Water and arid lands of the western United States

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Mohamed T. El-Ashry and Diana C. Gibbons

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5 Water resources of the Upper Colorado River Basin: problems and policy alternatives

CHARLES W. HOWE AND
W. ASHLEY AHRENS

Background*

The Colorado River is the major surface water resource of the Southwest. In spite of John Wesley Powell's forecast that the region would never be useful or inhabited, the river basin has been fought over and romanticized more than any western river. Certainly, it has been the subject of more writing – from geomorphology to politics – than any other western river. Nadeau (1950) wrote of the Owens Valley controversy and of the heroic attempts to conquer the Lower Colorado River. Terrell (1965) described in detail the political battle between Arizona and California over the waters of the Lower Basin, and Fradkin (1968) touchingly described the great changes in the river that have come about through human attempts to control and harness its forces. Throughout this history, the influence of the financial power and the concentration of political power on water issues have dominated the policy scene, and since passage of the Reclamation Act of 1902, the federal government through the Bureau of Reclamation has been the agent of project construction and water supply provision.

The Upper Basin has grown more slowly than the Lower Basin – a typical pattern for development for river basins – generally owing to the superior climate, soils, and accessibility of the Lower Basin. Because the Colorado River's waters are produced primarily by snowmelt in the mountains of Colorado, Wyoming, and Utah, this uneven growth pattern has created a pattern of mutual fears between Upper and Lower basins, the former fearing that the latter would establish title through

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*The physical description of the basin is taken mostly from Howe, 1977. The institutional aspects are drawn from Howe and Murphy, 1981.

early use, the latter fearing the former might eventually develop to a point at which it would be using much of the river's water. This competition is still present, sometimes explicit, sometimes under the surface, and it helps explain much of the current political and legal maneuvering in the basin.

The Upper Basin is perceived as a water-short area, and it appears to be in terms of low rainfall and runoff: 10 inches per year and 124 acre-feet per square mile per year. Yet its water supply is not really lowland precipitation and runoff, but the melting mountain snowpack, a supply that is widely distributed through the region in natural streams and man-made distribution systems. According to the U.S. Geological Survey, more than 70 percent of all man-made diversions of this supply are directed toward agriculture, and more than 90 percent of all consumptive uses occur in agriculture. The prospects of large-scale energy development that dominated water and environmental concerns a decade ago (for example, Spofford, Parker, and Kneese, 1980) have now largely faded from view. The projections of water use and population have fallen in keeping with the slower growth. Projected agricultural water use needs to be reduced to reflect the oversupply of agricultural commodities nationally and internationally, combined with an increasing reluctance of the federal government to subsidize new irrigation water supply.

It is a major contention of this study that the Upper Basin is not and will not be short of water if the states of the basin use their supplies in an economically reasonable way. Changing values call for greater protection of instream flows, and the high costs of developing new supplies for municipal and industrial uses indicate the desirability of transferring water from agriculture to urban areas. Only extreme shortsightedness and a thoughtless scramble to put all their water to use quickly could lead to a future water crisis.

The methods of water allocation used and the development of new uses take place within an institutional framework consisting of interstate compacts, state constitutional and legal provisions, public water agencies, and supervised water markets. This institutional framework that has developed over the past century is now outdated in some important respects that interfere with economically reasonable use of water in the face of changing values and demands. Water rights and other forms of claims to water can be exchanged, but often only within a limited geographical area and at high transactions costs. Institutional reform, perhaps assisted by new information technologies, can greatly improve the effectiveness with which water is used in the Upper Basin. Water markets, both intrastate and interstate, can play a much larger role in this process, though there will be conflicts between what individual water owners want to do and what their state is willing to approve.

Water management in the Upper Basin cannot be separated from land use and management. Forest areas constitute the main snowsheds of the Upper Basin, so forest management practices affect water yields, erosion, and water quality. Agricultural practices affect soil erosion and siltation of streams, and saline irrigation return flows resulting from excessive irrigation applications constitute the major water quality problem of the Upper Basin. Unfortunately, water quantity is administered separately from water quality, with the result that water quality (salinity) improvement programs in the basin are needlessly costly. Again, institutional changes are needed.

The Upper Colorado River Basin has an area of approximately 102,000 square miles, located in southwestern Wyoming, western Colorado, eastern Utah, northwestern New Mexico, and northeastern Arizona. Figure 5.1 shows the entire Colorado River Basin, of which the Green, Upper Main Stem, and San Juan river basins comprise what is called the Upper Basin.

The Upper Basin is sparsely populated, with about 537,000 persons (1980 census), for an average of 5.3 persons per square mile, compared with a national average density of 57.4. The low density is primarily due to the mountainous terrain and the arid to semiarid climate of much of the remainder of the region. The population is expected to grow at a rate of approximately 1.4 percent per year (Spofford et al., 1980, table 4, scenario A, p. 227), thus rising to about 706,500 in the year 2000. There are no major cities in the basin; the main towns are Green River, Wyoming (population 8,000); Grand Junction (30,000) and Durango, Colorado (12,000); and Farmington, New Mexico (22,000). However, water is exported to the Denver metropolitan area in the east and is likely to be exported to the Salt Lake City area in the future.

The climate ranges from continuous snow cover and heavy precipitation on the western slopes of the Rocky Mountains to desert conditions in the south. Most of the moisture falls as winter snow; spring and summer rainfall is localized infrequent storm activity. Thus, water supply in the basin is dependent upon construction of dams to capture spring runoff and distribution systems to carry the water to points of use. There is little transfer of water among subbasins of the Upper Basin.

The major economic activities of the basin have traditionally been agriculture, cattle and sheep raising, and the mining of metallic miner-

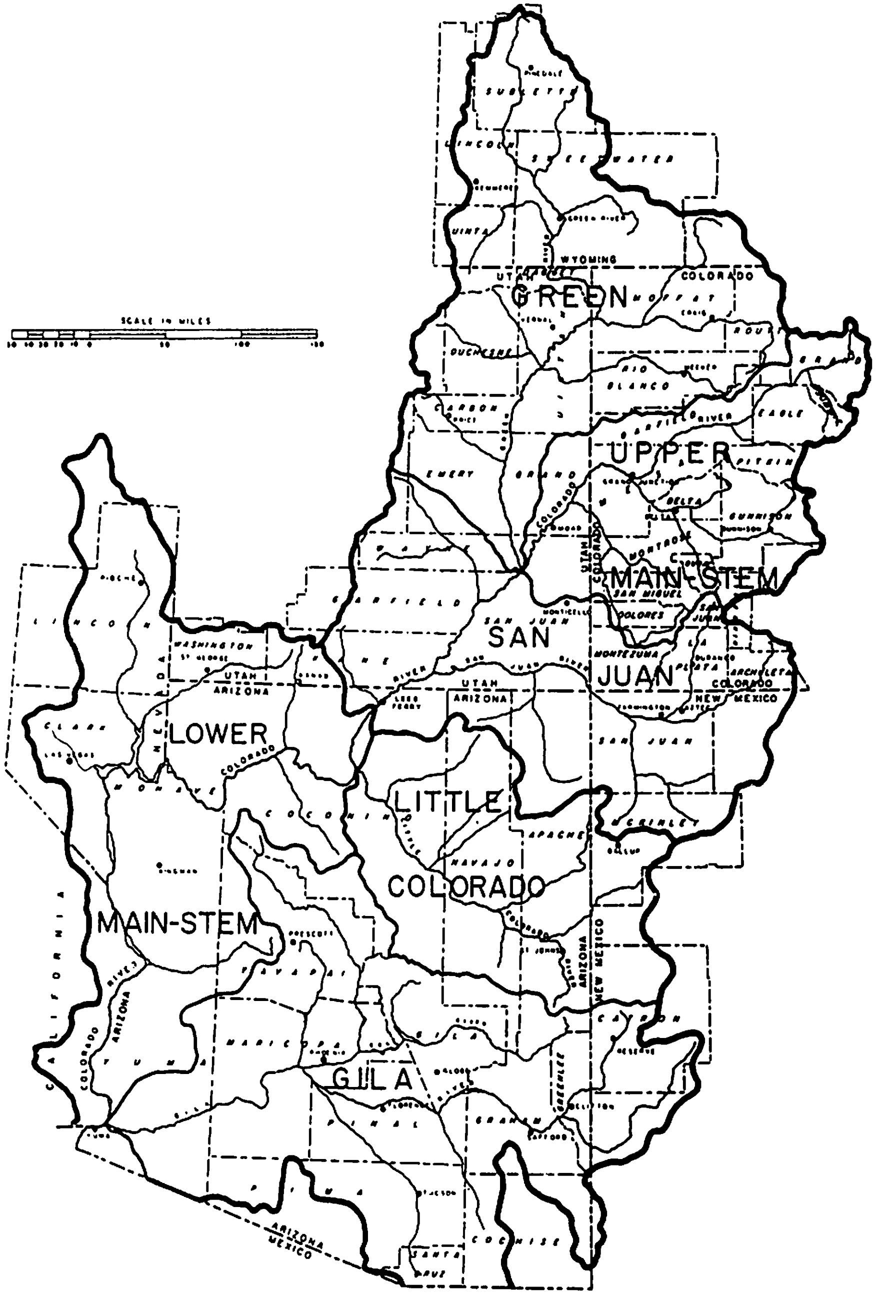

Figure 5.1. Major subbasins of the Colorado River Basin (U.S. Department of the Interior).

als. In the post-World War II period, recreational use of all parts of the basin has expanded tremendously, ranging from exclusive international skiing resorts like Aspen and Vail to mountain hiking, fishing, open river and reservoir boating, and desert area exploration. This broad recreational use is facilitated by the extensive federal land holdings that constitute 70 percent of the basin's area.

Throughout the 1970's, the huge coal and oil shale deposits that underlie much of the basin attracted development interest. From the mid-1970s until 1981, the federal government was intent upon development of these energy resources. The state governments of the area were less certain about the desirability of large-scale strip mining of coal, with associated power plants and the development of oil shale refining. Environmental problems could be critical, water requirements would be large, and interference with the growth of recreation and tourism could be severe. All energy development other than coal-fired thermal electric generation have now been abandoned.

The availability of water for further economic expansion of the basin is a major issue. At the time of the Colorado River Compact (ratified in 1929), average annual water availability was thought to be 15 million acre-feet (maf) per year. Since that time, estimates of long-term average flows have been decreasing; it is now felt that the average annual availability may be as low as 13.5 maf. In addition, a U.S.-Mexican treaty of 1944 calls for a guaranteed delivery of 1.5 maf per year to Mexico, and it is not clear how this obligation is to be divided between the Upper and Lower basins, although it has been declared a national obligation by more recent legislation. The Lake Powell Research Project estimated water available to the Upper Basin at 5.25 maf, and the U.S. Department of the Interior has used 5.8 maf, both figures dependent on the assumed long-term average virgin flow. It is probable that about 6.0 maf per year is legally available for consumptive use in the Upper Basin, with 2.5–3.0 maf now in consumptive use.

Certainly, Upper Basin demands will grow. Figure 5.2 presents demand projections commonly used during the energy boom of the mid- to late 1970s. The future energy use indicated on the demand side of Figure 5.2 has nearly disappeared with the collapse of the federal synthetic fuels program. It also seems unlikely that food and fiber consumption will increase at all, and it is likely to decrease. Annual exports from the basin to Colorado's Eastern Slope and the Wasatch Front in Utah will probably increase 400,000 acre-feet (Spofford et al., 1980, table 12, p. 393). Projected total consumptive uses for the year 2000 are thus likely to be around 4.2 maf, well short of either estimate of availability in

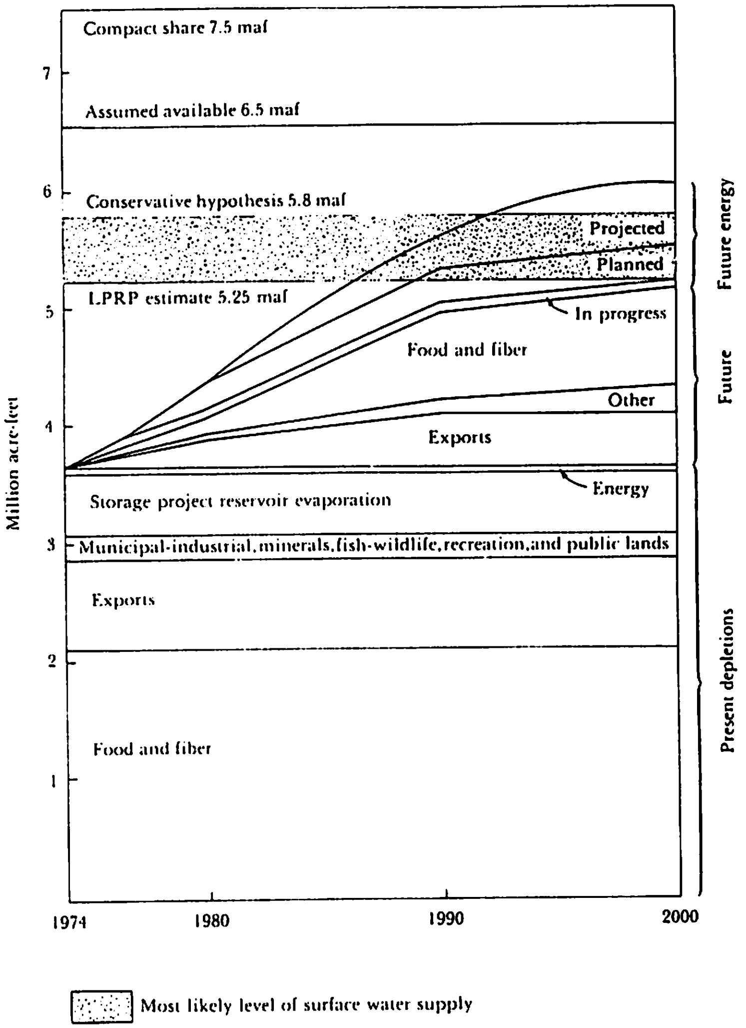

Figure 5.2. Surface water available for consumptive use, Upper Colorado River Basin (Weatherford and Jacoby, 1975, fig. 1, p. 186).

Figure 5.2. Naturally, these average figures do not preclude shortages during extreme drought or in local drainage basins.

The fact that the Upper Basin is not fully consuming the available water does not mean that the water is unused. The river's average flow is fully used, and indeed in a typical year no flow whatsoever reaches the river's original terminus, the Gulf of California.

