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Agriculture and Salinity Control in the Colorado River Basin

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AGRICULTURE AND SALINITY CONTROL IN THE COLORADO RIVER BASIN

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INTRODUCTION

The focus of this paper is irrigated agriculture and salinity problems in the Colorado River Basin. Although complete analysis and resolution of these problems requires consideration of sources of salt other than irrigation, classes of pollutants other than salt, and other nonagricultural water uses, it is infeasible to proceed so far within the confines of this paper. Also, we do not presume to argue the merits of irrigation development, although the value of additional irrigation needs to be considered in appraising various salinity control programs.

A. Irrigated Land Use

The total irrigated acreage in the Upper Colorado Basin did not change markedly from 1920 to 1955 and was around 1,400,000 acres. During the sixties, however, irrigated land in the Upper Basin was in the neighborhood of 1,600,000 acres, including substantial irrigated noncropland pasture and some land classed as idle irrigated.

The irrigated cropland acreage has increased greatly in the Lower Basin in the last several decades to 1,225,000 acres. This increase has been largely in the Phoenix-Tucson area based on ground-water development. The irrigated acreage in the State of Arizona more than doubled from 1940 to 1960. As a consequence, substantial depletions of the ground-water supply are occurring with concurrent deterioration in water quality.

Much more land could be irrigated in both the Upper and Lower Basins if water were available. The U.S. Soil Conservation Service has classified the following as land "suitable" for irrigation:

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	Acres
Lower Basin	38,760,000
Upper Basin	7,058,600
Total	45,818,600

B. Irrigated Crops

The Upper Basin is basically a forage-livestock economy. Relatively small acreages of fruit, sugar beets, beans, and vegetables are important to selected areas. Overall, the irrigated cropland is used largely for forage crops and feed grains. Nearly a fourth of the "irrigated" land is in nonrotation, permanent pasture. About 1.1 million acres are in harvested crops of which 944,000 acres are in forage crops.

About 58 percent of the irrigated acreage of 1,225,000 acres in the Lower Basin is devoted to forage and grains. The remainder is planted in highly intensive crops–cotton, vegetables, and citrus; citrus and vegetables have low salt tolerances, while cotton is a high tolerance crop.

A spectacular enlargement of the livestock feeding enterprise has occurred in the Lower Basin in recent years. The average number of cattle on feed in Arizona alone was 73,000 over the period 1945-54, but by 1972 had grown to 600,000 head. This activity is significant from the standpoint of crop production, water use, and water quality.

C. Salinity Levels

Limits of the salt tolerance of crops cannot be set in any absolute sense, but the Salinity Laboratory of USDA has established a general classification of the salinity hazard of irrigation water:[1]

	ppm
Low	100-250
Medium	250-750
High	750-2250
Very high	>2250

Estimates show pristine water quality at Hoover Dam to be 330 ppm and above Imperial Dam to be 383 ppm. Present actual salt content at Imperial Dam is around 850 ppm, suggesting sharp deterioration from pristine levels.

1. U.S. Salinity Laboratory, U.S. Dep't of Agriculture, Diagnosis and Improvement of Saline and Alkali Soils 69-82 (USDA Agriculture Handbook No. 60, Feb. 1954).

Salt contributions from irrigation and 30 major point sources in 1965-66 were estimated:[2]

	Irrigation tons/day	*Point sources tons/day*
Green Subbasin	3528	363
Upper Main Stem	5603	2061
San Juan	518	25
Upper CRB	9649	2449
Lower CRB	1180	1990
	10,829	4439

Total salt load in the Upper Basin (1963-64) was 26,160 tons per day. Fifty-two percent was contributed by overland runoff and ground-water inflow. Of the remaining 48 percent, 37 percent came from irrigated agriculture, 9 percent from natural point sources, and 2 percent from mining and industrial (M&I) uses. This amount of salt was associated with a flow of 19,263 cubic feet per second (cfs) which produces a salinity level increase of 499 ppm. The contribution of irrigation was about 185 ppm.

In the seven Colorado Basin states, nearly a third of the irrigable lands are classified as saline. That is, the salt content in these soils is sufficiently high to have significant impacts on crop production and incomes.

The salinity estimates at Imperial Dam listed below suggest the change that has occurred in the last 50 years. Presumably the changes are attributable to increased irrigation and out-of-basin diversions. But we understand that some question exists as to whether the changes were actually as great as shown.

	ppm
Pristine	383
1926-35	619
1941-68	751
1958-63	787
1941-68 modified[3]	865
1965	839

Distribution of sources with some quality impacts of irrigation are shown as follows:[4]

2. U.S. Environmental Protection Agency, The Mineral Quality Problem in the Colorado River Basin (1971).

3. The modification is based on the assumption that recent irrigation projects were operational during the entire period, and appropriate adjustments are made in the figures. U.S. Dep't of the Interior, Colorado River Water Quality Improvement Program (1972).

