Energy and Agriculture in Utah: Responses to Water Shortages

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Variability in water supplies is perceived as a major impediment to economic growth in both agricultural and energy sectors in the Intermountain West. A chance-constrained programming model of water allocations among agricultural, energy, municipal and industrial, and environmental activities for the Upper Colorado River Basin and the Great Basin in Utah was developed to analyze economically optimal water use as energy production increases. Estimates of the probabilities of various amounts of water production, representing different drought conditions, were used as right-hand sides in the model. Results indicate that water is not a constraining factor and that little, if any, water development is warranted, even during relatively intense periods of drought.

Key words: water allocations, chance-constrained programming, energy, irrigation, Intermountain West.

Water availability has been identified by many individuals and government agencies as a major constraint on energy and agricultural development in the Upper Colorado River and the Great Basins. Earlier studies (see, for example, Keith et al.) indicate that average annual water availabilities are sufficient for significant growth for both irrigated agriculture and energy production in Utah. However, it has been argued that the variability of precipitation and consequent stream flows causes severe water shortages for all users. In fact, much of water planning and development is targeted at increasing water availability during low-flow and/or drought periods to reduce the uncertainties of water dependency. This study examines the economically efficient allocations of water in the two basins for the average case and for cases in which high probabilities of water production could be assigned representing various drought conditions.

Modeling Approach

The approach used in this study involved constructing a chance-constrained programming model of the Upper Colorado and Utah's portion of the Great Basin. The model was developed in two steps. First, an existing linear programming model of water allocations in the basins (Snyder et al.) was modified to include a two-season water flow (January through June and July through December) with potential storage for interseasonal redistribution. Next, the probability distributions of water production for each major drainage in the basins were estimated using existing water production and gage data from U.S. Geological Survey data tapes. These data had varied periods of record. The water production consistent with selected probabilities (85%, 90%, and 95% certainty) from the estimated distributions was then used as the right-hand side for the water constraints in the model, following Taha as suggested by Charnes and Cooper (1959, 1963); Wagner; Hillier and Lieberman; and Bishop and Narayanan. This approach does not reflect an ex-

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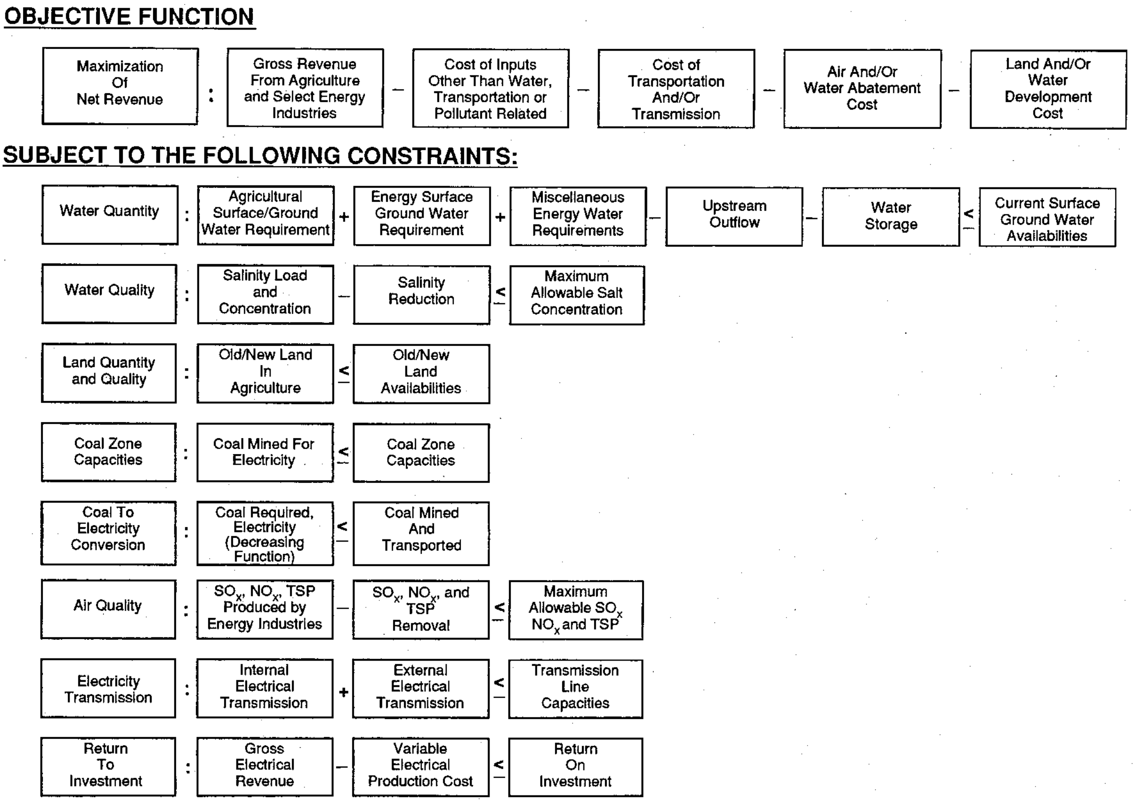

Figure 1. General economic feasibility model

pected value of the objective function; the solutions do not include consideration of the omitted tail of the distribution of water. Thus, the allocation results and the shadow values of the constraints suggest only the value of water at a given level of availability.

