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Impact of Energy Development on Colorado River Water Quality

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IMPACT OF ENERGY DEVELOPMENT ON COLORADO RIVER WATER QUALITY

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THE COLORADO RIVER BASIN: ENERGY RICH AND WATER POOR

The water of the Colorado River is the life blood of the arid mountain west, the southwestern United States, and the Mexicali Valley of northern Mexico. It presently serves the needs of some 15 million people in supplying water for cities, irrigated agriculture, energy production, industry, and mining and in supporting fish, wildlife, recreation, and areas of unparalleled aesthetic value. Within this vast region the Colorado River is the key to the basin's future ability to meet the diverse demands made upon its resources, with the people of two countries depending on it for their economic security, recreational, and aesthetic needs. Yet the Colorado River Basin is water short, producing the lowest outflow per unit area (60 acre-feet per square mile) of any river basin in the United States.

In contrast to being water poor, the Colorado River Basin is one of the richest storehouses of energy resources in the United States, including coal, oil, natural gas, uranium, tar sands, and oil shale deposits. Development of these resources has been relatively slow due to their remote location, but in the future national priorities will exert increasing pressures for development. For all these present and future activities, the river must serve as both a source of water and a carrier of residuals and by-products of man-made as well as natural processes. As a result of past development, the quality of the water in the Colorado has deteriorated over time, with problems of water use and pollution inputs being further compounded by the relatively small flow of the river in relation to the basin size.

The purpose of this paper is to examine the water quality problems associated with energy development within the Colorado River Basin. Certainly the future ability of the Colorado to sustain desired water uses in both the U.S. and Mexico is dependent on maintaining the qualities of water required for them.

ENERGY RESOURCES AND WATER DEMAND

The large potential impact of energy development on water quality

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is apparent, considering the vast energy reserves and the quantities of water required for their development. Of the abundant energy reserves in the Colorado Basin, coal is by far the most widespread (see Figure 1). The state of Arizona, Colorado, New Mexico, Utah and Wyoming produced only about 8½ percent of the nation's coal in 1975 yet these states have about 25 percent of the U.S. reserves. The Green River Formation covering extensive areas of Colorado, Utah, and Wyoming contains an estimated 600 billion barrels of recoverable oil. In these same areas tar sands deposits contain an estimated 16.5 billion barrels of recoverable oil, and there are also significant quantities of crude oil and natural gas.

Water is used in all aspects of energy production including mining, reclamation of mined lands, processing, transportation, refining, and energy conversion. However, the levels of future water use for energy development in the Colorado Basin are subject to considerable uncertainty from the standpoint of which developments will occur, the technology to be employed and the water requirement, and the timing and location of developments. Despite the uncertainties, development will undoubtedly take place over the years and substantial amounts of water will be required.

Concern as to whether sufficient water is available in the arid west to sustain various energy extraction and conversion activities has been the stimulus for a number of "water for energy" studies for the western states. Studies to date[1] have taken an inventory approach, itemizing the possible energy projects and determining the availability of water to meet estimated needs. A comparison of these estimates in Table 1 shows a range of some 300,000 to over 1 million acre-feet of water annually used for energy projects by 1990 to 2000. These estimates were based primarily on 1974 considerations, but since that time changes in conditions are already apparent, such as the deferral of the Kaiparowitz project. The overall impact of these projections on the Colorado River water supply is illustrated in Figure 2.

Not only do projected requirements exceed available supplies, but

1. G. Davis & L. Wood, Water Demands for Expanding Energy Development, Geological Survey Circular 703 (1974); Division of Water Resources, Utah Dep't of Natural Resources, Water for Oil Shale—White River (1973); Federal Energy Administration, Project Independence Blueprint, Final Task Rep., Water Requirements, Availabilities, Constraints and Recommended Federal Actions (1974); U.S. Bureau of Reclamation, Alternative Sources of Water for Prototype Oil Shale Development in Colorado and Utah (Draft 1974); Water for Energy Management Team, U.S. Dep't of the Interior, Report on Water for Energy in the Upper Colorado River Basin (1974); WATER RESOURCES COUNCIL, PROJECT INDEPENDENCE, WATER REQUIREMENTS, AVAILABILITIES, CONSTRAINTS, AND RECOMMENDED FEDERAL ACTIONS (1974); WESTERN STATES WATER COUNCIL, WESTERN STATES WATER REQUIREMENTS FOR ENERGY DEVELOPMENT TO 1990 (1974).

