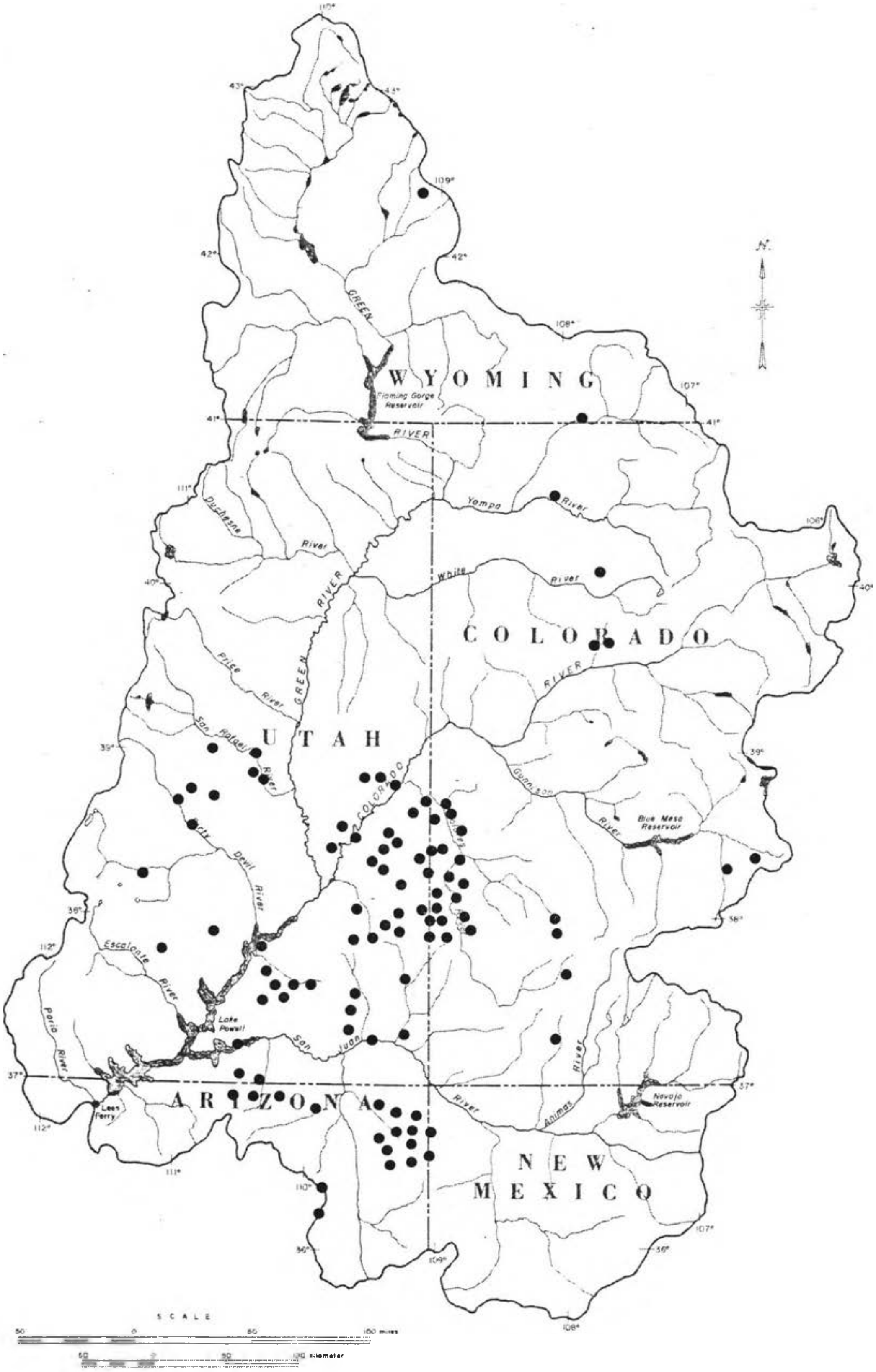


Figure 11. Known major uranium deposits in the Upper Colorado River Basin (Flug et al. 1977).

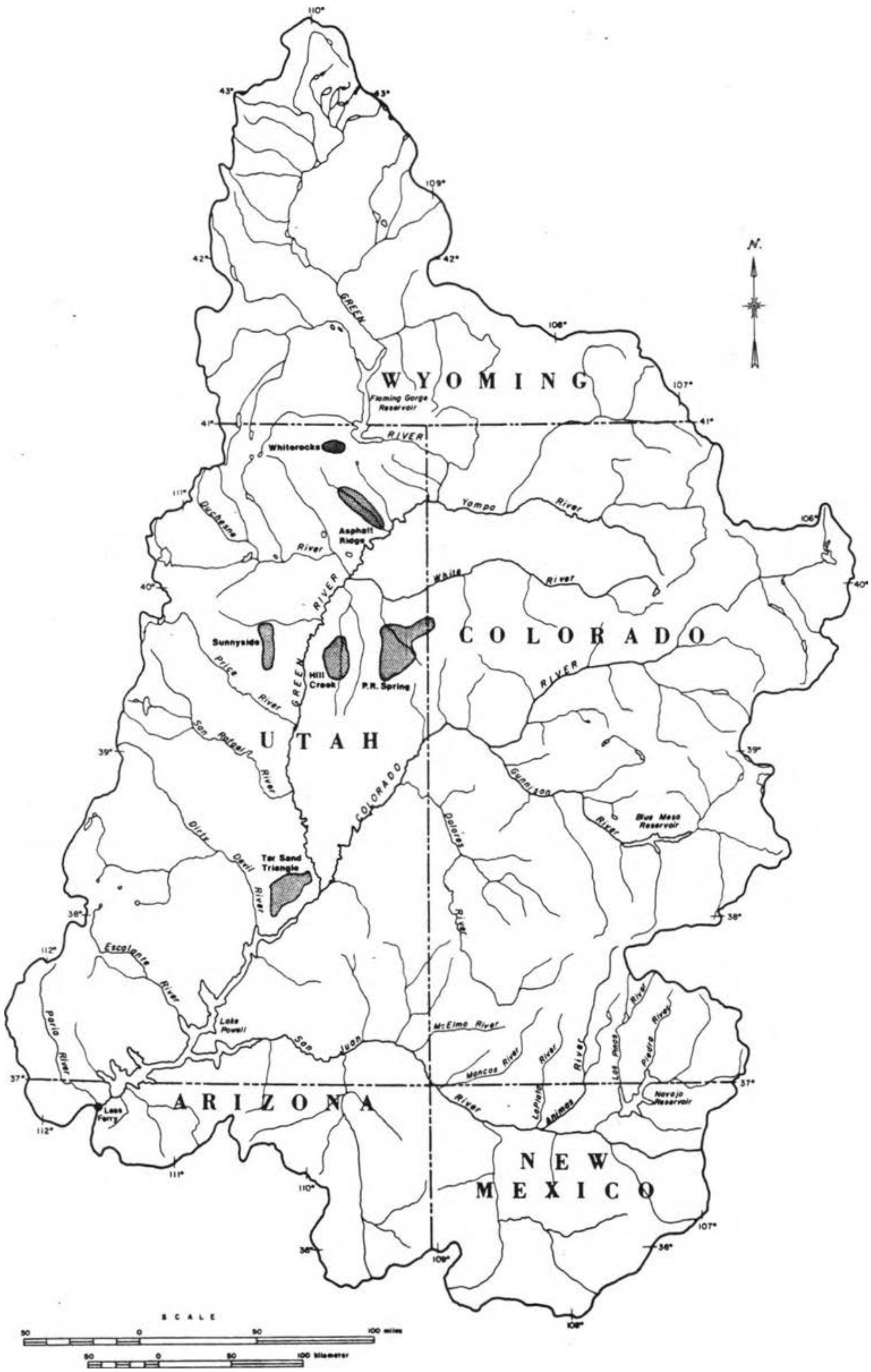


Figure 12. Significant tar sands deposits in the Upper Colorado River Basin (Keefer and McQuivey, 1979).

Table 2. Upper Colorado River future energy-fuels related development proposals (Corsentino, 1976 and USDI, 1974).

Type of Development	State					Total[7]
	Arizona	Colorado	New Mexico	Utah	Wyoming	
Coal mines and expansions	2	33	3	27[3]	9	74
Coal gasification plants			2	1	1	4
Coal slurry pipelines		1	1	1[5]		3
Coal electric power plants and expansions	1	2 5[4]	1 2[4]	5[3] 6[4]	2 4[4]	11 17
Hydropower Electric Power plants and expansions		2		1		3
Oil shale		7[1]		3	1[4]	10
Tar sands				3		3
Natural gas processing plants					1	1
Uranium mines and expansions			5	3		8
Geothermal		4[2]				4
Railroads		2		2[3]		4
TOTAL[7]	3	51	12	46	13	125

1 Mobil Oil, Texaco, Chevron, and Cities Service Company all hold oil shale lands although no definite development plans have been announced. Also, the Dept. of the Interior just announced plans to lease up to four more additional tracts.
2 Application for leases only.
3 Includes Kaiparowits project which is apparently abandoned.
4 USDI, 1974 estimate, other numbers reflect Corsentino (1976) unless noted.
5 USDI, GS, 1979
6 Most probable values.
7 Not including USDI, 1974 estimates.

dropped since this report was issued, but the relative numbers can be expected to remain approximately the same.

Energy interest groups have been actively involved in the purchase of agricultural water rights. The actual extent and quantity of this activity is difficult to assess, but the economic viability of many minor tributaries will be severely affected by these water transfers. The USDI (1974) conservatively estimates that about 5 percent (11,100 ha-m) of current agricultural water supplies in Colorado and Utah will be transferred to energy users by the year 2000. Plotkin et al. (1979) believe that the UCRB will be the site of a substantial amount of conflict between energy and agriculture for water supply, and that water will be the largest constraint to energy development.

Water consumption by energy related users is associated with, in order of expected usage, oil shale, thermal-electric fossil fuel power generation, coal gasification and liquefaction, and conventional coal mining. The remainder generally has little water requirements except for those associated with the increased population. Excluding coal slurry lines and based on some rather tentative high water requirements data, it is estimated that about 107,300 ha-m/yr of water will be needed to meet energy development needs in the UCRB by the year 2000 (USDI, 1974).

It is estimated that even moderate synfuels development in the state of Colorado will require water storage projects costing as much as $2.5 billion. By the year 2000 it is projected that there will be a 64,000 m^3/d shale oil industry and a quadrupling of uranium milling capacity, coal production and electric generation in Colorado. The water availability question in the Upper Basin states is discussed in more detail by Hansen (1976) and USDI, BR (1974). The potential conflicts of energy development and the existing legal water rights structures in the UCRB are examined by Weatherford and Jacoby (1975) and Gardner et al. (1976).

CHAPTER 3

EXISTING UPPER BASIN SALINITY CONTROL PLANS

THE GENERAL SALINITY PROBLEM

Early impressions of water quality in the Upper Basin are recorded in the names given to the streams in the area. Names such as Alkali Creek, Pleasant Creek, Bitter Creek, Mudhole Creek, Killpecker Creek, Sweetwater Creek, Poison Springs, Stinking Springs, and the Dirty Devil River, can be found in every region of the basin. As the names would indicate the water was often found to be undesirable for many uses due to natural processes.

Controlling salinity in a major river basin is a difficult task because it generally consists of a complex mixture of natural and man-made, point and diffuse sources. Some sources are amenable to preventative measures. Saline springs can be diverted and disposed of off-stream, irrigation return flows can be reduced or eliminated by rehabilitating the irrigation system and improving irrigation practices, reservoirs can be managed to minimize evaporation, and new water developments can be sited and operated to minimize water quality impacts. Other sources of salinity such as natural runoff may extend over such large areas that the only feasible measure for control is to desalt some of the aggregate flow at a downstream point. Skogerboe et al. (1979b) discuss some of the methodologies to determine and implement the most cost-effective salinity control program in an area.

At the planning level, the sources of salinity must be identified in conjunction with the detriments associated with salinity contributions. If the damages are more costly than the measures required to alleviate the problem, a salinity control project is needed.

The total salinity contributions for the various areas and subbasins in the UCRB have been tabulated in four main reports. The report by Iorns et al. (1965) is the most complete and is generally the most useful. The second set of reports of consequence are the biennial progress reports on the Quality of the Colorado River Basin by the Water and Power Resource Service (USDI, BR, 1979a). These reports describe each of the salinity control projects and tabulate the existing stream gaging station data. These reports extend the data of Iorns et al. (1965) to the present. The third report was compiled by the U.S. Environmental Protection Agency and others (EPA, 1971) and presents the results of a limited study (June, 1965 - May, 1966). The specific data and conclusions presented in this report often widely disagree with other published results. Finally, the study by Hyatt et al. (1970), which was developed from an electrical analog computer model of the Upper Colorado River Basin, schematically presents the water and salt flows of the basin. Again, these results agree very well with aggregated results of other studies, but the individual agricultural loading values tend to be much smaller. This is due to the fact that the agricultural salinity contribution was based solely on concentrating effects.

Natural runoff contributes 52 percent of the salt load from the Upper Basin (EPA, 1971). In an effort to control any salinity effects due to soil disturbance by livestock grazing and energy development in the basin, the Bureau of Land Management is pursuing a program of more restrictive grazing controls, interseeding of contour furrows, and chaining and seeding to control salinity from surface hydrologic events (Bently et al. 1978). Much of this program is based on work by Gifford et al. (1975) in the Price River area.

Ponce (1975) and Ponce et al. (1975) reported on non-point salt loading from grazing and its effects on Mancos Shales in the Price River Basin. Whitmore (1976) and White (1977) reported on the salinity aspects of Mancos soils and the effect of microchannels, respectively. All of these studies basically concluded that a practice which compacts or otherwise disturbs the soil structure, reduces infiltration and increases runoff and/or erosion on saline soils will increase salt yields. Similar results were obtained by Laronne and Schumm (1977) for the Grand Valley area. Thomas (1975) investigated the use of gully plugs and contour furrows to control erosion and had good success. McWhorter and Skogerboe (1979) investigated interflow as a transport mechanism for salt on Mancos soils, and determined that it had little effect.

The general consensus of investigations on nonpoint diffuse sources of salinity in the UCRB is that measures such as grazing controls, contour furrow and strict regulation of road and site development, construction of energy exploration activities will reduce man-caused salinity from these lands. However, the extreme natural variation in hydrologic events, stream and reservoir evaporation and other "buffering" effects will tend to mask the relative magnitude of these programs.

Economic Damages Caused by Salinity

The salinity levels expressed as total dissolved solids concentration or electrical conductivity may not adequately reflect the impacts on specific users. Domestic users are primarily concerned with hardness caused by calcium and magnesium. The important salinity constituents for industrial users, such as electrical power plants are primarily calcium carbonates and sulfates. Calcium carbonate is often the first salt to precipitate in recirculating cooling tower water and high levels can increase the amount consumed and/or treated.

The costs associated with using water impaired by high salinity levels are imposed on industrial, domestic and agricultural users. Industrial and domestic costs are associated with extra costs of treatment and softening, and with premature replacement of plumbing, boilers, water heaters, etc. Domestic damages can also be experienced by loss of landscapes with low salt tolerance. Estimated costs due to salinity increase in the Los Angeles area have been reported by Eubanks and d'Arge (1976), Lawrence (1975), and Tihansky (1974).

Agricultural costs can be measured by crop yield reduction, high leaching requirements which often necessitate costly subsurface drainage systems, special tillage practices and higher labor costs (Anderson and Kleinman, 1978, Robinson et al., 1976; and Moore et al., 1974). The soils and soil structure also can be severely damaged by excess salinity requiring many years to be reclaimed. Moore (1972) presents an interesting discourse on the necessary and sufficient conditions for long-term agriculture, primarily related to salinity. Moore et al. (1974b) have developed crop production functions relating quality and supply of water in the Colorado River Basin. Kleinman et al. (1974) and Kleinman and Brown (1977) discuss the damages to agricultural production by salinity in the UCRB.

The Soil Conservation estimates the total municipal damages in the Lower Colorado River Basin change at an annual rate of $291,200 per mg/l change in salt concentration. Agricultural damages increase $124,800 annually per mg/l (USDA, SCS, 1979b).

The USDI, WPRS (1980a) is presently using a total annual damage figure of $447,700 per mg/l increase at Imperial Dam (January 1, 1980 prices) for the range of concentrations expected in the next 20 years (825-1225 mg/l). These damage values do not consider costs passed into the Mexican use sector or the value of good international relationships. Oyarzabal-Tamargo and Young (1976) presented preliminary damage estimates at $5 million per year in 1975.

<u>Public Law 93-320</u>

Water resource development as well as all of the associated water demands of energy development can potentially increase the salinity in the Colorado River. The purpose of Public Law 93-320 (Colorado River Basin Salinity Control Act, June 24, 1974) is to mitigate salinity increases caused by the individual Colorado River Basin states in developing their respective allowances of water from the Colorado River. Title II of PL 93-320 (Section 207) specifically states that "nothing in this title shall be construed to alter, amend, repeal, modify, interpret, or be in conflict with the provisions of the Colorado River Compact (45 Stat., 1957), the Upper Colorado River Basin Compact (63 Stat., 31) . . .," or any other compact or agreement and/or any project which allocates the Colorado River as to quantity.

PL 93-320, Title II directs the Secretary of the Interior to investigate, plan and implement a salinity control program in the Upper Colorado River Basin. Cooperation and coordination by the Secretary of Agriculture and the U.S. Environmental Protection Agency were also required. The legislation authorized four projects for construction: (1) Grand Valley, Colorado; (2) Paradox Valley, Colorado; (3) Crystal Geyser, Utah; and (4) Las Vegas Wash, Nevada.

Twelve other projects above Imperial Dam were identified for further study.

The Lower Gunnison, Uintah Basin, Colorado Indian Reservation, and the Palo Verde Irrigation District were specifically identified as "irrigation source control programs." Point sources were identified as La Verkin Springs, Littlefield Springs, and Glenwood-Dotsero Springs. Other diffuse sources mentioned in the legislation which should also be investigated were Price River, San Rafael River, McElmo Creek, and the Big Sandy River. Measures by which the individual program goals should be obtained were specified only for the authorized construction projects. All of the authorized and potential projects are located in Figure 13.

According to a U.S. Government Accounting Office (GAO) Report in 1979, it is doubtful that the Salinity Control Program as defined in PL 93-320 will reduce the salt in the Colorado River as much as predicted. Furthermore, at least six of the seventeen projects are questionable economically. For example, Crystal Geyser and Las Vegas Wash, as formulated, have very high costs and will have a "minor impact in reducing the river's salinity . . ." However, the GAO analysis only examined the projects in aggregate as formulated by the U.S. Department of the Interior, and did not address the fact that individual components of a salinity control project may indeed be very cost-effective while a total program may not be economically viable. Therefore,

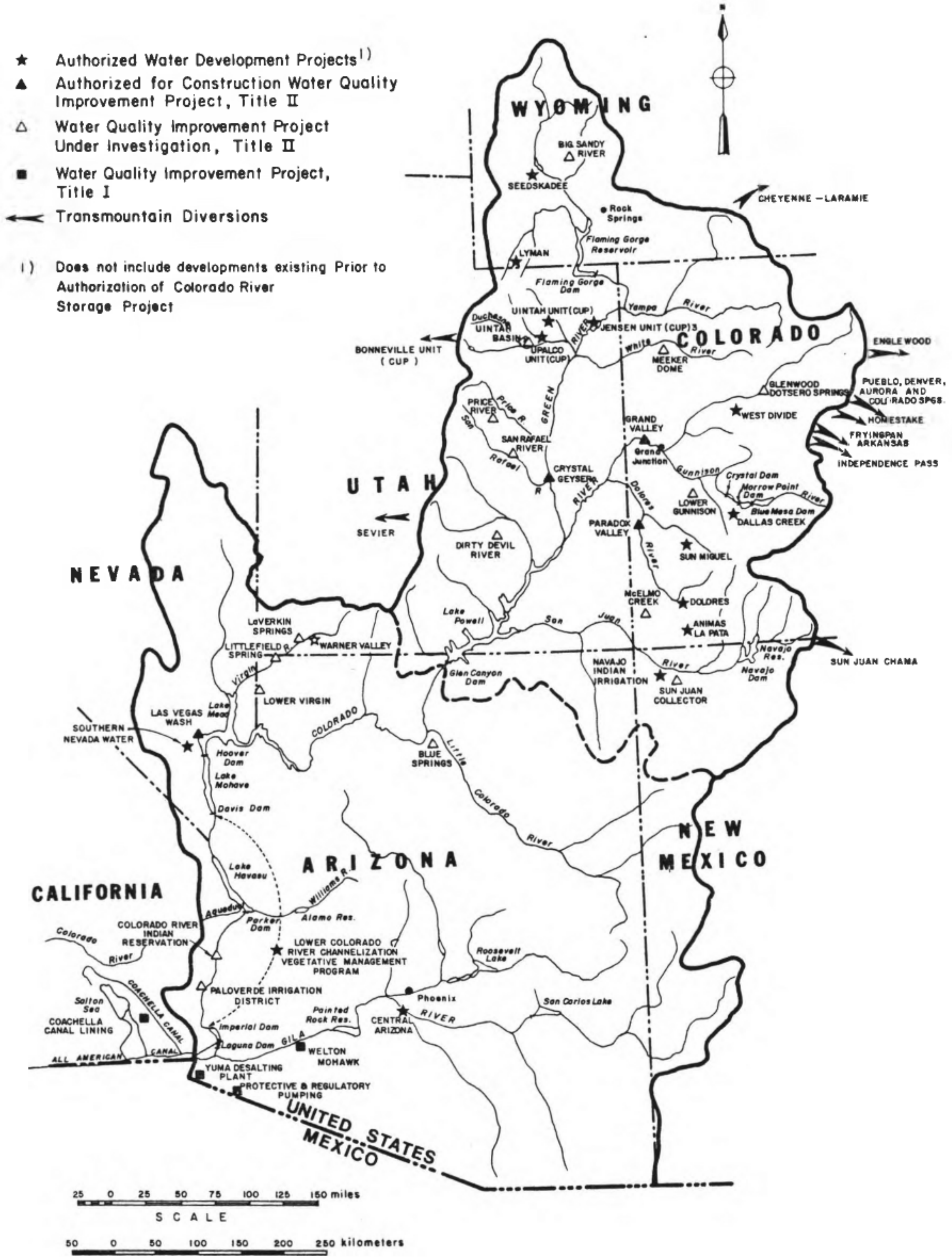


Figure 13. Salinity control projects designated by PL 93-320 (USDI, BR, 1979a).

the logical conclusion is that perhaps only selected portions of various salinity control projects should be constructed.

The primary question left unanswered by PL 93-320 is to what extent shall salinity control programs be constructed or how much effort should be expended in pursuit of the goals of this legislation. For example, without regard to benefits and costs, the WPRS (USDI, BR, 1979a) presents data illustrated in Figure 14 that indicate the difficulty of maintaining the 1972 salinity levels at Imperial Dam. Preliminary analyses has clearly shown that several of the projects noted in PL 93-320 have benefit cost ratios much less than one based on annual damages of $450,000 per mg/l increase at Imperial Dam.

Appendix 2 describes each of the significant projects in the Upper Basin which were specified in PL 93-320. This discussion has been divided into nonpoint and point source control projects. A summary of the salt loading from the respective area and the currently estimated potentially controllable salinity is given in Table 3.

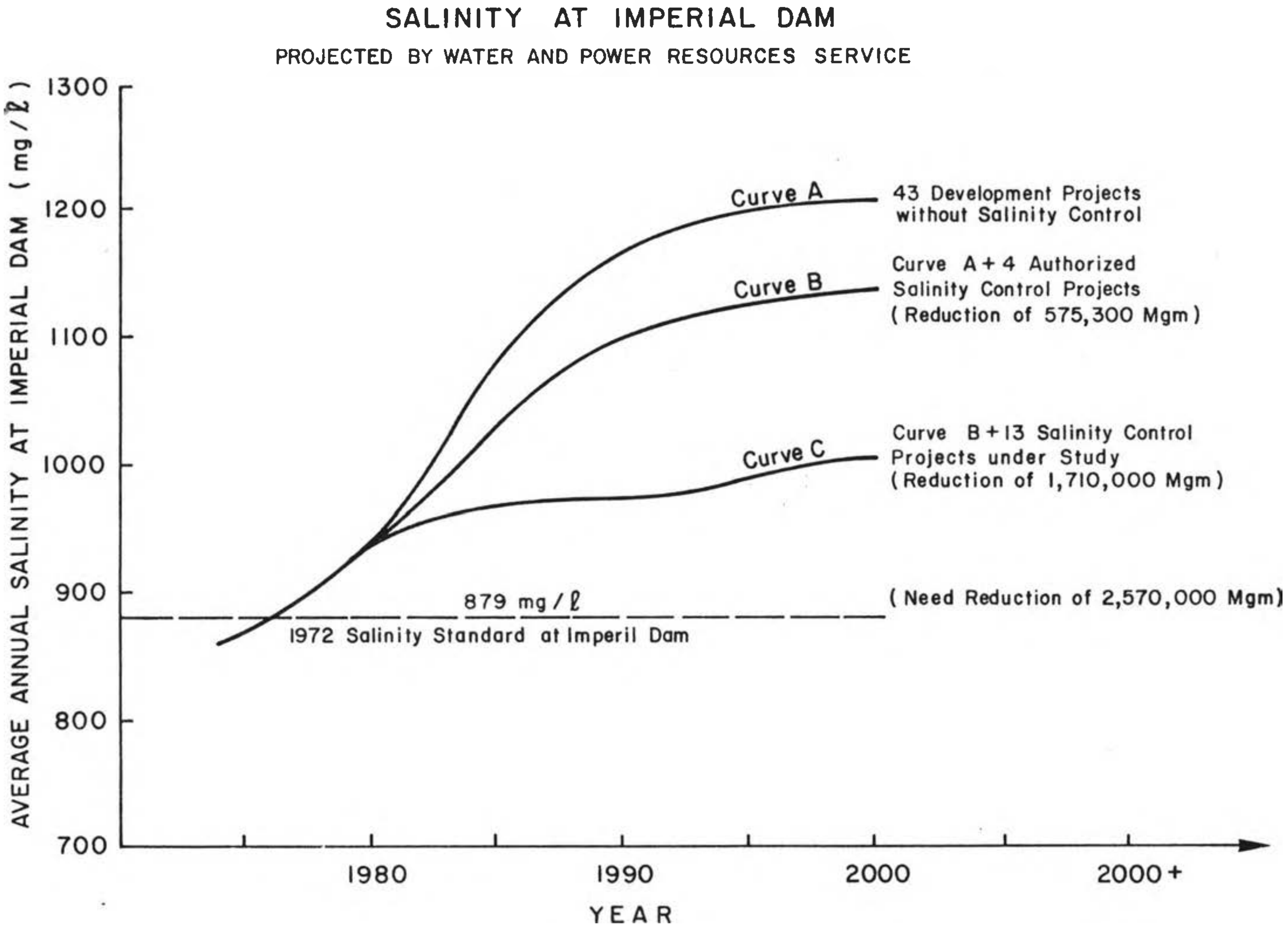


Figure 14. Salinity increase at Imperial Dam projected by the Water and Power Resources Service (USDI, BR, 1979d).

Table 3. Summary of salt loading attributed to the various sources and the estimated attainable salinity control levels for total programs of projects designated by PL 93-320 in the Upper Colorado River Basin.

Source	Total Salt Load Contribution Mgm	Salt Load Reduction Mgm	Estimated mg/1 Reduction at Imperial Dam
AGRICULTURAL CONTROL PROJECTS			
Grand Valley	630,000	372,000	43
Lower Gunnison	800,000	570,000	65
Uncompahgre Valley	350,000	220,000[1]	25.3
Uintah Basin	395,000	182,000	21
Price-San Rafael Drainage	210,000	50,000	7.3
Dirty Devil River	52,000	24,000	2.8
McElmo Creek	85,000	50,000	6.0
Big Sandy River	125,000	81,000	9.3
POINT SOURCE CONTROL PROJECTS			
Paradox Valley	180,000	163,000	18.7
Glenwood-Dotsero Springs	400,000	214,300	25.0
Meeker Dome	29,500	29,500	3.4
Crystal Geyser	2,720	2,720	0.3
			202.90

[1]Canal and Lateral Lining Only (USDI, WPRS, 1980c)

CHAPTER 4

METHOD OF ANALYSIS

The research approach developed for this work consisted of four phases:

1. Development of a cost-effectiveness analysis applicable to the salinity control problem in the Upper Colorado River Basin;
2. Evaluation of salinity sources in the basin;
3. Selecting an array of salinity control alternatives; and
4. Application of the analytical procedure to the Upper Basin conditions.

The fourth phase is encompassed in the following chapter. The second phase was described in general terms in Chapter 3 and will be expanded somewhat in this chapter.

COST-EFFECTIVENESS ANALYSIS

The method of salinity control program analysis was originally developed in a study of water quality improvement alternatives in the Utah Lake drainage area in central Utah (Walker et al., 1973). The approach involved decomposing a basin-wide problem into first hydrologic subbasin problems and from there into technological subunits. The principal assumption in the decomposition was that by evaluating net mass emission of salts from each subbasin, the problem consists of mutually exclusive components that could be added together in arriving at the basin-wide optimal program.

This assumption implies physically that: (1) water utilization at one location is not significantly affected by a change in water use practices elsewhere; and (2) salinity is a completely conservative pollutant. Walker and Skogerboe (1980) discuss the physical assumptions and show mathematically the relationship between the physical system and these assumptions.

A schematic view of the conceptual model is given in Figure 15 (Walker, 1978). The basic structure of the model is a function relating the cost of salinity control and the effectiveness of the investment in terms of reducing mass emission (Mgm/yr). Associated with each cost-effectiveness function are indications of how much of the cost and effectiveness is allocated to each alternative encompassed in the optimization. Examination of Figure 15 in some detail will serve to illustrate the additive construction of the overall optimal strategy.

Consider the analysis to begin at "Level 2" with four basic alternatives whose cost-effectiveness function is given and the allocation among "Level 1" alternatives is known. Two "Level 3" cost-effectiveness functions are developed by adding "Level 2" functions in an optimization analysis. The addition of individual cost-effectiveness functions becomes the objective function for the next level of aggregation. Constraints consist of limitations on the total effectiveness of each individual alternative and aggregate effectiveness at the level being developed.

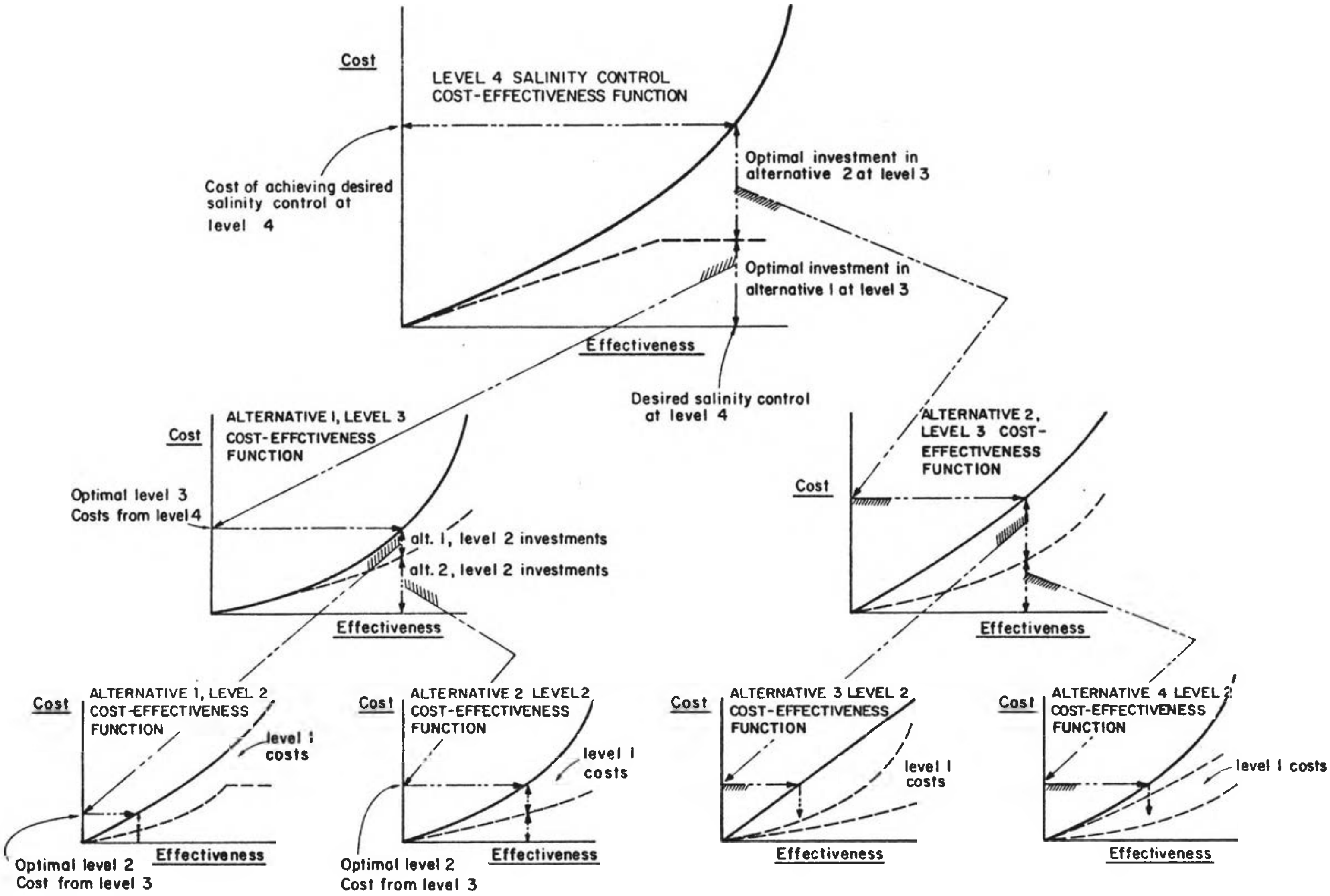


Figure 15. Schematic diagram of the multilevel optimization analysis (Walker, 1978).

Detailed mathematical descriptions of these procedures are given by Walker et al. (1979).

Optimization Procedure

The relationships between costs and salinity reductions are generally nonlinear. Aggregating the level to level cost-effectiveness function, therefore, requires an understanding of the various techniques for nonlinear optimization. Most water quality planners do not have sufficient background in these subjects for a technique like originally used by Walker (1973) and Walker et al. (1973) to be widely useful. As a result, a very simple optimization procedure was developed for application and demonstration in this writing. In fact, the entire basin-wide optimization was accomplished on an HP9825A desktop computer with only a total of 24K bytes of capacity.

For purposes of illustration, consider an irrigated valley which is supplied water through canals. Each canal has a total length of L_t meters, an inlet wetted perimeter of W_m meters and an inlet capacity of Q_m cubic meters per second. Walker (1978) reviewed canal lining cost-effectiveness for salinity control and derived the following relationship:

$$\overline{C}_c = K' \left[1 - \left(1 - \frac{bf(S_1)}{L_t}\right)^{1+K_2} \right] + K_3 f(S_1) \qquad (1)$$

in which,

$\overline{C}_c$ = capital construction cost necessary to impact the mass emission of salts due to seepage by S_1 Mgm/yr;

K_1, K_2, K_3 = empirical constraints relating canal size and lining costs;

b = empirical function describing the spatial distribution of canal deliveries to individual farm turnouts;

$$K' = K_1 Q_m^{K_2} L_t/(1 + K_2)b; \tag{2}$$

$$f(S_1) = \frac{L_t}{b} - \left[\left(\frac{L_t}{b}\right)^2 - \frac{2L_t}{K_2' \, b} S_1 \right]^{0.5}; \tag{3}$$

and

$$K_2' = \Delta S_c N_d \Delta SR \left(\frac{Q_g - Q_p}{Q_g} \right) WP_m \times 10^{-6} \tag{4}$$

where,

ΔS_c = change in salt concentration between irrigation water and groundwater, mg/l;

N_d = number of days seepage occurs;

ΔSR = change in seepage rate due to linings, m/day, which may vary throughout the year;

Q_g = total agricultural inputs to the groundwater system, ha-m; and

Q_p = phreatophyte use of groundwater, ha-m.

In order to develop an optimal cost-effectiveness relation for lining as a salinity control measure, the following problem must be solved repeatedly for various values of the constraint value $\overline{S}$:

$$C_\ell = \min \sum_{i=1}^{n} \overline{C}_c(S_1)_i \tag{5}$$

subject to,

$$(S_1)_i \leq (S_T)_i \tag{6}$$

and,

$$\sum_{i=1}^{n} (S_1)_i = \overline{S} \tag{7}$$

where,

C_ℓ = the minimum cost of lining sufficient canal lengths to produce a total salinity reduction of $\overline{S}$, megagrams;

$\overline{C}_c$ = the cost of lining the specified length of the ith canal (Eq. 1), millions of dollars;

$(S_1)_i$ = the salinity reduction to be achieved by lining the ith canal, Mgm/yr;

$(S_T)_i$ = the maximum achievable salinity reduction achieved by lining the entire length of the ith canal, Mgm/yr; and

n = the number of canals or ditches that can be lined to reduce salinity.

This curve of cost versus salt reduction always has the property of convexity, a necessary condition for optimality Wilde and Beightler (1967), and can be considered what Erlenkotter and Scherer (1977) refer to as a "continuous project." In other words, a cost can continually be assigned for any variable value of salt reduction. The functional relationship of this curve remains the same throughout the entire optimization process. The curve has the same basic shape and properties for canal lining in an individual area as well as for a basin-wide salinity control program. This property greatly simplifies the optimization process and the determination of the individual components of salinity control at any level of control.

Simplifying the Optimization--

As noted earlier, the optimization process requires that Equations 5-7 be solved repeatedly for values of $\overline{S}$ ranging from zero to $\sum_{i=1}^{n} (S_T)_i$, generating data from which the optimal function for canal lining is derived. The resulting canal lining cost-effectiveness function is characterized by increasing marginal costs with scale but the nonlinearity is not great. These functional features provide the opportunity to condense Equation 1 into a simple regression function. For example, the following expression has been found to produce good results:

$$\overline{C}_c = \frac{S_1}{AS_1 + B} \tag{8}$$

For specific canal, ditch, or lateral, the only unknowns in Equation 8 are $\overline{C}_c$ (dependent variable) and S_1 (independent variable). A range of S_1 values within the interval from zero to the maximum value of S_T can be generated from Equation 1 when different lengths L are arbitrarily substituted into the equation. Corresponding values of $\overline{C}_c$ are then calculated providing the x-y data for a regression fitting. A linear regression can be used for curve fitting if Equation 8 is transformed to:

$$y = Ax + Bx \tag{9}$$

where $y = 1/\overline{C}_c$ and $x = 1/S_\ell$.

This function can also be compared in an optimizational context with other similar strategies to formulate plans on a large scale. While this development still requires some prior understanding of operations research methodologies for those not so prepared, Equation 8 leads to a simple optimization solution based on the unique algebraic structure of the modified cost-effectiveness functions. The complex optimization procedure is reduced to a facile series of arithmetical calculations. If necessary, most of this procedure could be done with hand-held calculators.

The derivative or the slope of the particular function illustrated by Equation 8 has the simple form of:

$$\frac{d\overline{C}_c}{dS} = \frac{BB}{(AS_1 + B)^2} \tag{10}$$

The derivative has the significance of being the marginal cost of lining the ith canal for the specified salt load $(S_1)_i$. Thus, the smaller the value of the derivative, the more cost-effective the linings. The marginal cost values of represented Equation 8 must be equal for all individual lining projects at the specified value of total salt to be reduced, $\overline{S}$. They must also be constrained by the physical limits of each individual canal's values of $(S_T)_i$. Thus for their respective ranges of salt contribution:

$$0 \leq (S_1)_i \leq (S_T)_i \tag{11}$$

The value of $\overline{S}$ is determined from the combination of optimal least-cost values corresponding to each $(S_1)_i$. The simplified step-wise procedure is illustrated in Figure 16. The procedure is as follows:

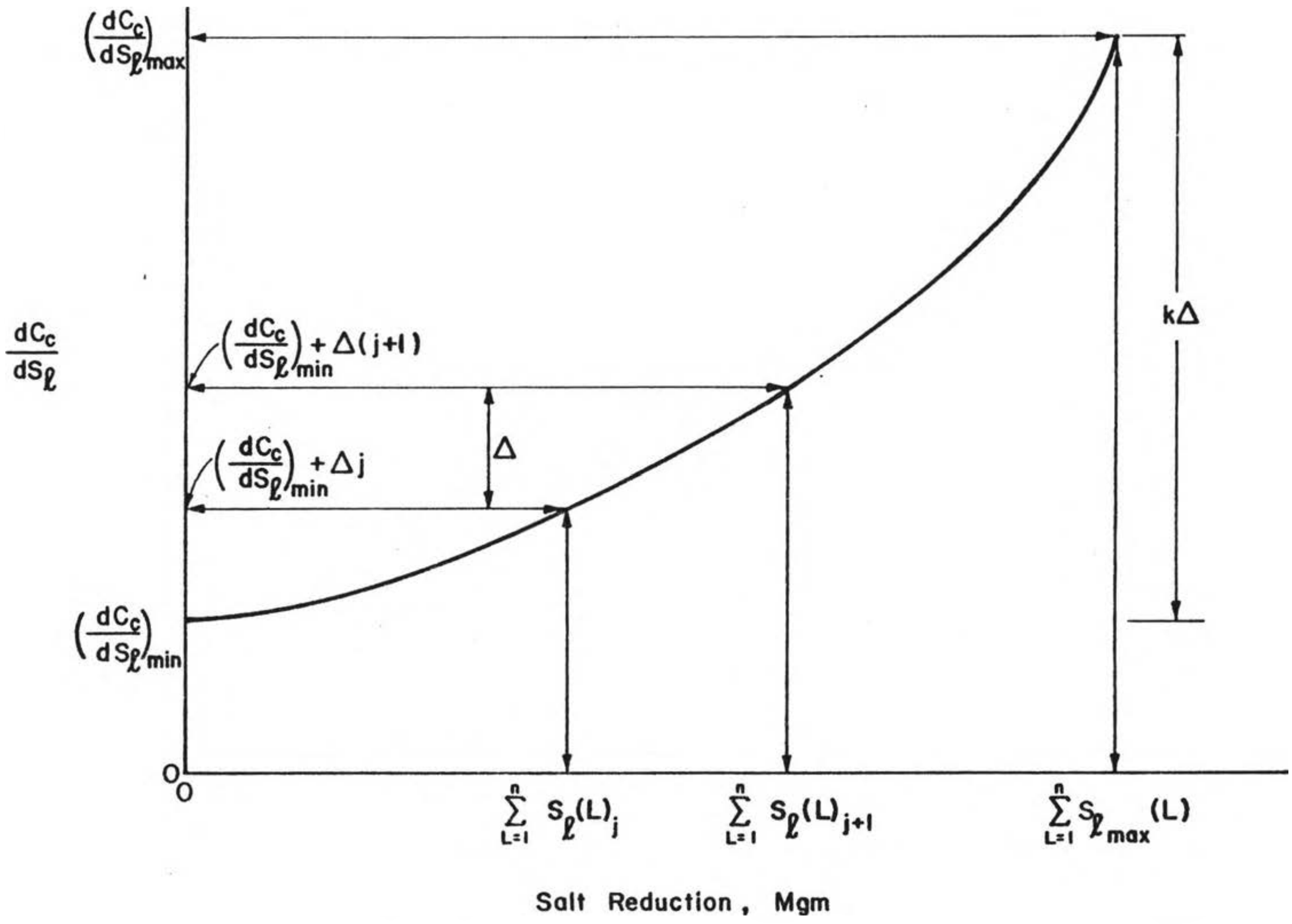


Figure 16. Schematic representation of the simplified optimization procedure for each alternative or area.

1. Two arrays are calculated using Equation 10 for every canal in the area being considered for lining. The first array will be for values at $(S_1)_i = 0$, and the second will be for $(S_1)_i = (S_T)_i$. Then, from the total array of minimum values the overall minimum value, $\frac{d\overline{C}_c}{dS_1}{}_{min}$ is selected. Similarly, the maximum value of the derivatives, $\frac{d\overline{C}_c}{dS_1}$, is determined. All of the remaining values in both arrays are then discarded.
2. After the maximum and minimum values have been selected, the marginal cost interval represented by these two values is divided into k increments, Δ, where k is any arbitrary value.

$$\Delta = \frac{\left(\frac{d\overline{C}_c}{dS_\ell}\right)_{max} - \left(\frac{d\overline{C}_c}{dS_\ell}\right)_{min}}{k} \tag{12}$$

Δ is now used to increment the value of $\frac{d\overline{C}_c}{dS_1}$ for subsequent calculations. Rearranging terms of Equation 10 for S_1, the following equation is obtained:

$$(S_1)_i = \frac{1}{A_i}\left[\left\{\frac{B_i}{\left(\frac{d\overline{C}_c}{dS_1}\right)}\right\}^{1/2} - B_i\right] \tag{13}$$

3. Equation 13 is solved for each $(S_1)_i$ at every successive value of $d\overline{C}_c/dS_1$, given by

$$\frac{d\overline{C}_c}{dS_1} = \left(\frac{d\overline{C}_c}{dS_1}\right)_{min} + j\Delta \qquad (14)$$

where j = 0, 1, 2, 3, . . ., k. Since all of the marginal costs are equal at each point, only the canals which have a value of $(S_1)_i$ greater than zero are cost-effective.

4. The calculated values of $(S_1)_i$ must be checked against their respective physical constraints and adjusted if necessary. These constraints are:

a) if $0 \leq (S_1)_i \leq (S_T)_i$; then $(S_1)_i = (S_1)_i$ (15)

b) if $(S_1)_i \leq 0$; then $(S_1)_i = 0$ (16)

c) if $(S_1)_i \geq (S_T)_i$; then $(S_1)_i = (S_T)_i$ (17)

5. The constrained values of $(S_1)_i$ are then substituted back into their respective cost-effectiveness equation which has the form of:

$$(\overline{C}_c)_i = \frac{(S_1)_i}{A_i\ (S_1)_i + B_i} \qquad (18)$$

and the costs for all canals are summed to obtain the total cost of reducing salinity by $\overline{S}$,

$$\overline{S} = \sum_{i=1}^{n} (S_1)_i. \qquad (19)$$

The costs are then annualized, if desired. This series of calculations of $\overline{S}$ and total costs describe the lining cost-effectiveness relationship which may be plotted for additional clarity. The above procedure is also utilized to optimize other practices and develop optimal functions for areas and subbasins. A general flow chart of the procedure is given in Figure 17.

SEGREGATION OF SALINITY SOURCES

This work did not involve any new data collection activity, but relied almost entirely on data which have been collected by the various governmental agencies. Data were obtained from the Soil Conservation Service, the Water and Power Resources Service, various state agencies and regional councils of governments for 208 studies. Topographic maps and aerial photographs were utilized to estimate canal and lateral lengths as well as to provide an indication of cropping patterns and field sizes. Automobile trips were made to the various areas to collect data from local organizations and to discuss the agricultural problems and practices with farmers and local administrators. Nevertheless, much of the data is incomplete and estimates of existing conditions were made based on data collected elsewhere, and the author's experience and judgment.

State and federal water records and existing reports were utilized to establish a basic water and salt budgets for each area including stream flow quality and quantity, qualitative and temporal distribution of individual diversions and groundwater quality. Then, within the structure of the areawide budgets, canal by canal water and salt

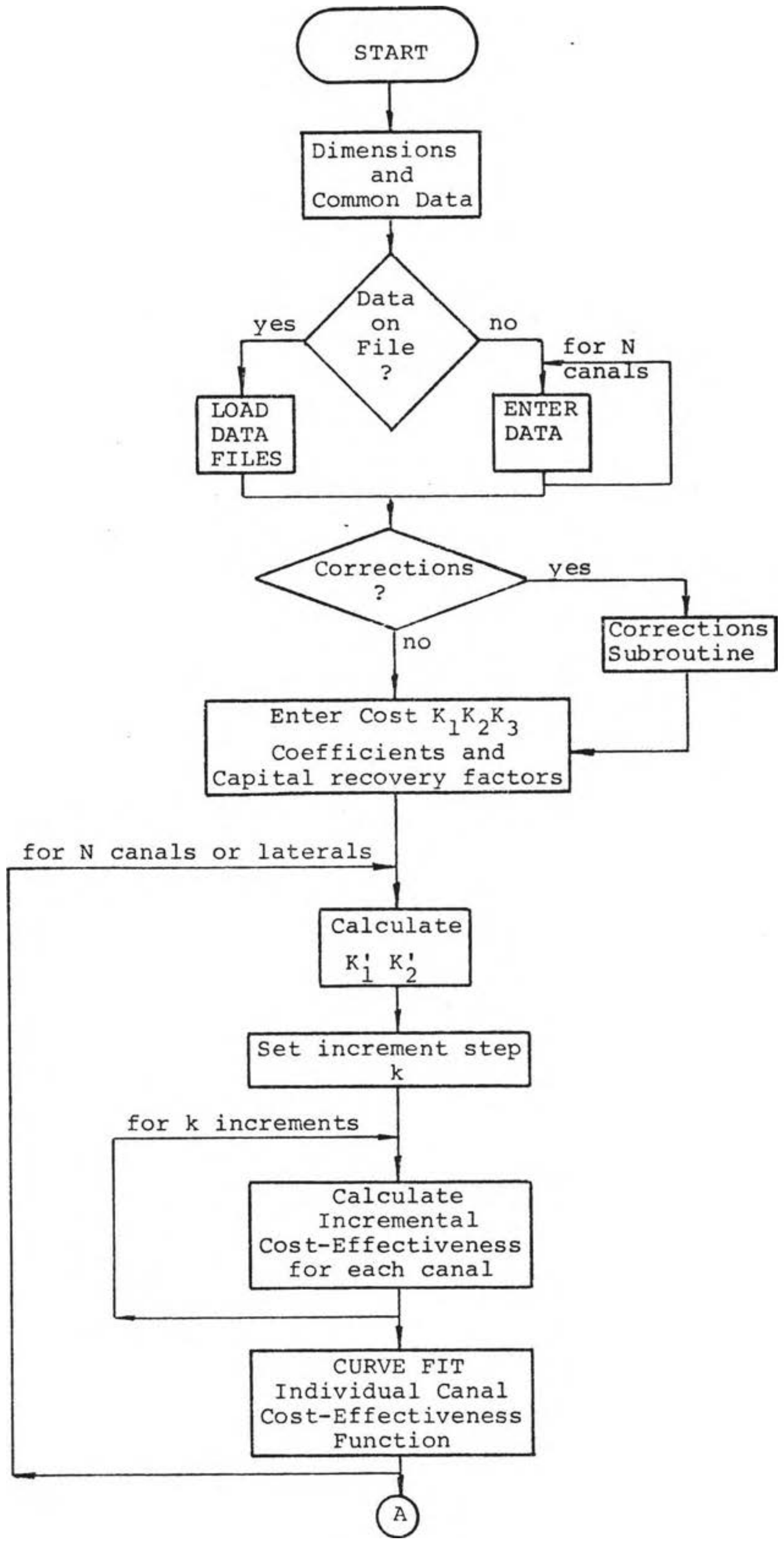


Figure 17. General flow chart of the canal cost-effective function and aggregate optimization.

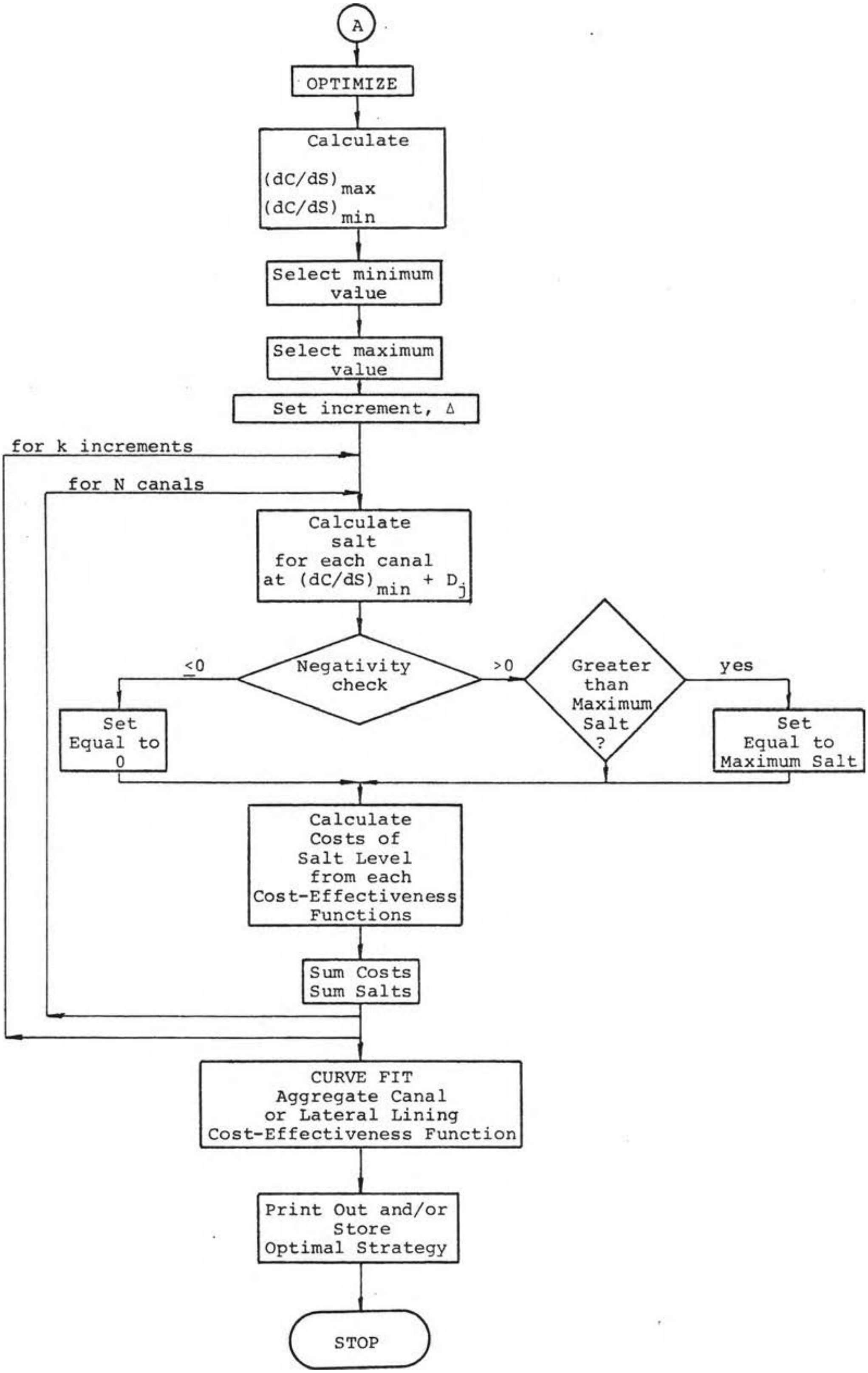


Figure 17. General flow chart of the canal cost-effective function and aggregate optimization (continued).

budgets were developed for each canal and the collective laterals under each canal. Existing seepage losses were made using existing seepage test data, if available, or extrapolated from other canals or areas. Equilibrium groundwater concentrations were estimated from well data and base flow water quality records from drains and streams in the areas for each canal. It was assumed throughout this study that groundwater concentrations would not change as a result of the projects, and this assumption has been reasonably validated by investigations in several areas in the basin (Skogerboe et al., 1979a; King and Hanks, 1975; and Bliesner et al, 1977).

Wetted perimeters and canal capacities were established from state engineers' records and other data sources relative to the inlet capacity. Utilizing aerial photographs and other data sources, the flow capacity at the end of each canal was estimated or measured. The wetted perimeter and flow were then assumed to vary linearly throughout the length of the canal. Average seepage volumes were computed and multiplied by the average number of estimated or known days of annual operation at the various selected water levels. The equilibrium concentrations of the groundwater were multiplied by the total annual seepage volume to obtain an estimated mass emission of salt from each canal and the aggregate laterals under that canal.

Annual existing aggregated on-farm mass emissions of salt which included estimated head ditch and tailwater ditch seepage losses were calculated from Soil Conservation Service data, Water and Power Resources Service data, or other published results. The amount of time water was generally available was estimated by published water records or by conversation with farmers and local ditch company officials.

The individual budgets were aggregated and compared to the areawide water and salt flows. If the results appeared to be unreasonable, the individual budgets were re-examined and re-computed if necessary. The results were compared with other studies and some were discussed with local water officials, and it is believed that they reasonably represent conditions in each of the irrigated areas.

The individual parameters were tested for sensitivity on the individual budgets. All of the budgets reacted to changes in the groundwater concentrations, and this is probably the single most difficult parameter to accurately determine. It is believed that the values which were used are within 10 percent.

Costs and salt contributions and attainable levels of reduction for Paradox Valley, Glenwood-Dotsero Springs and Crystal Geyser were taken almost entirely from reports by the Water and Power Resources Service. The projects were adjusted to January, 1980 prices and conditions and re-evaluated to determine the most cost-effective treatment.

EVALUATION OF SALINITY CONTROL ALTERNATIVES

The alternatives of managing salinity on a basin-wide scale fall into two categories: (1) those that reduce salinity concentrations by dilution or minimizing the loss of pure water from the system by transpiration and evaporation; and (2) those that improve water quality by reducing the mass emission of salt. Examples of the first category include weather modification to enhance stream flow, evaporation suppression, and phreatophyte control. In the second category, such measures as saline flow collection and treatment, reduction in agricultural return flows, and land use regulation can be applied to reduce the volume of salinity entering receiving waters. Although it is not necessarily the case, the two categories are often considered antithetical when considering individual projects because of the complicated interrelationships. At the present time, federally authorized salinity control projects involve only saline flow collection and treatment and reductions in irrigation return flows. This study in assuming the analytical structure presented above is also limited to these salinity control alternatives.

There is also a breakdown of mass emission control measures between what might be called "structural" and "nonstructural" measures. Authorized salinity control programs primarily emphasize the structural components for a number of reasons. First, salinity problems in areas like the Lower Colorado River Basin demand attention in the near future. Many nonstructural measures such as influent standards, water markets, taxation, land retirement, etc., require basic changes in the existing legal system. A second reason for structural emphasis is that nonstructural strategies must be preceded in several cases by structural measures. Furthermore, nonstructural strategies which are actually improved water management practices require long-term commitments from federal technical assistance and enforcement agencies. Manpower, funding, and internal agency restrictions often limit the duration of federal involvement.

Agricultural Salinity Control Options

For areas which primarily contribute salinity due to salt pickup, the emphasis of an agricultural salinity control program is to reduce the quantity of conveyance seepage and deep percolation losses. Individual practices will consist of canal and lateral lining to reduce seepage losses and minimize deep percolation by improved on-farm water management practices such as installation of accurate flow measurement devices, irrigation scheduling, and more uniform water applications. Since salinity problems result from a combination of both salt concentration and salt pickup effects, an integrated site-specific combination of the above types of strategies is usually required.

Achieving high irrigation efficiencies and other improved irrigation management practices are goals not only of water quality planners, but often of individual irrigators and irrigation organizations as well. King and Hanks (1975) and Willardson and Hanks (1976) discuss many of the effects of irrigation management on irrigation return flows. The technological solutions to salinity problems are often the solutions applicable to reducing agricultural energy consumption, achieving higher farm production and higher profits. Improving the physical aspects of the irrigation system, including structural rehabilitation and redesign and instituting better management practices for the operation of the water delivery system by irrigation scheduling, call periods, and limiting wastes, must be jointly considered in any program for improving the efficiencies of irrigation.

Institutional constraints may also contribute to the salinity of the basin. For example, much of the irrigated agriculture in the Upper Colorado River Basin is marginal and the income is often minimal or even negative. However, many ranchers and farmers freely admit that the only reason they maintain these lands in production is to meet forage production requirements for government grazing leases. These regulations should perhaps be re-examined in relation to salinity control programs.

Another nonirrigation practice which contributes to the salinity via the irrigation system is the diversion of water during the winter months for livestock water purposes which is commonly practiced in many irrigated areas in the Colorado River Basin, such as the Lower Gunnison and Price-San Rafael drainages. This is an often necessary, simple solution to provide water for cattle and sheep herds which winter in the lowlands, but this constant source of canal seepage has a very marked effect on the waterlogging and salination of lands below the canals. In the Lower Gunnison alone this practice contributes as much as 75,000 Mgm per year. There is little doubt that alternative supplies of livestock water would reduce salt loadings from these areas. The piping of livestock water should be included in salinity programs for regions which require the use of water supplies for these purposes, because the groundwaters are usually much too saline for even livestock use.

Within each basin grouping of salinity control alternatives, various combinations of specific projects can be selected to accomplish the control program goals. For the purpose of this case study, four groupings of agricultural salinity control alternatives will be considered: (1) canal and ditch lining; (2) lateral linings; (3) on-farm improvements; and (4) desalination of return flows. These agricultural salinity control programs listed above are not the only methodologies applicable in the UCRB, but they are the currently most accepted "Best Management Practices" (BMPs) and will indicate the proper approach to a basin-wide control program. However, a planner should not limit the array of potential solutions too quickly since optimal solutions are rarely intuitive in nature. A general discussion of selecting salinity control options for irrigated agriculture is given by Skogerboe et al. (1979b).

Canal and Lateral Linings--

Many unlined canals, ditches, laterals, and watercourses traverse long distances between the point of diversion and the farm. Where soils are well structured and permeable, seepage losses may be considerable. Traditionally, reaches with high seepage losses have been lined with a variety of alternative materials such as concrete, asphalt, bentonite clays, compacted earth, and plastic sheeting to prevent seepage with the economic justification based on the value of the water saved. Converting a closed conduit of concrete, asbestos-cement (A-C) or plastic is an effective alternative that offers advantages of better trafficability, reduced evaporation, maintenance of pressure due to gravity, and aesthetics.

Cost of conveyance channel lining vary with approximately the square root of the channel capacity, so unit costs diminish with increased scale of construction. Seepage rates per unit of channel area, on the other hand, tend to be higher with smaller-sized channels because of less maintenance, greater depths to a water table, and larger ratios of wetted perimeter to discharge capacity.

A review of concrete linings costs in the western United States by Walker (1978) indicated a reasonably high correlation between capacity and cost. Data presented by the USDI, Bureau of Reclamation (1952, 1963), and personal communication (USDI, BR, 1976) and Evans et al. (1976) indicate the following general form:

$$C_c = K_1 \, Q^{K_2} + K_3 \tag{20}$$

in which,

C_c = unit lining cost, in dollars per meter;

Q = conveyance capacity, in cubic meters per second;

K_1 and K_2 = empirical site-specific coefficients;

K_3 = fixed costs, in dollars per meter.

The slope of the canal would affect values of K_1 and K_2 since a given discharge can be conveyed in a smaller channel if the slope is increased. Many large canals have fairly flat slopes and can be estimated with Equation 20. If the channel slope is greater than 0.001, the coefficients should be re-evaluated.