The Programming Model

The programming model has been described previously in Keith et al.; Snyder et al.; and Keith and Snyder, which includes a very detailed discussion of each of the constraints and the objective function. Figure 1 is a schematic diagram of the model for a "low-flow" season (storage is added to, rather than subtracted from, the right-hand side availabilities). Figure 2 and table 1 indicate the drainages (hydrologic subunits, or HSUs) for which the model was developed. The following brief description of the model highlights its important features and provides an overview of the modeling approach.[1] The model included agricultural and energy sectors requiring water. The objective function consisted of profits (net returns) to both sectors. All costs and prices were adjusted to a base year of 1980, using appropriate indices where no direct cost data were available for 1980. The structure of the model was such that water rights were assumed to be freely transferable even among states. Alternative constraint sets were used to reflect cases in which rights were transferable only within a state, only within HSUs, or restricted in other specific institutional ways.

Agricultural Sector

Within the agricultural sector are existing and potential irrigated and dryland production on four land classes in each HSU. These classifications are based on the U.S. Soil Conservation Service classifications and include soil type, productivity, slope, irrigability, and growing season. Only variable costs were considered for land currently in production, whereas new land involves both a development cost (a 20-year annualized investment in clearing, leveling, and providing on-farm water

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[1] A complete model description and program are available from the authors.

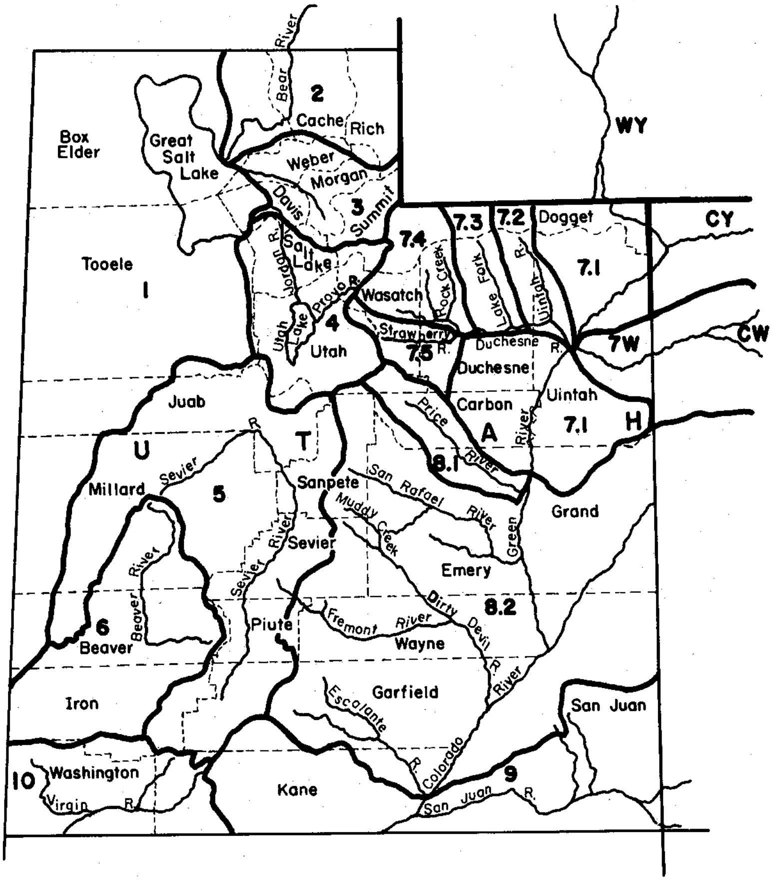

Figure 2. Topography of Utah's hydrologic units

delivery systems using a 10% interest rate) and variable costs.

The crops considered were those crops which are currently grown in the HSU and which might reasonably (environmentally and economically) be considered by local farmers. Crops included alfalfa, irrigated barley, irrigated wheat, corn for both grain and silage, fruits (apples, cherries, and peaches), sugar beets (although sugar beet crops currently are not grown in Utah), irrigated pastureland, dryland beans, and dryland wheat.[2] When the costs of transportation of sugar beets to distant processors in Idaho were included in the variable costs, the sugar beet activity was unprofitable.

Each crop was assigned a seasonal consumptive use water requirement per acre for the specific soil type and HSU based on current irrigation practices. Alfalfa and irrigated small grain production could take place with either full or partial irrigation in each season with appropriate changes in production. Corn and fruit production had a fixed requirement for both seasons, since lack of water in any season results in a very low or no yield. The model could select crops and water use based on the profits from the sale of each crop at fixed prices net of production costs other than water and land development (U.S. Department of Agriculture).

Energy Sector

The energy sector consists of coal mining, coal transportation activities, and the production and transmission of electrical power. Using an air quality model developed by Wooldridge (1979a, b) and existing air quality constraints

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[2] For perennial crops, part of the rotations included either a "nurse" crop associated with establishment (e.g., barley for alfalfa) or young plants with reduced output (e.g., immature fruit trees). The proportion of each "nurse," or young, crop was based on the relative life of the main crop (e.g., one-fifth to one-seventh of the rotation was a nurse crop for alfalfa, which is replanted each five to seven years). Costs of planting were annualized; all water requirements and production levels were adjusted according to average yield data.