4. U.S. Dep't of the Interior, Quality of Water—Colorado River Basin (Progress Rep. No. 3, Jan. 1967).

	Lee Ferry	*Hoover Dam*	*Imperial Dam*
1941-61	544	684	743
1941-61 modified	580	720	809

Salt pickup rates from irrigation return flows vary substantially among areas. Among the high pickup rate areas identified is Grand Valley, Colorado, where the rate is estimated at eight tons of salt per year for each irrigated acre. EPA projected an average pickup of a little less than two tons per acre per year in the Upper Basin on several hundred thousand acres of new irrigation land projected to the year 2010.

D. Costs of Salinity

An indication of the potential magnitude of the salinity problem can be obtained from a study by the Colorado River Basin Water Quality Control Project over the period 1960-1971.[5]

This study projected a Basin population of 8.5 million by 2010, assumed no augmentation of water supply or shifts of water among basins or areas, and assumed construction of the Central Arizona Project. Further, the study projected an increase by 2010 of 425,000 acres of irrigated land above Hoover Dam. Increased acreages in the Lower Main Stem Subbasin were more than offset by a projected decrease in irrigated acreage in the Phoenix-Tucson area. Acreages of vegetables and cotton were projected to increase relatively and, in the case of vegetables, absolutely.

The above assumptions and projections led to the following water quality values (ppm):

Year	*1960*	*1980*	*2010*
CRB–Hoover Dam	697	876	990
CRB–Imperial Dam	759	1056	1223

Penalty costs or effects of yield decrements in agriculture and nonagricultural costs from increased hardness were estimated for the Lower Basin and for Southern California. Total annual direct and indirect (input-output study) costs at 1960 prices by 2010 were estimated at $5.9 million in the Lower Main Stem, and $19.1 million in Southern California. More than 80 percent of the costs were in irrigated agriculture. Direct costs were about 60 percent of total costs. These costs are increases over the base period, assuming no remedial programs.

5. An Interindustry Analysis of the Colorado River Basin in 1960 with Projections to 1980 and 2010 (B. Udis ed. 1968); C. Stewert, Economic Impacts of Water Quantity and Quality Constraints on Agriculture of the Colorado River Basin (1969); U.S. Environmental Protection Agency, *supra* note 2.

These offsite costs are associated with new development and increased incomes and production in other areas. Their significance attaches (1) as a trade-off with the new development, and (2) to the evaluation of special control measures and programs to reduce the quality impacts of new development.

E. Summary

Over the years, neither the market system nor the institutional environment of the Colorado River Basin was conducive to prevention or retardation of water-quality deterioration. In fact, they have been conducive to non-action. Only when the problem became obvious as costs rose, did concern arise.

History has demonstrated a deterioration of quality with additional irrigation development and out-of-basin transfers of water. This lower quality is partly a function of increased loading of salts. It is also a function of less water as a result of productive use of water supplies upstream. The total effects have not all been adverse. Costs of more salt in less water downstream are associated with increased output and incomes upstream and in out-of-basin areas.

We proceed next to a conceptualization of that part of the salinity problem resulting from irrigation return flows. At least in part, however, our conceptualization may be quite appropriate for other non-irrigation sources of the problem.