For conditions in western Colorado and indexed to January, 1980 time base, the value of K_1 was found to be 99.34, K_2 was 0.56, and K_3 ranged from \$25-\$95/m with an average value of \$61.60/m. The costs included in the first term on the right-hand side of Equation 20 are earthwork, relocation, lining costs, service facilities, engineering and investigative and administrative expenses. Fencing, special diversion and cross drainage and safety structures are included in the coefficient, K_3. In a main irrigation delivery system, the discharge of the network declines along its length due to continuous withdrawal for irrigation and less acreage serviced per unit length.

Small ditches including field head ditches and laterals have basically the same cost-effectiveness characteristics as larger scale linings. However, two differences should be noted. First, the small capacities generally do not warrant expensive fencing, diversion, and safety structures and therefore K_3 in Equation 20 will be much smaller, and for head ditches it can be considered negligible. For laterals, K_3 is primarily related to inexpensive flow measurement structures which should be provided at each farmer's turn-outs. The second difference is that the operation of smaller conveyance channels is distinctly different from larger systems. Ownership is often private and sharing of flow is often rotated. Consequently, the discharge capacity generally does not diminish significantly along the channel length. For these conditions, Equation 1 reduces to:

$$\overline{C}_c = \frac{K_1 Q_m^{K_2} S_\ell}{K_2' \ (1+K_2)} \tag{21}$$

The coefficients include costs for earthwork, relocation and lining costs as well as investigations, flow measurement, diversions and road crossing structures, etc. They do not include fencing or other special safety structures since these are not necessary on small canals.

It is worth noting that using the large canal values of K_1, K_2, and K_3 coefficients for small ditches may introduce significant cost overestimation errors. Small ditches often have larger slopes and thereby carry a higher flow rate in a smaller cross-section. However, the largest source of error is that the construction specifications do not have to be as stringent, thereby reducing the costs. Low cost plastic pipelines can also be used to replace the small open ditches where feasible. For January 1980, values of K_1 = 48.5, K_2 = 0.56, K_3 = \$2.35/m appear to give representative values for lateral and small ditch concrete linings in the UCRB.

Defining the coefficients in Equation 21 can be accomplished by using typical values of 1980 contractor prices for Agricultural Stabilization and Conservation Service (ASCS) cost-sharing programs of slip-form concrete small ditch and lateral lining costs in the western United States, approximately 5-8 cm thickness, using the sulfate resistant specifications of the U.S. Department of Agriculture, Soil Conservation Service. These costs are currently about \$7.50/m^2 including all base preparation. Total lining costs for ditches carrying up to 0.4 m^3/sec range from 12/m to \$25/m. Thus, for a specified slope, the perimeter can be calculated, multiplied times the length and unit cost for an estimate of SCS lining costs. Administrative, investigative, engineering costs by the supervising agency, and other indirect costs can be estimated (usually 25 to 33 percent of construction costs), and the salinity related cost-effectiveness function is then determined directly. For purposes of this report, SCS values will be used since it is anticipated that they will be doing most of the lateral and head ditch linings.

The costs of converting a small ditch or lateral to a pipeline conveyance involves two cost estimates. The derivations of the cost-effectiveness functions are the same as given above. Irrigation pipeline materials range from plastic to concrete to metal. In addition to the costs of the pipe itself are the costs of installation. These installation costs for just the pipe are generally estimated at \$3.50/m to \$4.00/m depending upon the pipe size and local excavating conditions. The Soil Conservation Service in the Grand Valley is presently estimating pipeline costs, materials plus installation at \$0.55 per inch of diameter per foot (\$0.72/cm diameter/meter) including flow measurement, trash screens and inlet structures.

As a general rule, slip-form concrete and low head (50 feet-head) PVC pipelines have about the same salinity control cost-effectiveness. However, the use of low-head PVC pipe is generally not recommended. The use of other materials in these small capacity systems result in much higher costs and are, therefore, not generally cost-effective in comparison. The costs of commonly available pipeline materials are summarized in Appendix 3.

On-Farm Improvements--

The most significant improvements to reduce water diversions and control waterlogging and salinity problems potentially come from improved on-farm water management. This is particularly true for areas containing large quantities of naturally occurring salts in the soil profile. Poor irrigation practices on the farm are the primary cause of excessive water diversions, as well as the primary source of irrigation return flow quality problems.

A common misconception concerning salinity control is that improving irrigation efficiencies and reducing canal and lateral seepage would decrease the volume of percolating water, but may not decrease the total amount of salt leached. This would be true only if salt concentrating effects were the only phenomenon present and if the leaching water had an infinite capacity to dissolve salts. However, in most arid areas such as the Colorado River Basin, salt pickup rather than concentrating effects is the dominant source of salinity.

The exact chemical phenomenon involved with water moving through the soil profile is very complex and difficult to accurately predict or model. However, the basic processes is that as the dilute irrigated water moves through the soil profile it tends to dissolve salts which are inherent in the soil, while the salts which were concentrated by crop use tend to precipitate out of solution into the soil. Thus, as irrigation efficiencies are increased, the dissolved solids concentration in the soil also increase and there is a gradual shift from dissolution of salts to conditions favoring their precipitation. Therefore, an increase in irrigation efficiency will always reduce the amount of salt in the subsurface return flows (van Schilfgaarde and Oster, 1977).

The amount of salts which will be reduced by improvements in water management is very often nonlinear and difficult to access. Fortunately, in the UCRB the chemical properties of the saline soils and parent materials tend to force a linear relationship between the amount deep percolation and the corresponding salt reduction by imposing an upper limit on the groundwater concentrations. In other words, the reduction in salts is directly proportional to the reduction in subsurface flow volumes.

Increasing seasonal farm application efficiencies of an area to at least 65 percent will be a very difficult task almost anywhere in the Upper Colorado River Basin. Most of the fields are small with irregular shapes and variable slopes. Improvements in irrigation practices will be locally motivated and justified by increasing production and/or lower labor and other operational costs, and not by concerns for improved water quality.

The variety of structural improvements that might be effective in increasing irrigation efficiency includes lining or piping head and tailwater ditches to eliminate seepage conversion to alternative irrigation systems which applies water more uniformly with better control of the application depth. Modification of existing systems such as adding flow measurement devices, land leveling and automation should also be included. It is assumed in the analyses that all structural improvements also include sufficient technical assistance from federal agency and extension personnel so that the systems will operate as designed.

The improvement of irrigation efficiencies through on-farm seepage control can be evaluated with the methods outlined by Walker et al. (1977, 1979) for conveyance linings. On these small systems, the parameter, K_3, would normally be zero and K_1 would be reduced to a value which is about one-third of K_1 for large canal linings since construction specifications are less rigid and the ditches contain fewer control structures. The use of pipe rather than concrete linings, particularly gated pipe, can also be included in this manner.

The effectiveness of amending existing systems or converting to other methods of irrigation depends on the difference in application efficiency that can be achieved. Specifically, the change in deep percolation can be written as:

$$\Delta D_P = (1 - \Delta E_a)\, D_a \tag{22}$$

in which,

ΔD_P = reduced depth of deep percolation in centimeters;

D_a = average depth of applied water in centimeters.

By assuming that the soil chemical reactions can be considered in equilibrium, the prediction in salt pickup associated with a change in deep percolation is developed from:

$$\Delta S_E = \Delta S_c \Delta D_P \left(\frac{Q_g - Q_P}{Q_g} \right) x\ 10^{-4} \tag{23}$$

where,

ΔS_E = reduction in salt loading due to improved application efficiencies, in megagrams per year per hectare.

Evaluation of the term, ΔE_a, is a difficult task. It requires that existing efficiencies be characterized and that expected efficiencies for potential improvements be predictable. Both tasks are compounded by the highly variable and diffuse nature of irrigation systems. However, for the purposes of this report, attainable application efficiencies in Table 4 were used.

Cost of Irrigation Systems--

A general model describing irrigation system costs for various farming conditions is not readily available. It is not a difficult task to estimate these costs if the specific conditions at the farm are known, but in the absence of this information, irrigation improvement costs are usually given as representative values. The cost estimates presented here are annual costs per hectare and include capital and construction costs, operation and maintenance costs, and pumping energy costs. These cost estimates are current as of January, 1980.

Not all irrigating costs are included in this analysis because many are incident to the farming enterprise and do not affect the choice of system improvements for salinity control. This assumption is based on the fact that a farmer is committed by choice to the contribution of a certain level of labor, energy, capital, and water resources for continued irrigated agriculture. For example, seed, fertilizer, pesticides, taxes, and insurance are costs only minimally affected by system improvements and are not

Table 4. Suggested maximum attainable irrigation application efficiencies in the Upper Colorado River Basin.

Irrigation Method	Maximum Probable Attainable Efficiency
Gated Pipe	60
Siphon Tube-Furrow	60
Automatic Cutback Furrow	80
Automated Gated Pipe Furrow	80
Sprinklers	85
Drip	90
Borders	60
Level Basins	75
Automated Basins	90
Tailwater Reuse Systems	80

considered. Actually, many of these costs are often compensated for by higher yields and greater land values. It is obvious that the costs on which a specific on-farm salinity control measure should be compared with others are the differences between the total annual cost of the improved system minus the pre-implementation total annual costs and minus increases in net farm profit incurred as the result of better irrigation practices.

The pre-implementation of "base" conditions in the salinity affected regions of the UCRB is most likely to be the furrow irrigated field having moderate slopes less than 1.5 percent and relatively low intake soils. The water supply is delivered to the field in unlined ditches from river diversions or at the farm from wells. Water supply costs are already being paid and therefore would not affect the choice of the on-farm improvement. The exception is the case of the water supply being groundwater requiring a pump and a well. If the system improvement was to be a sprinkle or trickle system, the new pumping plant and higher energy costs must be included in the evaluation regardless of water source because these facilities would require substantial modification.

The base topological condition one might also expect would be relatively well graded fields, thereby eliminating large land shaping costs for most improved systems except for possibly wide border and basin irrigation. Water distribution on the farm itself would typically be with unlined ditches and application to the fields would be accomplished with cuts in the earthen ditch bank, siphon tubes, spiles, or small check structures. New systems and improvements would replace all of these facilities except siphon tubes. Rebuilt or new structures for flow measurement and regulation would be added.

Costs were developed for pressurized and gravity irrigation systems obtaining water from surface and groundwater sources. The results of averaging the scale distributed capital and construction costs are shown in Table 5. Depending on the type of improvement selected, annualized capital costs range from below \$30/ha to more than \$600/ha. Systems currently utilizing a groundwater resource and converting to a pressurized system involve substantial upgrading of the pumping systems thus such changes would not be necessary for the gravity or surface irrigation methods.

Appendix 3 presents suggested annual maintenance costs for various pressurized and surface irrigation systems, data on labor requirements per irrigation for selected types of systems, and listing of expected equipment life of various irrigation system components with a good maintenance program. Replacement costs of short-lived components are included in O & M cost estimates.

Annual expenditures to operate and maintain irrigation improvements are also given in Table 5. These costs which include labor are higher in all cases than the base conditions because of the previously stated assumption that

Table 5 . Annualized average costs for selected irrigation systems.

Description of System or Improvement	Annual Capital and Construction Cost $/ha	Annual O & M Costs $/ha	Annual Energy Costs $/ha
Concrete Ditch Linings	33	7	0
Gated-pipe Replacement of Head Ditches and Piped Connecting Systems	29	6	0
Automated Cutback System	83	17	0
Gated-pipe Tailwater Recovery and Reuse System	95	19	33
Big Gun Traveler Sprinkler System	272 - 349[1]	83 - 107[1]	125 - 188[1]
Solid-Set Sprinkler System with Above Ground Aluminum Piping	362 - 405[1]	185 - 206[1]	120 - 189[1]
Solid-Set Sprinkler System with Below Ground PVC Piping	642 - 683[1]	196 - 209[1]	109 - 173[1]
Hand Move Sprinkler System with Aluminum Piping	137 - 175[1]	70 - 89[1]	120 - 189[1]
Sideroll Sprinkler System	119 - 147[1]	49 - 60[1]	50 - 88[1]
Center Pivot Sprinkler System	70 - 91[1,2]	21 - 28[1,2]	55 - 80[1,2]
Trickle Irrigation System for Orchards and Widely Spaced Row Crops	312	127	19
Automated Basins			

1 Range of costs for surface water supplies (small values) and groundwater supplies (large values).
2 For center pivot systems covering more than 32 ha.

improved management would be a part of the program. Specifically, a farmer whose improvements ranged from simple head ditch linings to complex pressurized systems would be expected to include irrigation scheduling components at peak operating efficiency. If these assumptions are not valid or not included in the quality control program, many improvements would actually show negative O & M costs because of labor savings. The pressurized system should still have added O & M costs because of greater equipment complexity.

The costs of pumping and adding pressure to the irrigation water, above those for the base conditions, are presented in Table 5. These costs have been delineated from the O & M costs to illustrate the consequences of changing irrigation systems. Energy costs are increasing much faster than other irrigating costs and, therefore, should be evaluated carefully in selecting on-farm salinity control measures.

The energy cost results shown in the last column of Table 5 should be understood since the impression may be given that converting to sprinkle and trickle irrigation systems always means more energy bills. This may not be true if an existing groundwater supplied surface irrigation system is highly inefficient. For example, conversion to a sprinkler system may actually reduce energy costs since the increased efficiency means less water pumped even though the pressure is higher.

The total annual costs associated with each alternative irrigation system improvement can be determined by summing the average values. One can see that annual costs cover a wide range in the irrigation industry. Simple head ditch linings are more than an order of magnitude cheaper than most of the pressurized conversions. However, the improvement in application efficiency is also a factor in the cost-effectiveness of the measure as a salinity control alternative. Head ditch linings would improve the irrigation efficiency by the amount of seepage prevented, whereas the remaining improvements also create increases due to better water control and uniformity.

The values presented in Table 5 agree quite closely with the data presented by Reed et al. (1977) for the same field sizes. Reed et al. (1977) did not include annualized initial investment costs, but did include taxes, insurance, and depreciation.

Development of the On-Farm Cost-Effective Analysis--

The cost-effectiveness function for the on-farm improvements meets the same general criteria as the other salinity control measures. Specifically,

$$C_j = \lambda(m_j) \tag{24}$$

subject to:

$$0 \leq m_j \leq \bar{m}_j \tag{25}$$

where,

C_j = the annual cost of reducing the mass emissions of salt by mg;

λ_j = unit control cost associated with the $j^{\underline{th}}$ on-farm improvement which may be either linear or scale dependent; and

$\bar{m}_j$ = total controllable pollutant reduction achieves by full treatment.

The values of λ_j are defined from irrigation system design and can include management costs and has the form of:

$$\lambda_j = \frac{c_j}{R_j} \qquad (26)$$

where,

c_j = total annual cost of the improvement, \$/ha/yr; and

R_j = changes in pollutant emission achieved by the $j^{\underline{th}}$ improvement, Mgm/ha/yr, and includes the effects of efficiency.

On-farm optimizations are subjected to the same linear constraints presented in Equations 6 and 7, but also require an additional constraint to prevent more than one on-farm improvement being applied at the same source. For example, lining a head ditch and conversions to sprinkler systems are mutually exclusive in most cases. This constraint can be written as follows:

$$\sum_{j=1}^{n} \frac{m_j}{A_f} \leq \sum_{j=1}^{n} \bar{m}_j \qquad (27)$$

where,

A_f = the total of irrigated lands, hectares; and

n = the total number of the selected on-farm improvements to be considered for the area.

However, this constraint could not be easily included in the algebraic optimization procedure outlined earlier.

Due to the linearities of annual costs for the various irrigation systems over the range of field sizes and conditions applicable to the Upper Colorado River Basin, the aggregate on-farm strategy was optimized by linear programming. Figure 18 presents the dimensionless optimal combination of on-farm salinity control measures to be implemented in any area in the UCRB. Figure 18 also illustrates the potential range of salt reduction obtainable for each measure when implemented in the optimal sequence as shown.

The program for the optimal on-farm salinity control program depends on the desired level of control which was selected prior to implementation. Depending on the chosen level of salinity control for an area, head ditch lining would be the first measure to be implemented until approximately 42 percent of salt is to be removed, at which time cutback furrow irrigation (semi-automated) would start to replace the head ditch linings to remove up to 67 percent. If control above the 67 percent level is desired, then construction of gated pipe tailwater reuse systems or other similar automated systems are initiated to remove up to 80 percent of the attainable salt before sideroll sprinklers become cost-effective. Drip irrigation, if applicable, is the last alternative to be implemented. This additive approach is illustrated by Figure 19 which shows the nonlinearity of the cumulative on-farm cost-effectiveness function. The annual costs can be computed using Equation 8 and establishing the on-farm A and B values for each

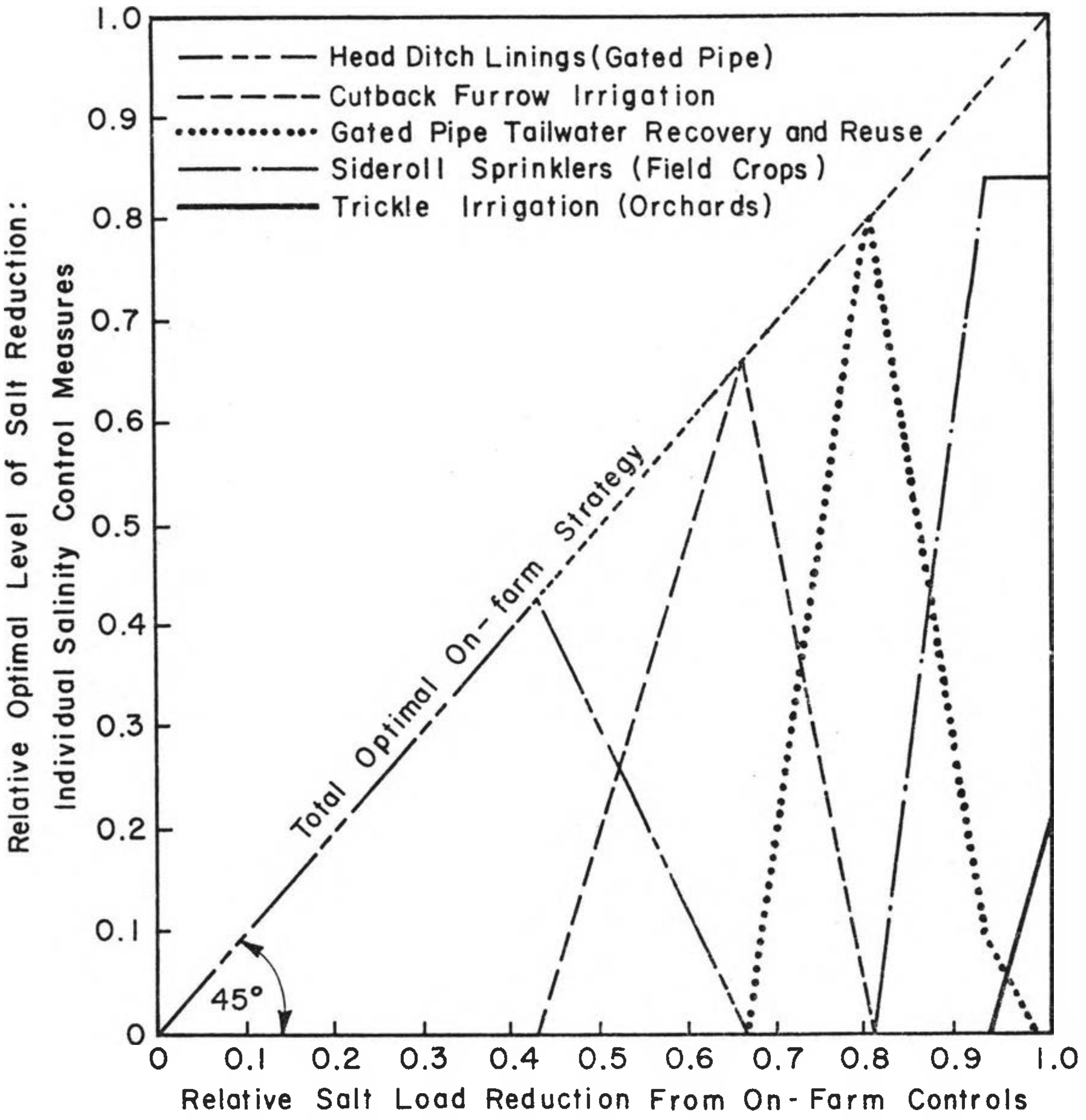


Figure 18. Dimensionless optimal on-farm salinity control implementation program.

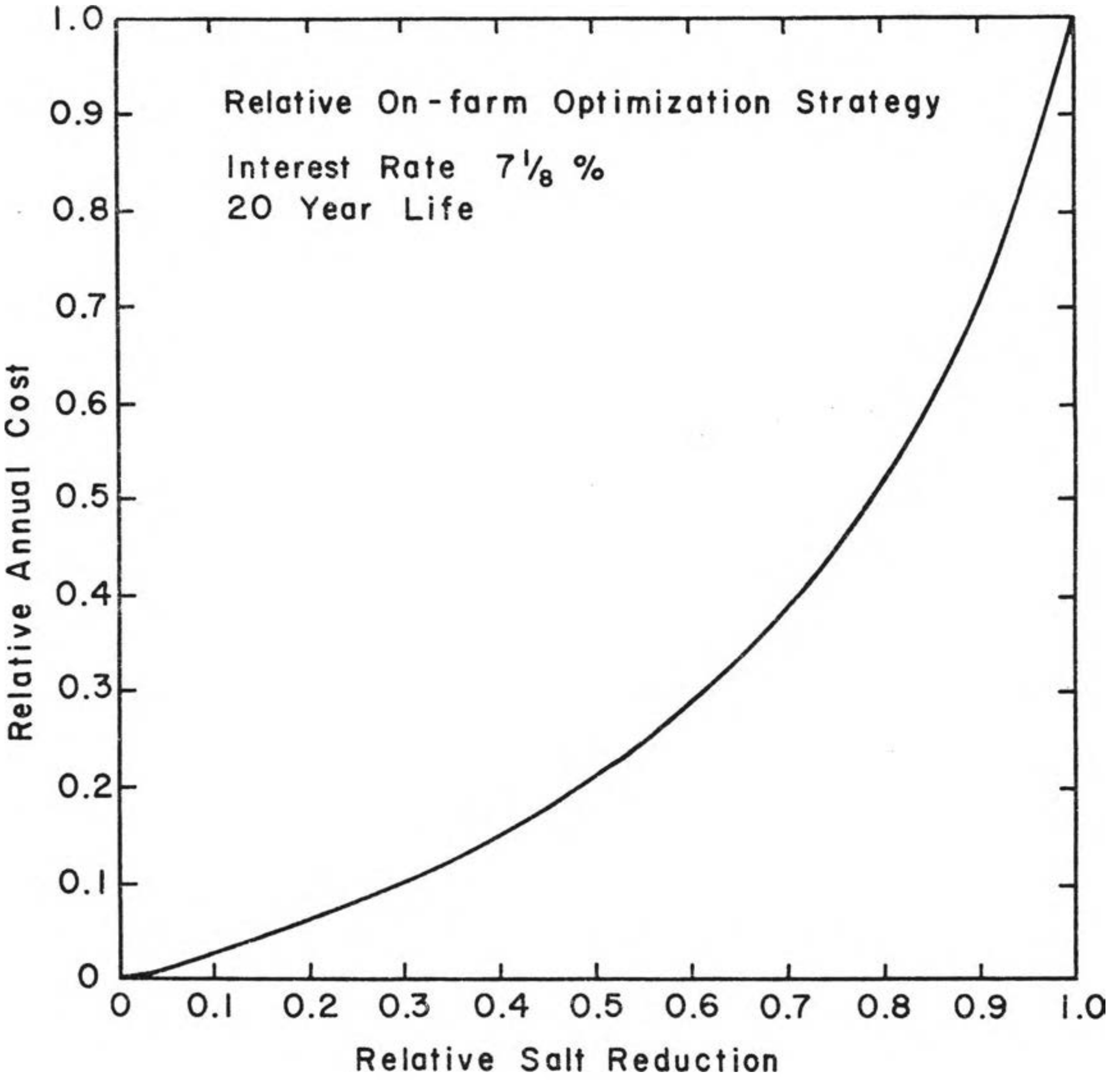


Figure 19. Dimensionless on-farm cost-effectiveness function.

irrigated area. Throughout this analysis it was assumed that irrigation scheduling and a higher level of management would be imposed on the on-farm irrigation programs.

This array of on-farm alternatives is not intended to be all inclusive, but rather to indicate the types of systems which should be implemented to achieve a desired level of control. The Soil Conservation Service or other implementing agency should approach this strategy in terms of establishing policies or priorities for distributing cost-sharing monies for on-farm improvements. For example, a graduated scale of cost-sharing percentages could be formulated with the highest level of government contribution being available for the most efficient on-farm improvements.

Collection, Treatment and Disposal of Return Flows--

In many cases where salt pickup is a particularly severe problem, subsurface return flows from irrigated lands may be so brackish that no further use of the water is possible. Such flows significantly degrade the quality of a river, stream, or groundwater resource. An alternative to expenditures aimed at reducing the volume of these flows by improving irrigation efficiency is to collect the subsurface return flows before they enter receiving waters. The collected flows can then be directed to a desalination plant that removes most of the salts and returns the water to the stream or directly to a disposal area. Major disposal alternatives include deep well injection and evaporation ponds. Various desalination methods are discussed in detail by Walker (1978).

The costs of collection, desalination, injection wells, and evaporation ponds are described for planning purposes by the United States Department of the Interior (1972). A mathematical description of the same information is given by Walker (1978). In general, the costs of the collection, desalination, and brine disposal for salinity control exceeds the costs required to achieve the same level of salt reduction by improving irrigation efficiencies. However, by comparison, lining large conveyance systems or implementing highly automated irrigation systems is costlier. The desalination alternative is relatively free of the institutional complications involved in improving an entire irrigated area, but is an intensive user of energy.

Desalination--

For regional salinity control evaluations, desalting costs are expressed in dollars per unit volume of salt extracted in the brine discharge rather than the conventional index of costs per unit volume of reclaimed product water. In this manner the respective feasibility of desalination and other alternatives for salinity management can be systematically compared during the processes of developing strategies for actual implementation of salinity controls. A desalting system as used herein consists of facilities for supplying raw water (water to be desalted) to the plant, the desalting plant itself and facilities to convey and dispose of the brine. Transportation of product water beyond the confines of this system is not considered.

While recognizing the site-specific nature of desalting technology as applied to regional water quality management, some generalization of the cost-effectiveness relationship can be made. A detailed evaluation of input parameters to a desalting cost analysis was presented by Walker (1978). All systems are most sensitive to the capacity of the desalting plant. When the costs are expressed in terms of salt removal, the unit costs stabilize to nearly constant values when the capacities are greater than about 10-15,000 m^3/day. Since desalting would be most competitive with the salinity control alternatives when the unit costs are minimal, only systems with capacities greater than 0.17 m^3/s (15,000 m^3/day) should be considered. The result of this consideration is that the desalting cost-effectiveness functions are approximately linear.

For the purpose of formulating a desalting cost-effectiveness function which can be evaluated along with other salinity control measures, the model by Walker (1978) was updated to January, 1980 conditions. Then, the model was used to generate cost-effectiveness curves for feedwater saline types ranging from 1,000 to 9,000 mg/l. These functions shown in Figure 20 were then considered into the following mathematical form:

$$\overline{C}_d = 0.5 + M'S_1 \qquad (28)$$

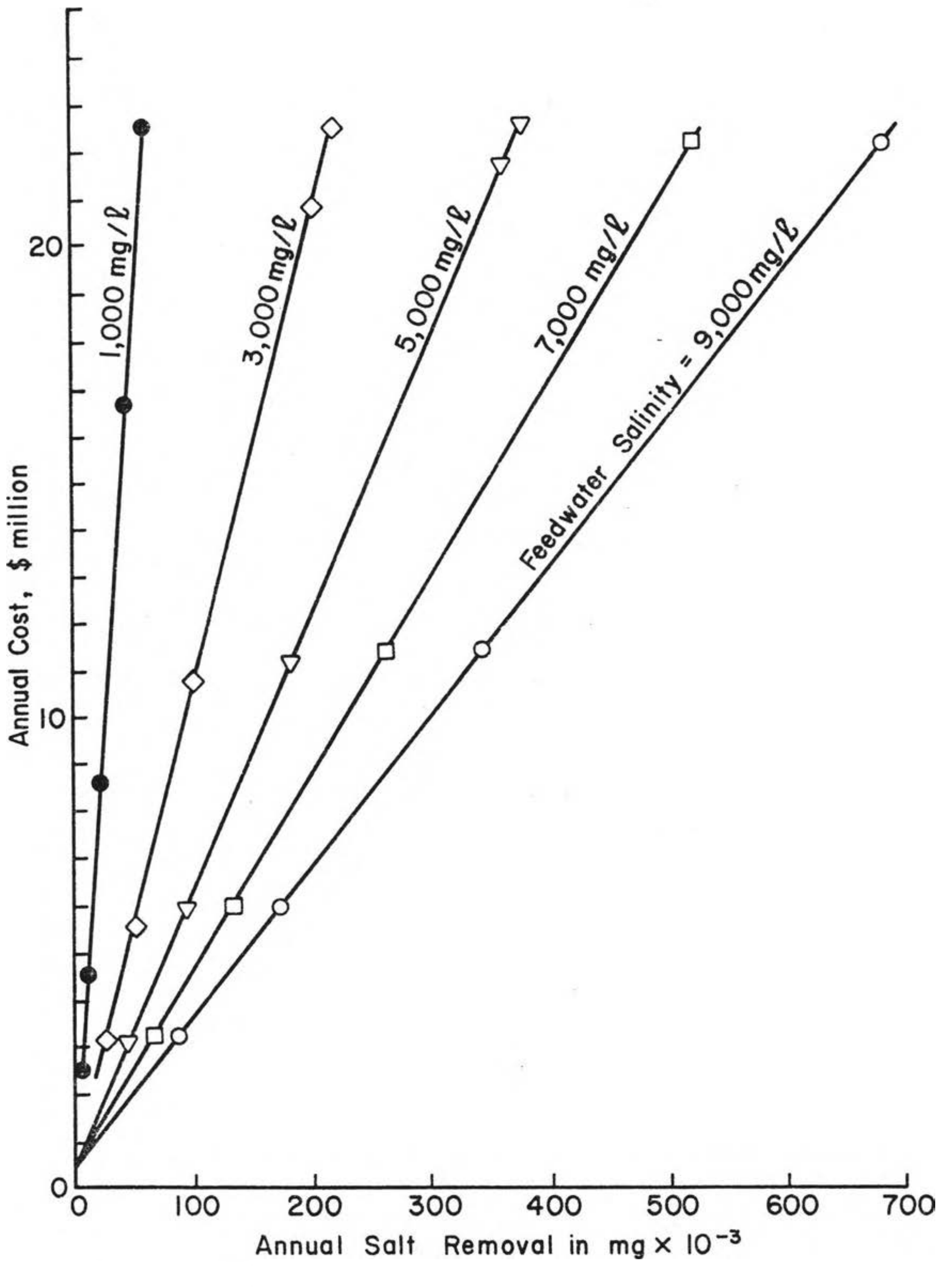


Figure 20. Annual costs of salt removed by reverse osmosis (RO) desalination process at various feedwater concentrations.

in which,

$\overline{C}_d$ = annual cost in \$ million of removing S_1, thousands of megagrams per year; and

$M' = 1{,}404\ TDS_i - 1.18$

where,

TDS_i = feedwater salinity, mg/l.

The disposal of brine from desalination plants and/or brine pumping programs such as the Paradox Valley Project, is a severe problem in many of the salinity control programs. The alternatives which are most commonly discussed are evaporation ponds and deep well injection. Ponds are limited by area and volume availability whereas injection techniques depend on the physical and chemical characteristics of the geologic formation where brine is to be stored.

There is some consideration of supplying brines to industries such as oil shale if they would want it or could use it. Milliken et al. (1979) discuss the legal and institutional factors associated with transfers of saline water to energy related users. In addition, there is some attention being given to alternatives such as piping the brines to natural salt sinks such as Sevier Lake in Utah.

Evaporation Ponds--

The area required for evaporation ponds depends on the total brine flow and natural precipitation and the rate of evaporation. For example, if the average annual evaporation rate for Paradox Valley or Glenwood Springs was about one meter, then the evaporation rate would average 3.2×10^{-4}

m^3/s/ha of pond surface and an inflow rate of 0.06 m^3/s would require a 190 hectare pond. Additional evaporation area capacity is required because the evaporation rates are depressed with increasing concentration (Crow, 1980; USDI-USDA, 1977). These ponds should also include storages for seasonal variations in evaporation since the inflow from a desalination plan or brine well field would be constant. The useful life of the pond depends on the salt and sediment deposition on the bottom. The density of rock salt is about 2.18 gm/cm^3 and a salt loading of 163,000 Mgm/yr into a pond would consume a minimum of 75,000 m^3 of capacity each year, and 236,000 Mgm/yr would annually deposit 104,000 m^3 of salt. The life of the ponds could be extended indefinitely if the salt had any marketable value and would be periodically removed.

Watersaver, Inc. (1980) indicated material costs for a 36 mil exposed reinforced Hypalon-type liner, not including earthwork, to be about \$4.74/m^2 or \$47,360/ha. Laying and sealing costs could be estimated on labor requirements of 150-200 man-hours/ha at \$15.00/man-hour which results in labor costs of \$2230 to \$2975/ha.

If the Hypalon-type liner were to be covered by earth, at least another \$7200/ha might be expected. A 30-mil PVC liner could not be exposed and would have to have an earthen covering, and total installed costs would be about \$38,500/ha, however, PVC would probably not be as durable as Hypalon-type liners. For purposes of this report, a conservative value of $54,600/ha for installation and a total installed cost of $102,000/ha was used. The USDI, WPRS (1980a) indicated that total costs including earthwork could approach $2,480,000/ha. The USDI, WPRS (1979) estimated that 247 ha of evaporation ponds, 6.1 m deep with a 20 mil PVC buried liner costs about $178,650/ha for the La Verkin Spring Project (October, 1978 prices). Inflating this cost to January, 1980, using the Engineering News Record Building Cost Index (ENR, 1980) factor of 1.10, the unit costs would be about $197,000/ha.

Deep Well Injection--

Deep well injection as a method of brine disposal offers several environmental benefits. The primary advantage is that very little terrestrial surface area is required since the brines are injected into subsurface geologic formations. The technology of deep well injection is fairly well developed and has seen wide use in the petroleum industry where oil field brines have been brought to the surface during the production of gas and oil. The oil field brines are usually reinjected into the same formation in which they originated, and there is presently a considerable effort in using the reinjected brine in the secondary recovery of oil.

Injection wells have also been used for the permanent underground storage of industrial wastes, radioactive wastes, wastes from small scale desalination plants and some from advanced waste treatment plants. However, the injection of these wastes has usually been on a fairly low volume at less than 3.16 lps in wells and on a short-term basis, unless some types of underground chambers had been prepared. For example, chambers have been made in salt domes for waste disposal and oil storage in places where the brine produced by the making of these chambers could be disposed by other means. Another method of making chambers is the use of nuclear explosives which has been demonstrated in Colorado and Wyoming to help in natural gas production as part of the Plowshare Program.

Deep well injection is generally not a long-term solution to a continuous disposal program because of reservoir limitation and the need to drill new wells at further and further distances from the source. The new wells are very expensive to construct and new piping systems are required. Bouwer (1974) indicated that well costs, up to about 1,000 meters deep in 1974, were about $160/m. In 1980, these costs would be about $265/m. Deeper wells would be much more expensive on a unit cost basis because of the different types of equipment required. In addition, the pressures involved in the injection process often exceed 100 atmospheres, and the pumping power requirement can be large.

Other Brine Disposal Possibilities--

The USDI, WPRS (1980a) is presently assessing several alternatives to the brine disposal problems for their salinity control projects in the Colorado River Basin. One possible alternative which they are examining is supplying the brine water to industries, such as oil shale, for their use. Another possibility is to construct a collection system and convey all of the brine to a suitable salt sink such as Sevier Lake in Utah or even to the Pacific Ocean.

Collection, Treatment, and/or Disposal of Other Saline Flows--

The Upper Colorado River Basin contains a number of natural saline seeps and springs which add substantial amounts of salt to the river. Alternatives for eliminating these salts include desalination as discussed earlier as well as direct collection and disposal through evaporation pond to deep well injection. The desalination cost-effectiveness for the nature saline springs and seeps are the same as described for the treatment of agricultural return flows.

Hagan (1971) and EPA (1971) estimated that the salinity contribution from point sources in the Upper Colorado River Basin is about 9 percent of the total salt load at Lee's Ferry, Arizona. The majority of these point sources are thermal springs, and Iorns et al. (1965) calculated that the annual discharge and dissolved solids concentration by all the thermal springs in the upper basin to be 7,287 ha-m and 491,500 Mgm, respectively. Dividing the flow and concentrations due to thermal springs among the three diversions is presented in Table 6. The major point sources of the UCRB are listed in Table 1-B in Appendix 1.

The EPA (1971) calculated that the total contribution of point sources in the Lower Basin is an additional 645,900

Table 6. Point source contributions in the Upper Colorado River Basin.

Drainage	ha-m	Salt Contribution Mgm/yr
Grand Division	5,060	437,400[1] 516,000[2]
Green Division	1,960	44,100[1] 131,950[2]
San Juan Division	270	9,980[1] 10,400[2]
TOTAL	7,290	491,500[1] 658,500[2] 804,900[3]

[1] Iorns et al. (1965)

[2] Hagan (1971)

[3] EPA (1971)

Mgm/yr which is about 15 percent of the total salt load from the Lower Basin. The USDI, BR (1979a) estimates the point source contribution in the Lower Basin at 687,000 Mgm/yr of dissolved solids. Thus, point sources account for about 21 percent of the total salt leaving the Colorado River Basin and is not a minor problem.

There are about four point sources in the Upper Colorado River Basin that might be cost-effective to treat. Paradox Valley, although not technically a point source, is probably the most cost-effective at this time if the by-pass alternative is adopted. The second most favorable is probably the thermal-mineral springs on the Colorado River near Glenwood Springs and Dotsero, Colorado. Crystal Geyser, near Green River, Utah, is an abandoned oil well and does not appear to be cost-effective at this time.

The salinity contribution of Meeker Dome, which is believed to result primarily from old abandoned oil wells which were improperly capped, is presently being investigated to determine a suitable treatment for reducing the salinity. One well was capped in 1968 and reduced the salinity contribution by about fifty percent (USDI, WPRS, 1980a).

Most of the salinity control plant source treatments involve desalination and/or evaporation of the brines or deep well injection of the brines.

CHAPTER 5

ANALYSIS AND RESULTS

This is a lack of good data outside of the Grand Valley for the irrigated areas in the Upper Colorado River Basin. In addition, there is substantial uncertainty associated with projections of future developments and their anticipated water demands. Nevertheless, decisions must be made and salinity control programs developed using these data. The results generated by these calculations suggest a foundation on which to formulate a basin-wide salinity control program. The analysis presented in this text demonstrates the procedures and data necessary to determine the most cost-effective basin-wide program.

PROCEDURAL CONSIDERATIONS

Once the hydro-salinity evaluation of a river basin is completed, it is only necessary to define the first level cost-effectiveness parameters for each area before the entire basin-wide analysis of the second, third and fourth level cost-effectiveness functions are only mathematical extensions of the Level 1 optimization. Figure 21 depicts the simplicity of this methodology. This easily applied procedure is further illustrated by the fact that the entire analysis was performed using a small desk-top computer with less than 24,000 bytes of capacity.

Throughout this analysis average values were used to represent the general conditions of each canal and/or area.

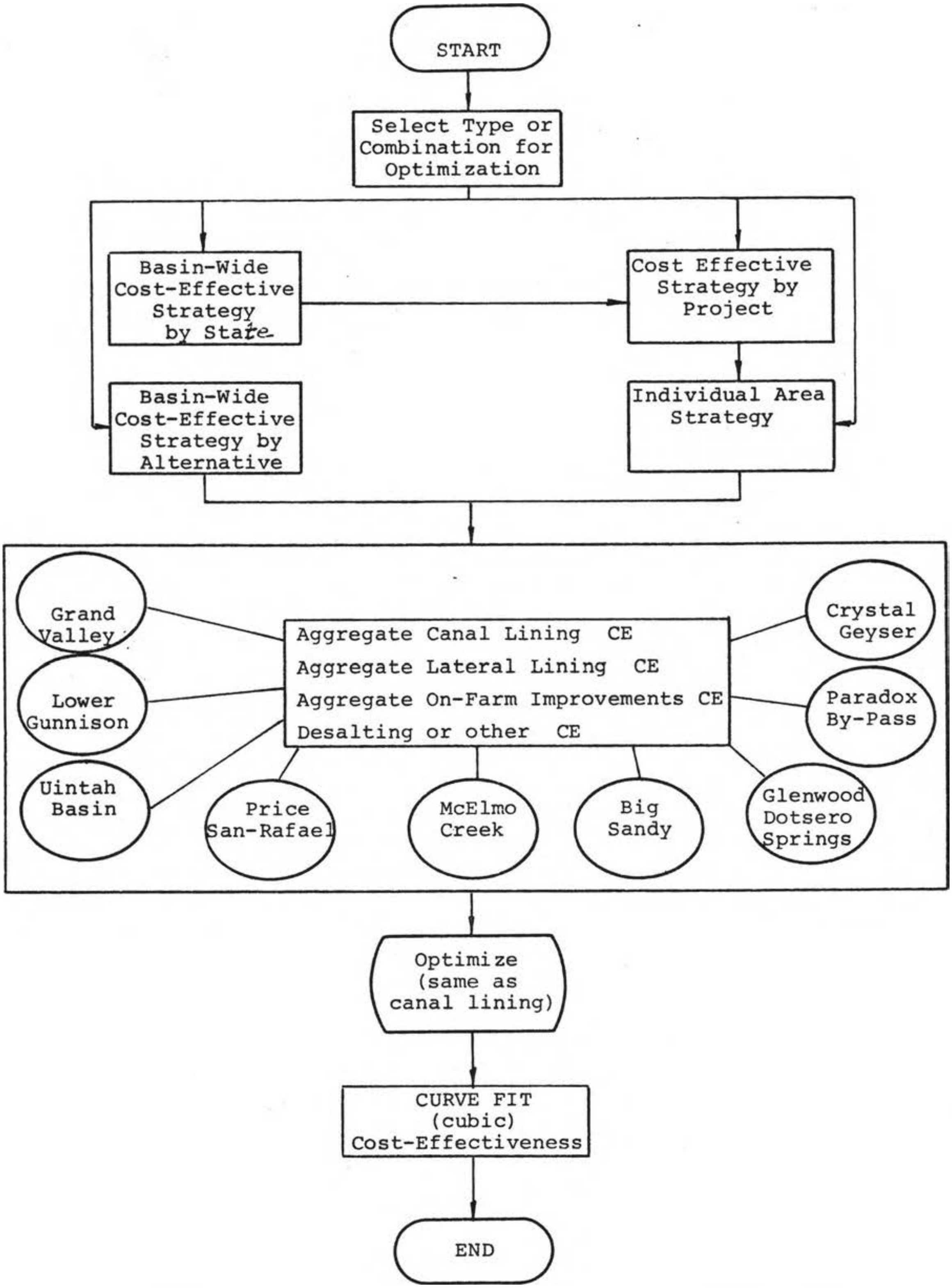


Figure 21. General schematic flow chart of project area, state and basin-wide optimization and development of the cost-effectiveness function.

It was further assumed that the groundwater salinity concentrations would remain unchanged as a result of any salinity control program. January, 1980, costs and estimates of conditions were used throughout the development of these results.

Salinity is basically a conservative pollutant, and it was assumed that the problem could be linearly decomposed into various levels in order to arrive at a basin-wide salinity control strategy. The lack of physical interaction and water utilization practices between the various areas delineated by PL 93-320 facilitated this analysis.

The Grand Valley of western Colorado was used to verify these procedures and assumptions because it is the only area in the Upper Basin where sufficient data are available to permit this type of analysis. Also, the Grand Valley is geologically and topographically similar to the other large agricultural salt producing areas in the basin. For example, field sizes are generally small with moderate slopes and have soils with low water intake rates.

The degradation of water quality associated with the irrigation of agricultural lands is usually most economically controlled on the croplands where the water is applied. The preventative structural measures, which were included in this analysis were limited to concrete canal and lateral linings and five broad categories of on-farm irrigation system improvements. Desalination of agricultural return flows by reverse osmosis procedure was included as the final measure to be implemented in the most cost-effective salinity control strategy. However, it was assumed that the on-farm program would include long-term and capable technical assistance in order to maximize the benefits of the respective systems.

The criterion of minimum cost was utilized in this analysis for two main reasons. One, the salinity problem and the associated damages are a classic example of a true economic externality, and purely economic forces are unable to cause remedial measures. Second, the goal of maintaining the 1972 salinity levels in the Colorado River Basin is a mandated requirement, and also not an economic consideration. Thus, the control must be accomplished via governmental action and minimum costs are an acceptable criterion for determining salinity control strategies.

PRESENTATION OF RESULTS

Figure 22 illustrates the graphical presentation of areawide salinity control programs. The heavy dark line represents the aggregate cost-effectiveness function for the area in terms of annual costs and salt load reduction. The area above the cost-effectiveness curve represents the salt load reduction which can be obtained from each alternative for any level of salinity control. Correspondingly, the area below the cost-effectiveness function defines the costs associated with each alternative. For example, the dashed lines in Figure 22 represent the optimal strategy for a

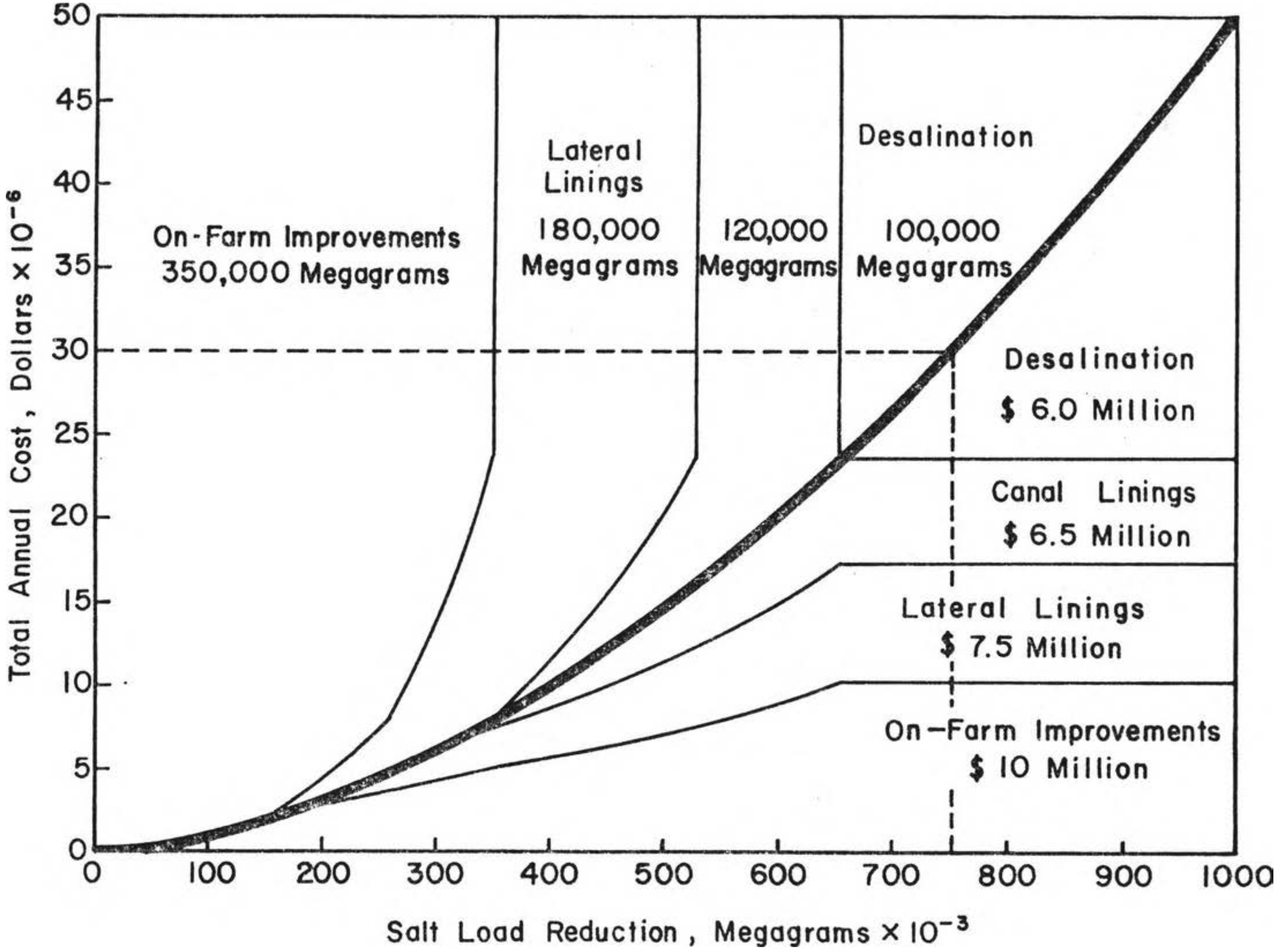


Figure 22. Example of salinity control cost-effectiveness function for a 750,000 Mgm reduction and an annual cost of $30 million.

given area to remove a total of 750,000 Mgm per year at a cost of $30 million annually. The values of salt and dollars which are listed on the "policy spaces" of Figure 20 correspond to this level of salinity control. The total salinity impact is achieved by investments of $10 million/yr in on-farm improvements, $7.5 million/yr in lateral linings, $6.5 million/yr in canal linings, and $6.0 million/yr in a desalination program. Each of these systems would be improved sufficiently if totally constructed to reduce salinity by 350,000 Mgm/yr, 180,000 Mgm/yr, 120,000 Mgm, and 100,000 Mgm/yr, respectively. A similar salinity control strategy can be identified in such diagrams as the delineation of the coordinates of the cost-effectiveness function.

The linearities introduced by desalination in the ranges where desalting would be implemented were better represented by a cubic relation than Equation 8. This equation has the form:

$$AS + BS^2 + CS^3 = \text{Annual Cost} \qquad (29)$$

where A, B, C are regression coefficients and S is the salt load reduction. Otherwise, the exact procedures and methodology are followed as were outlined in the previous chapter. Although it is not shown on the graphs, it should be mentioned that the very top of the desalting region is nonlinear and turns very sharply upward. This rapid change is due to the typically high costs of obtaining the last increment of control. However, it was found that desalting would very seldom be implemented to that extent, and further correction of the equation was not warranted in this analysis.

Tables presenting the data for the optimal areawide salinity control program are included in this chapter. The first column is the percentage of the total salt load which has been treated, and the second column is the estimated total combined annual cost. The third column is the estimated average cost per mg/l at Imperial Dam for these improvements; however, this is not marginal cost and should not be compared against the $450,000/mg/l damages which are a true marginal value. The columns under the various alternatives represent the amount of the attainable salt load reduction attributed to that alternative. Due to the linear relationship between the degree of salt loading and the level of control, the columns for canal and lateral linings can be almost directly translated into percent of lining length to be implemented at each level of control. The actual percentage of salt reduction in the canal lining column in the areawide program corresponds directly to the percentage of total salt reduction column in the specific area canal lining strategy tables presented in Appendix 4. Tables have not been presented for lateral lining because they correspond very closely to canal lining. The same seepage rates and groundwater quality for the aggregate laterals under a canal were assumed to be the same as the canal. Thus, the percentage of lateral lining in the areawide analysis will correspond directly to their respective canal in order of priority.

Tables listing the optimization parameters and the characteristics of each of the major canals and large laterals in each of the main agricultural areas can be found in Appendix 2. These tables represent the best estimate of representative conditions for each of the areas, and indicate the results of the hydro-salinity analysis which was performed for each area.

AREAWIDE ANALYSIS OF SALINITY CONTROL PROGRAMS

The areawide analyses of the individual salinity control projects indicate a fairly high degree of uniformity in the optimal order of implementation. In every agricultural area, except the Grand Valley, the on-farm improvements were the first programs to be implemented followed by lateral lining, canal lining and desalination. Table 7 presents the aggregate cost-effectiveness functions for canal lining, lateral lining and on-farm improvements and their estimated maximum salinity reduction potential.

The on-farm improvements are probably the most difficult components to quantify and to characterize in an optimization context. In this analysis it was necessary to assume a higher level of on-farm water management and long-term technical assistance by the implementing agency and/or extension personnel to the growers. The amount of salinity control is much easier to establish for fixed structural

Table 7 . Optimal Salinity Control Cost Effectiveness Parameters for Agricultural Salinity Control Programs in the Upper Colorado River Basin.

	Aggregate Function A	Aggregate Function B	$\left(\frac{dC_c}{ds_\ell}\right)_{max}$	$\left(\frac{dC_c}{ds_\ell}\right)_{min}$	Estimated Attainable Salt Load Reduction Mgm	Total Existing Estimated Salt Load Contribution Mgm
GRAND VALLEY CANALS	-1.598240E-07	3.535953E-02	218.89	26.99	110,000	142,100
GRAND VALLEY LATERALS	-2.841952E-07	1.198953E-01	22.70	5.87	140,900	203,200
GRAND VALLEY ON-FARM	-3.829764E-07	1.144168E-01	143.40	8.74	225,000	284,700
LOWER GUNNISON LARGE CANALS [1]	-9.352244E-08	2.010311E-02	887.71	21.58	176,200	220,000
[2]	-1.147490E-07	3.212852E-02	887.71	16.90	152,600	220,000
LOWER GUNNISON SMALL CANALS [3]	-2.396381E-05	2.743582E-01	111.41	5.35	8,860	14,250
LOWER GUNNISON LATERALS	-2.196342E-07	6.534075E-02	128.47	7.22	174,600	232,700
LOWER GUNNISON ON-FARM	-3.506144E-07	1.157612E-01	146.53	8.64	250,000	333,000
UINTAH CANALS [4]	-1.114302E-07	2.081652E-02	686.58	46.60	119,700	181,300
UINTAH LATERALS	-4.588612E-07	4.888924E-02	196.10	25.30	62,250	101,400
UINTAH ON-FARM	-1.049461E-06	1.173295E-01	148.32	8.52	85,000	112,300
PRICE-SAN RAFAEL-MUDDY CREEK CANALS [1]	-1.027021E-07	1.896152E-02	205.99	52.58	62,000	89,900
PRICE-SAN RAFAEL-MUDDY CREEK LATERALS	-1.773487E-07	3.752731E-02	48.79	22.22	43,900	63,550
PRICE-SAN RAFAEL ON-FARM	-2.521342E-06	1.264985E-01	24.17	8.44	39,000	56,550
McELMO CREEK CANALS [4]	-4.794219E-07	1.739172E-02	635.33	20.26	21,100	31,560
McELMO CREEK LATERALS	-2.345824E-07	8.033428E-02	13.05	12.45	8,000	12,000
McELMO CREEK ON-FARM	-3.101057E-06	1.183872E-01	149.45	8.45	29,100	41,500
BIG SANDY ON-FARM	-1.676666E-06	1.171796E-01	216.10	8.53	56,000	77,200

[1] No winter water in canals, including an estimated annual salt load reduction of about 70,000 Mgm

[2] With winter water in canals

[3] Less than 0.4 m^3/s inlet capacity diverting directly from the rivers and streams

[4] Includes most of major laterals

measures such as canal and lateral linings. However, there will also be an inherent amount of salinity reduction on the farmers' fields as a result of the improved water application and the easier water deliveries due to a conveyance lining program, even if the farmers revert as much as possible to past practices. Analysis of the areawide programs under lower irrigation efficiencies still indicated that on-farm improvements would be the first priority, but very little would be done beyond head ditch linings. Desalination in the agricultural areas would be increased to make up the difference, and canal and lateral linings would not be affected.

The array of on-farm practices used in this report is intended to provide an indication of the types and extent of improvements which would have to be implemented. There must be an accompanying commitment from the government to assist the farmers and to encourage their continued use of improved water management practices including irrigation scheduling.

Grand Valley

Figure 23 illustrates the optimal cost-effective salinity control program for the Grand Valley in western Colorado. Table 8 presents the numerical data which is summarized in Figure 23. As can be seen only 64 percent of the canal linings, 100 percent of the lateral linings, and 83 percent of the on-farm salinity reduction should be implemented before desalination should take over the control practice. Table 4-1 in Appendix 4 presents the optimal canal lining

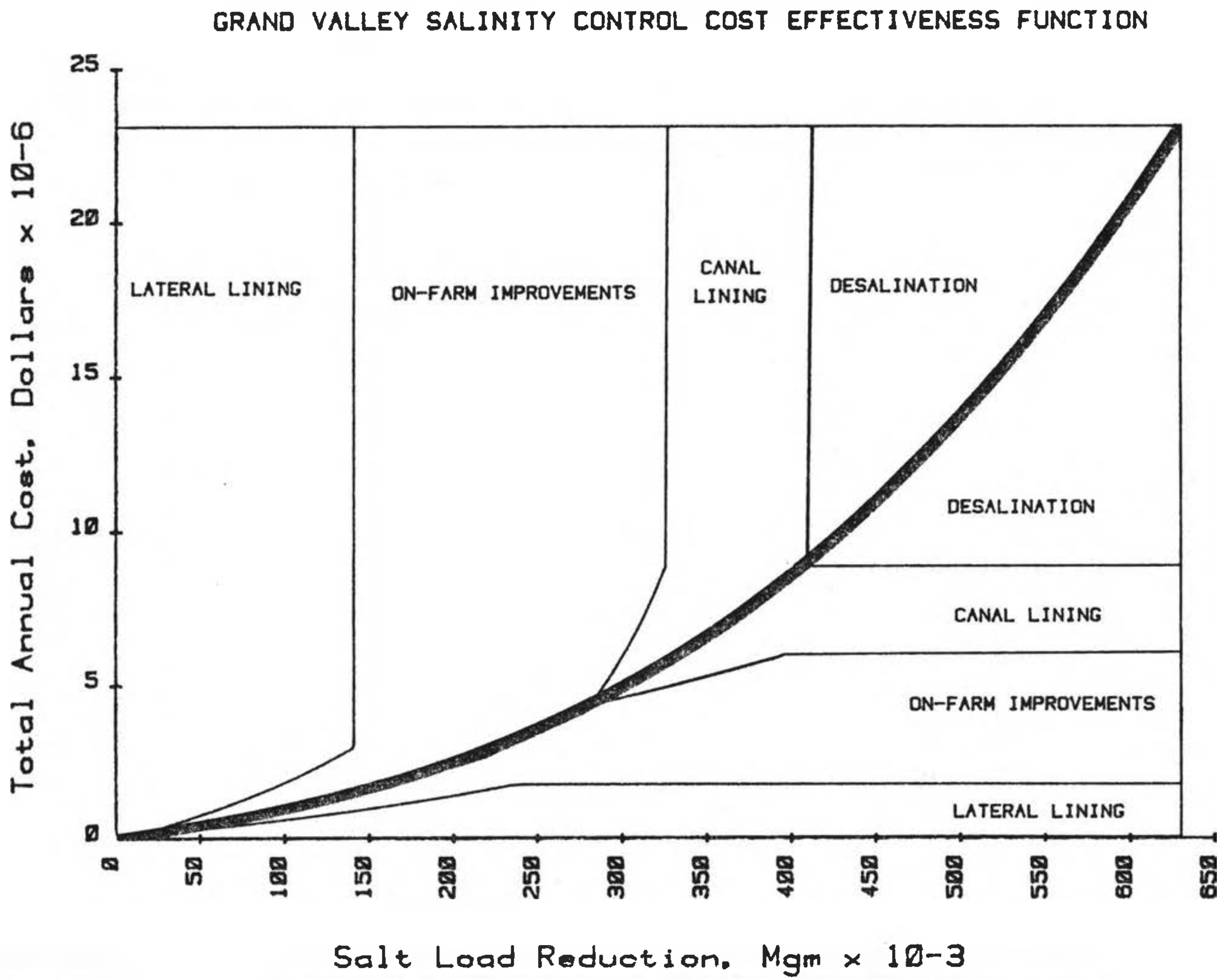


Figure 23. Optimal Grand Valley Salinity Control Program.

Table 8. Optimal Grand Valley Salinity Control Program.

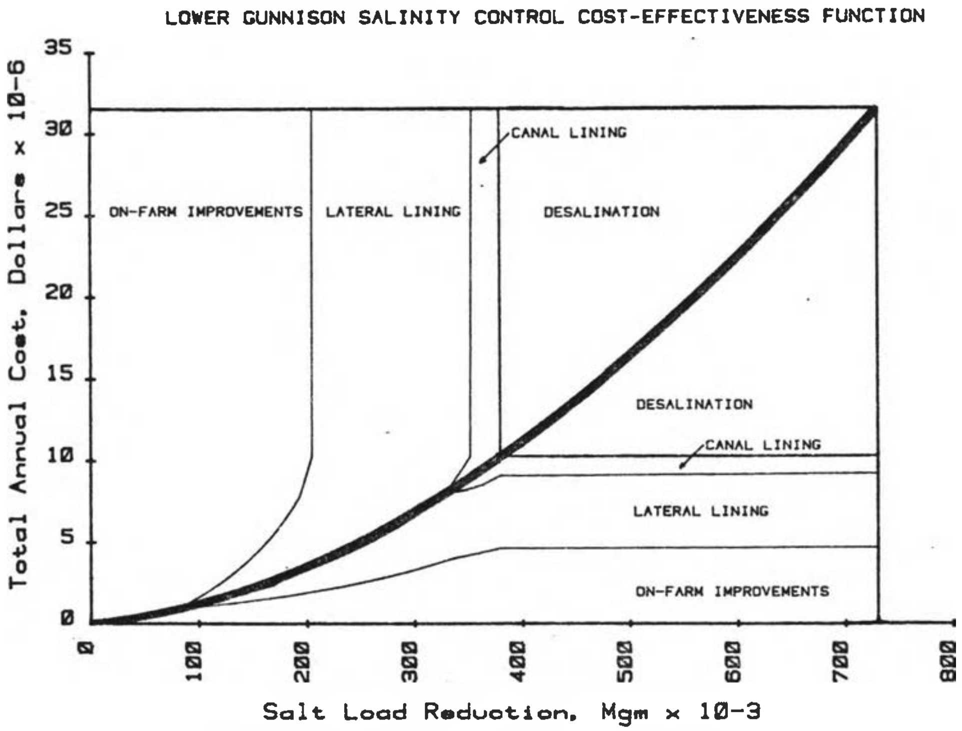
% Total Salt	Total Annual Cost	Average $/mg/l	Percent Attainable Reduction			
			Canal Lining	Lateral Lining	On-Farm Improvements	Desalination
5.44	305171	77179	0.00	17.01	4.58	0.00
11.00	651021	81640	0.00	31.41	11.12	0.00
15.78	980067	85700	0.00	43.81	16.75	0.00
19.96	1294544	89540	0.00	54.64	21.66	0.00
23.64	1596232	93208	0.00	64.20	26.00	0.00
26.93	1886574	96731	0.00	72.72	29.87	0.00
29.88	2166761	100128	0.00	80.37	33.34	0.00
32.56	2437791	103410	0.00	87.30	36.49	0.00
34.99	2700506	106591	0.00	93.61	39.36	0.00
37.22	2955627	109678	0.00	99.39	41.98	0.00
38.22	3075946	111164	0.00	100.00	44.39	0.00
39.02	3177533	112492	0.00	100.00	46.62	0.00
39.76	3276617	113844	0.00	100.00	48.69	0.00
40.44	3373376	115211	0.00	100.00	50.62	0.00
41.09	3467965	116589	0.00	100.00	52.42	0.00
41.69	3560525	117971	0.00	100.00	54.11	0.00
42.26	3651180	119354	0.00	100.00	55.70	0.00
42.79	3740043	120736	0.00	100.00	57.19	0.00
43.29	3827218	122114	0.00	100.00	58.60	0.00
44.23	3995948	124799	2.64	100.00	59.93	0.00
45.28	4191999	127879	6.08	100.00	61.20	0.00
46.28	4384704	130869	9.36	100.00	62.40	0.00
47.24	4574231	133777	12.47	100.00	63.54	0.00
48.14	4760730	136611	15.44	100.00	64.63	0.00
49.01	4944342	139377	18.27	100.00	65.67	0.00
49.83	5125198	142080	20.97	100.00	66.66	0.00
50.62	5303418	144724	23.56	100.00	67.61	0.00
51.38	5479114	147314	26.04	100.00	68.52	0.00
52.11	5652390	149854	28.42	100.00	69.39	0.00
52.81	5823343	152346	30.70	100.00	70.23	0.00
53.48	5992065	154793	32.90	100.00	71.04	0.00
54.12	6158641	157199	35.01	100.00	71.81	0.00
54.75	6323150	159565	37.05	100.00	72.56	0.00
55.35	6485668	161893	39.01	100.00	73.28	0.00
55.93	6646265	164185	40.90	100.00	73.98	0.00
56.48	6805008	166444	42.73	100.00	74.65	0.00
57.03	6961959	168670	44.50	100.00	75.30	0.00
57.55	7117179	170865	46.21	100.00	75.92	0.00
58.05	7270722	173031	47.87	100.00	76.53	0.00
58.54	7422642	175169	49.47	100.00	77.12	0.00
59.02	7572990	177279	51.02	100.00	77.69	0.00
59.48	7721813	179364	52.53	100.00	78.24	0.00
59.93	7869158	181424	53.99	100.00	78.78	0.00
60.36	8015066	183459	55.41	100.00	79.30	0.00
60.78	8159579	185472	56.79	100.00	79.81	0.00
61.19	8302737	187462	58.14	100.00	80.30	0.00
61.59	8444577	189430	59.44	100.00	80.78	0.00
61.98	8585134	191378	60.71	100.00	81.24	0.00
62.36	8724444	193306	61.95	100.00	81.70	0.00
62.72	8862537	195214	63.15	100.00	82.14	0.00
100.00	23098197	319180	64.32	100.00	82.57	100.00

program for the area. At the 64 percent level, the Government Highline Canal, the Orchard Mesa Power Canal, and the Redlands Power Canal are totally lined. Approximately 60 percent of the Grand Valley Mainline, the Grand Valley Highline, the Mesa County Ditch, and 67 percent of the combined Redlands ditches would be lined at this level. Whereas, 34 percent of Price ditch, 40 percent of the Orchard Mesa Canal and only 12 percent of the Keifer Extension are lined. The remaining canals are not improved. The on-farm program does not include sprinkle or trickle irrigation, but does include improvements up to that point.