Table 1. Hydrological Study Units in Utah

HSU No.	Basin Name	Drainage
1	Western Desert	Great Basin
2	Bear River	Great Basin
3	Ogden River	Great Basin
4	Jordan River	Great Basin
5	Sevier River	Great Basin
6	Cedar-Beaver	Great Basin
7.1	Green River	Colorado River
7.2	Uintah River	Colorado River
7.3	Lake Fork	Colorado River
7.4	Rock Creek	Colorado River
7.5	Headwaters of Strawberry and Duchesne Rivers	Colorado River
7.W	White River in Utah	Colorado River
8.1	Price River	Colorado River
8.2	West of Colorado and East of Wasatch including the Colorado River inflows to Utah[a]	Colorado River
9	South and East of Colorado River	Colorado River
10	Virgin River	Colorado River
WY	Wyoming Inflow	Colorado River
CY	Colorado Yampa	Colorado River
CW	Colorado White	Colorado River

[a] Modeling the upper main stem would have required extensive data collection and was beyond the scope of this study.

for sulfur dioxide, nitrogen oxides, and particulates, the zones for potential coal-fired electrical power generation in Utah were identified (fig. 3). Other generation zones currently being considered by public utilities and/or other researchers included Kemmerer, Wyoming; Star Lake, New Mexico; Harry Allen at Las Vegas, Nevada; and two zones in California—Barstow and Cadiz.

Existing and potential coal fields, coal quality (sulfur, nitrogen, and BTU content) and costs of production were identified from U.S. Department of Interior and U.S. Department of Energy (1979a, b) publications as were alternative forms and routes by which coal is transported from mine sites to generation zones. There are significant increasing efficiencies in coal use as the size of the boiler units of a generation plant increases. The declining feed rates for each coal (tons of coal per megawatt hour produced) were estimated by Snyder et al., and separable constraints were used to approximate this feed rate for each coal source/generation site combination.

Pollutants—sulfur oxides, nitrogen oxides, and particulates—were produced jointly with electricity; the quantity of each depended upon the quality of coal and boiler efficiencies. Ambient air standards and the air quality models were used to establish the maximum emissions of each pollutant within each zone (Wooldridge 1979a, b).[3] Treatment activities and costs for each pollutant were based upon existing technologies (U.S. Department of Energy publications 1978a, b, 1979a, b; Utah Division of Public Utilities). Variable costs of treatment (labor, material, etc.) were included directly in the objective function. However, the fixed costs (plant construction and investments in treatment facilities) were treated in constraints requiring that at least the average return to investment allowed by public utility commissions (roughly 13%) be earned, as indicated by the "profitability" or "return to" constraint in figure 1.[4] Water requirements included both direct (primarily for cooling purposes) and indirect (the growth of municipal demands related to the levels of energy production). A total containment policy for blowdown water was assumed for electrical generation.[5]

Maximum demand for electricity was taken from U.S. Department of Energy estimates for northern and southern California, Nevada, Idaho, Wyoming, and Utah (the demand centers supplied by the production zones which were examined). These demands were not price dependent; prices for energy production were exogenous. Several sets of 1980 "real" prices have been examined in previous studies. New power production came "on-line" only at "real" bus-bar prices of 4¢ per kilowatt hour, which was about double the 1980 price. (See Utah Consortium for Energy Research and Education for a discussion of price levels, projected demand for, and production of energy.) Net profits from the energy sector, including both the coal and generation activities, were part of the objective function.

Synfuel production in Utah and Colorado

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[3] Other approaches to air quality regulations including mandated treatment practices (NEPA's Best Practical and Best Available Technologies) also were examined using the model; the results did not differ substantially from the ambient air standards with respect to efficient water allocations.

[4] Public utility regulatory agencies establish maximum profit rates and set prices accordingly. For this model, energy prices were exogenously determined, so that a minimum profit constraint was used, which implicitly suggests that generation facilities are built if, and only if, they can achieve at least the "maximum" profit allowed at a given price.

[5] Point sources of effluents are required to have secondary or tertiary treatment facilities which are prohibitively expensive compared to total containment approaches.