AN ECONOMIC MODEL OF SALINE RETURN FLOWS

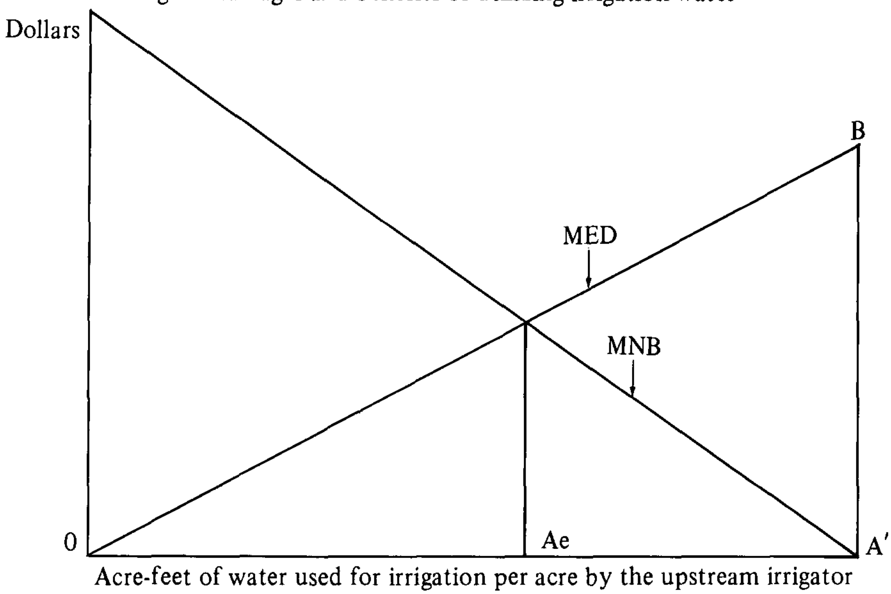
A. The Model

One fundamental reason for the salinity problem is the existence of what economists call "negative externalities" arising out of irrigation itself. Crops valuable to society and to the farmer are produced on saline soils. But as a consequence of irrigation, salts of the soil are dissolved in the water which enter the river as return flows. This saline water is then utilized in other areas down the river. The result is higher production costs for downstream users (we restrict our discussion to downstream irrigation) in the form of reduced yields and needed changes in cropping patterns to more salt-resistant, but profit-reducing varieties.

The irrigator upstream does not bear these increased costs imposed on downstream users. Although it is not his intention to injure anyone, the water course is used as a free resource for disposing of the dissolved salts which are produced along with the valuable crops. No legal or market mechanism exists that incorporates the cost of this salt in the price of the upstream crops. The upshot is that the social value (value to society) of the upstream irrigation is less than the net private benefits from producing crops.

Let MNB (Figure 1) represent the marginal net private benefits of using various quantities of irrigation water to produce crops on a

FIGURE 1.
Marginal damages and benefits of utilizing irrigation water



representative acre of saline land. Assume an optimal level of irrigation technology and optimal cropping patterns and technical production conditions as seen from the viewpoint of the irrigator. Variable production costs are subtracted from crop revenues yielding marginal *net* benefits. The function MNB is negatively sloped because of the conventional principle of diminishing marginal returns to increasing quantities of water, assuming adequate water supplies and optimal deliveries over the irrigation season. The function is presented as linear, but in reality it may not be. The logic of the analysis holds so long as it has negative slope.

MED (Figure 1) represents a schedule of marginal external damages inflicted on downstream users by diversions of increasing quantities of water upstream. These damages are related to two factors: (1) Irrigation water consumptively used upstream cannot be available to downstream users, and (2) the saline return flows impose higher production costs on downstream users. A priori, we would expect that the greater the upstream diversions the greater the damages downstream. MED may not be linear as presented, but a necessary condition to the argument is that it have a positive slope.

MED does not enter the decision calculus of the upstream irrigator. If we assume he attempts to maximize his own net benefits, he will extend his water use per acre to A′ acre-feet where MNB is zero. His total per acre net benefits is the area under the MNB curve. This may be referred to as his private water "rent." The external damages at that level of use are B dollars.

The socially-optimum position is A_e acre-feet where MED = MNB. If the upstream irrigator uses less water than A_e acre-feet, the marginal net benefits accruing to him exceed the marginal external damages imposed on others, and society benefits from expanding per acre water use. If the upstream irrigator uses more than A_e acre-feet, the reverse is true.

B. Options for Bringing Salinity Production Toward the Optimum

Let us assume that the American people wish to have the salinity problem managed so as to maximize the total national economic product from water use.[6] Several options for salinity control will be briefly discussed: (1) investment in water quality improvement, (2) litigation brought by downstream users, (3) imposition of quality standards, and (4) implementation of direct economic incentives to improve quality.

1. Investment in Quality Improvement

This option is basically different from the others discussed. Investment to improve quality could leave both upstream and downstream users better off, depending on the distribution of the costs of the investment. The other options basically reduce the welfare levels of one region while improving the welfare position of the other.

Investment in quality improvements could take many forms—investment in off-farm desalination plants or other mechanical

6. An implicit assumption utilized in the analysis should be made explicit at this point. We have assumed thus far in this section that a social optimum can be defined by an "efficiency" criterion, *i.e.*, an optimum situation will exist when the total value of the economic product along the entire system is maximized. Social welfare may well be influenced by "equity" considerations as well, however; *i.e.*, how the economic product is distributed among water users along the system. If equity criteria are deemed relevant, social welfare may be enhanced by permitting relatively low-income irrigators to utilize more water, even if marginal external damages exceed net benefits and total economic product is thus below a maximum. Thus, if both criteria are used to arrive at a social optimum, some weighing of "efficiency" and "equity" must be done.

devices to remove salt, investment in on-farm practices to reduce salt in the return flows or in water-saving methods that would reduce needed diversions and thus augment river flow downstream, and/or investment to increase water supplies in the entire system or to alter seasonal deliveries that would minimize the damages of given salt loads. Obviously, investment in quality improvement can apply to all forms and sources of pollution and may be about the only effective alternative for reducing salinity from overland runoff and natural or point sources.