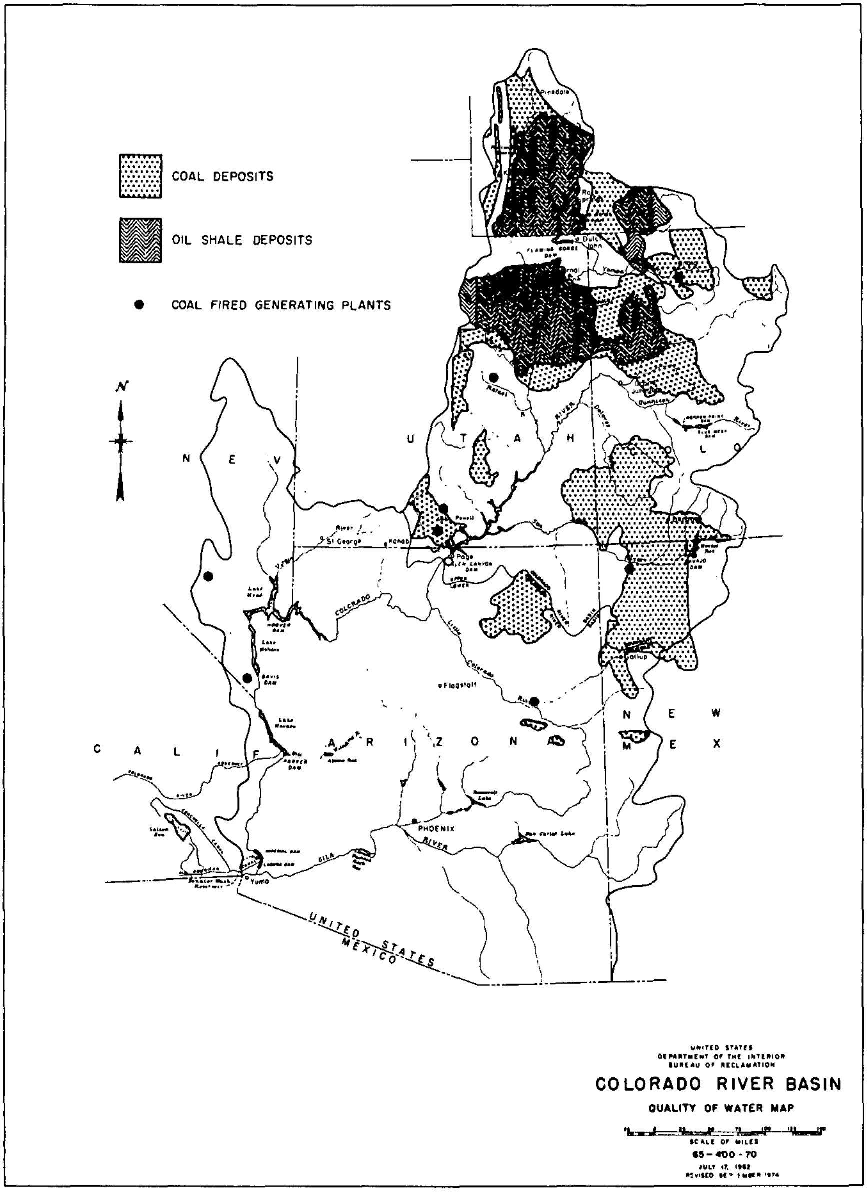


FIGURE 1

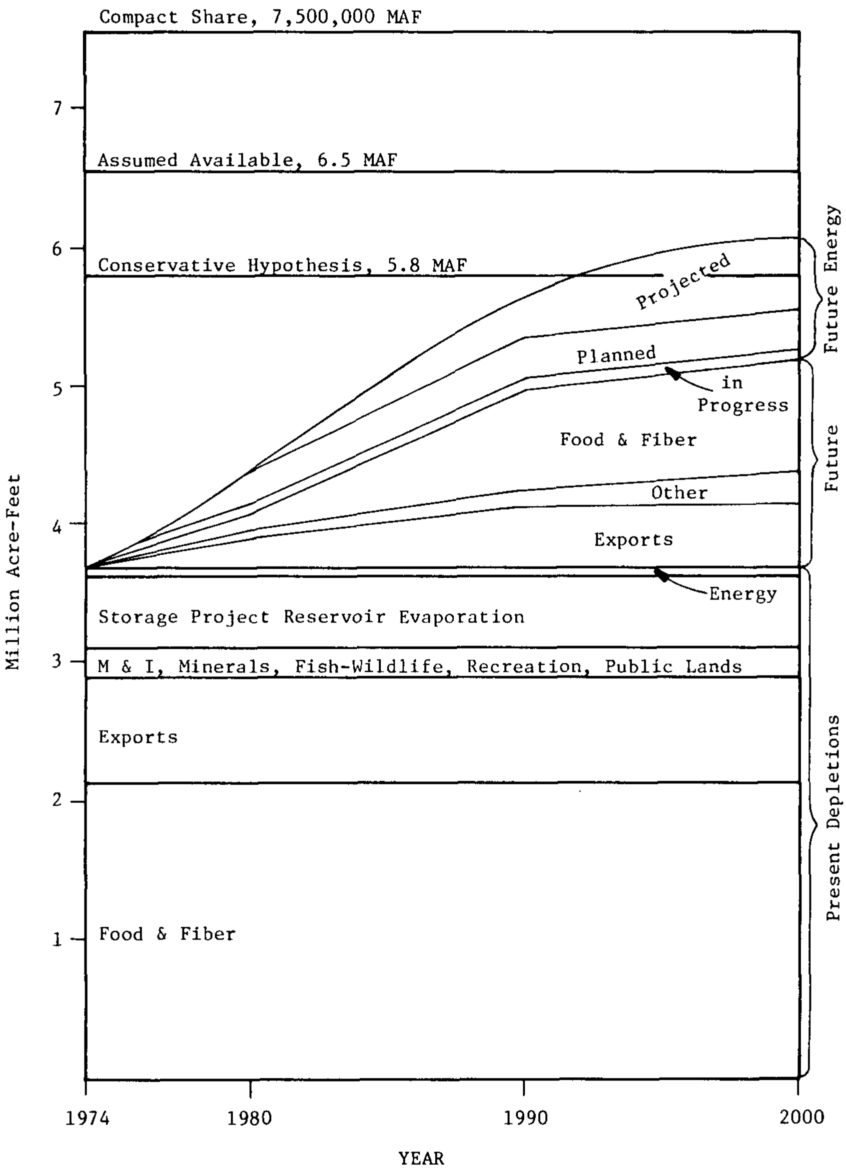
Energy Resources of the Colorado River Basin

TABLE 1

Projected Water Needs for Energy Development by the Time Period 1990-2000

		Projected Water Users in 1000's of Acre Feet						
Study		*Coal Fired Power*	*Coal Mining*	*Coal Gas/Liq.*	*Other Energy Process*	*Oil Shale*	*Nuclear*	*Total*
Western States Water Council		464	125	149	11	320	87	1156
Colorado River Salinity Forum	(L)		360			105		465
	(M)		405			130		535
	(H)		720			225		945
Colorado River Regional Assessment Study	(L)	243	4	0	2	0	50	299
	(M)	303	10	63	20	73	90	599
	(H)	525	16	142	23	229	105	1040
Water for Energy Management Team		506	X	273		257		1036

(L) = low, (M) = moderate, (H) = high levels of energy development.



SOURCE: Water for Energy Management Team, Rep. on Water for Energy in the Upper Colo. River Basin: U.S. Dept. of the Interior, 63 (1974).