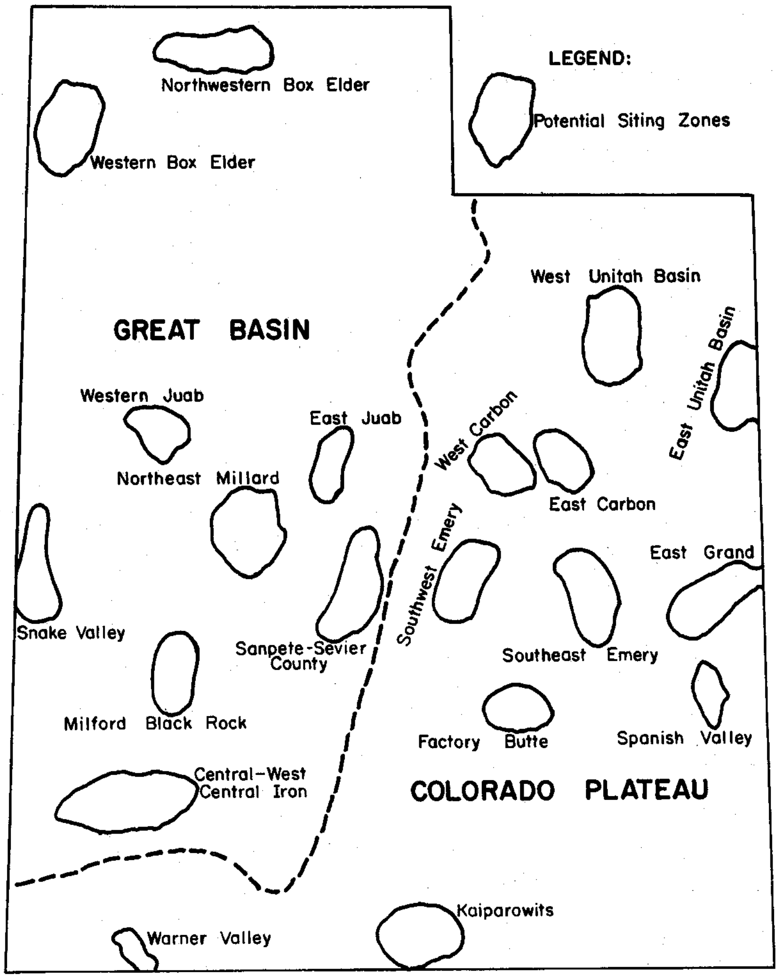

Figure 3. Potential electric power generating zones

(including oil shale, tar sands, and coal gasification) was also included in the model, even though none of these activities would have generated positive profits. The model used production projections for each of these activities from the U.S. Department of Energy and the State of Utah (Utah Consortium for Energy Research and Education). Projected water requirements for each of these activities is substantial, so that results from the model would overstate demands for water in the specific HSU in which the activity occurs if synfuels production does not occur.

Water Quantity

The water activities included water production in each HSU for each season, available groundwater, return flows from agriculture to both ground and surface water, outflows from one HSU to another, and evaporation. Since each "season"—the high runoff period from January to the end of June and the low runoff period from July to the end of December—is aggregated, it is implicitly assumed that some stream regulation occurs within each season. Because much of the early runoff occurs during the growing season (April through June), the intraseasonal regulation is probably of minimal importance. However, late season flow may be more crucial than the model indicates in any given month, week, or day, as a result of this implicit intraseasonal regulation. Because the model was large (approximately 10,000 variables and 4,000 constraints) and because each additional water "season" would double its size and require water availability data which was already sparse, further seasonal division of the model was not undertaken.

The model used a simple mass balance approach to calculate water availability in each HSU. The water quantity constraint for a given HSU included outflow activities from each upstream HSU (if any) and calculated the outflows from the given HSU from inflows, water production, consumptive use, evaporation, and return flows within the HSU. The right-hand side of each water quantity constraint was the local water production in each HSU. Outflow from the Upper Colorado River Basin at Lee's Ferry, Arizona (HSU 8.2), was constrained to a minimum of 7.5 million acre-feet per year (the current outflow minimum under the Colorado River Compact). This minimum outflow is based upon average annual water production in the Upper Basin and may be adjusted as long-term water production changes.

Costs of water included current (1980) operation, maintenance, and delivery costs for existing facilities (variable costs of use) and development costs for new storage (including 50-year annualized investment costs at 7.75% for both storage and main delivery systems; note that the discount rate was assumed to be lower than the private rate of interest for agricultural development, consistent with Water Resource Council guidelines). Storage linked early season flows to late season flows in each HSU; the variable and fixed costs associated with new storage were taken from existing Bureau of Reclamation and state water development agencies' cost estimates for various proposed projects adjusted to 1980 prices by the Construction Cost Index (Prentice-Hall).

Water Quality

The water quality analysis was limited to salinity, the most significant water quality problem in the Upper Colorado River Basin (Utah State University). Salt loading from both natural sources and irrigation was included. The latter was dependent on the characteristics of soil and runoff in each HSU and reductions in salt loading from available treatment activities. These treatments included canal lining and conversion to sprinkler irrigation systems, both assumed to be privately owned activities, although Franklin has suggested some public investment in salt treatment facilities might be economically justified. The costs for each type of treatment were included in the objective function. Current variable costs were included directly; fixed costs of investment were annualized also using a 7.75% interest rate (see Franklin; Keith et al. for a detailed listing of the costs). Reduced irrigation in regions of high salt loading (such as the Grand Valley region) also could result in reduced salinity. The maximum allowable concentration has been established for outflows of the Upper Basin by the Colorado River Basin Salinity Control Act (PL 92-320). In the model, concentration was converted to a variable constraint on salt loading relative to levels of outflow.