As further development takes place in the Upper Basin, some of the current Lower Basin uses of water will have to be foregone. Southern California is a prime candidate to give up water use, because the state has a legal right to only 4.4 maf per year although it currently uses 5.2 maf per year. These reductions will not be without cost. It has been calculated that the direct opportunity cost of marginal withdrawals of water from agriculture in southern California ranges from $6.50 to $30 per acre-foot (Vaux and Howitt, 1984); regional income effects might range up to $200 per acre-foot, depending upon the availability of substitute commodities as inputs into the agricultural and food-processing industries and the mobility of resources outside agriculture (Howe and Easter, 1971, updated). Additional water demands in the Upper Basin could also be met through reductions in current water uses in the Upper Basin itself.

We now know that the virgin flows of the Colorado River have been highly variable. Figure 5.3 shows Stockton's reconstruction of 400 years of annual runoff measured at Lees Ferry, Arizona. The filtered series in Figure 5.3 exhibits significant persistence, that is, sequences of years of positive deviation from the long-term mean (about 13.5 maf per year) followed by sequences of negative deviations. Table 5.1 gives estimated average virgin flows at Lees Ferry for various periods.

It is clear from these data that above-average or below-average flow can persist for 10 to 20 years, that is, for significant parts of the intended lifetime of a large water project. Given the current impossibility of long-term climate prediction, it is difficult to specify any one number as the average flow to use for planning purposes. Rather, attention must be paid to the nature and range of climatological variability likely to be faced and to the flexibility of the system being planned.

Accompanying the growth of water use in the Upper Basin has been a deterioration of water quality in the form of a rising trend of total dissolved solids (TDS). Current TDS levels at Imperial Dam in the Lower Basin average 850 parts per million, and they are predicted to rise to 1,100 parts per million by the year 2000 in the absence of a more effective salinity control program (Bureau of Reclamation, 1983a). Current TDS levels are 59 percent attributable to natural point and diffuse sources, 30 percent to agricultural return flows, and 11 percent to municipal-industrial uses and out-of-basin transfers. A major program of salinity reduction is being planned and carried out by the Bureau of Reclamation. The program involves control of several major natural point sources and increased efficiency of water use in the agricultural sector in the Upper Basin. Some agricultural areas are shallowly under-

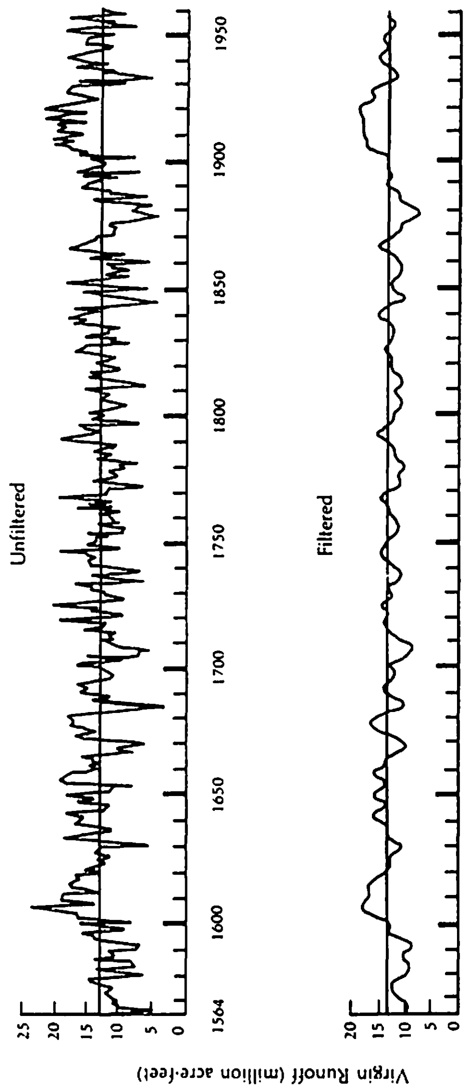

Figure 5.3. Tentative 400-year reconstruction of annual runoff at Lees Ferry, Arizona, 1564–1960 (Jacoby, 1975, fig. 4).

Table 5.1. *Estimated average annual virgin flows at Lees Ferry, Arizona*

Period	Flow (maf)	Remarks
1896–1968	14.8	Federal estimates
1896–1929	16.8	34-year wet period
1930–1968	13.0	38-year dry period
1914–1923	18.8	10-year wettest period
1931–1940	11.8	10-year driest period
1917	24.0	Greatest 1-year flow
1934	5.6	Smallest 1-year flow

Source: Dracup, 1977, p. 121.

lain by salt deposits and are estimated to contribute as much as 10 tons of salt per acre per year. Damages from increased salinity concentrations in the Lower Basin are estimated at approximately $493,000 per milligram per liter per year (Gardner, 1983). It takes approximately 10,000 tons of TDS in the Upper Basin to raise the concentration at Imperial Dam 1 milligram per liter per year, but salinity concentrations are also raised by consumptive uses and water exports. Thus, it is clear that further Upper Basin development will have significant water quality and quantity effects downstream.

Relationships among land forms, land uses, and water systems

Natural land forms, geological structures, land cover, and patterns of land use affect hydrologic patterns, including runoff, infiltration, wind and water erosion, sedimentation, dissolved solids, and other chemical properties of water. Land management measures can be utilized to improve hydrologic characteristics of the basin: agricultural practices can reduce erosion and salinity in return flows, forestry practices can affect snowpack and runoff, reseeding and reforestation of denuded areas can increase infiltration and reduce erosion, grazing controls can help maintain a healthy turf and reduce soil compaction, and controls over recreational activities can prevent excessive disruption of land cover. Management programs in the Upper Colorado Basin are facilitated by the fact that roughly 75 percent of the land area is public land (Upper Colorado Region Group, 1971). Figure 5.4 shows the approximate patterns of land ownership, administration, and vegetal cover, and Table 5.2 gives estimates of the total runoff, sediment, and salt loads from the public lands in Colorado, Wyoming, and Utah. Clearly, land management policies on the public lands are important factors in determining water quality and quantity in the Upper Basin.

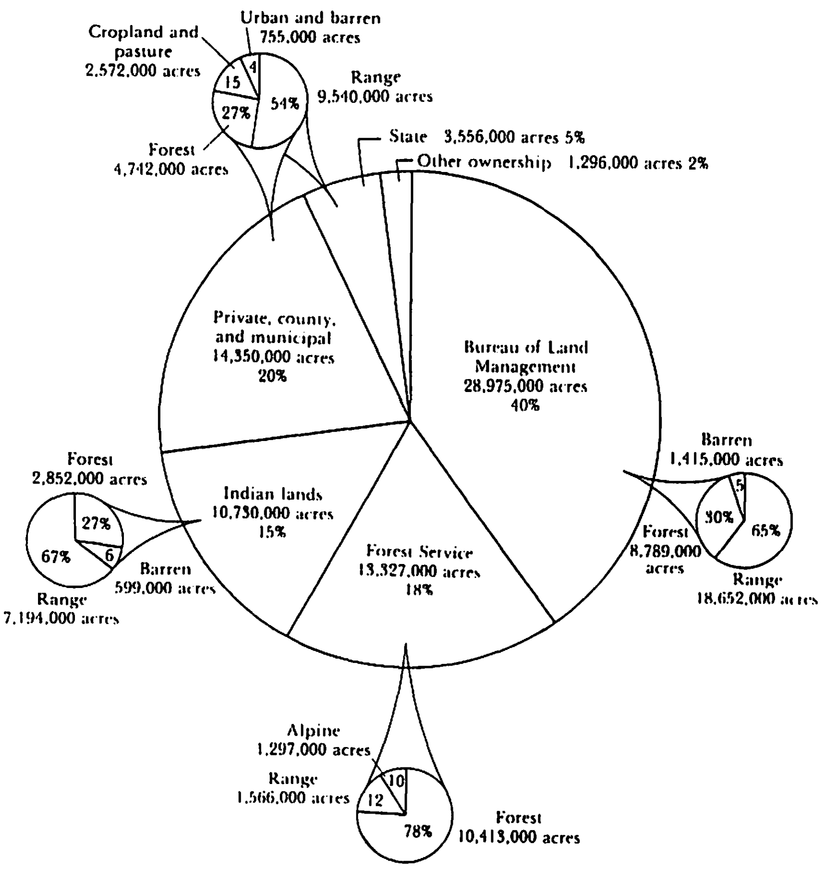

Figure 5.4. Land ownership, administration, and major vegetal cover types, Upper Colorado region (Upper Colorado Region Group, 1971, app. VIII).

Legal and institutional history of the Colorado Basin

The institutional framework for decision making in the Upper Basin consists of state law and a sequence of compacts and national laws that have evolved over the past 60 years to deal with perceived problems and development opportunities. The key compacts and federal laws, each of which significantly affects the management of Upper Basin water today, are listed and described below. Elaboration on this history is found in Hundley (1986).

The Colorado River Compact, 1922 (Meyers, 1966). The compact was ratified in 1922 by all states except Arizona. The major provisions are to (1) define Lees Ferry, Arizona, as the dividing point between the Upper and Lower basins; (2) limit the Upper Basin to 7.5 maf of beneficial consumption use per year; (3) limit the Lower Basin to 8.5 maf of beneficial consumptive use per year; (4) require the release from the Upper Basin of at least 75 maf over every ten-year interval; (5) require the two basins to share equally any future Mexican delivery requirement not met by surplus waters; and (6) forbid the Upper Basin from withholding any water that could not reasonably be applied to domestic and agricultural use.

Table 5.2. *Summary of estimated total runoff, sediment, and salt produced from public lands in the Upper Basin, by state*

	Salinity class			
	Highly saline	Moderately saline	Slightly saline	Total
Colorado				
Runoff (acre-feet)	7,600	17,900	287,000	312,500
Sediment (tons/yr)	897,000	986,000	8,099,000	9,982,000
Salt (tons/yr)	34,400	19,400	113,000	166,800
Utah				
Runoff (acre-feet)	36,900	40,000	445,000	521,900
Sediment (tons/yr)	4,363,000	2,210,000	12,550,000	19,123,000
Salt (tons/yr)	167,000	43,600	176,000	386,600
Wyoming				
Runoff (acre-feet)	7,000	21,300	201,000	229,300
Sediment (tons/yr)	831,000	2,449,000	5,658,000	8,938,000
Salt (tons/yr)	31,900	33,300	79,300	144,500
Total of three states				
Runoff (acre-feet)	51,500	79,200	933,000	1,063,700
Sediment (tons/yr)	6,091,000	5,645,000	26,307,000	38,043,000
Salt (tons/yr)	233,300	96,300	368,300	697,900

Source: Bureau of Land Management, 1977, p. 14.

The Boulder Canyon Project Act, 1928. This act provided for the construction of Boulder (later Hoover) Dam for Lower Basin water supply, flood control, and electric generation. As *quid pro quo* for the Upper Basin, the act provided for the study of the development of Upper Basin water. The result was the *Krug Report* of 1946, which identified the projects included in the 1954 Colorado River Storage Project.

The treaty with Mexico, 1944. To resolve long-standing conflicts with Mexico and to effect President Roosevelt's Good Neighbor

Policy, a treaty was signed in 1944 that guaranteed Mexico a minimum of 1.5 maf annually. Significantly, the treaty did not cover water quality.

The Upper Basin Compact of 1948. As noted in the *Krug Report*, the federal government felt it important that interstate divisions be clarified to facilitate long-term planning. Although this order of events seems backwards, it appeared unlikely that substantial federal aid for further water development would be forthcoming until basin waters were divided. The states agreed to a percentage allocation of annual available water: Colorado, 41.75 percent; Utah, 23 percent; Wyoming, 14 percent; New Mexico, 11.25 percent; and Arizona, a fixed 50,000 acre-feet per year.

Colo more 51?

The Colorado River Storage Project Act, 1956. This act was intended to provide for development of the Upper Basin waters in the way that Boulder Dam had controlled Lower Basin waters. Its passage involved the first major environmental fight over a dam proposed for Echo Park in Dinosaur National Monument. That dam was deleted from the final authorization that included Flaming Gorge in Wyoming; Blue Mesa, Morrow Point, and Crystal in Colorado; Navajo in New Mexico; and Glen Canyon in Arizona. (See Figure 5.1.)

? Crystal later

The Colorado River Basin Project Act, 1968. This act authorized the Central Arizona Project (CAP), long sought by Arizona as a way of transferring water from the Colorado to central Arizona, where groundwater was being overdrawn some 5 maf annually. Although such a project had been studied for decades, the economics was so poor that only a huge federal subsidy could ever pay for the project. Major environmental fights occurred over proposed power dams in Bridge and Marble canyons, revenues from which would presumably (in a bookkeeping sense) help to pay for the CAP. A large thermal power plant was finally included for this purpose.

In addition to authorizing the CAP, this act included the following steps that further defined or constrained development of the river: (1) assigning priority to California's 4.4 maf, so that Arizona would have to absorb any shortages that might occur from shortfalls of Upper Basin deliveries; (2) authorizing various Upper Basin projects and Hooker Dam on the Gila; (3) declaring the Mexican treaty obligation a national obligation to be satisfied (at federal expense) from any *future* supply augmentation plans; (4) forbidding any federal studies of importation of water from other river basins (to placate the fears of Columbia River Basin interests); (5) authorizing Upper Basin retention of waters not needed to satisfy compact and Mexican obligations to build up reservoir stocks sufficient to give reasonable protection to the Upper Basin's established consumptive uses; and (6) requiring approximate equality in the volumes of water in storage in Lake Powell and Lake Mead (Glen Canyon and Hoover dams).

Up Bsn Concept

To obtain aid from national programs in competition with other regions, a consensus among basin states was necessary. The potential magnitude of federal aid outweighed any gains likely from one state's taking advantage of its neighbor. Federal aid changed a zero-sum game into a positive-valued game for the Colorado Basin states. Obtaining consensus meant agreement on policies and projects, such as rules for distributing the river's waters and locating major storage projects. The effectiveness of the policies and projects chosen much depended on the true climatological and hydrologic regimes of the region, about which little was known at the time of many key decisions. Yet, the consensual process had to continue once it began, even when the scientific data base and desired study results were not at hand. The political costs of failure were perceived to be greater than any likely economic or physical inefficiencies that might result from decisions based on inadequate data.