Off-farm investment in developing new water supplies, in developing new storage facilities to improve the timing of deliveries, or in reducing evapotranspiration losses by phreatophytes would shift the MED curve to the right. Each level of water use by irrigators would inflict less damage on downstream users than under present conditions. This implies also an increase in optimal water use upstream, and thus both groups could be made better off. These investment alternatives should be evaluated by the economic criterion that if they produce more social benefits than their resource opportunity costs, they should be undertaken. They can only very indirectly contribute to the solution of the problem posed by Figure 1, however. Even though MED shifts to the right and the socially optimum level of water use upstream increases, there will still be a discrepancy between the social optimum A_e and the private optimum A' unless the shift is very large. There is no incentive for the upstream irrigator to act in a socially optimum manner. It is likely, therefore, that these investment options can mitigate the damages caused by the externality problem, but cannot solve the problem by inducing the irrigators to use the socially optimum quantity of water.

If the investment is made on-farm, and the irrigator bears the full costs, the expected result would be a leftward shift of MNB as well as a rightward shift of MED. If so, the private optimum will be less than A' acre-feet, but the social optimum might be more or less than A_e acre-feet, depending on the relative shifts of MED and MNB. The result of the investment would probably move the private optimum closer to the social optimum. But the irrigator would have no incentive to make the investment to hurt himself in order to aid downstream users. A good argument exists for public subsidy to pay for the social improvement downstream. Any investment to improve quality, whether on-farm or off-farm, should be undertaken if social benefits exceed resource costs, and the distribution of the costs of this investment should be as equitable as possible.

2. *Litigation*

It is generally true in our society that parties injured by actions of other parties can bring damage suits in courts of law to recover their losses. Downstream users could sue upstream irrigators and either prevent them from producing wastes or force them to pay damages. This is seldom done. Although their discussion applies mostly to industrial polluters, Kneese and Bower's explanation applies remarkably well to irrigation waste as well:[7]

> (1) Adversary proceedings are a cumbersome procedure.
> (2) Wide dispersion of damages makes it hard to bring suit for full damages [wide dispersion of "damagers" make it doubly difficult].
> (3) Waste discharge imposes costs in a highly variable fashion over time.
> (4) Damage may be irreversible.
> (5) Legal standards of "reasonable" [damages] are notoriously vague.

It is very difficult to see how an effective damage suit could be brought by so many damaged parties against so many prior users. Besides, as we argued earlier, the damages created by the return flows are not an intentionally harmful act by the irrigators, but an accepted consequence of irrigation that is sanctioned by established water rights, interstate water compacts, and international treaty.

3. *Quality Rules and Standards*

Crops and saline return flows are produced jointly in almost fixed proportions. Because of the intricate and diverse plant, soil, and water relationships in irrigation, however, return flows are very difficult to monitor and assign to an individual irrigator. Therefore, it is difficult to visualize how meaningful standards relative to return flow could be applied to each irrigator. Perhaps they could be to a given project or area. But then rules would have to be invoked that limited irrigation to certain times when return flows would be less salty or to the least saline soils. Restrictions could also be placed on the crops that could be grown, or the water right altered to reduce quantities diverted. Any of these actions would be costly to irrigators and reduce their management flexibility. They would also require a strong monitoring and enforcement agency. As still another alternative, irrigators may be forced to impose upon themselves investment

7. A. Kneese & B. Bower, Managing Water Quality: Economics, Technology, Institutions 85-86 (1968) (bracketed phrase supplied).

in water saving practices or quality improving mechanical devices. In terms of Figure 1, the MNB function would be shifted drastically to the left. In theory, MNB might shift far enough so that the private optimum would be at the previous social optimum A_e. But the social optimum has also shifted to the left. Many of the private net benefits upstream would be destroyed by employing such a standard, and this option would be highly inequitable, as well, as upstream users would bear higher costs in order to confer benefits downstream.

4. Economic Incentives

In recent years a sizeable literature has arisen on the issue of whether or not externalities, such as those discussed here, can be optimally regulated by negotiations between the injuring and the injured parties. R. H. Coase demonstrated in his now classic article[8] that this private bargaining would produce a socially optimal result, providing transactions costs were zero. Potential gainers would pay the polluters to reduce their pollution to levels that would make both groups better off. Transaction costs could be small if the number of negotiating parties is small. They most certainly would not be small in the situation we are considering where the number of irrigators causing the external damage, and those harmed by it number in the tens of thousands.[9] There is no conceivable way that they could bargain individually to the socially optimal level of salinity and water use.

