WATER RESOURCES BULLETIN
VOL. 31, NO. 5 AMERICAN WATER RESOURCES ASSOCIATION OCTOBER 1995

COMPETING WATER USES IN THE SOUTHWESTERN UNITED STATES: VALUING DROUGHT DAMAGES[1]

James F. Booker and Bonnie G. Colby[2]

ABSTRACT: Economic benefit functions of water resource use are estimated for all major offstream and instream uses of Colorado River water. Specific benefit estimates are developed for numerous agricultural regions, for municipal uses, and for cooling water in thermal energy generation. Economic benefits of hydropower generation are given, as are those for recreation on Colorado River reservoirs and on one free-flowing reach. Marginal and total benefit estimates for Colorado River water use are provided. The estimates presented here represent a synthesis of previous work, providing in total a comprehensive set of economic demand functions for competing uses of Colorado River water. Non-use values (e.g., benefits of preserving endangered species) are not estimated.

(KEY TERMS: water demand; drought; economic benefits; irrigation; municipal water demand; recreation; hydropower, salinity.)

INTRODUCTION

Water resources provide critical services to a wide range of consumptive and non-consumptive users in the southwestern United States. Water is consumptively used for irrigation of crops, and for municipal and industrial purposes in cities and towns, including cooling water for thermal electric generation. Instream flows (derived largely from storage in regional reservoirs) generate hydropower, provide unique habitat, and are required for a variety of recreational activities. While total benefits from use of all regional water resources might possibly be estimated, our purpose here is more modest. We are concerned primarily with estimation of damages (lost economic benefits) resulting from a range of marginal or incremental reductions in water availability, and also with examining water users' incremental adjustments to drought-induced water reductions.

We focus on those activities in the southwestern United States which typically utilize water from the Colorado River Basin, the dominant water supply for the region. Basin water can be delivered to a population of over 25 million across seven states, from Wyoming to California. Total consumptive use exceeds 10 million acre-feet (maf), with an additional 1.5 maf used in northern Mexico. Hydropower sufficient for the electricity needs of 4 million residential users is generated by water released from Basin reservoirs. The same reservoirs are also major recreational attractions, with approximately 17 million visitor days per year. Fishing and rafting on the mainstem and tributaries provide further benefits.

We value these sometimes competing uses of Basin water by developing economic benefit functions for the major uses. Economic benefits of consumptive use in agricultural, municipal, and energy sectors at a number of locations are first estimated. Many of these uses are affected by high concentrations of dissolved minerals (salinity) in Colorado River water which cause damages to water-using appliances in municipal uses, and reduce crop yields in irrigation uses. Damage estimates from a prior study by one of the authors (Booker and Young, 1991) are used to value these salinity damages. Economic benefit estimates for instream, non-consumptive uses (hydropower and recreation) are also developed. While instream flows provide general and critical habitat for a rich spectrum of Basin wildlife, no attempt is made to place an economic value on habitat for endangered or other species. Similarly, other non-use values are not treated.

---

[1] Paper No. 95032 of the *Water Resources Bulletin*. **Discussions are open until June 1, 1996.**

[2] Respectively, Assistant Professor, College of Business, Alfred University, Alfred, New York 14802; and Associate Professor, Department of Agricultural and Resource Economics, University of Arizona, Tucson, Arizona 85721.

Specific approaches to measuring economic benefits for each use are developed here and applied to evaluate the foregone benefits (damages) during drought. The benefit estimates presented here are largely based on previously reported research. Our primary contribution is the synthesis of studies by numerous authors covering a variety of offstream and instream uses. The result is a complete set of economic benefit functions suitable for use in estimating economic damages of reduced water resource availability in the southwestern United States. All monetary values are given in 1992 dollars.

We identify only the direct economic damages from drought. Additional indirect damages will occur through reductions in regional purchases and employment resulting from drought. For example, shortages of irrigation water may result in a failure to produce an agricultural crop. The resulting income loss to the landowner is the direct economic damage of drought reported by this study. Lost wages to farm workers and lost income to regional businesses supplying (or purchasing from) irrigated farms are termed indirect or secondary economic impacts. While potentially significant to local and regional economies, indirect impacts to national economies are zero under conditions of full employment. Because regional links to the national economy are not identified here, only partial equilibrium analysis of direct economic impacts is possible [see Brookshire *et al.* (1993) for a discussion of indirect and general equilibrium impacts of regional water supply reductions].

DEVELOPING ECONOMIC DEMAND FUNCTIONS FOR CONSUMPTIVE USES

Consumptive uses include irrigated crop production, provision of household services such as showers and landscaping, and evaporative cooling in industrial processes such as electric power generation. Consumptive use of Colorado River water is assigned to one of three sectors: agricultural, municipal, or energy use. Within each sector a single methodology is followed in developing economic demand estimates for water use. Economic demand estimates for actual offstream diversions are developed by scaling each regional, sectoral demand estimate to depletion data originally developed for use in the U.S. Bureau of Reclamation (USBR) Colorado River Simulation Model (1991) and modified for this study.