Probabilistic Water Availability

Two approaches may be used to examine the allocation effects of variability in water production: stochastic dynamic or chance-constrained programming. Stochastic dynamic programming characterizes the entire distribution of water availability. However, it requires a relatively large set of variables for each water source. Given the size and complexity of the study's linear programming model, the stochastic dynamic approach was infeasible. Chance-constrained programming, considering the water production right-hand side in each HSU as stochastic (as described in Taha, for example) was a more feasible alternative.

The amount of water produced in each HSU at given probabilities was estimated. Existing simulation models for the flow in each reach of the Basin which use historical flow data adjusted to account for consumptive use (such as the U.S. Bureau of Reclamation models) have been developed. These flow data are synthetic but have been calibrated using historic data. These flows generally are related to mainstem water flows and include upstream outflows as well as local water production. Given the structure of the programming model and the consumptive use and other adjustments in the simulation models, water production in each HSU was estimated directly. The programming model generated downstream total flows internally. The Bureau models were used to compare average seasonal water production within each HSU to the statistical estimations used in the study.

If seasonal flows are assumed to be independent (that is, water flow in one HSU is independent of climatic conditions in other HSUs), then the probability of the water production in the entire basin is a multiple of the probabilities in each HSU of the basin. Thus, a 90% probable seasonal water flow in each of the eleven HSUs in the Upper Colorado River would yield a probability of approximately 30% for the outflow from the basin. Conversely, a basin outflow representing a 90% probability would require a 99.1% probability of outflow in each of the upper basin HSUs, assuming equal probabilities in each HSU. Further, there are infinitely many combinations of drought events in the HSUs that would generate any given probable outflow.

The assumption of independence of drought conditions among HSUs seems unwarranted. Although no statistical study was made, the general historic meteorological and hydrological patterns for the past 40 years suggest that droughts in the Upper Colorado Basin tend to be general over all HSUs. However, it is also true that the variability of precipitation and water production over all HSUs does not exhibit perfect correlation. In order to be accurate, the correlations of water production among all HSUs and seasons would be required which was beyond the scope of the research. It was assumed, therefore, that climatic events in the Upper Basin were perfectly correlated; that is, a drought of a given severity (for example, water production consistent with a 90% certainty) would occur in every HSU. The approach used was to determine the drought events with given probabilities in each HSU, treat the associated water production as the right-hand side of the water availability constraint, and allow the model to solve for the optimal allocation of water. The term "90% probability" in this paper means that water production in each HSU would be equaled or exceeded with a 90% probability, yielding a drought condition of that severity. In effect, the distribution for each HSU was used to generate a "parameterization" of the constraints consistent with the given probabilities.[6]

In order to obtain the levels of water production for various probable events, an estimation of the distributions of water production for each HSU was required. Most of the gaged flows are not indicative of the variability of water production due to existing regulation and consumptive use upstream from the gage. In addition, because meteorologic data generally do not conform to an HSU's boundaries, rainfall data cannot be used to estimate water production and its variability for each HSU. Thus, it was necessary to apply the distributions of the gaged headwater flows (above any impoundments or consumptive use) to the total water production in an HSU. This "normalization" required knowing the mean seasonal water production for the entire HSU, finding the distribution of the headwater flows, determining the relationship between mean seasonal water production and the gaged headwater flows, and applying the headwater distributions to the total seasonal production from which the right-hand sides of the seasonal water quantity constraint could be obtained. Estimating distribution of water production at the headwaters was accomplished by using the USGS WATSTORE (1979) data tapes. Seasonal flow data were obtained for each HSU for the gaging stations above either storage facilities or significant human-related consumptive use for each stream in the HSU from the USGS tapes. For several of the streams in the region, only a limited number of years (three to five) of observations were available. The gaged flows, termed "headwater" flows (h_{ijk}), were summed over all j streams to obtain the headwater flows for the HSU (TH_{ik}):

$$TH_{ik} = \sum_{j=1}^{m} h_{ijk}, \tag{1}$$

where i is the HSU, k is the season, and j is the stream.

Several forms of the distribution function have been used in hydrologic modeling: normal, log normal, Weibull, and Gumbel distributions. In general, Haan suggests that the Weibull and Gumbel distribution functions perform best for extreme values, and the Weibull is particularly suited for minimum values. The gamma form of the Weibull distribution was used for this study. The two parameters of the density function associated with the incomplete gamma distribution function,[7] α and β, were estimated using the method of moments. There were no HSUs with an observed zero minimum flow; therefore, the minimum

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[6] The use of the probabilistic water production as right-hand-side values in the model is essentially a sensitivity analysis. Chance-constrained programming does not generate the expected values of losses or changes in allocations; rather, the solutions represent allocations under specifically constrained conditions.

[7] The incomplete gamma density function is:

$$f(x; \alpha, \beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad \text{for } x > 0; \alpha > 0; \beta > 0.$$

Table 2. Average Seasonal Surface Water Production by HSU (acre/feet × 10^3)

HSU	Season 1 January–June	Season 2 July–December
1	424.85	188.15
2	519.37	413.63
3	445.78	320.06
4	273.00	265.69
5	196.60	213.40
6	41.30	37.70
7.1	2,216.60	1,148.80
7.2	166.74	92.91
7.3	685.39	360.09
7.4	314.08	168.81
7.5	296.85	286.64
7.W	21.00	9.00
8.1	122.45	79.45
8.2	4,829.70	1,820.20
9	1,427.70	714.25
10	173.49	70.12
WY	1,114.23	682.97
CY	967.00	483.50
CW	345.20	177.15

Source: King et al.

observed seasonal flow in each HSU was used as the third parameter (lower bound) in the gamma function which gave the best overall fit for every HSU.