Of course, possibilities may exist for representatives of *groups* of individuals (say, state government officials) to bargain for their constituents. These bargaining decisions may well lead toward the socially optimal position if all constituents are fairly represented and a mechanism for making payments to alter pollution behavior could be conceived and implemented.[10] History, however, does not provide us with many examples of this kind of bargaining which have been successful. Let us now turn to penalties that might be imposed on irrigators or others that inflict external costs on others.

Perhaps the most straightforward type of economic sanction is a user surcharge or tax on water use. If this surcharge were placed on each unit of water diverted, the MNB curve of Figure 1 would shift downward by the amount of the surcharge. Obviously, if the position

8. Coase, *The Problem of Social Cost,* 3 J. L. & Econ. 1 (1960).

9. For a discussion of the inapplicability of the Coase solution where transactions costs are high, see Kneese, *Environmental Pollution: Economics and Policy,* 61 Am. Econ. Rev. 153 (1971).

10. *See* McKean, *Property Rights, Appropriability and Externalities in Government,* in Perspectives of Property 39 (G. Wunderlich ed. 1972).

of MNB and A_e were known, the surcharge could be set at the level which would produce a private optimum at A_e acre-feet of water use. The irrigator would respond to this surcharge in those ways which would affect his profit position least unfavorably. His management would be more flexible in responding to a water surcharge than to a water quality standard or quantity quota.

A tax surcharge on water utilized by Upper Basin irrigators would mean that they would be required to bear the costs for providing benefits to downstream users. This may be inequitable. The beneficiaries may be asked to help pay for these benefits. They could be required to pay a higher price for higher quality water, and with the proceeds a per acre lump-sum subsidy paid to the irrigators upstream.

Kneese and Bower report several instances where user charges have been successfully used to control industrial waste in Winnipeg, Canada, Springfield, Missouri, the Delaware estuary, and in the Ruhr industrial area of Germany.[11] They point out that private firms respond to these charges by changing production processes, improving management, and/or treating wastes. We know of no reason why irrigators would not behave in the same way.

It may be necessary to tax water used on highly saline soils at a higher rate, although this would be difficult to determine and enforce. Tietenburg has recently argued, however, that an

> efficient set of taxes for waste control will change over time and might be different for various firms, not only because the benefits of a unit reduction of pollutant concentrations change over time and the number of sources changes, but also because the relationship among pollutants and waste products is governed by varying and basically uncontrollable elements in nature. Hence, social efficiency will not, in general, be achieved by temporally uniform tax rates.[12]

This comment would seem to apply to irrigation waste and suggests that user surcharges (taxes) may need to vary over time as water supply conditions change and over various irrigators if the taxes are to be efficient.

SOME ALTERNATIVE FUTURES

While economics can specify conditions for optimality, the market system does not automatically achieve these conditions. In fact, the return-flow problem is a prime example where the market cannot handle the problem. Nor does action to remove point sources of

11. Kneese & Bower, *supra* note 7.
12. Tietenburg, *Specific Taxes and the Control of Pollution: A General Equilibrium Analysis*, 4 Q. J. Econ. 521 (1973).

pollution or to alleviate salt concentrations from diffuse sources come about by action in the private market. These are public problems that must be solved by public action.

The alternative futures noted below are program responses arising from public action. The focus is generally on the Upper Basin. In a general sense, the physical and hydrologic structure of the Upper Basin is largely one of independent subbasin entities, so that the quality output of one subbasin does not influence another subbasin. Diversions out of the Upper Basin are usually in the headwaters so that Upper Basin export areas are not greatly influenced by quality deterioration from the irrigated area. Rather, the immediate impacts of lowered quality are on the Lower Basin, Southern California, and Mexico. Major U.S. users of water below Hoover Dam are offstream and their actions are largely localized.

The status quo is hardly a viable alternative. Developments in the Upper Basin will diminish the quantity of water to the Lower Basin and undoubtedly lower the quality there in the absence of control programs. The Central Arizona Project will substantially decrease the supply of water at the international boundary.

As illustrations, we use several studies which have been made since 1960. These studies seem to have culminated in proposed legislation for a single program which presumably has been agreed upon by several federal agencies and by the respective states.

A. Colorado River Basin Water Quality Control Project

The assumptions and cost estimates of this comprehensive study have been discussed earlier in the paper.[13] Eight salinity control programs were analyzed: three salt-load reduction programs, four flow augmentation programs, and one program to demineralize water supplies at point of use. This study describes the water quality problem, estimates its present and potential economic dimensions, and locates, describes, and evaluates possible control measures and associated costs. A major source of salt, Blue Springs in the Little Colorado Subbasin, is a basic element in these program formulations; subsequently, however, the Department of the Interior concluded that the Blue Springs program was not feasible.