In spite of the complex legislative history summarized above, no river basin agency has management responsibility for the entire basin. Water has been legally allotted to individual states. This institutional setting has the following effects: (1) states with claims to water in excess of their current uses are eager to put this water to use regardless of efficiency considerations lest some change of law or adverse political alignments deprive them of their unused water, (2) it appears doubtful that water can be reallocated among states or between Upper and Lower basins without substantial changes in existing laws and compacts, and (3) states tend not to be concerned with the downstream quantity and quality effects of their actions.

Hydrology, water use patterns, and the value of water in the subbasins of the Upper Colorado River Basin

The first objective of this section is to characterize the surface hydrology of the eight principal subbasins of the Upper Basin by looking at the average surface outflows and the average net surface outflows, the latter defined as water originating in that subbasin less that subbasin's consumptive use. Each subbasin generates substantial net outflows that, on the average, total 11,145,000 acre-feet per year for the entire Upper Basin. If the obligation to the Lower Basin of 7.5 maf annually and half Mexico's obligation, 0.75 maf, are subtracted, the result is an average annual Upper Basin surplus of 2,894,000 acre-feet. Of course, these outflows are variable year by year, and this variability and its relation to the risks facing potential users are an important issue.

The second objective of this section is to describe patterns of consumptive water use in the Upper Basin. Because more than 90 percent of all water consumption is in agriculture and 65 percent of agricultural consumption is in the growing of low-value feed grain and forage crops, attention is directed to those low-value agricultural uses, involving an average of 1.6 maf per year.

A third objective is to estimate the values of this water to the farmer and to the state where the farming operation is located. From a slightly different viewpoint, the farmer's income per acre-foot consumed represents the price at which a farmer is likely to consider selling water. Among the low-valued crops considered, the highest net farm income per acre-foot is $72, with an average of about $25 per acre-foot. However, state income generated directly and indirectly ranges from $75 per acre-foot consumed in Subbasin 1 (Wyoming) to $160 per acre-foot consumed in Basins 5 (Colorado) and 8 (Utah) assuming a permanent shutdown of directly and indirectly linked activities – a worst case scenario. Thus, the effects of reallocating water from agricultural to nonagricultural uses may be seen quite differently by the individual farmer and the state government.

Further, water has quite significant values when left in the stream. The purposes served by increasing Upper Basin instream flows include better water quality, recreation, fish and wildlife values beyond their recreational values, hydroelectric generation, and more agricultural production in the Lower Basin. Estimates of these values make it clear that instream values today exceed the income-producing values to the farmer, and in some cases they significantly exceed the total income-producing value to the state. These findings have important implications for the desirable and likely patterns of future water use.

Hydrology of the subbasins

Wyoming, Colorado, Utah, and New Mexico all lie partly within the Upper Colorado River Basin. The three main subbasins, the Green, the Upper Main Stem of the Colorado, and the San Juan, are divided into smaller subbasins for analytical purposes in this paper. These subbasins are described in Table 5.3.

Table 5.3. *Characteristics of the subbasins of the Upper Colorado River Basin*

Subbasin	Name	Primary state	Counties included	Outlet gauging station, USGS[a]	Major reservoirs
1	Green River to Flaming Gorge	Wyoming	Sublette, Lincoln, Uinta, Sweetwater	9-2345	Fontenelle, Flaming Gorge
2a	Yampa River	Colorado	Routt, Moffat	9-2510	None
2b	White River	Colorado	Rio Blanco	9-3065	None
3	Green River above Colorado River	Utah	Carbon, Daggett, Duchesne, Emery, Uintah	9-3070	None
4	Gunnison	Colorado	Delta, Hinsdale, Gunnison, Ouray	9-1525	Blue Mesa, Morrow Point, Crystal
5	Upper Main Stem, Colorado	Colorado	Garfield, Grand, Eagle, Mesa, Pitkin, Summit	9-1635	None
6	Dolores	Colorado	Grand (Utah) Dolores, Montrose, San Miguel	9-1800	McPhee
7	San Juan	Colorado	Archuleta, La Plata, San Juan (New Mexico), San Juan, Montezuma	9-3795	Navajo
8	Colorado above Lees Ferry	Utah	Garfield, Kane, San Juan, Wayne	9-3800	Glen Canyon

[a] USGS = U.S. Geological Survey.

Table 5.4. *Monthly median discharges of the subbasins of the Upper Colorado River Basin*[a] *(thousand acre-feet)*

	Subbasin								
	1	2a	2b	3	4	5	6	7	8
Oct.	926	217	320	1,597	809	2,570	98	845	5,935
Nov.	969	217	287	1,604	865	2,681	99	669	5,387
Dec.	925	194	252	1,316	712	2,418	97	542	4,581
Jan.	843	177	252	1,255	645	2,069	103	508	4,110
Feb.	936	208	273	1,708	658	2,273	133	805	5,102
Mar.	1,012	407	383	2,627	797	2,397	181	1,023	6,629
Apr.	1,293	1,815	427	4,761	1,820	3,492	979	2,046	11,528
May	1,436	4,571	1,096	8,949	4,923	8,942	1,557	3,399	19,905
June	2,310	3,993	1,347	12,355	4,957	12,123	978	3,308	28,847
July	1,768	867	435	4,005	1,486	3,580	239	1,294	11,644
Aug.	1,392	246	327	1,897	746	2,226	160	968	8,115
Sept.	1,145	143	286	1,347	697	2,154	94	779	6,123

[a] The years between 1963 and 1983 are not reported for Subbasin 8 because filling Lake Powell (begun in 1963, with full capacity reached in 1983) caused the measured flows at Lees Ferry to diminish significantly. Observations for Subbasin 3 cover only 1951–1966 because the gauging station at Green River near Ouray, Utah, was discontinued in 1967.

Source: U.S. Geological Survey, Water Resources Division, Colorado District.

The hydrology of each of the eight subbasins can be partially represented by the median monthly outflows in acre-feet from the subbasin. (See Table 5.4.) The monthly discharges represent the flow that is met or exceeded 50 percent of the time in the water year. The basin outlet gauging stations for each subbasin are identified in Table 5.3. Computations are based on all daily values available, and sample sizes range from 18 to 84 years.

In a quantification of the water that might still be available for new uses, it is useful to estimate the amount of water that originates in and flows unused from each of the eight subbasins. This is water that would be available for out-of-basin uses without diminishing existing uses. Subbasins 1, 2, 4, and 7 are headwater basins that receive no water from other basins. Subbasin 6 is drained primarily by the Dolores River and can thus be considered a headwater basin, although a 30-mile segment of the Colorado main stream runs through the basin in Grand County, Utah. Subbasins 3, 5, and 8 receive water from Basins 1 and 2; 4; and 3, 5, 6, and 7, respectively. These inflows are netted out to compute the net increment to the flow from within the basin. Mean annual net discharges and their standard deviations for the eight subbasins are presented in Table 5.5. (These means and standard deviations are calculated over

different periods of record, so their sum is not the true time average of outflows.)

The sum of 11,144,926 acre-feet indicates that the states of the Upper Basin are far from fully utilizing their compact-apportioned waters. It also indicates that a potentially sizable amount of water is available for out-of-basin use without impairing existing uses. Subtracting required Lower Basin deliveries indicates excess outflows that the Upper Basin is entitled to consume. Potential out-of-basin users of these excess waters would surely be interested in the reliability of the supplies: more reliable supplies are certainly more valuable and would command a higher price in a water market. Those who need only supplemental water would not be as concerned about the reliability of the flow and would be willing to pay only a lower price for the water. The reliability of these subbasin net discharges can be pictured with a frequency distribution like Figure 5.5 (for Subbasin 1) or by statistical measures like the standard deviation and coefficient of variation.

Agricultural water uses and values

Agriculture and agriculturally related activities are the largest consumers of water in the Upper Basin. Livestock production is a dominant economic activity in the basin, to which agriculture plays a supportive role. Here the water consumed is quantified by the large-volume, low-value feed and forage crops of the basin. Alfalfa, barley, wheat, oats, corn grain and silage, potatoes, and pasture represent the predominant

Table 5.5. *Mean annual net outflows and standard deviations for the subbasins of the Upper Colorado River Basin (thousand acre-feet)*

Subbasin	Mean	Standard deviation	Coefficient of variation
1	1,512	569	0.38
2a	1,094	350	0.32
2b	503	150	0.30
3	930	476	0.51
4	1,843	670	0.36
5	2,615	893	0.34
6	581	373	0.64
7	1,657	821	0.50
8	405	217	0.54
Total mean outflow	11,140		
Less required deliveries	−8,250		
Excess water	2,890		

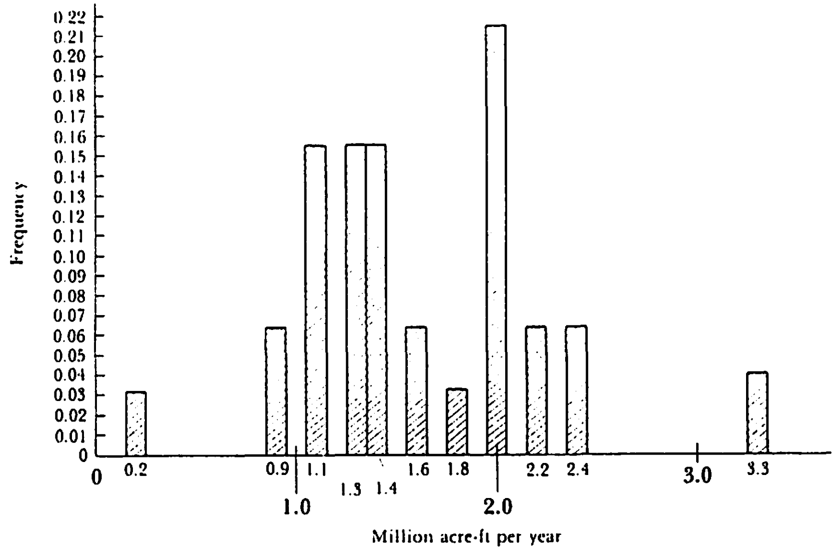

Figure 5.5. Frequency distribution of net discharges, Subbasin 1.

Table 5.6. *Irrigated acreages by crop, Upper Colorado River Basin*

Sub-basin	Alfalfa	Barley	Wheat	Oats	Corn Grain	Corn Silage	Potatoes	Pasture	Total
1	6,139	14,778	0	934	0	0	0	107,985	129,836
2	16,573	18	633	470	0	0	0	29,478	47,172
3	68,215	6,060	1,981	3,537	1,803	10,871	117	102,547	195,131
4	23,885	1,790	975	1,015	3,930	3,693	0	45,809	81,097
5	66,414	376	5,397	2,160	10,000	4,646	83	81,534	170,610
6	27,552	4,903	2,513	1,299	9,495	7,946	56	36,870	90,634
7	58,828	601	1,716	1,738	256	2,309	10	65,200	130,658
8	22,354	2,238	35	941	0	94	21	15,565	41,248
Total	289,960	30,764	13,250	12,094	25,484	29,559	287	484,988	886,386

uses of irrigation water in the basin. The crops are primarily forage and feed for livestock. Irrigated acres by crop are given in Table 5.6.

Total consumptive uses for each crop in each basin have been computed using Narayanan, Padungchai, and Bishop's (1979) data on consumptive use (acre-feet per acre per year; see Table 5.7) and the acres irrigated (U.S. Department of Commerce, 1982). The crops shown in Table 5.8 represent a total of 886,386 irrigated acres and consumptive use of 1,566,205 acre-feet of water per year, roughly 25 percent of the Upper Basin's compact-apportioned water.

Table 5.7. *Consumptive water use, Upper Colorado River Basin (acre-feet per acre per year)*

Subbasin	Alfalfa	Barley	Wheat	Oats	Corn Grain	Corn Silage	Potatoes	Pasture
1	1.77	1.2	0.00	1.6	0.00	0.00	0.00	1.75
2	1.61	1.2	1.67	1.6	0.00	0.00	0.00	1.70
3	1.77	1.2	1.67	1.6	2.08	1.4	1.75	1.80
4	1.67	1.2	1.67	1.6	2.08	1.3	0.00	1.70
5	1.67	1.2	1.67	1.6	2.08	1.3	1.83	1.70
6	2.50	1.4	1.67	1.6	2.08	1.8	1.83	2.20
7	1.57	1.3	1.67	1.6	2.08	1.8	1.83	2.00
8	1.57	1.3	1.67	1.6	0.00	2.08	1.83	2.00

Table 5.8. *Consumptive water use by crop, Upper Colorado River Basin (thousand acre-feet per year)*

Subbasin	Alfalfa	Barley	Wheat	Oats	Corn Grain	Corn Silage	Potatoes	Pasture	Total
1	11	18	0	2	0	0	0	189	219
2	27	1	1	1	0	0	0	50	79
3	121	7	3	6	4	15	I	185	340
4	40	2	2	2	8	5	0	78	136
5	111	1	9	4	21	6	I	139	289
6	69	7	4	2	20	14	I	81	197
7	92	1	3	3	1	4	I	130	234
8	35	3	1	2	0	1	I	31	71
Total	506	38	22	19	53	45	I	883	1,566

I = insignificant volume.

What is the value of this water? For the farmer, the value is the net return to water per acre-foot consumptively used. Consumptive use is the relevant measure because water transfers are generally limited by the water courts to that volume. Farm budget data (Narayanan et al., 1979), data on consumptive use (Table 5.7), crop yields per acre for the eight selected crops (Table 5.9), crop prices (Table 5.10), and production costs (Table 5.11) permit the calculation of the net return to water in dollars per acre-foot consumed. The data have been updated to 1982 through the use of U.S. Department of Agriculture (USDA) price and cost indices.