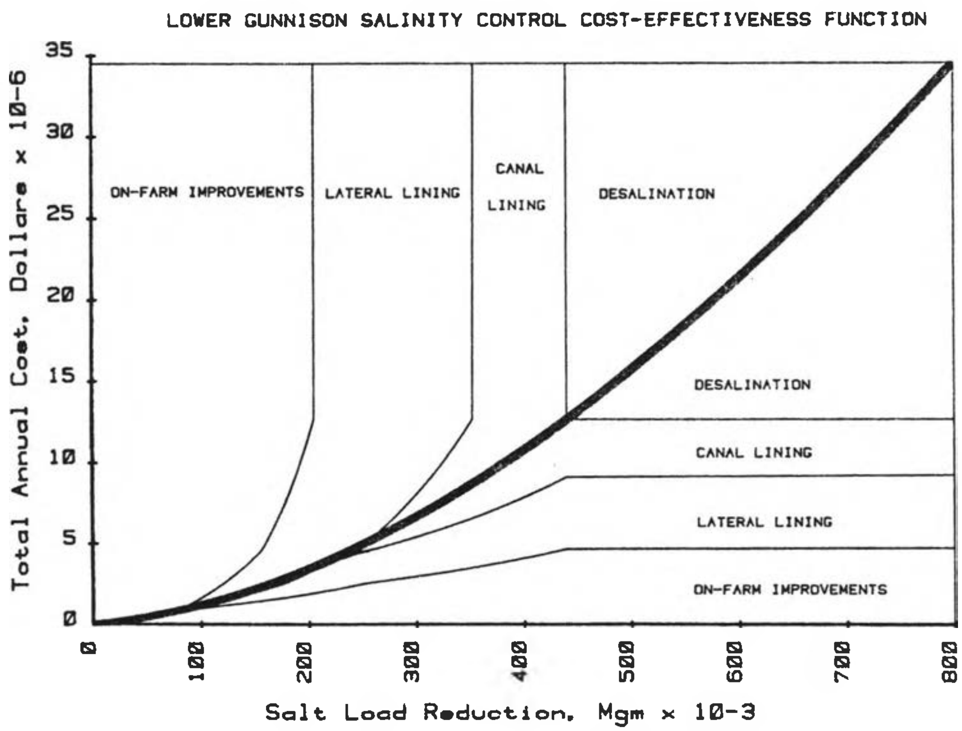
Lower Gunnison

The elimination of winter water from the canals in the Lower Gunnison region in western Colorado greatly reduces the importance of the canal lining program as can be seen by comparing parts a and b in Figure 24. The two canal lining programs shown in Figure 24 are intended to indicate the probable maximum and minimum extent of lining construction. The practice of winter livestock water via the canal system contributes at least 40,000 Mgm/yr up to an estimated maximum of 75,000 Mgm/yr. The actual case undoubtedly lies between the programs illustrated in Figure 22; however, this only affects the relative amount of canal linings.

The Lower Gunnison is the only area where the very small direct diversions from the rivers and streams were included. These ditches are quite small with less than a 0.4 m^3/sec capacity. These were treated as a separate item



(a) NO WINTER LIVESTOCK WATER



(b) WITH WINTER LIVESTOCK WATER

Figure 24. Optimal salinity control programs for the Lower Gunnison with and without winter water in the canals.

because their costs would be the same as laterals. However, the maximum salt load reduction from these small ditches was estimated at only 8,860 Mgm, and the small costs and salt contribution were not significant when plotted on the scale of Figure 22. Table 9 numerically presents the optimal salinity control program for the area.

The on-farm improvements do not include sprinklers or trickle although certain portions of the area do appear to offer substantial potential for gravity powered sprinklers in orchards and field crops. Essentially all of the laterals and only 20 percent of the canals should be lined. The cost-effective canal lining program is limited to Mancos Shale soil types. The total canal lining program can be found in Table 4-2 in Appendix 4. It should be mentioned that the Ironstone and M & D Canals were subjected to a partial Level D analysis for the Mancos and nonMancos shale areas.

The optimal salinity control program for the Uncompahgre Valley portion of the Lower Gunnison is included (Figure 25). At the present time, this is the only portion of the area which is being considered for improvement by the Water and Power Resources Service. PL 93-320 specified the Lower Gunnison as a potential salinity control project; however, the WPRS has apparently restricted their investigation to only the Uncompahgre River area. Stoppage of the winter water in this case also greatly diminishes the importance of canal lining for control in this area.

Table 9. Optimal Lower Gunnison Salinity Control Program.

% Total Salt	Total Annual Cost	Average $/mg/l	Percent Attainable Reduction Canal Lining	Lateral Lining	On-Farm Improvements	Small Canal Linings	Desalination
0.22	5745	28680	0.00	0.00	0.00	15.79	0.00
0.37	10858	33105	0.00	0.00	0.00	26.91	0.00
0.48	15511	36572	0.00	0.00	0.00	35.28	0.00
0.57	19810	39629	0.00	0.00	0.00	41.88	0.00
0.65	23824	42424	0.00	0.00	0.00	47.25	0.00
1.43	73919	60643	0.00	0.00	2.11	51.74	0.00
3.69	228698	73476	0.00	0.00	8.55	55.55	0.00
5.64	376157	79194	0.00	0.00	14.12	58.85	0.00
7.35	517247	83645	0.00	0.00	19.00	61.74	0.00
8.87	652727	87574	0.00	0.00	23.32	64.30	0.00
10.22	783219	91201	0.00	0.00	27.18	66.59	0.00
11.44	909234	94619	0.00	0.00	30.66	68.65	0.00
12.94	1075911	98999	0.00	1.66	33.81	70.52	0.00
15.13	1332793	104921	0.00	6.59	36.69	72.22	0.00
17.14	1582368	109997	0.00	11.12	39.32	73.78	0.00
18.99	1825228	114534	0.00	15.29	41.75	75.22	0.00
20.70	2061887	118699	0.00	19.15	44.00	76.55	0.00
22.29	2292797	122587	0.00	22.74	46.09	77.79	0.00
23.77	2518357	126262	0.00	26.08	48.03	78.94	0.00
25.16	2738923	129764	0.00	29.20	49.85	80.02	0.00
26.45	2954813	133123	0.00	32.13	51.56	81.03	0.00
27.68	3166312	136361	0.00	34.89	53.16	81.98	0.00
28.83	3373677	139493	0.00	37.49	54.68	82.88	0.00
29.91	3577143	142533	0.00	39.94	56.11	83.72	0.00
30.94	3776920	145491	0.00	42.26	57.46	84.52	0.00
31.92	3973203	148374	0.00	44.46	58.74	85.28	0.00
32.85	4166168	151189	0.00	46.56	59.96	86.00	0.00
33.73	4355979	153943	0.00	48.55	61.12	86.69	0.00
34.57	4542786	156639	0.00	50.44	62.22	87.35	0.00
35.38	4726726	159282	0.00	52.26	63.28	87.97	0.00
36.14	4907927	161875	0.00	53.99	64.29	88.57	0.00
36.88	5086509	164423	0.00	55.65	65.25	89.14	0.00
37.58	5262582	166926	0.00	57.24	66.18	89.69	0.00
38.26	5436249	169389	0.00	58.76	67.07	90.22	0.00
38.91	5607605	171813	0.00	60.23	67.92	90.72	0.00
39.53	5776741	174200	0.00	61.64	68.74	91.21	0.00
40.14	5943740	176553	0.00	62.99	69.53	91.68	0.00
40.71	6108683	178872	0.00	64.30	70.29	92.13	0.00
41.27	6271642	181159	0.00	65.56	71.03	92.56	0.00
41.81	6432688	183416	0.00	66.78	71.73	92.98	0.00
42.33	6591886	185644	0.00	67.95	72.42	93.39	0.00
42.84	6749300	187844	0.00	69.09	73.08	93.78	0.00
43.32	6904987	190017	0.00	70.18	73.72	94.16	0.00
43.80	7059003	192164	0.00	71.25	74.34	94.52	0.00
44.25	7211400	194287	0.00	72.28	74.94	94.88	0.00
44.70	7362230	196386	0.00	73.28	75.52	95.22	0.00
45.13	7511538	198461	0.00	74.25	76.09	95.56	0.00
45.54	7659371	200515	0.00	75.19	76.63	95.88	0.00
46.02	7831920	202908	0.49	76.10	77.17	96.20	0.00
46.69	8078836	206382	2.40	76.99	77.68	96.50	0.00
47.34	8323449	209624	4.25	77.85	78.19	96.80	0.00
47.98	8565821	212878	6.04	78.69	78.67	97.09	0.00
48.59	8806013	216070	7.80	79.51	79.15	97.37	0.00
49.19	9044082	219203	9.50	80.31	79.61	97.65	0.00
49.78	9280085	222280	11.16	81.08	80.07	97.92	0.00
50.35	9514074	225304	12.78	81.84	80.51	98.18	0.00
50.91	9746099	228278	14.36	82.57	80.93	98.43	0.00
51.45	9976209	231204	15.90	83.29	81.35	98.68	0.00
51.98	10204451	234086	17.40	83.99	81.76	98.92	0.00
52.49	10430870	236925	18.87	84.68	82.16	99.16	0.00
100.00	31454714	375126	20.30	85.35	82.55	99.39	100.00

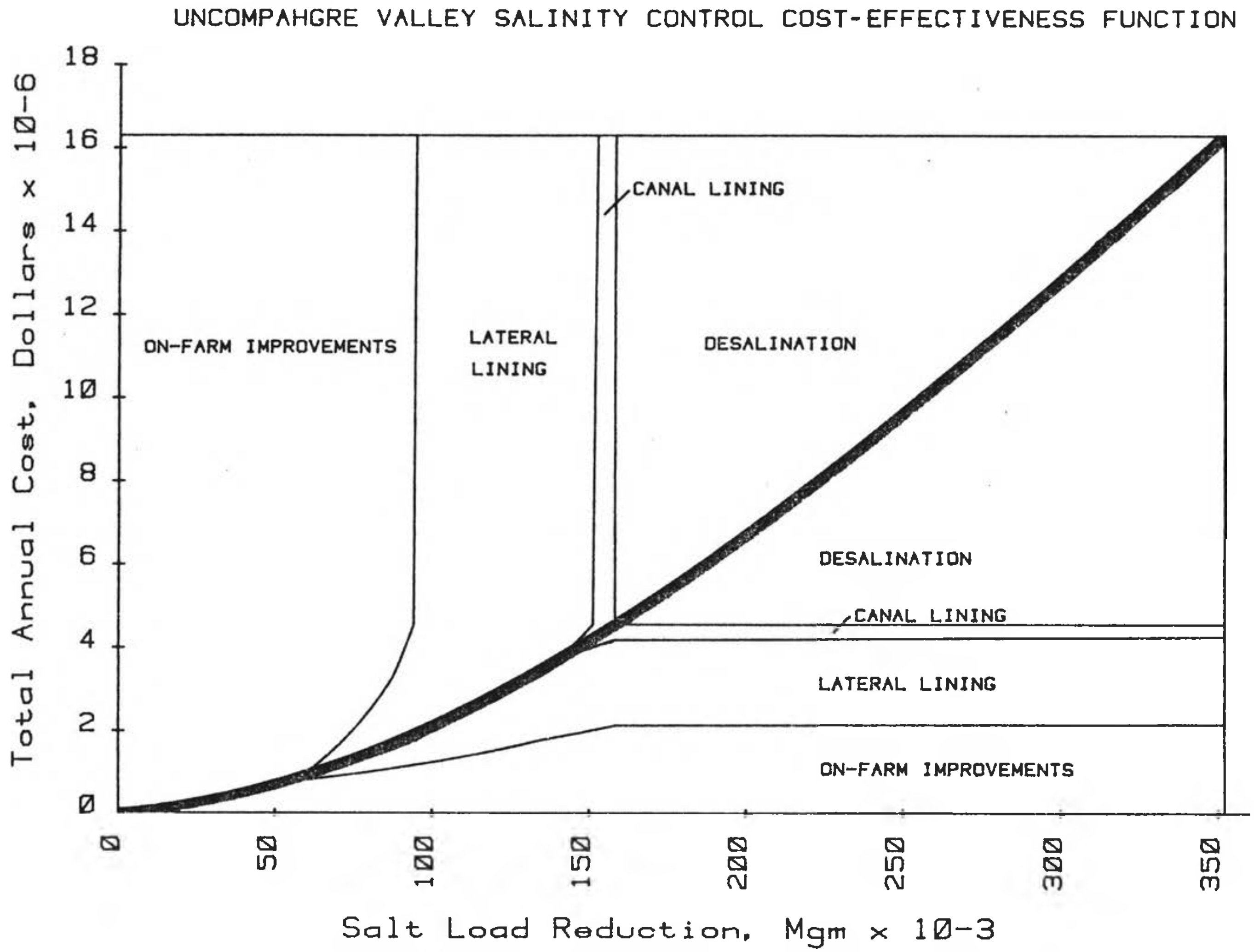


Figure 25. Optimal salinity control program for the Uncompahgre Valley with no winter livestock water in the canals.

Uintah Basin

Figure 26 presents the optimal salinity control strategy for the Uintah Basin including the Ashley Creek and Brush Creek drainages. The canal lining which is indicated on the graph and in Table 10 is basically the canal lining to be done under the Central Utah Project and little more needs to be done. Most of the remaining canal lining will be in the Ashley Valley. This analysis did not consider the consolidation of several of the canals in the Ashley Valley near Vernal, Utah, which is being proposed by the Water and Power Resources Service. The optimal canal lining program for the area can be found in Table 4-3 in Appendix 4.

The Uintah Basin is expected to lose a considerable amount of its water to energy and related development in the area because of its proximity to oil shale, coal and tar sands deposits. The effect or the quality of this depletion cannot be determined at this time.

Price-San Rafael-Muddy Creek Drainages

Figure 27 illustrates the optimal cost-effective salinity control program for this area. The crescent-shaped band of irrigation development is located almost entirely in Mancos Shales and has operation and irrigation characteristics similar to the Lower Gunnison of Colorado. The canals in this region are also used for winter livestock water and elimination of this practice will reduce an estimated 30,000 Mgm of salt per year to the Colorado River. Table 4-4

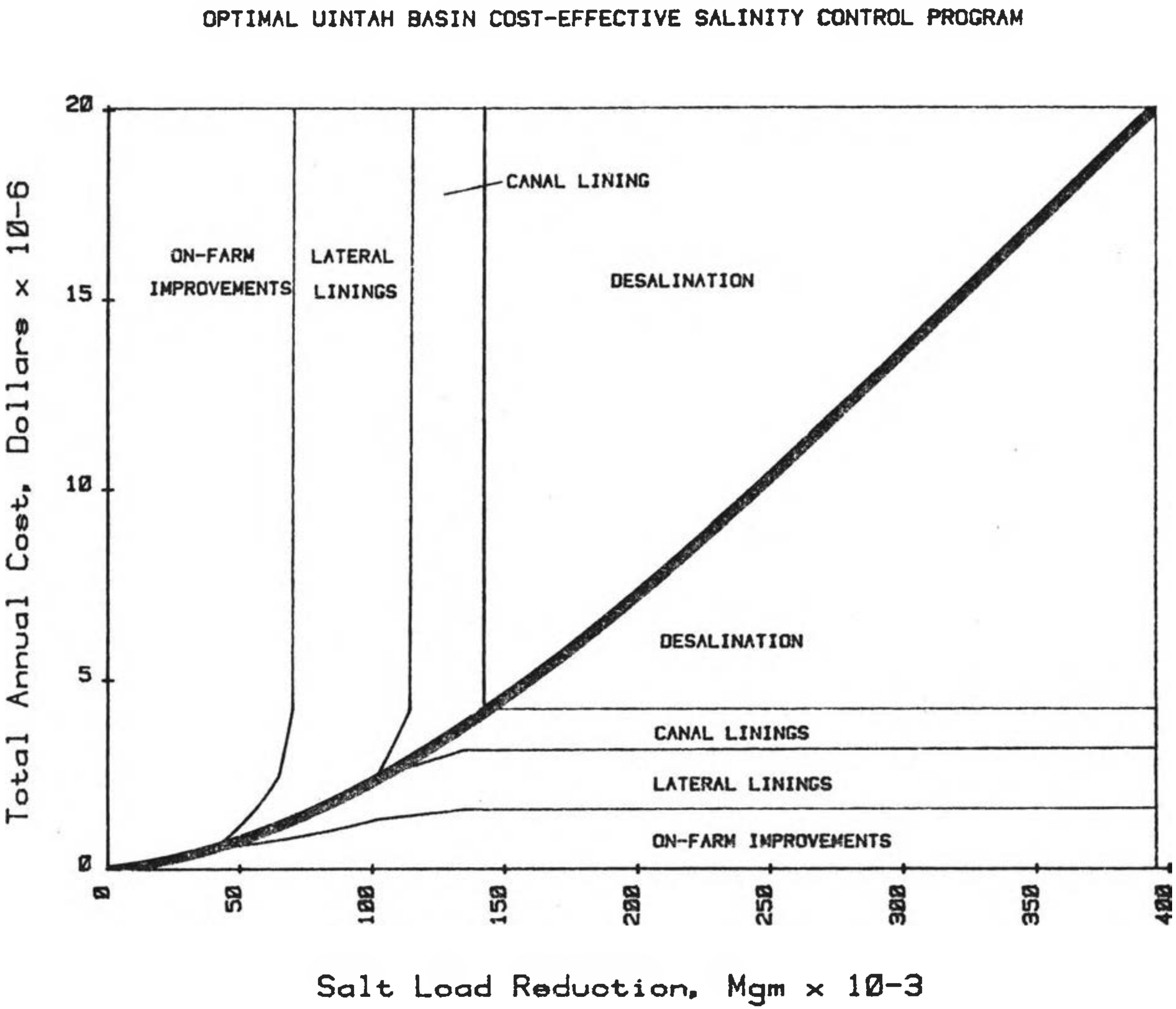


Figure 26. Optimal Uintah Basin Salinity Control Program.

Table 10. Optimal Uintah Basin Salinity Control Program.

% Total Salt	Total Annual Cost	Average $/mg/l	Percent Attainable Reduction			
			Canal Lining	Lateral Lining	On-Farm Improvements	Desalination
1.40	49495	75808	0.00	0.00	6.49	0.00
2.61	96658	80457	0.00	0.00	12.10	0.00
3.67	141791	84301	0.00	0.00	17.02	0.00
4.60	185135	87841	0.00	0.00	21.37	0.00
5.44	226888	91190	0.00	0.00	25.27	0.00
6.20	267213	94394	0.00	0.00	28.77	0.00
6.88	306247	97479	0.00	0.00	31.95	0.00
7.51	344107	100461	0.00	0.00	34.86	0.00
8.08	380893	103350	0.00	0.00	37.52	0.00
8.61	416691	106158	0.00	0.00	39.97	0.00
9.10	451576	108890	0.08	0.00	42.24	0.00
9.56	485616	111554	0.00	0.00	44.35	0.00
9.98	518869	114153	0.00	0.00	46.32	0.00
10.88	592882	119685	0.00	3.20	48.16	0.00
11.80	671704	125061	0.00	6.68	49.88	0.00
12.66	748925	129945	0.00	9.95	51.50	0.00
13.48	824639	134453	0.00	13.04	53.03	0.00
14.25	898931	138666	0.00	15.95	54.47	0.00
14.98	971879	142640	0.00	18.71	55.84	0.00
15.67	1043553	146417	0.60	21.33	57.14	0.00
16.33	1114017	150028	0.00	23.81	58.37	0.00
16.95	1183330	153496	0.00	26.18	59.54	0.00
17.55	1251548	156841	0.00	28.43	60.66	0.00
18.12	1318721	160078	0.00	30.59	61.73	0.00
18.66	1384894	163218	0.00	32.65	62.75	0.00
19.18	1450112	166273	0.00	34.62	63.72	0.00
19.68	1514415	169249	0.00	36.51	64.66	0.00
20.16	1577840	172154	0.00	38.32	65.56	0.00
20.62	1640422	174994	0.00	40.06	66.42	0.00
21.07	1702194	177775	0.00	41.74	67.25	0.00
21.49	1763187	180500	0.00	43.35	68.05	0.00
21.90	1823429	183174	0.00	44.90	68.82	0.00
22.30	1882947	185800	0.00	46.40	69.56	0.00
22.68	1941768	188380	0.00	47.85	70.28	0.00
23.05	1999914	190918	0.00	49.25	70.97	0.00
23.41	2057409	193417	0.00	50.60	71.64	0.00
23.75	2114273	195877	0.00	51.90	72.29	0.00
24.09	2170528	198302	0.00	53.17	72.91	0.00
24.41	2226193	200693	0.00	54.39	73.52	0.00
24.73	2281285	203051	0.00	55.58	74.11	0.00
25.03	2335822	205379	0.00	56.74	74.68	0.00
25.33	2389820	207677	0.00	57.85	75.24	0.00
25.61	2443296	209946	0.00	58.94	75.77	0.00
26.12	2538593	213955	0.73	60.00	76.30	0.00
26.82	2675127	219535	2.17	61.02	76.81	0.00
27.51	2810412	224886	3.56	62.02	77.30	0.00
28.18	2944181	230031	4.92	62.99	77.78	0.00
28.83	3077366	234991	6.25	63.94	78.25	0.00
29.46	3209098	239782	7.54	64.86	78.71	0.00
30.08	3339706	244420	8.79	65.76	79.15	0.00
30.68	3469220	248917	10.02	66.64	79.59	0.00
31.27	3597665	253286	11.21	67.49	80.01	0.00
31.85	3725069	257537	12.38	68.33	80.43	0.00
32.41	3851455	261678	13.52	69.14	80.83	0.00
32.95	3976848	265717	14.63	69.94	81.22	0.00
33.49	4101271	269662	15.71	70.71	81.61	0.00
34.01	4224746	273520	16.77	71.47	81.98	0.00
100.00	20026499	441305	17.81	72.22	82.35	100.00

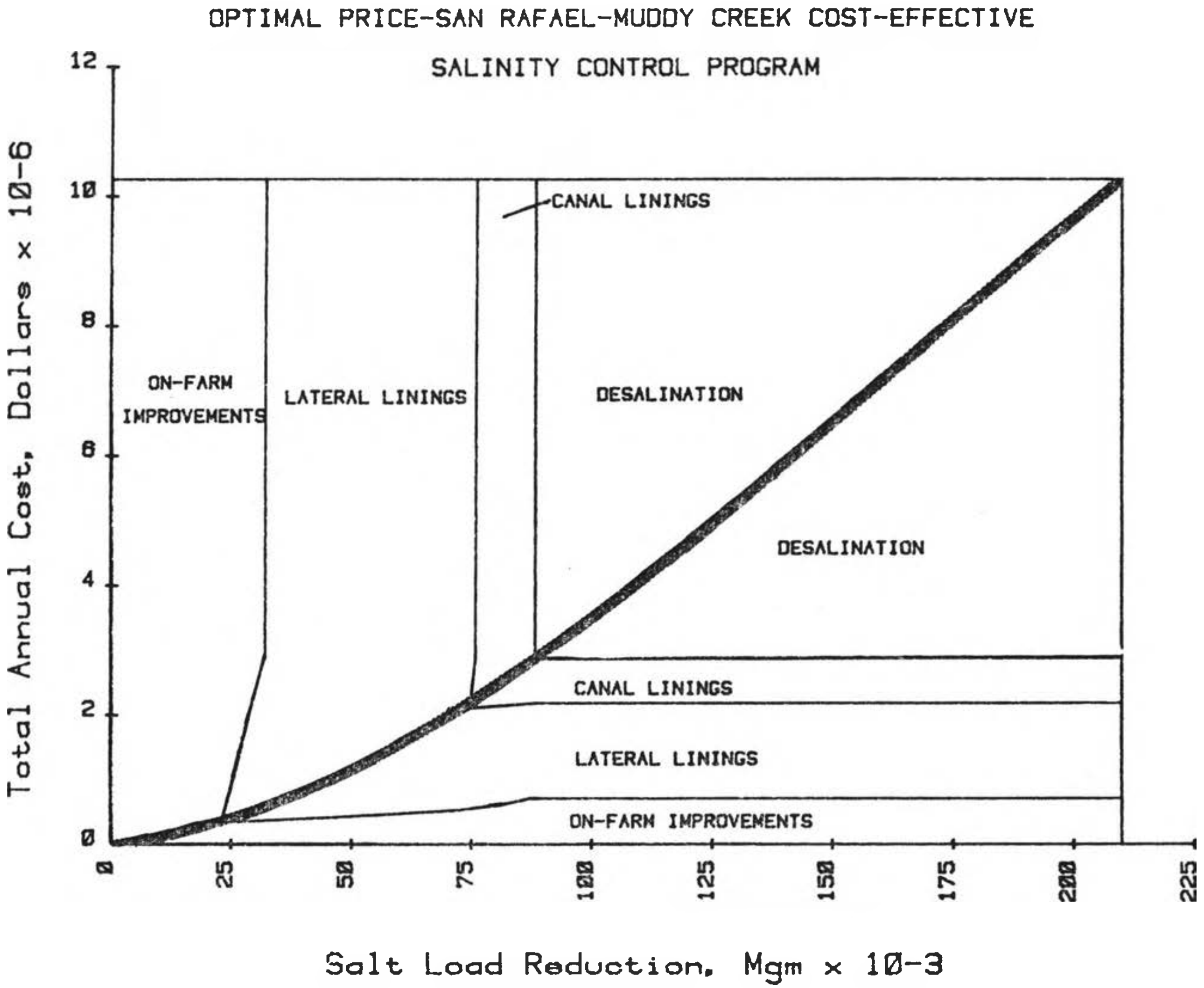


Figure 27. Optimal salinity control program for the Price River-San Rafael River and Muddy Creek Drainages without winter livestock water in the canals.

in Appendix 4 tabulates the total optimal canal lining for this area.

It is expected that much of the area's agricultural water rights will be transferred to energy related users. Some transfers have already taken place to supply cooling water for fossil fuel thermal-electric generation facilities. In addition, there is a large coal slurry pipeline proposed for the Muddy Creek drainage which will require substantial amounts of water.

Table 11 presents the data which have been plotted in Figure 25. One hundred percent of laterals in the area should be lined under existing conditions. The on-farm program includes the improvement of existing surface irrigation systems to their maximum attainable irrigation efficiency. Sprinklers were not included in the optimal array of on-farm improvements for this area.

McElmo Creek

The very small amount of available data for the McElmo Creek area in southwestern Colorado introduced substantial uncertainty into this analysis. Fortunately, the total salt contribution is relatively small. The completion of the Dolores Project will cause an increase salt loading from the area. The Water and Power Resource Service's report on the Dolores Project did not assume any additional salt loading from the presently irrigated lands. In addition, there are only 4.8 Mgm per hectare from the new lands which is a very low value considering the saline nature of the soils.

Table 11. Optimal Price-San Rafael-Muddy Creek Drainages Salinity Control Program.

% Total Salt	Total Annual Cost	Average $/mg/l	Percent Attainable Reduction: Canal Lining	Lateral Lining	On-Farm Improvements	Desalination
1.25	21806	68314	0.00	0.00	6.70	0.00
2.31	42530	73718	0.00	0.00	12.46	0.00
3.24	62320	77772	0.00	0.00	17.47	0.00
4.06	81290	81375	0.00	0.00	21.88	0.00
4.79	99536	84726	0.00	0.00	25.81	0.00
5.45	117134	87901	0.00	0.00	29.33	0.00
6.04	134150	90939	0.00	0.00	32.51	0.00
6.58	150636	93862	0.00	0.00	35.41	0.00
7.07	166640	96686	0.00	0.00	38.06	0.00
7.52	182201	99423	0.00	0.00	40.49	0.00
7.94	197356	102082	0.00	0.00	42.74	0.00
8.33	212132	104669	0.00	0.00	44.83	0.00
8.69	226559	107191	0.00	0.00	46.77	0.00
9.02	240659	109653	0.00	0.00	48.58	0.00
9.34	254454	112059	0.00	0.00	50.28	0.00
9.63	267963	114414	0.00	0.00	51.87	0.00
9.91	281202	116719	0.00	0.00	53.37	0.00
10.17	294188	118980	0.00	0.00	54.78	0.00
10.42	306934	121197	0.00	0.00	56.12	0.00
10.66	319453	123374	0.00	0.00	57.39	0.00
10.91	333256	125773	0.00	0.13	58.59	0.00
12.77	439048	141725	0.00	8.01	59.74	0.00
14.54	543139	154088	0.00	15.52	60.83	0.00
16.23	645608	164187	0.00	22.68	61.87	0.00
17.84	746530	172757	0.00	29.53	62.86	0.00
19.38	845971	180242	0.00	36.08	63.81	0.00
20.86	943995	186926	0.00	42.35	64.72	0.00
22.28	1040662	192999	0.00	48.36	65.60	0.00
23.64	1136025	198593	0.00	54.14	66.44	0.00
24.95	1230138	203803	0.00	59.69	67.24	0.00
26.21	1323046	208699	0.00	65.02	68.02	0.00
27.42	1414796	213332	0.00	70.17	68.76	0.00
28.59	1505430	217745	0.00	75.12	69.48	0.00
29.72	1594987	221969	0.00	79.91	70.18	0.00
30.81	1683505	226029	0.00	84.52	70.85	0.00
31.86	1771019	229945	0.00	88.99	71.50	0.00
32.88	1857563	233735	0.00	93.30	72.12	0.00
33.86	1943169	237412	0.00	97.48	72.73	0.00
34.50	1999412	239795	0.00	100.00	73.32	0.00
34.60	2008999	240210	0.00	100.00	73.89	0.00
34.70	2018487	240633	0.00	100.00	74.44	0.00
34.80	2027881	241064	0.00	100.00	74.97	0.00
34.90	2037183	241501	0.00	100.00	75.49	0.00
34.99	2046396	241944	0.00	100.00	76.00	0.00
35.09	2055522	242392	0.00	100.00	76.49	0.00
35.17	2064563	242846	0.00	100.00	76.97	0.00
35.26	2073523	243304	0.00	100.00	77.43	0.00
35.34	2082403	243767	0.00	100.00	77.88	0.00
35.43	2091205	244233	0.00	100.00	78.33	0.00
35.51	2099931	244702	0.00	100.00	78.75	0.00
36.18	2174600	248722	2.01	100.00	79.17	0.00
36.97	2264735	253464	4.45	100.00	79.58	0.00
37.75	2354133	258058	6.83	100.00	79.98	0.00
38.51	2442811	262516	9.15	100.00	80.37	0.00
39.25	2530787	266850	11.42	100.00	80.75	0.00
39.97	2618076	271069	13.64	100.00	81.12	0.00
40.68	2704695	275181	15.80	100.00	81.48	0.00
41.37	2790658	279195	17.92	100.00	81.83	0.00
42.04	2875981	283118	19.99	100.00	82.18	0.00
100.00	10254520	424881	22.01	100.00	82.52	100.00

Figure 28 presents the optimal salinity control program for the presently irrigated lands in the McElmo Creek drainage. This analysis assumed a longer seasonal water availability than has been the past practice because of the construction of the Dolores Project. Table 12 indicates the optimal strategy for each individual alternative. There is basically no canal lining included in this program; however, the total canal and major lateral lining program is delineated in Table 4-5 in Appendix 4.

Big Sandy River

Based almost entirely on costs furnished by the USDA, SCS (1980a) and updated to January, 1980 prices, the optimal strategy for the Big Sandy area in Wyoming was found to consist of only a small amount of on-farm improvements and utilizing the Sublette Flats evaporation area. Figure 29 presents the optimal salinity control strategy which includes only these two alternatives.

Sublette Flats is a large natural depression which would be used as an evaporation area for saline groundwater to be collected by a series of barrier wells. The on-farm improvements consist only of head ditch linings or gated pipe. Canal and lateral lining were not included in the analysis since most of these have already been lined by compacted earth methods.

The Sublette Flats and barrier well alternatives were assumed to be linear functions with marginal costs of \$11.55/Mgm per year. The "buy-out" alternative which has

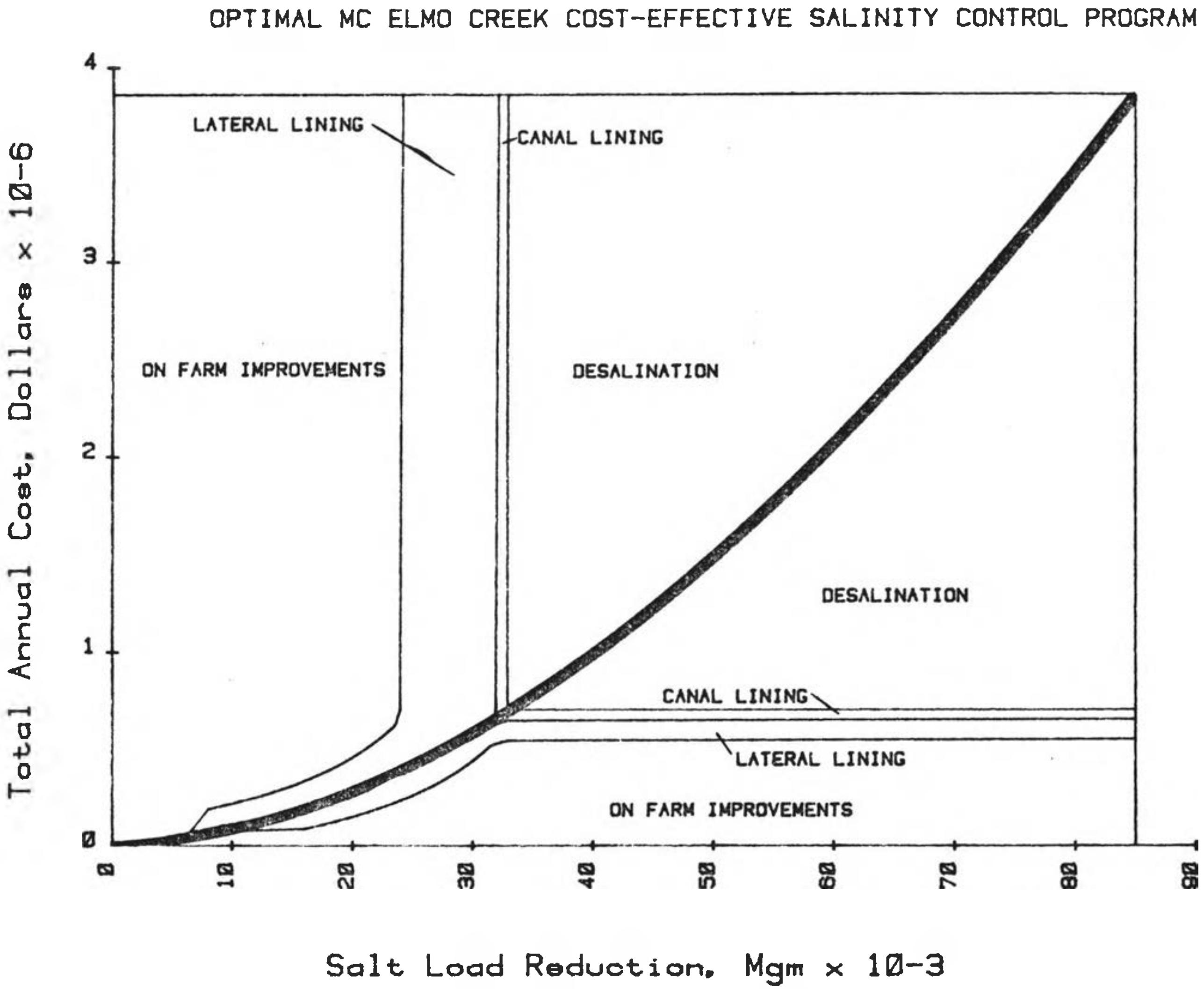


Figure 28. Optimal salinity control program for McElmo Creek.

Table 12. Optimal McElmo Creek Salinity Control Program.

% Total Salt	Total Annual Cost	Average $/mg/l	Percent Attainable Reduction			
			Canal Lining	Lateral Lining	On-Farm Improvements	Desalination
3.04	23430	74169	0.00	0.00	8.89	0.00
5.54	45370	81064	0.00	0.00	16.18	0.00
7.64	66073	86430	0.00	0.00	22.31	0.00
18.84	187694	100999	0.00	100.00	27.55	0.00
20.40	206445	102684	0.00	100.00	32.10	0.00
21.77	224407	104659	0.00	100.00	36.10	0.00
22.99	241670	106799	0.00	100.00	39.66	0.00
24.08	258312	109030	0.00	100.00	42.84	0.00
25.06	274395	111311	0.00	100.00	45.71	0.00
25.95	289971	113612	0.00	100.00	48.32	0.00
26.77	305085	115917	0.00	100.00	50.70	0.00
27.52	319777	118214	0.00	100.00	52.89	0.00
28.21	334080	120495	0.00	100.00	54.91	0.00
28.85	348023	122756	0.00	100.00	56.78	0.00
29.45	361633	124993	0.00	100.00	58.52	0.00
30.00	374931	127205	0.00	100.00	60.14	0.00
30.52	387939	129390	0.00	100.00	61.66	0.00
31.01	400674	131547	0.00	100.00	63.09	0.00
31.47	413154	133678	0.00	100.00	64.43	0.00
31.90	425392	135780	0.00	100.00	65.69	0.00
32.31	437403	137856	0.00	100.00	66.89	0.00
32.70	449198	139904	0.00	100.00	68.02	0.00
33.07	460789	141927	0.00	100.00	69.10	0.00
33.42	472187	143924	0.00	100.00	70.12	0.00
33.75	483400	145896	0.00	100.00	71.09	0.00
34.07	494437	147843	0.00	100.00	72.02	0.00
34.37	505306	149767	0.00	100.00	72.90	0.00
34.66	516014	151668	0.00	100.00	73.75	0.00
34.94	526570	153546	0.00	100.00	74.56	0.00
35.20	536978	155403	0.00	100.00	75.34	0.00
35.46	547245	157239	0.00	100.00	76.09	0.00
35.71	557377	159054	0.00	100.00	76.81	0.00
35.94	567378	160849	0.00	100.00	77.50	0.00
36.17	577254	162624	0.00	100.00	78.16	0.00
36.39	587009	164381	0.00	100.00	78.80	0.00
36.60	596648	166120	0.00	100.00	79.42	0.00
36.81	606174	167840	0.00	100.00	80.02	0.00
37.00	615592	169544	0.00	100.00	80.59	0.00
37.40	634995	173044	0.83	100.00	81.15	0.00
38.04	667043	178723	2.68	100.00	81.69	0.00
38.66	698750	184221	4.47	100.00	82.21	0.00
100.00	3859549	394628	6.20	100.00	82.72	100.00

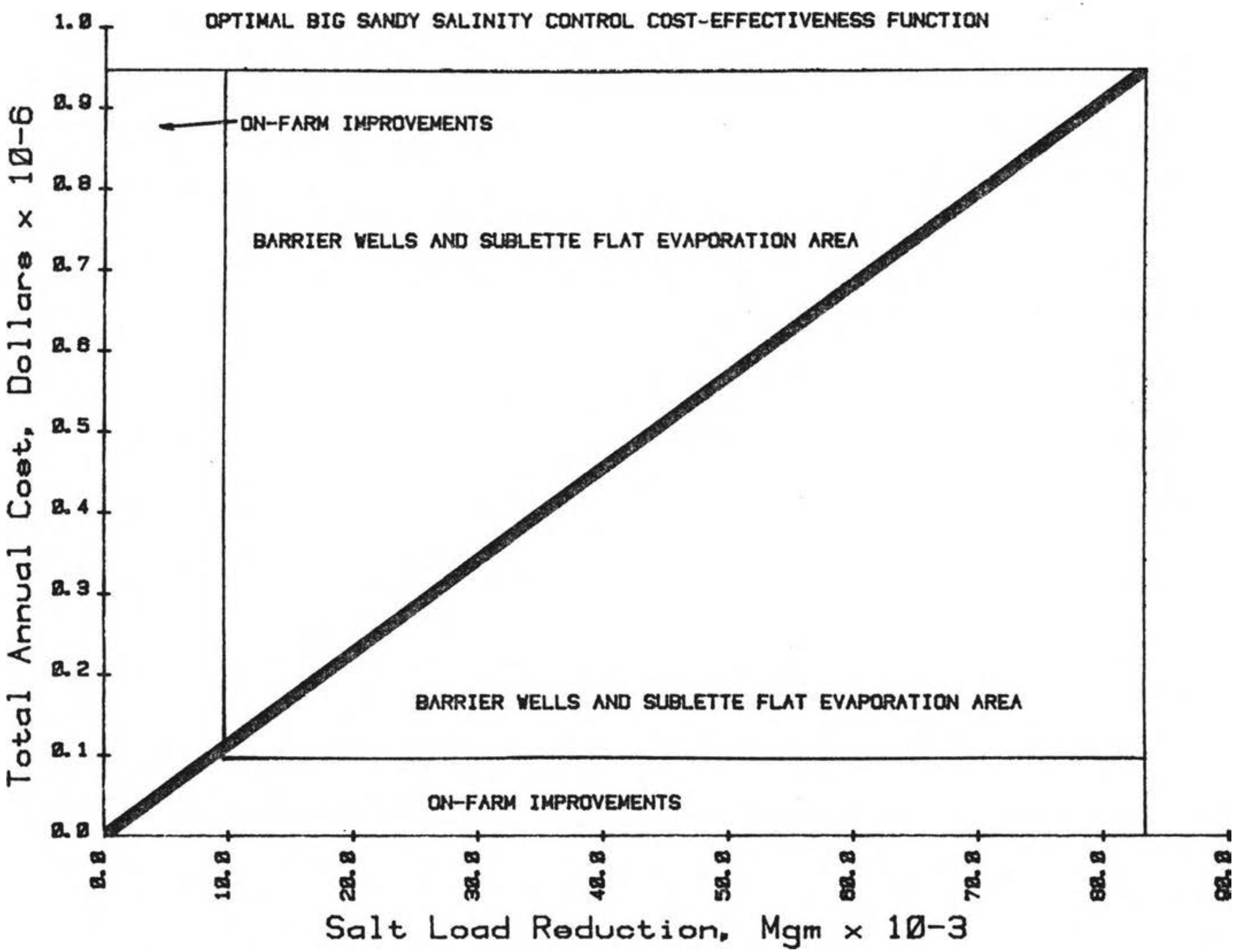


Figure 29. Optimal Big Sandy salinity control program.

been proposed by some local landowners to remove the irrigation water from the land (See Appendix 2) was not as feasible as the well field-evaporation pond alternative. This is particularly evident if the remaining repayment requirements for the existing Bureau of Reclamation project are superimposed on the "buy out" proposal. Therefore, the "landowner" preferred alternative was not considered.

Point Source Salinity Control Projects

Desalination costs were assumed to be linear with a system of barrier wells to intercept the saline groundwater and evaporation ponds for disposal. A marginal cost of $60.62/Mgm was used for all of the agricultural areas. Glenwood-Dotsero Springs had a marginal desalting cost with evaporation ponds of $57.40/Mgm. The Paradox By-pass was also assumed linear with a marginal cost of $32.71/Mgm.

IMPORTANCE OF AGRICULTURAL DESALINATION

Desalination of agricultural return flows presents many environmental and institutional concerns. Environmentally there is a problem of brine disposal, and institutionally or politically this may not be an acceptable alternative.

Reverse osmosis desalting was included as an agricultural salinity control alternative because it permits a much higher level of control from a relatively small area. For example, in the Lower Gunnison, desalination could potentially reduce the area salt load by an additional 20 mg/l over a total agricultural control program consisting of canal and lateral linings and on-farm improvements. The totally agricultural control program had an estimated total average annual cost of about $420,000 per mg/l reduction at Imperial Dam compared with $375,000 per mg/l for a total program which includes desalination.

Figure 30 illustrates the cost differential and the attainable salinity control levels for agricultural salinity control programs in the Upper Colorado River Basin. However, the graph only includes desalination for the Glenwood-Dotsero Springs Project.

"SAVED" WATER

Historically, in the Upper Colorado River Basin, water rights claims and potential irrigated acreage exceed the water supply. However, the irrigation of lands higher in the drainage tend to stabilize the streamflows by the time lag induced by subsurface return flows. The returns and seepage losses are rediverted and applied to other lands. Hence, water "saved" by improved water management practices is thereby utilized to augment the application to lower lands instead of augmenting the river flow below the project area. If the river diversions are reduced by irrigation system improvements, under the prior appropriations doctrine governing the water laws in the states of UCRB the saved water could be used to satisfy the water rights of more junior appropriators either upstream or downstream. In this case, the water cannot be used for new land, but may be

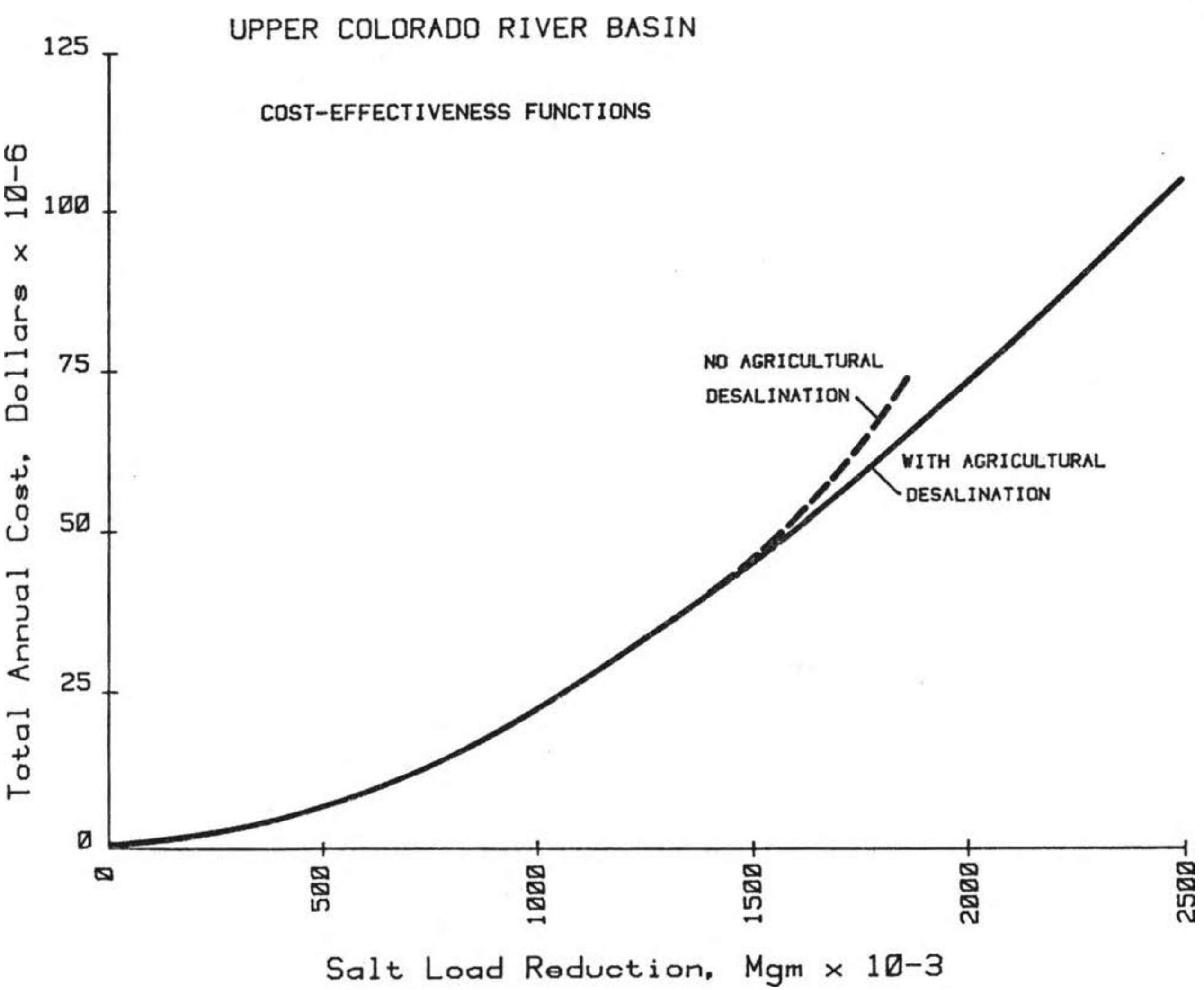


Figure 30. Effect and cost of desalination for agricultural salinity control.

applied to existing land for longer periods each year. It is possible that little salinity reduction would result.

The major effect of "saved" water would be in the downstream direction. In the Upper Colorado Rivers there are very few areas which are spatially sequenced to receive return flows from other upstream areas. Although almost every individual area has a very well-developed capacity to internally capture return flows from higher lands. There are essentially no large salinity contributing areas where the return flows would affect other irrigated areas in the Upper Basin. The use of this water in the upstream direction is unlikely without legal processes. Under the present water rights system, increased upstream river diversions would actually be equivalent to a new project. The expected result is that even though diversion requirements would be less, the diversion will continue at approximately historical levels and the "excess" water returned directly to the stream with very little salinity impact.

Improved practices do improve water quality and affect the time distribution of the natural stream flows. However, improved irrigation practices will generally not result in more water being available in the river for fishery enhancement and recreational uses. In some cases, improved irrigation practices and reduced return flows may actually damage a downstream water right. This would result because of a change in the temporal distribution of stream flows, which could actually cause less water to be available late in the season when crop water demands are the highest.

AGGREGATE SALINITY CONTROL PROGRAMS

To date there have not been analyses made of salinity control projects in which the most cost-effective strategies and alternatives for implementation in an areawide or basin-wide program were identified. The preceding discussion illustrated the areawide approach, and the following discussion demonstrates the next optimized level of the analysis which is a basin-wide cost-effective salinity control program.

Table 13 presents the most cost-effective salinity control program by alternative in each area for the Upper Colorado River Basin. Figure 31 illustrates the results of this basin-wide level of optimized salinity control by alternative and Figure 32 indicates the individual states which contain projects that were included in PL 93-320. As can be seen, on-farm improvements and lateral lining constitute the largest portion of the program. The state of Colorado contains the largest and the most designated salinity projects and would have most of the construction.

Utilizing the values for remaining unused Colorado River Compact water which were presented in Table 14, it is estimated that if this remaining water were totally consumed (no salt loading only concentrating effect), Colorado would contribute about 97 mg/l at Imperial Dam while Utah would contribute about 54 mg/l, New Mexico 26 mg/l, and Wyoming

Table 13. Optimal Upper Colorado River Basin Salinity Control Program.

% Total Salt	Total Annual Cost	Average $/mg/l	GRAND VALLEY Canal Lining	GRAND VALLEY Lateral Lining	GRAND VALLEY On-Farm Improvements	GRAND VALLEY Desalination	LOWER GUNNISON Canal Lining	LOWER GUNNISON Lateral Lining	LOWER GUNNISON On-Farm Improvements	LOWER GUNNISON Small Canal Lining	LOWER GUNNISON Desalination	UINTAH BASIN Canal Lining	UINTAH BASIN Lateral Lining	UINTAH BASIN On-Farm Improvements	UINTAH BASIN Desalination
0.08	9466	36125	0.00	0.00	0.00	0.00	0.00	0.00	0.00	23.89	0.00	0.00	0.00	0.00	0.00
0.13	17437	42905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	38.07	0.00	0.00	0.00	0.00	0.00
2.02	445617	74292	0.00	13.84	3.14	0.00	0.00	0.00	3.87	47.73	0.00	0.00	0.00	4.71	0.00
6.38	1570311	83290	0.00	38.81	14.48	0.00	0.00	0.00	15.08	54.85	0.00	0.00	0.00	15.78	0.00
12.87	3521815	92929	0.00	58.20	23.28	0.00	0.00	0.00	23.79	60.38	0.00	0.00	0.00	24.39	0.00
15.50	4466856	97501	0.00	73.82	30.37	0.00	0.00	0.00	30.80	64.84	0.00	0.00	0.00	31.31	0.00
18.08	5502102	103007	0.00	86.75	36.24	0.00	0.00	6.45	36.60	68.53	0.00	0.00	0.00	37.05	0.00
20.45	6568146	108675	0.00	97.69	41.20	0.00	0.00	14.88	41.51	71.64	0.00	0.00	0.00	41.90	0.00
22.11	7387111	113071	0.00	100.00	45.47	0.00	0.00	22.13	45.74	74.33	0.00	0.00	0.00	46.07	0.00
23.60	8195474	117540	0.00	100.00	49.20	0.00	0.00	28.46	49.42	76.67	0.00	0.00	6.33	49.71	0.00
24.93	8982973	121945	0.00	100.00	52.48	0.00	0.00	34.03	52.67	78.73	0.00	0.00	12.81	52.92	0.00
26.12	9740676	126220	0.00	100.00	55.41	0.00	0.00	39.00	55.56	80.57	0.00	0.00	18.58	55.78	0.00
27.33	10569627	130913	0.00	100.00	58.03	0.00	0.00	43.46	58.16	82.22	0.00	0.00	23.76	58.34	0.00
28.72	11590000	136602	3.94	100.00	60.41	0.00	0.00	47.50	60.51	83.71	0.00	0.00	28.45	60.67	0.00
30.08	12654467	142384	9.83	100.00	62.57	0.00	0.00	51.17	62.65	85.07	0.00	0.00	32.71	62.78	0.00
38.33	19575824	172876	15.23	100.00	64.56	0.00	0.00	54.53	64.60	86.31	0.00	0.00	36.62	64.71	0.00
39.48	20581016	176464	20.20	100.00	66.38	0.00	0.00	57.62	66.40	87.46	0.00	0.00	40.21	66.49	0.00
40.54	21560058	180018	24.78	100.00	68.06	0.00	0.00	60.48	68.07	88.52	0.00	0.00	43.53	68.14	0.00
41.52	22514891	183533	29.04	100.00	69.62	0.00	0.00	63.13	69.61	89.50	0.00	0.00	46.61	69.66	0.00
42.44	23447226	187005	33.00	100.00	71.07	0.00	0.00	65.60	71.05	90.41	0.00	0.00	49.47	71.08	0.00
43.30	24358582	190432	36.70	100.00	72.43	0.00	0.00	67.91	72.39	91.26	0.00	0.00	52.15	72.41	0.00
43.97	25104753	193269	40.16	100.00	73.70	0.00	0.00	70.07	73.65	92.06	0.00	0.00	54.66	73.65	0.00
44.59	25828288	196057	43.42	100.00	74.90	0.00	0.00	72.09	74.83	92.81	0.00	0.00	57.02	74.82	0.00
45.18	26537479	198819	46.49	100.00	76.02	0.00	0.00	74.00	75.94	93.52	0.00	0.00	59.23	75.92	0.00
45.86	27384712	202145	49.38	100.00	77.09	0.00	0.00	75.81	76.99	94.19	0.00	2.59	61.33	76.96	0.00
46.66	28424051	206226	52.12	100.00	78.09	0.00	3.51	77.51	77.99	94.82	0.00	5.36	63.31	77.94	0.00
47.46	29509190	210472	54.71	100.00	79.04	0.00	6.90	79.13	78.93	95.42	0.00	7.98	65.18	78.87	0.00
48.30	30687301	215051	57.17	100.00	79.95	0.00	10.27	80.66	79.82	95.98	0.00	10.48	66.97	79.75	0.00
49.11	31845921	219522	59.52	100.00	80.81	0.00	13.39	82.12	80.67	96.57	0.00	12.85	68.66	80.59	0.00
58.23	45323216	263491	61.75	100.00	81.62	0.00	16.37	83.51	81.48	97.04	0.00	15.10	70.28	81.39	0.00
98.40	107943253	371363	63.88	100.00	82.41	100.00	19.22	84.04	82.25	97.53	100.00	17.26	71.82	82.16	100.00

% Total Salt	Total Annual Cost	Average $/mg/l	PRICE-SAN RAFAEL-MUDDY Canal Lining	PRICE-SAN RAFAEL-MUDDY Lateral Lining	PRICE-SAN RAFAEL-MUDDY On-Farm Improvements	PRICE-SAN RAFAEL-MUDDY Desalination	McELMO CREEK Canal Lining	McELMO CREEK Lateral Lining	McELMO CREEK On-Farm Improvements	McELMO CREEK Desalination	BIG SANDY On-Farm Improvements	Sublette Flats	Paradox By-Pass	Glenwood-Dotsero Desalting	Crystal Geyser
0.08	9466	36125	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.13	17437	42905	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.02	445617	74292	0.00	0.00	9.19	0.00	0.00	0.00	5.27	0.00	4.65	0.00	0.00	0.00	0.00
6.38	1570311	83290	0.00	0.00	19.64	0.00	0.00	0.00	16.28	0.00	15.77	0.00	0.00	0.00	0.00
12.87	3521815	92929	0.00	0.00	27.75	0.00	0.00	67.64	24.83	0.00	24.41	100.00	0.00	0.00	0.00
15.50	4466856	97501	0.00	0.00	34.28	0.00	0.00	100.00	31.72	0.00	24.41	100.00	0.00	0.00	0.00
18.08	5502102	103007	0.00	0.00	39.69	0.00	0.00	100.00	37.42	0.00	24.41	100.00	0.00	0.00	0.00
20.45	6568146	108675	0.00	0.00	44.26	0.00	0.00	100.00	42.24	0.00	24.41	100.00	0.00	0.00	0.00
22.11	7387111	113071	0.00	0.00	48.20	0.00	0.00	100.00	46.39	0.00	24.41	100.00	0.00	0.00	0.00
23.60	8195474	117540	0.00	0.00	51.63	0.00	0.00	100.00	50.81	0.00	24.41	100.00	0.00	0.00	0.00
24.93	8982973	121945	0.00	0.00	54.66	0.00	0.00	100.00	53.20	0.00	24.41	100.00	0.00	0.00	0.00
26.12	9740676	126220	0.00	0.00	57.35	0.00	0.00	100.00	56.84	0.00	24.41	100.00	0.00	0.00	0.00
27.33	10569627	130913	0.00	8.24	59.77	0.00	0.00	100.00	58.59	0.00	24.41	100.00	0.00	0.00	0.00
28.72	11590000	136602	0.00	23.32	61.96	0.00	0.00	100.00	60.90	0.00	24.41	100.00	0.00	0.00	0.00
30.08	12654467	142384	0.00	37.05	63.95	0.00	0.00	100.00	63.00	0.00	24.41	100.00	0.00	0.00	0.00
38.33	19575824	172876	0.00	49.61	65.78	0.00	0.00	100.00	64.92	0.00	24.41	100.00	100.00	0.00	0.00
39.48	20581016	176464	0.00	61.17	67.46	0.00	0.00	100.00	66.69	0.00	24.41	100.00	100.00	0.00	0.00
40.54	21560058	180018	0.00	71.86	69.01	0.00	0.00	100.00	68.33	0.00	24.41	100.00	100.00	0.00	0.00
41.52	22514891	183533	0.00	81.76	70.45	0.00	0.00	100.00	69.84	0.00	24.41	100.00	100.00	0.00	0.00
42.44	23447226	187005	0.00	90.99	71.79	0.00	0.00	100.00	71.25	0.00	24.41	100.00	100.00	0.00	0.00
43.30	24358582	190432	0.00	99.60	73.04	0.00	0.00	100.00	72.57	0.00	24.41	100.00	100.00	0.00	0.00
43.97	25104753	193269	0.00	100.00	74.21	0.00	0.00	100.00	73.81	0.00	24.41	100.00	100.00	0.00	0.00
44.59	25828288	196057	0.00	100.00	75.31	0.00	0.00	100.00	74.97	0.00	24.41	100.00	100.00	0.00	0.00
45.18	26537479	198819	0.00	100.00	76.35	0.00	0.00	100.00	76.06	0.00	24.41	100.00	100.00	0.00	0.00
45.86	27384712	202145	0.00	100.00	77.33	0.00	0.00	100.00	77.09	0.00	24.41	100.00	100.00	0.00	0.00
46.66	28424051	206226	0.00	100.00	78.25	0.00	0.00	100.00	78.07	0.00	24.41	100.00	100.00	0.00	0.00
47.46	29509190	210472	1.73	100.00	79.13	0.00	0.00	100.00	78.99	0.00	24.41	100.00	100.00	0.00	0.00
48.30	30687301	215051	6.71	100.00	79.96	0.00	0.00	100.00	79.87	0.00	24.41	100.00	100.00	0.00	0.00
49.11	31845921	219522	11.45	100.00	80.75	0.00	0.00	100.00	80.71	0.00	24.41	100.00	100.00	0.00	0.00
58.23	45323216	263491	15.96	100.00	81.51	0.00	2.04	100.00	81.50	0.00	24.41	100.00	100.00	100.00	0.00
98.40	107943253	371363	20.27	100.00	82.23	100.00	4.64	100.00	82.26	100.00	24.41	100.00	100.00	100.00	0.00

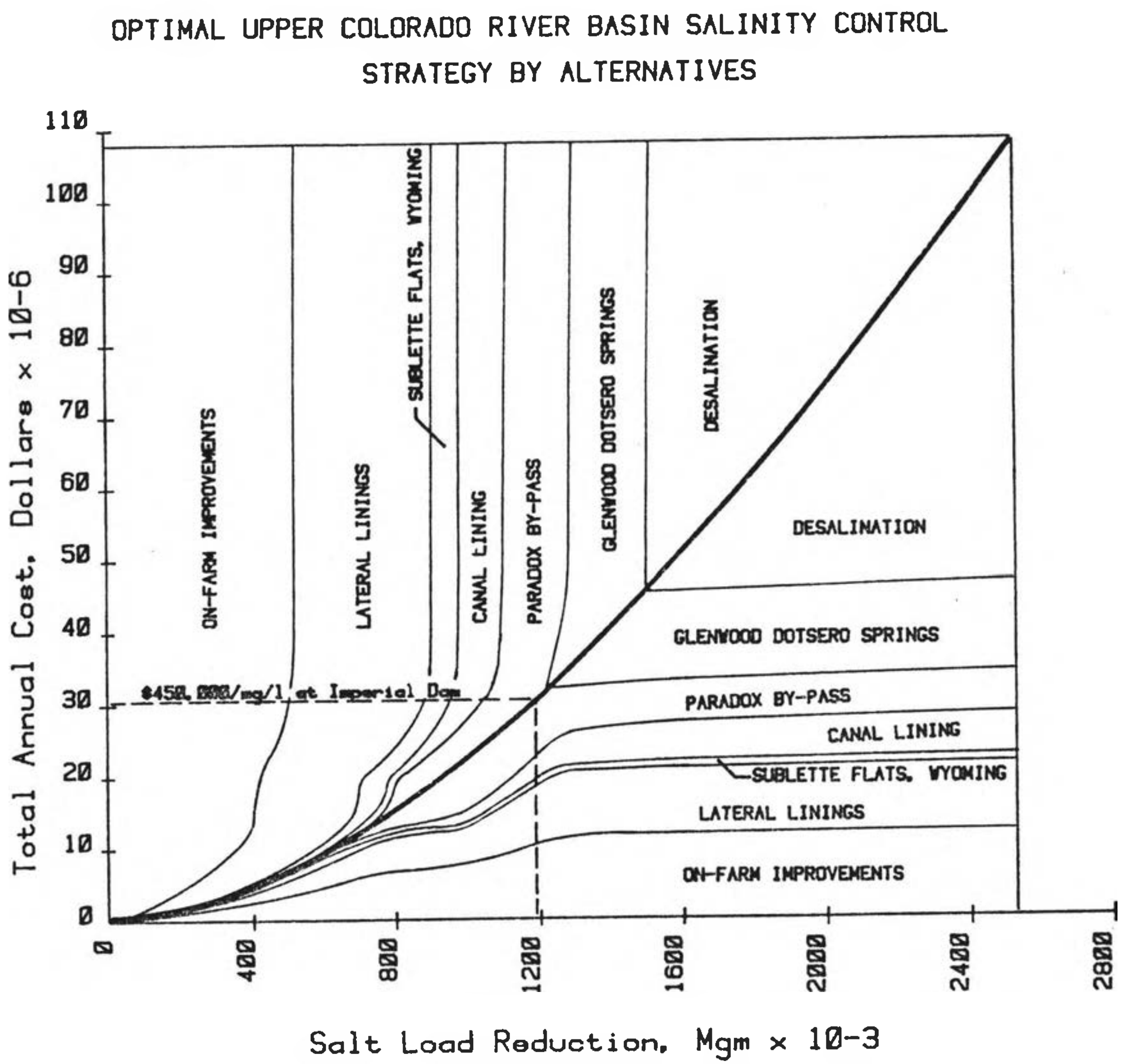


Figure 31. Optimal Upper Colorado River Basin Salinity Control by alternatives.