Then, the mean headwater values were normalized to the total seasonal flow for each HSU using the expected value of TH_{ik} (obtained from King et al. and listed in table 2) and a parameter, δi, which accounts for the unmeasured headwaters and other runoff produced in the HSU:

$$(2)\quad E(SF_i) = (1 + \delta_i)E(TH_i) = E(1 + \delta_i)TH_i,$$

where $E(.)$ is the expected value operator, and SF_i is the seasonal water production. In the best of cases, δ_i is low. For this study, *i* did not exceed 1.0 and was generally less than .25. Given equation 2, the variance of the seasonal water production is

$$(3)\quad V(SF_i) = E\{(1 + \delta_i)TH_i - E[(1 + \delta_i)TH_i]\}^2 = (1 + \delta_i)^2E[TH_i - E(TH_i)]^2,$$

where $V(.)$ is the variance operator.

Using the first two moments of seasonal water production, the distribution functions for water production in each HSU were estimated and the seasonal surface water production in each HSU for given probabilities was calculated, as indicated in table 3. In HSU 1, the data were insufficient to predict water production with any accuracy. The streams in HSU 4 (the Jordan River) are already highly regulated, and, given a normal carry-over in storage from the preceding year, there is sufficient water to provide the average flow even at a 95% probability. For these reasons, the two HSUs were omitted from table 3. In HSUs 3, 5, and 6, and in HSU 7.1 at the 90% and 95% probabilities, the "low" flow season produced more water than the "high" flow season. The seasonal average flows in HSU 5 followed a similar pattern, and the flows in each season for HSU 6 were almost equal. For HSU 3 and 7.1, these results were not expected; the anomalies are probably due to limited data for the

Table 3. Probabilistic Seasonal Surface Water Production by HSU in Utah (Acre/Feet)

	Season 1 (January–June)			Season 2 (July–December)		
HSU	85%	90%	95%	85%	90%	95%
2	337,210	285,143	261,619	280,956	256,891	223,907
3	216,960	183,642	141,265	238,393	222,640	200,633
5	103,440	89,154	70,651	154,378	142,215	127,709
6	16,898	13,731	9,869	18,660	15,858	12,278
7.1	13,663	10,337	6,579	12,410	10,815	8,726
7.2	117,229	108,039	95,351	67,859	63,092	56,456
7.3	542,198	513,427	427,734	230,242	207,615	177,011
7.4	194,441	174,025	146,612	68,496	55,550	39,791
7.5	199,298	181,741	157,739	214,183	200,920	181,466
7.W	11,835	10,366	8,433	5,489	4,796	4,103
8.1	59,580	51,440	40,880	21,234	16,086	10,263
8.2	1,231,670	893,040	52,280	1,160,030	1,045,240	890,060
9	658,370	550,310	414,540	342,368	288,769	220,949
10	51,922	39,144	34,769	43,679	39,149	33,060
WY	640,798	563,848	462,177	403,930	357,742	296,340
CY	357,608	283,685	194,773	169,435	132,694	89,594
CW	101,305	75,536	46,891	58,409	54,077	29,686

Table 4. Irrigated Acreages by HSU in Utah (Acres)

HSU		Base Total Acres	Base NSC Total Acres	85% NSC Change From Base NSC	90% NSC Change From Base NSC	95% NSC Change From Base NSC
1	Western Desert	13,803	40,000			
2	Bear River	212,000	237,548			
3	Ogden River	144,366	144,366			
4	Jordan River	179,478	179,478			
5	Sevier River	272,200	282,701		[6,800][a]	[26,700]
6	Cedar-Beaver	71,500	75,866	[3,120]	[3,120]	[3,120]
7.1	Green River	4,600	4,600			
7.2	Uintah River	20,000	20,000			
7.3	Lake Fork	21,000	21,000			
7.4	Rock Creek	36,000	36,000			(6,220)[b]
7.5	Strawberry and Duchesne Rivers	27,911	27,911			
7.W	White River, Utah	0	0			
8.1	Price River	17,944	18,000		[700]	[1,100]
8.2	West of Colorado and East of Wasatch	51,510	62,500			
9	South and East of Colorado River	9,585	11,442			
10	Virgin River	20,300	20,300	[3,400]	[3,400]	[3,400] (659)
WY	Wyoming	184,116	251,185			
CY	Colorado Yampa	36,374	36,374			
CW	Colorado White	5,753	22,371	(5,099)	[200] (5,503)	[1,500] (8,664)

[a] [acres] = acres reduced from full to partial irrigation.
[b] (acres) = acres eliminated from production.

gaging stations. The calculated water production was then used as the right-hand-side values for the surface water constraints for each HSU in the allocation model to determine the effect of drought on economically optimal water use.

