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Project Summary

Optimizing Salinity Control Strategies for the Upper Colorado River Basin

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Salinity is the most serious water quality problem in the Colorado River Basin. Its impact, felt largely in the Lower Basin, is acute because that basin is approaching conditions of full development and utilization of all available water resources. Current estimates indicate that each mg/l-increase in salinity concentration at Imperial Dam results in $450,000 annual damages. To offset salinity caused by development of the basin's 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 formulate cost-effective salinity control strategies for 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 type of alternatives to be implemented in a least-cost basin-wide salinity control program. The results also qualitatively indicate the anticipated salt load reduction and anticipated annual costs of each increment of salinity reduction for any preselected level of control. The analysis was limited to projects designated in PL 93-320 (Colorado River Basin Salinity Control Act, June 24, 1974). 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 also were 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 indicates 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 (one megagram is equal to one metric ton). In addition, it was concluded that maintenance of the 1972 salinity concentration levels at Imperial Dam cannot be cost-effectively achieved and perhaps should be allowed to rise over the 1972 figure 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, Utah and Wyoming, as well as for 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.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully docu-

mented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The primary water quality problem in the Colorado River Basin is salinity. This problem 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. 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 more than 850 mg/l at Imperial Dam. Further deterioration of Colorado River quality is expected as a result of both water and energy resource development. This deterioration will occur even if salinity reduction measures are instituted, although it would then occur at a slower rate. If no salinity control measures are developed, salinity increases at Imperial Dam will range from 1,150 mg/l to 1,340 mg/l by the year 2000.

To date, all salinity control planning has been oriented toward reducing the salt load of the Colorado River; the economics of control have not been of overriding concern. Development of cost-effective programs, or design of construction projects with benefit-cost ratios greater than one, has not had a high priority; although control 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 (Figure 1) 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 projects.

The purpose of Public Law 93-320 was 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. The legislation specifically names several projects for construction and further study. The projects in the Upper Colorado River Basin are summarized in Table 1.