The results of this study are a basic information source for consideration of water quality in the Colorado River Basin. The study is also basic to subsequent studies and formulation of programs. However, rather than present more findings and conclusions of the study,

13. See text accompanying note 5, *supra*; U.S. Environmental Protection Agency, *supra* note 2, Udis, *supra* note 5; Stewert, *supra* note 5.

we direct our attention to subsequent and more current studies and proposals which might be viewed as modifications and applications of the Water Quality Control Project Study.

B. U.S. Water Resources Council Studies[14]

The U.S. Water Resources Council conducted a number of more recent comprehensive river basin studies in the Upper and Lower Basin.

1. The Upper Basin Study

The Upper Basin study group analyzed four alternative projections: (1) basic OBERS,[15] (2) regional interpretation (RI) of OBERS, (3) states alternative 1, and (4) states alternative 2. Projected populations (1970 = 346,000) for 2020 ranged from 616,000 to 902,000, respectively. Water depletions (3.4 million acre-feet in 1965) ranged from 5.1 million (OBERS) to 8.1 million acre-feet (states-2). Only alternatives (3) and (4) assumed oil shale development and less irrigation along with more people. Also, alternative (4) enlarged depletion to 8.1 million acre-feet on the assumption that the Mexican Treaty is a national obligation.[16]

Under the OBERS-RI projection of 500,000 acres of new irrigated land, the salt concentration at Lee Ferry would increase by 2020 from 586 ppm to 820 ppm without, and 600 ppm with, an improvement program. The program viewed most favorably is largely on irrigated land plus one stream diversion and one desalination project. Capital costs by year 2000 were estimated at $230 million.

As indicated earlier, the OBERS and OBERS-RI projections did not provide for oil shale development. State alternative 1 with 6.5 million acre-feet depletion included 1 million barrels per day by 2000 in Colorado and 0.5 million barrels by 2020 in Utah. State alternative 2 would include 4 million barrels per day by 2020.

Recent actions suggest that oil shale development might get underway in the near future. At a magnitude of 1 to 4 million barrels per day by 2020, water requirements with present processes would be

14. U.S. Water Resources Council, Upper Colorado Region Comprehensive Framework Study (1971). A similar study and 18 subject matter reports were done for the Lower Colorado Region.

15. The OBERS label attaches to the national-interregional projections program of the U.S. Water Resources Council. The analyses were made by the former Office of Business Economics (OBE-Commerce) and Economic Research Service (ERS-Agriculture). Thus, OBE + ERS=OBERS. These projections were basic to the two regional studies. *See* U.S. Water Resources Council, 1972 OBERS Projections (1972).

16. Selected acreage, water, and quality projections are shown in the table preceeding note 20, *infra*.

200,000-800,000 acre-feet diversions per year with net disappearance 50 percent of diversions.

2. The Lower Basin Study

The Lower Basin study centered primarily on two projections—OBERS and modified OBERS—with the latter set the primary focus. Apparently both projections are optimistic and may be unrealistic because augmentation of the present or prospective Basin water supply would be necessary. The "modification" is based on an assertion that OBERS did not fully recognize likely new development on Indian lands and in some ground-water areas.

Qualities projected in 2020 without a control program were 1050 ppm at Hoover Dam and 1350 at Imperial Dam. While not explicit about a control program, the study showed "with program" salinity levels in 2020 to 850 ppm and 1030 ppm at these two locations.

A large number of potential improvement measures were listed in the Lower Basin. But the study group concluded that these measures were mostly infeasible now for institutional, legal, and economic reasons. The most promising measures are (1) reduction of evaporation, (2) vegetation management to increase water yield, and (3) augmentation of supply through importation or desalination.

C. Proposed Legislative Programs

In 1972, the U.S. Bureau of Reclamation set forth a 10-year water quality program for the Colorado River Basin,[17] and in 1973 this program was introduced in the U.S. Congress.[18] The basic policy incorporated into the legislation was approved by the respective states in April 1972 and by EPA on June 9, 1972. Public Law 93-320, the "Colorado River Basin Salinity Control Act," was approved by Congress June 24, 1974.[19]

The stated objective of this program is to maintain salinity concentrations at or below levels now found in the Lower Main Stem of the Colorado River. This goal views the salinity problem as basinwide. The present modified quality at Imperial Dam is 865 ppm.

Comparisons of the Water Resources Council (WRC) and Bureau of Reclamation (BR) studies are shown below. Briefly, the BR proposal is for less new land, less new water depletions, and higher quality downstream.

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17. U.S. Dep't of the Interior, *supra* note 3.
18. S. 1807, 93d Cong., 1st Sess. (1973).
19. 88 Stat. 266, 1974 U.S. Code Cong & Ad. News 1685. Title II of the Act is essentially the same as S. 1807, 93d Cong., 1st sess. (1973), *supra* note 18.