Table 5.9. *Annual crop yield per acre of irrigated land, Upper Colorado River Basin*

Subbasin	Alfalfa (ton)	Barley (bushel)	Wheat (bushel)	Oats (bushel)	Corn Grain (bushel)	Corn Silage (ton)	Potatoes (hundred weight)	Pasture (animal unit months)
1	3.25	50.0	0.00	50	0.00	0.00	0.00	4.5
2	3.10	50.0	50	50	0.00	0.00	0.00	6.8
3	3.35	62.5	50	62	55.43	12.50	106.30	6.8
4	3.35	55.0	50	50	99.80	16.44	0.00	6.8
5	3.35	57.0	50	50	97.58	15.38	145.70	6.8
6	3.85	62.0	50	50	87.64	17.72	212.38	6.8
7	3.08	50.0	50	50	87.64	11.80	90.25	6.8
8	3.08	62.5	50	62	0.00	10.75	156.25	6.8

Table 5.10. *Crop prices, Upper Colorado River Basin, 1982 (dollars per unit)*

	Alfalfa (ton)	Barley (bushel)	Wheat (bushel)	Oats (bushel)	Corn Grain (bushel)	Corn Silage (ton)	Potatoes (hundred weight)	Pasture (animal unit months)
Colorado	62.08	2.46	3.40	1.70	2.64	19.75	3.2	12.27
New Mexico	81.08	2.06	3.58	NA	2.87	19.75	3.2	12.27
Utah	66.67	2.06	3.55	1.70	3.27	19.75	3.2	12.27
Wyoming	55.92	2.42	3.55	1.62	3.04	19.75	3.2	12.27

NA = not applicable.

Table 5.11. *Estimated annual cost of production, Upper Colorado River Basin (1982 dollars per acre)*

Subbasin	Alfalfa	Barley	Wheat	Oats	Corn Grain	Corn Silage	Potatoes	Pasture
1	131.10	225.01	0.00	69.35	0.00	0.00	0.00	21.06
2	134.00	119.03	138.72	69.35	0.00	0.00	0.00	24.58
3	127.73	144.32	138.72	69.35	155.03	168.31	333.71	24.58
4	138.84	119.03	138.72	69.35	180.27	219.73	0.00	24.58
5	138.84	119.03	138.72	69.35	176.24	219.73	457.50	24.58
6	185.25	230.70	138.72	69.35	158.30	219.73	666.90	24.58
7	143.74	119.03	138.72	69.35	158.30	219.73	283.36	24.58
8	113.03	176.56	138.72	69.35	0.00	168.31	490.63	24.58

Table 5.12. *Net return on water consumptively used, Upper Colorado River Basin (dollars per acre-foot)*

Subbasin	Alfalfa	Barley[a]	Wheat	Oats	Corn Grain	Corn Silage	Potatoes	Pasture
1	28.67	−86.68	0.00	7.28	0.00	0.00	0.00	21.95
2	36.30	3.31	18.73	9.78	0.00	0.00	0.00	36.65
3	54.02	9.92	23.22	22.53	12.61	56.08	3.69	34.61
4	41.40	13.56	23.22	9.78	40.00	3.82	0.00	36.65
5	41.40	17.66	23.22	9.78	39.12	64.64	4.78	36.65
6	10.61	−55.84	23.22	9.78	41.76	72.36	6.95	28.32
7	48.87	3.05	23.22	9.78	35.13	7.40	2.97	31.15
8	58.80	−15.62	18.73	22.53	0.00	21.15	5.12	31.15

[a] Negative returns to barley occur when it is used as a nurse crop for alfalfa.

The cost data include all relevant variable and fixed production costs, including an allowance for family farm labor and the opportunity costs of management. Thus, the estimated net return per acre of irrigated land for each of the eight crops represents a pure return to water. Dividing the estimated net return by the amount of water consumptively used, the average net return per acre-foot of water consumed is derived (Table 5.12). Several biases affect this figure. First, some cropping operations are integrated with cattle operations. The integrated operation should be budgeted as a unit. Doing so would probably increase some values per acre-foot of consumption. Unfortunately, no information on farm structure is available for the region. Second, conservation measures such as reduced water application initially affect yields very little. As conservation steps are increased in intensity, their costs increase. Therefore, our figures *overstate* the values of initial quantities of water that might be withdrawn from crop irrigation. Further, if water were to be partially withdrawn from some of these cropping operations, a rational response by the farmer would be to change cropping patterns. All these steps could be included in a programming approach to derive more accurate value figures (for example, see Gisser et al., 1979). A programming approach was not feasible for this study.

In Table 5.13, consumptive uses in acre-feet are ranked according to the net crop values of Table 5.12. Crop 1, crop 2, etc., are different for each basin. In Subbasin 4, for example, water exhibits its lowest net value when used in the cultivation of corn for silage. If farmers in this area were offered more than $4 per acre-foot for their water, it is likely that they would stop raising corn for silage, and each year about 5,000 acre-feet of water would be available for other uses. If the offer price for

Table 5.13. *Direct farm income per acre-foot of consumptive use, by crop, in ascending order, with cumulative thousand acre-feet*

					Corn			
Subbasin	Alfalfa	Barley	Wheat	Oats	Grain	Silage	Potatoes	Pasture
1	$1	$7	$22	$29				
	18	20	208	219				
2	$3	$10	$19	$36	$37			
	I	I	2	28	79			
3	$4	$10	$13	$23	$23	$35	$54	$56
	I	8	11	17	20	205	326	341
4	$4	$10	$14	$23	$37	$40	$41	
	5	6	9	10	88	96	136	
5	$5	$10	$18	$23	$37	$39	$41	$65
	I	4	10	11	149	170	281	289
6	$1	$7	$10	$11	$23	$28	$42	$72
	7	8	9	78	82	163	183	197
7	$3	$3	$7	$20	$23	$31	$35	$49
	I	I	5	8	11	141	142	234
8	$1	$5	$19	$21	$23	$31	$59	
	3	3	3	3	5	36	71	

Total consumptive use = 1,566

I = negative value or insignificant quantity.

water were to rise to approximately $10 per acre-foot, farmers might be induced to stop producing oats, providing up to an additional 1,624 acre-feet per year for a total of 6,425, etc. This schedule constitutes a crude supply curve for water taken out of existing uses.

For the Upper Basin as a whole, combining all eight subbasins, offer prices in excess of $15 per acre-foot would lead to cessation of the production of barley, oats, and potatoes, in the longer term freeing 139,118 acre-feet per year for other uses. An offer price of $25 per acre-foot would be likely to induce farmers to drop the production of wheat, making available a total of 348,671 acre-feet per year. Further, if the offer price for water were higher than $72 per acre-foot, none of the crops presented here would likely be produced in the long run, and 1,566,200 acre-feet per year would be available for other uses.

State income effects of agricultural water use

There are sectors in the states' economies that are tied to agriculture either as suppliers (backward linkages) or as processors of agricultural outputs (forward linkages). In Colorado, for example, the food-processing sector is one of the largest sectors in the state owing primarily to the processing of meat provided by the livestock sector, which in turn is largely fed by outputs of irrigated agriculture (Gray and McKean, 1975). Taking crops out of production may affect these sectors to some extent. To what extent would the withdrawal of irrigation water in the Upper Basin affect the various state economies? State governments and the state water agencies can be expected to consider the overall effect on state income and employment, not simply the direct loss of income to the farmer, even though from a national accounting stance, these secondary income impacts may largely cancel out, with gains to other areas.

What are the determinants of the extent to which state income losses might exceed the direct loss of farm income? The following factors would be important:

- The extent to which the agricultural crops being phased out have been exported without further value added or the extent to which they have been used as inputs into other state sectors, for example, livestock;
- The extent to which substitute agricultural inputs are available through imports to sustain the agriculturally linked activities;
- Whether the water released from agriculture substitutes for costly new supply projects to service continuing state growth; and
- Whether the money from the sale of agricultural water is reinvested within the state.

If one can answer "to a large extent" to the first two items and "yes" to the remaining two, then one would expect few income losses beyond the loss of direct farm income. If the answers are "to a very small extent" and "no," one would expect fairly severe income losses beyond the farm level.

In Colorado, 92 percent of irrigated agriculture's output is used in the livestock sector, food processing, and consumption or export (Gray and McKean, 1975). The crops in western Colorado that would be phased out are primarily feed grains and forage crops, so the relevant linkage is to the livestock sector, because the rest is exported. The livestock sector, in turn, is linked to food processing. Regarding substitutes, it seems unlikely that *no* agricultural substitutes would be available from in-state or out-of-state sources. It is assumed here that half the reduction in agricultural outputs could be substituted from such sources.

Western Colorado has a surfeit of water overall (although some localities experience shortages), but eastern Colorado will provide a ready market for agricultural water from the Colorado Basin through sequences of exchanges, if not by direct transmission. It seems likely that waters withdrawn from agriculture are likely to substitute for expensive

Table 5.14. *State income lost on the average per acre-foot of reduced consumptive use: worst case scenario with forward linkage to feeding livestock and processing food*

Subbasin	Income lost
1	$ 75
2	90
3	149
4	151
5	160
6	145
7	137
8	160

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new in-state projects. On the other hand, it seems unlikely that the money from water sales will be reinvested in Colorado, certainly not in western Colorado.

Thus, state income impacts beyond direct loss of farm income would range from moderate for in-state sales of water to fairly severe for out-of-state sales. The statewide income impacts are estimated for a worst case scenario.

The methodology for estimating these direct and indirect income losses is complicated by the absence of appropriate models. As water is progressively withdrawn *from* agriculture, farmers substitute other inputs (labor, capital) for water, and they adjust their cropping patterns and their total acreage. These adjustments result in a nonlinear response of farm income to water withdrawal. A detailed programming model is needed to approximate the kinds of decisions that would be made by a profit-maximizing farmer.

The models that are available are state input-output (I-O) models for Colorado and Utah. (None is available for Wyoming.) I-O models are fixed coefficient models that imply no substitution possibilities. However, they do present the historical interrelationships among the sectors of the state economy. If used with good judgment and an acquaintance with the workings of the state economy, the I-O models can provide reasonable approximations of statewide effects.

The sequence of steps in the analysis is as follows: (1) a reduction in irrigated output is postulated, (2) the reduction is divided into reductions in deliveries to final demand (consumption or export) and reductions in inputs into the livestock sector, (3) reductions in livestock output are calculated and treated as reductions in inputs into the food-processing sector, (4) all reductions in food-processing output are treated as reductions in deliveries to final demand, and (5) all reductions in deliveries to final demand are "run through" the I-O model to obtain the total reduction in payments to households, insurance, real estate, rent, interest, and profits. The average result for Colorado and Utah is that a $1 reduction in irrigated agricultural output leads to a $1.80 reduction in state incomes. The results are given in Table 5.14. These state income losses should be compared with the direct on-farm income losses shown in Table 5.13. The higher state income losses are likely to lead to state resistance to private out-of-state water sales.

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The value of water in instream uses

Values of water consumed in agriculture to the farmer and to the state economy have been estimated. Naturally, some of this water will be bid away from agriculture for other uses, either inside or outside the Upper Basin itself. However, the water would generate quite substantial values if left in the stream: in hydroelectric power generation, in recreation, in maintaining higher water quality, and in downstream consumption. In many cases, these values far exceed the value to the farmer, and in some cases they exceed state income losses that would follow from withdrawing the water from agriculture.

The doctrine of beneficial use in western water law generally does not allow the appropriation of water rights for instream uses of water. However, hydroelectric power generation is treated as a nonconsumptive diversion use for which water can be appropriated. Federal installations have not filed for such flow rights. The value of water in hydroelectric production is the value of the marginal electric power produced by an acre-foot of water. Reservoir releases are generally managed so that most of the water passing through the reservoir is used in hydroelectric production.

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The Colorado River Storage Project (CRSP) provides for developing the Upper Basin's compact-apportioned waters while still meeting its flow obligations at Lees Ferry, Arizona. Four storage units, Flaming Gorge, Wayne Aspinall (formerly Curecanti, consisting of Blue Mesa, Morrow Point, and Crystal), Glen Canyon, and Navajo, were authorized to provide long-term regulatory storage. The reservoirs created by the CRSP have a combined storage capacity of 34 maf (Water and Power Resources Service, 1981, p. 355). All but one of the units, Navajo, create hydroelectric power. The power-producing units are located in Subbasins 1, 4, and 8. A complex transmission system has been provided for the electricity created by the CRSP. Data on the energy generated and the revenues from sale to electric utilities were obtained from the Bureau of Reclamation's *Annual Report* (1981, app. III). Average revenue

? What is baseline avoided cost estimate ?

from electricity sales for the entire CRSP is found by dividing total revenue by the kilowatt hours sold. The average revenue from electricity sales in the Upper Basin is $0.0106 or 10.6 mills per kilowatt hour (based on 1981 data). This figure might be compared with the Bonneville Power Authority's minimum surplus power rate of 18 mills or Idaho Power's avoided cost rate for cogeneration of 44 mills (Gardner, 1985). New thermal power-generating and distribution costs are around 8.5 cents per kilowatt hour (Hamilton and Lyman, 1983). It is quite clear that Bureau of Reclamation power is substantially underpriced.

Flaming Gorge Dam is located on the Green River approximately six miles south of the Utah-Wyoming border, thus placing it in Subbasin 1. The facility's net electricity production in 1981 was 360,789,000 kilowatt hours (Water and Power Resources Service, 1981, p. 357). Total revenue accruing from electricity sales was $3,834,430. The flows available for hydroelectric production amounted to 1,042,753.6 acre-feet in 1981 (flows measured at Greendale, Utah). Thus, the marginal value of an acre-foot of water allowed to pass through the turbines in the power plant is $3.68 if priced at 10.6 mills or, more realistically, $14.72 if valued at short-run avoided cost rates.

The Aspinall Unit (consisting of Blue Mesa, Morrow Point, and Crystal dams) is located on a 40-mile segment of the Gunnison River in Subbasin 4. It is assumed that the 1981 flow of 743,600 acre-feet on the Gunnison above the North Fork (but before the substantial diversions to the Uncompaghre Valley) passed through the three dams. Blue Mesa Dam is approximately 30 miles southwest of Gunnison, Colorado. Total revenue from electricity sales of 245,859,300 kilowatt hours in 1981 was $2,625,145. Consequently, the value of an additional acre-foot of water allowed to pass through the turbines is $3.53, or $13.20 at avoided cost rates. Net electrical generation of 314,808,000 kilowatt hours at Morrow Point produced revenues of $3,362,849 in 1981. The marginal value product of water at Morrow Point Dam is thus $4.53, or $18.12 avoided cost. Crystal Dam is six miles downstream from Morrow Point Dam, near the town of Montrose, Colorado. Active capacity of the reservoir is 13,000 acre-feet (Water and Power Resources Service, 1981, p. 360). Net hydroelectric production in 1981 amounted to 159,604,400 kilowatt hours, bringing revenues of $1,808,699. The value of an acre-foot of water passing through the power plant is thus $2.43, or $9.72 avoided cost.