FIGURE 2

Upper Colorado River Basin Projected Water Use for Energy and Other Purposes—1974 to 2000 the Department of Interior Water for Energy Management Team also concludes:

> From available data, it is obvious that the water supply exceeds that which is presently being utilized in the Basin (Upper Colorado River Basin). However, it is also apparent that the supply is in turn exceeded by the presently recognized rights to utilize water which have been granted by most of the states in the Basin.[2]

Thus, the water supply is limited not only in terms of quantity available as compared to desired uses, but also in terms of the institutional restrictions on water allocation in the form of international treaties, compacts, court decrees and water rights. Eventually water demands in the basin will most certainly exceed physically and legally available supplies. While the exact time this occurs is uncertain, the occurrence is nevertheless inevitable.

WATER QUALITY PROBLEMS AND ENERGY DEVELOPMENT

As the Colorado River flows from its mountain headwaters across the Colorado Plateau, through the low desert areas of Arizona and California into Mexico, there is a corresponding degradation of water quality. The change in quality is the result of both natural processes (primarily adding dissolved salt) and man-made activities that add all forms of pollutants that are further concentrated through consumptive use of water. The array of activities associated with energy development, which include direct discharge of pollutants, surface disturbance, air emissions returned to the hydrologic system with rain, population growth, and withdrawal and consumptive use of water, all represent sources of additional impacts on water quality of the Colorado River.

Overview of Present Water Quality Conditions

To identify current water quality problems, a comparison of existing water quality data with state and federal standards was made in order to develop a profile of various problem types throughout the basin.[3] Analysis of the water quality parameters that exceed standards yields the general list of problems presented in Table 2. When viewed from the standpoint of both sources of the problem and the incidence of effects, problems are primarily local (although they may occur in several places in the basin), or both local and region-wide where the

2. Report on Water for Energy in the Upper Colorado River Basin, *supra* note 1, at 1.
3. A. BISHOP, *et al.*, COLORADO RIVER REGIONAL ASSESSMENT STUDY (1975) (prepared for Nat'l Comm. on Water Quality by Utah Water Research Laboratory).

problem is of a pervasive nature. Energy and mineral developments have caused water quality problems that are serious in specific locales. These include acid mine drainage and heavy metal pollution in tributaries of the west slope of the Rockies, impacts on water temperature, sedimentation problems, and increasing downstream salinity through depletions.

At present, from the standpoint of the entire basin, the most critical water quality problem in the Colorado River is the salinity or total dissolved solids (TDS) content of the water. It is also the problem that is most affected by the natural background conditions of the basin. Comparisons of salt loading and salinity concentrations at various points on the river system have been estimated in a number of different studies.[4] These studies have employed techniques for identifying and separating the sources of salinity. While varying their estimates, they suggest that approximately ⅔ of the salt burden (tons per year) and 50 percent of the concentration (tons per acre-foot) in the river at Lake Mead originates from natural point and diffuse sources. Comparisons of salt loading at various points on the river system as estimated by four of these studies are given by Table 3. Historically, salinity concentration at Imperial Dam (shown by figure 3) have tended to increase as a result of both salt loading and consumptive use of water.

POLLUTION PROBLEMS OF FUTURE ENERGY DEVELOPMENTS

The impacts of pollutants on stream quality levels in the Upper Colorado River Basin are potentially singificant in areas of intense energy development. Reaches typical of areas with high potential for energy development contain range or forest lands and low population densities (less than three persons per square mile). In such reaches, projected stream flow diversion and concomitant waste loading will have the most serious effects.

A broad assessment of possible pollutants resulting from energy related activities in the major drainages of the Upper Colorado River Basin is presented in Table 4. At present, uranium, hydroelectric, and fossil fuels are already well developed in certain areas. As needs for

4. COLORADO RIVER BOARD OF CALIFORNIA, NEED FOR CONTROLLING SALINITY OF THE COLORADO RIVER (1970); M. HYATT, J. RILEY, M. McKEE & E. ISRAELSEN, COMPUTER SIMULATION OF THE HYDROLOGIC SALINITY FLOW SYSTEM WITHIN THE UPPER RIVER BASIN (1970) (Utah St. U. Water Research Laboratory); W. Iorns, C. Hembree, D. Phoenix & G. Oakland, Water Resources of the Upper Colorado River Basin—Basic Data, U.S. Geological Survey Professional Paper 442 (1964); U.S. Dep't of the Interior, Quality of Water—Colorado River Basin (1975) (Progress Rep. No. 7); U.S. ENVIRONMENTAL PROTECTION AGENCY, THE MINERAL QUALITY PROBLEM IN THE COLORADO RIVER BASIN (1971).

TABLE 2

Occurrence of Significant Water Quality Problems in the Colorado River Basin

Basin/River Reach	Sub-Basins: Hydro-logic	Sub-Basins: OBERS	SALT: Sources	SALT: Damages	BOD-DO	Eutrophication	Sediment Production	Hvy. Metals–I, M, & Nat.	ΔTemp-Energy	Phenols + Petroleum Spills	NO_3-N-DWS	Potential Development of Energy Resources
New Fork	UG 1	1401										
GR above LaBarge	2	1401						X				
GR above Fontenelle	3	1401										Hydro
Big Sandy Creek	4	1401	X									
GR above GRC, Wy.	6	1401			X				X	X		Coal
Blacks Fork	7	1401	X	X					X	X		Coal
GR above FG Dam	8	1401			X				X			Hydro, Coal
Little Snake	9	1402			X				X			Coal
Yampa R	10	1402			X				X			Coal, oil, oil shale
GR above Jensen	11	1402			X				X			Coal, oil, oil shale
Ashley Creek	12	1403	X						X			Oil