Allocation Effects of Water Availability

In order to provide a base to examine the effects of drought, a solution for the average seasonal availabilities was obtained. Results for irrigated acreages are listed in table 4 under the column "Base." A small amount of salt treatment (conversion to sprinkler systems) was indicated in HSU 6. The model generated positive but relatively small shadow values for water (less than $10 per diverted acre-foot) in HSUs 1, 5, 6, 8.1, 8.2, 9, WY, and CW. These values are the result of insufficient flows to irrigate all available land and meet the nondegradation requirement imposed on salinity. The shadow values represent the marginal value of water in irrigation, as it is constrained by the limits on the salinity concentration. In the other HSUs, water quantity is not a constraining factor on either irrigation or salinity levels.

Next, the seasonal availabilities for the 85% probability level (the amount of water produced which would be equaled or exceeded with a probability of 85%) were used as right-hand sides for each HSU. The solution was infeasible because salinity concentrations in the basin outflows exceeded the quality constraints. There was insufficient water available in the Upper Colorado Basin to dilute the natural load, primarily because salt loading from natural sources does not decrease proportionately with water availabilities (Jeppson et al.). As less water was available (those flows associated with probabilities of 90% and 95%), the salinity standards became constraining.

A solution for a base case with no salinity constraint (NSC) was generated to provide an alternative and consistent comparison with reduced water availabilities. Given that PL 92-320 requires only a long-term average annual salinity level, the relaxation of these constraints in periods of low water production seems reasonable. There are some important differences between the Base NSC solution and the Base solution. The agricultural land presently under irrigation (Classes I, II, III, and irrigated pasture) was increased in most cases to existing (1979) maximums, and the amount

Table 5. Shadow Price of Water ($ per Acre Foot)

		Season 1 (January–June)				Season 2 (July–December)			
HSU		Base Case	85%	90%	95%	Base Case	85%	90%	95%
5	Sevier River[a]	4.41	5.27	5.27	5.27				
6	Cedar-Beaver[a]	6.13	6.13	6.13	6.13				
7.5	Headwaters of Strawberry and Duchesne Rivers					0.00	0.74	7.78	9.14
7W	White River, Utah					0.00	0.00	6.34	19.87
8.1	Price River	1.40	2.26	2.26	2.26	1.40	26.28	34.08	34.09
10	Virgin River	0.00	0.00	0.00	4.77				
CW	Colorado White					0.00	0.00	6.34	19.87

[a] Note that since water availability is least in the early or "high" flow season in HSUs 5 and 6, the shadow price is positive in that season.

of water application (partial irrigation to full irrigation) was also increased (table 4). These differences imply that, as energy development takes place, a nondegradation salinity constraint will require some reductions in irrigated agriculture, assuming no major public involvement in salinity management. Accompanying the increases in irrigation was a drop in the shadow price of water to zero in all HSUs except 5, 6, and 8.1 (table 5). Energy production, with its relatively high marginal value of water, remained the same for both Base NSC and Base solutions (table 6). One implication of these results is that marginal agriculture cannot generate profits sufficient to pay for treatment of the associated increased salinity. A second is that, as energy production or other water-using activities increase, water quality (salinity in the case of the Upper Colorado River Basin) may be far more constraining than water availability.

With reductions in surface water production (to 85%, 90%, and 95% probabilities), there was no decrease in irrigated acres with the exception of HSUs 6, 7.4, 10, and CW. Other than in HSU CW, the reduced acreage was in irrigated pasture (the least profitable, least productive activity). The remaining reduction in water use resulted from changes in water applications (full to either partial irrigation for two seasons or irrigation for only one season on alfalfa and irrigated grain) instead of re-

Table 6. Electrical Production (MWH)

Plant	Base Total MWH	85% NSC Change From Base	90% NSC Change From Base
East Juab	10,735,200	46,800	46,800
East Uintah Basin	665,780		
Sanpete Sevier	2,690,040		
Warner Valley	2,817,149	(309,223)[a]	(72,006)
Western Box Elder	1,752,000	(1,687,016)	(1,687,016)
Northwest Box Elder	3,832,398	243,532	6,305
Northeast Millard	5,693,816		
Milford-Black Rock	2,944,668		
Iron	864,578		
Southeast Emery	750,887		
West Carbon	2,295,393		
East Carbon	1,721,545		
Southwest Emery	1,147,696		
East Grand	210,220		
Harry Allen	723,440		
Star Lake	34,063	(124)	(124)
Barstow	419,629	979,134	979,134
Cadiz	6,590,086	707,564	707,564
Kemmerer	3,190,997	19,228	19,228

[a] ( ) Indicates production decrease.

duced acreages (table 4). Profits forgone increase as a result of decrements in water availability in the HSUs in which water quantity becomes constraining, as evidenced by the increases in shadow prices (table 5), although the values are relatively low in all but one HSU.