Glen Canyon Dam and Lake Powell are located on the mainstream of the Colorado River (Subbasin 8) approximately four miles south of the Arizona-Utah boundary and 15 miles upstream from Lees Ferry, Arizona. The lake provides the largest storage for the Upper Basin, with an active capacity of 20,876,000 acre-feet (Water and Power Resources Service, 1981, p. 355). Net hydroelectric production in 1981 was 3.8 billion kilowatt hours, and revenue was $41.3 million. Based on 8.3 maf of unused water flowing through Lees Ferry in 1981, the marginal value product of an acre-foot of water in electrical production is $4.97, or $19.88 avoided costs.

Table 5.15. *Hydroelectric power values foregone through consumptive use of 1 acre-foot in the subbasins of the Upper Colorado River*

Subbasin	Power generating stations	Value per acre-foot at: 10.6 mills/kWh	44 mills/kWh
1	Flaming Gorge	$ 3.68	$14.72
	Glen Canyon	4.97	19.88
	Hoover	2.76	11.48
		$11.41	$46.08
2, 3, 5–8	Glen Canyon	$ 4.97	$19.88
	Hoover	2.76	11.48
		$ 7.73	$31.36
4	Blue Mesa	$ 3.53	$13.20
	Morrow Point	4.53	18.12
	Crystal	2.43	9.72
	Glen Canyon	4.97	19.88
	Hoover	2.76	11.48
		$18.22	$72.40

Water that is released from Lake Powell proceeds downstream to Lake Mead in back of Hoover Dam. Enroute and during storage in Lake Mead, water is lost by evaporation and seepage, so an acre-foot released is roughly equal to 0.9 acre-feet available for release from Hoover Dam. Historically, Hoover Dam has generated about 290 kilowatt hours per acre-foot of water released (Bureau of Reclamation, 1981). Thus, the value of an acre-foot released upstream, allowed to enter Lake Mead and then released, would be 290 × 0.0106 × 0.9 = $2.76 if priced at 10.6 mills, or $11.48 valued at avoided cost. Table 5.15 summarizes the hydroelectric values calculated above as they relate to water released in each subbasin.

In addition to the hydropower values of water left in or released to the stream, recreation values can be enhanced for both stream-related and reservoir-based recreation. For stream-related recreation, the stabilization of flow at levels that enhance aesthetics and fish life is important, but both extremely high and low flows are detrimental. For reservoir-

Table 5.16. *Willingness to pay for increased flows for recreational activities on the Cache La Poudre River, Colorado, 1978*

Flow rate (cubic feet per second)	Marginal values (dollars per cubic foot per second per day)		
	Whitewater	Fishing	Shoreline
100	—	23	16
200	0.95	17	14
300	0.95	11	11
400	0.95	4	8
500	0.95	−2	6
600	0.95	−8	3
700	0.95	−15	0
800	0.95	−21	−2

Source: Daubert and Young, 1980, table 4.

related recreation, maintenance of the reservoir level, that is, avoidance of a large drawdown, is most important.

Many studies of instream flow values for fishing and shoreline activities have been carried out, but Daubert andYoung's (1980) measurement of marginal willingness to pay for increased streamflow on the Cache La Poudre River is closest to what is needed for estimating the recreational opportunity cost of water consumed in agricultural and other uses. Table 5.16 summarizes their results.

These figures show that, under some conditions, higher streamflows are highly valued for recreation, but these values depend on timing. For example, an increase above 200 cubic feet per second (cfs) during the late summer would be valued at $23 per cfs per day. Because 1 cfs maintained over a day totals 2 acre-feet, a release of 2 acre-feet per day would generate recreation values of $11.47 per acre-foot. On the other hand, added releases during spring high flows would reduce recreational values. Thus, such values are quite specific to certain river reaches, and little can be said about such values in the absence of specialized studies.

Reservoir recreation is also valuable. Howe et al. (1982) estimated the worth of reservoir recreation along the Denver–Fort Collins corridor at $18.75 per person per day. Values at a unique site such as Lake Powell may well be even higher in spite of the lake's remote location. Again, such values are highly site specific. However, the issue for this study is the *marginal* effect of added streamflow. In dry years, increased flows would reduce reservoir drawdown, adding to recreational values, but in wet years, the water would simply be passed through the reservoir. On

the average, however, the additional water would have some value, but no specific studies are available for the Upper Basin.

The other quite important instream value stems from the increases in water quality that would result from reductions in Upper Basin consumptive uses. As explained in detail in the following section on water quality issues, the removal of high-quality (low total dissolved solids) water in the Upper Basin increases the TDS concentration downstream in two ways: the removal of low TDS water reduces the dilution factor for the lower-quality waters downstream, and the return flows from the water, if any, may be high in TDS, thus increasing the overall TDS concentration.

The average salinity of the river at its source is 50 milligrams (mg) per liter; at Imperial Dam, the last major diversion point before it reaches Mexico, it is more than 800 mg per liter. The Bureau of Reclamation estimates that 59 percent of the salinity concentration at Hoover Dam emanates from natural sources (saline springs, erosion of sediments, and the concentrating effects of evaporation and transpiration), and 41 percent comes from man-made causes (irrigation applications, municipalities and industry, and out-of-basin transfers) (Bureau of Reclamation, 1983a). Of the man-made sources of salinity, roughly 72 percent (or 30 percent of the total) can be attributed to the extensive irrigated agriculture within the basin.

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Most of the damages attributable to high salinity concentrations are borne by the water users in the Lower Colorado River basin. The extremely high salt load of 9 million tons annually entering Lake Mead adversely affects more than 12 million people and about 1 million acres of irrigated farmland (Bureau of Reclamation, 1983a). Total (direct plus indirect) agricultural damages in the 875–1,100 mg per liter range (the hypothesized salinity values with and without control) are estimated at $121,969 per mg per liter per year; municipal impacts have been estimated at $371,000 per mg per liter per year. Thus, total damages to the Lower Basin are $492,969 per mg per liter (Gardner, 1983). The Bureau of Reclamation estimates total damages (agricultural, municipal, and industrial) at $561,000 (1984 dollars) per mg per liter increase at Imperial Dam. Annual municipal damages, 70 percent of total damages, are allocated as follows: Metropolitan Water District, 54 percent; Central Arizona Project, 8 percent; and lower main stem users, 8 percent (U.S. Department of the Interior, 1985, p. 15). Damages to agriculture account for the remaining 30 percent.

Consider first the effects of consumptively using (or exporting) water in (from) the Upper Basin at some point where the TDS concentration is

Table 5.17. *Instream values per acre-foot of reduced consumptive use in the Upper Colorado River Basin*

Subbasin	Water opportunity cost in Lower Basin	Salinity damages averted	Power value at 44 mills	Total
1	$30	$ 38	$46	$114
2, 3, 6–8	30	38	31	99
4	30	38	72	140
5	30	280	31	341

100 mg per liter. One acre-foot contains approximately 0.136 tons of dissolved solids. The approximate *change* in TDS concentration at Imperial Dam is then 0.000078 mg per liter per acre-foot. Using Gardner's damage figures, the removal of 1 acre-foot would cause $38.50 in Lower Basin damages.

Now consider the effects of consumptively using an acre-foot in crop irrigation in the Grand Valley of Colorado, on the Colorado River main stem. With a consumptive fraction of about 50 percent in that area, this consumptive use would be accompanied by a 1 acre-foot return flow. Return flows in the area average a TDS concentration of 4,200 mg per liter (Soil Conservation Service, 1977, p. 49), or 5.7 tons per acre-foot of return flow. The resulting change in the TDS concentration at Imperial Dam is approximately 0.00057, or added damage of $281 to Lower Basin users.

In addition to the instream values mentioned above, there is the opportunity cost of the water to downstream users in the Lower Basin. Vaux and Howitt (1984) estimated these costs as in the $8–$30 per acre-foot range; Howe and Young (1978) estimated a $30 value. The sum of all these foregone values is shown by subbasin in Table 5.17. Thus, it seems clear that the values generated by leaving water in the stream considerably exceed many of the values generated on-farm in agriculture. (See Table 5.13.)

Water quality issues in the Colorado Basin

The previous section discussed costs to the Lower Basin caused by increased salinity concentrations. Consumptive uses, evaporation, and exports in the Upper Basin cause these increased TDS levels. Thus, Upper Basin uses cannot be fully evaluated without quantifying the consequent water quality impacts.

An ideal river basin management scheme would simultaneously optimize both the allocation of water quantities and the control of water quality. A property right in water is not fully specified unless the dimensions of water quality are specified. Howe, Shurmeier, and Shaw (1986) have shown that economically efficient water allocation can be achieved only by joint quantity-quality optimization. In this practice, this jointness has been finessed by specifying ambient water quality standards. A water right is then defined in terms of quantities that are better than or equal to the standard quality.

In the absence of laws and agencies that might provide joint optimization of water quantities and quality, it is important that the quality standards be reached at minimum cost. This section identifies the various steps that can be taken to improve water quality, estimates their costs, and arranges them in increasing order of cost.

The Environmental Protection Agency (1971) has called salinity the major water quality problem in the Colorado River Basin. Since 1949, the general trend in salinity concentrations at Imperial Dam has been upward, reaching a high of over 900 mg per liter in the mid-1950s. Concentrations at Imperial Dam have decreased since 1970 owing primarily to the filling of Lake Powell behind Glen Canyon Dam. However, without an accelerated salinity control program, concentrations are expected to reach 1,100 mg per liter by the year 2010 (Bureau of Reclamation, 1983a).

The United States–Mexico Treaty for Utilization of Waters of the Colorado and Tijuana Rivers and of the Rio Grande, signed in 1944, guarantees Mexico an annual delivery of 1.5 maf from the Colorado River below Imperial Dam. Between 1951 and 1960, Mexico received an average of 4 maf per year, the quality of which was near that of the water used in California and Arizona. However, Glen Canyon Dam was completed in 1961, and the need for storage in Lake Powell caused the flows to Mexico to fall to the compact limit. At the same time, the Wellton-Mohawk Irrigation Project came into operation, discharging large volumes of brine into the river. The saline concentration of the water delivered to Mexico rose to approximately 1,500 mg per liter, causing extensive damage to irrigated agriculture in the Mexicali Valley (Oyarzabal-Tamargo and Young, 1978).

With passage of the Colorado River Storage Project Act in 1956, the Secretary of the Interior was directed by Congress to study the quality of the Colorado River and its tributaries and to investigate possible means by which the quality of water could be improved. In 1971, the Colorado River Water Quality Improvement Program (CRWQIP) was initiated; its purpose was to analyze methods by which salinity control objectives can be set and achieved. Title II of the 1974 Salinity Control Act instructs the Secretary of the Interior to expedite the salinity control program outlined by the CRWQIP (Colorado River Basin Salinity Control Forum, 1984). Numerical salinity criteria established for Hoover, Parker, and Imperial dams were 723 mg, 747 mg, and 879 mg per liter, respectively. It was estimated that 2.2–2.8 million tons of salt per year would have to be removed from the river system by 2010 in order to meet the criteria. Title II authorized the construction, operation, and maintenance of four salinity control units (Grand Valley, Paradox Valley, Las Vegas Wash, and Crystal Geyser) and the completion of preliminary reports on 12 other projects. The 1984 amendments to the Salinity Control Act direct the secretaries of the interior and agriculture to give preference to projects that reduce salinity at the least cost per unit of reduction, instruct the Secretary of the Interior to submit final implementation reports to Congress and basin states prior to spending construction funds, and direct the Secretary of the Interior to undertake feasibility studies on the use of saline or brackish wastewaters in industrial production.

Subbasin 5, the Grand Valley, encompasses 126,000 acres of land in west central Colorado along the mainstream river. Agricultural activity covers roughly 50,000 acres, mostly irrigated from unlined canals and laterals. The valley itself is cut into the Mancos shale formation, which is a high salt-bearing shale. The average salinity of the water delivered to farms is 500 mg per liter. The Soil Conservation Service (1977, p. 49) has tested the return flows at numerous locations and found concentrations ranging from 1,600 to 9,000 mg per liter and averaging 4,200 mg per liter. The Bureau of Reclamation estimates the Grand Valley salt load contribution at 580,000 tons (U.S. Department of the Interior, 1983, p. 52), that is, 11.6 tons per irrigated acre, raising the concentration at Imperial Dam 59 mg per liter. The salts emanate from deep percolation from irrigation applications and seepage from conveyance systems coming into contact with the Mancos shale.

The Bureau of Reclamation's Grand Valley Unit was built to increase irrigation efficiency by improving conveyance systems and irrigation techniques. Stage I involves lining 6.8 miles of the Government Highline Canal and associated laterals in order to reduce conveyance seepage. Monitoring of Stage I to date indicates a reduced salt load of 14,200 tons (a reduction of 14.2 mg per liter at Imperial Dam) (Colorado River Basin Salinity Control Forum, 1984). The ultimate objective of Stage I is to remove 28,000 tons of salt annually. Stage II entails lining the west, middle, and east reaches of the Government Highline Canal and associated laterals. An estimated 164,000 tons of salt will eventually be removed from the river at an annual cost of $719,000 and $766,000 per mg per liter reduction at Imperial Dam for stages I and II, respectively (U.S. Department of the Interior, 1985, p. 63).

While the Bureau of Reclamation has been establishing large capital-intensive projects, the Department of Agriculture (USDA) has been experimenting with various on-farm measures for reducing the salt load of the river. The USDA Salinity Laboratory is experimenting with the use of saline water in irrigating certain salt-tolerant crops; the Soil Conservation Service has been evaluating automated irrigation systems in Colorado.

The USDA's beneficial saline strategy involves intercepting irrigation drainage return flows before they are mixed with the river (Bureau of Reclamation, 1984). This saline water in turn is used for irrigation at certain periods during the irrigation season of some crops. When the drainage water is no longer useful for irrigation, the water is discharged to evaporation ponds. This strategy is intended to reduce diversions and the salt loading of the river by irrigating salt-sensitive crops (lettuce, alfalfa, corn, etc.) in rotation with river water, while salt-tolerant crops (wheat, cotton, sugar beets, barley, oats, etc.) are irrigated with drainage water. The switch to drainage water would occur after seedling establishment, and preplant and initial irrigations would be done with river water. Long-term feasibility has not yet been established.