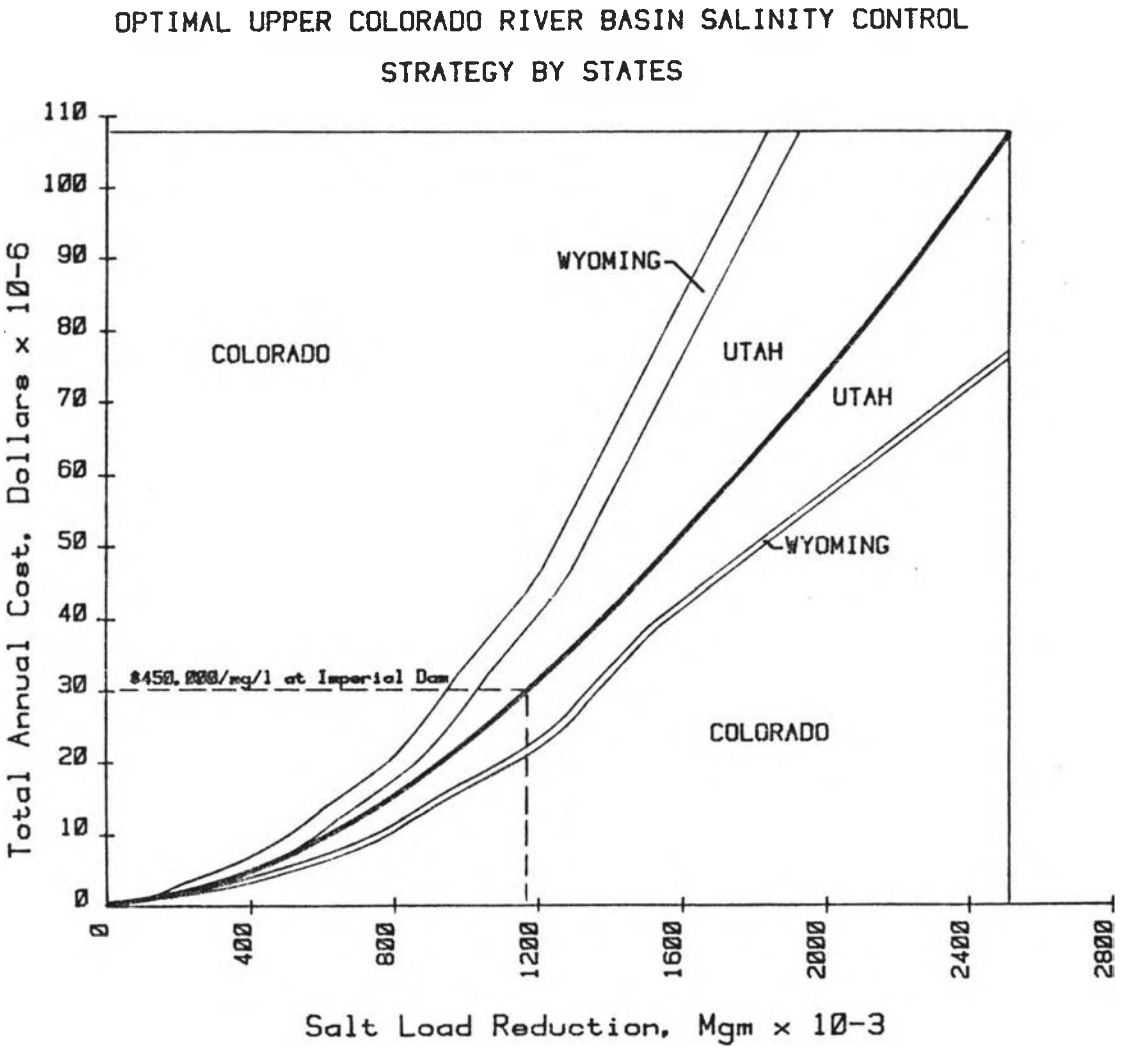


Figure 32. Optimal Upper Colorado River Basin Salinity Control Program delineated by state.

Table 14. Recent best-estimate of Upper Basin use of Colorado River water in thousands of hectare-meter including known proposed energy development (USDI, BR, 1979a).

State	Year	State UCRB Allocation[1]	Allocation Utilized	Remaining UCRB Allocated
Colorado	1980	367.0[1]	274.4	92.6
	1990	367.0	339.5	27.5
	2000	367.0	350.8	16.2
Utah	1980	163.0	109.6	53.4
	1990	163.0	141.7	21.3
	2000	163.0	147.2	15.8
New Mexico	1980	79.8	53.5	26.3
	1990	79.8	91.1	-11.3
	2000	79.8	92.0	-12.2
Wyoming	1980	99.3	55.0	44.3
	1990	99.3	73.6	25.7
	2000	99.3	81.8	17.5
Total UCRB	1980	715.1	498.6	216.5
	1990	715.1	652.2	62.9
	2000	715.1	677.9	37.2

[1] Based on a total annual average of 715,100 ha-m (5.8 million acre feet) being available.

approximately 44 mg/l. If salt loading were included, these values would be higher. The maximum amount of potential salinity control from PL 93-320 projects in each state is 210 mg/l, 70 mg/l, 0, and 9.6 mg/l at Imperial Dam, respectively. If an agricultural area desalination was not included, Colorado could control about 168 mg/l, Utah 48 mg/l and Wyoming 9.6 mg/l at Imperial Dam. Obviously, Colorado and Utah will have to compensate for development in Wyoming and New Mexico which raises some very important questions. For example, should the water depletions attributable to salinity control in Colorado to offset Wyoming development be charged to Wyoming, to Colorado or to the Lower Basin states?

If each state was forced to control their own salinity increases, it is apparent that only Colorado and Utah could do it in a cost-effective manner. It is doubtful if Wyoming could reduce the salinity by at most another 25 mg/l from the Blacks Fork and other irrigated areas. Therefore, Wyoming would probably have to resort to large scale desalination of the river and/or the point sources to achieve their goal. This would be extremely expensive with a downstream damage reduction/cost ratio much less than one.

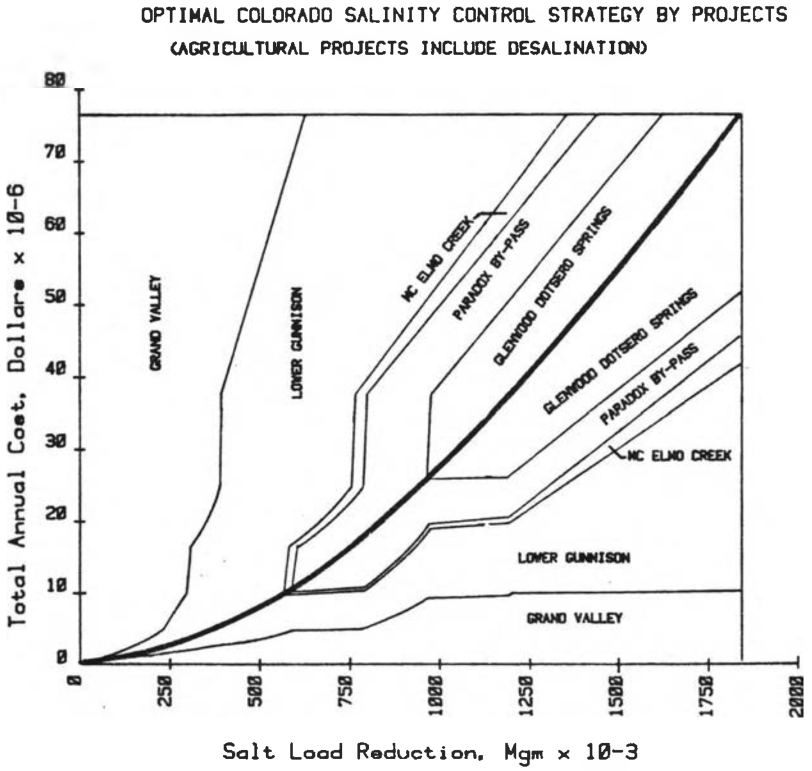
New Mexico is actually expected to overdraw their Colorado River water allocation by 1985. However, the agricultural salinity control or a large scale collector-desalination system would be very costly to implement for widely dispersed areas with relatively low salinity contributions.

Figure 33 indicates the optimal salinity control program for Colorado and Utah by alternative and by project. Agricultural desalination is separated as if it were a separate project because desalting will probably be legislated as individual construction efforts. The relative location of "policy spaces" under the cost-effectiveness curves indicate the inverse order of implementation. Utilizing these graphs, on-farm improvements and lateral linings should be implemented first. The work should be initiated in the Grand Valley and Lower Gunnison in Colorado and the Uintah Basin in Utah.

SENSITIVITY ANALYSIS

The optimization modeling procedure and variables have been subjected to a sensitivity analysis to determine the parameters which are the most critical. This was done to determine the effect at each level of the optimization analysis.

Essentially the only "original" data in this analysis is introduced at the first level in establishing the cost-effective equation for each individual canal or on-farm practice in each area. Thus, the sensitivity analysis must be initiated at this level and move progressively upward through the hierarchial structure of the optimization.



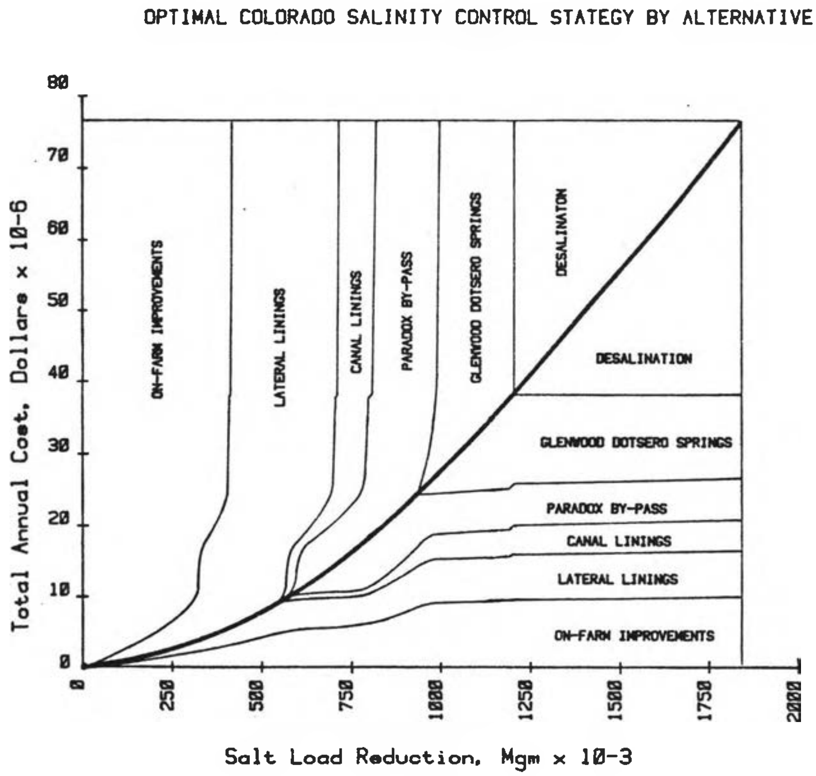


Figure 33. Optimal Salinity Control Program for Colorado delineated by project and by alternatives.

The individual alternative parameters were tested for sensitivity on the individual budgets. All of the budgets reacted to changes in the groundwater concentrations, and this is probably the single most difficult parameter to accurately determine, but it is believed that the values which were used are within 10 percent. However, $\pm$ 10 percent variation has less than a 5 percent effect on the total areawide cost-effectiveness functions.

Canals and laterals were sensitive to seepage rates. For example, a change in seepage rates from 0.10 m^3/m^2/day to 0.08 m^3/m^2/day in the Price-San Rafael area actually caused canal lining to go from 20 percent of the canals to be lined to not being included at all in the areawide cost-effectiveness salinity control program where desalination was included.

On-farm estimates of deep percolations influenced the on-farm salinity and water budgets, but variations of $\pm$ 25 percent did not change order of the optimal strategy of the area. The 25 percent variation affected the areawide total salinity control cost-effectiveness function by less than 4 percent, and the location on the curve where lateral or canal lining became feasible varied by about 5 percent.

Figure 34 illustrates the net effect of increasing lateral lining costs and on-farm improvement costs for every agricultural area by 50 percent over the estimated values. At the basin-wide (Level 4) level, this very large increase caused a 5 percent upward shift in the cost-effective

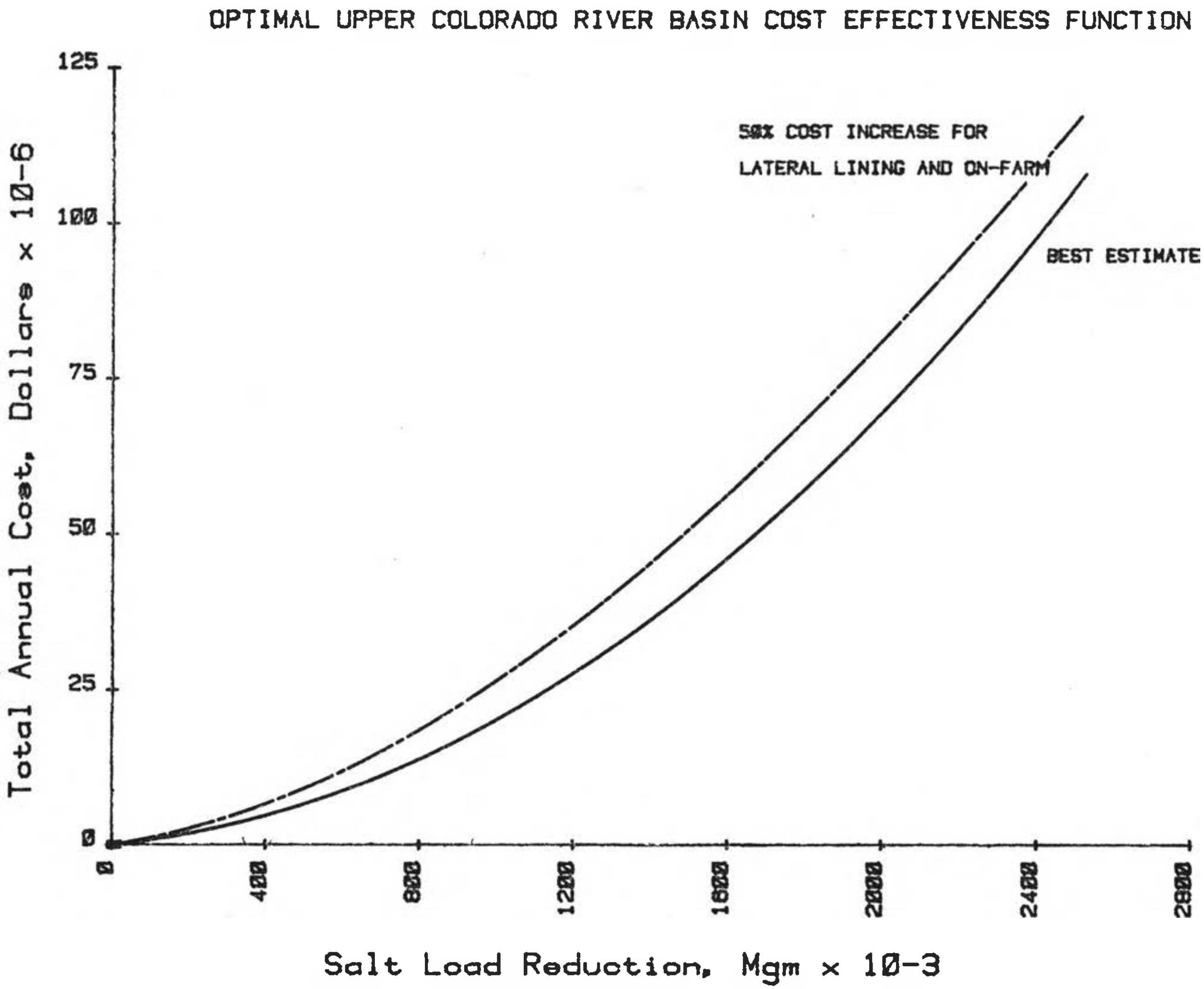


Figure 34. Sensitivity of the optimal Upper Colorado River Basin cost-effectiveness function to a 50 percent increase in lateral and on-farm costs for every area, holding all other costs constant.

function. This large cost increase also did not change the optimal order of the improvements, but less of these improvements were done before desalination became cost-effective. At the local (Level 2) level, the 50 percent lateral and on-farm cost increases resulted in a 12 percent variation in the areawide cost-effectiveness function for the Lower Gunnison. If desalination was not included as an alternative, the variation in costs approaches the 14 percent level on the basin-wide no-desalt function.

In a sensitivity analysis for the Lower Gunnison area, a 25 percent increase in the canal and lateral salt loading contribution, a corresponding decrease in the on-farm portion, and holding the unit costs the same, resulted in an 8 percent increase in the cost-effectiveness program but did not change the order of implementation. For the same area, a ± 50 percent increase in lateral lining costs holding the other costs and the salt loading distribution the same, resulted in only a 6 percent variation for the area cost-effectiveness function. Holding all unit costs constant a ± 25 percent variation in salt loading from laterals in the Lower Gunnison also resulted in a 6 percent shift in the cost-effectiveness function. Other similar large relative scale variations in costs and salt from canals and on-farm generally produced less than 5 percent variation in the areawide functions. When optimized up to the basin-wide level, holding all other areas constant, the variation was almost insignificant, particularly where desalination was included as an agricultural alternative.

The inclusion or exclusion of desalination as an agricultural control measure in an area had a large influence on the total areawide cost-effectiveness function. In addition, the maximum achievable level of salt reduction was less without desalination. For example, in the Uintah Basin, at a maximum treatment level of 270,000 Mgm without desalting, the average per mg/l at Imperial Dam treatment cost was over $720,000. Whereas, with desalination the maximum treatment level approached 395,000 Mgm at an average treatment cost of about $440,000/mg/l.

Variations in the costs of desalination produced marked results in the final cost-effectiveness function of an area. A 25 percent increase in the cost of desalination in the Grand Valley produced a 14 percent increase in the final costs for the area, a 16 percent increase in the amount of canal linings and 5 percent increase in on-farm improvements.

The Sublette Flats evaporation area alternative in the Big Sandy River was examined, and it was found that even if the costs of this were twice the estimated value, it was still more cost-effective than much of the canal linings elsewhere in the basin. On-farm improvements were increased under this more expensive option.

DISCUSSION OF RESULTS

Figure 35 presents the optimal cost-effective basin-wide salinity control alternatives which have been plotted under the Water and Power Resources Service forecast curve of salinity increase at Imperial Dam. As can be seen, almost all of the salinity control projects except agricultural desalination should be implemented by 1985. Fortunately, the salinity increases have not followed this curve and are presently at a somewhat lower level than the 879 mg/l annual average which occurred in 1972. This has been due partially to delayed construction of projects, delayed energy resources development, and some relatively high runoff years. The 1980 average annual value is estimated to be 802 mg/l. However, present indications are that the rapid increases have been offset at most by about 10 years, and that all of the cost-effective projects should be on-line at the latest by 19 5. In other words, it is expected that the salinity concentration at Imperial Dam will again reach the 1972 levels by 1985.

If the January, 1980, damage cost of $450,000/mg/l at Imperial Dam is accepted as a true cost, then it is possible to assess the damage costs of increased concentrations due to delaying construction of the salinity control program. For example, using the 1985 salinity levels from Figure 35 (210 mg/l increase) for comparison, and only one-fourth of the necessary salinity control is constructed at that time, then the annual costs of the delay are about $71 million.

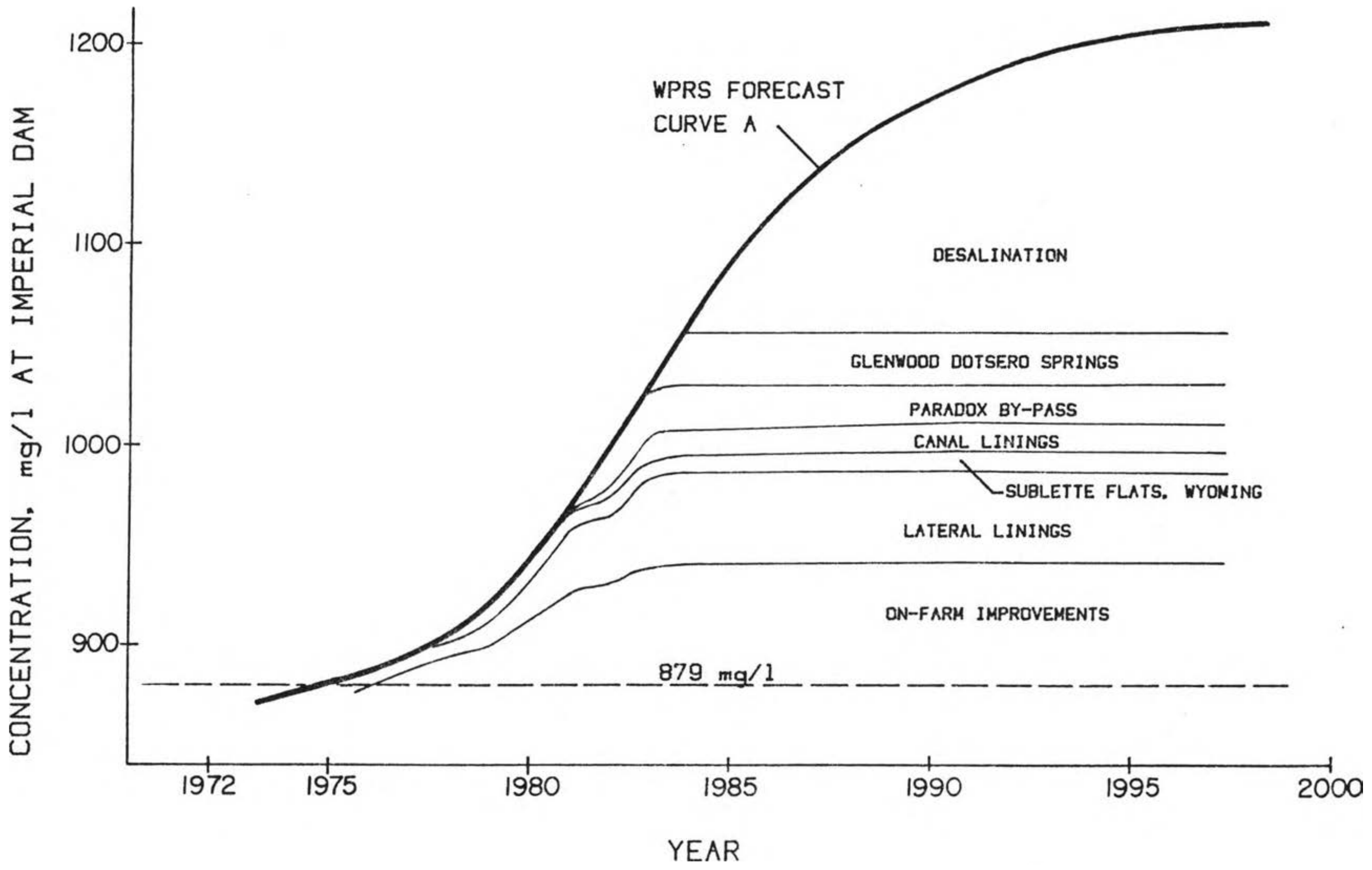


Figure 35. Cost-effective implementation strategy for optimal level of salinity control alternatives in the Upper Colorado River Basin.

Correspondingly, if only one-third is complete, the delay cost is about $63.3 million annually. This also assumes that the 1972 level of 879 mg/l should be maintained.

Figure 36 presents basically the same information as Figure 35, but illustrates the necessary capacity by state and includes agricultural desalination which was also indicated in Figure 31. Colorado has the largest and highest priority programs.

Marginal Cost Analysis

The use of average treatment costs per mg/l can be very misleading in determining the scope of salinity control programs. For example, Table 13 indicates that the average cost of full treatment for the Upper Basin could be accomplished for about $370,000 mg/l at Imperial Dam. However, the actual marginal cost of the basin-wide cost-effectiveness function at the same level of treatment approaches $600,000/mg/l. The average marginal cost is only the slope of the starting and end points while the true marginal cost is the slope of the cost-effectiveness function at the level of interest. This difference between average and true marginal cost is illustrated in Figure 37. The basin-wide salinity control level corresponding to an approximate marginal cost of $450,000 mg/l is indicated by the dashed lines on Figures 31 and 32. This value equals the annual damage figure which is presently accepted by the Water and Power Resources Service, and results in a program

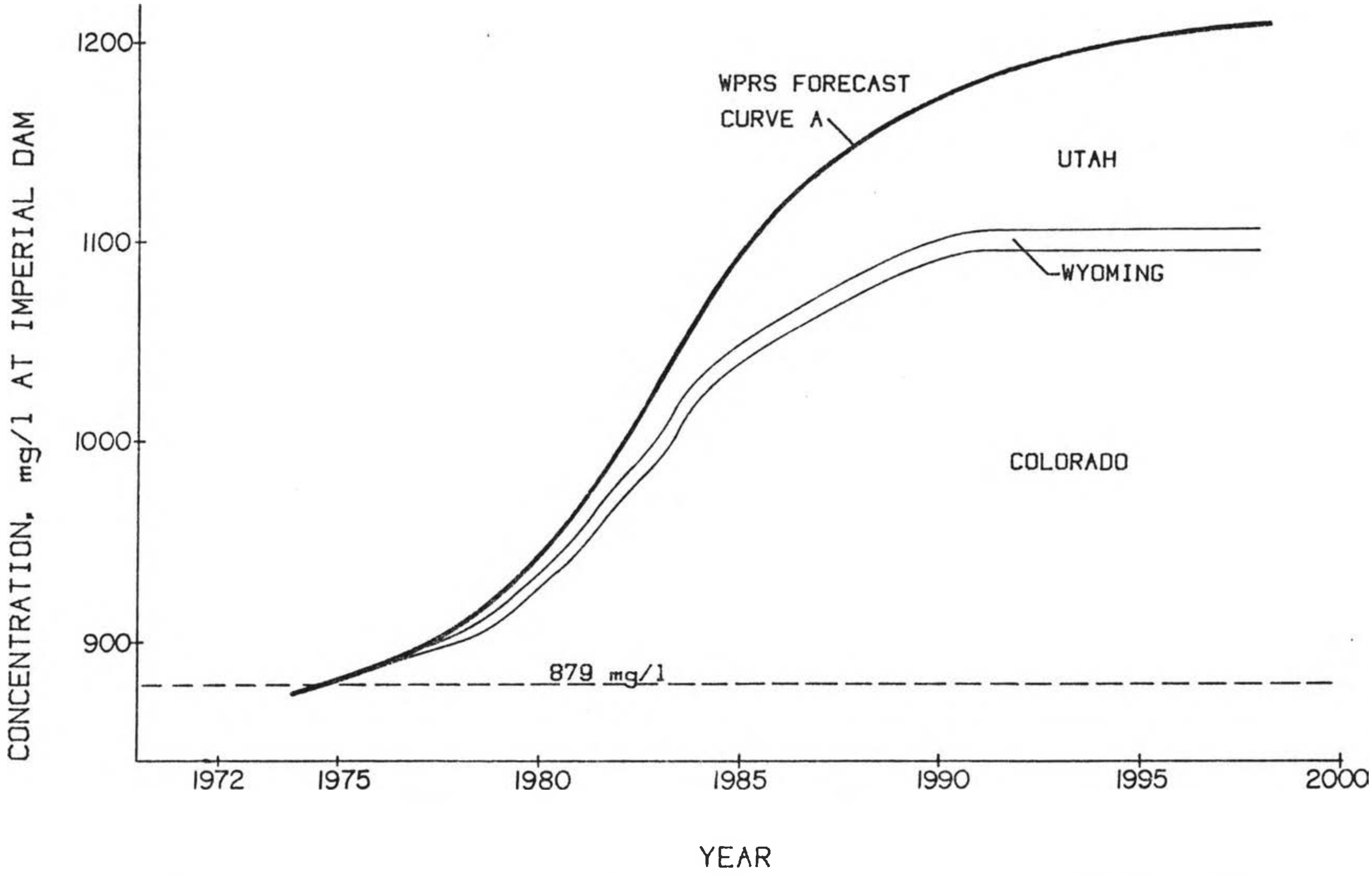


Figure 36. Cost-effective implementation strategy by state for optimal levels of salinity control in the Upper Colorado River Basin.

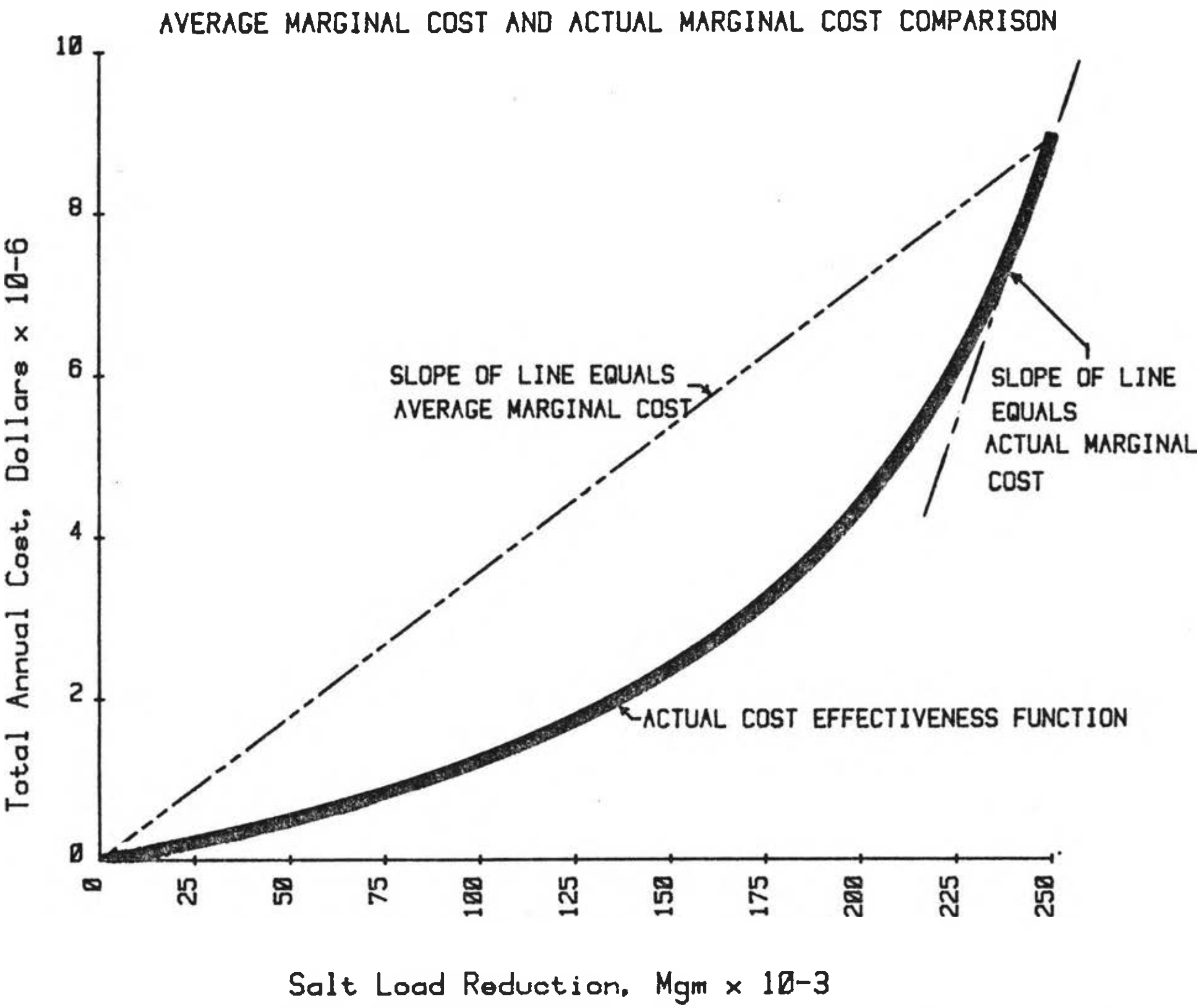


Figure 37. Comparison of average and actual marginal costs.

with an annual cost of $30 million and approximately a 145 mg/l reduction at Imperial Dam.

Evaluation of the 1972 Concentration Level Criterion--

The derivation of the $450,000/mg/l in damages has not yet been released by the Water and Power Resources Service. However, when the actual damage function for the range of concentrations from 800 to 1300 mg/l becomes available, it can be easily used in conjunction with the analysis presented in this report to effectively evaluate the 1972 concentration goals.

If the damage function was linear with a slope of $450,000/mg/l, and using the basin-wide cost-effective salinity control function derived in this manuscript, the concentration levels at Imperial Dam could rise to as high as 1060 mg/l. This is a maximum level, and it is likely that the cost-effective level will be about 20 to 30 mg/l less than this value.

Intuitively, the actual damage function would be slightly convex upward similar to the cost-effectiveness functions in the expected concentration range. If this is the case, then the point when marginal costs equal marginal benefits which is the economic salinity concentration level for Imperial Dam would probably be about 1040 mg/l. Although, the exact level cannot be determined with existing information, it is obvious that the arbitrary target of 879 mg/l level at Imperial Dam is much too low to be cost-effectively maintained, and should be allowed to rise by 150 to 180 mg/l.

It is realized that the minimum costs presented in this analysis do not include all of the associated costs such as the higher level of on-farm technical assistance which will be required. However, the $450,000/mg/l which is equilibrated to the benefits of control, also does not include the benefits of increased crop yields from better water management or reduced labor requirements due to the improved systems. Nevertheless, comparison of the two values does indicate the relative levels of implementation.

Additional Uses of this Analysis and Methodology

As newer and better information becomes available it should be possible to easily refine and continually update the most cost-effective salinity control program for the basin or an area. Also, if information is available it is possible to define a "Level 0" optimization. For example, if the hydraulic characteristics, seepage rates, groundwater salinity concentrations, and the actual costs of lining associated with specific sections of a canal can be determined, it is a relatively simple matter to optimize these sections to define the Level 1 cost-effectiveness function. In fact, the Level 0 analysis is a necessary step to delineate the phasing and extent of an actual construction program.

Another beneficial use of this analysis is the evaluation of the salinity control alternatives of a specific new water resource development project or energy development project. The procedure can be used to quantitatively and qualitatively determine the most cost-effective location or alternative for compensating salinity reductions. In some cases, it may be much less expensive and more expeditious to compensate for salinity increases in an off-site location such as an agricultural area.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

A simple multi-level nonlinear optimization procedure was utilized to develop an array of strategies for the most cost-effective salinity control program for the Upper Colorado River Basin. The results quantitatively indicate the location and general types of alternatives to be implemented and the associated annual costs for any selected level of basin-wide control. The results presented in this analysis were generated with January 1980 costs, and the 1980 best estimates of existing conditions for the major salinity control projects delineated in PL 93-320.

CONCLUSIONS

1) The conceptual model, simple nonlinear optimization and the resulting array of cost-effective salinity control strategies for the Upper Basin represent and illustrate the use of an easily used environmental quality planning tool.
2) Cost-effective salinity control strategies to compensate for new resource development or water transfers into or out of the basin which affect salinity can be easily developed and evaluated.
3) As new data become available or changes in political attitudes or directives may dictate, the optimal salinity control strategies can be easily and continually updated and re-evaluated.

4) The methodology and results indicate with a fair degree of certainty the priority and magnitude of control for each alternative, for each area, and for the basin-wide PL 93-320 salinity control program.

5) Some degree of on-farm improvements and lateral linings are cost-effective in every agricultural area examined in the Upper Basin. However, this must be accompanied by greatly increased technical assistance to the growers by the implementing agency and/or extension personnel. These programs are the most cost-effective and better information and/or data are not likely to affect their implementation as a salinity control measure.

6) One hundred percent of the laterals or 58 percent of the on-farm improvements (cutback irrigation) in the Grand Valley should be constructed before lining any of the Government Highline Canal. In fact, some on-farm and lateral linings should be done in all agricultural areas before canal lining is initiated.

7) At current damage estimates of $450,000/mg/l at Imperial Dam, only about 57 percent of the canals in the Grand Valley should be lined. The Grand Valley has the largest amount of canals to be lined of any area at this level of damages.

8) Most of the on-farm, lateral lining, and the very small canal (actually smaller than many laterals) lining salinity control program should be constructed in the Lower Gunnison area before canal linings are initiated.

9) Programs in the Uintah Basin, Price-San Rafael rivers, Muddy Creek, and McElmo Creek will basically consist of on-farm and lateral linings with very little canal lining.

10) The use of canals for winter livestock water causes substantial salt loading from several areas in the basin and contributes numerous local waterlogging and soil salination problems.

11) The barrier well network and Sublette Flat evaporation area as proposed by the USDA, Soil Conservation Service, and minimal on-farm improvements is the most cost-effective salinity program for the Big Sandy area in Wyoming. The "buy-out" alternative as proposed by some local landowners was evaluated and not found cost-effective.

12) Collection and reverse osmosis desalination of agricultural return flows should be included as a viable salinity control alternative in all irrigated areas. However, at current estimates of downstream damages, desalination would not be implemented.

13) The by-pass alternative for the Paradox Valley was evaluated and found to be more cost-effective than the proposed Radium evaporation pond alternative. This was primarily due to the greatly increased costs of evaporation ponds.

14) The proposed desalination of the Glenwood-Dotsero Springs in Colorado was evaluated in detail as part of

this study. It was concluded that the most economical alternative was a primary reverse osmosis plant followed by a much smaller secondary multi-stage flash distillation unit. However, at current average damage estimates, this project is marginally feasible.

15) The use of average costs per mg/l of treatment is misleading and should not be used in the delineation or phasing of salinity control projects.

16) At current average damage estimates, it is cost-effective to treat only about 48 to 50 percent of the total attainable salt load reduction from the projects designated in PL 93-320.

17) All of this analysis points to the fact that the arbitrary target of maintaining 1972 salinity levels at Imperial Dam cannot be cost-effectively attained. In fact, these results indicate that the target level should be increased to about 1,030 or 1,040 mg/l or more.

18) Present trends indicate that all of the cost-effective salinity control programs should be on-line no later than 1995. The damage costs due to delayed construction of these projects can be substantial.

19) Sensitivity analysis of the data and the optimization procedure indicate that substantial error in costs and the respective salt load contributions of the individual alternatives would have to occur to change the

optimal order of implementation of a basin-wide salinity control program.

RECOMMENDATIONS

1) It is necessary to determine desired level of salinity control which should be implemented as soon as possible since this will dictate the type and extent of many of the alternatives. This is especially the case for on-farm improvements.
2) Because on-farm improvements and lateral linings are cost-effective in all of the irrigated areas which were examined in this analysis, it is recommended that the list of areas included in PL 93-320 be expanded. It appears that these basic on-farm improvements should be implemented in all of the agricultural areas as the initial most cost-effective salinity control program.
3) The Soil Conservation Service, the Extension Service and the other technical agencies involved in salinity control should make a long-term commitment of adequate technical assistance to the growers. The on-going work in the Grand Valley clearly indicates the need for this type of program. It will be necessary to recruit and specially train personnel for this type of activity.
4) On-farm improvement and lateral lining programs consistent with selected level of basin-wide salinity control policy should be started as soon as possible in all of the irrigated areas.

5) The Sublette Flats evaporation area and a network of barrier wells and a minimal on-farm improvement program should be initiated as the total salinity control program for the Big Sandy area in Wyoming.

6) The use of canals and laterals for winter livestock water should be eliminated, if dependable alternative water supplies such as rural water districts or groundwater could be developed.

7) Design and construction of the by-pass alternative for the Paradox Valley salt source should begin as soon as possible. In addition it may be necessary to construct a series of small wells to intercept some of the groundwater inflow to the salt dome-brine interface.

8) A salinity damage function is presently being developed under contract to the Water and Power Resources Service. When this information becomes available it is recommended that the feasibility of maintaining the 1972 salinity concentration levels at Imperial Dam be re-evaluated.

9) Results of this analysis indicate the advisability of implementing the identified most cost-effective salinity control program regardless of where or which state the salinity increases occurred. Colorado will contain the major programs, and these projects will serve to counter-balance salinity increases in other areas. Wyoming could not physically be able to control its own salinity increases.

10) The scope of the Lower Gunnison project should be expanded by the Water and Power Resources Service to include all of the irrigated lands in the area, and not be restricted to only the Uncompahgre Project lands. The canal and lateral lining program which has been proposed by the WPRS is not cost-effective and should be re-evaluated. The possibilities for gravity-powered sprinkler systems and closed conduit canal and lateral linings in the North Fork of the Gunnison River should be examined.

11) There is a definite need to obtain a better data base for several of the areas, especially McElmo Creek in southwestern Colorado. The groundwater base flows in the Lower Gunnison, McElmo Creek and the Uintah Basin require further effort. Seepage rate data for canals and laterals in almost all of the areas are lacking and need to be collected in order to define the most cost-effective incremental canal and lateral lining programs for each area.

12) It is recommended that studies be initiated in the Price-San Rafael, Uintah, McElmo and Lower Gunnison areas to determine the relative magnitude of the natural salt contribution for the irrigated areas. This information would be necessary to delineate the more exact cost-effectiveness functions for a detailed construction program.

REFERENCES

American Association of Petroleum Geologists. 1967. Geological Highway Map - Southern Rocky Mountain Region. Geological Highway Map Committee, Map No. 2, Second Printing, Gulf Printing Company, Houston, Texas.

American Association of Petroleum Geologists. 1972. Geological Highway Map of the Northern Rocky Mountain Region. Geological Highway Map Committee, Map No. 5, Gulf Printing Company, Houston, Texas.

Anderson, J. C. and A. P. Kleinman (Eds.). 1978. Salinity management options for the Colorado River: damage estimates and control program impacts. Water Resources Planning Series Report P-78-003. Utah Water Research Laboratory, Utah State University, Logan. June, p. 344.

Austin, L. H. and G. V. Skogerboe. 1970. Hydrologic inventory of the Uintah Study Unit. Report No. PR WG 40-5, Utah Water Research Laboratory, College of Engineering, Utah State University, Logan. March, p. 200.

Barrett, J. K. and R. H. Pearl. 1978. An appraisal of Colorado geothermal resources. Bulletin 39, Colorado Geological Survey, Department of Natural Resources, Denver, Colorado. p. 224.

Bently, R. G. Jr., K. O. Eggleston, D. Price, E. R. Frandsen and A. R. Dickerman. 1978. The effects of surface disturbance (primarily livestock use) on the salinity of public lands in the Upper Colorado River Basin--1977 Status Report. USDI, Bureau of Land Management, Division of Standards and Technology, Watershed Staff. February, p. 208.

Bishop, A. B., M. D. Chambers, W. O. Mace and D. W. Mills. 1975. Water as a factor in energy resources development. Utah Water Research Laboratory Publication, PRJER 028-1, Utah State University, Logan. June, p. 104.

Bliesner, R. D., R. S. Hanks, L. G. King and L. S. Willardson. 1977. Effects of irrigation management on the quality of irrigation return flow in Ashley Valley, Utah. Journal Soil Science Society of America, Vol. 41, No. 2. March-April, p. 424-428.

Boettcher, A. J. 1972. Groundwater occurrence in the northern and central parts of western Colorado. Colorado Water Resources Circular No. 15, Colorado Water Conservation Board and U.S. Geological Survey, Denver, Colorado. p. 28.

Bouwer, H. 1974. What's new in deep well injection? Civil Engineering, American Society of Civil Engineers, Vol. 44, No. 1, New York, January. p. 58-61.

Carlson, D. and J. Rubingh. 1979. Agricultural land conversion in Colorado, Volume I: Analysis, Volume II: Appendices. Resource Analysis Section, Colorado Department of Agriculture. Denver, Colorado. November, p. 112 (Vol. I) and p. 187 (Vol. II).

CH2M-Hill. 1977. Clean water report for southwestern Wyoming. Technical Report for Southwestern Wyoming Water Quality Planning Association (208 Study) D 9524.FO, Denver, Colorado. September, p. 312.

Colorado Department of Local Affairs. 1979. Water Quality Management Plan for District 10. District 10 Regional Planning Commission, Montrose, Colorado. September, p. 117.

Colorado River Board of California. 1970. Need for controlling salinity of the Colorado River. Colorado River Board of California, Los Angeles, California. August, p. 98.

Colorado Water Conservation Board and U.S. Department of Agriculture. Water and related land resources, Yampa River Basin, Colorado and Wyoming. Denver, Colorado. April, p. 179.

Colorado Water Conservation Board and U.S. Department of Agriculture. 1972. Water and related land resources, Dolores River Basin, Colorado and Utah. Denver, Colorado. September, p. 223.

Corsentino, J. S. 1976. Projects to expand fuel sources in western states: a survey of planned or proposed coal, oil shale, tar sand, uranium, and geothermal supply expansion projects, and related infrastructure, in states west of the Mississippi River (as of May, 1976). U.S. Department of the Interior, Bureau of Mines Information Circular 8719. Intermountain Field Operations Center. Denver, Colorado. p. 208.

Crow, F. R. 1980. Evaporation from brine storage reservoirs. Paper No. 80-2024 presented at 1980 Summer Meeting of American Society of Agricultural Engineers, San Antonio, Texas. June 15-18, p. 15.

Eisenhauer, D. E. and P. E. Fischbach. 1977. Comparing costs of conventional and improved irrigation systems. Irrigation Age. May-June, p. 36-37.

Engineering News Record. 1980. Materials and labor cost trends in the United States. Vol. 24, No. 12, McGraw-Hill, Inc. New York. March 20, p. 112-113.

Erlenkotter, D. and C. R. Scherer. 1977. An economic analyses of optimal investment scheduling for salinity control in the Colorado River. University of California, Water Resources Center, Berkeley. December, p. 267.

Eubanks, L. and R. D. d'Arge. 1976. Water quality damage functions, a statistical analysis of residences in Los Angeles. Research Paper No. 157, Department of Economics, University of Wyoming, Laramie. February, p. 71.

Evans, R. G., W. R. Walker, G. V. Skogerboe and C. W. Binder. 1978a. Implementation of agricultural salinity control technology in Grand Valley. Report EPA-600/2-78-161. Robert S. Kerr Environmental Research Laboratory, U. S. Environmental Protection Agency, Ada, Oklahoma. July, p. 209.

Evans, R. G., W. R. Walker, G. V. Skogerboe and S. W. Smith. 1978b. Evaluation of irrigation methods for salinity controls in Grand Valley. Report EPA-600/2-78-160. Robert S. Kerr Environmental Research Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma. July, p. 188.

Evans, R. G., S. W. Smith, W. R. Walker and G. V. Skogerboe. 1976. Irrigation field days report 1976. Agricultural Engineering Department, Colorado State University, Fort Collins. August, p. 56.

Felts, R. D. 1966. Water from bedrock in the Colorado plateau of Utah. Utah State Engineer Technical Publication No. 15. Utah State Engineer's Office, Salt Lake City, Utah. p. 82.

Flug, M., W. R. Walker, G. V. Skogerboe and S. W. Smith. 1977. The impact of energy development on water resources in the Upper Colorado River Basin. Report to U.S. Department of the Interior, Office of Water Research and Technology, Washington, D. C. February, p. 158.

Fox, R. L., J. J. Phelan and W. D. Criddle. 1954. Progress Report on irrigation for Eden Valley, Wyoming. Reclamation Project, USDA Soil Conservation Service and Agricultural Research Service, Casper, Wyoming. June, p. 76.

Gardner, B. D., K. S. Lyon and R. O. Tew. 1976. The effects on agriculture in Utah of water transfer to oil shale development. Department of Economics and Utah Water Research Laboratory, Utah State University, Logan. Publication PRJAE-027-1. June, p. 57.

Gardner, D. B. and G. E. Stewart. 1978. Agriculture and salinity. In Values and Choices in the Development of the Colorado River Basin. Edited by D. F. Peterson and A. B. Crawford. University of Arizona Press, Tucson. p. 121-143.

Gifford, G. F., R. H. Hawkins and J. S. Williams. 1975. Hydrologic impacts of livestock grazing on natural resource lands on the San Luis Valley. Completion Report to the Bureau of Land Management by Utah State University Foundation.

Goslin, I. V. 1978. Colorado River development. In Values and Choices in the Development of the Colorado River Basin. Edited by D. F. Peterson and A. B. Crawford. University of Arizona Press, Tucson. p. 18-60.

Hagan, R. H. 1971. Upper Colorado region. Comprehensive Framework Study, Appendix XV, Water Quality Pollution Control and Health Factors. Upper Colorado Region State-Federal Inter-Agency Group. Pacific Southwest Inter-Agency Committee. Water Resources Council. June, p. 219.

Hansen, D. C. 1976. Water availability for energy--Upper Colorado River Basin. Journal of the Water Resources Planning and Management Division, Americal Society of Civil Engineers, Vol. 102, No. WR2. November, p. 341-348.

Hansen, E. M., F. K. Schwarz and J. T. Riedel. 1977. Probable maximum precipitation estimates, Colorado River and Great Basin drainages. NOAA-S/T 77-2774, Hydrometeorological Report No. 49, National Weather Service, U.S. Department of Commerce, Silver Spring, Maryland. September, p. 161.

Hart, W. E. 1975. Irrigation system design. Department of Agricultural Engineering, Colorado State University, Fort Collins.

Hawkins, R. H., G. F. Gifford and J. J. Jurinak. 1977. Effects of land processes on the salinity of the Upper Colorado River Basin. Department of Forest Science, Utah State University, Logan. October, p. 196.

Hedland, J. D. 1971. Upper Colorado region. Comprehensive Framework Study, Appendix V, Water Resources. Upper Colorado Region State-Federal Inter-Agency Group, Pacific Southwest Inter-Agency Committee, Water Resources Council. June, p. 66.

Holburt, M. B. 1977. The 1973 agreement of Colorado River salinity between the United States and Mexico. In Proceedings of National Conference on Irrigation Return Flow Quality Management, Fort Collins, Colorado. May 16-19, p. 325-333.

Howe, C. W., J. F. Kreider and B. Udis. 1972. An economic analysis of the pollution problems in the Colorado River Basin: the upper mainstream basin. COM-74-11311, U.S. Department of Commerce, Office of Economic Research, Washington, D. C. October, p. 257.

Hyatt, M. L., J. P. Riley, M. L. McKee and E. K. Israelsen. 1970. Computer simulation of the hydrologic-salinity flow system within the Upper Colorado River Basin. Utah Water Research Laboratory Report PRWG54-1, Utah State University, Logan. July, p. 255.

Iorns, W. V., C. H. Hembree and G. L. Oakland. 1965. Water resources of the Upper Colorado River Basin. Technical Report, U.S. Geological Survey Professional Paper 441. U.S.G.P.O., Washington, D. C., p. 370.

Johansen and Tuttle Engineering, Inc. 1977. Muddy Creek watershed canal seepage study. Study for USDA Soil Conservation Service, Salt Lake City, Utah. November, p. 20.

Johnson, R. W. 1975. Legal and institutional problems in the management of salinity. NTIS-PB-244-730, OWRR A-076-WASH, Office of Water Resource Research, U.S. Department of the Interior, Washington, D. C. August, p. 35.

Keefer, T. N. and R. S. McQuivey. 1979. Water availability for development of major tar sands areas in Utah. Report SCR 337-79-010, LETC-0013-1 (NTIS), U. S. Department of Energy. May, p. 257.

Keys III, J. W. and R. I. Strand. 1979. Irrigation in the Colorado River Basin: solving the salinity problem to save a giant. Paper presented at ICID Conference, Phoenix, Arizona. September, p. 8.

King, L. G. and R. J. Hanks. 1975. Management practices affecting quality and quantity of irrigation return flow. EPA 66012-75-005, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma.

Kleinman, A. P., G. J. Barney and S. G. Titmus. 1974. Economic impacts of changes in salinity levels of the Colorado River. U.S. Department of the Interior, Bureau of Reclamation, Denver, Colorado. February, p. 41.

Kleinman, A. P. and F. B. Brown. 1977. Analysis of farmer response to saline irrigation water in the Colorado River Basin. Western Journal of Agricultural Economics. June, p. 145-151.

Konikow, L. F. and M. S. Bedinger. 1978. Evaluation of hydrogeologic aspects of the proposed salinity control program in Paradox Valley, Colorado. U.S. Department of the Interior, Geologic Survey. Openfile Report 78-27, Denver, Colorado. January, p. 23.

Kruse, E. G. 1977. Minutes of the Grand Valley Salinity Coordinating Committee. Grand Junction, Colorado. February.

Lacewell, R. D. and W. F. Hughes. 1971. A comparison of the capital requirements and labor use, alternative sprinkler irrigation systems, Texas high plains. Texas Agricultural Experiment Station Information Report No. 71-3. p. 15.

Larome, J. B. and S. A. Schumm. 1977. Evaluation of the storage of diffuse sources of salinity in the Upper Colorado River Basin. Completion Report No. 79, Environmental Resources Center, Colorado State University, Fort Collins. September, p. 111.

Lawrence, C. H. 1975. Estimating indirect costs of urban water use. Journal of the Environmental Engineering Division, American Society of Civil Engineers, Vol. 101, No. EE4. August, p. 517-533.

McWhorter, D. B. and G. V. Skogerboe. 1979. Potential of interflow as a salt transport mechanism, Upper Colorado River Basin. Report for U.S. Department of the

Interior, Bureau of Land Management, Division of Standards and Technology, Denver, Colorado. February, p. 74.

Mann, D., G. Weatherford and P. Nichols. 1974. Legal-political history of water resource development in the Upper Colorado River Basin. Lake Powell Research Project Bulletin No. 4, Institute of Geophysics and Planetary Physics, University of California, Los Angeles. September, p. 62.

Milliken, J. G., L. C. Lohman, A. S. Trumbly and L. Roll. 1979. Overcoming legal and institutional barriers to planned reuse of water in the Colorado River Basin. OWRT/RU-79/3, Office of Water Research and Technology, U.S. Department of the Interior, Washington, D. C. April, p. 211.

Moore, C. V. 1972. On the necessary and sufficient conditions for a long-term irrigated agriculture. Water Resources Bulletin, American Water Resources Association, Vol. 8, No. 4. August, p. 802-812.

Moore, C. V., J. H. Snyder and P. Sun. 1974a. Effects of Colorado River quality and supply on irrigated agriculture. Water Resources Research, Vol. 10, No. 2. April, p. 137-144.

Moore, C. V. and J. H. Snyder. 1974b. Management of saline water. Report No. 29, Water Resources Center, University of California, Davis. March, p. 20.

Morris, G. E. 1977. An optimization model of energy related economic development in the Upper Colorado River Basin under conditions of water and energy resource scarcity. Los Alamos Scientific Laboratory, LA-6732 T, Los Alamos, New Mexico. March, p. 553.

Narayanan, R., R. Padungchai and A. B. Bishop. 1979. An economic evaluation of the salinity impacts from energy development: the case of the Upper Colorado River Basin. UWRL/P-79/07, Utah Water Research Laboratory, Utah State University, Logan. December, p. 71.

Nelson, Haley, Patterson and Quirk, Inc. 1976. Meeker Dome Project, Hydrogeologic literature review. Report prepared for U.S. Bureau of Reclamation, Upper Colorado Regional Office, Salt Lake City, Utah. November, 4 volumes.

Oyarzabal-Tamargo, F. and R. A. Young. 1976. The Colorado River salinity problem: economic damages in Mexico. Paper presented at Western Agricultural Economics Association Annual Meeting, Colorado State University, Fort Collins. July, p. 9.

Pair, C. H. 1975. Sprinkler irrigation. The Irrigation Association, 4th Edition, Silver Spring, Maryland. p. 615.

Pitchford, E. J. and J. C. Wilkinson. 1975. A cost comparison of several sprinkler irrigation systems in large scale agricultural development. Paper presented at Ninth Congress of the International Commission on Irrigation and Drainage, Vol. 5 Proceedings, Moscow, USSR. July.

Plotkin, S. E., H. Gold and I. L. White. 1979. Water and energy in the western coal lands. Water Resources Bulletin, Vol. 15, No. 1, American Water Resources Association. February, p. 94-107.

Ponce, S. L., III. 1975. Examination of a non-point source loading function for the Mancos Shale wildlands of the Price River Basin, Utah. Unpublished Ph.D. dissertation, Department of Civil and Environmental Engineering, Utah State University, Logan. p. 177.

Ponce, S. L., R. H. Hawkins, J. J. Jurinah, G. F. Gifford and J. R. Riley. 1975. Surface runoff and its effect on diffuse salt production from Mancos Shale members. Watershed Management: Proceedings of Conference by American Society of Civil Engineers, Irrigation and Drainage Division, Logan, Utah. August 11-13, p. 140-168.

Price, D. and K. M. Waddell. 1973. Selected hydrologic data in the Upper Colorado River Basin. Hydrologic Investigations Atlas HA-477. U.S. Department of the Interior, Geological Survey.

Radosevich, G. E. and G. V. Skogerboe. 1978. Achieving irrigation return flow quality control through improved legal systems. EPA-600/2-78-184, U.S. Environmental Protection Agency, Rober S. Kerr Environmental Research Laboratory, Ada. Oklahoma. December, p. 312.

Reed, A. D., J. L. Meyer, F. K. Aljibury and A. W. March. 1977. Irrigation costs. Water and Irrigation, Vol. 1, No. 1. November, p. 12-13, 24-25.

Riley, J. P. and J. J. Jurinak. 1979. Irrigation management for river salinity control. Vol. 105, No. IR4, Journal of the Irrigation and Drainage Division, American Society of Civil Engineers. December, p. 419-432.

Robinson, F. E., J. N. Luthin, R. J. Schnagl, W. Padgett, K. K. Tanji, W. F. Lehman and K. S. Mayberry. 1976. Adaptation to increasing salinity of the Colorado River. Contribution No. 160, California Water Resources Center, Davis, California. October, p. 51.

Rollins, Brown and Gunnell, Inc. 1971. Muddy Creek Dam and Reservoir, Emery County feasibility study. Report prepared for Utah Division of Water Resources, Salt Lake City, Utah. August, p. 57.

Scherer, C. R. 1977. Water allocation and pricing for control of irrigation related salinity in a river basin. Water Resources Research, Vol. 13, No. 2. April, p. 225-238.

Shafer, P. S. 1971. Upper Colorado region. Comprehensive Framework Study, Appendix X, Irrigation and Drainage. Upper Colorado Region State-Federal Inter-Agency Group, Pacific Southwest Inter-Agency Committee, Water Resources Council. June, p. 98.

Sheffield, L. F. 1977. The economics of irrigation. Irrigation Journal 27(1): 18-22, 33.

Six County Commissions Organization. 1978. Water quality management plan, Wayne County. Draft, Richfield, Utah. January, p. 64.

Skogerboe, G. V. 1980. Personal communication.

Skogerboe, G. V. and W. R. Walker. 1972. Evaluation of canal lining for salinity control in Grand Valley. Report EPA-R2-72-047, Office of Research and Development, Environmental Protection Agency, Washington, D. C., October, p. 212.