As surface water production was reduced, the potential for storing any excess early season runoff was available in the model. Storage entered the solution only in HSU 8.1 (Price River) at 90% and 95% probabilities. These results indicate that, in general, agriculture is not profitable enough to justify the development of new storage. In HSU 8.1, the existence of coal-fired electrical production (East and West Carbon) and a coal gasification plant reduced water availability so that only the highest valued crops (particularly corn) and best available land were in production in the Base NSC case. Thus, the shadow value of water was correspondingly high in that HSU. Even with the best land, only 620 and 6,443 acre-feet of storage were indicated at the 90% and 95% probability levels, respectively. Clearly, as energy or other high-valued users of water develop, water variability likely will result in transfers of water from irrigation of small grains, hay, and pasture to the developing uses so long as those transfers are permitted. Typical irrigated crops in the Intermountain West are not sufficiently valuable to pay for storage developments to insure water supplies, particularly at the margin. Water rights sales from irrigators to the Intermountain Power Project in the Sevier River Basin support this conclusion.

Electrical production was redistributed as water availability changed (table 6). For the 85% probability level, a shift of electrical production occurred from Western Box Elder in Utah to the Barstow and Cadiz sites in California. Some smaller shifts also occurred within the Utah sites. Only minor shifts occurred with the reduction of water availability to the 90% probability, and none occurred with further reductions of water production. These shifts resulted from the very small difference in electrical generation profitability among the various generation sites and coal-source combinations coupled with changes in the profitability of irrigated agriculture (the opportunity cost of water in energy production). It is not certain that shifts in electrical production sites actually would occur; rather, the similarity of production costs is itself of interest. The model results suggest that variables other than water likely will be the significant influences on the location of new electrical generation plants in the Upper Colorado River Basin.

Solutions were obtained for the case in which no interstate transfers of water were allowed (the current legal situation). This was accomplished by limiting water use in each state to that prescribed by the Colorado River Compact and the judicial decrees pertaining to it. No significant changes in allocations occurred under the reduced water production scenarios. Thus, while the prohibition of interstate transfers is currently the legal standard (recent court action in Colorado prohibited storage rights in Colorado to be sold to California demanders), such restrictions are not likely to cause serious problems for energy development in the Upper Colorado River or Great Basins. This is generally the result of the local transfer of water from irrigation to energy.

In an effort to determine those conditions under which added storage capacity would be developed in the Colorado River Basin in Utah, an examination of proposed storage development on the White River in Utah was undertaken. The White River in Utah has no irrigation from which to transfer water and has been frequently labeled one of the most "water short" river basins in Utah. Storage would provide water for proposed oil shale production, for which water provision was a predetermined requirement.[8] Only under the most stringent of circumstances did this storage enter the solution; when water production was reduced to six times the smallest monthly flow in each season, interstate water transfers were prevented, and water sales from Native American water rights were prohibited, a significant amount of new storage (20,000 acre-feet) entered the solution. The water availability used represents a more conservative estimate than a 100% probability level of water production. Thus, storage development seems unwarranted, even under relatively stringent circumstances, as long as institutions provide even limited flexibility of water rights transfers. It is highly likely that similar results would be found in all other HSUs, since all contained irrigation water which could be transferred, and cropping included considerable acreage in small grains, hay, and pasture.

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[8] There is little or no data on which to estimate values of the marginal profit for oil shale or any of the included synfuels.

Conclusions and Recommendations

The results from the chance-constrained model indicate that, in general, water quantity is not a significant constraint in regional economic growth in the Upper Colorado River Basin and the Utah portion of the Great Basin, particularly if water rights are relatively freely transferable. Even under the most severe case examined, where water production was consistent with a 95% probability, only marginal changes in irrigated agriculture were evidenced while major production increases in energy sectors were indicated. The Sevier River and Colorado portion of the White River were the only basins with reductions in irrigation on more than a few thousand acres and on lands of more than the lowest productivity classes.

Water quality constraints appear to have a significant impact on agriculture as energy development occurs, particularly since private salinity treatment programs appear to be economically infeasible. Only a publicly financed system could be expected to counteract the concentrating effects of energy development, and it appears from the model results that those programs probably are not economically justifiable.

The development of new storage also appears to be unwarranted because the water user with the lowest marginal value, irrigated agriculture, cannot afford to pay the costs of construction and operation. If water rights transfers between agriculture and energy are severely restricted, it is possible that storage would be indicated for cases in which some reduction in energy production or high-valued crops might occur.

Results appear to indicate that, at least in the near term, other impediments to large scale energy development are more important than water availability in the Upper Colorado and Great Basin regions even under drought conditions. If water markets or water banks were implemented, it would be likely that irrigators would sell or lease water rights to energy producers at more than the water's marginal value in irrigation (as was the case in the Sevier Basin for the Intermountain Power Plant). Alternative water applications, such as partial irrigation, might be expected to mitigate some of the water transfer. Given that the types of crops grown in the river basins studied are typical of many areas in the Intermountain West, it is likely that these results could be generalized to most of the Intermountain West.

A closer examination of the effects of water quality standards, particularly nondegradation rules, on economic growth in the Upper Colorado and Great Basins appears to be warranted. Model results appear to indicate that salinity constraints are more binding than water availability in the base case (using average availabilities) and would become even more binding as water production is reduced, if quality standards are not adjusted to flows.

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