Duchesne Rw. above Duc.		13	1403										
Duc. above Randlett		14	1403	X	X				X	X			Oil
White River		15	1402	X					X	X			Oil, oil shale
Price River		16	1403	X		X		X	X	X		X	Coal
GR above Green River, Ut.		17	1403							X			Coal
San Raphael		18	1403	X				X		X			Coal
CR above Hot Sulpher	UM	1	1405			X			X				
Eagle River		2	1405										
CR above Glenwood Sp.		3	1405			X			X	X			Coal
Roaring Fork		4	1405										
CR above Plateau G.		5	1405			X							
Plateau Creek		6	1405			X			X				
Gunnison R above Gun.		7	1404			X			X				
CR above NFGR		8	1404			X			X				
Uncompahgre		9	1404,6	X	X	X			X				
CR above Grand Junct.		10	1404,6	X									
CR above Col.-Ut. Line		11	1405	X	X	X			X	X			Coal
San Miguel & Dolores		12	1406	X		X			X			X	
CR above Cisco, Ut.		13	1406							X			Coal
CR above Lee Ferry		14	1406,8			X	X	X	X	X	X		Hydro, coal
San Juan above Amboles	US	1	1407			X							
SJ above Archeleta		2	1407			X	X		X	X			Hydro, coal
Animas		3	1407			X	X		X	X			Coal
SJ above Farmington		4	1407						X	X			Coal
LaPlata		5	1407							X			Coal
SJ above Shiprock		6	1407										
SJ above Bluff		7	1408			X		X	X		X	X	

TABLE 3

Estimates of Salt Loads at Selected Stations on the Colorado River by Various Studies

Sub-Basin	Station	Salt Loading, Tons/Yr. x 1000			
		EPA[a] *(1965-1966)*	*USBR*[b] *(long term avg.)*	*USU*[c] *(long term avg.)*	*Colo. River*[d] *Brd. of Cal.*
UG-6	Green River near Green River, Wyoming	945	558	494	
UG-11	Green River near Greendale, Utah	1177	956	1222	
UG-14	Duchesne River near Randlett, Utah	726	405	422	
UG-17	Green River at Green River, Utah	3167	2644	2405	
UG-18	San Rafael River near Green River, Utah	327	221	243	
UM-3	Colorado River near Glenwood Springs, Colo.	639	593	610	
UM-5	Colorado River near Cameo, Colorado	1595	1524	1540	
UM-10	Gunnison River near Grand Junction, Colo.	1704	1474	1647	
UM-13	Colorado River near Cisco, Utah	4672	4145	4713	

US-2	San Juan River near Archuleta, New Mexico	359	204	197	
US-7	San Juan River near Bluff, Utah	1496	998	1010	
UM-14	Colorado River at Lee Ferry, Arizona	6446 (release)	8566 (inflow)	8570 (inflow)	8430 (inflow)
LM-1	Colorado River near Grand Canyon, Arizona	7289	9676		6020 (release)
LM-2	Virgin River at Littlefield, Arizona	165	348		
LM-4	Colorado River below Hoover Dam, Ariz.-Nev.	7983	10410		8120
LM-6	Colorado River below Parker Dam, Ariz.-Calif.	6617	8813		7120
LM-7	Colorado River at Imperial Dam, Ariz.-Calif.	6851	9074		7470
LM-8	Colorado River at U.S.-Mexico border (Arizona)	8994			

a. ENVT'L PROTECTION AGENCY, Appendix A (1971).
b. U.S. BUREAU OF RECLAMATION, PROGRESS REP. NO. 7 (1975).
c. HYATT, M., RILEY, J., MCKEE, M., and ISRAELSON, E., COMPUTER SIMULATION OF THE HYDROLOGIC SALINITY FLOW SYSTEM WITHIN THE UPPER RIVER BASIN, Utah Water Research Laboratory, Utah St. U. (1970).
d. COLO. RIVER BASIN SALINITY CONTROL FORUM, PROPOSED WATER QUALITY STANDARDS FOR SALINITY INCLUDING NUMERIC CRITERIA AND PLAN OF IMPLEMENTATION FOR SALINITY CONTROL—COLO. RIVER SYSTEM (1975).

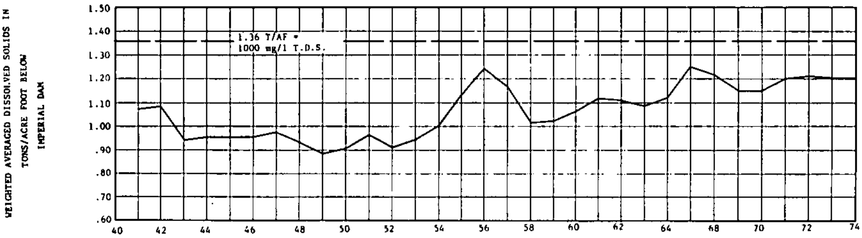


FIGURE 3

Weighted Average Dissolved Solids Concentrations,
Colorado River Below Imperial Dam

new energy sources become more immediate, efforts will turn toward the less easily developed fossil fuels such as deeper coal seams, tar sands, and oil shales in geographical areas delineated by the Flaming Gorge Dam, the Uinta-White River Basins, the San Juan River, and the high plateau areas near Lake Powell. The concomitant water pollution consequences of such development can be expected to be widespread in the Upper Basin. As Table 4 indicates, the major energy related activities contributing to pollution problems are surface

TABLE 4

Potential Pollution Problems from Energy Development in the Colorado River Region

Geographical Areas	*Activities*	*Pollutants*
Upper Green River	Coal mining, coal fired generation, urbanization, oil shale	Salts, organics
Yampa River	Two proposed dams, coal mining, coal fired generation, oil shale, slurry	Salts, temperature, organics, sediment
Uintah-White River Basins	Oil shale, tar sands, oil and gas, urbanization	Salts, sediments, organics, nitrates, pesticides
Upper Colorado-Gunnison River (Denver, etc.)	Coal, oil and gas	Salts, sediments
Dolores River	Coal and other mining	Salts, metals (toxicity)
Lake Powell	Coal, coal fired generation, gasification, slurry	Eutrophication, DO, temperature, sediments
San Juan River	Coal, coal fired generation, gasification, uranium	Salts, radiation, toxicity, temperature

disturbances producing sediments and salt, mine drainage producing heavy metals and other toxics, wastewater discharges containing organics and carcenogenic agents, and temperature increases from blowdown water.

Such problems will be accentuated by the energy industries' diversion and consumptive use of water, which correspondingly decreases the stream's capacity for assimilating pollution discharges. The significance of this is emphasized by the fact that there does not seem to be a single new electrical generating plant, coal gasification plant, or oil shale processing plant being planned for which the designers have not opted for the total containment of wastewater. Projected increase in population induced by energy development could also add a significant increment to pollution concentrations in smaller streams.