There is growing evidence that light, frequent irrigations are beneficial to plant growth and that they reduce the salt load entering the river (Bureau of Reclamation, 1982). With a "cablegation" automated irrigation system, soil water contents generally do not reach the extreme lows and highs of typical flood irrigation. Through avoidance of the lows, water stress and associated crop yield reductions are lessened. Eliminating extremely high soil water avoids deep percolation, thereby reducing the return of saline water to the river.

A major project of the Salinity Control Program is the Paradox Valley Project. The Paradox Valley is a collapsed salt anticline in west central Colorado along the Dolores River. Numerous brine seeps enter the river along a 1.2-mile stretch. With an average concentration of 260,000 mg per liter, the brine contributes about 205,000 tons of salt to the river system each year (Colorado River Basin Salinity Control Forum, 1984). The salinity control proposal calls for lowering the freshwater-brine interface below the river channel by groundwater pumping, injecting the brackish water into deep wells within the valley. The project is to remove 180,000 tons of salt annually from the river system at a cost of $11–$28 per ton, or $107,000–$266,000 per mg per liter (Bureau of Reclamation, 1983b).

Another major project involves Las Vegas Wash in Nevada, a natural drainage channel, the lower reach of which is now a perennial stream owing to sewage discharges from the Las Vegas metropolitan area and other wastewaters. Nearly 230,000 tons of salt were discharged in 1982 (Bureau of Reclamation, 1982). The high salt load is caused by the disposal of wastewater and the consequent leaching of salt from the underlying saline deposits. Reducing groundwater flow has been proposed to reduce salinity. The Las Vegas Wash Unit is to remove 71,000 tons of salt from the river system at an annual cost of $10.30–$11.50 per ton, or $102,000–$114,000 per mg per liter (Bureau of Reclamation, 1983b).

Economic analysis of salinity control alternatives indicates that salinity control should be undertaken to the point at which the marginal benefits of salinity reduction (that is, damages avoided) equal the marginal cost of control. We have seen (Gardner, 1983) that these damages approximate $492,969 per mg per liter in the 875–1,100 mg per liter range. Both the Paradox Valley and Las Vegas Wash Units appear to be cost-effective means for salinity control because benefits appear to exceed costs per ton of salt removed. For the Grand Valley Unit, however, costs of abatement are greater than the damages avoided. The other CRWQIP projects authorized by Congress (LaVerkin Springs, Lower Gunnison Basin, Unita Basin, McElmo Creek Basin, Glenwood-Dotsero Springs, and Big Sandy River) have benefit-cost ratios of less than one (Gardner, 1983, p. 187). A summary of Bureau of Reclamation and Department of Agriculture salinity projects is given in Table 5.18 and Figures 5.6 and 5.7.

In addition to the poor cost-effectiveness of most of the projects, annual salt removal is significantly below what is needed to ensure meeting the criteria in 2005. The Bureau of Reclamation, in cooperation with private firms, is therefore looking at new ways of either disposing of or putting to beneficial use saline and brackish water. The most promising prospects for wastewater use at this point are in energy development, slurry lines, and disposal in dry lakes (for example, Sevier Dry Lake and dry lakes in the desert of southeastern California). Roughly 610,000 acre-feet per year of saline water containing 2.6 million tons of salt could be collected for disposal or use in energy development and in slurry lines (Colorado River Basin Salinity Control Forum, 1984, p. 40). Desalination or evaporation of the saline waters could cost $4–8 billion. The same degree of salinity control through beneficial consumptive use of saline waters may cost much less (Bureau of Reclamation, 1983a). One possibility is the use of highly saline wastewater in power plant cooling. With

Table 5.18. *Salinity control program summary, Upper Colorado River Basin*

Unit	Potential salt reduction[a] (1,000 tons/yr)	Estimated salt reduction to date (1,000 tons/yr)	Annual cost[b] ($/ton)	Effect at Imperial Dam	
				TDS reduction (mg/liter)	Annual cost[b] ($/mg/liter)
U.S. Department of the Interior					
Authorized for construction and/or completed					
Grand Valley, Stage I	28	17.7	72	2.8	719,000
Grand Valley, Stage II	136		77	13.6	766,000
Las Vegas Wash	92		10	9.2	102,000
Lower Gunnison Basin	141		71	14.1	712,000
McElmo Creek	24		50	2.4	500,000
Meeker Dome	57	48	15	4.8	152,000
Paradox Valley	180		25	18	250,000
Authorized for planning					
Big Sandy River	78		69	7.8	691,000
Dirty Devil River	20		74	2	740,000
Glenwood–Dotsero Springs	284		121	28.4	1,210,000
LaVerkin Springs	53		190	5.3	1,900,000
Lower Gunnison Basin, North Fork	NA		NA	NA	NA
Lower Virgin River	NA		NA	NA	NA
Palo Verde Irrigation District	11		28	1.1	280,000
Price–San Rafael Rivers	30		35	3	350,000
Saline Water use	160		NA	NA	NA
San Juan River	NA		NA	NA	NA
Sinbad Valley (BLM)	7		75	0.7	751,000
Uinta Basin	26		90	2.6	903,000
U.S. Department of Agriculture[c]					
Authorized for construction					
Big Sandy River	35		30	3.5	300,000
Grand Valley[a]	130	23.3	24	13.0	240,000
Lower Gunnison Basin	335		56	33.5	560,000
Mancos Valley (preliminary)	20		89	2.0	890,000
McElmo Creek	38		79	3.3	790,000
Moapa Valley	20		38	2.0	380,000
Price River (preliminary)	62		NA	6.2	NA
San Rafael River (preliminary)	62		NA	6.2	NA
Uinta Basin	77	12.8	96	7.6	960,000
Virgin Valley	37		9	3.7	90,000

NA = not available.

[a] Reflects values presently included in the Colorado River Salinity Study data base.

[b] The estimates represent, at best, either appraisal- or feasibility-level costs. Caution must be used in drawing comparative conclusions for placing priorities on projects based on these cost-effectiveness values.

[c] Indexed to 1982 prices.

Source: U.S. Department of the Interior, 1983.

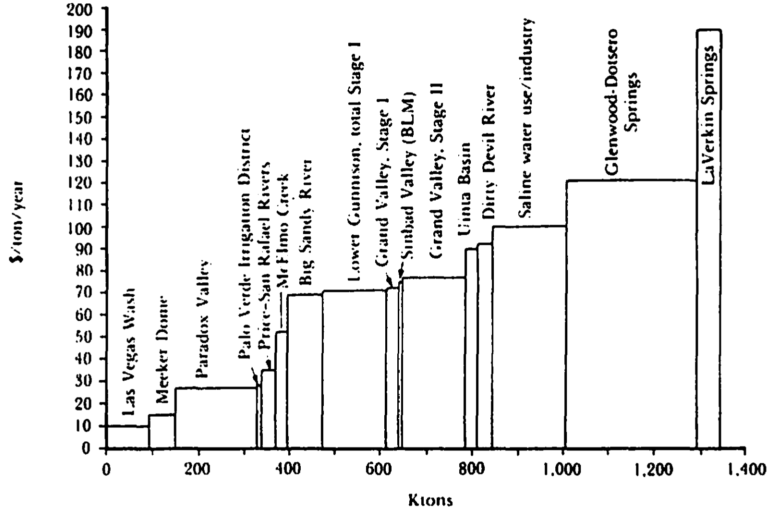

Figure 5.6. Cost-effectiveness and salt reductions for Department of the Interior projects at Imperial Dam (U.S. Department of the Interior, 1985).

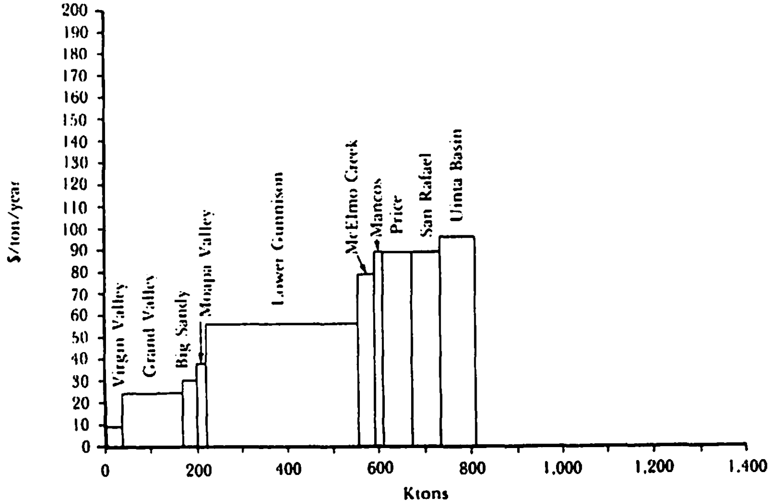

Figure 5.7. Cost-effectiveness and salt reductions for Department of Agriculture projects at Imperial Dam (U.S. Department of the Interior, 1985).

minimal pretreatment, water from 2,100 to 4,000 mg per liter TDS can be used in some cooling processes (Water and Power Resources Service, 1980, p. 3). California, Wyoming, and Utah are active in this pursuit.

The Big Sandy River rises in the Wind River Mountains of southwestern Wyoming, and the water is of good quality. By the time irrigation return flows from the Eden project are mixed with the river, 19,565 acre-feet of highly saline water (1,000–6,000 mg per liter) and 164,000 tons of salt are discharged into the Green River (U.S. Department of the Interior, 1985). The Bureau of Reclamation has recommended piping saline water to the Jim Bridger Power Plant for use in power plant cooling (Bureau of Reclamation, 1985a).

In May 1985, the Bureau of Reclamation issued its final report on using Big Sandy River Unit water at the Jim Bridger Power Plant. One option would remove 50,250 tons of salt from the river per year at a cost of roughly $70 per ton (Bureau of Reclamation, 1985a, tables ES-4 and ES-5). This option would reduce the salinity concentration at Imperial Dam 4.57 mg per liter at an annual cost of $70,000 per mg per liter. The most cost-effective process option would remove 25,125 tons of salt per year at an annual cost of $45 per ton, for reduced salinity concentrations at Imperial Dam of 2.54 mg per liter at an annual cost of $450,000 per mg per liter. Thus, the latter option may be economically marginal. The Bureau of Reclamation has studied available technology for saline water use at Hunter Powerplant in Utah. Findings indicate that the binary cooling tower is not cost effective compared to other saline water use equipment and that other processes involving off-the-shelf hardware are efficient in using saline water in cooling applications (Colorado River Basin Salinity Control Forum, 1984).

Although interest in using saline water for cooling is widespread, the process is acceptable only for new generating capacity. The use of highly saline water in other forms of energy development (oil shale, tar sands, coal gasification, etc.) holds promise if those resources are ever developed.

The use of saline water in slurry pipelines for transporting coal, potash, trona, and other marketable minerals from western fields to market areas is under consideration in a number of instances. The most ambitious program is the Aquatrain program. All the aforementioned uses of saline wastewater would be tied together by a pipeline carrying highly saline water to points of beneficial consumptive use in the western states. In its original form, the project envisioned a saline water pipeline carrying plastic capsules of clean, dry coal to the West Coast. In 1983, this proposal was dropped in favor of a double-barrel pipeline, one carrying saline water and the other carrying a liquid carbon dioxide and coal slurry. A report completed in 1984 identified various input and output points (that is, coal mines, carbon dioxide, saline water sources, power plants, and export sites) in southwestern Wyoming, western Colorado, Utah, northern Arizona, central and southern Nevada, and southern California. Probable uses of the saline water include power plant cooling, oil shale development, solution mining, tar sand development, and hydraulic mining. If all potential sources of saline water are used, 160,000 acre-feet per year of water could be transported to users and 900,000 tons of salt could be removed annually (Bureau of Reclamation, 1985b, p. 88). The Bureau of Reclamation will attempt to determine the potential benefits and costs of the project.

The disposal alternative (transporting water to dry lake beds and evaporating the water) for removing highly saline water from the river system is probably the least viable. It will most likely involve an interbasin transfer of water because the proposed dry lake beds lie in areas outside the basin of origin. Consequently, a plethora of legal and institutional constraints are brought into the picture. The Bureau of Reclamation proposed to Wyoming the piping of saline water into the Great Divide Basin, and the state rejected the proposal. Colorado law, in addition to requiring compensatory storage for the basin of origin in transbasin diversions, does not recognize evaporation as beneficial use of water.

Regulation of the Colorado's natural flow has significantly altered the seasonal and annual variations in flow and salinity concentrations. Between 1963 and 1980, massive net amounts of water were stored in the basin. Storage capacities reached 50 maf in 1980 (U.S. Department of the Interior, 1985, p. 25). Between 1976 and 1980 the average yearly reservoir evaporation in the Colorado River Basin was 2,114,000 acre-feet (U.S. Department of Interior, 1985, p. 14), leaving lower-quality water to pass through the turbines or spillways for downstream uses. With the initial filling of Flaming Gorge, Reudi Reservoir, and Lake Mead, significant leaching of calcium sulfate (gypsum) occurred. Long-term salt leaching at Flaming Gorge Reservoir is being studied. There is strong evidence that between 1965 and 1980, Flaming Gorge Reservoir and Lake Powell stored high TDS water and routed lower TDS spring runoff downstream (U.S. Department of the Interior, 1985, p. 25). Bank storage, chemical precipitation, ion exchange, and oxidation reduction are thought to have prevented high TDS water from being released from these reservoirs. TDS may also be influenced by sedimentation in reservoirs. In contrast to a riverine environment, where suspended sediment may continue to release salts and exchange ions, sediment once settled out in a reservoir may limit salt and ion exchange capabilities (U.S. Department of the Interior, 1985, p. 25).

Unconventional approaches to salinity control

The alternative approaches discussed above include both large capital-intensive projects and some on-farm measures by the Soil Conservation Service (USDA). The latter involve installing gated pipe and other improved mechanical systems for improving irrigation efficiency. In addition, Young and Leathers (1978) have studied other on-farm options that primarily involve more careful management of irrigation water application and modified cropping patterns.

Howe and Young (1978) and Howe and Orr (1974) studied the savings in consumptive use of water and salt in the return flow that would be involved in phasing out marginal agricultural lands in the Grand and Uncompaghre Valleys of Colorado. The former study considered a phase-out of 8,800 acres in the Grand Valley and 10,200 in the Uncompaghre, calculating the direct and indirect losses that might ensue. Income losses were about $16.30 per ton of salt reduction, but for every ton of salt reduction, 0.17 acre-feet of consumptive use was also avoided. Valuing this water saved at the hydroelectric opportunity cost of $31.36 per acre-foot (Table 5.16) plus the direct Lower Basin agriculture opportunity cost of $30 per acre-foot, the net cost is reduced to about $6.50 per ton from the viewpoint of the entire Colorado Basin.