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

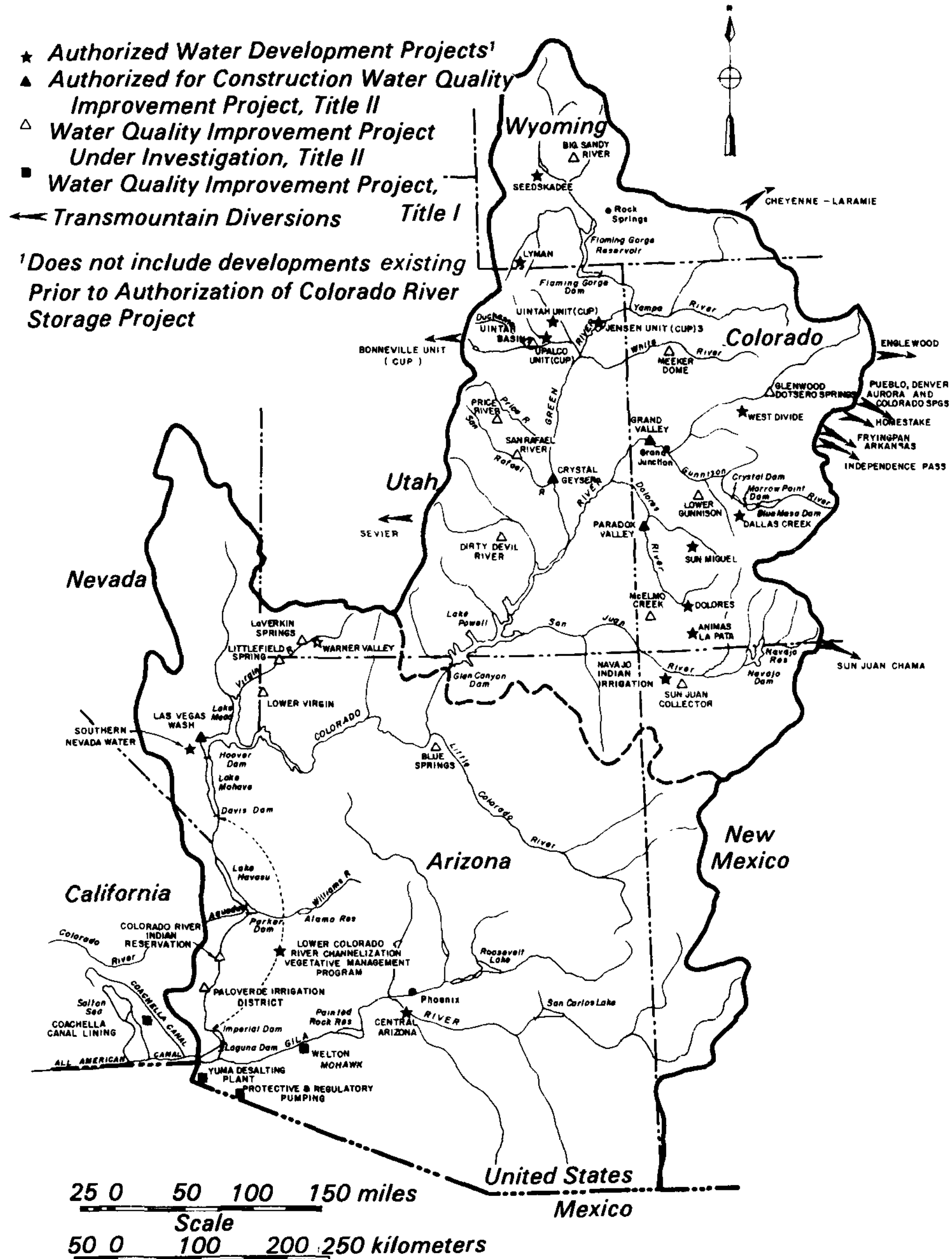

Figure 1. *The Colorado River Basin and salinity control projects designated by PL 93-320.*

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. They did not consider that perhaps only selected portions of various salinity control projects should be constructed, which research has shown to be the case.

The primary questions left unanswered by PL 93-320 are the extent of salinity control programs construction and the degree of effort to be expended in pursuit of the goals of this legislation. For example, without regard to benefits and costs, the Water and Power Resources Service (WPRS) presents data illustrated in Figure 2 that indicate the difficulty of maintaining the mandated 1972 salinity levels at Imperial Dam. Preliminary analyses have 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.

Aggregate Salinity Control Programs

To date, analyses have not been 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.

The most cost-effective salinity control program for the Upper Colorado River Basin is presented in Figures 3 and 4. Figure 3 lists the results of this basin-wide level of optimized salinity control by alternative, and Figure 4 indicates the individual state projects included in PL 93-320. Figure 3 shows, 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 control projects, as seen in Figure 4.

If each state was required to control its own salinity increases, only Colorado and Utah could do so 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 its goal. This would be extremely expensive with a downstream damage reduction/cost ratio much less than one.

New Mexico is actually expected to overdraw its Colorado River water allocation by 1985. However, 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 5 presents the optimal cost-effective basin-wide salinity control alternatives plotted under the Water and Power Resources Service forecast

Table 1. *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/l 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).*

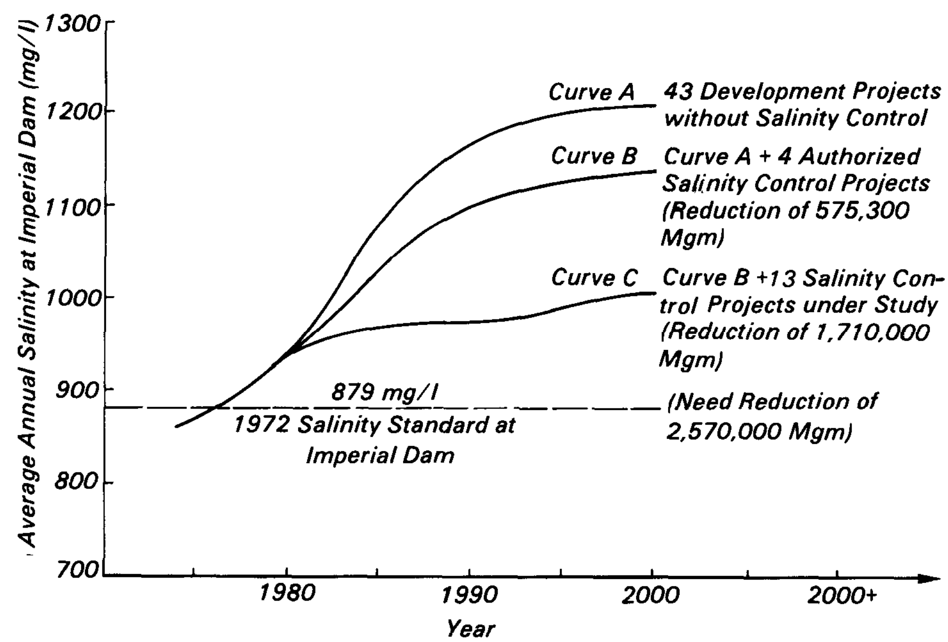

Figure 2. *Salinity increase at Imperial Dam projected by the Water and Power Resources Service (USDI, BR, 1979d).*

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 projected 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 1995. 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 salinity concentrations due to delaying construction of the salinity control program. For example, using the 1985 salinity levels from Figure 5 (210 mg/l increase) for comparison, and if only one-fourth of the necessary salinity control is constructed at that time, then the annual costs of the delay are about $71 million. 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.