EFFECTS OF ENERGY DEVELOPMENT ON COLORADO RIVER SALINITY

The most pervasive and important water quality problem facing both the United States and Mexico is salinity. Since the two countries have agreed under Minute 242 on a salinity level for water delivered to Mexico, an important water quality concern is the effect of energy development on future salinity levels in the river. The Federal Water Pollution Control Act Amendments of 1972[5] stipulate that industrial wastewaters, such as those from energy developments, should be treated using the best practicable technology (BPT) by 1977, the best available technology by 1983, with a goal of elmination of discharge (EOD) by 1985. In response to these requirements, it appears that the large volumes of water that may be drawn for energy development will not be returned to the river.

It is generally recognized that the total containment technology for water use in energy development will lead to reduced salt load in the river. However, the reduction in stream flow from total containment will increase salinity concentrations in the downstream reaches of the river, other things being equal. This can be seen from the mass balance of a hypothetical stream reach shown in Figure 4 where flow and salt concentration typically increase downstream, as in the Colorado River.

Assume the flow at the point A, a planned diversion for energy development, is 1000 acre-feet and the salt concentration is 0.20 tons per acre-foot. Thus the salt load passing A is 200 tons. The outflow measured at point B is 2000 acre-feet per day with a concentration of

5. Federal Water Pollution Control Act Amendments of 1972, §301, 33 U.S.C. §1311 (1972).

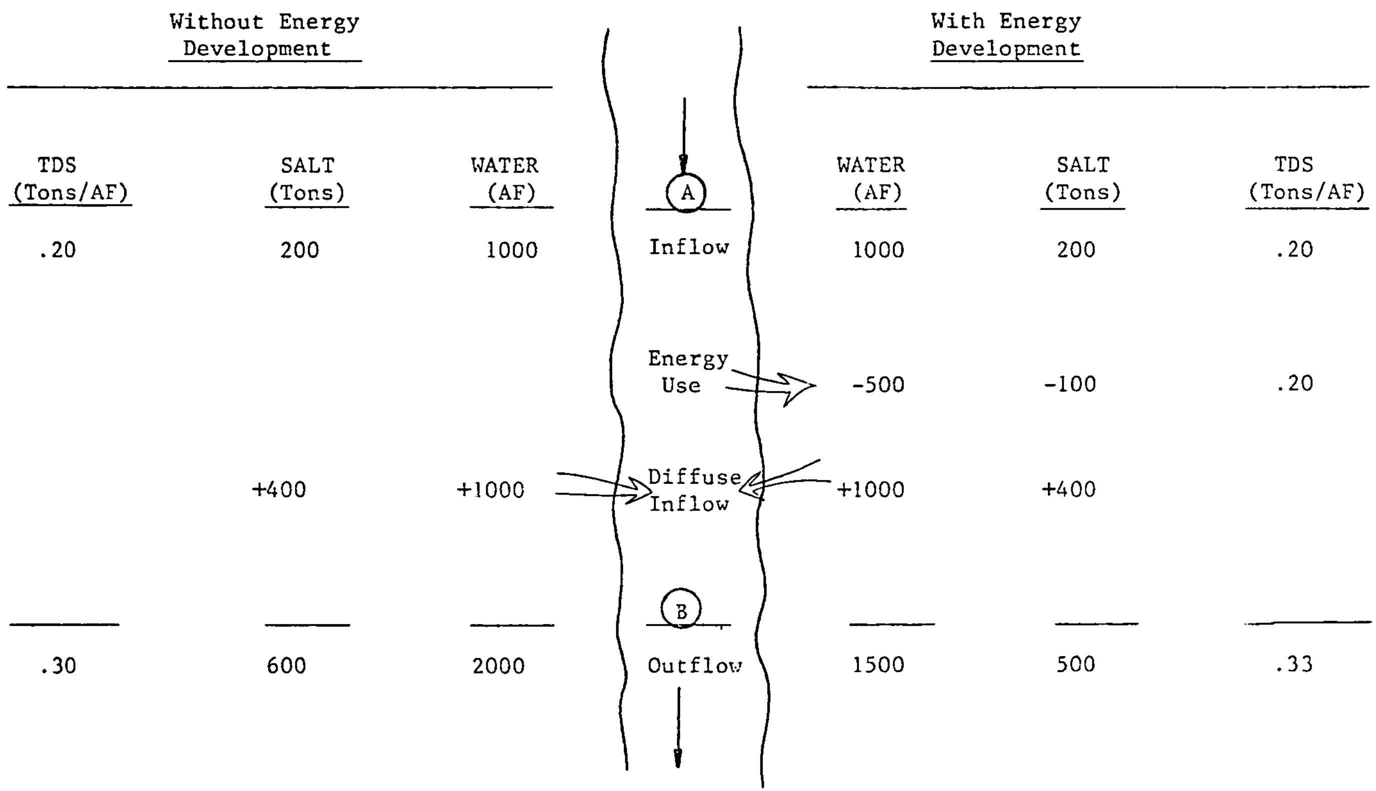


FIGURE 4

Water and Salt Mass Balance for an Example Stream Reach With and Without Energy Use.

0.30 tons per acre-foot, and a corresponding salt load of 600 tons. Between A and B there has been a net gain of 1000 acre-feet of water and 400 tons of salt from diffuse sources. An energy project diverts 500 acre-feet of water at point A and with it a salt load of 100 tons. The net result of the new equilibrium is a reduction in flow past B to 1500 acre-feet of water and 100 tons of salt. The salt concentration at B has increased from 0.30 to 0.33 tons per acre-foot due to the containment of higher quality water upstream. Considering only increased water use for energy, salinity concentrations can be expected to increase, but of course the situation is much more complex than this. Other factors such as shifting water from present uses into energy, diversions on tributaries with low or high salt concentrations, use of ground water, fluctuation in total flow, choices among wet, dry or combined wet and dry cooling, and changes in process technology will all affect whether salt concentrations increase and how much.