Taking into account both the salt reductions and changed consumptive uses (positive and negative), the net costs per ton of salt reduced are compared in Table 5.19. The activities have been ranked by net cost per ton of salt reduction from a basinwide viewpoint. It is clear that on-farm management and irrigation system changes and irrigated acreage constitute the most cost-effective approaches to salinity reduction. The larger projects are substantially more costly.

The problem is to motivate use of the low-cost alternatives. The on-farm measures of Young and Leathers (1978) would be paid for by the farmer, and all the federal programs are likely to be paid for by the federal government. Acreage retirements could be made attractive to farmers by having the state government or a federal agency offer to buy either the land or the irrigation water. Given the low direct income per acre (or per acre-foot), the offering price would not have to be high.

sion of the ability to effect the utilization of compact-granted water has occurred because of salinity control programs and the Endangered Species Act. As a result of these fears, political pressures have risen for the construction of new water projects to tie down this water. Some projects proposed largely for this purpose (for example, the Animas–La Plata Project in Colorado) are grossly inefficient from an economic viewpoint and would certainly tie the water to uses of little value in the long run, rather than protecting it for important future developments.

It is clear that the status of potential interstate water sales by either private appropriators or public bodies is in a state of legal flux. Although it seems clear from *Sporhase* v. *Nebraska* and *City of El Paso* v. *Reynolds* that blanket prohibitions of interstate transfers are unconstitutional, necessary conditions for legal sales have not become clear. An interesting recent proposal is that of the Galloway Group, Ltd., a Colorado corporation that wants to sell surface water apportioned to the state of Colorado but purportedly claimed under Colorado water rights by entities in Arizona and Southern California. (For an excellent analysis, see Gross, 1985.) Galloway claims to have water rights to 1.3 maf of water per year on the Yampa and White rivers in western Colorado, in the Upper Colorado Basin. Galloway intends to raise more than $200 million of private capital to build dams on the two rivers to generate electric power and store water.

In August 1984, the San Diego Water Authority paid Galloway $10,000 for an option to lease 300,000–500,000 acre-feet for 40 years. Many questions remain unanswered. Gross (1985) has concluded that the Colorado River Compact and the Upper Colorado River Compact preclude the Galloway proposal, mainly through implied territorial use limitations. Gross further concludes that the compacts, as federal law, are immune from Commerce Clause attack.

On the economic side, there are questions of the price it would be reasonable for San Diego to pay, given the alternatives, and the effects that a clearing of legal barriers would have on the total supply coming from the Upper Basin. At a time when the western power market is overbuilt, when Colorado has excess storage capacity in existing Western Slope reservoirs, and when the Colorado Basin's total storage is so large that total basin yields fall with added storage, it seems to make little sense from the financial and economic viewpoints to make such large investments in storage. If the proposal is someday permitted, it should be without the waste of added storage.

The answers to many questions are yet unknown. Must the water be confined to a pipeline? Is it sufficient that it be made part of a larger product (chicken soup or coal slurry)? Can water sold be allowed to remain in the stream to be abstracted downstream by the buyer? Can a state government lease part of the water allocated to it under interstate compact but not currently used (for example, waters unappropriated under state water law or held by the state for state uses)?

Would interstate water leases or sales help affirm the titles to such waters? Would there be a market for such water? Against which state's compact allotment would such transactions be counted? Would California, which has been using waters unused in Colorado and Arizona for many decades, be willing to pay something for a longer-term lease that would assure continued delivery for a known period? Would such an arrangement eliminate the pressure for nonsensical "use it or lose it" projects? The status of water allocated to western Indian tribes under the federal reservation doctrine and the *Winters* decision could be a much larger issue in the next decade.

In a river basin context, supplies of water for transfers out of state or from the Upper Basin to the Lower Basin can come from unused water in excess of deliveries that may be required by compact and from water withdrawn from current consumptive uses. Regarding unused water, it is not clear that conditions for exchange exist, because there is no practical way to withhold the water; nor is it clear that the Upper Basin can legally claim water that it cannot use consumptively. The water cannot be stored unless there is a consumptive use, and it will continue flowing downstream anyway. The only motivation for making a contract on such water would be to guarantee that consumptive uses will not be developed over a specified time so that continued downstream availability could be guaranteed.

Table 5.5 showed the mean annual discharge of unused water originating in each subbasin of the Upper Colorado Basin. Out-of-basin parties willing to pay the Upper Basin not to develop this excess water (averaging 2,894,000 acre-feet per year) would naturally be concerned about the reliability of this supply. However, there is so much storage on the main-stem Colorado and its major tributaries (55.6 maf of active storage, approximately 4.3 years' average flow) that water deliverable below Hoover Dam could be made quite reliable through Bureau of Reclamation storage and release arrangements.

Water could also be transferred out of the Upper Basin through transfer of established water rights that are currently being used. Only agricultural rights are relevant to potential transfers because of their relatively low value, and they represent 70 percent of total diversions and more than 90 percent of total consumptive use. The annual consumptive use of water by crop in each subbasin and the associated net return to the farm enterprise per acre-foot of consumptive use were presented in

Table 5.20. *Supply curve for water trading, Upper Colorado River Basin*

Offering price per acre-foot	Incremental offering (acre-feet)	Cumulative acre-feet offered
$ 5	36,452	36,452
10	30,565	67,017
15	65,803	132,820
20	7,591	140,411
25	208,079	348,490
30	92,171	440,661
35	346,646	787,307
40	322,256	1,109,563
45	170,548	1,280,111
50	92,361	1,372,427
55	120,741	1,493,213
60	15,219	1,508,432
65	18,400	1,516,832
72	49,373	1,566,205

Table 5.13. These data permit construction of a crude supply curve of water from existing agricultural uses, assuming that offer prices in excess of the net returns experienced per acre-foot consumed will, sooner or later, induce farmers to sell that water. For each subbasin, such a supply curve can be constructed by arranging the crops in increasing order of net return and cumulating the quantities of water that would be forthcoming at that net return (or lower).

Based on the data of Table 5.13, a supply, or offer, curve is constructed for the Upper Basin, using $5 offering price intervals and cumulating the amounts of water that might be forthcoming at each offering price (see Table 5.20).

The conclusion is that lots of water is likely to be forthcoming from the agricultural sector at relatively low prices if the process is not subject to state control. The above data represent a private agricultural sector point of view of accounting stance, that is, private profitability as a criterion for giving up irrigation water. However, from a state or overall Upper Basin viewpoint, things look quite different, as shown earlier in Table 5.15. In the various subbasins, average state income losses per acre-foot consumed range from $74 to $160 per acre-foot. A regional official looking at Table 5.15 would be concerned that the loss of regional income would not be made up by new water-using activities (that might be out-of-state) or that the proceeds to the seller might not be reinvested in the state. Transfers that are highly beneficial from a national stance and are modestly beneficial from a private stance can be perceived as highly harmful to the economy of the exporting region.

This difference will continue to be a major point of contention regarding out-of-state or out-of-basin sales.

Principal findings and policy recommendations

Principal findings

The Upper Colorado River Basin is not and under foreseeable circumstances will not be short of water for consumptive uses. Estimated current consumptive uses per year total 2.7 maf (Spofford et al., 1980, chap. 6, modified), including those associated with publicly supplied waters, rural domestic and livestock supplies, irrigation, self-supplied industrial uses, thermal-electric generation, tributary groundwater use, and export. Table 5.21 indicates the Upper Basin and state availabilities for consumptive use under three assumed values for average virgin flow. The 13.5 maf estimate is the lowest in current use, but because there are periods of persistent low flow, the effects of a repetition of the lowest ten-year flow in this century (from 1931 to 1940) are considered. Only in the latter case could there be a shortage. Then, the annual shortage could be met by net releases from the 50 maf of active storage on the river and the reallocation of water from agriculture to other uses in order to avoid serious damage to the nonagricultural sectors.

It should also be noted that the average excess outflows from the Upper Basin of 2,890,000 acre-feet (Table 5.5) exhibit high year-to-year

Table 5.21. *Upper Colorado River Basin and state water availabilities for consumptive use under three virgin flow assumptions (million acre-feet per year)*

	Assumed virgin flows		
	13.50[a] −8.30[d]	14.05[b] −8.30	11.80[c] −8.30
Upper Basin availability	5.20	5.75	3.50
Colorado (51.75%)	2.691	2.976	1.811
New Mexico (11.25%)	0.585	0.647	0.394
Utah (23.00%)	1.196	1.322	0.805
Wyoming (14.00%)	0.728	0.805	0.490

[a] Lake Powell research project estimate (Jacoby, 1975).

[b] Used by U.S. Department of the Interior Water for Energy Management Team.

[c] Lowest ten-year flow in the twentieth century (Dracup, 1977, p. 121).

[d] Release required by Colorado River Compact plus half the Mexican obligation plus 50,000 acre-feet per year for Arizona.

Source: Modified from Spofford et al., 1980, table 10, p. 387.

variability as a source of supply for the Upper Basin, capable of being regulated only at high cost. However, these same supplies can be regulated and made available to the Lower Basin at no additional cost (as they are today) through the vast amount of storage on the river system.

Low-valued agricultural uses consume approximately 31 percent of the water available to the Upper Basin (that is, 1.6 maf, Table 5.8, out of 5.2 maf, Table 5.21). The values of these waters in terms of net farm income per acre-foot consumed range up to $72 but average $25 per acre-foot. On the other hand, if some of this water were to be transferred out of the Upper Basin, there would be somewhat larger impacts on state incomes, ranging from $75 to $160 per acre-foot (Table 5.15). These estimated state income effects stem from a "worst case" scenario and do not take into account the positive income effects of new in-basin uses or the possibility that agricultural sellers might reinvest their sales proceeds in Upper Basin activities. As more market incentives are felt to transfer agricultural water, this conflict between individual willingness to sell and state concern will escalate, with the states (rightly or wrongly) increasingly opposing transfers that are privately profitable, especially out of state.

Instream value of waters currently consumed in the Upper Basin, when viewed from the standpoint of the entire Colorado Basin, are quite high, often surpassing even the state income values that may be associated with the consumptive uses. These values arise from the effects on water quality, water-based recreation, fish and wildlife values (beyond direct recreational values), hydroelectric power generation, and Lower Basin irrigation uses. Some of these values have not been quantified in monetary terms, but it is possible to place values on the hydroelectric power effects, the value of the water to Lower Basin irrigators, and the water quality effects. The hydroelectric values were shown to range from $31 to $46 per acre-foot, depending on the subbasin of origin (Table 5.15). The likely value of irrigation water at the margin of application in the Lower Basin is about $30 per acre-foot, allowing for evaporative losses. (See the preceding section on hydrology, water use patterns, and the value of water.) The effect of consumptive use on the concentration of dissolved solids and the consequent damages to the municipal and agricultural sectors of the Lower Basin range from about $38.50 per acre-foot of consumption for water exported from the headwaters areas of the Upper Basin to about $280 per acre-foot for water applied in the Mancos shale areas of the Grand Valley (in Colorado). Thus, not counting recreational and fish and wildlife values, the values of water left in stream range from approximately $100 to $350. Surely, some rethinking of water allocation among uses is called for by the differences between these values and the private and state income values mentioned earlier.

Bureau of Reclamation electric power generated within the Colorado River Storage Project sells at extremely low prices, an average of only 11 mills per kilowatt hour. Compare this figure with the cost-avoided prices being paid for cogenerated power of around 44 mills or, in the extreme, the approximate full cost of electric energy from newly constructed coal-fired thermal electric plants (being built in the Southwest) of 8.5 cents (85 mills) per kilowatt hour. Such underpricing leads to misallocation of energy resources and energy-related investments, and it shortchanges the regions that provide the water for the hydroelectric generation.

A basic motivational problem is created by the fact that most of these instream values accrue not to the Upper Basin but to the Lower Basin and wider areas that use the power.

The high levels of dissolved solids in the Lower Basin have been seen to cause quite significant damage, approximately $0.5 million per mg per liter of water (Gardner, 1983). Yet, the Colorado River Salinity Control Program is failing to make adequate use of the most cost-effective methods of reducing salinity: changes in on-farm irrigation water management and the retirement of irrigated land in areas that contribute huge amounts of salt through their return flows (Table 5.19). The reasons for this failure are again motivational: the Bureau of Reclamation and the Soil Conservation Service find administering on-farm programs for large numbers of farmers difficult compared to constructing large point-source projects, although the farmers themselves prefer projects whose costs they do not share.

There exists no basinwide agency that is concerned with or is able to study and influence the pattern of public values and negative externalities noted above, that is, the impacts of changes in Upper Basin water use on Lower Basin users. Results of the absence of such oversight include increased Upper Basin fear of Lower Basin political power over the use of water, a consequent "hurry up, build any kind of project" attitude, lack of concern with substantial Lower Basin losses and power losses, and fear of considering ways for reallocating water over the short and long terms to the mutual benefit of all parts of the basin.

Further, it seems clear that there exists an unexploited potential in the Upper Basin for an increased role for water markets. Although water markets cannot solve all problems, they can provide the flexibility in water allocation that economic and demographic change necessitates. State water agencies can facilitate an expanded market function by providing information (for example, where there are excess water and shortages); there is also a need for public monitoring of the water market process in order to ensure important public values. Cases of successful markets need to be studied with an eye to replication.

Colorado lags behind the other Upper Basin states in relying on the water court system to deal with water reallocation and in having no mechanism for guarding public values. All the Upper Basin states lack the tools for reflecting instream values adequately. The water laws of all the states fail to recognize conservation as a beneficial use; they in fact encourage inefficient uses.

Policy recommendations: basinwide

1. Because there exists *no* river basin agency with interest in and responsibility for monitoring and overseeing the entire Colorado River Basin, and in light of the potential benefits to be gained from the existence of such an agency as noted above, it is recommended that the Colorado River Basin states that are signatory to the Colorado River Compact consider establishment of an interstate river basin commission along the lines of the Potomac and the Delaware river basin commissions, to act as a focal point for study, exchange of information, continuing dialogue, and enforcement and monitoring of agreed-upon policies. Basinwide management implies the need for basinwide compensatory arrangements so that all parties can benefit from both water planning and water transfers.