Skogerboe, G. V., D. B. McWhorter and J. E. Ayers. 1979a. Irrigation practices and return flow salinity in Grand Valley. EPA-600/2-79-148, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma. August, p. 218.

Skogerboe, G. V., W. R. Walker and R. G. Evans. 1979b. Environmental planning manual for salinity management in irrigated agriculture. Report EPA-600/2-79-062. Office of Research and Development, U.S. Environmental

Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma. March, p. 237.

Stockton, C. W. and G. C. Jacoby, Jr. 1976. Long-term surface water supply and streamflow trends in the Upper Colorado River Basin based on tree-ring analyses. Institute of Geophysics and Planetary Physics, University of California, Los Angeles. March, p. 77.

Swenson, J. L., D. T. Erickson, K. M. Donaldson and J. J. Shiozaki. 1970. Soil Survey, Carbon-Emery Area, Utah. U.S. Department of Agriculture, Soil Conservation Service, U.S. Department of the Interior, B.L.M., Utah Agricultural Experiment Station, U.S.G.P.O., Washington, D. C. December, p. 120.

Thomas, D. B. 1975. The effects of gully plugs and contour furrows on erosion and sedimentation in Cisco Basin, Utah. Unpublished M.S. Thesis, Utah State University, Logan. p. 89.

Thorfinnson, T. S., M. Hunt and A. W. Epp. 1955. Cost of distribution of irrigation water by different methods. University of Nebraska Agricultural Experiment Station Bulletin No. 432, Lincoln. August, p. 28.

Thorne, J. P., and L. Wilson, T. B. Hutchings and J. L. Swenson. 1967. Chemical and physical properties of soils in the Carbon-Emergy area, Utah. Utah Agricultural Experiment Station, Utah Resources Series 39, Utah State University, Logan. September, p. 37.

Tihansky, D. P. 1974. Economic damages from residential use of mineralized water supply. Water Resources Research, Vol. 10, No. 2. April, p. 145-154.

Tipton and Kalmback, Inc. 1965. Water supplies of the Colorado River. Report for the Upper Colorado River Commission, Salt Lake City, Utah. Part I: Text, Part II: Appendices. July, p. 32 (Part I).

Uintah Basin Association of Goverments. 1979. Uintah Basin 208 Water Quality Management Plan: agricultural non-point source assessment. Roosevelt, Utah. December, p. 124.

U.S. Department of Agriculture, Soil Conservation Service. 1976. On-farm salinity control investigation for Lower Gunnison Basin Unit. Plan of work, Denver, Colorado. September, p. 17.

U.S. Department of Agriculture, Soil Conservation Service. 1979a. Personal communication.

U.S. Department of Agriculture, Soil Conservation Service. 1979b. Letter to Mr. Robert Strand, U.S. Bureau of Reclamation (Denver, Colorado) from Mr. John D. Hedlund (Portland, Oregon). p. 4.

U.S. Department of Agriculture, Soil Conservation Service. 1979c. Land use inventory data (computer tapes), Lower Gunnison Salinity Study, data collected 1977-78. Denver, Colorado.

U.S. Department of Agriculture, Soil Conservation Service. 1979d. USDA plan of study for the Price and San Rafael Rivers Unit. Colorado River Basin Salinity Control Study, State of Utah, Salt Lake City. January, p. 54.

U.S. Department of Agriculture, Soil Conservation Service. 1979e. The Uintah Basin Unit. Colorado River Basin Salinity Control Study, State of Utah, Salt Lake City. January, p. 173.

U.S. Department of Agriculture, Soil Conservation Service. 1979f. Colorado economics handbook. Denver, Colorado.

U.S. Department of Agriculture, Soil Conservation Service. 1980a. Big Sandy River, Colorado River Basin, Salinity Control Study. Interagency and Public Review Draft, Casper, Wyoming. March, p. 166.

U.S. Department of Agriculture, Soil Conservation Service. 1980b. Personal communication.

U.S. Department of the Interior. 1974. Report on water for energy in the Upper Colorado River Basin. Water for Energy Management Team, Denver, Colorado. July, p. 76.

U.S. Bureau of Reclamation. 1952. Canal linings and methods of reducing costs. U.S. Government Printing Office, Washington, D. C. p. 69.

U.S. Bureau of Reclamation. 1963. Linings for irrigation canals. U.S. Government Printing Office, Washington, D. C. p. 149.

U.S. Department of the Interior, Bureau of Reclamation. 1964. Price and San Rafael River Basins, Utah Basin Report, Salt Lake City. December, p. 98.

U.S. Department of the Interior, Bureau of Reclamation. 1967. Eden Project, Wyoming Improvement Program, Salt Lake City, Utah. February, p. 43.

U.S. Department of the Interior, Bureau of Reclamation. 1974. Alternative sources of water for prototype oil shale development, Colorado and Utah. Draft, Salt Lake City, Utah. September, p. 116.

U.S. Department of the Interior, Bureau of Reclamation. 1975a. Rehabilitation of the Montezuma Valley, Irrigation Company's Canal System--Dolores Project. Open-file memorandum. March 27, p. 3.

U.S. Department of the Interior, Bureau of Reclamation. 1975b. Critical problems facing the eleven western states: westwide study. (Chapter V Regional Problems 1, 2, 3 and 4), Denver, Colorado. April, p. 457.

U.S. Department of the Interior, Bureau of Reclamation. 1976a. Glenwood-Dotsero Springs Unit, Colorado. Preliminary Appraisal Report, Colorado River Water Quality Improvement Program. Upper Colorado Region, Salt Lake City, Utah. June, p. 32.

U.S. Department of the Interior, Bureau of Reclamation. 1976b. Personal communication, Grand Junction Projects Office, Grand Junction, Colorado.

U.S. Department of the Interior, Bureau of Reclamation. 1977. Dolores Project, Colorado. Definite Plan Report. April, p. 194.

U.S. Department of the Interior, Bureau of Reclamation. 1978a. Paradox Valley Unit--Definite Plan Report, Colorado River Basin Salinity Control Project. Salt Lake City, Utah. September, p. 91.

U.S. Department of the Interior, Bureau of Reclamation. 1978b. Unpublished memorandum on salinity budgets for the Uncompahgre Project lands. Grand Junction, Colorado. p. 28.

U.S. Department of the Interior, Bureau of Reclamation. 1979a. Quality of water. Colorado River Basin Progress Report No. 9. Upper Colorado Region, Salt Lake City, Utah. January, p. 206.

U.S. Department of the Interior, Bureau of Reclamation. 1979b. Final Environmental Statement, Paradox Valley Unit. Colorado River Basin Salinity Control Project, Salt Lake City, Utah. March, p. 301.

U.S. Department of the Interior, Bureau of Reclamation. 1979c. Bureau of Reclamation personal communication.

U.S. Department of the Interior, Bureau of Reclamation. 1979d. Draft environmental statement, Animas-La Plata Project, Colorado-New Mexico, Salt Lake City, Utah. July, p. 305.

U.S. Department of the Interior, Bureau of Reclamation and Office of Saline Water. 1972. Desalting handbook for planners. Denver, Colorado. May, p. 274.

U.S. Department of the Interior, Geolgical Survey. 1976. Salt-load computations--Colorado River: Cameo, Colorado to Cisco, Utah, Parts 1 and 2. Openfile report, Denver, Colorado.

U.S. Department of the Interior, Geological Survey. 1979a. Final environmental statement: development of coal resources in central Utah, Part 1: regional analysis, Reston, Virginia. p. 474.

U.S. Department of the Interior, Geolgical Survey. 1979b. Final environmental statement: development of coal resources in southern Utah, Part 1: regional analysis Reston, Virginia. p. 483.

U.S. Department of the Interior and U.S. Department of Agriculture. 1977. Final environmental statement, Colorado River Water Quality Improvement Program. Bureau of Reclamation and Soil Conservation Services, Denver, Colorado. May, p. 285, 819.

U.S. Department of the Interior, Water and Power Resources Service. 1979. La Verkin Springs Unit, Utah Status Report, Denver, Colorado. December, p. 24.

U.S. Department of the Interior, Water and Power Resources Service. 1980a. Personal communication. Denver, Colorado.

U.S. Department of the Interior, Water and Power Resources Service. 1980b. Public meeting report, Meeker Dome Unit, 4th public meeting, Openfile Report J 710.105. Grand Junction, Colorado. February 14.

U.S. Department of the Interior, Water and Power Resources Service. 1980c. Environmental scoping meeting for the Lower Gunnison Basin Unit of the Colorado River Water Quality Improvement Program, Olathe, Colorado. April 30.

U.S. Environmental Protection Agency. 1971. Mineral quality problem in Colorado River Basin, Appendix A. Natural and Man-made conditions affecting mineral quality. Regions VIII and IX, San Francisco, California, p. 168.

U.S. Environmental Protection Agency. 1972. The Meeker Dome and other phenomenon in the vicinity of the Meeker Dome. Rio Blanco County, Colorado--A summary report on the feasibility of control of seepage of saline groundwater. SA/TSB-15, Region VIII, NTIS PB-255-258, Denver, Colorado. December, p. 61.

U.S. Government General Accounting Office, Comptroller General of the United States. 1977. More and better uses could be made of billions of gallons of water by improving irrigation delivery systems. CED-77-177, Report to the Congress, Washington, D. C. September, p. 11.

U.S. Government Accounting Office, Comptroller General of the United States. 1979. Colorado River basin water problems: how to reduce their impact. CED-79-11, Washington, D. C. May, p. 137.

Utah Division of Water Resources, Department of Natural Resources. 1975. Fremont River study. Salt Lake City, Utah. April, p. 75.

Utah State University. 1975. Colorado River: regional assessment study. Report prepared for National Commission on Water Quality (4 parts). Utah State University, Utah Water Research Laboratory, Logan. October.

vanSchilfgaarde, J. and J. D. Oster. 1977. Irrigation management conserves water. California Agriculture, Vol. 31, No. 5, University of California, Division of Agricultural Sciences, Richland, California. May, p. 15-16.

Walker, W. R. 1973. Mathematical modeling of urban water management strategies. Unpublished Ph.D. dissertation, Agricultural Engineering Department, Colorado State University, Fort Collins. August, p. 191.

Walker, W. R. 1978. Integrating desalination and agricultural salinity control alternatives. U.S. Environmental Protection Agency, EPA-600/2-78-074, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma. April, p. 193.

Walker, W. R. 1979. Developing cost-effectiveness function for selected agricultural salinity control alternatives: a planning level guide (mimeo). Draft of report for Department of Agricultural Engineering, Cornell University, Ithaca, New York. September, p. 113.

Walker, W. R., T. L. Huntzinger and G. V. Skogerboe. 1973. Coordination of agricultural and urban water quality management in the Utah Lake drainage area. Technical Completion Report to the Office of Water Resources Research, U.S. Department of the Interior. Report AER72-73WRW-TLH-GVS27. Environmental Resources Center, Colorado State University, Fort Collins. June, p. 151.

Walker, W. R. and G. V. Skogerboe. 1980. Developing optimal river basin solutions for alleviating environmental impacts from irrigated agriculture. In Proceeding of ASCE Specialty Conference, Boise, Idaho. July 22-25.

Walker, W. R., G. V. Skogerboe and R. G. Evans. 1977. Development of best management practices for salinity control in Grand Valley. In Proc. National Conference on Irrigation Return Flow Quality Management, J. P. Law and G. V. Skogerboe (Eds.), Department of Agricultural and Chemical Engineering, Colorado State University, Fort Collins. May, p. 385-393.

Walker, W. R., G. V. Skogerboe and R. G. Evans. 1978. Best management practices for salinity control in Grand Valley. EPA-600/2-78-162, U.S. Environmental Protection Agency, Ada, Oklahoma. p. 125.

Walker, W. R., G. V. Skogerboe and R. G. Evans. 1979. Reducing salt pickup from irrigated lands. Journal Irrigation and Drainage Division, Vol. 105, No. IR2, p. 1-14.

Warner, D. L., L. F. Koederite, A. D. Simon and M. G. Yow. 1979. Radius of pressure influence of injection wells. EPA-600/2-79-170, U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma. August, p. 203.

Watersaver, Inc. 1980. Personal communication with Stuart Lang. Denver, Colorado. March.

Weatherford, G. D. and G. C. Jacoby. 1975. Impact of energy development on the law of the Colorado River. Natural Resources Journal, Vol. 15, No. 1. January, p. 171-213.

Westesen, G. L. 1975. Salinity control for western Colorado. Unpublished Ph.D. dissertation, Agricultural Engineering Department, Colorado State University, Fort Collins. February, p. 251.

White, R. B. 1977. Salt production from micro-channels in the Price River Basin, Utah. Unpublished M.S. Thesis, Department of Civil and Environmental Engineering, Utah State University, Logan. p. 130.

Whitmore, J. C. 1976. Some aspects of the salinity of Mancos Shale and Mancos derived soils. Unpublished M.S. Thesis, Department of Soil Science and Biometeorology, Utah State University, Logan. p. 76.

Wilde, D. J. and C. S. Beightler. 1967. Foundations of optimization. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. p. 480.

Willardson, L. S., R. J. Hanks and R. D. Bliesner. 1977. Field evaluation of sprinkler irrigation for management of irrigation return flow. Proceedings of National Conference on Irrigation Return Flow Quality Management. Colorado State University, Fort Collins. May 16-19, p. 109-114.

BIBLIOGRAPHY

Beardall, K. 1977. Memorandum on agriculture in Carbon and Emery counties for 208 study. USDA, Soil Conservation Service, Price, Utah. p. 5 (mimeo).

Bolton, H. E. 1950. Pageant in the wilderness, the story of the Escalante Expedition to the Interior Basin, 1776. Utah State Historical Society, Salt Lake City, Utah. p. 265.

Bos, M. G. and J. Nugteren. 1974. On irrigation efficiencies. International Institute for Land Reclamation and Improvement. Pub. 19, P. O. Box 45, Wageningen, The Netherlands.

Bessler, M. B. and J. T. Maletic. 1975. Salinity control and the Federal Water Quality Act. Journal of the Hydraulics Division, ASAE. Vol. 101, No. HY5. May, p. 581-594.

Cater, F. W. 1970. Geology of the salt anticline region in southwestern Colorado. U.S. Geological Survey Professional Paper No. 637, U.S. Government Printing Office, Washington, D. C. p. 80.

Cline, A. J., C. Spears, F. Mehaffey, E. Kubin, R. Franklin and C. Pachek. 1967. Soil survey: Delta-Montrose area Colorado. U.S. Department of Agriculture, Soil Conservation Service and Colorado Agricultural Experiment Station, U.S.G.P.O., Washington, D. C. July, p. 100.

Coffin, D. L., F. A. Welder, R. K. Glanzman and X. W. Dutton. 1968. Geohydrologic data from Piceance Creek Basin between the White and Colorado Rivers, northwestern Colorado. Colorado Water Conservation Board, Circular No. 12, Denver, Colorado. p. 38.

Coffin, D. L., F. A. Welder and R. K. Glanzman. 1971. Geohydrology of the Piceance Creek Structural Basin between the White and Colorado Rivers, northwestern Colorado. U.S. Geological Survey, Hydrology Investigations Atlas AH-370, Reston, Virginia.

Colorado Department of Health, Colorado Water Quality Control Commission. 1971. Water quality standards and stream classification. Adopted April 13, 1971 and effective September 1, 1971. Denver, Colorado. p. 30.

Colorado Water Conservation Board and U.S. Department of Agriculture. 1962. Water and related land resources, Gunnison River Basin--Colorado. Salt Lake City, Utah. November, p. 103.

Colorado Water Conservation Board and U.S. Department of Agriculture. 1966. Water and related land resources, White River Basin in Colorado. Denver, Colorado. November, p. 101.

Colorado Water Conservation Board, U.S. Department of Agriculture. 1974. Water and related land resources, San Juan River Basin in Arizona, Colorado, New Mexico and Utah. Denver, Colorado. June, p. 231.

Conroy, L. S. and F. K. Fields. 1977. Climatological and hydrologic data, southeastern Uintah Basin, Utah and Colorado, water years 1975 and 1976. Utah Basic Data Release No. 29, U.S. Department of the Interior, Geological Survey, Salt Lake City, Utah. p. 244.

Craig, T. W. 1971. Groundwater of the Uncompahgre Valley, Montrose County, Colorado. Report No. LR-011, M.S. Thesis, University of Missouri--Rolla. p. 113.

Cruff, F. W. and J. W. Hood. 1976. Seepage study of the Rocky Point Canal and Grey Mountain--Pleasant Valley Canal Systems, Duchesne County, Utah. Technical Publication No. 50, Utah Department of Natural Resources, Division of Water Rights. Salt Lake City, Utah. p. 59.

Davis, G. H. and L. A. Wood. 1974. Water demands for expanding energy development. Geolgical Survey Circular 703, U.S. Department of the Interior, Geological Survey, Reston, Virginia. p. 18.

Duke, H. R., E. G. Kruse, S. R. Olsen, D. F. Champion and D. C. Kincaid. 1976. Irrigation return flow quality as affected by irrigation water management in the Grand Valley of Colorado. Agricultural Research Service, U.S. Department of Agriculture, Fort Collins, Colorado. October, p. 129.

Elkin, A. D. 1976. Grand Valley salinity study: investigations of sediment and salt yields in diffuse areas, Mesa County, Colorado. Review draft sub. for State Conservation Engineer, Soil Conservation Service, Denver, Colorado.

Erickson, J. R. 1943. Consumptive use of irrigation water in Lower Uncompahgre Valley investigations of 1938-1941 with description of Uncompahgre River Basin, western Colorado. Colorado Water Conservation Board, Denver, Colorado. July, p. 63.

Evans, R. G. 1977. Improved semi-automatic gates for cutback surface irrigation systems. Trans. ASAE 20(1): 105-112, January.

Ficke, J. F., J. B. Weeks and F. A. Welder. 1974. Hydrologic data from the Piceance Basin, Colorado. Colorado Water Resources Basic Data Release No. 31, Colorado Department of Natural Resources, Denver, Colorado. p. 254.

Gold, H. and D. J. Goldstein. 1979. Water related environmental effects in fuel conversion, I: summary volume. U.S. Department of Energy, FE-2445-1 (Vol. 1), G.P.O., Washington, D. C. p. 231.

Hall, T. L. and J. H. Taylor. 1973. Water and land resources in Eden Valley, Wyoming. Report No. AER72-73-TLH-JHT21, Environmental Resources Center, Colorado State University, Fort Collins. February, p. 180.

Hansen, Vaughn and Associates. 1977. Seepage loss studies, Uintah Basin canal systems. Colorado River Water Quality Improvement Program Supplemental Report. Vol. I--Appendices A and B, Vol. II--Appendices C and D, Contract with U.S. Department of the Interior, Bureau of Reclamation. July.

Helweg, O. J. and D. Alvarez. 1978. Economic impact of water quality on river basin management contribution. No. 168, California Water Resources Center, University of California, Davis. March, p. 61.

Holburt, M. B. 1975. International problems of the Colorado River. Natural Resources Journal, Vol. 15, No. 1. January, p. 11-26.

Hood, J. W. 1976. Characteristics of aquifers in the northern Unitah Basin area, Utah and Colorado. Technical Publication No. 53, Utah Department of Natural Resources, Division of Water Rights, Salt Lake City, Utah. p. 77.

Hood, J. W., J. C. Mundorff, and D. Price. 1976. Selected hydrologic data, Unitah Basin area, Utah and Colorado. Utah Basic Data Release No. 26, U.S. Department of the Interior, Geological Survey, Salt Lake City, Utah. p. 326.

Hood, J. W. 1977a. Hydrologic evaluation of Ashley Valley northern Uintah Basin area, Utah. Technical Publication No. 54, Utah Department of Natural Resources, Division of Water Rights, Salt Lake City, Utah. p. 29.

Hood, J. W. 1977b. Hydrologic evaluation of the Upper Duchesne River Valley, northern Uintah Basin area, Utah. Technical Publication No. 57, Utah Department of Natural Resources, Division of Water Rights, Salt Lake City, Utah. p. 38.

Horrocks and Carollo Engineers. 1976a. Water quality sampling program data within the Uintah Basin 208 planning area. Interior Output Report No. 2, Uintah Basin Association of Governments. January, p. 114.

Horrocks and Carollo Engineers. 1976b. Groundwater and groundwater quality within the Uintah Basin. Interior Output Report No. 10, Uintah Basin Association of Governments. October, p. 72.

Howe, C. W. and D. V. Orr. 1974. Effects of acreage reduction on water availability and salinity in the Upper Colorado River Basin. Water Resources Research, Vol. 10, No. 5. October, p. 893-897.

Hunter, W. R. and C. F. Spears. 1975. Soil survey of Gunnison area, Colorado. U.S. Department of Agriculture, Soil Conservation Service and the Colorado Agricultural Experiment Station, U.S.G.P.O., Washington, D. C. August, p. 112.

Hydro-Search, Inc. 1977. Hydrogeologic study, Lower Gunnison Unit, Colorado. Report prepared for U.S. Department of the Interior, Bureau of Reclamation, Salt Lake City, Utah. October 24.

Jensen, M. E. 1975. Scientific irrigation scheduling for salinity control of irrigation return flows. EPA-600/2-75-964, Robert S. Kerr Environmental Protection Agency, Ada, Oklahoma. November.

Johnson, B. B. 1979. Energy price levels and the economics of irrigation. Paper presented at the 2nd Western Irrigation Forum, Denver, Colorado. March 7-9.

Khan, I. A. 1977. A hierarchical approach to salinity management in river basins. Unpublished Ph.D. dissertation, Department of Civil Engineering, Colorado State University, Fort Collins. p. 209.

King, L. G. 1973. Irrigation management for control of irrigation return flow. U.S. Environmental Protection Agency, EPA-R2-73-265, Ada, Oklahoma. June, p. 307.

Knutson, C. F. and C. R. Boardman. 1973. Hydrology of the Piceance Creek Basin and its impact on oil shale development. Paper presented at Rocky Mountain Regional Meeting of the Society of Petroleum Engineers of AIME, SPE 4409, Casper, Wyoming. May 15-16, p. 8.

Kruse, E. G. 1980. Lateral sizes for efficient level basin irrigation. Paper No. 80-2074 presented at 1980 Summary Meeting of American Society of Agricultural Engineers, San Antonio, Texas. June 15-18, p. 13.

Larson, D. T., L. D. James, K. R. Kimball, J. Mulder, A. B. Crawford, C. Johnson, L. Rovig and K. Sizemore. 1979. Levels of analysis in comprehensive river basin planning. UWRL/P-79/05, Utah Water Research Laboratory, Utah State University, Logan. May, p. 110.

Law, J. P., Jr. and H. Bernard. 1970. Impact of agricultural pollutants on water uses. Trans. ASAE, Vol. 13, No. 4. p. 474-478.

Law, J. P., Jr. and G. V. Skogerboe. 1972. Potential for controlling quality irrigation return flows. Journal of Environmental Quality, Vol. 1, No. 2. Madison, Wisconsin. April-June, p. 140-145.

Lawrence, D. F. and B. C. Saunders. 1975. Allocation of Utah's Colorado River water. In Age of Competition for Resources, Proceeding of Specialty Conference, American Society of Civil Engineers, Irrigation and Drainage Division, Logan, Utah. August 13-15, p. 82-94.

Leathers, K. L. and R. A. Young. 1976. Evaluating economic impacts of programs for control of saline irrigation return flows: a case study of the Grand Valley, Colorado. U.S. Environmental Protection Agency, Region VIII, Denver, Colorado. June, p. 162.

Longenbaugh, R. L. and I. F. Wymore. 1977. Analyses of methods for the determination of water availability for energy development. Federal Energy Administration, FEA/G-77/059. May, p. 125.

Lusby, G. C., V. H. Reid and O. D. Knipe. 1971. Effects of grazing on the hydrology and biology of the Badger Wash Basin in western Colorado, 1953-1966. Water Supply Paper 1532-D, U.S. Geolgical Survey. p. 90.

Marchant, L. C. and L. A. Johnson. 1977. U.S. Energy Research and Development Administration tar sand research update. Department of Energy Research Center, Laramie, Wyoming. p. 7.

Meeks, T. O. 1950. Reconnaissance of groundwater conditions in the Uncompahgre Valley, Colorado, M-239. U.S. Department of Agriculture, Soil Conservation Service, Albuquerque, New Mexico. September, p. 27.

Milliken, J. G., L. C. Lohman, S. A. Lyon and G. W. Sherk, Jr. 1977. State and local management options to reduce Colorado River salinity. EPA 908/3-77-002, U.S. Environmental Protection Agency, Region VIII, Denver, Colorado. September, p. 370.

Mundorff, J. C. 1972. Reconnaissance of chemical quality of surface water and fluvial sediment in the Price River Basin, Utah. Technical Publication No. 39, U.S. Department of the Interior, Geological Survey and Utah State Department of Natural Resources, Salt Lake City, Utah. p. 55.

Mundorff, J. C. 1977. Reconnaissance of water quality in the Duchesne River Basin and some adjacent drainage areas, Utah. Technical Publication No. 55, Utah Department of Natural Resources, Division of Water Rights, Salt Lake City, Utah. p. 53.

Peterson, D. F. and A. B. Crawford (Eds.). 1978. Values and choices in the development of the Colorado River Basin. The University of Arizona Press, Tucson, Arizona. p. 337.

Price, D. and L. L. Miller. 1975. Hydrologic reconnaissance of the southern Uintah Basin, Utah and Colorado. Technical Publication No. 49, Utah Department of Natural Resources, Division of Water Rights, Salt Lake City, Utah. p. 72.

Radian Corporation. 1977. An investigation of the potential for utilizing of saline groundwater in energy-related processes. DCN-77-200-152-01, FE-2444-1, Energy Research and Development Administration, Washington, D. C. May, p. 203.

Rector, C. D., E. W. Mustard and J. T. Windell. 1978. Preliminary report: Lower Gunnison River Basin wetland inventory and evaluation. Published by U.S. Department of Agriculture, Soil Conservation Service, Denver, Colorado. February, p. 71.

Shaffer, M. S., R. W. Ribbens and C. W. Huntley. 1977. Prediction of mineral quality of irrigation return flow, Volume V. Detailed return flow salinity and nutrient simulation model. EPA-600/2-77-179e, Robert S. Kerr Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Ada, Oklahoma. August, p. 228.

Skogerboe, G. V., J. W. H. Barrett, B. J. Treat and D. B. McWhorter. 1979. Irrigation practices, return flow salinity, and crop yields. EPA-600/2-79-149, Office of Research and Development, U.S. Environmental Protection Agency, Ada, Oklahoma. August, p. 208.

Skogerboe, G. V., W. R. Walker, R. S. Bennett, J. E. Ayars and J. H. Taylor. 1974a. Evaluation of drainage for salinity control in Grand Valley. Report EPA-600/2-74-052, Office of Research and Development, Environmental Protection Agency, Washington, D. C. August, p. 108.

Skogerboe, G. V., W. R. Walker, J. H. Taylor and R. S. Bennett. 1974b. Evaluation of irrigation scheduling for salinity control in Grand Valley. Report EPA-600/2-74-084, Office of Research and Development, Environmental Protection Agency, Washington, D. C. June, p. 93.

Skold, M. D. 1977. Farmer adjustments to higher energy prices--the case of the pump irrigator. U.S. Department of Agriculture, Economic Research Service, ERS-663. p. 15.

Sloggett, G. 1977. Energy and U.S. agriculture: irrigation pumping, 1974. U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 376. p. 39.

Southeastern Utah Association of Governments. 1977. Nonpoint assessment. Waste Water Quality Management 208 Planning for Emery, Carbon and Grand Counties, Price, Utah. June, p. 136-148.

Swenson, J. L. 1980. Report of drain inventory Duchesne and Uintah Counties, Colorado River Salinity Study. U.S. Department of Agriculture, Soil Conservation Service, Openfile report, Salt Lake City, Utah. August, p. 34 (mimeo).

Swenson, J. L. 1977a. Report of drain inventory, Carbon and Emery Counties, Colorado River Salinity Study. Openfile report, U.S. Department of Agriculture, Soil Conservation Service, Salt Lake City, Utah. December, p. 23 (mimeo).

Swenson, J. L. 1977b. Salt accretion in irrigation water as influenced by soil depth over Mancos shale. Open-file report, U.S. Department of Agriculture, Soil Conservation Service, Salt Lake City, Utah. December, p. 11 (mimeo).

Turner, F. P. 1975. Feasibility study of brine disposal by deep well injection on Paradox Valley Unit, Colorado. Openfile report, U.S. Department of the Interior, Water and Power Resources Service, Denver, Colorado. November, P. 48.

Uintah Basin Association of Governments. 1977. Uintah Basin areawide water quality management plan. In conjunction with Horrocks and Carollo Engineers, Roosevelt, Utah. October, p. 402.

U.S. Department of Agriculture, Agricultural Research Service. 1975. Alleviation of salt load in irrigation water return flow of the Upper Colorado River Basin. FY75 Annual Progress Report for USDI, Bureau of Reclamation, Fort Collins, Colorado. July, p. 112.

U.S. Department of Agriculture, Soil Conservation Service. 1969. An appraisal of outdoor recreation potentials, Delta County, Colorado. U.S. Department of Agriculture, Soil Conservation Service, Denver, Colorado. June, p. 75.

U.S. Department of the Interior, Bureau of Land Management. 1978. 1977 status report: the effects of surface disturbance on the salinity of the public lands in the Upper Colorado River Basin (primarily livestock use). Watershed Staff, Division of Standards and Technology, Colorado River Salinity Team, Denver, Colorado. February, p. 208.

U.S. Department of the Interior, Bureau of Land Management. 1979. Final environmental statement, Proposed domestic livestock grazing program for the Uncompahgre Basin Resource area. Montrose, Colorado. p. 515.

U.S. Department of the Interior, Bureau of Land Management. 1979. Proposed domestic livestock grazing management program for the Sandy area, Draft environmental statement. Rock Springs, Wyoming. p. 669.

U.S. Department of the Interior, Bureau of Land Management. 1979. Final environmental statement, Emery Power Plant, Units 3 and 4, Utah Light and Power. Salt Lake City, Utah. p. 309.

U.S. Department of the Interior, Bureau of Reclamation. 1975. Dallas Creek Project, Colorado. Effects on salinity of the Colorado River. Openfile report, June 1974, Grand Junction, Colorado. August, p. 22 (revised).

U.S. Department of the Interior, Bureau of Reclamation. 1976b. Final environmental statement, Dallas Creek project, Colorado. Salt Lake City, Utah. September, p. 415.

U.S. Department of the Interior, Bureau of Reclamation. 1977b. Final environmental statement, Dolores project, Colorado. Salt Lake City, Utah. May, p. 445.

Utah Department of Natural Resources, Division of Water Resources. 1975. Hydrologic inventory of the Price River study unit. State of Utah, Salt Lake City, Utah. June, p. 69.

Utah Department of Natural Resources, Division of Water Resources. 1976. Hydrologic inventory of the San Rafael River Basin. State of Utah, Salt Lake City, Utah. January, p. 93.

U.S. Department of the Interior, Bureau of Reclamation. 1978. Canal seepage tests--1977, Lower Gunnison Basin Unit. Unpublished memorandum on results of 1977 canal seepage tests, Grand Junction, Colorado. p. 14.

Utah Division of Water Resources. 1979. White River Dam Project, proposed action plan--revised. Salt Lake City, Utah. August, p. 70.

Utah State University Foundation. 1976. Final report: Uintah Basin seepage meter study, Colorado River Basin Salinity Control Study, Utah, June 1 to October 31, 1976. Department of Agricultural and Irrigation Engineering, Utah State University, Logan. p. 23.

U.S. Department of the Interior, Bureau of Reclamation. 1961. Emery County definite plan report. Salt Lake City, Utah.

Valentine, V. E. 1974. Impacts of Colorado River salinity. Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 100, No. IR4. December, p. 495-510.

van Schilfgaarde, J., L. Bernstein, J. D. Rhoades and S. L. Rawlins. 1974. Irrigation management for salt control. Journal of Irrigation and Drainage Division, ASCE 100 (IR3). p. 321-338.

Waddell, K. M., H. L. Vickers, R. T. Upton and P. K. Contratto. 1978. Selected hydrologic data, 1931-1977, Wasatch Plateau--Book Cliffs Coal-Fields area, Utah. Utah Basic Data Release No. 31, U.S. Geological Survey, Openfile report 78-121, Salt Lake City, Utah. p. 33.

Walker, W. R. 1970. Hydro-salinity model of the Grand Valley. M.S. Thesis CET-71WRW8, Civil Engineering Department, Colorado State University, Fort Collins. August. p. 94.

Walker, W. R. 1975. A systematic procedure for taxing agricultural pollution sources. Grant NK-42122, Civil and Environmental Technical Program, National Science Foundation, Washington, D. C. October.

Walker, W. R. 1978. Identification and initial evaluation of irrigation return flow models, EPA-600/2-78-144. U.S. Environmental Protection Agency, Ada, Oklahoma.

Water Resources Council. 1968. The nation's water resources. U.S. Water Resources Council, Washington, D. C.

Weeks, J. B., G. H. Leavesley, F. A. Welder and G. J. Saulnier, Jr. 1974. Simulated effects of oil shale development on the hydrology of Piceance Basin, Colorado. U.S. Geological Survey Professional Paper No. 908, Reston, Virginia. p. 91.

Weeks, J. B. and F. A. Welder. 1974. Hydrologic and geophysical data from the Piceance Basin, Colorado. Colorado Water Resources Basic Data Release No. 35, Colorado Department of Natural Resources, Denver, Colorado. p. 127.

Western States Water Council. 1974. Western states water requirement for energy development to 1990. Salt Lake City, Utah. November, p. 44.

Wierenga, P. J. 1977. Influence of trickle and surface irrigation on return flow quality. EPA-600/2-77-093, U.S. Environmental Protection Agency, Ada, Oklahoma. May, p. 176.

Williams, J. S. 1975. The natural salinity of the Colorado River. Occasional Paper 7, Utah Water Research Laboratory, Utah State University, Logan. June, p. 18.

Wymore, I. F. 1974. Water requirements for stabilization of spent shale. Ph.D. dissertation, Department of Earth Resources, Colorado State University, Fort Collins. August, p. 137.

Young, R. A., G. E. Radosevich, S. L. Gray and K. L. Leathers. 1975. Economic and institutional analysis of Colorado water quality management. Completion Report Series No. 61, Environmental Resources Center, Colorado State University, Fort Collins. March.

APPENDIX 1

BASIC HYDROLOGIC AND SALINITY DATA

Table 1-1 presents some of the basic salt loading data which has been published for the Upper Colorado River Basin. Table 1-2 presents a compilation of the significant point sources in the Upper Colorado River Basin. Reservoir storage capacity and locations are presented in Table 1-3.

Table 1-1. Compilation of estimates of salinity contributions for the various areas in the Upper Colorado River Basin.

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR PICKUP MGM/YR	MGM/HA/YR
COLORADO RIVER UPPER MAINSTEM (GRAND DIVISION)					
Above Hot Sulphur Spgs.	Hyatt et al	8901	17241	907	0.11
	EPA (1971)	--	18874	4968	--
	Iorns et al	6352	16605	6352	2.24-1.01
Eagle River	Hyatt et al	8213	184202	27222	3.36
	EPA (1971)	--	162606	--	1.35
	Iorns et al	6433	--	--	--
Above Glenwood Springs	Hyatt et al	27432	553514	58981	2.24
	EPA (1971)	--	579602	102672	4.26
	Iorns et al	21080	580010	111610	3.36
	USDI,BR,1979a	--	537181	--	--
Roaring Fork	Hyatt et al	11005	276757	31759	2.92
	EPA (1971)	8497	329205	66240	7.85
	Iorns et al	12704	272129	85477	6.73
Above Plateau Ck.	Hyatt et al	20392	1397396	27222	1.35
	EPA (1971)	--	1448210	9936	5.16
	Iorns et al	13190	1431877	126855	9.64
	USDI,BR,1979a	--	1387415	--	--
Above Plateau Ck. (inclusive)	Hyatt et al	75903	1397396	146091	2.02
	EPA (1971)	--	1448210	183817	--
	Iorns et al	66112	1431877	330294	4.93
Plateau Ck.	Hyatt et al	8173	43555	2722	--
	EPA (1971)	--	53323	24845	--
	Iorns et al	11774	59979	34481	2.92

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR. PICKUP MGM/YR	MGM/HA/YR
Grand Valley	Hyatt et al	32085	3812895	240461	7.49
	EPA (1971)	35605	3312010	637562	17.94
	Iorns et al	31842	1942562	399800	12.56
	USDI,BR,1979a	30750	--	707772	--
GUNNISON RIVER BASIN					
Above Gunnison	Hyatt et al	20472	115240	17241	0.90
	EPA (1971)	4451	103997	2985	0.67
	Iorns et al	20392	113298	--	--
Above North Fork	Hyatt et al	13230	145184	16333	1.35
	EPA (1971)	--	182496	--	--
	Iorns et al	17155	251441	32666	1.79
Lower Gunnison Uncompahgre R. (total irrig. area Delta-Montrose area)	Hyatt et al	38842	414682	269498	6.95
	EPA (1971)	--	414001	--	10.09
	Iorns et al	--	--	--	--
Gunnison River @Gr. Junction	Hyatt et al	63805	1494488	766753	12.11
	EPA (1971)	68782	1546709	1018443	14.80
	Iorns et al	71412	1378341	812758	11.44-12.11
	USDI,BR,1979a	--	--	--	--
Gunnison River Basin	Hyatt et al	97509	1494488	783086	8.07
	EPA (1971)	--	1546709	1026723	9.42-10.54
	Iorns et al	108999	1378341	886530	8.07
	USDI,BR,1979a	--	1317545	--	--
Mainstem Colorado River above Dolores R.	Hyatt et al	213669	3812895	467583	2.24
	EPA (1971)	--	3709451	--	--
	Iorns et al	218727	3320358	1692301	--
	USDI,BR,1979a	--	3702192	--	7.85

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR PICKUP MGM/YR	MGM/HA/YR
San Miguel River	Hyatt et al	10196	198888	19963	2.02
	EPA (1971)	2428	180173	15235	6.28
	Iorns et al	10358	99088	38020	3.59-6.28
Dolores River (at mouth) (includes San Miguel)	Hyatt et al	5907	453700	9074	1.57
	EPA (1971)	--	549794	--	--
	Iorns et al	4653	417585	64698	2.69
	USDI,BR,1979a	--	433737	--	--
	1976 Mod.	--	433737	--	--
	CWCB, 1972	19036	--	--	--
Above Green River (from Dolores R.)	Hyatt et al	1012	4327391	907	0.90
	EPA (1971)	--	4173133	--	--
	Iorns et al	2225	3815254	12976	5.83
Colorado Mainstem Above Green R.	Hyatt et al	230784	4327391	497527	2.24
	EPA (1971)	235963	4173133	--	--
	Iorns et al	235963	3815254	1807995	7.63
GREEN RIVER DRAINAGE (GREEN DIVISION)					
New Fork River	Hyatt et al	17802	71685	9074	0.52
	EPA (1971)	--	70877	--	--
	Iorns et al	20635	24863	11615	0.56
Big Sandy Creek	Hyatt et al	7283	78944	32666	4.49
	EPA (1971)	5260	275559	66240	12.56
	Iorns et al	5260	58346	44463	8.52
	USDI,BR,1979a	--	163332	--	--
	USDA,SCS,1980a	6352	135384	113334	17.94
	USDI,WPRS (1980a)	--	143006	107255	16.82

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR PICKUP MGM/YR	MGM/HA/YR
Above Green River, Wyoming	Hyatt et al	41512	448255	23592	0.67
	EPA (1971)	32773	857811	19872	0.67
	Iorns et al	35443	457330	111519	3.14
	USDI,BR,1979a	--	575292	--	--
Blacks Fork (inct) Hams Fork	Hyatt et al	26501	177850	16333	0.67
	EPA (1971)	31559	293444	159303	5.16
	Iorns et al	30143	94823	49000	1.57
	CH2-M HILL (1977)	26299	--	113425	4.49
Hams Fork	EPA (1971)	4451	--	15426	3.36
Henry's Fork	Hyatt et al	7283	--	--	--
	EPA (1971)	7283	118905	80486	10.99
	Iorns et al	9023	--	--	--
	CH2-M HILL (1977)	7283	--	--	--
Above Yampa River (includes Henry's Fork)	Hyatt et al	9508	697791	59888	6.28
	EPA (1971)	--	639218	--	--
	Iorns et al	13069	877547	70142	5.16
Above Yampa River	Hyatt et al	102607	697791	144277	1.35
	EPA (1971)	103173	639263	325902	3.14
	Iorns et al	104549	877547	290822	2.69
Yampa River (includes Little Snake)	Hyatt et al	35726	408330	49907	1.35
	EPA (1971)	44142	364321	34118	0.67
	Iorns et al	29819	368223	55351	1.79
	CWCB-USDA (1969)	37830	--	--	--
	Austin-Skogerboe (1970)	--	426478	--	--

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR PICKUP MGM/YR	MGM/HA/YR
Brush-Ashley Creeks, Utah	Hyatt et al	9306	69870	10889	1.12
	EPA (1971)	10155	302073	76176	9.42
	Iorns et al	9670	56440	44826	4.71
	Austin & Skogerboe (1970)	--	95277	--	--
Duschesne River above Duschesne, Utah (incl. Strawberry River)	Hyatt et al	6069	136110	2722	0.45
	EPA (1971)	--	106520	--	--
	Iorns et al	2630	66603	20598	7.40
Duschesne River (above Randlett)	Hyatt et al	54014	364775	28129	
	EPA (1971)	67164	659090	447121	0.45
	Iorns et al	54904	417585	295359	6.73
	USDI,BR,1979a		361145	--	5.38
	Austin & Skogerboe (1970)	--	417404	--	--
White River	Hyatt et al	11814	311238	18148	1.57
	EPA (1971)	11329	380881	6624	0.67
	Iorns et al	12300	299986	148814	12.11
	USDI,BR,1979a	--	268590	--	--
	Austin & Skogerboe (1970)	--	326664	--	--
Green River above Ouray	Hyatt et al	219131	1926410	251350	1.12
	EPA (1971)	--	2209111	889942	4.04
	Iorns et al	214478	2184112	857674	4.04
Price River	Hyatt et al	6676	225035	13611	2.02
	EPA (1971)	10115	293090	225217	--
	Iorns et al	6878	204791	86838	12.56
	USDI,BR,1979a	--	217776	--	--

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRRI PICKUP MGM/YR	MGM/HA/YR
San Rafael	Hyatt et al	13352	220498	27222	2.02
	EPA (1971)	14566	297083	96048	6.50
	Iorns et al	14566	155438	104714	7.18
	USDI,BR,1979a	--	172406-187832	--	--
Duschesne River (above Duschesne, Utah) (incl. Strawberry River)	Hyatt et al	6069	136110	2722	0.45
	EPA (1971)	--	106520	--	--
	Iorns et al	2630	66603	20598	7.40
Green River at Green River, Utah (does not incl. San Rafael River)	Hyatt et al	--	2182297	--	--
	EPA (1971)	--	267320	--	--
	Iorns, et al	222773	2406425	947326	4.26
	USDI,BR,1979a	--	2369221	--	--
Dirty Devil	Hyatt et al	10034	--	--	--
	EPA (1971)	10115	160610	31795	3.14
	Iorns et al	9427	179302	48546	5.16
	USDI,BR,1979a	--	181480	--	--
Escalante River	Hyatt et al	2428	--	--	--
	EPA (1971)	--	--	--	--
	Iorns et al	2832	22866	7350	2.69
Paria	Hyatt et al	1214	--	--	--
	EPA (1971)	--	14246	--	--
	Iorns et al	1214	31124	1906	1.57
	USDI,BR,1979a	--	27222	--	--

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR PICKUP MGM/YR	MGM/HA/YR
SAN JUAN RIVER BASIN					
Above Arboles, CO	Hyatt et al	4046	73499	5444	1.35
	EPA (1971)	--	123860	--	--
	Iorns et al	5381	69870	11705	2.24
Below Navajo Res. (Archuleta, NM)	Hyatt et al	22132	178758	17241	0.9
	EPA (1971)	--	325575	--	--
	Iorns et al	26946	169684	36296	1.35
	USDI,BR,1979a	--	180573	--	--
Animas River	Hyatt et al	11410	223220	29944	2.69
	EPA (1971)	--	264961	--	--
	Iorns et al	14444	--	--	--
La Plata	Hyatt et al	10520	27222	7259	0.67
	EPA (1971)	--	34753	--	--
	Iorns et al	10520	25498	17785	1.68
Above Bluff, Utah	Hyatt et al	27311	916474	58981	2.24
	EPA (1971)	--	1357924	20326	--
	Iorns et al	26744	90468	187923	6.95
	USDI,BR,1979a	--	887437	--	--
McElmo	USDI,BR,1979a	--	108888	--	--
San Juan (above Lake Powell)	Hyatt et al	84602	916474	131573	1.57
	EPA (1971)	--	1318180	--	--
	Iorns et al	83509	973640	261422	3.14
	USDI,BR,1979a	--	887437	--	--

Table 1-1. (continued)

AREA	DATA SOURCE	IRRI-GATED HECTARES	TOTAL MGM AT POINT	IRR PICKUP MGM/YR	MGM/HA/YR
Total Above Lee's Ferry, AZ	Hyatt et al	571659	7776418	970737	1.79
	EPA (1971)	--	5849100	--	--
	Iorns et al	570486	7481751	3155484	5.61
	USDI,BR,1979a	--	7082257	--	--

Table 1-2. Significant Identified Point Sources in the Upper Colorado River Basin, Springs and Abandoned Flowing Wells.

Source	Estimated Discharge l/s	Approx. Concentration ppm	Estimated Salinity Contribution Mgm/y	Data Source*
GRAND DIVISION				
Hot Sulphur	<2.8	1200		1
Springs			136	2
	<5.6	1650		3
Dotsero Springs			293026	4
-Glenwood			450335	2
Springs			417312	3
	850.	14420	489570	5
	991	15130	466754	6
Arsenic Springs	56.6	2000	3629	6
	56.6	2030	3629	5
Ouray Hot	<28.0	1500	1270	1
Springs			1497	2
Ridgeway	25.5	2800	2268	6
Springs	28.3	2850	2313	5
Paradise Hot	2.00	6300		1
Springs	3.12	5490	562	8
			562	2
Donton Hot Springs	2.0	1300		
Castle Creek Springs	7.08	4390	962	5
Onion Creek Springs	3.40	9120	998	5
GREEN DIVISION				
Steamboat Springs			7947	2
Steamboat Spring	1.13	6170		1
Heart Spring	8.5	900		1
Lithia Springs	0.6	5770	100	5
Steele Hot Springs	5.6	300		3
Kendall Springs	220		8891	
Warren Bridge	85	1000		

Table 1-2. (continued)

Source	Estimated Discharge l/s	Approx. Concen-tration ppm	Estimated Salinity Contribu-tion Mgm/y	Data Source*
Ragen/Reagan			662	
Spring	2.6	9210	726	
Abandoned Coal			1987	
Mine (Oak Ck.,	20	3400	2087	6
CO)	19	3430	2050	5
Ashley Valley	0.2	2670	5262	
Oil Field				
Split Mountain			16874	2
Spring	556	1000	17872	6
Iles Dome Oil	8.2	2180	5625	5
Field				
Meeker Dome			24494	7
Oil Well				1
	88	18900	49896	6
Piceance Creek	0.6	4650	65	5
Spring				
Yellow Creek				
Spring	2.55	9370	762	5
Crystal Geyser	42.5	13100	17509	6
	5.66	14000	2722	5
SAN JUAN DIVISION				
Pagosa Springs	17.0	3300		1
	56.6	3600		3
			6623	2
	55.1	3200	6623	6
Pinkerton Hot	14.16	3670	1651	5
Springs	3.4	3900		1
			1633	2
Trimble Hot	14.16	3700	1633	6
Spring	19.82	3250	33	5
IornWash and				
Buckhorn Sprs.	-	-		
(San Rafael (R.)	-	-		
Loa Fish Hatchery	-	-	163	2
(Dirty Devil R.	-	-	2631	2

*1 = Barrett and Pearl, 1978.
2 = EPA, 1971.
3 = Iorns, et al., 1968.
4 = Hyatt, et al., 1970.
5 = USBR, 1979, p. 31.
6 = Hagen, 1971.
7 = WPRS, 1980, Personal Comments.

Table 1-3. Usable active storage capacity of major irrigation and power reservoirs in Upper Colorado River Basin.

	ha-m
Colorado	
Shadow Mountain	220
Lake Granby	57,400
Willow Creek	1,120
Williams Fork	890
Troublesome	130
Barber	550
Green Mountain	18,100
Robinson	310
Ivanhoe	170
Missouri Heights	350
Harvey Gap	590
Leon Lake	370
Big Creek No. 1	330
Bonham	150
Atkinson	180
Cottonwood Lake	350
Vega	4,020
Rifle Gap	1,500
Gunnison River	
Taylor Park	13,100
Gould	740
Crawford	1,730
Overland	320
Island Lake	140
Deep Ward Lake	170
Baron Lake	120
Eggleston Lake	330
Trickle Park Lake	400
Cedar Mesa	120
Fruitgrowers	550
Paonia	2,250
Blue Mesa	102,300
Morrow Point	14,400
Crystal	3,200
Silver Jack	1,670
Ridgeway	6,780
Green River	
New Fork Lake	2,800
Willow Lake	1,860
Fremont Lake	1,330
Boulder Lake	1,580

Table 1-3. (continued)

	ha-m
Juan Lake	620
Captain Tom	210
Jackson Gulch	1,210
Bauer Lake	130
Summit	590
Narraguinnep*	1,150
Wheatfield	120
Many Farms	3,080
Lower Rock Point	120
Marsh Pass	140
Lemon	4,810
Navajo	209,000
Ridges	16,000
Southern Ute	4,930
Price River	
Fairfield	230
Scofield	8,110
Desert Lake	900
Olson	430
San Rafael	
Huntington North	480
Cleveland	290
Joes Valley	6,730
Millers Flat	690
Ferron	150
Buckhorn	190
Dolores River	
Groundhog	2,680
Buckeye	370
Lake Hope	280
Trout Lake	330
Gurley	1,080
Lone Cone	220
Valley City	220
McPhee	28,200
Fremont (Dirty Devil) River	
Fish Lake	490
Forsythe	420
Johnson Valley	490
Mill Meadows	640
Bourns	390

Table 1-3. (continued)

	ha-m
Escalante River	
Spectacle Lake	150
Colorado	
Lake Powell	3,083,000

*filled from Dolores River

APPENDIX 2

DESCRIPTION OF PL 93-320 SALINITY CONTROL PROJECT IN UPPER COLORADO RIVER BASIN

NONPOINT SOURCE SALINITY CONTROL PROJECTS

The Grand Valley

The Grand Valley (Figure 2-1) is located in west central Colorado near the western edge of Mesa County, and receives an average annual precipitation of only 210 mm. Grand Junction, the largest city in Colorado west of the Continental Divide, is the population center of the valley. The valley was carved in the Mancos shale formation by the Colorado River and its tributaries. The Colorado River enters the valley from the east, is joined by the Gunnison River at Grand Junction and then exists to the west.

Salinity Contribution--

The Grand Valley was identified as an important agricultural source of salinity in the Colorado River Basin through a water and salt mass balance. Iorns et al. (1965) evaluated stream gaging records for the 1914 to 1957 period, concluding that the net salt loading (salt pickup) from irrigation ranged from about 450,000 to 800,000 Mgm annually. Similar analyses by Hyatt et al. (1970), Skogerboe and Walker (1972), and the WDI, Geological Survey (1976) substantiated this range of salt loadings. Most studies indicate an average, long-term salt pickup rate of between 600,000 to 700,000 Mgm/yr. This mass of salts is added

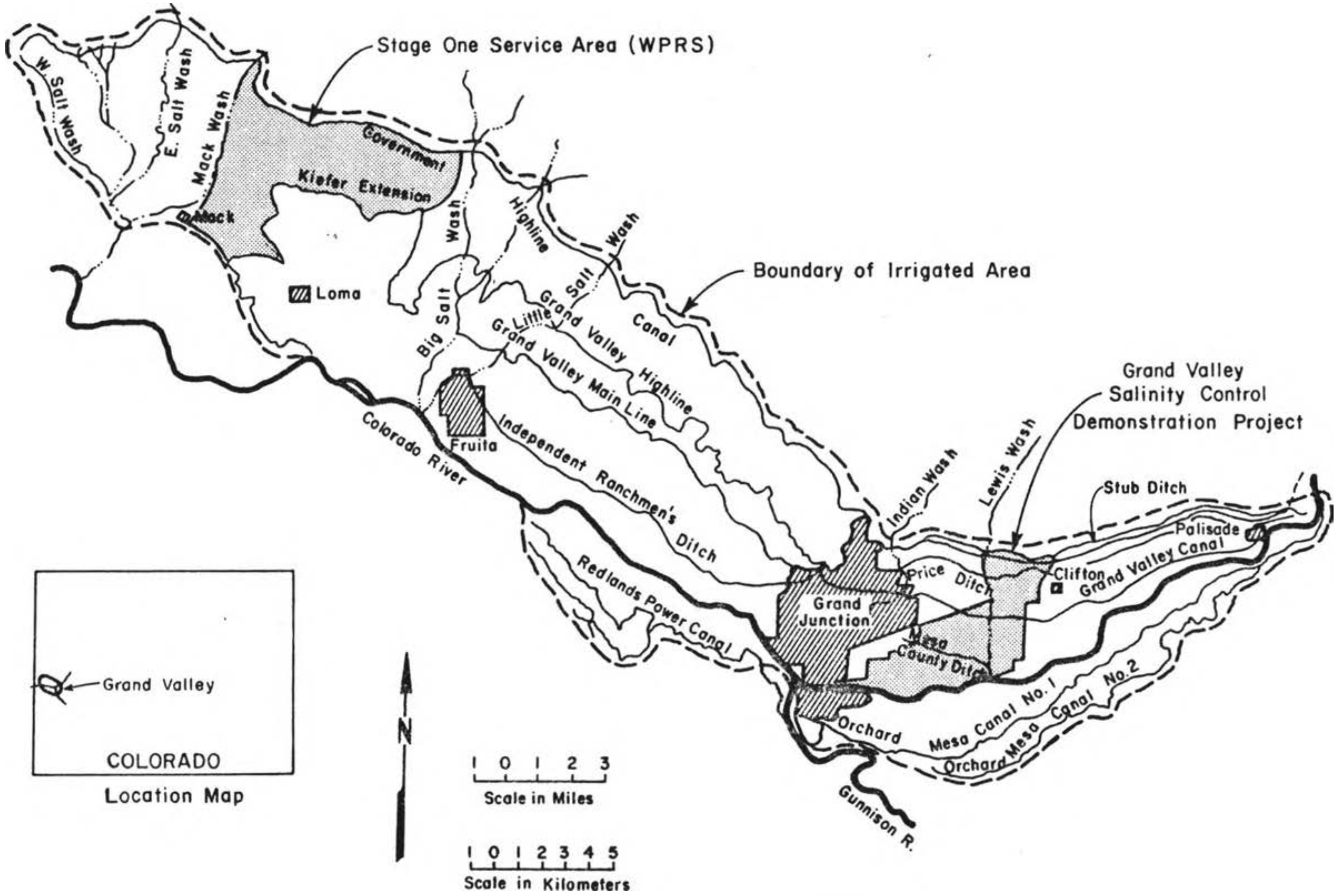


Figure 2-1. The Grand Valley Canal System also showing location of the Grand Valley Salinity Control Demonstration Project and Stage One of the USDI, WPRS.

primarily by irrigation return flows, thereby necessitating a delineation of the components and practices.

Probably no other single issue has been considered with more intensity by the several research and planning groups associated with the Grand Valley than the total and relative sources of contributions to the net salt loading from the valley. This figure is central to any salinity study because it defines the boundaries within each segment that the agricultural hydrology must fit. By subtracting the salt carried in the irrigation water supplies from the volume of subsurface and drainage return flow, the net agricultural contribution can be delineated.

At the time of this writing, there are basically two principal hydro-salinity budget estimates for the Grand Valley (Table 2-1). In various meetings and conferences, the differences have been noted and the essential areas of disagreement identified. It should be noted that the basis of the Kruse (1977) estimate has been expanded to be congruent with the analyses of Walker et al. (1977).

Salinity Control--

The Grand Valley is presently the site of the only active salinity control program in the Upper Colorado River Basin. The programs under way include water systems improvement (canal and lateral lining), irrigation management services (irrigation scheduling), and the Soil Conservation Service sponsored on-farm improvements. When implemented, this total program is expected to reduce the salinity by

Table 2-1. Mean annual Grand Valley water and salt budgets (Walker, et al., 1977).

	Water (ha-m)		Salt (Mgm)	
	Walker, et al.	Kruse	Walker, et al.	Kruse
River Inflows				
Plateau Creek	13,800	13,800	62,600	62,600
Colorado River near Cameo	297,650	297,650	1,352,600	1,352,600
Colorado River near Grand Junction	178,000	178,000	1,371,700	1,371,700
	489,450	489,450	2,786,900	2,786,900
Evaporation and Phreatophyte Use (net)	3,450	2,950	--	--
Canal Diversions				
Lateral Diversions	52,900	54,100	301,100	307,900
Seepage	3,700	7,620	21,100	43,400
Operational Wastes	12,400	22,100	70,600	125,800
	69,000	83,820	392,800	477,100
Lateral Diversions				
Seepage	5,300	6,100	30,200	34,700
Field Tailwater	24,600	25,140	140,000	143,100
Cropland Consumptive Use	18,600	19,100		
Cropland Precipitation	-3,100	-3,100		
Deep Percolation	7,500	6,860	130,900	130,100
	52,900	54,100	301,100	307,900
Irrigation Return Flows (Subsurface)[a]				
Canal Seepage	3,700	7,620	163,200	268,500
Lateral Seepage	5,300	6,100	232,200	231,700
Deep Percolation	7,500	6,860	416,800	368,000
Phreatophyte Withdrawals (net)	-8,100	-8,400		
	8,100	12,180	812,200	868,200
Irrigation Return Flows (surface)				
Operational Wastes	12,400	22,100	70,600	125,800
Field Tailwater	24,600	25,140	140,000	143,100
	37,000	47,240	210,600	268,900
River Outflows				
Colorado River at Colorado-Utah State Line	462,100	462,100	3,445,900[b]	3,518,500[c]

[a]This segment of the budget includes all salt pickup and mass balance for salts will not be achieved.

[b]Includes 30,000 Mg of naturally contributed salts.

[c]Includes 72,600 Mg of naturally contributed salts.

Note: 1 ha-m = 8.108 acre-ft; 1 Megagram = 1.102 English short tons.

372,000 Mgm/yr or a reduction of approximately 43 mg/l at Imperial Dam (USDI, BR, 1979a). Tables 2-2 and 2-3 describe the canal and lateral characteristics of the Grand Valley area. Table 2-4 presents the optimization parameters for the Grand Valley canals.

An initial phase of the water systems improvement portion of this project, known as Stage One, is to be constructed in FY1981 in a study on the western end of the valley. A portion of the Government Highline Canal would be lined, and the laterals lined or placed in pipe to reduce seepage. A wildlife area and watering ponds will be provided by the WPRS to compensate for wildlife habitat losses resulting from implementation of the total program.

Stage One is being constructed with an extensive monitoring network to quantitatively determine the project effects on reducing salinity and damages to wildlife. The results from Stage One will be thoroughly evaluated before deciding to proceed with the rest of WPRS program. This initial phase is projected to decrease the salinity concentration at Imperial Dam by 2.5 mg/l by the reduction of 21,800 Mgm of salt from the river. Approximately 11 kilometers of canal and 49 kilometers of laterals will be lined. The construction bids for Stage One canal lining were opened in June, 1980, and the cost will be $7.4 million.

The Grand Valley is the site of a sizeable on-farm water management improvement program for salinity control. The SCS is participating on lateral improvements outside of

Table 2-2. Maximum Salt Load Reductions of the Grand Valley Canal Systems.

	Area Served (ha)	Length (m)	Maximum Inlet Capacity (m^3/s)	Inlet Wetted Perimeter (m)	Days of Operation	Seepage Rate $m^3/m^2/day$	Maximum Salt Load Reduction (Mgm)	Annual Cost of Linings	Estimated mg/l at Imperial Dam
Government Highline	10220	73700	16.99	19.19	214	0.091	48671	$2080650	-5.61
Grand Valley Canal	1790	19800	18.41	16.67	214	0.045	9550	780236	-1.12
Grand Valley Mainline	3250	21700	7.08	13.86	214	0.061	7340	427274	-0.86
Grand Valley Highline	3040	37000	8.50	12.62	214	0.061	19229	918479	-1.77
Kiefer Extension	2460	24500	3.96	7.25	214	0.061	4640	392921	-0.55
Mesa County Ditch	536	4000	1.13	6.67	214	0.061	622	39074	-0.09
Independent Ranchmens Canal	990	17400	1.98	3.17	214	0.061	1754	232437	-0.22
Price Ditch	1750	9500	2.83	7.27	214	0.061	1693	129231	-0.21
Stub Ditch	245	11300	0.85	2.94	214	0.061	830	104518	-0.11
Orchard Mesa Power	225	3900	24.07	18.20	365	0.076	6358	182205	-0.75
Orchard Mesa Canal #1	1900	24100	3.12	6.46	214	0.076	4517	332056	-0.54
Orchard Mesa Canal #2	1230	26100	1.98	3.58	214	0.076	2816	310829	-0.34
Redlands Power Canal	80	2900	24.07	16.88	365	0.065	3752	135486	-0.45
Redlands Canals	1160	10800	1.70	3.95	214	0.137	2207	119482	-0.27
TOTAL							109980	6184880	-12.90

Table 2-3. Maximum salt load reduction from laterals in the Grand Valley Lateral Systems.

Canal Name	Estimated Length (m)	K'	K_2'	A	B	Maximum Salt Load Reduction Mgm	Annual Cost of Linings	Estimated mg/l @ Imperial Dam
Government Highline	154090	54282670.2	0.374	-3.9164E-08	8.8649E-02	54695	632264	-6.30
Grand Valley	38760	9467436.2	0.138	-2.2517E-07	4.6307E-02	5073	112329	-0.60
Grand Valley Mainline	56009	13678442.4	0.194	-1.5585E-07	6.5305E-02	10337	162292	-1.21
Grand Valley Highline	58350	12979594.0	0.184	-1.6436E-07	6.7432E-02	10186	154901	-1.19
Kiefer Extension	31710	7053691.9	0.184	-3.0243E-07	6.7432E-02	5535	84180	-0.65
Mesa County	15070	3680966.6	0.194	-5.7914E-07	6.5305E-02	2782	43674	-0.34
Independent Ranchmen's	26700	5939248.7	0.184	-3.5910E-07	6.7432E-02	4661	70880	-0.55
Price Ditch	73100	14532272.2	0.172	-1.4691E-07	7.0030E-02	11933	174775	-1.39
Stub Ditch	9700	1928359.0	0.172	-1.1072E-06	7.0030E-02	1583	23192	-0.20
Orchard Mesa Power	8820	1641494.1	0.210	-1.3012E-06	9.1094E-02	1762	19839	-0.22
Orchard Mesa No. 1	44700	8886355.3	0.219	-2.4026E-07	8.9129E-02	9287	106874	-1.09
Orchard Mesa No. 2	35400	7037516.2	0.219	-3.0337E-07	8.9129E-02	7355	84638	-0.86
Redlands Power	0	0.0	0.169	0.0000E 00	0.0000E 00	0	0	0.00
Redlands 1 and 2	42000	7816638.5	0.393	-2.7326E-07	1.7048E-01	15700	94472	-1.82
TOTAL						140989	1764311	-16.43

Table 2-4. Optimization parameters for the Grand Valley Canal Systems.