Recent studies have attempted to assess the changes in Colorado River salinity as a consequence of future development, including energy. Two models have been developed by the Bureau of Reclamation for water and salt flow in the Colorado River. One model[6] uses hydrologic traces that have been stochastically generated to examine a number of variables, including flows and salinities, for various demand schedules representing levels of development from 1975 to 2000. Presently the model is being documented and improved. Results of model runs are not available in a form that will allow determination of specific salinity effects of energy development. The other model, which has been applied to the river below Lake Powell, is basically a deterministic flow and salt accounting system using a routing time frame of one month. It has been used[7] to estimate the effects of both water resource development and salinity control measures contemplated by the Colorado River water quality improvement program[8] within the Colorado River Salinity Control Act.[9] An integrated set of economic-hydrologic-salinity models for the Upper

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6. C. HUNTLEY, R. MAIN & W. LANE, STREAMFLOW SIMULATION WITH THE COLORADO RIVER SIMULATION MODEL IN COLORADO RIVER BASIN MODELING STUDIES (1976) (Utah St. U. Water Research Laboratory); W. LANG & A. BIGGS, APPLICATION OF STOCHASTIC HYDROLOGY TO SIMULATE STREAMFLOW AND SALINITY IN THE COLORADO RIVER (1973) (U.S. Bureau of Reclamation, Engineering & Research Center).

7. R. RIBBENS & R. WILSON, APPLICATION OF A RIVER NETWORK MODEL TO WATER QUALITY INVESTIGATIONS FOR THE COLORADO RIVER (1973) (U.S. Bureau of Reclamation, Engineering & Research Center).

8. U.S. BUREAU OF RECLAMATION, COLORADO RIVER WATER QUALITY IMPROVEMENT PROGRAM (1974).

9. Colorado River Basin Salinity Control Act, 43 U.S.C. §§1556 *et seq.* (1974).

Colorado River Basin has been developed by Howe and others.[10] Economic models of the regional input-output type generate total gross output data that is converted to water demands and other impacts for use in a hydro-salinity model. The model has been run for projected future economic conditions involving changes in agricultural acreages and activities, and direct and indirect changes in water demands of non-agricultural sectors. Phasing out of agricultural activities, which involves some shifts of water to energy, results in a reduction of total salt load. However, downstream changes in salinity concentration directly attributable to energy are not separable. In another study, Roefs and Gum[11] estimate that the implementation of the first stage or 1985 levels of energy development under the Western Systems energy plan would add about 7 mg/1 to the salt concentration at Imperial Dam if plants are built according to specifications. In two studies that have estimated the changes in salinity at key points in the Colorado River system, the effects of energy development can be separated out.

THE COLORADO RIVER REGIONAL ASSESSMENT STUDY

The purpose of the Assessment Study,[12] conducted for the National Commission on Water Quality, was to evaluate the impacts of Public Law 92-500 on the Colorado Basin. The study recognizes that the kinds and rates of energy development are decisions affected by public policy and economics. Since future development and water use levels are highly uncertain, "alternative futures" representative of a range of possible combinations of energy and water resource developments were adopted as a basis for analyzing salinity impacts. The alternative future resource developments were specified in terms of increments of change in water use for energy production, irrigated agriculture, and water exports out of the basin from the base year of 1972. Three levels of development were assumed to occur, namely, low, medium (most likely), and high. For example, high energy coupled with low agriculture and medium water export represents one of the alternative futures that could result from an array of public and private policy decisions. The effects of these alternative futures

10. B. Udis, C. Howe & J. Kreider, The Inter-relationship of Economic Development and Environmental Quality in the Upper Colorado River Basin: An Inter-industry Analysis, NTIS COM-73-11970 (1973); B. UDIS, C. HOWE & J. KREIDER, ECONOMIC AND ENVIRONMENTAL MODELING IN THE COLORADO BASIN VIA INPUT-OUTPUT ANALYSIS IN COLORADO RIVER BASIN MODELING STUDIES (1976) (Utah St. U. Water Research Laboratory).

11. T. Roefs & R. Gum, Coal-Fired Energy Development on the Colorado Plateau: Economic, Environmental and Social Impacts (1974) (unpublished paper, U. Ariz.).

12. A. BISHOP, *et al.*, *supra* note 3.

were evaluated at three points in time, 1977, 1983, and 1990-2000, which in effect represent levels of possible development.

The analytical tool used to evaluate the salinity impact of the alternative futures was a steady state water and salt mass balance model for the river system. The model is completely general and may be applied to any river basin by specifying the appropriate network of nodes. Each node represents a subbasin of the total system, and any number of projects having specific salt loads and water diversions may be associated with each node. For the model, the Colorado River Basin was divided into 16 river reaches from the headwaters of the Green River to Imperial Dam. These reaches were selected to coincide with the ones used by the Bureau of Reclamation[13] and by the Salinity Forum[14] for the Lower Basin. Historical data on flow and water quality are available at the downstream boundary of each subbasin represented by nodes in the model. The model was calibrated to calendar year 1972 average flow and salinity conditions, agricultural acreages, consumptive use, and irrigation efficiences. Reservoir evaporation and changes in storage at Flaming Gorge, Lake Powell, and Lake Mead were obtained from United States Geological Survey and United States Bureau of Reclamation published reports for the base year. In addition to these established data, the ungaging flow and salt load contributed by each subbasin, which represents the net effects of natural runoff and all other exports, are accounted for in calibrating the model. A steady state model represents the salinity conditions that would eventually be reached in the system for a specific level and type of development. It shows the ultimate condition toward which the system is adjusting. Essentially, the model accumulates the effects of future changes in water use in each subbasin, and moving downstream displays the resulting change in salinity at specific locations in the stream system.

Model runs were made for alternative future levels of agriculture irrigation, energy development, and water export out of the basin. In the various run combinations displayed in Table 5, the activity levels of agriculture, energy, and water export are indicated by x's under each run combination. The resulting alternative futures, designated by the capital letters, are obtained by running the model at the indicated development levels for the target years 1977, 1983-85, and 1990-2000 at an assumed virgin flow for the river. For purposes of comparisons the baseline case, A, is taken to be most likely (M) levels

13. *Supra* note 7.