2. In light of the excess water supply in the Upper Basin that will be costly to develop for Upper Basin purposes but is now regulated through storage for Lower Basin use at almost no cost, and given the Upper Basin fears that are leading to the costly development of inefficient consumptive uses, it is recommended that thought be given to mechanisms needed to negotiate a long-term agreement with the Lower Basin states, especially California, by which the Upper Basin would be paid to agree *not* to develop new uses for a portion of the water during a specified time.

3. In light of the low private values generated by much of the consumptive water use in the Upper Basin and the likely opposition of state governments to transfers out of agriculture under current institutional arrangements, it is recommended that:

   a. studies be undertaken to quantify the direct and indirect recreational values generated *in* the Upper Basin by added streamflows;
   b. hydroelectric prices for power from the Colorado River Storage Project be raised toward market levels; and
   c. revenues from CRSP power sales be shared proportionally among the Upper Basin states, thereby providing them with badly needed revenues and motivating them to recognize instream values.

Policy recommendations: state level

4. Because appropriations doctrine fails to recognize conservation as a beneficial use of water, thereby denying the owner any reward for increased efficiency in use, it is recommended that the Upper Basin states consider legislation such as the Katz-Bates bill in California (1983) that so recognizes water conservation. This change would be doubly effective in motivating on-farm water management change that also reduces return flows and their dissolved solids loads. It would also motivate retirement of unproductive acreage.

5. The salinity management program is unable to motivate on-farm measures and acreage retirement sufficiently. Cost sharing as practiced by the Soil Conservation Service is not adequate because farmers resist any increase in cost that does not provide directly offsetting benefits. Although Recommendation 3 above will help, it is recommended that further steps be taken to redefine "beneficial use" in a way that reflects the availability of modern water management methods available at moderate costs. Beneficial use should require reasonable water control methods and should be differentially defined among areas to reflect special attributes of each area, especially where return flows are extremely saline.

6. To facilitate market transactions but simultaneously to give weight to those public values not reflected fully in private values (water quality, aesthetics, species preservation, public recreation, etc.), it is recommended that the riparian states consider changing to the New Mexico system under which the office of the state engineer, rather than the water courts, monitors water transfers, carries out needed hydrologic studies, and imposes public interest criteria. This change would decrease transactions costs of transfers while protecting public values.

7. In all Upper Basin states, it is recommended that the state engineer's office facilitate water transfers by providing information on local water availability and shortage. Systems such as Colorado's satellite-linked water monitoring system can provide valuable information for this purpose.

8. It is recommended that an agency of state government stand ready to buy water rights at stated prices from designated low productivity-high salinity lands to facilitate the retirement of those lands. The water would be either sold or retained by the state for instream flow maintenance.

9. It is recommended that efficiently working markets such as the Northern Colorado Water Conservancy District be carefully studied with an eye to their extension to all conservancy and irrigation districts.

The real issues confronting the Colorado Basin are primarily institutional, not technical. More research, including actual experimentation, should be devoted to institutional-motivational design. A basinwide institution is needed to identify and negotiate "win-win" changes in water allocation and management for all parts of the basin. These are exciting challenges.

Appendix: Detailed derivation of state income impacts

Use of a state input-output (I-O) model allows analysis of the forward and backward linkages from irrigated agriculture to other sectors of the state economy. An analysis of the effects of the withdrawal of water currently consumed in agriculture in Colorado and Utah has been undertaken. Because of economic proximity, it is assumed then that Grand County, Utah, and all the San Juan River Basin are part of Colorado. No I-O table from Wyoming is available.

Colorado has a well-developed economy characterized by a high degree of interdependence among the various producing sectors. The 28-sector Colorado I-O model based on 1970 data is taken from Gray and McKean (1975). The flows of five sectors are shown in Table 5.22. The household sector was included so that wage and salary income changes could be estimated and consumer multiplier effects included.

Table 5.22. *Gross flows, 1970 (thousand dollars)*

	Livestock	Irrigated agriculture	Food processing	Households	Other	Total intermediate demand
Livestock	$265,585	$ 0	$ 585,110	$ 12,454	$ 45,931	$ 909,080
Irrigated agriculture	192,276	0	77,127	144	27,047	296,594
Food processing	0	34,529	54,599	172,410	672,557	934,095
Households	151,330	61,586	161,333	850	3,017,818	3,392,917
All other	156,660	142,868	104,061	3,592,523	15,361,357	19,357,469
Total interindustry	765,851	238,983	982,230	3,778,381	19,124,710	24,890,155
Primary inputs	185,405	81,999	805,030	4,306,453	8,159,536	13,538,423
Total	$951,256	$320,982	$1,787,260	$8,084,834	$27,284,246	$38,428,578

To estimate the state income effect of withdrawing an acre-foot of water from agriculture in Colorado, one needs to use both the input-output model and certain judgments. To illustrate our calculations, we work through a typical sequence of assumptions and calculations for a reduction of irrigation output in western Colorado. First we observe that 92 percent of irrigated agriculture's output is used for livestock, for food processing, and for consumption and export. Because the irrigated crops on the Western Slope are primarily forage crops and feed grains, it appears reasonable to eliminate the direct linkage to food processing.

Because the technical coefficient for the input from irrigated agriculture per dollar of livestock output is 0.2, a $1 reduction in irrigated agriculture deliveries to livestock may cause as much as a $5 (1/0.2) reduction in livestock output if no substitutes are available. However, complete absence of substitutes seems unlikely, so we assume that one-half the reduction of irrigated agriculture inputs into the livestock sector will be substituted by imported supplies. The reduction of $1 of Colorado irrigated inputs into the livestock sector would then cause a $2.50 reduction in livestock output.

Livestock output is mainly for the food-processing sector (62 percent); the remainder is largely inputs to itself (cow-calf outputs into range livestock, etc.). Thus, each $1 reduction in livestock output would result in a $0.62 reduction in deliveries to food processing. Because the input coefficient for livestock into food processing is 0.33, the reduction in food processing output would be $1.89 (0.62/0.33).

In summary, as a consequence of our assumptions about the structure of the regional economy of western Colorado, a $1 reduction in irrigated agricultural output would exhibit the following consequences: (1) $0.11 represents a reduction in deliveries in final uses; (2) $0.89 comes from livestock, causing a $2.23 reduction in livestock output; (3) the $2.23 reduction in livestock output causes a $1.38 ($0.62 × $2.23) reduction in livestock deliveries to food processing; (4) the $2.23 reduction in livestock output also causes a $0.85 ($0.38 × $2.23) reduction in deliveries to final uses; and (5) the $1.38 reduction in livestock deliveries to food processing may lead to a $4.18 (1.38/0.33) reduction in food-processing output that then represents a reduction in deliveries to final demand because processing output is mostly exported.

The direct and indirect state income effects of these reductions in deliveries to final demand depend upon the average reductions in outputs by the various sectors and the related reductions in wage and salary payments and financial payments. In particular, the reduction in wage and salary payments to the household sector for each dollar reduction in

Table 5.23. *Cumulative reduced consumptive use, state income lost per acre-foot of reduced consumptive use, incremental state income lost (thousand dollars), and cumulative state income lost (thousand dollars)*[a]

	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6	Crop 7	Crop 8	Average income loss/acre-foot[b]
Subbasin 1									
Water used[c]	17,734	19,928	208,020	219,067					$\bar{v}$ = $75
Income loss ($/acre-foot)[d]	182	91	57	185					
Total loss ($1,000s)[e]	3,228	136	10,772	2,010					
Cumulative loss ($1,000s)[f]	3,228	3,364	14,136	16,146					
Subbasin 2									
Water used	22	774	1,831	28,348	78,629				
Income loss ($/acre-foot)	185	96	184	216	89				$\bar{v}$ = $90
Total loss ($1,000s)	4	72	194	2,347	4,460				
Cumulative loss ($1,000s)	4	76	270	2,617	7,077				
Subbasin 3									
Water used	205	7,477	11,227	16,886	20,195	204,779	325,520	340,739	
Income loss ($/acre-foot)	349	193	156	118	191	83	227	317	$\bar{v}$ = $149
Total loss ($1,000s)	72	1,403	585	668	632	15,321	27,408	4,824	
Cumulative loss ($1,000s)	72	1,475	2,060	2,728	3,360	18,681	46,089	50,913	
Subbasin 4									
Water used	4,801	6,425	8,573	10,201	88,077	96,251	136,139		
Income loss ($/acre-foot)	450	96	203	184	86	228	225		$\bar{v}$ = $151
Total loss ($1,000s)	2,160	156	436	300	6,697	1,864	8,975		
Cumulative loss ($1,000s)	2,160	2,316	2,752	3,052	9,749	11,613	20,588		
Subbasin 5									
Water used	152	3,608	10,084	10,712	149,320	170,120	281,031	289,431	
Income loss ($/acre-foot)	459	96	210	183	88	223	224	421	$\bar{v}$ = $160
Total loss ($1,000s)	70	332	95	1,649	12,198	4,648	24,844	2,543	
Cumulative loss ($1,000s)	70	402	497	2,146	14,344	18,932	43,826	46,369	
Subbasin 6									
Water used	6,864	6,967	9,145	78,025	82,222	163,336	183,085	197,371	
Income loss ($/acre-foot)	196	670	95	172	183	68	200	350	$\bar{v}$ = $145
Total loss ($1,000s)	1,345	68	197	11,862	768	5,516	3,950	5,006	
Cumulative loss ($1,000s)	1,345	1,413	1,610	13,472	14,240	19,756	23,706	28,712	
Subbasin 7									
Water used	18	800	4,956	7,737	10,602	141,002	141,534	233,895	
Income loss ($/acre-foot)	284	170	234	96	183	75	201	219	$\bar{v}$ = $137
Total loss ($1,000s)	5	133	973	267	524	9,780	107	20,227	
Cumulative loss ($1,000s)	5	138	1,111	1,378	1,902	11,682	11,789	32,016	
Subbasin 8									
Water used	2,909	2,948	3,006	3,202	4,707	35,837	70,933		
Income loss ($/acre-foot)	178	490	190	182	118	75	235		$\bar{v}$ = $160
Total loss ($1,000s)	518	19	11	36	178	2,335	8,248		
Cumulative loss ($1,000s)	518	537	548	584	762	3,097	11,345		

[a] The phasing out of crops in each subbasin is assumed to be in ascending order of private profitability, as in Table 5.12.

[b] Average loss of basin income per acre-foot of consumptive use.

[c] Cumulative amount of water consumed by the crop, in acre-feet.

[d] Loss in basin income per consumptive acre-foot for the crop.

[e] Total loss if each crop phased out, in thousands of dollars.

[f] Cumulative loss if all crops phased out, in thousands of dollars.

irrigated output equals $1.61. For each dollar reduction in irrigated agriculture output under the foregoing assumptions, payments to insurance, real estate, rent, interest, and profits are reduced $1.92. Having no information on the distribution of these financial payments between in-state and out-of-state parties, the authors chose one-third to represent an income loss to the state, the rest of interest, dividends, etc., going to out-of-state parties. The total state income loss in Colorado per dollar reduction in irrigated agricultural output in Colorado would then be $1.61 + $0.64 = $2.25.

Similar calculations for Utah resulted in a Utah multiplier of 1.34, that is, for each dollar of reduction in irrigated grain output, state income will fall $1.34.

These multipliers have been derived from state input-output tables, each representing the entire state. Colorado, on average, has a more integrated, more extensive economy, leading to its higher multiplier. However, the Upper Basin areas of the two states are somewhat isolated from the more highly developed parts of each state and are, in fact, closely linked because of physical proximity. Thus, multiplier effects should be similar throughout the basin, rather than differing across the (arbitrarily designated) state lines. We judge that Colorado's multiplier is too high for the region and Utah's is somewhat low (partly because of lack of information on some of the financial payments). We have chosen the average of the two multipliers, 1.80, to estimate the state income impacts throughout the Upper basin.

It is now possible to evaluate the effects on the Upper Basin economy if water is transferred out of agriculture. The estimated income losses are expressed per acre-foot of reduced consumptive use in Table 5.23. The first line for each subbasin gives the cumulative amount of water used by the crops, and the second line shows the loss in basin income per consumptive acre-foot for that particular crop. (Note: the order of crops by value is that shown in Tables 5.6–5.13.) The third line represents the cumulative loss in basin income as the various crops are progressively phased out. The average loss of basin income per acre-foot of consumptive use for each subbasin is given in the last column, the range being $75 to $160. This range represents what the local area might expect to lose in income as water is moved out of agriculture. It seems unlikely that offsetting investments in new industries will take place in the same area. From the state point of view, the water withdrawn might support new industries in the state, but whether it will is quite uncertain. If the water is transferred out of state, the above state income losses are likely.

The private values of water consumed, ranging from zero to $72 per acre-foot (Table 5.13), contrast sharply with possible state income loss of $57–$490 (Table 5.14). We can anticipate sharply differing views among many who will want to sell water and state officials concerned with state effects.

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6 Growth and water in the South Coast Basin of California

HENRY J. VAUX, JR.

The South Coast Basin of southern California includes the second largest urban area in the United States as well as the two largest cities in California. In addition to the major centers of Los Angeles and San Diego, there are numerous other urban and suburban communities. The 1980 population of the entire region was 12.01 million, compared with a prewar (1940) total of only 2.9 million. Over the past 40 years, the dramatic growth in population, which has averaged 10 percent annually, has been fueled by a variety of factors, including a favorable climate and the rise of defense and aerospace-related industry. This growth was achieved despite the severe limitations of local water supplies.

Mean annual precipitation in the region averages only 14 inches. Over the period of record, annual precipitation has been quite variable, ranging between 5 and 38 inches annually. In addition, the area has a typically Mediterranean climate in which rainfall occurs predominantly between November and April. As a consequence, there exists not only a dearth of locally generated water supplies but an incongruity between the winter period, when those supplies are more readily available, and the summer period, when water demands are at a peak.

The modern history of the region has been characterized by the development of supplemental water supplies and the storage facilities necessary to regulate water flows so as to redress the natural imbalance between periods of peak supply and peak demands. The physical manifestations of this development include three major aqueducts that, with their associated storage facilities, permit the South Coast Basin to import water from the Colorado River, the Central Valley of California, and the Owens Valley to the northeast. A major justification for the development of all these facilities rested on the proposition that water is necessary to support continued population growth and related economic development. This view was probably most succinctly stated by the legendary William Mulholland, who observed at one point during the con-