New Irrigated Land (acres)	*WRC Type I Studies*		*BR Program*	
Upper Basin	500,000[1]		350,140	
Lower Basin	358,000[2]		88,640	
Water depletions (million acre-feet)	*Total*	*New*	*New*	
Upper Basin	6.5	2.1	1.9	
Lower Basin	4.8	0.9	.3	
Water Quality (ppm)	*Program[3]*		*Program*	
	W/out	*With*	*W/out*	*With*
Lee Ferry	820	600	—	—
Hoover Dam	1050	850	—	—
Imperial Dam	1350	1030	1250[4]	845[5]

[1] Regional Interpretation–OBERS.
[2] Modified OBERS.
[3] Year 2020.
[4] Year 2000.
[5] Stabilized after 1990.

Public Law 93-320 authorizes construction of the Paradox Valley, Grand Valley, Crystal Geyser, and Las Vegas Wash salinity control units as the initial stage.[20] Completion of planning reports on other point, diffuse, and irrigation units listed is authorized. Irrigation source control areas include Lower Gunnison, Uintah Basin, Colorado River Indian Reservation, and Palo Verde Irrigation District.[21]

1. Point Source Control Projects

These projects are all above Hoover Dam. Their characteristics are:

	Salt tons/yr.	*Program reduction tons/yr.*	*Effect at Hoover Dam ppm*
LaVerkin Springs	100,000	100,000	– 6
Little Field Springs	30,000	30,000	– 2
Glenwood-Dolores Springs	500,000	200,000	–15
Paradox Valley	200,000	180,000	–14
Crystal Geyser (oil test well)	4,000	4,000	– 1
Blue Springs	550,000	–	–

20. Pub. L. No. 93-320, § 202.
21. Pub. L. No. 93-320, § 203.

Blue Springs on the Little Colorado in Arizona, is a major source of salt. The study did not recommend a program there because the springs are (1) a source of 160,000 acre-feet of water, or half the Little Colorado, (2) inaccessible, and (3) adjacent to Indian artifacts.

The total program would reduce salt concentration by 38 ppm at Imperial Dam. Water losses would also be incurred, however.

2. Diffuse Source Control

These projects pose difficult data and control problems, but they are all listed in the Act.[22] These areas are heavy contributors of salt. To achieve a reduction of 32 ppm apparently would require substantial costs and losses of water.

	Flow acre-feet	*Salt tons*	*Salt removal tons*	*Water loss acre-feet*	*Effect at Imperial Dam ppm*
Price River	74,000	240,000	100,000	25,000	− 8
San Rafael River	95,000	190,000	90,000	30,000	− 7
Dirty Devil River	72,000	200,000	80,000[1]	NA	− 7
McElmo Creek	31,000	115,000	40,000[1]	NA	− 3
Big Sandy River	30,000	180,000	80,000[1]	NA	− 7
Totals	302,000	925,000	390,000		−32

[1] Method not shown.

3. Irrigation Source Control

Point and diffuse source proposals would achieve a reduction of 70 ppm at Imperial Dam. This places the major reduction burden on irrigation—335 ppm of a total program of 405 ppm. Investments, economic sanctions, standards and rules, educational programs, legislation, and other institutional arrangements would be extensive and complex.

The goal of the scheduling and farm management program would be to reduce salt loading from irrigation return flows. This would be accomplished by minimizing the quantity of water that enters the ground-water regime where saline formations are contacted.

Irrigation efficiency may be increased by (1) proper and timely irrigation applications without more labor, (2) additional labor inputs, and (3) improved on-farm systems and total distribution systems through capital investment. Improved scheduling and management of farm irrigation would require a substantial increase in informational and operational programs as well.

22. Pub. L. No. 93-320, § 203(a)(1)(iii).

A major obstacle to this program is the institutional structure of Western water laws. "Water savings" may diminish water rights if less water is diverted through time. Increased irrigation efficiency in use of a given quantity diverted may not only reduce water deliveries downstream, but the return flows will likely be more saline. Only interstate compacts that specify both quantity and quality of deliveries can adequately protect all water users. So far, we don't have such compacts.

Point and natural runoff sources which are a major segment of quality effects, present a different potential than irrigation return flows in terms of control, solutions, and responsibilities. Point and natural sources of salinity relate generally to the public and public agencies, and control thus does not impair private property rights. In contrast, irrigation return flows and associated salinity largely involve private farmers and effective control presents a different set of problems. Most importantly, all salinity sources involve offsite or external relationships and effects, which give rise to extremely complicated questions of responsibility, water rights, net economic and social impacts, and institutional and other arrangements for corrective action.