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

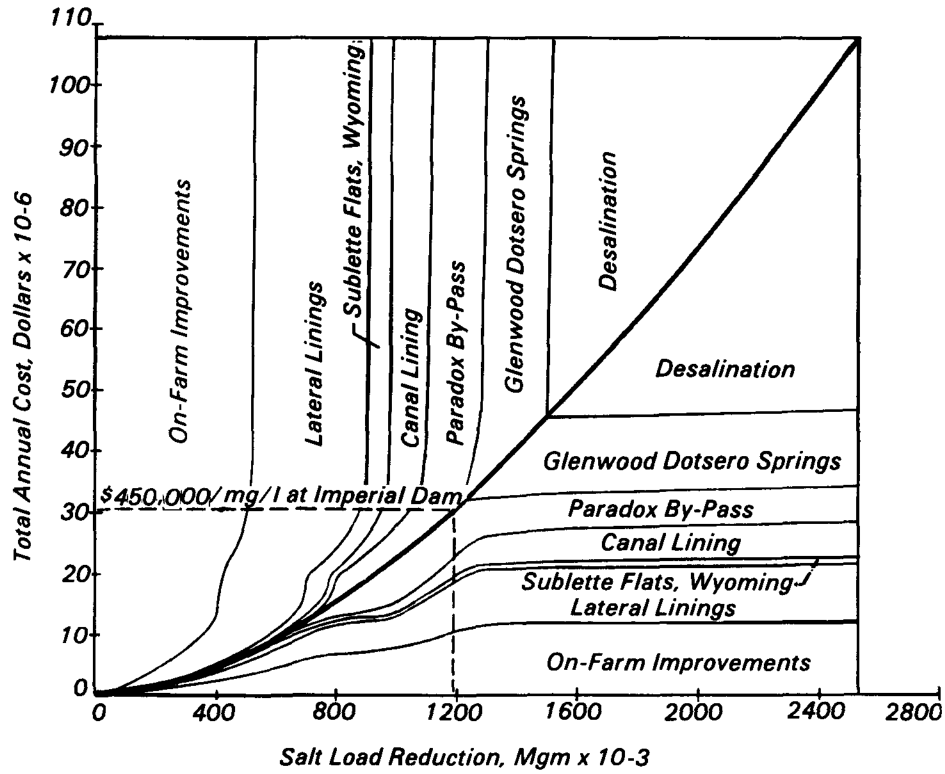

Figure 3. *Optimal Upper Colorado River Basin salinity control by alternatives.*

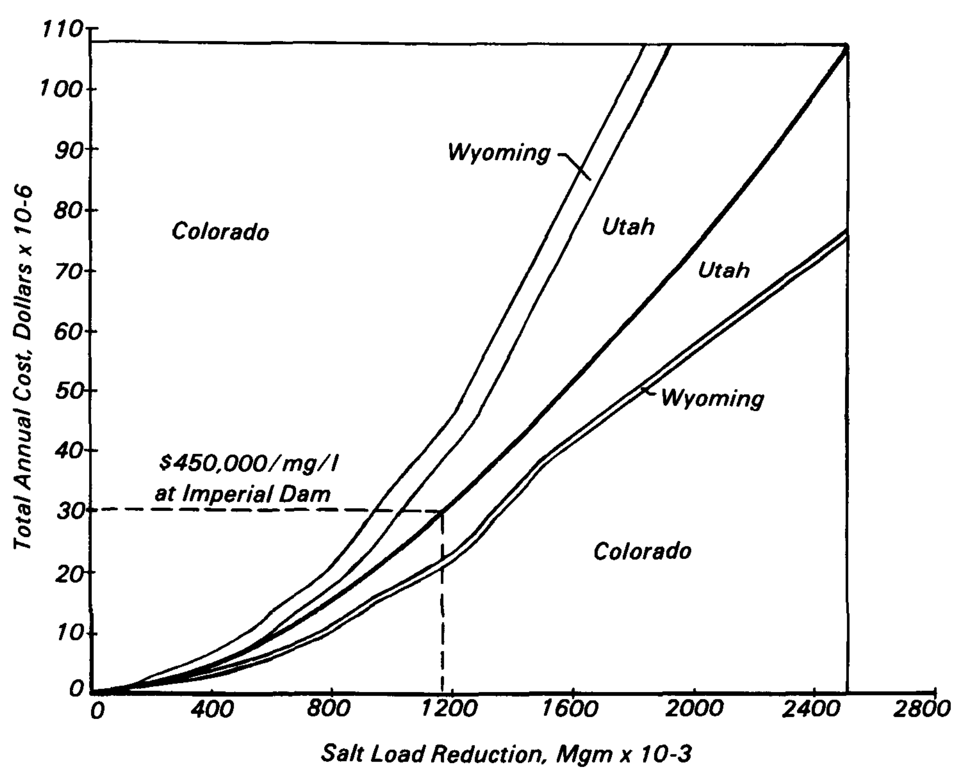

Figure 4. *Optimal Upper Colorado River Basin salinity control program delineated by state.*

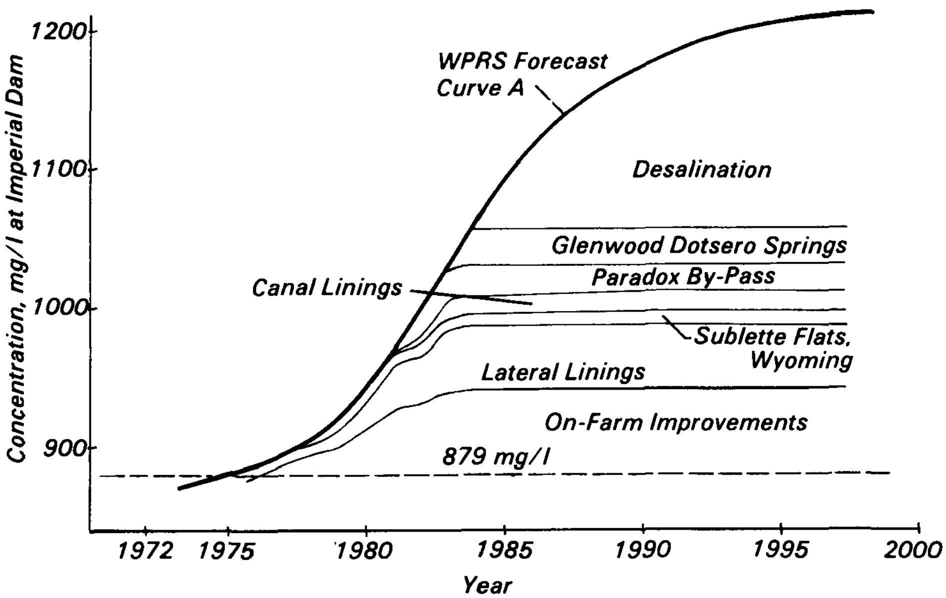

Figure 5. *Cost-effective implementation strategy for optimal level of salinity control alternatives in the Upper Colorado River Basin.*

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 work 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. All lining of the laterals and 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 most 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 Creeks, 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 problems of local waterlogging and soil salination.
11. The barrier well network and Sublette Flat evaporation area as proposed by the USDA, Soil Conservation Service, and minimal on-farm improvements are 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 found not 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 increased 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. Desired levels of salinity control must be determined and implemented as soon as possible since they will dictate the type and extent of many of the alternatives. This is especially true for on-farm improvements.

2. Because on-farm improvements and lateral linings are cost-effective in all of the irrigated areas examined in this analysis, the list of areas included in PL 93-320 should be expanded. 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. Recruiting and training personnel for this type of activity will be necessary.
4. On-farm improvement and lateral lining programs consistent with selected levels of basin-wide salinity control 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, the feasibility of maintaining the 1972 salinity concentration levels at Imperial Dam should be reevaluated.
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 counterbalance salinity increases in other areas. Physically, Wyoming would not 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 proposed by the WPRS is not cost-effective and should be reevaluated. 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 project areas are lacking. These data should be collected to define the most cost-effective incremental canal and lateral lining programs for each area.
12. Studies should be initiated in the Price-San Rafael, Uintah, McElmo and Lower Gunnison areas to determine the relative magnitude of the natural salt contribution for each irrigated area. This information would be necessary to delineate the more exact cost-effectiveness functions prior to undertaking a construction program.

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The complete report, entitled "Optimizing Salinity Control Strategies for the Upper Colorado River Basin," (Order No. PB 83-136 143; Cost: $19.00, subject to change) will be available only from:
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