Canal Name	K'	K_2'	A	B
Government Highline	23883837.3	1.270	-2.8063E-07	3.7051E-02
Grand Valley	28013478.1	0.545	-8.7154E-09	1.3072E-02
Grand Valley Mainline	4594469.9	0.615	-1.3538E-06	2.7116E-02
Grand Valley Highline	14736692.1	0.560	-2.3255E-07	2.0123E-02
Kiefer Extension	4112075.6	0.321	-1.2624E-06	1.7667E-02
Mesa County	287117.6	0.296	-2.1861E-05	2.9497E-02
Independent Ranchmen's	2849748.0	0.141	-1.2442E-06	9.7295E-03
Price Ditch	1203596.9	0.324	-5.1018E-06	2.1737E-02
Stub Ditch	755150.2	0.130	-7.0632E-06	1.3803E-02
Orchard Mesa Power	14746561.8	1.716	-1.4504E-07	3.5816E-02
Orchard Mesa No. 1	3055058.8	0.357	-2.1815E-06	2.3457E-02
Orchard Mesa No. 2	2677510.5	0.198	-2.2929E-06	1.5519E-02
Redlands Power	10965392.1	1.362	-1.9505E-07	2.8427E-02
Redlands 1 and 2	964280.7	0.393	-6.8359E-06	3.3560E-02

the Stage One and on-farm improvements throughout the valley. The SCS is estimating total costs of automated surface irrigation systems ranging from \$30-\$50/m for a pipeline-gated pipe system and \$30-\$40/m for an automated concrete ditch system. The only sprinkler systems which are presently eligible for cost sharing are the very expensive buried solid-set systems.

At the present time, the Agricultural Conservation and Stabilization Service is cost sharing on a 90-10 percent ratio for automated systems, making even these high costs less than total farmer financing costs for conventional systems. However, if the ASCS reverts back to the more common 75-25 percent cost sharing ratio, the automation program will not be as acceptable because the 25 percent costs are the comparable or greater than the full cost of conventional concrete ditch linings and siphon tube systems which the farmers in that area generally prefer.

Skogerboe (1980) indicates that most of the automation installed in the Grand Valley is not being used as automated, but as traditional systems. Thus, the anticipated benefits of increased efficiencies due to automation have not materialized. And, until water supplies become limiting in the area, it is doubtful that automation would be generally accepted. This lack of acceptance of automation is also partially due to little technical assistance and follow through by the SCS and other agencies.

Lower Gunnison Salinity Control Unit

The Lower Gunnison area encompasses about 74,800 hectares of irrigated land (Figure 2-2). In an average year, approximately 3,250 hectares are idle (USDA, SCS, 1976, 1979c). Five federal reclamation projects provide full or supplemental service to about 44,300 hectares: (1) the Uncompahgre Project -- 30,900 ha; (2) Fruitgrowers Dam Project -- 1,090 ha; (3) Paonia Project -- 6,200 ha; (4) the Smith Fork Project -- 3,840 ha; and (5) the Bostwick Park Project supplies water to an additional 2,270 ha in the Cimarron Creek Drainage about 15 km east of Montrose. The irrigated areas which contribute the most salinity to the Lower Gunnison River are in the Smith Fork-Crystal, North Fork and Uncompahgre Subbasins.

Salinity Contribution--

The approved 208 plan for the area (Colorado Department of Local Affairs, 1979) stated that agriculturally induced salinity is the most significant water quality problem in the area. However, that report erred in reporting that salt levels do not cause problems within the region. This is refuted by observing the large amounts of waterlogged, salinized soils as a result of overirrigation and restricted drainage.

Iorns et al. (1965) estimated that 71,480 hectares of irrigated land along the Lower Gunnison-Uncompahgre Rivers produced an average of 11.4 Mgm/ha for a total of 812,800 Mgm. The USDI, BR (1979a) estimates the total annual salt

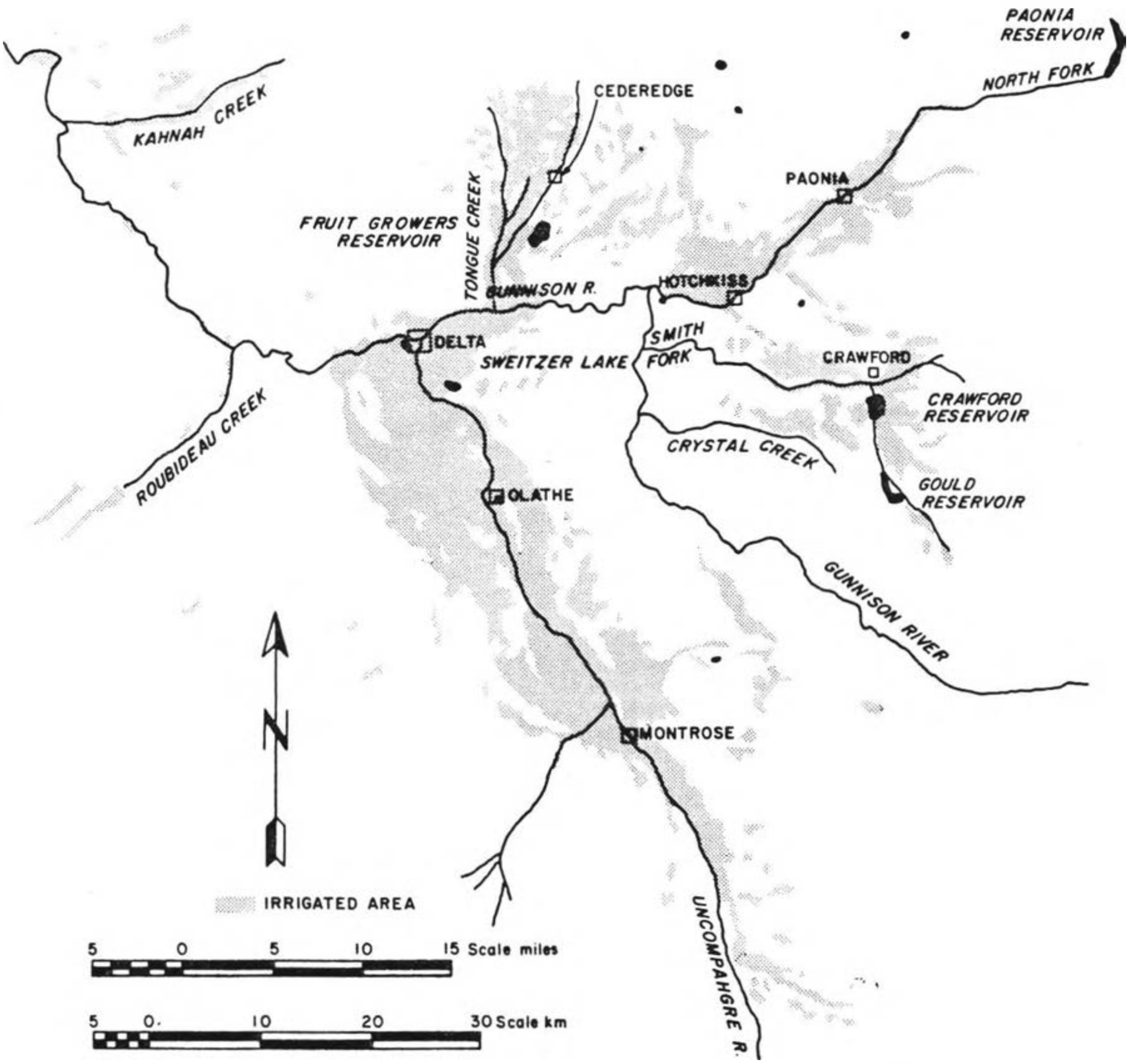


Figure 2-2. Irrigation areas in the Lower Gunnison Salinity Control Project area.

load from the Lower Gunnison at 1.0 x 10^6 Mgm for a total average salt load of about 13.5 Mgm/ha. The EPA (1971) computed the salt load from the areas above the Curecanti Project to vary from 0.67 Mgm/ha to about 2.25 Mg/ha, and that the irrigation of 66,420 hectares in the Lower Gunnison Valley annually contributed about 15 Mgm/ha. Primarily as a result of agricultural activities, the average flow weighted concentration of the Uncompahgre River rises from about 200 mg/l at Ouray to over 1,100 mg/l near Delta.

A memorandum of the USDI, BR (1978) calculated the two year average (1976-77) of irrigation-related salinity contribution for the area. The Mancos shale soils on the east side of the Uncompahgre River contributed a total of approximately 253,000 Mgm or average of 15 Mgm/ha of salt to the river, while the terrace deposits on the west side annually contributed about 100,000 Mgm or an average of about 4.5 Mgm/ha. This difference is due to low amounts of salt inherent in the soils of the terraces, and relatively short travel times for the groundwater to be in contact with the underlying Mancos shales. Figure 2-3 illustrates the extent of the Mancos shale and terrace deposits in the area. The numbers and letters on Figure 2-3 correspond to the same designations on Table 2-5.

The WPRS is presently only investigating lands under the Uncompahgre Project which is about one-half of the total irrigated area and accounts for about one-third of the salinity. The majority of the remaining irrigated lands are

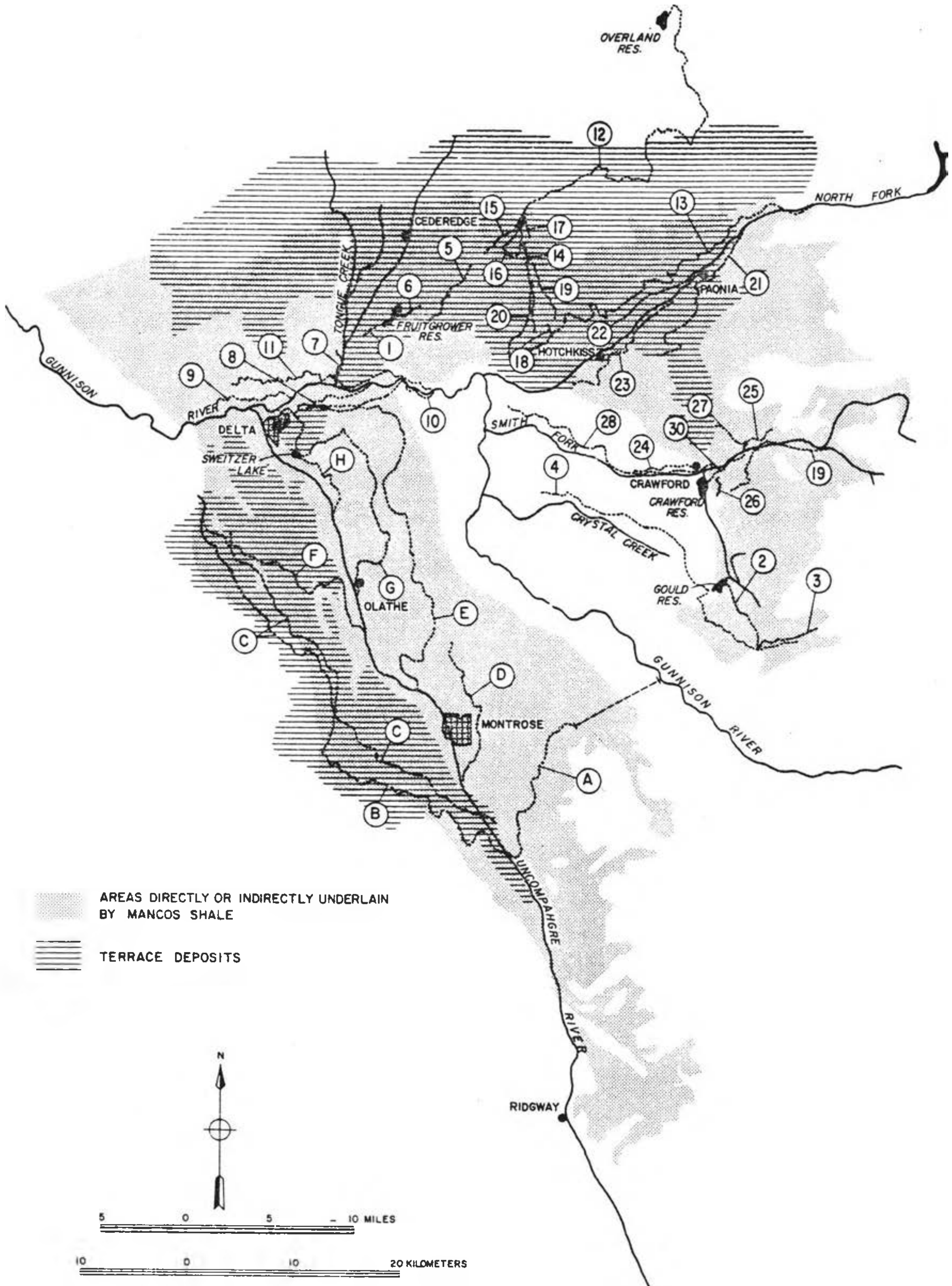


Figure 2-3. Areal extent of Mancos shale and terrace deposits in the Lower Gunnison. Numbers and letters refer to the same designations on Table 2-5.

Table 2.5. Maximum salt load reduction for canals and ditches in the Lower Gunnison System.

Canal Number	Canal Name	Area Served (ha)	Length (m)	Estimated Maximum Inlet Capacity m^3/s	Estimated Inlet Wetted Perimeter (m)	Days of Operation 1	Estimated Seepage Rate $m^3/m^2/day$	Maximum Salt Load Reduction of Lining	Annual Cost	Estimated mg/l @ Imperial Dam 1
	Large Canals									
1	Stell	730	900	2.00	7.34	180		84	11224	-0.03
2	Cedar Canon	1140	16700	1.78	4.73	180		2698	199695	-0.72
3	Dyer Fork	300	4100	0.50	3.10	50	0.120	120	33562	-0.03
4	Fruitland	2020	44900	10.63	14.75	90	0.120	11296	1111511	-1.48
5	Durkee	260	10100	0.71	3.49	180	0.120	2571	90768	-0.44
6	Transfer	0	3800	1.78	4.73	180	0.120	1312	45440	-0.21
7	Park	100	3600	0.53	3.15	180	0.080	145	29833	-0.04
8	Bonafide	1660	13000	1.78	4.73	180	0.120	1432	155451	-0.23
9	Hartland	1140	9800	1.49	4.46	180	0.120	2497	110332	-0.38
10	Relief	1250	16000	1.78	4.73	180	0.120	1980	191325	-0.31
11	North Delta	390	29000	1.06	3.99	180	0.120	2690	293005	-0.44
12	Overland	1590	54900	3.54	9.31	180	0.120	5996	848586	-1.31
14	Highline	550	9700	1.78	4.73	180	0.120	794	115991	-0.22
15	Currant Creek	290	5800	0.43	2.94	180	0.120	295	45636	-0.09
16	Stull	200	5400	1.78	4.73	160	0.120	393	64572	-0.07
17	Cow Creek	210	3600	0.56	3.22	180	0.120	167	25305	-0.04
18	Leroux Creek	1660	400	4.95	10.72	180	0.120	117	8773	-0.04
19	Midkoff & Arnold	80	6100	0.53	3.15	180	0.120	333	50551	-0.06
20	Allen Mesa	400	8500	0.64	3.36	50	0.120	137	74104	-0.04
13	Fire Mountain	3110	56000	6.55	12.05	160	0.120	14700	1323602	-1.92
21	Stewart	1570	25600	2.30	7.78	150	0.120	3271	335796	-0.44
22	North Fork Farmers	690	19600	1.20	4.15	180	0.120	501	205730	-0.08
23	Short	970	18900	0.71	3.49	160	0.120	2231	169853	-0.31
24	Crawford Clipper	1410	9400	3.36	9.12	180	0.080	1610	142419	-0.47
25	Pilot Rock	140	4700	0.53	3.15	180	0.120	505	38949	-0.15
26	Daisy	290	3500	3.36	9.12	180	0.120	1089	53028	-0.25
27	Needle Rock	930	6800	1.59	4.56	180	0.120	1058	78254	-0.29
28	Grandview	1810	28600	4.78	10.56	180	0.080	5673	499210	-1.61
29	Saddle Mountain	890	15700	1.78	4.73	180	0.120	1409	187738	-0.20
30	Smith Fork Feeder	0	5200	3.36	9.12	180	0.120	2562	96434	-0.42
A	South	2840	12300	20.00	19.21	180	0.030	7120	494760	-1.02
B	West	2330	33600	3.10	8.01	180	0.120	3130	472793	-0.83
C	M&D Canal (Mancos)	10230	3200	2.00	7.34	180	0.080	802	47014	-0.24
C	M&D Canal (nonMancos)	0	47300	11.23	15.09	180	0.120	7205	1110350	-1.88
D	Loutzenhizer	2510	18800	2.20	7.64	180	0.080	2560	228150	-0.74
E	Selig	4030	31700	4.00	9.00	180	0.080	5354	480516	-1.52
F	Ironstone (Mancos)	9130	4600	1.05	4.00	180	0.080	709	65869	-0.22
F	Ironstone (nonMancos)	0	25500	7.13	12.48	180	0.120	3212	490023	-0.85
G	East	3100	16900	2.50	8.06	180	0.080	3228	214625	-0.93
H	Garnet	640	15800	2.00	7.34	180	0.000	3176	193436	-0.47
										-21.03

Table 2.5. (continued)

Canal Name	Area Served (ha)	Length (m)	Estimated Maximum Inlet Capacity m^3/s	Estimated Inlet Wetted Perimeter (m)	Days of Operation [1]	Estimated Seepage Rate $m^3/m^2/day$	Maximum Salt Load Reduction of Lining Mgm	Annual Cost ($)	Estimated mg/l @ Imperial Dam [1]
Small Canals [2]									
Circle	40	2100	0.23	2.39	120	0.120	67	3562	-0.03
Whiting	70	3700	0.17	2.16	180	0.120	152	5254	-0.04
P-W	24	2700	0.06	1.53	180	0.120	83	2405	-0.03
Alum Gulch	200	2700	0.25	2.46	180	0.080	156	4224	-0.04
Nyman Comstock	80	3700	0.14	2.03	175	0.080	217	4908	-0.04
Dry Creek	170	2600	0.20	2.20	180	0.120	541	3643	-0.09
Gallant	80	2600	0.17	2.16	180	0.120	615	3692	-0.16
Morton	70	6400	0.14	2.03	185	0.120	1458	8266	-0.19
Newburt	55	1100	0.11	1.87	180	0.080	131	1299	-0.03
Oak Park	110	5800	0.23	2.39	100	0.120	843	9570	-0.12
Fuller No. 2	40	4800	0.11	1.87	175	0.120	1007	5667	-0.13
K-M	95	1500	0.11	1.87	185	0.120	55	1725	-0.03
Perkins	75	1100	0.08	1.68	170	0.120	35	1118	-0.02
Forked Tongue	140	5200	0.17	2.16	185	0.080	101	6730	-0.03
Oasis	130	8900	0.23	2.39	195	0.080	329	14685	-0.06
Shindledecker	100	3000	0.17	2.16	75	0.120	70	4260	-0.03
Duke	80	3500	0.23	2.39	185	0.120	223	5775	-0.04
Lone Rock	120	3700	0.17	2.16	180	0.080	225	5254	-0.06
Virginia	330	1400	0.23	2.39	180	0.080	22	2374	-0.02
Gove	65	4300	0.14	2.03	180	0.080	245	5554	-0.07
Hotchkiss No. 1	26	800	0.03	1.19	185	0.120	27	515	-0.02
Ross	16	1000	0.03	1.19	155	0.120	28	644	-0.02
J.B. Drake	32	2400	0.09	1.71	125	0.080	141	2508	-0.04
Mt. View Mesa	162	5500	0.11	1.89	35	0.120	63	6049	-0.03
Didway	8	1200	0.11	1.89	170	0.120	247	1435	-0.05
P&S	32	1200	0.03	1.19	70	0.120	64	773	-0.03
B&S	32	1500	0.17	2.16	180	0.080	96	2188	-0.03
Combined Ditches [3]									
Alfalfa Run	142	5100	0.03	1.15	105	0.120	69	3174	-0.03
Dry Creek	353	9800	0.04	1.29	110	0.120	890	6970	-0.12
Forked Tongue Creek	55	3100	0.01	0.89	140	0.120	43	1440	-0.02
Leroux Creek	134	4900	0.05	1.43	100	0.120	106	3987	-0.03
Smith Fork River	863	21500	0.03	1.15	125	0.080	513	13379	-0.08
TOTAL							190,000[4]	10,577,247	-22.78

[1] No winter water in canals.

[2] Diversions less than 0.4 m^3/s

[3] Several very small diversions on these drainages combined together and treated as one.

[4] Included 75,000 Mgm due to elimination of winter diversions.

located on Mancos shale derived soils, and, if the 15 Mgm/ha loading were attributed to the rest of these lands, the total salt load would approach the commonly estimated 1.0×10^6 Mgm/yr contribution. PL 93-320 authorized the "Lower Gunnison" as irrigation salinity source control planning unit, and did not specify any measures or only the Uncompahgre River portion of the Lower Gunnison in the language of the Act. Tables 2-5 and 2-6 describe the canal and lateral systems in the Lower Gunnison. Table 2-7 presents the canal optimization parameters for the Lower Gunnison canals.

Salinity Control--

The Regional 208 Water Quality Plan (Colorado Department of Local Affairs, 1979) urges that the total region be evaluated in a salinity control program and that dollars should be spent where the greatest effects can be obtained. Improved water conveyance, distribution, application and removal systems will be required for any agricultural salinity control program. This would also include irrigation scheduling services in conjunction with the other on-farm improvements.

Two major salinity efforts presently being conducted in the Lower Gunnison area are being done by the USDA, Soil Conservation Service (SCS) and the U.S. Department of the Interior, Water and Power Resources Services (WPRS). The WPRS has established an extensive surface and subsurface monitoring program in the Uncompahgre Valley and a surface water quality program in the rest of the Lower Gunnison.

Table 2.6. Maximum salt load reduction of the Lower Gunnison Lateral Systems.

	Estimated Length (m)	K'	K_2'	A	B	Salt	Annual Cost Linings	Estimated mg/l@ Imperial Dam
Stell	16500	5235377.7	0.075	-4.0638E-07	1.9553E-02	1169	61263	-0.15
Cedar Canon	25300	14875240.7	0.448	-1.4245E-07	6.4755E-02	10769	170333	-1.26
Fruitland	43500	15676532.0	0.073	-1.3559E-07	1.6910E-02	3012	182421	-0.36
Durkee	6100	917106.0	0.263	-2.3317E-06	1.3859E-01	1524	11287	-0.19
Bonafide	35200	7948675.9	0.278	-3.1013E-07	4.3153E-02	8805	217830	-1.03
Hartland	25300	11462263.0	0.398	-1.8515E-07	7.4019E-02	9556	132256	-1.12
Relief	27700	6082274.1	0.312	-4.0530E-07	4.8503E-02	7573	166682	-0.89
North Delta	9000	1993772.8	0.106	-1.0700E-06	3.8932E-02	904	23801	-0.12
Overland	34800	9164355.0	0.059	-2.3248E-07	1.8492E-02	1953	108263	-0.24
Highline	12500	2845198.2	0.080	-7.4965E-07	2.8692E-02	949	33985	-0.13
Stull	4700	1247897.9	0.073	-1.7072E-06	2.2671E-02	326	14735	-0.06
Cow Creek	5000	564042.5	0.046	-3.7929E-06	3.1341E-02	218	7158	-0.04
Leroux Creek	36200	8019397.2	0.079	-2.6602E-07	2.8958E-02	2703	95731	-0.33
Midkiff-Arnold	2000	250742.4	0.051	-8.5325E-06	3.1840E-02	97	3143	-0.03
Allen Mesa	9200	1578916.6	0.037	-1.3535E-06	1.7070E-02	320	19207	-0.06
Fire Mountain	64600	63092694.5	0.265	-3.3505E-08	2.3273E-02	16252	715074	-1.89
Stewart	34300	18828700.5	0.186	-1.1258E-07	2.8807E-02	6075	215997	-0.72
North Fork Farmers	15600	5207088.0	0.033	-4.0843E-07	8.1750E-03	485	60792	-0.07
Short	21700	5207686.9	0.151	-4.0941E-07	5.1656E-02	3116	61854	-0.38
Crawford	31000	10127030.8	0.127	-2.1004E-07	3.2360E-02	3737	118346	-0.45
Daisy	6700	725182.4	0.101	-2.9497E-06	7.1475E-02	644	9250	-0.09
Needle Rock	20800	3838678.9	0.139	-5.5646E-07	6.0702E-02	2747	46425	-0.33
Grandview	39300	8313367.5	0.098	-2.5670E-07	3.7656E-02	3655	99547	-0.44
Saddle Mountain	19900	5589442.8	0.097	-3.8099E-07	2.8495E-02	1829	65801	-0.23
South Canal	94500	16359653.4	0.173	-1.5891E-07	2.8388E-02	13883	530233	-1.61
West	27200	7450447.5	0.075	-3.1426E-07	1.1637E-02	1835	165927	-0.23
M&D Canal (Mancos)	3700	2026960.0	0.209	-1.0458E-06	3.2398E-02	735	23254	-0.10
M&D Canal (nonMancos)	164300	45003989.7	0.090	-5.2025E-08	1.3964E-02	13302	1002270	-1.55
Loutzenhizer Canal	36700	5445798.5	0.181	-5.0390E-07	2.9902E-02	5495	202499	-0.65
Selig Canal	75100	41973018.1	0.281	-5.0497E-08	4.2688E-02	20057	481266	-2.32
Ironstone (Mancos)	23300	4033650.0	0.189	-6.4452E-07	3.0969E-02	3734	130735	-0.45
Ironstone (nonMancos)	136500	24926129.4	0.075	-1.0426E-07	1.1690E-02	8698	806586	-1.02
East	80100	13866753.9	0.245	-1.8748E-07	4.0260E-02	16688	449435	-1.94
Garnet	15300	1075500.3	0.136	-2.4370E-06	5.2960E-02	1772	36430	-0.22
TOTAL						174614	6469733	-20.70

Table 2-7. Optimization parameters for the Lower Gunnison canal systems.

Canal Name	K'	K_2'	A	B
Large Canals				
Stell	105615.8	0.155	-4.0772E-05	1.1555E-02
Cedar Canon	1833061.9	0.269	-2.7888E-06	2.1032E-02
Dyer Fork	221368.9	0.049	-1.9878E-05	5.9840E-03
Fruitland	13424561.8	0.419	-3.7817E-07	1.4435E-02
Durkee	664952.3	0.424	-6.9990E-06	4.6321E-02
Transfer	417103.9	0.576	-1.2256E-05	4.4967E-02
Park	199756.7	0.067	-2.2215E-05	8.0963E-03
Bonafide	1426934.4	0.184	-3.5826E-06	1.4337E-02
Hartland	974342.3	0.425	-5.1787E-06	3.5562E-02
Relief	1756226.9	0.206	-2.9109E-06	1.6115E-02
North Delta	2388096.0	0.155	-2.0477E-06	1.4690E-02
Overland	8866494.0	0.182	-5.6691E-07	1.0466E-02
Highline	1064712.6	0.137	-4.8014E-06	1.0664E-02
Currant Creek	285914.0	0.085	-1.4940E-05	1.0857E-02
Stull	592726.6	0.121	-8.6248E-06	9.4793E-03
Cow Creek	173021.2	0.093	-2.5945E-05	1.0956E-02
Leroux Creek	623790.1	0.309	-3.3921E-06	1.3785E-02
Midkoff and Arnold	338476.6	0.091	-1.3111E-05	1.0938E-02
Allen Mesa	525820.4	0.027	-8.7077E-06	3.0493E-03
Fire Mountain	34053476.7	0.309	-7.6882E-08	1.2236E-02
Stewart	3248756.2	0.213	-1.5979E-06	1.4967E-02
North Fork Farmers	1727854.4	0.043	-2.8654E-06	3.8692E-03
Short	1244316.6	0.197	-3.7402E-06	2.1482E-02
Crawford Clipper	1475598.8	0.286	-3.4013E-06	1.6784E-02
Pilot Rock	260793.4	0.179	-1.7016E-05	2.1572E-02
Daisy	549425.1	0.519	-9.1349E-06	3.0486E-02
Needle Rock	701161.7	0.259	-7.2329E-06	2.1177E-02
Grandview	5463874.2	0.331	-9.2606E-07	1.6616E-02
Saddle Mountain	1723297.7	0.150	-2.9665E-06	1.1684E-02
Smith Fork Feeder	6530309.8	0.519	-3.2052E-07	2.7387E-02
South	13975270.1	0.681	-1.8823E-07	1.5730E-02
West	4476564.6	0.169	-1.3757E-06	1.0925E-02
M&D Canal (Mancos)	1502091.3	0.278	-1.5048E-06	1.8259E-02
M&D Canal (nonMancos)	12205506.5	0.290	-5.4270E-07	1.0399E-02
Loutzenhizer	1959704.1	0.259	-3.3582E-06	1.9817E-02
Selig	4618370.9	0.322	-1.4501E-06	1.8906E-02
Ironstone (Mancos)	2296683.0	0.169	-9.5944E-07	1.1442E-02
Ironstone (nonMancos)	5134262.1	0.240	-1.3061E-06	1.0751E-02
East	1892383.1	0.364	-3.4967E-06	2.6329E-02
Garnet	1745076.7	0.350	-3.1961E-06	2.6569E-02
Small Canals				
Circle	286684.4	0.034	-7.4617E-06	1.9385E-02
Whiting	213226.1	0.046	-1.1099E-05	3.0659E-02
P-W	173678.3	0.032	-1.2217E-05	3.5435E-02
Alum Gulch	77242.7	0.077	-4.2746E-05	4.3569E-02
Nyman Comstock	382516.8	0.062	-5.5911E-06	4.5379E-02
Dry Creek	65644.3	0.277	-5.0353E-05	1.7578E-01
Gallant	149834.5	0.263	-1.5794E-05	1.7629E-01
Morton	330825.4	0.253	-7.1517E-06	1.0684E-01
Newburt	99355.0	0.125	-2.1504E-05	1.0348E-01
Oak Park	395897.5	0.162	-5.9758E-06	9.3147E-02
Fuller No. 2	433549.1	0.221	-4.9280E-06	1.8273E-01
K-M	67742.0	0.041	-3.4894E-05	3.3694E-02
Perkins	83126.6	0.034	-2.5633E-05	3.2272E-02
Forked Tongue	119867.6	0.026	-2.7591E-05	1.7770E-02
Oasis	607497.8	0.041	-3.8943E-06	2.3716E-02
Shindledecker	172886.0	0.026	-1.3688E-05	1.7420E-02
Duke	238903.6	0.071	-9.9027E-06	4.0867E-02
Lone Rock	213226.1	0.068	-1.1099E-05	4.5396E-02
Virginia	191122.9	0.016	-1.1193E-05	9.4597E-03
Gove	222273.3	0.063	-1.0644E-05	4.6812E-02
Hotchkiss No. 1	33783.7	0.035	-6.1406E-05	5.3537E-02
Ross	42229.7	0.029	-4.9125E-05	4.4855E-02
J.B. Drake	187630.3	0.062	-1.1364E-05	5.7628E-02
Mt. View Mesa	126079.3	0.014	-2.3325E-05	1.1799E-02
Didway	110032.8	0.217	-1.9420E-05	1.7681E-01
P&S	50675.6	0.056	-4.0937E-05	8.5417E-02
B&S	172886.0	0.068	-1.2375E-05	4.5266E-02
Combined Ditches				
Alfalfa Run	205386.7	0.014	-1.0061E-05	2.2427E-02
Dry Creek	473557.4	0.096	-4.4223E-06	1.3148E-01
Forked Tongue Creek	80969.3	0.015	-2.4184E-05	3.1032E-02
Leroux Creek	281399.3	0.023	-7.5087E-06	2.7476E-02
Smith Fork River	865846.0	0.025	-2.3865E-06	3.9532E-02

The SCS program varies from the WPRS in that it includes the entire Lower Gunnison drainage (Smith Fork, North Fork and Uncompahgre). SCS studies in 1980 indicate several areas including North Delta, Tongue Creek, certain areas near Hotchkiss, Paonia and Crawfords also contribute high salt loads (USDA, SCS, 1979a).

The approved Colorado State 208 Plan for the area has also specifically identified the Tongue Creek below Cedaredge area for improvement. Tongue Creek flows into the Gunnison River from the northwest just above Delta. These lands include about 1,960 hectares in the North Fork subbasin. Much of this irrigated area is also underlain by Mancos shales. There are about 66 km of canals and 134 km of farm ditches serving the area. Nearly all the irrigation in Tongue Creek is by gravity surface methods (Kepler, 1979). Annual diversions from the major Tongue Creek has averaged about 1,585 ha-m for an average of 0.97 ha-m/ha which is below the average for the rest of the Lower Gunnison.

Due to the steep topographic conditions and the crops grown, much of the irrigated area in the North Fork and Smith Fork subbasins is almost ideally suited for gravity, pressurized sprinkle irrigation systems. Properly designed and operated sideroll-wheel move sprinklers would work well on the small grain and forage crops. Considering recent advances in low pressure-low application rate sprinkle equipment technology, undertree sprinklers would be well suited for the orchards. The sprinklers would also offer some energy efficient frost control benefits which would not be available under trickle irrigation. The sprinklers would have to be designed for the low intake capacity of the Mancos shale soils, but could greatly increase the irrigation application efficiency, which is presently estimated by the SCS around 20-35 percent for these areas. In addition, a central pressurized pipeline system would eliminate the seepage losses from the many small and often parallel canals and laterals which often flow relatively long distances to irrigate a few hectares.

Uncompahgre Valley--

The WPRS (USDI, WPRS, 1980c) has developed a preliminary lining program for 540 km of the total 830 km of canals and laterals in the Uncompahgre River area, which covers the area from the towns of Montrose to Delta. Approximately 160 km of the linings are located on the "adobe" or Mancos areas on west side of the Uncompahgre River. WPRS Project personnel are estimating that with the selected program the salinity at Imperial Dam would be reduced by about 20 mg/l or 220,000 Mgm which is 63 percent of the total agricultural salinity contribution from the Uncompahgre Project area. Although this is only an appraisal study, these estimates of salt reduction due to canal and lateral linings even with winter diversions, appear to be much higher than results from other Mancos shale salinity control areas might indicate. This is the result of the incorrect "incremental cost-effectiveness" methodology used, and which is strongly biased in favor of canal linings. In addition, WPRS estimates of on-farm deep percolation are much lower than should be expected. Some of the canal linings included in the WPRS proposal were not on Mancos soil; however, it was believed by WPRS that their low lining costs due to low-gradients and few structures were still less than the expected salinity control benefits.

Re-evaluation and careful analysis of the existing WPRS data on the Uncompahgre Salinity Control Project revealed a total maximum combined salinity contribution from all the canals and laterals to be 203,500 Mgm/yr out of the estimated 352,000 Mgm total agricultural contributions. The west side canal salinity contribution is high because of their long length and of the seepage in the winter months. The on-farm component is about 148,500 Mgm/yr. Approximately 66,850 Mgm are contributed by 106.4 km of large canals and 328 km of laterals on nonMancos areas. About 116,000 Mgm are contributed by the canals and laterals on the Mancos Shales on both sides of the Uncompahgre River. The actual on-farm contribution, including head ditch and tailwater ditch seepage plus deep percolation from the Mancos soils is estimated at about 9.5 Mgm/ha and 1.50 Mgm/ha from the nonMancos area. At the 0.02 m^3/m^2/day effectiveness, a lining program of all canal and lateral sections in only the "adobe" or Mancos soils without reducing winter diversions would reduce the salt load by about 91,000 Mgm. This is roughly translated to a salinity reduction at Imperial Dam of 10.7 mg/l. Stopping the winter livestock in the canals would add another 4.5 mg/l reduction to this figure. A maximum 100 percent effective program lining all of the canals and laterals in the Uncompahgre Valley would reduce the salt load by approximately 23.7 mg/l compared to the WPRS value of 30 mg/l at Imperial Dam, however, much of these linings would not be cost-effective. It is believed that these numbers (Table 2-5) are more realistic values than the initial analysis presented by the WPRS.

A significant problem which must be addressed in a canal and, to a lesser extent, lateral lining program, is the diversion of water in the canals in the winter for livestock use. This practice and the resultant freezing and thawing action would be very destructive to concrete linings and negate their effectiveness in a short time. Also, this practice now adds to the salinity contribution from the area due to the increased seepage volume from the canals.

The local farmers are quite concerned about the availability of "free" water for livestock, and to a certain extent, their cooperation could be dependent on a satisfactory solution to this problem. The low cost of this winter water may, in fact, be an erroneous belief because the practice unquestionably adds substantially to the present operation and maintenance costs as evidenced by the present extensive structure replacement program.

The WPRS is pursuing alternative methods to supply the livestock water, and one of the most probable solutions is to utilize the existing rural potable water districts which cover most of the irrigated areas in the Lower Gunnison. The groundwater is too saline. A problem exists in that the present water district distribution system capacity is presently over-taxed in many areas and may require financial assistance. The subsidies may be outright grants to the water districts or to the farmers or the installation of a new, larger distribution system. In addition, it may be wise to provide for emergence water service in the event of a water supply breakdown due to the heavy water demands of large livestock operations.

If this winter water were stopped as anticipated, it alone would substantially reduce the salinity contribution from the area. On the westside, implementation of only the curtailment of winter diversions may be the most cost-effective salinity control alternative on the nonMancos portions. For the whole canal system, stoppage of winter water with no linings would reduce the annual salt load by an estimated 30,000 to 39,000 Mgm/yr. Damages of $450,000 mg/l at Imperial Dam translates to almost $2.0 million per year damage cost reductions, which theoretically would be available for alternative supplemental winter livestock water supplies in just the Uncompaghre Valley. It is estimated that a total canal lining program and no winter water would reduce the estimated canal salt contribution from 94,650 to 36,500 Mgm/yr.

Uintah Basin

The Uintah (also spelled Uinta) Basin is located in the northeast portion of Utah and is politically composed of Daggett, Duchesne and Uintah counties (Figure 2-4). The major population centers are Duchesne, Roosevelt and Vernal. The 1975 population was about 30,390 people. The projected 1995 population is 60,050 people.

The area is bounded by the Uinta Mountains along the northern flank. The Uinta Mountains have been subjected to repeated glaciation and, as a result, have a spectacular sculptured topography. A portion of this beautiful mountainous region has been designated the High Uintas Primitive Area. The western boundary is the Wasatch Mountains of the Great Basin and on the east and south by the Green River and the Roan Plateau. Flaming Gorge Dam and Reservoir are located along the northeastern edge of the Basin.

As the high quality Uinta Mountain streams enter the lower elevations they traverse several relatively soft geologic formations of heavily weathered rocks, alluvial deposits and residual soils, many of which are high in easily soluble salts. The Duchesne, Myton and Roosevelt areas are primarly underlaid by the Uinta and Duchesne Shales and sandstones which are the most common formations. The Ashley Valley is underlaid by Mancos shale.

The Uintah Basin has several unique physical and socio-economic features which are unique to the Upper Colorado River Basin. For instance, from 1861 to 1905, the majority

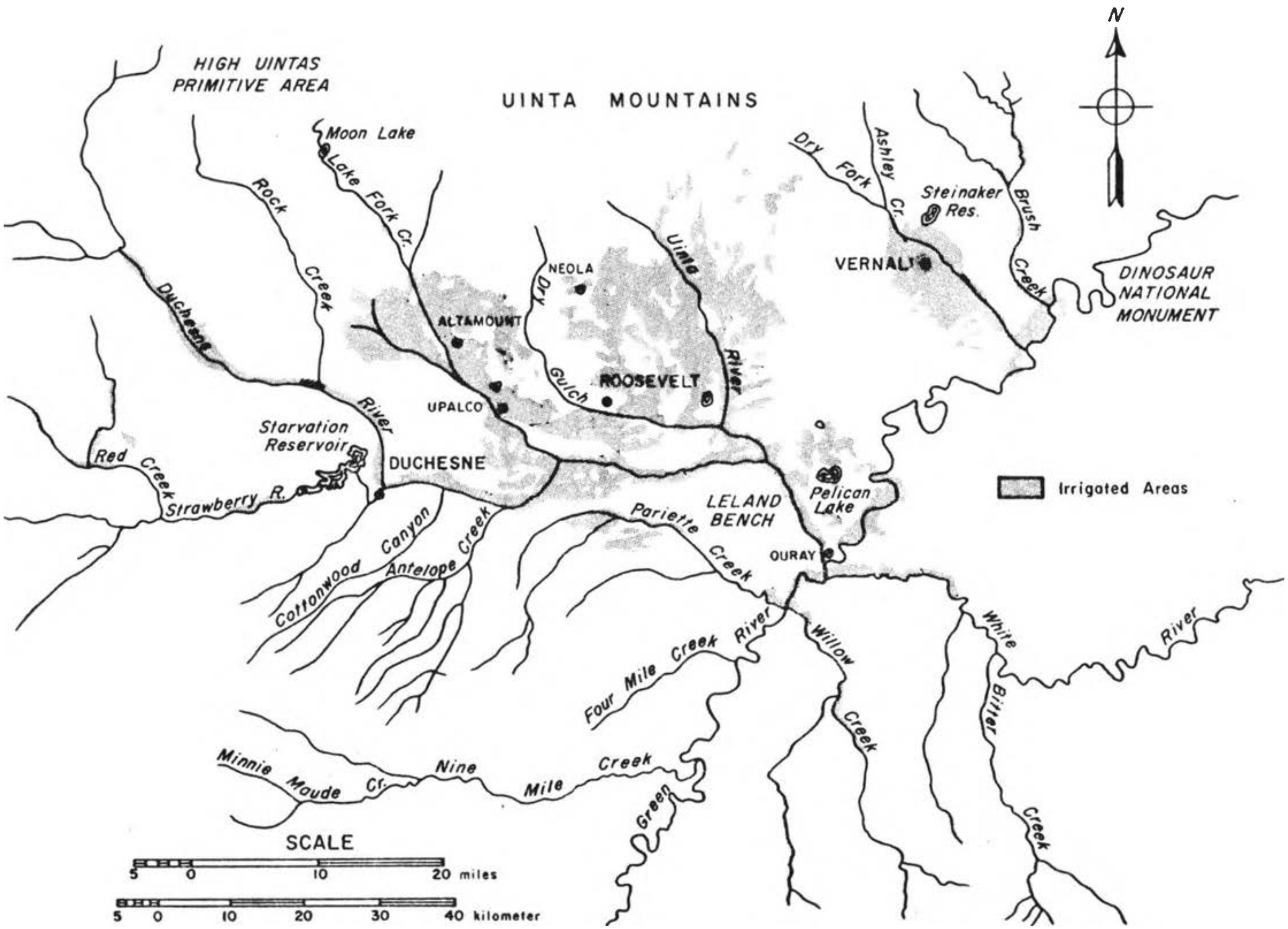


Figure 2-4. Irrigated lands in Uintah Basin, Utah.

of the Basin was allocated to the Ouray and Uintah Indian Reservations. In 1905, the Reservation was opened to non-Indian homesteading and the old reservation became a checker-board of diffuse ownership. To add to the confusion, the water rights for Indian and nonIndian lands are different and range from 0.9 to 1.2 ha-m/ha. Some canals carry both Indian and nonIndian water, each with different water right quantities and priorities. In other cases, duplicate canals, structures and facilities have been constructed in an effort to administer the two types of water and lands.

An ever present source of dissention and controversy in the region is the priority of Ute Indian versus nonIndian water rights as some of the water rights in the basin have never been adjudicated. The Indian, nonIndian differences are also evident in many other areas of the local society. The socio-economic, institutional, and the complex physical constraints will undoubtedly make the implementation of any effective salinity control program in the Uintah Basin a very complicated, and often frustrating experience.

The canal system in the Uintah Basin is a very complex system as can be seen in Figure 2-5. The first conveyance systems in the area were small projects constructed by horsedrawn and hand equipment. These and other canal systems were expanded as the need arose, and the lack of overall coordination of planning is evident in many ways in the system today. It is estimated that there are at least 1,200 km of often intertwining, overlapping and duplicating

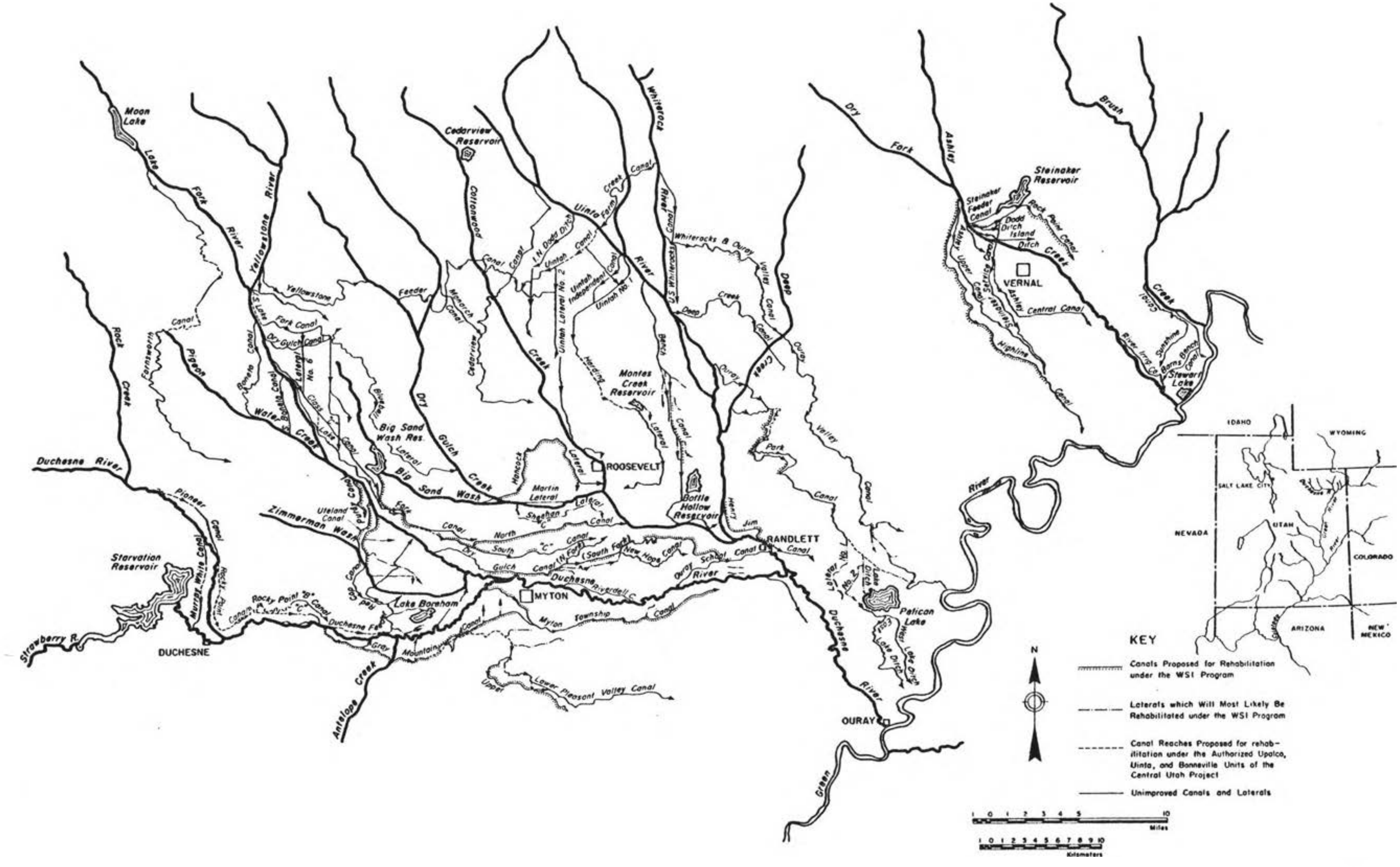


Figure 2-5. Canal system in the Uintah Basin.

major canals and 1,400 km of laterals in the syster
Examinations of U.S. Geological Survey maps and Uta
Engineer's water records indicate at least 100 canal
significant laterals in just the Duchesne-Lake Fork-l
Dry Gulch drainages. Tables 2-8, 2-9 and 2-10 describ
canal and laterals and their optimization parameters i
Uintah Basin.

Many of the paralleling canals and laterals have r
where lush phreatophyte growths and/or alkali flats both
which indicate excessive seepage losses. On the other ha
some canals such as the Midview actually gain water throu
out their lengths because of seepage from higher lands.

Salinity Contribution of the Uintah Basin--

Iorns et al. (1965) included the Uintah Basin as part of their comprehensive water resources study on the Colorado River, and reported that the Duchesne River near Randlett carried a total of about 417,600 Mgm per year of which 295,400 Mgm was attributable to the irrigation of 55,000 ha of land. The EPA (1971) estimated that irrigation in Ashley Valley-Brush Creek contributed 76,200 Mgm and that irrigation in Duchesne River-Uintah River area contributed an average total of 95,300 Mgm and the Uintah Basin a total of 417,400 Mgm per year.

The WPRS (USDI, BR, 1979a) indicates that the Uintah Basin including Ashley Valley and Brush Creek contributes a total salt load of 410,000 Mgm per year. Much of the salt loading is attributed directly to the irrigation of

Table 2-8. Maximum salt load reduction for canal and major lateral lining in the Uintah Basin.

Canal Name	Area Served (ha)	Estimated Length (m)	Estimated Inlet Capacity (m^3/s)	Estimated Wetted Perimeter (m)	Estimated Days of Operation	Estimated Seepage Rate $m^3/m^2/day$	Maximum Salt Load Reduction (Mgm)	Annual Cost of Linings ($)	Estimated mg/l @ Imperial Dam
Highline	710	28900	3.68	9.47	150	0.080	5883	471103	-0.69
Ashley Upper	3960	21200	8.50	13.43	150	0.080	6123	494781	-0.72
Ashley Central	2100	16000	7.08	12.45	150	0.080	4281	344145	-0.51
Rock Point	650	11900	2.27	7.74	150	0.080	2284	170635	-0.28
Island	330	4000	0.85	3.70	150	0.080	269	36634	-0.05
Union	270	13800	1.20	4.15	130	0.080	1479	167874	-0.19
Sunshine	530	10500	1.20	4.15	100	0.080	471	127730	-0.07
Burton	230	4000	1.00	3.91	100	0.080	169	45697	-0.04
Murray	160	3800	0.60	3.29	100	0.080	135	36898	-0.03
Burns Bench	780	8900	1.50	4.48	100	0.080	430	117306	-0.07
Mosby	1270	16000	2.70	8.32	120	0.130	1501	230845	-0.19
US Whiterocks	1090	32700	2.70	8.32	120	0.130	3446	471788	-0.41
Whiterocks and Ouray Valley	3040	24860	6.23	11.80	120	0.130	4171	540435	-0.50
Ouray Valley	930	15400	1.13	4.07	110	0.130	519	106987	-0.08
Ouray Park	1020	30700	2.83	8.49	100	0.130	2011	407905	-0.25
Deep Creek	2480	63200	3.00	8.69	120	0.130	6903	1010951	-0.81
Moffat	750	16100	1.70	4.67	120	0.100	683	219926	-0.10
Henry Jim	410	10300	1.42	4.39	150	0.100	894	135757	-0.12
US Farm Creek	520	23000	2.00	7.34	120	0.130	756	296638	-0.11
Uintah River Canal	4370	9700	9.06	13.80	120	0.130	1510	280735	-0.19
Uintah No. 1	3350	7000	3.68	9.47	120	0.130	748	134898	-0.10
Indian Bench	2390	22100	7.81	12.97	120	0.130	3815	581587	-0.46
Monarch	200	26600	2.00	7.34	120	0.130	1278	399218	-0.17
Martin Lateral	440	9700	0.42	2.92	150	0.080	627	85098	-0.09

Table 2.8. (continued)

Canal Name	Area Served (ha)	Estimated Length (m)	Estimated Inlet Capacity (m^3/s)	Estimated Wetted Perimeter (m)	Estimated Days of Operation	Estimated Seepage Rate $m^3/m^2/day$	Maximum Salt Load Reduction (Mgm)	Annual Cost of Linings ($)	Estimated mg/l @ Imperial Dam
Sheehan Lat.	650	11900	0.57	3.24	150	0.080	851	113806	-0.12
Hancock Lat	830	16700	1.13	4.07	150	0.080	1168	181978	-0.15
Farnsworth	4700	95000	8.50	13.43	120	0.130	5519	2217178	-0.65
F Canal	2200	13600	3.00	8.69	120	0.130	511	204395	-0.08
US Lake Fork	4400	20000	6.00	11.61	120	0.130	1904	400129	-0.13
Lake Fork Western	970	12700	1.90	4.84	120	0.130	307	170297	-0.05
Dry Gulch No. 1	1500	21600	3.00	8.69	120	0.130	1124	373270	-0.15
Bluebell Lat.	1510	23300	3.00	8.69	120	0.130	1213	402648	-0.16
Class C	3590	13100	3.40	9.16	150	0.130	2607	244084	-0.32
Lake Fork	710	30000	1.40	4.37	150	0.080	1114	360426	-0.15
North C Lat.	830	12400	1.13	4.07	150	0.080	1530	150561	-0.19
South C Lat.	1140	11900	1.13	4.07	150	0.080	1468	144490	-0.19
US Dry Gulch	1450	36500	1.70	4.67	150	0.080	4650	514542	-0.55
Purdy	100	4900	0.57	3.24	120	0.080	372	46861	-0.06
Uteland	240	3600	0.42	2.92	120	0.080	261	32058	-0.05
Redcap	950	17000	1.70	4.67	120	0.080	1808	232220	-0.23
A Pioneer	3260	27200	0.70	3.47	150	0.130	3643	249693	-0.44
B Pioneer	560	10500	1.20	4.15	150	0.100	1174	113576	-0.15
Rocky Point	1620	29300	3.30	9.05	150	0.080	5066	457210	-0.60
Gray Mountain	1890	22000	9.10	13.82	180	0.080	10774	645980	-1.26
Pleasant Valley	3540	25700	6.80	12.24	180	0.080	10286	634554	-1.20
Myton Townside	1920	24400	3.70	9.49	150	0.080	3688	367761	-0.44
Duchesne F.	1950	22200	5.38	11.10	180	0.080	6714	453563	-0.79
Pahcease	360	8800	0.71	3.49	150	0.080	882	91510	-0.12
Riverdale	230	8500	0.57	3.24	150	0.080	405	69966	-0.07
Ouray School	850	10100	2.27	7.74	150	0.080	1144	126754	-0.15
TOTAL							119670	15995082	-14.69

Table 2-9. Maximum salt load reduction of the Uintah Basin Lateral Systems.

Canal Name	Estimated Length (m)	K'	K'_2	A	B	Salt	Annual Cost Linings	Estimated mg/l @ Imperial Dam
Highline	33900	14585007.1	0.089	-1.2098E-07	9.3675E-03	2855	316432	-0.35
Ashley Upper	40100	25660285.0	0.112	-7.5415E-08	9.4656E-03	4280	468107	-0.51
Ashley Central	25600	13351503.3	0.099	-1.3892E-07	9.4604E-03	2418	265036	-0.30
Rock Point	19000	7584571.6	0.085	-2.2754E-07	9.3084E-03	1530	170770	-0.19
US Whiterocks	17000	7366911.0	0.044	-2.4002E-07	4.6735E-03	717	159273	-0.10
Whiterocks & Ouray Valley	43000	23334700.3	0.056	-8.0209E-08	5.1743E-03	2273	455311	-0.28
Ouray Valley	27200	4830412.4	0.022	-4.4232E-07	9.9132E-03	566	58596	-0.08
Ouray Park	112300	19878058.6	0.022	-1.0749E-07	1.0142E-02	2384	241197	-0.29
Deep Creek	48700	24471355.4	0.026	-7.5125E-08	2.5052E-03	1193	493838	-0.16
Henry Jim	9400	1717800.0	0.036	-1.2436E-06	1.6055E-02	325	20791	-0.06
US Farm Creek	12000	4602009.6	0.016	-3.7034E-07	1.8366E-03	187	105754	-0.04
Uintah River Canal	39000	27443162.5	0.041	-7.1676E-08	3.2227E-03	1505	483010	-0.19
Uintah No. 1	170800	94012433.9	0.035	-1.9971E-08	3.2347E-03	5691	1823319	-0.67
Indian Bench	76100	40566408.4	0.043	-4.5953E-08	4.0248E-03	3097	797644	-0.37
Farnsworth	48200	37008605.9	0.024	-5.3859E-08	1.7963E-03	1097	631444	-0.14
US Lake Fork	28800	13741311.4	0.018	-1.3207E-07	1.8032E-03	493	283894	-0.08
Lake Fork Western	5000	2332437.1	0.018	-7.7351E-07	1.8011E-03	85	48694	-0.03
Dry Gulch No. 1	10000	4960143.3	0.018	-3.6946E-07	1.8063E-03	175	100681	-0.04
C Canal	20700	12471688.0	0.067	-1.5340E-07	5.8889E-03	1325	233002	-0.17
Lake Fork	17400	6790950.7	0.052	-2.5236E-07	5.7734E-03	859	154661	-0.12
North C Lateral	6000	2328201.8	0.093	-7.3476E-07	1.0330E-02	529	53181	-0.08
South C Lateral	5100	2063838.5	0.095	-8.3971E-07	1.0372E-02	461	46150	-0.07
US Dry Gulch	46400	23358312.7	0.098	-7.8740E-08	9.4740E-03	4303	470991	-0.51
Uteland	5200	789161.9	0.061	-2.7097E-06	3.1777E-02	300	9704	-0.05
Redcap	57200	24190238.8	0.086	-7.2585E-08	9.2096E-03	4694	529243	-0.56
Gray Mountain	30000	30034410.7	0.218	-6.8472E-08	1.3591E-02	6203	471111	-0.73
Pleasant Valley	90300	55832551.4	0.109	-3.4439E-08	9.3386E-03	9310	1032349	-1.09
Myton Townsite	21400	11815713.4	0.090	-1.5901E-07	8.2928E-03	1831	228857	-0.23
Duchesne Feeder	23700	16976346.9	0.110	-1.1620E-07	8.6322E-03	2477	296861	-0.30
Pahcease	2000	318950.3	0.058	-6.7028E-06	2.9096E-02	111	3904	-0.03
Riverdale	18900	3096611.6	0.052	-6.9029E-07	2.5486E-02	939	37817	-0.13
Ouray School	14300	6822942.8	0.076	-2.6598E-07	7.6263E-03	1036	140961	-0.14
TOTAL						65248	10632585	-8.10

Table 2-10. Optimization parameters for the Uintah Canal System.

Canal Name	K'	K'_2	A	B
Highline	5453485.2	0.313	-7.9913E-07	1.7190E-02
Ashley Upper	6393107.1	0.444	-6.8991E-07	1.6599E-02
Ashley Central	4355521.1	0.412	-1.0118E-06	1.6772E-02
Rock Point	2398562.3	0.256	-1.3601E-06	1.6495E-02
Island	258399.5	0.122	-2.1681E-05	1.3191E-02
Union	4866202.1	0.119	-4.4701E-07	9.4694E-03
Sunshine	3702545.1	0.050	-5.8750E-07	3.9658E-03
Burton	1273589.7	0.047	-1.6777E-06	3.9793E-03
Murray	908903.7	0.040	-2.2057E-06	3.9643E-03
Burns Bench	3556073.0	0.054	-6.2328E-07	3.9365E-03
Mosby	2538547.0	0.144	-1.6975E-06	9.0492E-03
US Whiterocks	5188155.4	0.162	-8.3059E-07	1.0165E-02
Whiterocks & Ouray Valley	8798214.4	0.224	-3.7440E-07	9.2802E-03
Ouray Valley	10501327.6	0.035	-1.8634E-07	2.8715E-03
Ouray Park	3684806.9	0.125	-1.8836E-06	8.5554E-03
Deep Creek	14891365.9	0.146	-2.1706E-07	8.3270E-03
Moffat	5519971.3	0.048	-4.2702E-07	3.3976E-03
Henry Jim	7982120.0	0.091	-2.5004E-07	6.8120E-03
US Farm Creek	3084651.8	0.051	-1.3752E-06	3.5886E-03
Uintah River Canal	21220865.0	0.164	-1.0058E-07	5.5319E-03
Uintah No. 1	9246393.6	0.112	-2.2705E-07	5.7154E-03
Indian Bench	22245717.3	0.192	-1.0602E-07	6.9635E-03
Monarch	24972268.3	0.051	-8.1825E-08	3.3059E-03
Martin Lateral	1900031.9	0.072	-9.9665E-07	7.9867E-03
Sheehan Lateral	2765708.7	0.079	-7.1939E-07	8.0921E-03
Hancock Lateral	1897967.2	0.100	-1.8583E-06	8.5880E-03
Farnsworth	28648357.1	0.089	-1.5396E-07	3.3387E-03
F Canal	2288908.0	0.058	-1.8909E-06	3.4685E-03
US Lake Fork	4962450.8	0.077	-8.8672E-07	3.4011E-03
Lake Fork Western	2317049.4	0.032	-1.3931E-06	2.2296E-03
Dry Gulch No. 1	12723635.4	0.058	-1.8125E-07	3.2163E-03
Bluebell Lateral	13725032.6	0.058	-1.6802E-07	3.2163E-03
Class C	16553851.2	0.210	-1.2649E-07	1.1012E-02
Lake Fork	4612989.9	0.049	-6.8401E-07	3.8518E-03
North C Lateral	8455614.4	0.130	-2.3143E-07	1.0514E-02
South C. Lateral	8114662.2	0.130	-2.4115E-07	1.0514E-02
US Dry Gulch	31285551.7	0.134	-6.4644E-08	9.3375E-03
Purdy	1138821.2	0.084	-1.7471E-06	8.5889E-03
Uteland	1410333.0	0.076	-1.2166E-06	8.4434E-03
Redcap	5828541.1	0.122	-4.0441E-07	8.5169E-03
A Pioneer	2026408.7	0.206	-1.8860E-06	2.1460E-02
B Pioneer	1057870.0	0.172	-3.8522E-06	1.4854E-02
Rocky Point	5201599.9	0.266	-8.3494E-07	1.5310E-02
Gray Mountain	96497355.9	0.502	-2.1069E-08	1.6905E-02
Pleasant Valley	23939092.1	0.445	-9.8356E-08	1.7222E-02
Myton Township	3592029.0	0.275	-1.7223E-06	1.6382E-02
Duchesne F.	7254719.1	0.403	-4.5300E-07	1.7845E-02
Pahcease	4625800.6	0.106	-4.0170E-07	9.9962E-03
Riverdale	439001.4	0.087	-1.2052E-05	1.0671E-02
Ouray School	1130974.7	0.206	-5.3800E-06	1.5177E-02

68,850 ha of land served by diversions from the several streams which intersect the valleys.