D. Costs and Cost-Sharing

In benefit-cost analysis terminology, the problem of offsite or external effects is one of incidence of the benefits and costs of the external effect itself and the corrective action. If the beneficiaries of economically feasible corrective action can be identified, an equitable distribution of the costs would relate cost allocation to benefits received.

Capital expenditures in the 1972 program were estimated at $400-500 million.[23] Substantial funding would be needed also for investigations, feasibility studies, educational programs, etc. The report recommended that costs be "shared by the beneficiaries." Differences of opinion no doubt exist as to who the beneficiaries are and how much they benefit.

The legislation relies on federal responsibility to Mexico along with federal land ownership and federal pollution control policy to justify allocating 75 percent of the total costs as nonreimbursable. The remaining 25 percent would be allocated between the Upper and Lower Basin Development Funds with the allocation dependent on benefits, causes of salinity, and availability of revenues in the funds with an upper limit of 15 percent to the Upper Basin Fund.[24]

23. U.S. Dep't of the Interior, *supra* note 3.

24. Pub. L. No. 93-320, § 205(a).

SUMMARY AND CONCLUSIONS

Clearly, the economic or environmental optimum levels of salinity at Hoover Dam or Imperial Dam have not been established. The proposed 850 ppm salinity level at Imperial Dam seems to be more of an historical coincidence than a scientifically based optimum. Apparently this goal was set at a point in time when someone decided that the level of quality should not deteriorate further at this location.

Quality goals and programs appear to have been settled without adequate research foundations in economic and institutional feasibility analyses. The irrigation return flow problem seems particularly lacking in data, analysis, and synthesis. In our opinion, we simply do not yet know what is the optimum level of water quality in the Basin at various locations. What levels can be achieved? What programs are economically feasible and institutionally possible?

It is clear that if the present salinity of 850 ppm at Imperial Dam is to be maintained or reduced, a heavy burden will be placed on future agricultural development. Corrective action will be especially costly to farmers in upstream areas unless incentives are provided. This control program is also by far the most complex one to implement. Inducements or enforcements leading to farmer and irrigation district action would seem to be necessary.

One major problem is the conflict between developmental and environmental interests, whether real or imagined. The Water Resources Council Principles and Guidelines propose project objectives both to enhance national economic development and to enhance quality of environment. Which is consistent with a quality level of 850 ppm at Imperial Dam? Should this level be the reference point, or should a broader look be taken? What are the tradeoffs between these two objectives as the quality is increased or decreased from this level? This broader look is difficult as long as Upper and Lower Basins are viewed largely as independent economies. At this point in time, the prevailing view seems to be that new development that deteriorates quality must be offset by quality control programs by the new developers or by their neighbors. It ought to be at least considered that downstream users bear part of the cost of upstream quality control.

There is some hope in some quarters that water importation in major quantities is possible. The WRC study in the Lower Basin clearly assumed this, but the more recent Bureau of Reclamation proposal is based on substantially less new irrigation development and water depletions.

Although we have largely avoided discussing the recent water quality agreement between the United States and Mexico, it is quite obviously a crucial issue in resolution of water quality problems in the Colorado River Basin if it is taken seriously. The Basin states are holding to the view that the international agreement is a national problem and that they can proceed independently with development. It is difficult to see how the agreement can be met without regard to Basin development.

In many ways this paper has attempted to report the present status of the water quality problem. We have also discussed in principle various policy options that might be considered in coping with the problem. We have attempted to survey the relevant literature. In the end, we are impressed that many more research results are required if our planning and policies are to match our hopes for success.

In the first place, there must be a synthesis of the economics and hydrology of the Basin as a whole. We see no way that a socially optimum level of water quality can be estimated without giving empirical content to the marginal net benefit and marginal external damage functions of Figure 1. At this point in time we have more hydrologic and water quality information than economic. Studies that show the value productivity of irrigation water in the Upper Basin and the value productivity of various levels of water quality in the Lower Basin must be given top research priority.

We also need hard economic data on the costs and expected benefits of alternative programs to improve quality. Many government agencies seem to be proceeding with quality improvement as if it were obvious that the benefits will exceed the costs. It is our opinion that public and congressional support for these programs would be more easily obtained if it were clear that they are economically feasible.

Finally, there are great gaps in our knowledge in assessing the institutional workability of the various policy options to control salinity. We have suggested alternatives that have been employed elsewhere without firm evidence that they could be successfully applied to the Colorado River Basin. A great deal of attention should be given to organizational arrangements that would permit negotiation between Upper and Lower Basin states. Perhaps some kind of regional authority or basinwide conservancy district is needed. How the costs of quality-improving investment and institutional improvement should be distributed between Upper Basin irrigators and Lower Basin beneficiaries is also a problem of first priority.