14. COLORADO RIVER BASIN SALINITY CONTROL FORUM, PROPOSED WATER QUALITY STANDARDS FOR SALINITY INCLUDING NUMERIC CRITERIA AND PLAN OF IMPLEMENTATION FOR SALINITY CONTROL–COLORADO RIVER SYSTEM (1975).

TABLE 5

Model Run Combination for Analysis of Salinity Impacts of Energy Development

Development Levels and River Flows		*Run Identification*						
		A	*J*	*L*	*N*	*R*	*U*	*X*
Assumed Virgin Flow	16					X		
at Lee Ferry	14	X	X	X	X		X	
(10^6 AF/Yr)	12							X
	H							
Agriculture	M	X	X	X		X		X
	L				X		X	
	H		X		X			
Energy	M	X				X	X	X
	L			X				
	H							
Water Export	M	X	X	X	X	X	X	X
	L							

of water use for agriculture, energy, and exports at an assumed Virgin Flow at Lee Ferry of 14 million acre-feet. Total containment of all water used in energy production is assumed. The two key comparisons of salinity impacts are the effects of high energy development over the baseline case, and the effect of water transfers from agriculture to energy development.

Impact of High Energy Development on Salinity

The effect of increased energy utilization when virgin flow is assumed to be 14 million acre-feet and agricultural use is held at the medium level is seen by comparing cases A and J in Figure 5. The plots suggest that as energy development proceeds through time, the total salt load decreases relative to the base condition, A. This trend is expected under a total containment policy since both water and salt are removed from the river system. Subbasins where tonnages removed are greatest include Green River, Wyoming; Randlett, Utah; Cameo, Colorado; Bluff, Utah; Lee Ferry, Arizona; and below Parker, Arizona. Naturally, these are the subareas where the energy development potential is greatest. The obvious reason for the reduction in tonnage is the reduced flow of the river. The flow at Lee Ferry, Arizona, is projected to decline from the base by an amount of 1,730,000 acre-feet per year in 1990-2000 due to the increase from a medium to a high rate of energy development. While salt tonnage is reduced, salt concentrations in the river rise with the accelerated energy development (Figure 5). This increase is attributable to the reduced flows of water for dilution. The energy developments contain the water and the accompanying salt load, but this is more than offset by the reduction in dilution water, with the result that concentrations increase markedly.

Effects of Water Shift From Agriculture to Energy

Comparing case N with A in Figure 5 illustrates the impact of

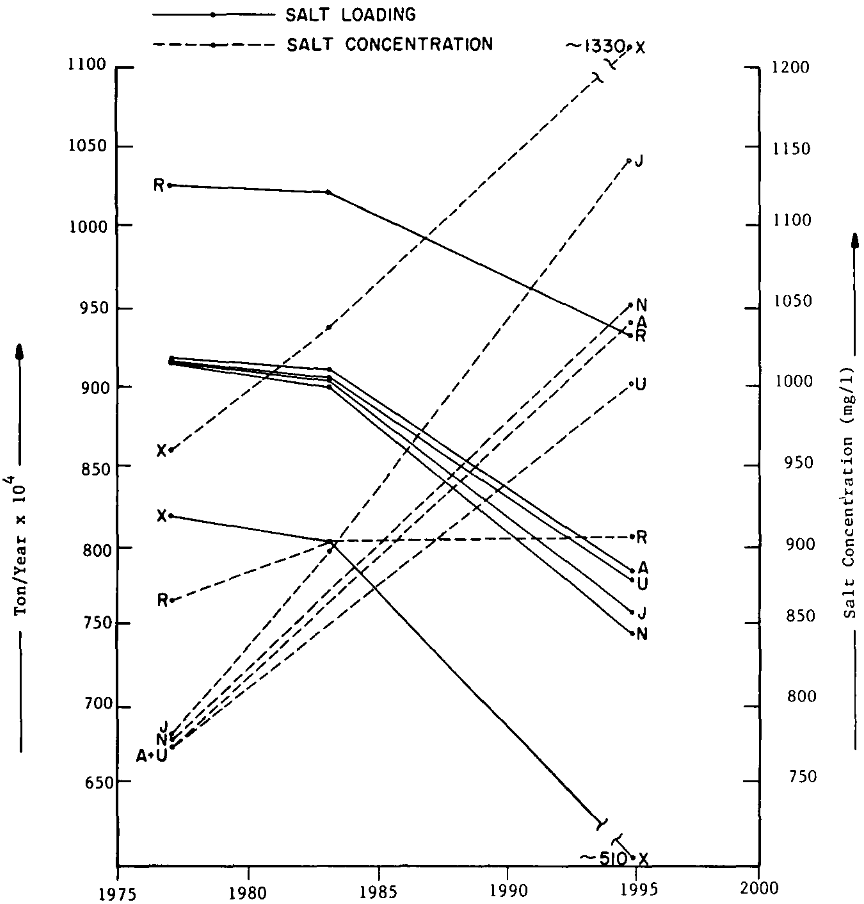

FIGURE 5

Predicted Salinity Effects at Imperial Dam for Alternative Energy Development Futures and Stream Flow Conditions.

shifting water from agriculture to sustain high rates of energy development. Under these transfers the salt load for N is reduced from the base A, but the increases in salt concentrations for both cases are about the same. By reducing agricultural water use to support moderate energy development, case U, the same general trends occur. In general, there is a decrease in salt load accompanying the energy increases over time. However, it appears that concentrations will still increase substantially due to consumptive use of water that would otherwise serve for dilution. It is interesting to note that the salt load reductions of transferring water from agriculture are essentially offset by the increased consumptive use of high energy development levels as seen from curves N and A. However, the concentration increases for N are relatively less than those for J, reflecting a larger amount of water flowing in the river for dilution under scenario N where some water is transferred from agriculture.

Sensitivity to Average Annual Flows

The sensitivity of salt concentration to the annual volume of natural flow is also indicated in Figure 5 by curves R and X. Curve R represents average annual salinity concentrations expected for a moderate rate of development assuming a high virgin flow of 16 million acre-feet per year, and curve X for moderate development with a low flow of 12 million acre-feet per year. Clearly, future salinity levels will be significantly affected by the prevailing natural flow conditions.