Salinity Control Investigations--

Under provisions and directives of PL 93-320, the Water and Power Resources Service is presently conducting a limited evaluation of the feasibility and scope of a salinity control program in the Uintah Basin which includes all of the Duchesne River and its tributaries and all of the Ashley-Brush Creek drainages. In a cooperative effort, the USDA, SCS has completed preliminary on-farm salinity control study in the region (USDA, SCS, 1980b). However, the SCS study encompasses a much larger area than the WPRS study (Figure 2-6). The WPRS has eliminated certain upland areas such as the Neola Bench and Altamont section from consideration due to limited water quality sampling and superficial geologic investigation which indicated low salt loading rates, and have concentrated on the low lying portions of the basin. The WPRS is generally concerned with the Lower Duchesne River, Uintah River, Lower Lake Fork and Ashley Valley areas. Agreement on the scope and/or the exact areas in the Duchesne, Lake Fork and Uintah River drainages which should be treated as part of the Uintah Basin Salinity Control Program has not yet been reached between the WPRS and the SCS. Contracts for wildlife, vegetation and archeological studies have been completed by the USDI, WPRS (USDI, BR, 1979c). In addition, limited canal sizing and cross-drainage investigations are continuing.

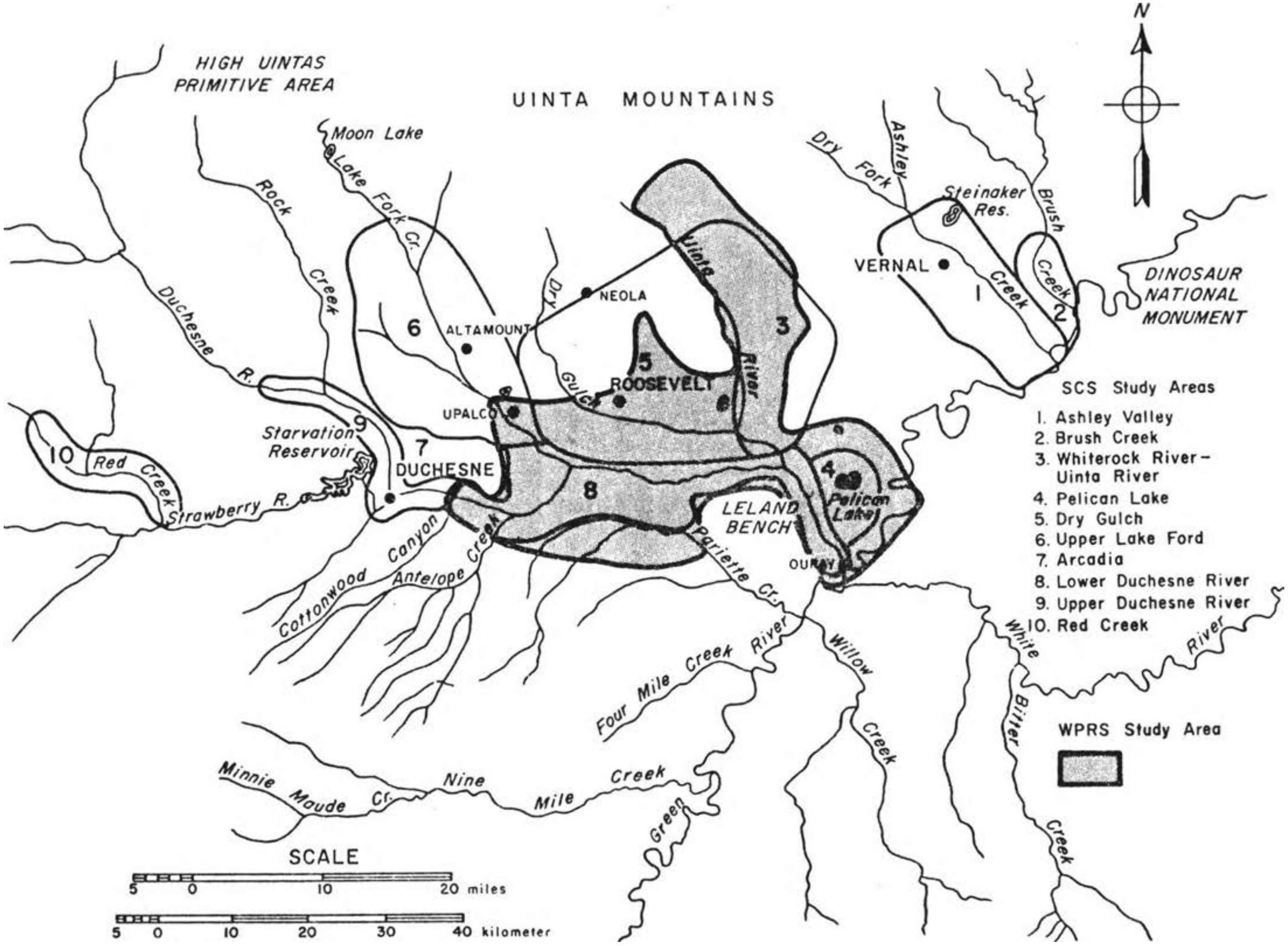


Figure 2-6. USDI and USDA Study Areas in the Uintah Basin (USDA, SCS, 1980b).

As part of the Central Utah Project (CUP) to provide storage of high runoff flows and, thus, the late season waters in exchange for the transbasin diversions of the Bonneville Unit, it was necessary to provide increased reservoir capacity, canal rehabilitation, and high country lake modification. The canal rehabilitation consists principally of lining reaches with the highest losses and new control structures. These improvements will include lining of the Pleasant Valley and Duchesne Feeder Canals in the Bonneville Unit, two of the highest salinity contributors in the Uintah Basin (USDI, WPRS, 1980a), and lining of seventeen kilometers of high seepage areas on the Class C canal already completed in the Upalco Unit. Five to six kilometers of high seepage were abandoned on the Lake Fork Irrigation Canal which is under the Class C Canal. These linings are justified only on water savings and water supply benefits, and not on salinity control, although there will be salt load reductions associated with all of the improvements.

As part of the proposed Uintah Basin Salinity Control Project, the WPRS is presently considering an improvement program on 230 km of canals including some of the larger canals and laterals lined as part of the CUP. This program would also include a substantial amount of consolidation of canal systems, particularly in the Ashley Valley area. The estimated total salinity reduction from this proposed plan including the canal lining and rehabilitation under the CUP would be about 112,000 Mgm per year (USDI, WPRS, 1980a). In view of the physical and social complexity of the basin, it is questionable whether more canal linings could be logically expected to attain a substantial decrease in salt loading. The feasibility report on the Uintah Basin originally was due by the end of February, 1982, but it is not anticipated until sometime in February, 1984.

The Soil Conservation Service (USDA, SCS, 1979e) estimates that an on-farm salinity control program on 49,500 ha would reduce the salt loading by an additional 69,500 Mgm per year. The question of whether the Soil Conservation Service or the Water and Power Resources Service would be conducting the lateral lining program is evidently still to be decided. Indications, however, are that the SCS will most likely conduct a lateral lining program as part of their on-farm program. The possibility of sprinkle irrigation is being seriously explored and has been evaluated by Willardson et al. (1977).

<u>Salinity Control Program for the Price-San Rafael Rivers</u>

The Price and San Rafael Rivers originate on the eastern slope of the Wasatch Mountains in Central Utah, and flow in a southeasterly direction to the Green River near Green River, Utah (Figure 2-7). The rivers flow over Mancos shale and other very saline formations. The two rivers are generally considered together because irrigation return flows from each stream can flow into the other stream.

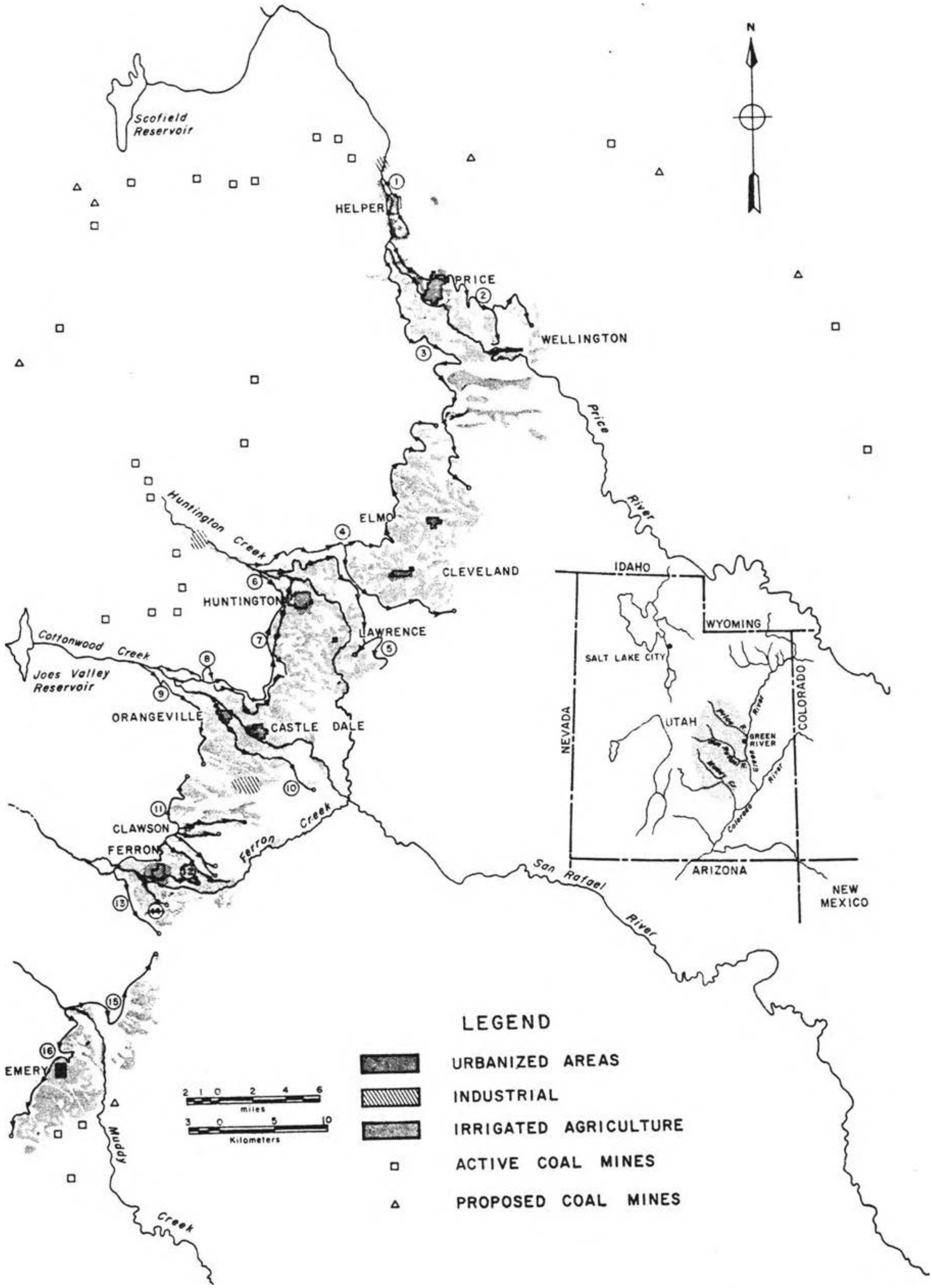


Figure 2-7. Irrigated lands, canal distribution systems and energy development in the Price-San Rafael-Muddy Creek drainages. Numbers correspond to the same designations on Table 2-11.

The annual precipitation of the area ranges from 180 mm to 300 mm in the valleys to more than 900 mm in the higher mountains. The principal rainfall season is from July to October with the largest amounts occurring in August in thunderstorms. Most of the mountain precipitation is in the form of snow. The winter climate for the valleys is typically dry and cold.

Soils in the Price-San Rafael have been formed primarily from water deposited sediment bedrock materials, but vary considerably in response to changes in geology, topography, climatic conditions and vegetation. Thorne et al. (1967) and Swenson et al. (1970) present brief descriptions of the landforms, climate, chemical and physical properties, and the use of the various soils. Almost all of the irrigated lands are derived from Mancos shale formations. These soils are generally poorly drained, saline and clayey textured. Engineering uses are limited because of the high shrink-swell potential.

Salinity Contribution--

Iorns et al. (1965) estimated that 6,880 ha in the Price River contributed 86,840 Mgm out of the total 204,800 Mgm/yr of salt to the Colorado River. The EPA (1971) estimated that out of the total of 293,000 Mgm/yr, irrigation contributed 225,200 Mgm from 10,100 ha. However, the EPA report indicated the presence of a large amount of ungaged groundwater inflows to the area which was included in the irrigation values. The WPRS (USDI, BR, 1979a) indicates that the Price River contributes a total 218,000 Mgm on the long-term average.

The San Rafael River is estimated to contribute about 187,800 Mgm/yr to the Colorado River (USDI, BR, 1979a). Iorns estimated a total of 155,450 Mgm and the EPA a corresponding total of 297,100 Mgm per year from the San Rafael. Respectively, irrigation was estimated to contribute 104,700 Mgm and 96,000 Mgm from 14,570 ha of irrigated land.

The Southeastern Utah Association of Governments (SUAG) utilized much of the data from studies by Vaughn Hansen and Associates for Utah Light and Power to ascertain the salinity impacts of the Huntington and Emery fossil fired power generating complexes. From analysis of these data, it appears that at least 9 Mgm/ha is a reasonable value of total salt loading from all the irrigated acres. Essentially, no ungaged inflows occur within the irrigated areas, contrary to statements by EPA (1971).

The 208 Report (SUAG, 1977) indicates that forest lands contribute about 0.7 Mgm/ha per year, and grazing land contributions were too small to be measured. The Price salinity contribution from the Mancos rangelands in the drainage area has also received considerable attention from the USDI, BLM (1976) who sponsored studies by Ponce (1975), White (1977), Whitmore (1976) and summarized by Hawkins et al. (1977).

Salinity Control--

The agricultural salinity contribution problems of the Price and San Rafael Basins have received little attention from state or federal agencies. Many governmental administrators believe that the agriculture of the area will be almost nonexistent in twenty years because of energy development. The large water requirements for energy will have to come from agricultural uses because there is no surplus water in the area. Consequently, there will be no need for an agricultural salinity control program and future problems are still unidentified. However, the USDA, SCS is presently involved in a very limited water and salt budget program to attempt to quantify the estimated needs of a salinity control program if it should be needed.

The practice of diverting water through the canals to furnish livestock water for at least 10 months a year has persisted since the canals were first constructed. This is a common practice in many areas in the UCRB, and it has large effects on waterlogging and salinization of lands below the canals. The USDA-SCS (1979) estimates that stopping these wintertime diversions is going to require a piping system for livestock water and would reduce the salt load by about 9,100 Mgm per year. Also, the freezing action in the winter will damage concrete linings of canals and laterals. The SCS also estimates that a combined distribution and on-farm irrigation improvement program would reduce the salt loading by another 55,000 Mgm. This appears to be a somewhat optimistic estimate. Tables 2-11, 2-12, and 2-13 describe the canal and lateral system of this area. Cost-effectiveness analysis assumed no winter waters.

An annual reduction of only 63,500 Mgm of salt from the Colorado River appears to be minimally feasible. Landowners are not likely to be receptive to much more sophisticated irrigation systems and water management to reduce deep percolation losses unless substantial labor savings and operational costs are demonstrated. Automation of these systems is an alternative. In addition, there is less than sufficient motivation to improve irrigation practices due to the cause and effect relationship between marginal crops and insufficient storage to adequately irrigate the crops through the season. The benefits of increased water availability, if adequate storage were available, which may result from the more efficient use of water are difficult to accomplish and demonstrate without a very strong long-term water management program.

Dirty Devil River Basin

The Fremont River and Muddy Creek meet at Hanksville, Utah, and form the Dirty Devil River which then flows in a southeasterly direction into Lake Powell. The Dirty Devil River and its tributaries are located in south central Utah and flow through a remote and sparsely populated area. The total drainage area is about 10,900 km^2. Due to the same basic physical characteristics and the closer proximity, the

Table 2-11.. Maximum salt load reduction of canals in the Price-San Rafael-Muddy Creek Drainages.

Canal Number	Canal Name	Area Served (ha)	Length (m)	Estimated Inlet Capacity m^3/s	Estimated Wetted Perimeter m	Estimated Days of Operation	Estimated Seepage Rates $m^3/m^2/day$	Maximum Salt Load Reduction (Mgm)	Annual Cost of Linings	Estimated mg/l @ Imperial Dam
1	Carbon	4200	48300	4.70	10.49	120	0.100	10679	846234	-1.25
2	Price Wellington	2100	19500	2.80	8.45	120	0.100	4010	294648	-0.48
3	Spring Glen	300	9800	1.10	4.03	120	0.100	825	100086	-0.11
4	Cleveland	5700	51200	5.70	11.37	120	0.100	15181	1072821	-1.76
5	Huntington	2000	14000	2.10	7.49	120	0.100	2553	189512	-0.31
6	North Huntington	1200	28000	1.40	4.37	120	0.100	2555	308950	-0.31
7	Cottonwood-Huntington	0	27100	2.50	8.06	120	0.100	4556	366590	-0.54
8	Mammoth	1200	17700	1.40	4.37	120	0.100	1615	195301	-0.20
9	Clipper Western	1400	17100	3.00	8.69	120	0.100	4653	295505	-0.55
10	Blue Cut	900	14600	1.30	4.27	120	0.100	1300	157238	-0.17
11	North	2800	19200	3.40	9.16	120	0.100	3670	292169	-0.44
12	Molen	500	6400	0.60	3.29	120	0.100	440	54902	-0.07
13	South	1050	10100	1.40	4.37	120	0.100	922	111443	-0.12
14	King	400	4600	0.60	3.29	120	0.100	316	39461	-0.06
15	Emery	2100	20700	3.40	9.16	120	0.100	5606	367746	-0.66
16	Independent	1100	16500	2.30	7.78	120	0.100	3125	231116	-0.38
	TOTAL							62006	4923721	-7.42

Table 2-12. Maximum salt load reduction from laterals in the Price-San Rafael-Muddy Creek Drainages.

Canal Name	Estimated Length (m)	K'	K_2'	A	B	Maximum Salt Load Reduction Mgm	Annual Cost of Linings	Estimated mg/l @ Imperial Dam
Carbon	86000	22869834.5	0.103	-9.3154E-08	3.2000E-02	8429	270026	-0.99
Price-Wellington	47000	8915549.4	0.084	-2.3954E-07	3.5897E-02	3765	107597	-0.45
Spring Glen	9000	972600.0	0.060	-2.1994E-06	4.2671E-02	515	12408	-0.08
Cleveland	110000	34376336.0	0.114	-6.1897E-08	3.0225E-02	11871	402550	-1.38
Huntington	45000	7859263.5	0.080	-2.7188E-07	3.6880E-02	3432	95467	-0.41
North Huntington	28000	2486415.0	0.054	-8.5912E-07	4.4993E-02	1426	32583	-0.18
Mammoth	28000	3792257.0	0.059	-5.6410E-07	3.3953E-02	1559	47152	-0.20
Clipper Western	32000	6459538.2	0.074	-3.3048E-07	2.9890E-02	2262	77602	-0.28
Blue Cut	22000	1166587.5	0.034	-1.8045E-06	4.2889E-02	700	16821	-0.10
North	60000	14410204.3	0.063	-1.4795E-07	2.1549E-02	3597	171148	-0.43
Molen	13000	1196536.1	0.036	-1.7859E-06	2.8974E-02	440	15598	-0.07
South	25000	3530191.4	0.046	-6.0590E-07	2.5636E-02	1092	43709	-0.14
King	11000	915668.7	0.034	-2.3309E-06	2.9730E-02	350	12119	-0.06
Emery	47000	9912332.5	0.067	-2.1530E-07	2.5989E-02	3008	118718	-0.36
Independent	26000	4110032.9	0.057	-5.2018E-07	2.8557E-02	1401	50351	-0.18
TOTAL						43848	1473849	-5.32

Table 2-13. Optimization parameters for the canals in the Price-San Rafael-Muddy Creek canal system.

Canal Number	Canal Name	K'	K'_2	A	B
1	Carbon	9240685.6	0.365	-5.4742E-07	1.8466E-02
2	Price-Wellington	3683760.7	0.294	-1.0204E-06	1.7701E-02
3	Spring Glen	822840.3	0.140	-5.9647E-06	1.3163E-02
4	Cleveland	17281818.2	0.395	-1.9035E-07	1.7041E-02
5	Huntington	2251226.3	0.261	-1.6454E-06	1.7672E-02
6	North Huntington	2690910.8	0.152	-1.8658E-06	1.3036E-02
7	Cottonwood-Huntington	3603506.1	0.280	-1.4464E-06	1.9017E-02
8	Mammoth	1701040.0	0.152	-2.9515E-06	1.3036E-02
9	Clipper Western	10072878.0	0.302	-2.2894E-07	1.6812E-02
10	Blue Cut	1346079.5	0.148	-3.7057E-06	1.3081E-02
11	North	3032766.6	0.319	-1.6555E-06	1.8638E-02
12	Molen	382696.3	0.115	-1.1853E-05	1.3228E-02
13	South	970650.0	0.152	-5.1725E-06	1.3036E-02
14	King	275063.0	0.115	-1.6490E-05	1.3228E-02
15	Emery	8719204.1	0.319	-2.9565E-07	1.6900E-02
16	Independent	2791899.9	0.271	-1.3336E-06	1.7691E-02

Muddy Creek drainage has been considered as part of the Price-San Rafael salinity control program.

There are basically three small irrigated areas in the basin. The Emery area is the upper portion of Muddy Creek, and the very small irrigated areas near Hanksville and Cainville are located on about 3,700 ha of Mancos Shale derived soils. The largest irrigated area is from Torey to the Loa-Fremont area on the upper portions of the Fremont River. This area is almost totally oriented toward the production of forage, pasture and small grains to support the livestock industry. Much of the upper Fremont River is irrigated by the sideroll wheel move or aluminum hand move sprinkler systems. The Upper Fremont or "Rabbit Valley" area is generally considered to have a low salinity contribution. There is also a very small irrigated area in the Capital Reef National Park at Fruita. Iorns et al. (1965) and others estimated the total irrigated land in the basin at about 10,000 ha.

The geologic boundary of the Dirty Devil drainage to the north is the San Rafael Swell, which is a dome structure trending northeast for about 110 km. The southern boundary is composed of part of the Henry Mountains, Awapa and Aquarius Plateaus, and Boulder Mountain. The western part of the basin is composed of the Parker Mountains of the Wasatch Plateau.

There are numerous petroglyphs and pictographs carved on cliff walls in the Capital Reef area. It is hypothesized that these are the work of prehistoric basketmakers and Pueblo peoples who are thought to be the ancestors of the Hopi Indians. The first white man to enter the area was probably a man named Dennis Julian. Julian's name and the date 1836 have been found scratched in numerous rocks in the area (Six County Commissioners Organization, 1978). The second recorded intrusion of nonIndians into the Dirty Devil Basin was an exploration party headed by John C. Fremont in 1853, for whom the river and town of Fremont were named. The basin was more systematically explored by Mormon parties sent by Brigham Young in 1873. The first settlements occurred in the Rabbit Valley and the Upper Muddy areas. The town of Emery was founded in 1883 (Utah Division of Water Resources, 1977).

The Dirty Devil River was purportedly named in 1869 by a member of John Wesley Powell's famous boat expedition down the Colorado River. Upon sighting the mouth of the river, he aptly exclaimed, "She's a dirty devil!" (Utah Division of Water Resources, 1977).

Utah Division of Water Resources (1975) estimates that phreatophytes consume about 3,000 ha-m meters in the Fremont River drainage. Agricultural consumptive use is calculated at 2,250 ha-m for Rabbit Valley and 1,100 ha-m for the Fruita-Cainville-Hanksville area. The annual outflow of the Dirty Devil River into Lake Powell averages about 9,740 ha-m. Approximately 1,470 ha-m of outflow is contributed by the Muddy Creek drainage.

The EPA (1971) calculated the total salt load from the Dirty Devil Drainage at 160,600 Mgm per year. Iorns et al. (1965) reported 179,300 Mgm, and USDI, BR (1979a) uses a value of 181,500 Mgm per year. The EPA (1971) estimated the salt contribution of irrigated lands in the Rabbit Valley area of 0.9 Mgm/ha, and the irrigated areas on Muddy Creek and Hanksville areas contributed about 7 Mgm/ha. Also, about 2,650 Mgm/yr was contributed by the Loa fish hatchery. Iorns et al. (1965) reported an average salinity contribution from irrigation for the whole basin of 52,000 Mgm or 5.2 Mgm/ha. Current estimates by the Water and Power Resource Service (USDI, BR, 1979a) indicate that potentially about 72,600 Mgm of salt could be removed by an agricultural salinity control program in the basin. However, the WPRS has done little investigation other than limited stream gaging and water quality sampling to qualify this rather optimistic forecast of an 8 mg/l reduction at Imperial Dam.

Approximately 80 percent of the total salt load from the basin is from natural, diffuse sources, and it is doubtful that this load could be reduced. The rainfall in the basin is very low and livestock use on the lower, salt producing areas is severely limited by the scant vegetation. Thus, grazing control programs which have been proposed for other areas will have minimal effects. The Regional 208 plans have delegated all nonpoint source pollution activities to the Soil Conservation Districts and the WPRS.

If there is an agricultural salinity program for the Dirty Devil River, it will likely be centered in the Emery area. A seepage study by Johansen and Tuttle, Inc., for the Soil Conservation Service in 1975 reported fairly high seepage losses. The 19 km Emery Canal had an estimated total conveyance loss of 25 percent, and the 14.5 km Independent Canal had average lossed of 22 percent of the diversions.

The fields in the Emery area are irregularly shaped with variable slopes. Field boundaries are generally determined by the natural drainage. Crops are very marginal with many wetland areas with obvious local soil salination problems. There a few gated pipe systems and some head move and a few sideroll wheel move sprinklers.

Due to coal and uranium deposits, it is quite probable that the Emery area will be an area to subject to extensive water transfers to industrial uses. The new Consol mine (Emery Coal Company, No. 1) southeast of town has just opened, and there is serious consideration of a large coal gasification plant in the area. Energy Reserves Group has a coal mine in the Rock Creek area. In addition, Boeing is proposing a coal slurry pipeline further downstream on Muddy Creek to convey coal to Ventura, California, for exploration (USDI, GS, 1979a). There are two environmental statements on coal development which cover portions of the Dirty Devil drainage. Muddy Creek development is discussed by the USDI, GS (1979a), and the Hanksville area is covered to the USDI, GS (1979b). In addition, the large Tar Sands Triangle is in the Dirty Devil, although these deposits lie along the Colorado River and would likely use that water.

The required 208 plan for the Fremont River (Six County Commissioner's Organization, 1978) discusses a proposed 3,000 MW coal fired power project which may be located near Cainville at Salt Wash. There is also a proposed Aldrich Dam which would also be located in this area with a total capacity of about 11,600 ha-m.

McElmo Creek

McElmo Creek drains about 900 square kilometers including about 15,180 ha of irrigated land in the Montezuma Valley near the "Four Corners" area in southwestern Colorado (Figure 2-8). McElmo Creek flows into the San Juan River a few miles below the Colorado-Utah state line. The Montezuma Valley lands are irrigated with water diverted from the Dolores River via the Dolores Tunnel, which has a capacity of 8.92 m^3/s with a salt load of 13,600 to 18,150 Mgm/yr.

Salinity Contribution--

Approximately 25 percent of the irrigated area, which is also generally the lowest lying in elevation, is underlain by Mancos shale. The remaining 75 percent of the irrigated lands are on benches and terrace remnants or the "red" sandy soil, primarily derived from the Dakota and Morrison formations. The USDI, WPRS (1980a) estimates that the Mancos area contributes as much as 22.7 Mgm/ha which is high compared to other "Mancos" areas in the UCRB. On the other hand, the red soil contributes 2.5 to 5 Mgm/ha per

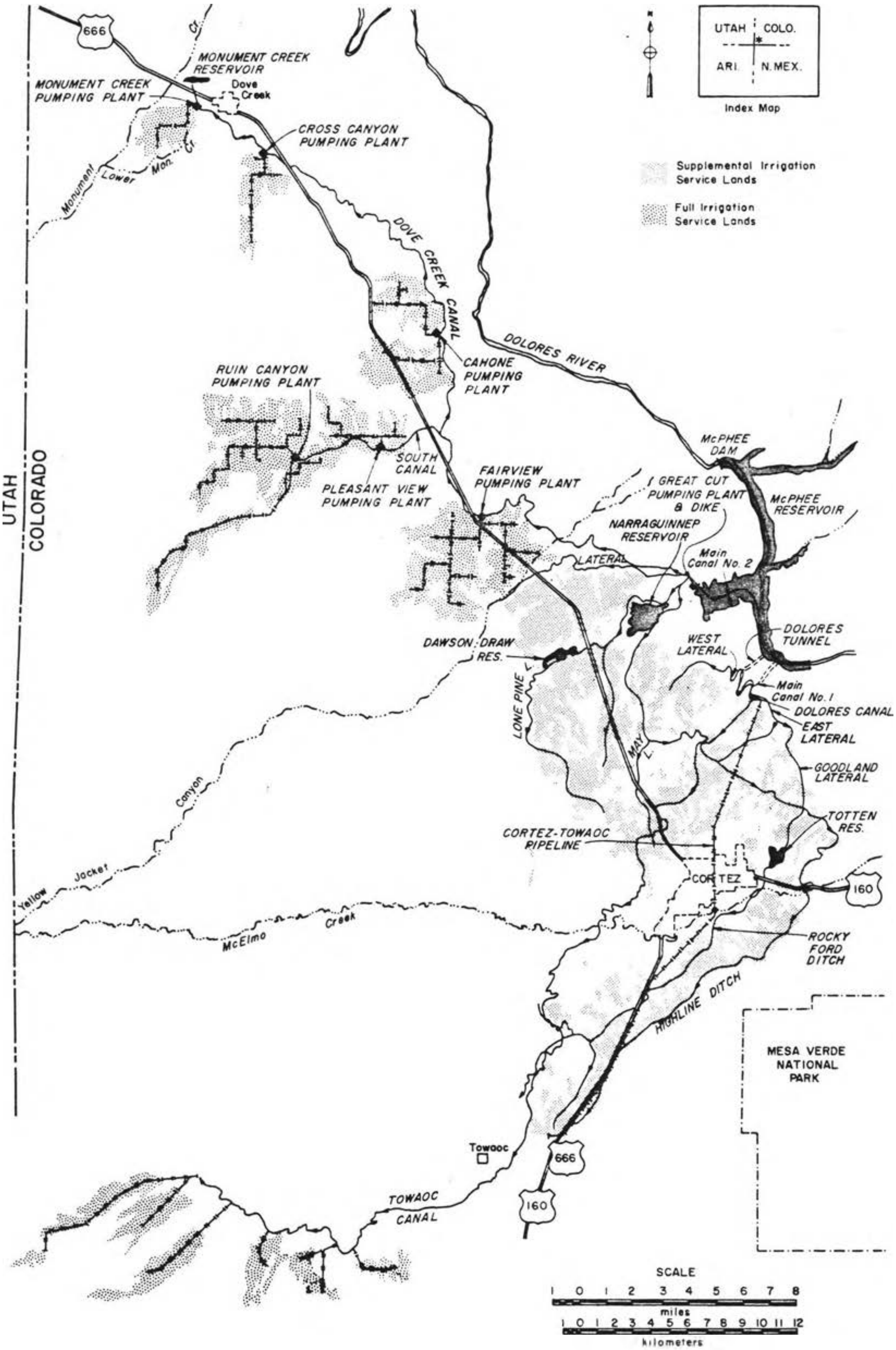


Figure 2-8. Location map of McElmo Creek Salinity Control Project and the Dolores Project. (USDI, BR, 1977).

year. The hydro-salinity budgets have not yet been established for the area with any degree of confidence.

Water quality measurements indicate that the McElmo drainage annually contributes an average of 108,900 Mgm/yr in a flow of about 3,950 ha-m with surface water concentrations up to 4,000 mg/l and a low of about 2,100 mg/l. The Dolores River water contributions are about 18,000 Mgm/yr leaving about 90,900 Mgm as the contribution from all sources in the McElmo drainage.

As mentioned previously, the surface and subsurface hydrology of the McElmo Creek area has not yet been clearly defined. For example, how much groundwater inflows are being introduced to the Mancos shale areas from the higher sandy mesas and benches is not known. If there are significant subsurface inflows, just treating the high salt producing Mancos soil would not be a successful program. The USDI, WPRS (1980a) estimates that about 10,440 ha of the presently irrigated land are the "red" soils over sandstones, about 1,620 ha are red soils over Mancos shales, 200 hectares are Mancos soil over sandstones, 2,800 ha are Mancos soil over Mancos shales. Based on results elsewhere in the Upper Colorado River Basin, the Mancos soils overlying the shales are the largest contributors.

The WPRS has established a public participation group to evaluate the proposed alternatives for salinity abatement in the McElmo area. The feasibility reports on the project are scheduled for 1983.

The agriculture is almost totally aimed at the production of livestock and forage. Higher value cash crops which could be grown such as vegetables are not produced because of marketing problems. The area has traditionally been short of water in the later parts of the summer which undoubtedly reduces the total annual average salt flows from the valley. However, with the advent of the Dolores Project and a guaranteed late water supply, the salt load will quite probably increase significantly and also result in a corresponding increase in waterlogging problems. This observation is substantiated by examining the water quality records for the years with high water availability such as 1973 and 1979. In 1973, the annual total salt flows passing the state line station were 177,000 Mgm. In 1979, the corresponding salt load was almost 152,090 Mgm, compared to the average of 109,000 Mgm. The average salt contribution would be 10.44 Mgm/ha and 8.8 Mgm/ha, for 1973 and 1979, respectively. Tables 2-14 and 2-15 describe the McElmo Creek canal and lateral system and their respective cost-effectiveness functions.

If almost all of the salt leaving the McElmo drainage were a direct result of irrigation activities, the average salinity contribution would be 6 Mgm/ha. Assuming that the 4,420 hectares of irrigated soils overlying the Mancos shale contributed a conservative average of 13.45 Mgm/ha per year, the salt load would be 92,600 Mgm/yr. With the Dolores

Table 2-14. Maximum salt load reduction for canal and major lateral lining in McElmo Creek, Colorado.

Canal Name	Length (m)	Inlet Capacity m^3/s	Estimated Wetted Perimeter (m)	Estimated Days of Operation	Estimated Seepage Rate $m^3/m^2/day$	Maximum Salt Load Reduction (Mgm)	Annual Cost of Lining ($)	Estimated mg/l @ Imperial Dam
U Lateral	17400	1.90	4.84	150	0.120	742	205141	-0.10
Goodland Lateral	6400	0.42	2.92	150	0.120	180	50216	-0.04
Lone Pine Lateral	37000	3.40	9.16	150	0.120	2851	526659	-0.35
Corkscrew Lateral	4800	0.42	2.92	150	0.120	118	36199	-0.03
Moonlight Lateral	7700	0.34	2.72	150	0.120	176	11375	-0.04
Ute Mtn. Lateral	8050	0.28	2.55	150	0.080	374	11151	-0.06
Upper Hermana	15000	5.50	11.20	150	0.120	1480	265372	-0.19
Lower Hermana	8500	4.00	9.80	150	0.120	734	132111	-0.10
May Lateral	5600	1.05	3.97	150	0.120	196	54540	-0.04
Garret Ridge	6100	0.57	3.24	150	0.120	174	50211	-0.04
East Lateral	5500	2.00	7.34	150	0.120	582	80805	-0.09
West Lateral	10000	1.98	4.91	150	0.120	708	146348	-0.10
Hartman Draw	4500	4.70	10.49	150	0.080	1483	96458	-0.19
Main Canal No. 1	2700	11.33	15.15	150	0.120	622	86933	-0.09
Main Canal No. 2	9500	11.33	15.15	150	0.120	1210	223886	-0.16
Lower Arickaree	4000	0.29	2.59	150	0.120	91	5656	-0.03
Rocky Ford 1	28000	0.70	3.47	150	0.080	1767	243098	-0.22
Rocky Ford 2	2400	2.83	8.49	150	0.080	640	41413	-0.09
Highline Ditch	48900	2.30	7.78	150	0.080	6922	616581	-0.81
TOTAL						21052	2884153	-2.78

1 Below Totten Reservoir

2 Above Totten Reservoir

Table 2-15. Optimization parameters for the major McElmo Creek canals and laterals.

Canal Name	K'	K'_2	A	B
U Lateral	1763633.4	0.078	-3.4171E-06	6.1564E-03
Goodland Lateral	313407.3	0.047	-1.3598E-05	6.0288E-03
Lone Pine Lateral	4921595.0	0.147	-1.3569E-06	9.2815E-03
Corkscrew Lateral	197941.5	0.047	-2.9616E-05	6.7577E-03
Moonlight Lateral	137724.9	0.044	-4.7295E-05	2.3860E-02
Ute Mtn. Lateral	136326.1	0.084	-4.2308E-05	4.9360E-02
Upper Hermana	2757093.0	0.179	-2.2553E-06	8.9164E-03
Lower Hermana	1307162.5	0.157	-4.7401E-06	9.0391E-03
May Lateral	407203.1	0.064	-1.4097E-05	6.3564E-03
Garret Ridge	315048.1	0.052	-1.6793E-05	6.3898E-03
East Lateral	2581719.5	0.118	-8.7549E-07	7.7126E-03
West Lateral	4667690.7	0.079	-4.8395E-07	5.1799E-03
Hartman Draw	6816899.2	0.347	-3.1004E-07	1.5834E-02
Main Canal No. 1	6694714.7	0.243	-3.1927E-07	7.3585E-03
Main Canal No. 2	2479523.9	0.243	-2.6885E-06	8.6595E-03
Lower Arickaree	69350.4	0.041	-8.3101E-05	2.3723E-02
Rocky Ford[1]	1622445.0	0.115	-3.3647E-06	1.3213E-02
Rocky Ford[2]	2736599.2	0.281	-7.5980E-07	1.5937E-02
Highline Ditch	5516117.3	0.257	-1.1038E-06	1.8866E-02

[1] Below Totten Reservoir

[2] Above Totten Reservoir

Project, the Mancos shale lands could contribute as high as 20 Mgm/ha because of the increased time of water availability.

Previously, the Montezuma Valley Irrigation Company had stated that the only involvement they wanted with the Dolores Project was the purchase of water (USDI, BR, 1975a). However, an irrigation redevelopment alternative which has considerable recent local support is to utilize an enlargement of the pressurized pipeline to Towaoc (Ute Mountain Indian Reservation), which is part of the Dolores Project, to also furnish pressurized water to a sprinkle irrigation program in the Montezuma Valley. This would probably be very feasible for the Mancos shale irrigated areas, which also offer the highest potential for gravity pressurization for sprinkle systems. This would also require a strong complimentary irrigation scheduling water management program from government agencies. Another alternative would be to explore the possibilities of collecting all the saline flows from McElmo Creek and offer the water for use in as yet unidentified coal slurry pipeline or cooling water for thermal power generation plants.

Mancos River--

A nearby area which could also be considered under the McElmo project is the higher and relatively small area with a maximum of 4,230 ha near the town of Mancos, Colorado. These lands are also located on Mancos shale derived soils. Sprinkle irrigation could be achieved by a potential of

120 m of elevation for gravity pressurization. Irrigation scheduling services should also be included.

An idea which has support from many of the 144 Mancos area landowners and is locally termed "superduct", is a system of lined ditches and/or pipelines which would convey water to the Chicken Creek and the Mancos River irrigated areas. The area is located very near the Mesa Verde National Park and the visible impact of the project will be a major consideration. The salt loading from agriculture in the area is not known, but is probably in the typical range for Mancos shale soils of 13.5 - 18 Mgm/ha/yr. The total Mancos River drainage averages about 35,140 Mgm per year of total dissolved solids (Iorns et al., 1965).

As recently as 1978, the WPRS has prepared proposals for upgrading Jackson Gulch Reservoir and the canal delivery system which feeds the Mancos Valley. In 1978, about 3,498 ha were irrigated by farm deliveries of 1,338 ha-m. The Bureau of Reclamation originally built Jackson Gulch Reservoir as part of the Mancos Project for supplemental irrigated water.

The Animas-La Plata Project will also have return flows entering the Mancos River. The USDI, BR (1979d) estimates that this would add about 10,900 Mgm/yr to the Mancos River at the State Line. This corresponds to an increase of about 60 mg/l in the average annual dissolved solids concentration (averaged over 45 years) of the river.

Big Sandy River

The Big Sandy River, which also is called Big Sandy Creek, is located in the Green River Subbasin of the Colorado River Basin, in southwestern Wyoming (Figure 2-9). The irrigated area is located in the Eden Valley area about 65 km north of Rock Springs, Wyoming. The two community centers are Farson and Eden with a 1970 combined population just over 300 persons. The present estimated combined population is 575 persons.

Big Sandy Creek and its tributary Little Sandy Creek rise in the Wind River Mountains. Big Sandy Creek flows in a generally southeast direction for about 105 km to the town of Farson where it is jointed by Little Sandy Creek. The stream then flows in a southwesterly direction to the Green River below Fontanell Reservoir. Dry Sandy Creek and Pacific Creek are tributary to Little Sandy Creek. There are numerous swampy wetland areas in the irrigated section of the drainage which are a primary result of the irrigation activity. These areas undoubtedly contribute substantially to the volume of subsurface return flows but do offer excellent wildlife habitat. Thus, almost all of the alternatives must offer some wildlife habitat migration, if any is removed or damaged.

The irrigated area is about 217 m above sea level, and the average growing season for frost tolerant crops is about 124 days. Climatic records indicate that freezing

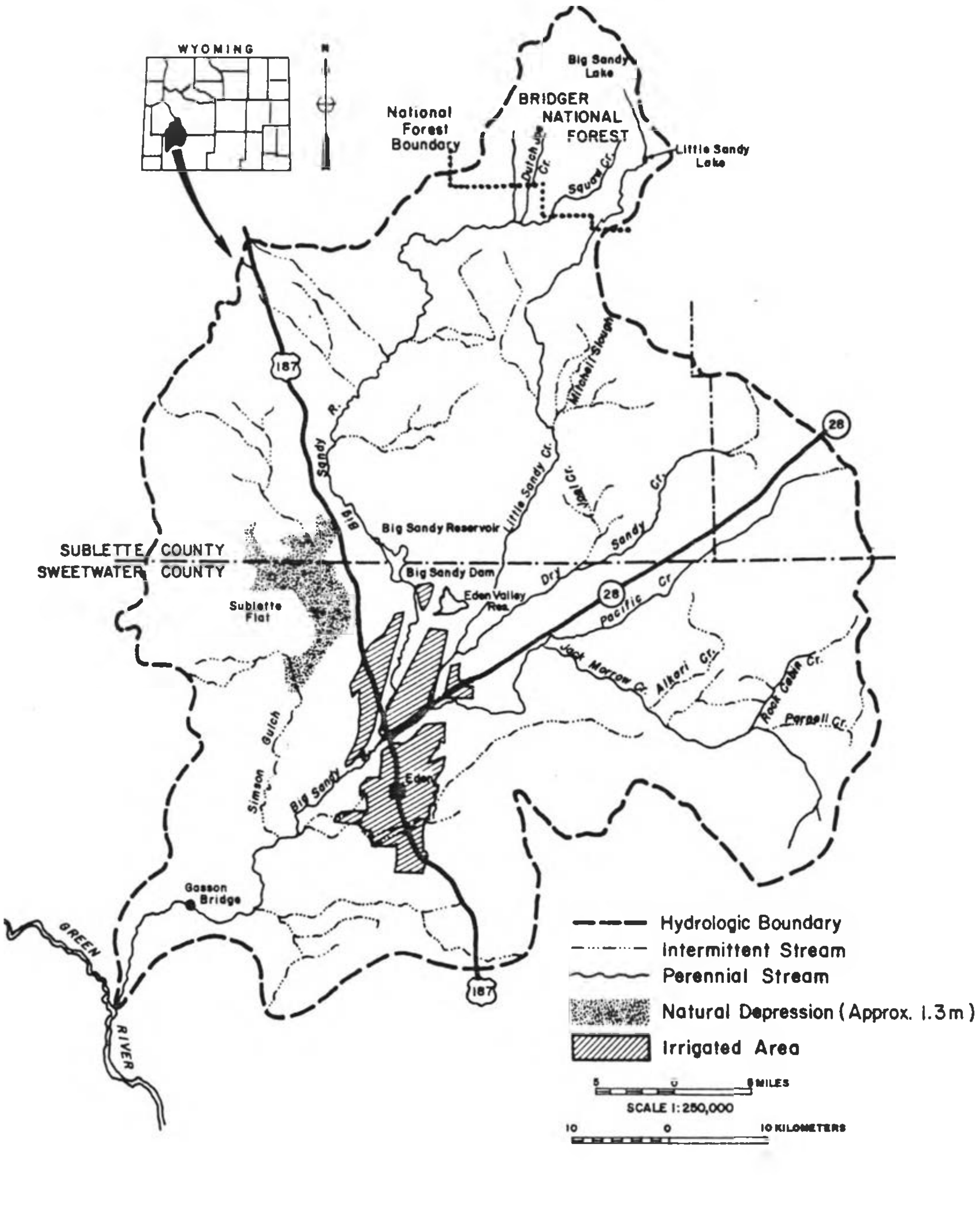


Figure 2-9. Big Sandy Salinity Control Project area (USDA, SCS, 1980a).

temperatures have occurred in every month of the year. Annual precipitation is about 220 mm.

The geology of the area has a profound influence on the occurrence, behavior, and chemical quality of the water resources just as in all the other significant salinity contributors in the Upper Colorado River Basin. The Eden Valley does not receive sufficient natural precipitation to significantly impact the groundwater storage (Fox et al., 1954), and most of the water bearing aquifers result from high precipitation areas in the nearby mountains. The Tipton tongue member of the Green River formation appears to be the principle artesian aquifer in the valley and is saline with high sodium content at depths of 150 to 550 m.

The shallow groundwater in the area is primarily the result of irrigation although it appears that there are some connections between the very saline artesian flows and the shallow water (USDI, BR, 1980). Several wells and seeps in the southern portions of Eden Valley experience high concentrations of trona or "soda ash" (sodium carbonate) which is locally referred to as "black water."

Salinity Contribution--

Water and salt budgets by the USDA, SCS (1980a) show that for the Big Sandy River over the past few years, the salinity contributions were higher than the 1960-1977 annual average of 135,400 Mgm. This increase is partially due to the decrease in water management due to the increase in part-time farming by the operators who hold other employment.

The USDI, BR (1967, 1979a) estimates that the total Big Sandy Basin contributes about 163,340 Mgm/yr with concentrations at its confluence with the Green River ranging from 300 to 3,900 mg/l. The EPA (1971) estimated 275,600 Mgm/yr. The WPRS (USDI, WPRS, 1980a) indicates that about 998,000 Mgm/yr are contributed in the 24 km reach below the irrigated area by numerous saline seeps and springs is believed to be where most of the subsurface irrigation return flows from Eden Valley return to the river.

The USDI, WPRS (1980a) has drilled 75 exploratory holes and conducted aquifer tests to determine the aquifer properties, and has drilled 25 holes in the vicinity of Big Sandy Reservoir to investigate seepage losses from the reservoir. The results of the reservoir seepage investigation indicate that about 740 ha-m were lost from Big Sandy Reservoir, but that 70 percent had returned directly back to the river in the first 2.4 km below the dam (USDI, WPRS, 1980a). Eden Reservoir appears to have much lower seepage loss.

The WPRS is still evaluating their information, but it appears that roughly 25 percent of the salt outflows are from natural sources while about 75 percent are from irrigation return flows (USDI, WPRS, 1980a). The USDA, SCS (1980) estimates that the irrigation delivery systems and on-farm practices contribute about 113,340 Mgm annually while runoff, erosion and natural seeps contribute about 22,050 Mgm per year. This amounts to 84 percent and 16 percent of the total average annual contribution of 135,390 Mgm, respectively. The evaporation from the reservoirs is about the same as the volume of seepage. However, the concentrating effects of this are fairly minor because of the relatively high quality water which enters the reservoirs (< 150 ppm).

Salinity Control--

The alternative for salinity reduction which has been recommended by the USDA, SCS (1980a) is primarily a local landowner proposal. This plan calls for the permanent retirement from irrigation of about 87 percent of the project area, and substantial irrigation system improvements on the remaining 730 ha to increase irrigation efficiencies. If all the unused water remained in the river, this alternative would result in an annual reduction of 103,700 Mgm of total dissolved solids resulting in a decrease of about 14.5 mg/l at Imperial Dam (USDA, SCS, 1980a).

Implementation of this plan would cost around $35.9 million. Land retirement costs would be about $28.8 million ($4,950/ha), $5.5 million for irrigation system improvements on the remaining 730 ha, and $1.6 million for wetland mitigations (USDA, SCS, 1980a). Including lost crop revenues at $115/ha, the total annual costs of this project are about $3.34 million (1980 dollars). The annual cost-effectiveness is therefore $32.00/Mgm.

In reality, this partial land retirement project has little chance to be adopted or be accepted in the state of Wyoming. Because of the economically marginal agriculture, it has some appeal at the local level. The market values of the land and water rights is about half the $4,950/ha proposal cost. However, the state of Wyoming is obviously reluctant to lose its rights to that water from its Colorado River allocation. If this land retirement were adopted, in all likelihood, any water which may be unused would go toward energy development such as coal slurry pipelines, trona plants, municipalities or coal-fired thermal power plants. The net result would be a reduction in salt pickup from the agricultural lands, but a greatly increased concentrating effect due to the permanent removal of water from the streams. The exact magnitude of any salinity reduction would depend on the nature of the composite uses for the "saved" water. For example, under this alternative about 5,550 ha-m would be unused annually for irrigation. If the average concentration of this water were 300 mg/l, and it was totally consumed by energy, the net salinity reduction from the Big Sandy land retirement would be about 87,100 Mgm making the annual cost-effectiveness $38.35/Mgm.

Two other alternatives or a combination of the two merit further considerations as the most likely to be implemented. One alternative is to line all farm head ditches and automate the border irrigation. The second alternative, which has a very definite role as a secondary management component, is to install a series of barrier wells to intercept the saline subsurface return flows above the seep and spring area and pump into a 3,240 ha natural depression called Sublette Flats for evaporation. The Sublette Flat alternative would more than adequately provide for wildlife habitat mitigation. The USDA, SCS (1980a) has calculated the annual costs for the automated border irrigation alternative at $1.43 million. The annual costs for the evaporation alternative were calculated at $996,000. The salt reduction would be 22,300 Mgm and 73,800 Mgm per year, respectively, for a combined total of 96,100 Mgm. This combined total annual cost would be $2.42 million for an annual cost-effectiveness of $25/Mgm. The Wyoming State Engineer has stated that the water for the evaporation ponds (max. 1,600 ha-m/yr) would come from the Lower Basin allocation, but that is subject to considerable dispute (USDA, SCS, 1980b).

POINT SOURCE SALINITY CONTROL PROJECTS

Paradox Valley Salinity Control Project

The Paradox Valley is located on the Dolores River in Montrose and San Miguel Counties of southwestern Colorado about 7 km above the confluence with the San Miguel River. The project purpose is to reduce the inflow of surfacing brine groundwater from a collapsed salt anticline. The 8 km reach contributed about 186,000 Mgm/yr to the Colorado River. Approximately 179,799 Mgm/yr are contributed by the salt dome and about 6,350 Mgm/yr are contributed by runoff and irrigation return flows on West Paradox Creek.

Konikow and Bedinger (1978) state that most of the groundwater discharges result from a less than 150 m thick three-dimensional flow system, with the dissolution of salts occurring at or near the gypsum-anhydrite caprock and the underlying salt deposits. The alluvian and the caprock have high to moderate permeability. The salt beds are reputed to contain high pressure gas pockets and are subject to plastic deformation and have very low permeabilities. The strongest vertical hydraulic gradients occur near the river and the upward flow in this area is sufficiently strong to force the relatively high density brine to surface. Measures which include reducing the hydraulic gradients and recharge sources have the highest potential for a successful long-term answer to the problem.

Salinity Control Program--

The plan presently endorsed by the WPRS is the establishment of a shallow barrier well field for pumping the brine groundwater and 68 groundwater monitoring wells (USDI, BR, 1978a). The brine would be piped from the 18 wells to a nearby hydrogen-sulfide strippling plant, where the corrosive and potentially toxic gas would be converted to sulfur. The treated brine and the sulfur would be piped for 35 km through 8 pumping plants with a maximum lift of 620 m to the proposed Radium Evaporation Pond in the Dry Creek Basin. The conservative costs presented in the Paradox Valley Unit, Definite Plan Report (USDI, BR, 1978a) were based on pumping 0.14 m^3/s which is about twice the maximum expected sustained pumping amount. The economic recovery of any marketable minerals from the brine is believed impractical. This plan would reduce the salinity at Imperial Dam by an estimated net value of 18.2 mg/l (USDI, BR, 1979b).

Approximately 163,000 Mgm/yr are expected to be removed, and the annual depletion of streamflow to be about 490 ha-m at the 0.14 m^3/s level. The present estimate is that 0.02 to 0.06 m^3/s will be required, or an annual streamflow depletion of 72 to 180 ha-m. The costs (January, 1977 prices) were estimated to be $50,390,000 with an annual O & M cost of $332,300. At a 5-5/8 percent discount rate, the total annual costs over 100 years were $4,507,000. The annual cost-effectiveness for 163,300 Mgm is $21.47 per Mgm. The power costs were based on 1977 Colorado River Storage Project power rates of 3.4 mills/kwh and a wheeling rate of 1.5 mills/kwh.

At January, 1980 levels developed by using an Engineering News Record (1980) multiplier and estimating the evaporation pond costs at $78,150/ha, the total construction cost for the presently proposed project would be $136,100,000. Assuming a 7-1/8 percent discount rate and a recovery period of 100 years yields a total annual cost of about $10,200,000. The annual cost-effectiveness is $62.47/Mgm or an increase of almost three times the 1977 estimate.

Other Salinity Control Alternatives--

There are three basic alternatives which are presently being investigated. The first is replacing the Radium Evaporation Pond by a pond located in Sinbad Valley, 22.5 km to the north of Paradox Valley. The second alternative is to divert the Dolores River into a lined by-pass channel across the salt anticline section. And, the third alternative which is being investigated in detail at the present time is deep well injection of the brine into geologic formations below the salt dome. Desalination was not considered since the brines were already extremely concentrated.

Adjusting the projected costs of Sinbad Valley to January, 1980 levels at a 7-1/8 percent discount rate results in an annual cost-effectiveness of $138.32/Mgm which is still twice the Radium Pond Value. The 1980 by-pass alternative annual cost-effectiveness was determined to be $32.71/Mgm which is considerably less than either of the evaporation pond alternatives. Costs of deep well injection are not yet available, and this disposal process does not appear to be a long-term solution.

The by-pass alternative or a variation of this alternative which would also reduce the hydraulic gradient of the brine appears to offer the best long-term solution to the problem among the proposed WPRS solutions. This alternative offers significant long-term advantages primarily because of the relatively large amounts of pumping energy required by the other alternatives. A possible modification might include constructing a larger upstream dam for flood control and thus, a smaller eastern dike. Analysis of the results by Konikow and Bedinger (1978) indicated that this alternative will possibly require measures to intercept inflows from East Paradox Creek and programs to control the source of the majority of the recharge and other measures to reduce the hydraulic gradients. Because of the lower cost-effectiveness of the by-pass alternative, it was the only option included in the optimization analyses. In addition, due to great economics of scale with a project of this nature, the cost-effectiveness function reduces to basically a single value. Also, the effect of the Dolores Project on increasing and stabilizing the low summer streamflows, low-head hydropower could possibly be included at the drop structure back to the river.

Glenwood-Dotsero Springs Salinity Control Project

The USDI, BR (1976a) estimates that the 25 kilometer reach of the Colorado River between Glenwood Springs and the Dotsero rail siding gains about 3,100 ha-m and about 487,850 Mgm per year. Approximately one-half of the water and salts come from 18 accessible mineral springs clustered on both sides of the river. The remainder of the salt and flows evidently enter the river via springs and seeps located in the river channel. Very little salt loading is attributed to surface runoff or causes other than the springs in this area. The EPA (1971) estimated the total salt load at 450,450 Mgm/yr and interpolation of data presented by Iorns et al. (1965) results in an estimation of about 417,400 Mgm/yr. Hagan (1971) estimated that the total contribution was about 466,900 Mgm/yr and Hyatt et al. (1970) estimated the salt load to be 293,200 Mgm/yr. About 90 percent of the total salt is sodium chloride (Iorns et al. 1965).

Salinity Control Program--

A U.S. Bureau of Reclamation Appraisal Report (USDI, BR, 1976a) based on limited studies and an analysis of existing technology, stated that the most feasible means for control of salts from the identified springs is a multistage flash distillation (MSF) desalting process. The proposed single plant would be located near the town of Newcastle (about 16 kilometer downstream from the mouth of the Roaring Fork River) and would include both the Dotsero and Glenwood sources 0.45 m^3/s of saline water which would be collected and piped to the plant. In addition, a total of 754 ha in three ponds would be required for evaporation of the brines, and associated piping and construction costs. The report estimated that the system would collect about 227,000 Mgm/yr and would lower the salinity at Imperial Dam by about 23 mg/l. The USDI, BR (1976a) estimated that the development would deplete the annual flow by about 400 ha-m. However, using formulas proposed by USDI, BR and Office of Saline Water (1972) this depletion could be as much as 750 ha-m. And, from USDI, BR and Office of Saline Water (1972) formulae, based on flows of 0.45 m^3/s and an average feedwater concentration of 14,450 mg/l, the salt reduction would be 210,000 Mgm/yr. The water returned to the river would have about 5 to 50 mg/l total dissolved solids (Walker, 1978). Construction costs for this alternative were estimated at $69,500,000 (July, 1974 prices) with a 30-year project life.

Based on the 1974 prices, the USBR annual cost per Megagram removed was $43 for 227,000 Mgm. Updating these USBR (1976) costs to January, 1980 prices (from the Engineering News Record, 1980) index, the total construction cost would be about $120,820,000 with annual O & M at $6,200,000. The annual cost per Megagram removed would be about $70.40 Mgm/yr at a 7-1/8 percent discount rate for 30 years for 227,000 Mgm. The total construction cost of just the plant and pipelines and other structures, not including the evaporation ponds, is estimated at $62 million.

Other Salinity Control Alternatives--

The USDI, BR (1976a) also investigated the possibility of having two smaller MSF desalination plants. One would be located near Dotsero and the other near Newcastle. However, due to the economics of scale experience by the larger plants, this second alternative was more expensive.

It should be added that MSF processes are often used in conjunction with other distillation-type desalination or reverse-osmosis techniques to maximize its efficiency and reduce power requirements. However, at today's high energy costs, almost any distillation procedures should be carefully examined in the context of uncertain future energy availability.

Another alternative which was investigated as part of this project was a combined reverse osmosis (RO) desalination plant combined with a small MSF plant. This would require some additional dilution water from the river, but offers a considerable cost reduction. Under this alternative, the annual cost-effectiveness was determined to be $57.40/Mgm for a 214,300 Mgm per year reduction.

Meeker Dome Salinity Project

The Meeker Dome salinity point source project is the site of the Meeker Well, Marland Well and about six other abandoned oil wells and is located on a local anticline uplift in northwestern Colorado. The site is about 5 km upstream from the town of Meeker in the northern bank of the White River between confluences of Curtis Creek and Coal Creek. Nelson, Haley, Peterson and Quirk (1976) identified a total of 22 oil, gas and/or exploratory drill holes and 146 water wells in the area, not all of which were located near the Dome. The Meeker Well was drilled in the early 1920's to a depth of about 240 meters and was abandoned but not plugged until 1968. Prior to 1968, the well was flowing at a rate of 0.08 m^3/s and its highly saline flows of 19,200 mg/l were adding about 52,000 Mgm/yr to the river (USDI, BR, 1979a). The Marland Well was drilled about the same time and is now believed to be the primary source of the salinity. This well is located about 920 m northwest of the Meeker Well and was drilled to a depth of about 610 m. This well was never plugged although it has been filled with various types of debris (USDI, WPRS, 1980a). The elevation of the outlet of the Marland Well is about 100 m higher than the casing outlet of the Meeker Well.

The Meeker Well was plugged in August, 1968, under the guidance of the Bureau of Reclamation and with funds from Federal Water Pollution Control Administration (EPA, 1972). In February, 1969, the two abandoned Kritsas Wells about 3.5 km north of the Meeker Well began to flow saline waters. These wells were plugged by a private group in October, 1969. In March, 1979, new saline seeps along the south side of the Dome were reported.

EPA (1972) reports in October, 1972, that salinity increases in that stretch of the White River after plugging the Meeker were about 29,500 Mgm/yr, or a decrease of around 17,700 Mgm/yr. This has also been observed by the WPRS who estimate the present flows to be about 0.04 m^3/s of 19,000 mg/l water and contribute about 22,700 - 27,200 Mgm of salt per year.

The Bureau of Reclamation reinitiated investigations in FY1976 by taking water samples and establishing a weather station. A contract with a private engineering consulting firm to identify and study methods of reducing saline flows was awarded in May, 1979, by the Bureau of Reclamation. In addition, a multidisciplinary team has been organized to actively involve the federal, state and local government and private interests in the project and to recommend the form to the final project.

The present theory (USDI, WPRS, 1980b) is that prior to the 1968 plugging of the Meeker Well at a depth of 166 m, the saline waters from the Weber formation flowed up the shaft of the Marland Well and spread laterally through the saline Entrada formation at a depth of about 244 m and exited via the Meeker Well because of its lower elevation. When the Meeker Well was plugged, the saline waters were then forced to move up and spread laterally through the Morrison and Dakota formations and is now surfacing in several seeps along the south side of the Dome.

The WPRS is utilizing the services of the aforementioned private consulting firm to verify the existing theory by the installation of a monitoring network, and the redrilling, cleaning, testing and plugging of the Marland, Scott and James Wells. This program should be completed in the fall of 1980. In the event that this program does not result in an almost total reduction in salt from this source, which is highly probable, results should still be very beneficial in determining the recommended plan to be presented to Congress for authorization. The feasibility report and the draft Environmental Impact Statement are scheduled for the winter of 1983. After appropriate public hearings, the Final Environmental Impact Statement is scheduled to be released in the fall of 1983.

Crystal Geyser

The Crystal Geyser is located in a natural saline spring area on the east bank of the Green River, about 5.6 km downstream of the town of Green River, Utah. The actual "geyser" is a privately owned oil test well which contributes about 2,720 Mgm/yr to the river. The saline water erupts for about 6 minutes at approximately 5-6 hour intervals due to carbon dioxide accumulations (USDI, BR, 1979d). Water also issues from one small spring east of the well and another small spring north of the geyser (USDI-USDA, 1977). The maximum instantaneous flow has been estimated at 0.42 m^3/s with a total volume of about 0.01 ha-m per eruption. The total flow amounts to approximately 18.50 ha-m annually with dissolved solids concentrations of 11,000 to 14,000 mg/l. During eruptions, water issues from all three sources and some activity has been observed in the river. The salts are primarily sodium chloride.

A 50 cm diameter well which was drilled to a depth of 800 m was completed on the site in July, 1936. The geyser did not exist prior to the drilling of this well, but since that time, the well has erupted in spectacular but irregular periodic eruptions. The well apparently offers a local relief point for dissolved carbon dioxide and water which has most likely been trapped in the Navajo formation. The two natural springs at the site are natural openings along an existing fault line and they flow because of both hydraulic and gas pressure (USDI-USDA, 1977). However, the well probably greatly increased the salinity contribution from the area.

Woodside Geyser about 45 km north of Crystal Geyser along Highway 6 and 50 between the towns of Price and Green River, is used for commercial production of carbon dioxide. Little information is available about this minor geyser since the salinity contribution would be small. Woodside Geyser and Crystal Geyser were also used for local tourist attractions.

The Crystal Geyser was authorized for construction by PL 93-320. The Definite Plan Report, Environmental Assessment and Negative Determination of Environmental Impact have been compiled and were submitted in June, 1976 (USDI, BR, 1979a).

The proposed treatment plan for Crystal Geyser is to collect the flows and convey them to an evaporation pond about 5 km downstream. The reduction in salinity at Imperial Dam is estimated at 0.3 mg/l. The July, 1975, total construction costs were estimated at $2.69 million. Inflating these costs to January, 1980 prices the costs are $4.07 million. The 1980 annual construction cost at 7-1/8 percent would be $300,400 and annual O & M costs would be about $30,000. The annual cost-effectiveness for 2,720 Mgm removed would be about $121.40/Mgm. The Water and Power Resources Services has indefinitely postponed construction of this project.

APPENDIX 3

COSTS OF IRRIGATION SYSTEMS

In order to present representative estimates of irrigation system improvement costs, actual designs were proposed for fields ranging in size from 4 to 90 hectares. Quantity takeoffs for materials, construction, operation-maintenance (including labor), and energy were priced and used to estimate annual costs. Typical values of crop water demands and growing seasons were used to establish system capacities and operating hours. For capital cost items, an interest rate of 7.5 percent and an expected system life of 20 years was used to annualize the cost estimates. No salvage value was given to any irrigation system component. The costs presented should not be considered as absolute, but should be used in the context of relative costs for the same sized systems. It is believed that the costs are representative.

All irrigation systems were analyzed under the same soil conditions (loamy soil with a moderate infiltration rate) and field slope (0.1 percent cross slope and 0.5 percent average slope in the direction of irrigation). Leveling costs were considered only for surface irrigation methods. The surface source is a canal or a small lake or pond. No annual cost of water was assessed for surface water. Groundwater supplies were standardized as pumping electrically from 30 meters of depth, the well cased and screened with a column pipe to 46 meters. Total dynamic head included pumping depth plus pressure requirements. Pumps over 10HP were all turbines.

Costs are based on January, 1980, prices when available. Older data were updated using the Engineering News Record cost indices. All systems, except drip irrigation, were analyzed for field crops only. Drip irrigation was analyzed for orchard crops only. Leveling costs were calculated at \$750/ha for furrow irrigation systems. Wide border irrigation leveling costs were estimated at \$1,000/ha (\$1.00/m^3).

The following tables present the other basic data which was used to estimate the annual costs of irrigation systems. Table 3-1 presents some cost index comparisons of the various systems. The sideroll sprinkler system costs were taken as the base at each acreage and the costs of the other systems at that acreage were divided by the base cost. As can be seen, under the labor cost assumptions used, the cutback systems are very competitive on an annual cost basis. Sideroll sprinklers had a very low cost in almost every case, but are limited to low growing crops. The center pivot is very competitive, even with high energy costs, but unless crop values or labor costs are high, center pivots tend to be restricted to areas with low land values. Table 3-2 presents a summary of annual maintenance cost estimates as a percentage of the total initial capital costs of investment. Table 3-3 summarizes labor requirements for various methods of irrigation which Table 3-4 presents a

Table 3-1. Cost index comparisons for surface water supply.

System	COST INDEX[1]					
	40 ac		80 ac		160 ac	
	Annual[2]	Initial[3]	Annual[2]	Initial[3]	Annual[2]	Initial[3]
Sideroll	1.00	1.00	1.00	1.00	1.00	1.00
Center Pivot	1.55	1.79	1.44	1.25	1.21	0.97
Handmove Al.	1.80	1.26	1.80	1.38	1.69	1.32
Traveler	2.09	2.26	2.11	2.17	2.33	2.39
Drip	2.23	3.55	2.50	4.06	3.08	5.32
Solid Set Al.	2.77	3.74	3.06	4.53	2.97	4.00
Solid Set PVC	3.50	6.32	3.89	7.34	4.53	7.74
Cutback	0.87	1.53	1.00	1.72	1.05	1.77
Gated Pipe	1.07	1.00	1.22	1.22	1.40	1.35
Siphons	1.12	1.11	1.28	1.31	1.45	1.42
Reuse	1.57	1.92	1.56	2.09	1.63	2.16

[1] Cost Index was computed by the sideroll system being assigned a value of 1.00. The other systems are a ratio of their costs of sideroll system at that acreage.

[2] Total annual cost.

[3] Initial investment costs.

Table 3-2. Annual maintenance costs[1] as a percent total initial capital cost of each component.

Irrigation System	Pumps[2]	Mains[2]	Irrigation System		Misc.
Handmove	3	2	5[2]	4[3]	
Towline	3	2	7		
Sideroll	3	2	4	4[4]	
Traveler	3	2	5		
Traveling Boom	3	2	5		
Center Pivot	3[5]	2	3	2[5]	
Solid Set	3	2	2		
Permanent Solid Set	3	2	3		
Drip	3	2	4		
Gated Pipe			1.4[6]		
Holding Ponds					1-3[7]
Grassed Waterways					5[7]
Concrete Ditch		2[7]			
Earth Ditch		10[7]			
Land Leveling					2[7]
Drainage Tile Line					5[7]

[1] Taxes and insurance are usually estimated at about 2% of the initial investment. This table does not include depreciation, interest, taxes, and insurance, or other overhead costs.

[2] Pitchford and Wilkinson (1975).

[3] Pair, et al. 19

[4] Lacewell and Hughes (1971).

[5] Sheffield, L.F. (1977).

[6] Eisenhauer and Fischbach (1977).

[7] USDA, SCS, 1979f.

Table 3-3. Representative labor requirements in hours per acre per irrigation, (1 acre = 0.4046 ha).

Data Source/Method	Reed et al. (1977)	USDA, SCS (1979_)	Pair, et al. (1975)	Others	
Contour Furrow		0.5 - 1.5			
Level Furrow		0.1 - 0.5			
Furrow (siphon tubes)	3	0.4 - 1.2		1.27[2]	0.9[5]
Automated Furrow		0.5 - 0.15			
Handmove Sprinkler	2	0.5 - 1.5	0.7 - 1	0.92[2]	1.2[5]
Side Roll	1	0.1 - 0.3	0.3 - 0.6	0.55[2]	-0.43[3]
Traveler		0.1 - 0.3	0.2 - 0.4	0.15[2]	
Center Pivot (125 ac)[4]	0.12	0.05 - 0.15	0.05 - 0.3	0.5[1]	
Towline		0.2 - 0.4	0.2 - 0.4	0.54[2]	
Center Pivot (corner system-153 ac)	0.12		0.05 - 0.1	0.11[2]	
Portable Solid Set		0.2 - 0.5	0.5 - 1.0		
Permanent Solid Set	0.5	0.05 - 0.1	0.1 - 0.2		
Boom (self-propelled)		0.2 - 0.5	0.2 - 0.4	0.78[2]	
Drip	8 hrs/yr/acre	0.05 - 0.15			
Gated Pipe w/o moving				0.2[1]	-0.53[2] -0.71[5]
Gated Pipe w/moving				1.03[1]	
Automated Level Borders		0.05 - 0.15			
Border		0.2 - 1.0			
Contour Ditch		1.0 - 2.0			
Corrugations		0.4 - 1.2			

1 Eisenhauer and Fischbach (1977)
2 Hart, W.E. (1975)
3 Lacewell and Hughes (1971)
4 Includes large lateral moving machines
5 Thorfinnson, et al. (1955)

Table 3-4. Expected lifetime of irrigation equipment with good maintenance (Pair, et al., 1975).

Equipment	Hours	Years				
		Eisenhauer & Fischback, 1977	USDA, SCS, 1979	Hart, 1975	Reed, et al., 1976	Pair, et al., 1975
Well (incl. screen, casing, gravel pack)						20-25
Pump House						20
Turbine Pump						
Bowls	16,000					8
Columns	32,000					16
Centrifugal Pump	32,000					16
Gearhead	30,000					12-15
Diesel Power Unit	28,000					12-15
Natural Gas-Propane Power Unit						14
Gasoline Power Unit (water cooled)	18,000					9
Fuel Tanks				20		
Electric Motor	50,000					15-20-25
PVC Pipeline						40-50
Concrete-Asbestos Pipeline						40
Concrete Pipe						20
Aluminum Tubing						10-15
Aluminum Gated Pipe						10
Collapsible Plastic Gated Pipe				2-8		
Pipe Trailer				10		20
Sprinkler Systems (in general)						10-15
Sprinkler Nozzles						2-3
Sprinkler Heads						
Plastic	2,000				5	
Brass	5,000					8
Aluminum Handmove					5	
Traveling Boom Sprinklers				10		
Center Pivot Sprinklers				15		
Sideroll Sprinklers				10		12-15
Towline				10		
Permanent Solid Set						15-20
Aluminum Portable Solid Set				12-15	10	
Traveler: "Big Gun"				15		
Hose						4-6
Reservoirs (no silting basin)				20		
Tailwater Reuse System Pit (concrete lined)		20				
Electric Control Panels/Switches				20		
Drip System					10	
Emitters					10	
Polyethylene line and fittings					10	
Filtration Equipment					15	
Valves and Regulators					15	
Propeller Meter (with good maintenance)		15				
Land Leveling (with poor annual maintenance)			7-20			
Land Plane				15		
Concrete Ditch			20-25			
Holding Ponds			25			
Drainage Tile Line			25			
Concrete Structures						20
Galvanized Sheet Metal Structures (flumes)				20-15		

completion of published information on the expected lifetime of various irrigation equipment. Finally, Table 3-5 presents January, 1980, prices for various pipe sizes and classifications.

Table 3-5. Approximate materials cost for large lots of commonly available sizes of irrigation pipe as of February, 1979, including gaskets and couplings (S/100 ft).

Nominal Pipe Diameter (inches)	PLASTIC IRRIGATION PIPE[2] 50 ft head (40'jts)	50 psi (40'jts)	80 psi (20jts)	100 psi (20jts)	REINFORCED CONCRETE Nonreinforced (ASTM C 118) A25	Reinforced A75	CLASS 150[3] Aluminum Tubing (40' jts, 100 psi)	LOW PRESSURE Aluminum Pipe (0.051 ga.) (w/o gates)
2							97.00	
3							128.00	
4				76.00			173.00	
5							221.00	
6	71.36	99.00	134.00	160.00	116.00		290.00	163.00
8	113.06	164.00	232.00	284.00	226.50		336.00	220.00
10	166.58	248.00	356.00	444.00	276.60		376.00	283.00
12	243.18	380.00	528.00	636.00	357.00			
15	363.76[4]	556.00	816.00	1001.00	518.25			
18					934.00	1,163.00		
24					1,228.00	1,678.00		
30					1,702.00	2,497.00		
36					2,472.00	3,347.00		

Table 3-5. (continued)

Nominal Pipe Diameter	Black Iron Pipe (Sch 40)[5]	PLASTIC CLASS PIPE Class 160 20' length	Class 200 20' length	Schedule 40 20' length	Schedule 80 20' length	Polyethylene Tubing 80 psi	100 psi
3/4	81.00			29.00	43.00	10.00	16.00
1	114.00		23.00	43.00	58.00	15.81	26.00
1-1/4	150.00	29.00	35.00	56.00	80.00	26.61	44.00
1-1/2	178.00	37.00	45.00	66.00	97.00	36.13	59.00
2	241.00	55.00	68.00	89.00	134.00	63.24	115.00
2-1/2	--	80.00	99.00	141.00	274.00		
3	486.00	119.00	145.00	183.00	400.00		
4	573.00	193.00	235.00	258.00			
6	1,292.00	414.00	504.00				
8	1,864.00	698.00	856.00				
10	2,263.00						
12	3,224.00						

[1] 100 feet = 30.48 meters

[2] solvent weld, cost includes estimated solvent and cement, other pipe categories are gasketed unless stated.

[3] 40' lengths, shorter lengths will cost as much as 50% more since couplings will have to be provided depending on type and lengths.

[4] 20' joint

[5] Plain ends, no threads, no couplings, 21' random lengths.

APPENDIX 4

OPTIMAL CANAL LINING STRATEGIES

The following tables present the optimal canal lining strategies for each of the five irrigated areas evaluated as part of this study. The results are tabulated by canal. The first column is the percentage of the total attainable salinity reduction attributed to lining all of the canals. The values listed under each canal are the percentages of attainable reduction for the individual canals at that level of control. The actual salt load per canal can be found in Appendix 2.

Table 4-1. Optimal canal lining program for the Grand Valley, Colorado.

% of Total Salt Reduction	Annual Cost ($)	Percentage of salt reduction required from each individual canal[1]													
		CANAL													
		Government Highline	Grand Valley Canal	Grand Valley Main line	Grand Valley High-line	Kiefer Exten-sion	Mesa County Ditch	Independent Ranchmen's Canal	Price Ditch	Stub Ditch	Orchard Mesa Power Canal	Orchard Mesa No. 1	Orchard Mesa No. 2	Redlands Power Canal	Redlands Canals No. 1 & 2
13.52	429637	17.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	3.75
20.24	669280	31.91	0.00	0.00	0.00	0.00	2.41	0.00	0.00	0.00	100.00	0.00	0.00	0.00	16.21
29.73	1049555	44.15	0.00	5.82	0.00	0.00	13.37	0.00	0.00	0.00	100.00	0.00	0.00	100.00	26.76
35.46	1313830	54.69	0.00	16.21	0.00	0.00	22.84	0.00	0.00	0.00	100.00	0.00	0.00	100.00	35.84
40.85	1565896	63.89	0.00	29.02	1.30	0.00	31.08	0.00	0.48	0.00	100.00	9.33	0.00	100.00	43.76
46.03	1840329	72.00	0.00	36.57	1.63	0.00	38.36	0.00	13.31	0.00	100.00	18.28	0.00	100.00	50.75
53.27	2053480	79.23	0.00	47.07	22.39	0.00	44.85	0.00	19.87	0.00	100.00	26.25	0.00	100.00	56.98
59.39	2659745	85.73	0.00	54.71	40.85	2.66	50.57	0.00	26.94	0.00	100.00	33.42	0.00	100.00	62.58
66.17	3071538	91.61	0.00	61.62	57.56	12.33	55.95	0.00	34.66	0.00	100.00	39.90	0.00	100.00	67.64
71.94	3473821	96.95	0.00	67.92	72.78	20.73	60.75	0.00	40.54	0.38	100.00	45.81	1.72	100.00	72.26
76.53	3811991	100.00	0.00	73.66	86.71	28.84	65.14	0.00	46.46	0.00	100.00	51.22	6.43	100.00	76.48
79.52	4045829	100.00	0.00	78.99	99.73	36.11	69.19	0.00	51.94	0.97	100.00	56.17	14.61	100.00	80.37
81.07	4175672	100.00	3.95	83.89	100.00	42.82	72.73	0.00	56.95	5.90	100.00	60.77	20.31	100.00	83.96
85.44	4532616	100.00	41.65	88.44	100.00	49.05	76.40	0.00	61.68	12.40	100.00	65.05	25.60	100.00	87.29
89.49	4920631	100.00	76.75	92.67	100.00	54.64	79.62	0.00	66.64	17.52	100.00	69.02	30.53	100.00	90.39
92.44	5200478	100.00	100.00	96.63	100.00	60.26	82.61	0.00	70.11	22.30	100.00	72.73	35.14	100.00	93.29
93.30	5285405	100.00	100.00	100.00	100.00	65.33	85.41	0.00	73.93	26.78	100.00	76.21	39.45	100.00	96.01
93.89	5346719	100.00	100.00	100.00	100.00	71.19	88.12	0.00	77.52	30.99	100.00	79.48	43.51	100.00	98.56
94.43	5404720	100.00	100.00	100.00	100.00	74.57	90.62	0.50	80.91	34.96	100.00	82.55	47.32	100.00	100.00
94.94	5462367	100.00	100.00	100.00	100.00	78.63	92.99	2.09	84.08	38.70	100.00	85.46	50.73	100.00	100.00
95.53	5536041	100.00	100.00	100.00	100.00	82.64	95.22	10.08	87.10	42.25	100.00	88.20	54.33	100.00	100.00
96.08	5596519	100.00	100.00	100.00	100.00	86.54	97.34	17.65	89.96	45.60	100.00	90.80	57.57	100.00	100.00
96.50	5661861	100.00	100.00	100.00	100.00	90.25	99.35	24.83	92.67	48.77	100.00	93.26	60.63	100.00	100.00
97.09	5725203	100.00	100.00	100.00	100.00	93.65	100.00	31.67	95.25	51.82	100.00	95.63	63.55	100.00	100.00
97.56	5787069	100.00	100.00	100.00	100.00	96.95	100.00	38.19	97.72	54.71	100.00	97.87	66.35	100.00	100.00
98.00	5847337	100.00	100.00	100.00	100.00	100.00	100.00	44.40	100.00	57.47	100.00	100.00	68.99	100.00	100.00
98.18	5872753	100.00	100.00	100.00	100.00	100.00	100.00	50.35	100.00	60.10	100.00	100.00	71.52	100.00	100.00
98.35	5897798	100.00	100.00	100.00	100.00	100.00	100.00	56.03	100.00	62.82	100.00	100.00	73.95	100.00	100.00
98.51	5922438	100.00	100.00	100.00	100.00	100.00	100.00	61.48	100.00	65.04	100.00	100.00	76.27	100.00	100.00
98.67	5946337	100.00	100.00	100.00	100.00	100.00	100.00	66.70	100.00	67.36	100.00	100.00	78.50	100.00	100.00
98.82	5970860	100.00	100.00	100.00	100.00	100.00	100.00	71.72	100.00	69.58	100.00	100.00	80.65	100.00	100.00
98.97	5994576	100.00	100.00	100.00	100.00	100.00	100.00	76.54	100.00	71.72	100.00	100.00	82.75	100.00	100.00
99.11	6017977	100.00	100.00	100.00	100.00	100.00	100.00	81.18	100.00	73.78	100.00	100.00	84.68	100.00	100.00
99.24	6041054	100.00	100.00	100.00	100.00	100.00	100.00	85.65	100.00	75.76	100.00	100.00	86.59	100.00	100.00
99.36	6063731	100.00	100.00	100.00	100.00	100.00	100.00	89.96	100.00	77.67	100.00	100.00	88.43	100.00	100.00
99.50	6086497	100.00	100.00	100.00	100.00	100.00	100.00	94.12	100.00	79.51	100.00	100.00	90.21	100.00	100.00
99.62	6108303	100.00	100.00	100.00	100.00	100.00	100.00	98.14	100.00	81.30	100.00	100.00	91.92	100.00	100.00
99.71	6124774	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	83.02	100.00	100.00	93.58	100.00	100.00
99.76	6135276	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	84.68	100.00	100.00	95.13	100.00	100.00
99.81	6145267	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	86.29	100.00	100.00	96.73	100.00	100.00
99.86	6155349	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	87.85	100.00	100.00	98.24	100.00	100.00
99.91	6165328	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	89.37	100.00	100.00	99.59	100.00	100.00
99.93	6169233	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	90.83	100.00	100.00	100.00	100.00	100.00
99.94	6171575	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	92.26	100.00	100.00	100.00	100.00	100.00
99.95	6173845	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	93.64	100.00	100.00	100.00	100.00	100.00
99.96	6176093	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	94.98	100.00	100.00	100.00	100.00	100.00
99.97	6178320	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	96.29	100.00	100.00	100.00	100.00	100.00
99.98	6180526	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	97.56	100.00	100.00	100.00	100.00	100.00
99.99	6182712	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	98.80	100.00	100.00	100.00	100.00	100.00
100.00	6184880	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[1] Columns indicate the extent of individual canal linings to be completed to achieve the percentage of salt reduction recorded for each canal.

Table 4-2. Optimal large canal lining program for the Lower Gunnison, Colorado.

% of total canal salt reduction	Annual Cost ($)	Stell	Cedar Canon	Dyer Fork	Fruit-land	Durkee	Transfer	Park	Bonafide	Hartland	Relief	North Delta	Overland	Highline	Currant Creek
18.83	685995	0.00	42.68	0.00	0.00	66.75	58.55	0.00	0.00	35.77	0.00	0.00	0.00	0.00	100.00
43.78	2705783	0.00	83.19	23.88	0.00	100.00	97.57	0.00	0.00	78.67	7.37	3.98	2.09	23.96	100.00
70.51	5597647	0.00	100.00	72.77	21.58	100.00	100.00	0.00	32.94	100.00	42.16	37.68	39.99	56.21	100.00
90.11	8642126	0.00	100.00	100.00	51.22	100.00	100.00	0.00	56.60	100.00	64.74	59.58	64.62	77.16	100.00
94.56	9224899	9.80	100.00	100.00	72.52	100.00	100.00	3.73	75.55	100.00	80.93	75.27	82.26	92.17	100.00
97.13	9777564	27.77	100.00	100.00	88.74	100.00	100.00	19.79	86.46	100.00	93.26	87.22	95.70	100.00	100.00
98.63	10149528	42.41	100.00	100.00	100.00	100.00	100.00	32.54	96.72	100.00	100.00	96.71	100.00	100.00	100.00
98.94	10236459	54.24	100.00	100.00	100.00	100.00	100.00	43.80	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.13	10296772	64.16	100.00	100.00	100.00	100.00	100.00	51.76	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.29	10354006	72.64	100.00	100.00	100.00	100.00	100.00	59.25	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.42	10406014	79.99	100.00	100.00	100.00	100.00	100.00	65.75	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.52	10451465	86.44	100.00	100.00	100.00	100.00	100.00	71.45	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.62	10495146	92.17	100.00	100.00	100.00	100.00	100.00	76.51	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.70	10534498	97.30	100.00	100.00	100.00	100.00	100.00	81.34	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.75	10562943	100.00	100.00	100.00	100.00	100.00	100.00	85.13	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.77	10575395	100.00	100.00	100.00	100.00	100.00	100.00	88.64	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.79	10588461	100.00	100.00	100.00	100.00	100.00	100.00	92.25	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.81	10600675	100.00	100.00	100.00	100.00	100.00	100.00	95.34	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.83	10612564	100.00	100.00	100.00	100.00	100.00	100.00	98.21	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.85	10623684	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.86	10633619	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.87	10643326	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.88	10652820	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.89	10662115	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.90	10671222	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.91	10680153	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.92	10688917	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.93	10697524	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.94	10705981	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	10714276	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	10722477	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	10730529	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	10738458	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	10746270	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	10753967	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10759998	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10761694	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10763375	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10765034	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10766673	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10768292	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10769891	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10771471	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10773034	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10774579	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10776107	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10777619	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10779115	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10780595	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10782062	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-2. (continued)

% of total canal salt reduction	Annual Cost ($)	Stull	Cow Creek	Leroux Creek	Midkoff & Arnold	Allen Mesa	Fire Mountain	Stewart	North Fork Farmers	Short	Crawford	Pilot Rock	Daisy	Needle Rock	Grandview
18.83	885995	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.15	40.73	64.08	42.80	20.88
43.78	2705783	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.76	71.40	76.97	100.00	84.68	72.96
70.51	5597647	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	51.65	98.60	96.59	100.00	100.00	100.00
90.11	8442126	0.00	14.17	100.00	13.86	0.00	94.41	10.68	0.00	71.07	100.00	100.00	100.00	100.00	100.00
94.56	9224099	20.18	32.37	100.00	32.00	0.00	100.00	29.45	0.00	84.99	100.00	100.00	100.00	100.00	100.00
97.13	9777504	37.25	46.24	100.00	45.81	0.00	100.00	43.60	0.00	95.59	100.00	100.00	100.00	100.00	100.00
98.63	10149528	56.88	57.26	100.00	56.79	0.00	100.00	54.84	0.00	100.00	100.00	100.00	100.00	100.00	100.00
98.94	10236459	62.05	66.29	100.00	65.70	0.00	100.00	64.04	0.00	100.00	100.00	100.00	100.00	100.00	100.00
99.13	10296772	71.41	73.86	100.00	73.32	0.00	100.00	71.77	0.00	100.00	100.00	100.00	100.00	100.00	100.00
99.29	10354006	79.41	80.32	100.00	79.77	0.00	100.00	78.36	0.00	100.00	100.00	100.00	100.00	100.00	100.00
99.42	10406014	86.35	85.93	100.00	85.36	0.00	100.00	84.09	1.02	100.00	100.00	100.00	100.00	100.00	100.00
99.52	10451465	92.44	90.86	100.00	90.27	0.00	100.00	89.11	10.25	100.00	100.00	100.00	100.00	100.00	100.00
99.62	10495140	97.85	95.23	100.00	94.62	0.00	100.00	93.57	18.44	100.00	100.00	100.00	100.00	100.00	100.00
99.70	10534490	100.00	99.14	100.00	98.52	0.00	100.00	97.56	25.77	100.00	100.00	100.00	100.00	100.00	100.00
99.75	10562943	100.00	100.00	100.00	100.00	6.35	100.00	100.00	32.37	100.00	100.00	100.00	100.00	100.00	100.00
99.77	10575895	100.00	100.00	100.00	100.00	12.80	100.00	100.00	38.39	100.00	100.00	100.00	100.00	100.00	100.00
99.79	10588461	100.00	100.00	100.00	100.00	18.69	100.00	100.00	43.88	100.00	100.00	100.00	100.00	100.00	100.00
99.81	10600675	100.00	100.00	100.00	100.00	24.10	100.00	100.00	48.91	100.00	100.00	100.00	100.00	100.00	100.00
99.83	10612564	100.00	100.00	100.00	100.00	29.69	100.00	100.00	53.56	100.00	100.00	100.00	100.00	100.00	100.00
99.85	10623684	100.00	100.00	100.00	100.00	33.71	100.00	100.00	57.86	100.00	100.00	100.00	100.00	100.00	100.00
99.86	10633619	100.00	100.00	100.00	100.00	38.06	100.00	100.00	61.86	100.00	100.00	100.00	100.00	100.00	100.00
99.87	10643326	100.00	100.00	100.00	100.00	42.30	100.00	100.00	65.59	100.00	100.00	100.00	100.00	100.00	100.00
99.88	10652628	100.00	100.00	100.00	100.00	45.75	100.00	100.00	69.08	100.00	100.00	100.00	100.00	100.00	100.00
99.89	10662115	100.00	100.00	100.00	100.00	49.27	100.00	100.00	72.35	100.00	100.00	100.00	100.00	100.00	100.00
99.90	10671222	100.00	100.00	100.00	100.00	52.57	100.00	100.00	75.43	100.00	100.00	100.00	100.00	100.00	100.00
99.91	10680153	100.00	100.00	100.00	100.00	55.69	100.00	100.00	78.33	100.00	100.00	100.00	100.00	100.00	100.00
99.92	10688917	100.00	100.00	100.00	100.00	58.64	100.00	100.00	81.08	100.00	100.00	100.00	100.00	100.00	100.00
99.93	10697524	100.00	100.00	100.00	100.00	61.43	100.00	100.00	83.68	100.00	100.00	100.00	100.00	100.00	100.00
99.94	10705981	100.00	100.00	100.00	100.00	64.66	100.00	100.00	86.15	100.00	100.00	100.00	100.00	100.00	100.00
99.95	10714296	100.00	100.00	100.00	100.00	66.69	100.00	100.00	88.49	100.00	100.00	100.00	100.00	100.00	100.00
99.95	10722477	100.00	100.00	100.00	100.00	68.99	100.00	100.00	90.72	100.00	100.00	100.00	100.00	100.00	100.00
99.96	10730529	100.00	100.00	100.00	100.00	71.28	100.00	100.00	92.85	100.00	100.00	100.00	100.00	100.00	100.00
99.97	10738458	100.00	100.00	100.00	100.00	73.46	100.00	100.00	94.88	100.00	100.00	100.00	100.00	100.00	100.00
99.97	10746270	100.00	100.00	100.00	100.00	75.55	100.00	100.00	96.83	100.00	100.00	100.00	100.00	100.00	100.00
99.98	10753969	100.00	100.00	100.00	100.00	77.55	100.00	100.00	98.69	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10759990	100.00	100.00	100.00	100.00	79.47	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10761694	100.00	100.00	100.00	100.00	81.30	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10763375	100.00	100.00	100.00	100.00	83.07	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10765034	100.00	100.00	100.00	100.00	84.77	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10766673	100.00	100.00	100.00	100.00	86.41	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10768292	100.00	100.00	100.00	100.00	87.98	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10769891	100.00	100.00	100.00	100.00	89.50	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10771471	100.00	100.00	100.00	100.00	90.97	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10773034	100.00	100.00	100.00	100.00	92.39	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10774579	100.00	100.00	100.00	100.00	93.76	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10776107	100.00	100.00	100.00	100.00	95.09	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10777619	100.00	100.00	100.00	100.00	96.38	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10779115	100.00	100.00	100.00	100.00	97.62	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10780596	100.00	100.00	100.00	100.00	98.83	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10782062	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-2. (continued)

% of total canal salt reduction	Annual Cost ($)	Saddle Mountain	Smith Fork Feeder	South	West	M & D Canal (Mancos)	M & D Canal (non-Mancos)	Loutzenhizer	Selig	Ironstone Canal (Mancos)	Ironstone Canal (nonMancos)	East	Garnet
18.83	805975	0.00	100.00	0.00	0.00	100.00	0.00	28.55	20.11	100.00	0.00	74.27	0.00
43.78	2705783	0.00	100.00	0.00	15.07	100.00	4.66	96.75	100.00	100.00	12.82	100.00	67.59
70.51	5597647	0.00	100.00	100.00	69.77	100.00	61.14	100.00	100.00	100.00	61.23	100.00	100.00
93.11	8442126	21.29	100.00	100.00	100.00	100.00	97.04	100.00	100.00	100.00	93.21	100.00	100.00
94.56	9224199	41.57	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.13	9777504	57.02	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.63	10149528	69.29	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.94	10236459	79.35	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.13	10296772	87.73	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.29	10354086	94.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.42	10406014	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.52	10451465	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.62	10495140	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.70	10534490	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.75	10562943	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.77	10575895	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.79	10588461	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.81	10600675	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.83	10612564	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.85	10623684	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.86	10633619	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.87	10643326	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.88	10652620	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.89	10662115	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.90	10671227	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.91	10680153	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.92	10688917	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.93	10697524	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.94	10705981	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	10714296	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	10722477	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	10730527	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	10738458	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	10746270	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	10753969	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10757990	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10761674	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10763375	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10765034	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10766673	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10768292	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10769891	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10771471	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	10773034	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10774579	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10776107	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10777619	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10779115	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10780596	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	10782062	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-3. Optimal salt control lining program for the Uintah Basin, Utah.

% of total canal salt reduction	Annual Cost ($)	Percentage of salt reduction required from each individual canal													
		CANAL													
		Highline	Ashley Upper	Ashley Central	Rock Point	Island	Union	Sunshine	Burton	Murray	Burns Bench	Mosby	US Whiterocks	Whiterocks & Ouray	Ouray Valley
29.18	2058586	31.32	27.32	28.78	35.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40.83	3079910	62.40	61.31	62.10	81.42	12.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48.83	3921243	86.16	87.30	87.58	100.00	28.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59.38	5220599	100.00	100.00	100.00	100.00	42.14	57.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
66.86	6259068	100.00	100.00	100.00	100.00	53.10	100.00	0.00	0.00	0.00	0.00	0.14	20.19	0.02	0.00
73.99	7377249	100.00	100.00	100.00	100.00	62.31	100.00	0.00	0.00	0.00	0.00	19.06	38.64	90.85	0.00
76.60	7830271	100.00	100.00	100.00	100.00	70.19	100.00	0.00	0.00	0.00	0.00	35.25	53.31	100.00	0.00
79.48	8382125	100.00	100.00	100.00	100.00	77.03	100.00	0.00	0.00	0.00	0.00	49.30	66.57	100.00	0.00
82.05	8918073	100.00	100.00	100.00	100.00	83.04	100.00	0.00	0.00	0.00	0.00	61.65	78.22	100.00	0.00
84.11	9385465	100.00	100.00	100.00	100.00	89.37	100.00	0.00	0.00	0.00	0.00	72.61	88.57	100.00	0.00
85.95	9830121	100.00	100.00	100.00	100.00	93.15	100.00	0.00	0.00	0.00	0.00	82.43	97.84	100.00	0.00
87.29	10180901	100.00	100.00	100.00	100.00	97.47	100.00	0.00	0.00	0.00	0.00	91.30	100.00	100.00	0.00
87.91	10352914	100.00	100.00	100.00	100.00	100.00	100.00	0.00	0.00	0.00	0.00	97.35	100.00	100.00	0.00
88.55	10541717	100.00	100.00	100.00	100.00	100.00	100.00	33.87	35.53	31.17	29.39	100.00	100.00	100.00	0.00
89.23	10751823	100.00	100.00	100.00	100.00	100.00	100.00	71.91	72.75	66.45	68.50	100.00	100.00	100.00	0.00
89.79	10935761	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.00	100.00	100.00	100.00	100.00	0.00
89.90	10976463	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
90.06	11032431	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
90.25	11105597	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
90.59	11241091	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
91.98	11821934	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
93.40	12433306	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
94.42	12894197	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	0.00
95.39	13345410	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	13.75
95.90	13591834	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	38.50
96.36	13823451	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	62.14
96.80	14051193	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	84.53
97.19	14263643	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.50	14431972	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.78	14592248	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.05	14750159	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.31	14911918	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.58	15075482	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.83	15236830	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.07	15396048	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.31	15553219	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.53	15708420	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.75	15861722	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.87	15949088	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.90	15970051	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.91	15979177	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.92	15988201	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.93	15997127	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.94	16005958	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	16014696	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	16023346	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	16031908	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	16040386	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	16048783	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	16057100	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-3. (continued)

% of total canal salt reduction	Annual Cost ($)	Percentage of salt reduction required from each individual canal — CANAL: Ouray Park	Deep Creek	Moffat	Henry Jim	US Farm Creek	Uintah River Canal	Uintah #1	Indian Bench	Monarch	Martin Lateral	Sheehan Lateral	Hancock Lateral	Farnsworth	F Canal
29.18	2058586	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40.88	3079910	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48.83	3921243	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59.38	5220599	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
66.86	6259068	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	21.69	30.87	35.53	0.00	0.00
73.99	7377249	0.00	7.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88.73	99.65	100.00	0.00	0.00
76.68	7830271	7.67	33.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	100.00	100.00	0.00	0.00
79.48	8382125	23.00	56.81	0.00	63.46	0.00	0.00	0.00	18.58	0.00	100.00	100.00	100.00	0.00	0.00
82.05	8918073	36.47	76.95	0.00	100.00	0.00	0.00	0.00	42.27	0.00	100.00	100.00	100.00	0.00	0.00
84.11	9385465	48.44	94.83	0.00	100.00	0.00	0.00	3.91	63.31	0.00	100.00	100.00	100.00	0.00	0.00
85.95	9830121	59.15	100.00	0.00	100.00	0.00	24.43	56.84	82.15	0.00	100.00	100.00	100.00	0.00	0.00
87.29	10180901	68.83	100.00	0.00	100.00	0.00	59.76	100.00	99.16	0.00	100.00	100.00	100.00	0.00	0.00
87.91	10352914	77.61	100.00	0.00	100.00	0.00	91.85	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.00
88.55	10541717	85.64	100.00	0.00	100.00	0.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.00
89.23	10751823	93.01	100.00	0.00	100.00	0.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.00
89.79	10935761	99.82	100.00	0.00	100.00	0.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.00
89.98	10976463	100.00	100.00	0.00	100.00	0.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.00
90.06	11032431	100.00	100.00	13.41	100.00	0.00	100.00	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.00
90.25	11105597	100.00	100.00	21.70	100.00	6.69	100.00	100.00	100.00	0.00	100.00	100.00	100.00	0.00	0.92
90.59	11241091	100.00	100.00	32.26	100.00	13.93	100.00	100.00	100.00	0.51	100.00	100.00	100.00	2.00	8.57
91.98	11821934	100.00	100.00	42.17	100.00	20.72	100.00	100.00	100.00	65.31	100.00	100.00	100.00	18.02	15.75
93.40	12433306	100.00	100.00	51.50	100.00	27.11	100.00	100.00	100.00	100.00	100.00	100.00	100.00	17.56	22.50
94.42	12894197	100.00	100.00	60.29	100.00	33.13	100.00	100.00	100.00	100.00	100.00	100.00	100.00	24.67	28.88
95.39	13345410	100.00	100.00	68.61	100.00	38.83	100.00	100.00	100.00	100.00	100.00	100.00	100.00	31.39	34.90
95.90	13591834	100.00	100.00	76.48	100.00	44.23	100.00	100.00	100.00	100.00	100.00	100.00	100.00	37.76	40.60
96.36	13823451	100.00	100.00	83.95	100.00	49.35	100.00	100.00	100.00	100.00	100.00	100.00	100.00	43.81	46.01
96.80	14051193	100.00	100.00	91.06	100.00	54.22	100.00	100.00	100.00	100.00	100.00	100.00	100.00	49.55	51.16
97.19	14263643	100.00	100.00	97.82	100.00	58.85	100.00	100.00	100.00	100.00	100.00	100.00	100.00	55.02	56.06
97.50	14431972	100.00	100.00	100.00	100.00	63.27	100.00	100.00	100.00	100.00	100.00	100.00	100.00	60.24	60.73
97.78	14592248	100.00	100.00	100.00	100.00	67.49	100.00	100.00	100.00	100.00	100.00	100.00	100.00	65.22	65.19
98.05	14750159	100.00	100.00	100.00	100.00	71.52	100.00	100.00	100.00	100.00	100.00	100.00	100.00	69.78	69.46
98.31	14911918	100.00	100.00	100.00	100.00	75.39	100.00	100.00	100.00	100.00	100.00	100.00	100.00	74.55	73.55
98.58	15075482	100.00	100.00	100.00	100.00	79.10	100.00	100.00	100.00	100.00	100.00	100.00	100.00	78.92	77.47
98.83	15236830	100.00	100.00	100.00	100.00	82.65	100.00	100.00	100.00	100.00	100.00	100.00	100.00	83.12	81.23
99.07	15396048	100.00	100.00	100.00	100.00	86.07	100.00	100.00	100.00	100.00	100.00	100.00	100.00	87.16	84.84
99.31	15553219	100.00	100.00	100.00	100.00	89.36	100.00	100.00	100.00	100.00	100.00	100.00	100.00	91.04	88.32
99.53	15708420	100.00	100.00	100.00	100.00	92.53	100.00	100.00	100.00	100.00	100.00	100.00	100.00	94.78	91.67
99.75	15861722	100.00	100.00	100.00	100.00	95.58	100.00	100.00	100.00	100.00	100.00	100.00	100.00	98.38	94.90
99.87	15949088	100.00	100.00	100.00	100.00	98.52	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	98.61
99.90	15970051	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.91	15979177	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.92	15988201	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.93	15997127	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.94	16005958	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	16014696	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	16023346	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	16031908	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	16040386	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	16048783	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	16057100	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-3. (continued)

% of total canal salt reduction	Annual Cost ($)	Percentage of salt reduction required from each individual canal CANAL														
		US Lake Fork	Lake Fork Western	Dry Gulch #1	Bluebell Lateral	Class C	Lake Fork	North C Lateral	South C Lateral	US Dry Gulch	Purdy	Uteland	Redcap	A Pioneer	B Pioneer
29.18	2058586	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.69	0.00
40.88	3079918	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	61.41	22.28
48.83	3921243	0.00	0.00	0.00	0.00	0.00	0.00	34.79	34.79	0.00	0.00	0.00	0.00	81.08	46.28
59.38	5220599	0.00	0.00	0.00	0.00	60.65	0.00	100.00	100.00	51.85	0.00	0.00	0.00	96.74	65.40
66.86	6259068	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	68.77	58.62	69.49	100.00	81.10
73.99	7377249	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	94.28
76.68	7836271	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
79.48	8382125	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
82.05	8918073	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
84.11	9385465	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
85.95	9830121	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
87.29	10180981	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
87.91	10352914	0.00	0.00	0.00	0.00	100.00	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
88.55	10541717	0.00	0.00	0.00	0.00	100.00	4.70	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
89.23	10751823	0.00	0.00	0.00	0.00	100.00	18.32	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
89.79	10935761	0.00	0.00	0.00	0.00	100.00	33.69	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
89.98	10976463	0.00	0.00	0.00	0.00	100.00	42.53	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90.06	11032431	0.00	0.00	0.00	0.00	100.00	53.36	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90.25	11105597	0.00	0.00	0.00	0.00	100.00	63.46	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90.59	11241091	5.45	0.00	0.00	0.00	100.00	72.91	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
91.98	11821934	13.16	0.00	11.23	11.23	100.00	81.78	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
93.48	12433306	20.43	0.00	42.39	42.39	100.00	93.13	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
94.42	12894197	27.27	0.00	71.19	71.19	100.00	98.60	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
95.39	13345410	33.75	0.00	98.70	98.70	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
95.98	13591834	39.88	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
96.36	13823451	45.70	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
96.80	14051193	51.23	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.19	14263643	56.49	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.58	14431972	61.52	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.78	14592248	66.31	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.05	14750159	70.90	0.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.31	14911918	75.29	4.40	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.58	15075482	79.51	11.51	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.83	15236830	83.55	18.33	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.07	15396048	87.44	24.08	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.31	15553219	91.17	31.19	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.53	15708420	94.77	37.26	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.75	15861722	98.24	43.11	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.87	15949088	100.00	48.75	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.90	15970051	100.00	54.20	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.91	15979177	100.00	59.46	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.92	15988201	100.00	64.55	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.93	15997127	100.00	69.47	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.94	16005958	100.00	74.24	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	16014696	100.00	78.87	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	16023346	100.00	83.35	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	16031988	100.00	87.69	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	16040386	100.00	91.92	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	16048783	100.00	96.12	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	16057130	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-3. (continued)

% of total canal salt reduction	Annual Cost ($)	Percentage of salt reduction required from each individual canal							
		CANAL							
		Rocky Point	Gray Mountain	Pleasant Valley	Myton Townsite	Duchesne Feeder	Pahcease	Riverdale	Ouray School
29.18	2058586	11.28	100.00	72.40	8.34	100.00	0.00	0.00	0.00
40.63	3079910	43.68	100.00	100.00	41.57	100.00	0.00	0.00	26.89
48.83	3921243	68.80	100.00	100.00	66.98	100.00	0.00	1.55	52.16
59.38	5220599	88.66	100.00	100.00	87.22	100.00	91.10	18.56	72.2
66.86	6259068	100.00	100.00	100.00	100.00	100.00	100.00	32.52	88.82
73.99	7377249	100.00	100.00	100.00	100.00	100.00	100.00	44.24	100.00
76.60	7836271	100.00	100.00	100.00	100.00	100.00	100.00	54.27	100.00
79.48	8382125	100.00	100.00	100.00	100.00	100.00	100.00	62.98	100.00
82.05	8918073	100.00	100.00	100.00	100.00	100.00	100.00	76.64	100.00
84.11	9385465	100.00	100.00	100.00	100.00	100.00	100.00	77.44	100.00
85.95	9830121	100.00	100.00	100.00	100.00	100.00	100.00	83.52	100.00
87.29	10180901	100.00	100.00	100.00	100.00	100.00	100.00	87.02	100.00
87.91	10352914	100.00	100.00	100.00	100.00	100.00	100.00	94.01	100.00
88.55	10541717	100.00	100.00	100.00	100.00	100.00	100.00	98.57	100.00
89.23	10751823	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
89.79	10935761	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
89.90	10976463	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90.06	11032431	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90.25	11105597	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
90.59	11241891	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
91.98	11821934	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
93.40	12433306	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
94.42	12894197	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
95.39	13345410	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
95.90	13591834	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
96.36	13823451	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
96.80	14051193	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.19	14263643	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.50	14431972	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
97.78	14592248	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.05	14750159	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.31	14911918	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.58	15075482	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
98.83	15236830	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.07	15396048	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.31	15553217	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.53	15708420	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.75	15861722	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.87	15949088	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.90	15970051	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.91	15979177	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.92	15988231	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.93	15997127	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.94	16005958	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.95	16014696	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	16023346	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	16031908	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	16040386	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	16048783	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	16057100	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-4. Optimal canal lining program for the Price-San Rafael-Muddy Creek Drainages, Utah.

% of total canal salt reduction	Annual Cost	Percentage of salt reduction required from each individual canal															
		CANAL															
		Carbon	Price-Wellington	Spring Glen	Cleveland	Huntington	North Huntington	Cottonwood Huntington	Mammoth	Clipper Western	Blue Cut	North	Molen	South	King	Emery	Independent
1.66	56130	4.28	0.00	0.00	0.00	0.00	0.00	8.07	0.00	0.00	0.00	5.55	0.00	0.00	0.00	0.00	0.00
5.40	189083	12.53	8.28	0.00	0.10	7.71	0.00	15.50	0.00	0.00	0.00	13.53	0.00	0.00	0.00	0.00	0.00
17.14	628257	20.16	18.95	0.00	15.01	18.10	0.00	22.36	0.00	29.76	0.00	20.90	0.00	0.00	0.00	21.84	18.48
29.87	1096523	27.24	28.85	0.00	28.76	27.73	0.00	28.74	0.00	66.83	0.00	27.74	0.00	0.00	0.00	45.73	28.19
40.08	1549567	33.83	38.18	0.00	41.58	36.71	0.00	34.67	0.00	100.00	0.00	34.12	0.00	0.00	0.00	67.98	37.25
48.04	1892410	39.99	46.78	0.00	53.55	45.10	0.00	40.22	0.00	100.00	0.00	40.08	0.00	0.00	0.00	88.78	45.71
54.75	2193916	45.77	54.77	0.00	64.78	52.96	0.00	45.42	0.00	100.00	0.00	45.66	0.00	0.00	0.00	100.00	53.64
61.25	2451828	51.21	62.37	2.02	75.32	60.35	0.75	50.30	0.75	100.00	1.20	50.90	2.53	0.75	2.53	100.00	61.09
65.97	2738563	56.31	69.52	7.15	85.26	67.35	6.01	54.91	6.01	100.00	6.43	55.85	7.38	6.01	7.38	100.00	68.11
71.37	3004823	61.13	76.27	11.99	94.64	73.88	10.99	59.25	10.99	100.00	11.36	60.51	11.96	10.99	11.96	100.00	74.73
75.61	3226771	65.70	82.66	16.57	100.00	80.10	15.69	63.37	15.69	100.00	16.03	64.73	16.38	15.69	16.38	100.00	81.08
78.39	3378272	70.03	88.72	20.91	100.00	86.80	21.16	67.26	21.16	100.00	20.45	69.11	20.41	20.16	20.41	100.00	86.95
81.04	3527195	74.15	94.47	25.84	100.00	91.63	24.39	70.97	24.39	100.00	24.65	73.03	24.31	24.39	24.31	100.00	92.59
83.55	3673667	78.06	99.94	28.96	100.00	96.92	28.43	74.49	28.43	100.00	28.65	76.87	28.02	28.43	28.02	100.00	97.97
85.37	3783318	81.79	100.00	32.70	100.00	100.00	32.27	77.05	32.27	100.00	32.46	80.47	31.56	32.27	31.56	100.00	100.00
86.89	3877547	85.35	100.00	36.27	100.00	100.00	35.94	81.05	35.94	100.00	36.10	83.92	34.94	35.94	34.94	100.00	100.00
88.34	3978384	88.75	100.00	39.69	100.00	100.00	39.44	84.11	39.44	100.00	39.57	87.20	38.17	39.44	38.17	100.00	100.00
89.73	4061870	92.00	100.00	42.95	100.00	100.00	42.80	87.04	42.80	100.00	42.90	90.35	41.25	42.80	41.25	100.00	100.00
91.06	4152063	95.12	100.00	46.38	100.00	100.00	46.01	89.85	46.11	100.00	46.30	93.36	44.21	46.81	44.21	100.00	100.00
92.34	4241817	98.11	100.00	49.08	100.00	100.00	49.09	92.55	49.09	100.00	49.14	96.26	47.05	49.09	47.05	100.00	100.00
93.39	4316498	100.00	100.00	51.96	100.00	100.00	52.05	95.13	52.05	100.00	52.08	99.04	49.78	52.05	49.78	100.00	100.00
93.99	4360687	100.00	100.00	54.74	100.00	100.00	54.90	97.62	54.90	100.00	54.79	100.00	52.40	54.90	52.40	100.00	100.00
94.52	4400121	100.00	100.00	57.43	100.00	100.00	57.64	100.00	57.64	100.00	57.62	100.00	54.92	57.64	54.92	100.00	100.00
94.85	4426050	100.00	100.00	59.97	100.00	100.00	60.28	100.00	60.28	100.00	60.23	100.00	57.36	60.28	57.36	100.00	100.00
95.18	4451666	100.00	100.00	62.45	100.00	100.00	62.83	100.00	62.83	100.00	62.76	100.00	59.71	62.83	59.71	100.00	100.00
95.49	4476980	100.00	100.00	64.84	100.00	100.00	65.28	100.00	65.28	100.00	65.19	100.00	61.96	65.28	61.96	100.00	100.00
95.79	4502002	100.00	100.00	67.15	100.00	100.00	67.65	100.00	67.65	100.00	67.54	100.00	64.14	67.65	64.14	100.00	100.00
96.08	4526742	100.00	100.00	69.38	100.00	100.00	69.95	100.00	69.95	100.00	69.82	100.00	66.26	69.95	66.26	100.00	100.00
96.36	4551209	100.00	100.00	71.54	100.00	100.00	72.16	100.00	72.16	100.00	72.02	100.00	68.30	72.16	68.30	100.00	100.00
96.64	4575413	100.00	100.00	73.63	100.00	100.00	74.31	100.00	74.31	100.00	74.14	100.00	70.27	74.31	70.27	100.00	100.00
96.90	4599362	100.00	100.00	75.65	100.00	100.00	76.39	100.00	76.39	100.00	76.21	100.00	72.19	76.39	72.19	100.00	100.00
97.16	4623063	100.00	100.00	77.62	100.00	100.00	78.41	100.00	78.41	100.00	78.21	100.00	74.05	78.41	74.05	100.00	100.00
97.40	4646524	100.00	100.00	79.52	100.00	100.00	80.36	100.00	80.36	100.00	80.14	100.00	75.85	80.36	75.85	100.00	100.00
97.65	4669752	100.00	100.00	81.37	100.00	100.00	82.26	100.00	82.26	100.00	82.02	100.00	77.59	82.26	77.59	100.00	100.00
97.88	4692754	100.00	100.00	83.16	100.00	100.00	84.10	100.00	84.10	100.00	83.85	100.00	79.29	84.10	79.29	100.00	100.00
98.11	4715536	100.00	100.00	84.96	100.00	100.00	85.89	100.00	85.89	100.00	85.63	100.00	80.94	85.89	80.94	100.00	100.00
98.33	4738106	100.00	100.00	86.60	100.00	100.00	87.63	100.00	87.63	100.00	87.35	100.00	82.54	87.63	82.54	100.00	100.00
98.54	4760467	100.00	100.00	88.25	100.00	100.00	89.33	100.00	89.33	100.00	89.03	100.00	84.10	89.33	84.11	100.00	100.00
98.75	4782627	100.00	100.00	89.65	100.00	100.00	90.97	100.00	90.97	100.00	90.67	100.00	85.62	90.97	85.62	100.00	100.00
98.96	4804591	100.00	100.00	91.41	100.00	100.00	92.58	100.00	92.58	100.00	92.26	100.00	87.09	92.58	87.09	100.00	100.00
99.16	4826362	100.00	100.00	92.73	100.00	100.00	94.14	100.00	94.14	100.00	93.80	100.00	88.53	94.14	88.53	100.00	100.00
99.35	4847948	100.00	100.00	94.41	100.00	100.00	95.66	100.00	95.66	100.00	95.31	100.00	89.94	95.66	89.94	100.00	100.00
99.54	4869352	100.00	100.00	95.86	100.00	100.00	97.15	100.00	97.15	100.00	96.79	100.00	91.30	97.15	91.30	100.00	100.00
99.72	4890578	100.00	100.00	97.27	100.00	100.00	98.60	100.00	98.60	100.00	98.22	100.00	92.64	98.60	92.64	100.00	100.00
99.90	4911551	100.00	100.00	98.64	100.00	100.00	100.00	100.00	100.00	100.00	99.62	100.00	93.94	100.00	93.94	100.00	100.00
99.94	4916460	100.00	100.00	99.99	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	95.21	100.00	95.21	100.00	100.00
99.96	4918312	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	96.45	100.00	96.45	100.00	100.00
99.97	4920129	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	97.66	100.00	97.66	100.00	100.00
99.99	4921932	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	98.84	100.00	98.84	100.00	100.00
100.00	4923721	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-5. Optimal canals and major lateral lining program for the McElmo Creek Drainage, Colorado.

% of total canal salt loading	Annual Cost ($)	Percentage of salt reduction required from each individual canal													
		CANAL													
		U-Lateral	Goodland Lateral	Lone Pine Lateral	Corkscrew Lateral	Moonlight Lateral	Ute Mountain Lateral	Upper Hermana	Lower Hermana	May Lateral	Garret Ridge	East Lateral	West Lateral	Hartman Draw	Main Canal #1
1.17	6329	0.00	0.00	0.00	0.00	0.00	65.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.91	12263	0.00	0.00	0.00	0.00	7.56	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5.32	51543	0.00	0.00	0.00	0.00	41.09	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.96	289681	0.00	0.00	0.00	0.00	63.82	100.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
29.45	393110	0.00	0.00	0.00	0.00	81.21	100.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
35.26	500268	0.00	0.00	0.00	0.00	95.06	100.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
39.93	598623	0.00	0.00	0.00	0.00	100.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00
46.39	752439	0.00	0.00	11.32	0.00	100.00	100.00	7.44	8.95	0.00	0.00	0.00	0.00	100.00	0.00
53.45	937817	0.00	0.00	22.32	0.00	100.00	100.00	19.93	21.82	0.00	0.00	7.61	0.00	100.00	0.00
64.87	1245752	0.00	0.00	31.87	0.00	100.00	100.00	30.79	31.49	0.00	0.00	73.71	0.00	100.00	96.58
69.23	1406554	0.00	0.00	40.26	4.78	100.00	100.00	40.32	40.70	0.00	0.00	100.00	0.00	100.00	100.00
72.42	1515242	3.97	1.48	47.72	11.82	100.00	100.00	48.78	48.88	7.35	7.54	100.00	0.00	100.00	100.00
75.52	1628821	12.26	9.99	54.41	18.12	100.00	100.00	56.37	56.20	15.89	14.87	100.00	0.00	100.00	100.00
78.32	1738584	19.74	17.67	60.42	23.31	100.00	100.00	63.21	62.01	22.07	21.49	100.00	0.00	100.00	100.00
82.34	1906735	26.54	24.65	65.90	28.90	100.00	100.00	69.43	68.02	28.41	27.50	100.00	43.94	100.00	100.00
86.09	2072884	32.75	31.82	70.96	33.70	100.00	100.00	75.11	74.30	34.21	32.99	100.00	86.14	100.00	100.00
88.69	2194678	38.46	36.88	75.50	38.04	100.00	100.00	80.33	79.34	39.53	38.04	100.00	100.00	100.00	100.00
90.66	2292300	43.72	42.28	79.74	42.04	100.00	100.00	85.14	85.99	44.45	42.69	100.00	100.00	100.00	100.00
92.40	2383318	48.60	47.29	83.66	45.75	100.00	100.00	89.63	88.30	49.00	47.01	100.00	100.00	100.00	100.00
93.86	2463178	53.14	51.94	87.32	49.28	100.00	100.00	93.75	92.30	53.25	51.02	100.00	100.00	100.00	100.00
95.22	2541215	57.37	56.28	90.72	52.41	100.00	100.00	97.62	96.04	57.18	54.76	100.00	100.00	100.00	100.00
96.41	2612228	61.33	60.35	93.91	55.43	100.00	100.00	100.00	99.54	60.87	58.26	100.00	100.00	100.00	100.00
97.16	2659001	65.05	64.16	96.90	58.25	100.00	100.00	100.00	100.00	64.34	61.55	100.00	100.00	100.00	100.00
97.76	2698472	68.54	67.75	99.72	60.91	100.00	100.00	100.00	100.00	67.60	64.64	100.00	100.00	100.00	100.00
98.01	2715346	71.84	71.14	100.00	63.42	100.00	100.00	100.00	100.00	70.68	67.55	100.00	100.00	100.00	100.00
98.21	2729437	74.96	74.34	100.00	65.79	100.00	100.00	100.00	100.00	73.59	70.31	100.00	100.00	100.00	100.00
98.40	2743275	77.91	77.37	100.00	68.03	100.00	100.00	100.00	100.00	76.35	72.92	100.00	100.00	100.00	100.00
98.58	2756874	80.71	80.24	100.00	70.16	100.00	100.00	100.00	100.00	78.96	75.40	100.00	100.00	100.00	100.00
98.76	2770245	83.38	82.90	100.00	72.19	100.00	100.00	100.00	100.00	81.45	77.76	100.00	100.00	100.00	100.00
98.92	2783400	85.71	85.58	100.00	74.12	100.00	100.00	100.00	100.00	83.81	80.00	100.00	100.00	100.00	100.00
99.07	2796348	88.33	88.06	100.00	75.96	100.00	100.00	100.00	100.00	86.07	82.14	100.00	100.00	100.00	100.00
99.22	2809108	90.64	90.43	100.00	77.71	100.00	100.00	100.00	100.00	88.23	84.18	100.00	100.00	100.00	100.00
99.36	2821664	92.85	92.78	100.00	79.39	100.00	100.00	100.00	100.00	90.29	86.13	100.00	100.00	100.00	100.00
99.50	2834047	94.97	94.87	100.00	81.00	100.00	100.00	100.00	100.00	92.26	88.01	100.00	100.00	100.00	100.00
99.63	2846258	97.00	96.96	100.00	82.54	100.00	100.00	100.00	100.00	94.16	89.80	100.00	100.00	100.00	100.00
99.76	2858304	98.95	98.96	100.00	84.02	100.00	100.00	100.00	100.00	95.97	91.52	100.00	100.00	100.00	100.00
99.84	2866576	100.00	100.00	100.00	85.45	100.00	100.00	100.00	100.00	97.72	93.18	100.00	100.00	100.00	100.00
99.88	2873273	100.00	100.00	100.00	86.82	100.00	100.00	100.00	100.00	99.40	94.77	100.00	100.00	100.00	100.00
99.90	2872937	100.00	100.00	100.00	88.13	100.00	100.00	100.00	100.00	100.00	96.30	100.00	100.00	100.00	100.00
99.92	2874997	100.00	100.00	100.00	89.40	100.00	100.00	100.00	100.00	100.00	97.78	100.00	100.00	100.00	100.00
99.94	2877633	100.00	100.00	100.00	90.63	100.00	100.00	100.00	100.00	100.00	99.20	100.00	100.00	100.00	100.00
99.95	2878506	100.00	100.00	100.00	91.81	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.96	2879239	100.00	100.00	100.00	92.95	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	2879764	100.00	100.00	100.00	94.06	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.97	2880686	100.00	100.00	100.00	95.13	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	2881397	100.00	100.00	100.00	96.16	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.98	2882191	100.00	100.00	100.00	97.17	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	2882765	100.00	100.00	100.00	98.14	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
99.99	2883472	100.00	100.00	100.00	99.08	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
100.00	2884153	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 4-5. (continued)

% of total canal salt loading	Annual Cost ($)	Percentage of salt reduction required from each individual canal — CANAL: Main Canal #1	Lower Arickaree	Rock Ford[1]	Rock Ford[2]	High-line
1.17	6329	0.00	0.00	0.00	0.00	0.00
1.90	12263	0.00	9.59	0.00	0.00	0.00
5.32	51543	0.00	44.18	0.00	0.00	9.15
22.96	289681	0.00	69.12	0.00	100.00	31.23
29.45	393110	0.00	88.19	8.43	100.00	48.12
35.26	500288	0.00	100.00	22.98	100.00	61.57
39.93	598623	0.00	100.00	34.78	100.00	72.62
46.39	752439	3.60	100.00	44.76	100.00	81.90
53.45	937817	16.24	100.00	53.30	100.00	89.84
64.07	1245752	27.20	100.00	60.72	100.00	96.74
69.23	1406554	36.84	100.00	67.24	100.00	100.00
72.42	1515242	45.41	100.00	73.02	100.00	100.00
75.52	1628821	53.07	100.00	78.21	100.00	100.00
78.32	1730584	59.99	100.00	82.89	100.00	100.00
82.34	1906735	66.28	100.00	87.14	100.00	100.00
86.09	2072884	72.03	100.00	91.02	100.00	100.00
88.69	2194678	77.30	100.00	94.59	100.00	100.00
90.66	2292300	82.17	100.00	97.88	100.00	100.00
92.40	2383318	86.68	100.00	100.00	100.00	100.00
93.86	2463178	90.88	100.00	100.00	100.00	100.00
95.22	2541215	94.79	100.00	100.00	100.00	100.00
96.41	2612228	98.45	100.00	100.00	100.00	100.00
97.16	2659001	100.00	100.00	100.00	100.00	100.00
97.76	2698472	100.00	100.00	100.00	100.00	100.00
98.01	2715346	100.00	100.00	100.00	100.00	100.00
98.21	2729437	100.00	100.00	100.00	100.00	100.00
98.40	2743275	100.00	100.00	100.00	100.00	100.00
98.58	2756874	100.00	100.00	100.00	100.00	100.00
98.76	2770245	100.00	100.00	100.00	100.00	100.00
98.92	2783400	100.00	100.00	100.00	100.00	100.00
99.07	2796348	100.00	100.00	100.00	100.00	100.00
99.22	2809100	100.00	100.00	100.00	100.00	100.00
99.36	2821664	100.00	100.00	100.00	100.00	100.00
99.50	2834047	100.00	100.00	100.00	100.00	100.00
99.63	2846258	100.00	100.00	100.00	100.00	100.00
99.76	2858304	100.00	100.00	100.00	100.00	100.00
99.84	2866576	100.00	100.00	100.00	100.00	100.00
99.88	2870273	100.00	100.00	100.00	100.00	100.00
99.90	2872937	100.00	100.00	100.00	100.00	100.00
99.92	2874997	100.00	100.00	100.00	100.00	100.00
99.94	2877633	100.00	100.00	100.00	100.00	100.00
99.95	2878506	100.00	100.00	100.00	100.00	100.00
99.96	2879239	100.00	100.00	100.00	100.00	100.00
99.97	2879964	100.00	100.00	100.00	100.00	100.00
99.97	2880680	100.00	100.00	100.00	100.00	100.00
99.98	2881389	100.00	100.00	100.00	100.00	100.00
99.98	2882091	100.00	100.00	100.00	100.00	100.00
99.99	2882785	100.00	100.00	100.00	100.00	100.00
99.99	2883472	100.00	100.00	100.00	100.00	100.00
100.00	2884153	100.00	100.00	100.00	100.00	100.00

1 Below Totten Reservoir

2 Above Totten Reservoir

m.R.
027077