SALINITY FORUM SALT ROUTING STUDIES

The Colorado River Basin Salinity Control Forum, comprised of representatives of the seven basin states, conducted a series of salt routing studies[15] to estimate the future flow-weighted average salinity levels at selected points in the basin under various assumptions as to water availability and future water uses. The studies were conducted in response to the EPA regulation,[16] which calls for maintenance of salinity in the lower main stem of the river near the average value during 1972 while the states continue to develop their compact-apportioned waters.

The study was carried out using the salt routing computer model developed by the Bureau of Reclamation.[17] Water use and salt loadings were modeled for the river from Lake Powell to Imperial

15. *Id.*
16. Water Quality Standards, 40 C.F.R. §120.5 (1976).
17. *Supra* note 7.

Dam. No attempt was made to model the river above Lake Powell. The studies were made on a monthly time basis over a 17 year period (1973-1990) using a range of water supply conditions from 12 million acre-feet per year and for high, moderate, and low depletion rates (see Table 1). The model assumed no return flow from electrical generating cooling, coal gasification or other coal development, or from the oil shale industry. Under the conditions specified for the model for the 14 million base flow case, the salinity levels are shown to increase as future development proceeds. There is, however, an estimated reduction in the increase of about 27 mg/1 resulting from total containment of energy process wastewater (see Figure 6).

SUMMARY

There is a broad range of potential water quality impacts from energy development in the Colorado River Basin. While the problems of point source pollution may be effectively controlled by existing water quality legislations, such as Public Law 92-500 and state water quality standards, many energy related activities such as land surface disturbance, mining operations, air emissions, and water withdrawals are not easily controlled and could affect water quality.

The water quality problem of most concern to both the U.S. and Mexico is salinity. Water and salt mass balance model studies have analyzed the effect of future development of compact-apportioned waters in the basin. For a range of alternative energy development futures, the total dissolved solids concentrations are seen to increase below Imperial Dam even though the total salt load in the river is reduced via water diversion for energy. Thus, salinity concentrations are affected more by taking water that serves for dilution out of the river than by the removal of some salt load with the water. Even so, the control strategy of no salt return in the form of highly concentrated brines from cooling and other energy processes does reduce the salinity impact from energy development. This reduction is estimated on the order of 27 mg/1 by the Salinity Forum[18] and 34 mg/1 based on data from the Colorado River Regional Assessment Study.[19] These effects of future development will need to be considered in the planning and implementation of programs to meet water quantity and quality commitments to Mexico.

RESUMEN

La cuenca del Río Colorado es una región que tiene abundantes

18. *Supra* note 14.
19. A. BISHOP, *et al., supra* note 3.

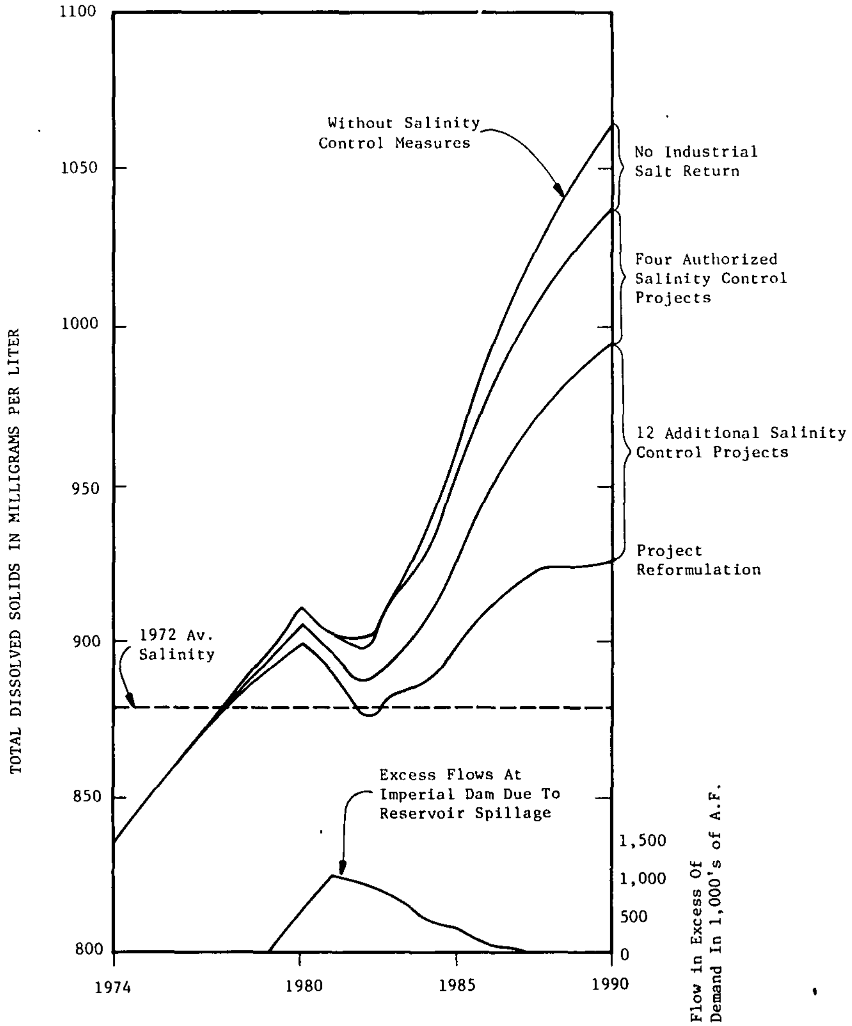

FIGURE 6

Projected Salinity at Imperial Dam at 14 M. Af./Yr. Supply and Moderate Depletion Rate

recursos enérgicos pero que falta recursos acuíferos. El uso actual de las aguas ha contribuído a la degredación en calidad del Río Colorado, y el problema de la salinidad creciente es de importancia particular a los Estados Unidos y México. Se presenta el sumario de datos existentes tomados por todas partes de la cuenca sobre problemas actuales de calidad de agua, y se nota las calidades potenciales por sub-cuencas específicas, según projecciones sobre el uso de grandes cantidades de agua en desarrollos enégicios. También se presenta estimaciones sobre el impacto en la salinidad del Río Colorado debido a varios desarrollos enégicos.