Agricultural Demand Functions

Water demand functions which summarize the direct marginal economic benefits of utilizing irrigation water from the Colorado River are derived here from linear programming models of regional irrigated agricultural production. Several independent modeling efforts were utilized in developing the comprehensive set of benefit functions presented here. For consistency, all water use figures given in the original modeling efforts were converted to consumptive use figures, with benefit estimates updated to 1992 dollars using the GNP price deflator.

Linear programming models frequently require the use of ad hoc crop flexibility constraints to calibrate predicted crop acreage to observed crop acreage (as reported in state crop summary reports, for example). In several of the studies used here, lower bounds on crop acreage resulted in models giving unreasonably high predictions of damages from reductions in crop production caused by irrigation water shortages. Uncritical acceptance of such estimates would suggest unrealistically inelastic water demand functions, and hence unrealistically high marginal water values at large reductions from existing use levels. Because the underlying calibration constraints which cause this difficulty vary greatly between studies, an attempt was made to correct for this effect. First, an estimate of the average benefit of irrigation water use was developed to help identify artificially high damage estimates (e.g., greater than \$100/acre-foot (af) in Upper Basin uses). Because agricultural land values implicitly reflect the average value of water in irrigated crop production, average benefits of irrigation water use were estimated from state land values (U.S. Department of Agriculture, 1990) using average irrigation water requirements for each state (U.S. Department of Agriculture, 1992). A 4 percent discount rate was used to calculate annualized irrigated land values. Reported marginal water values (shadow prices) which exceeded the average estimated water value by more than 20 percent at greater than 50 percent of full water supply were then excluded from the benefit function estimates reported here.

After adjustments for the programming artifacts described above, water demand (marginal benefit) schedules were developed from the reported programming solutions for each region. For any particular region, this initial demand schedule frequently included marginal values estimated from several studies. From this initial schedule a single marginal benefit, or (inverse) demand function of the form

$$p(x) = p_0 \, (x/x_0)^{\alpha} \tag{1}$$

for $0 < x \leq x_0$, was estimated by least squares regression. In Equation (1), x_0 is the maximum water delivery, p_0 is the willingness to pay for addition water at full delivery, and α is the inverse of the price elasticity of demand. The Cobb-Douglas form was chosen because it successfully fit most demand schedules constructed for this study; linear demand functions were particularly limited in capturing the nonlinearities in most schedules. The range of R^2 for the 11 estimated functions was 0.55 to 0.95; $R^2 \geq 0.8$ and 2 to 3 degrees of freedom were typical. The underlying demand schedules included meaningful marginal benefit values for use reductions to approximately $0.5\ x_0$. Use of the estimated demand functions for greater water use shortfalls would require extrapolating beyond any data available to this study.

Total benefit functions were also desired as a baseline from which to measure drought damages. Because the estimated (inverse) demand functions have little empirical content below 50 percent of full water delivery, however, simple integration of Equation (1) is inappropriate. Instead, the average water values described above were utilized to derive total benefit functions $V(x)$ such that $V(x_0) = x_0\ \overline{v}$, where $\overline{v}$ is the average benefit (in $/af) from irrigation water use calculated from irrigated land values. By maintaining that the estimated demand functions do not hold for low water use, the problem of nonconvergence of an inelastic Cobb-Douglas demand function is also avoided. Table 1 gives estimated total benefit functions, average water values, elasticities, and marginal water values at full delivery, for 11 agricultural regions covering agricultural users of basin water.

Because the studies on which Table 1 is based were published over a broad time span (1973 to 1988), there was concern that real changes in agricultural water values might have resulted from changes in farm income due to trends in output versus input prices, and technological change. Our data showed no evidence of real changes in marginal water values, however: adjusting marginal water values for changes in reported farm income (U.S. Department of Agriculture, 1984, 1991) did not decrease variances across studies.

Central and Southern Region. The region includes uses in portions of Colorado, New Mexico, and Utah. Studies by Booker and Young (1991) for the Grand Valley; Oamek (1990) for the mainstem of the upper Colorado, the Gunnison, and the Dolores; and Howe and Ahrens (1988) (similar regions to Oamek) were utilized in part to develop the water demand functions. Irrigation uses in the San Juan River Basin are also included. Demand estimates for the region by Oamek (1990) and Howe and Ahrens (1988) were used, together with estimates at three sub-regional elevations by Gollehon *et al.* (1981).

Northern Region. The region includes uses in Wyoming (mainstem of the Green River) and portions of Colorado and Utah. Tributary uses on the Yampa, White, Duchesne, Price, and San Rafael Rivers are included. Four previous studies are available from which to estimate the water demand functions. Marginal values are given by Anderson (1973) for the Uintah Basin in Utah; by Gollehon *et al.* (1981) for

TABLE 1. Estimated Agricultural Total Benefit Functions.*
Average water values, elasticities, and marginal water values at full delivery for each use (1992 dollars).

Agricultural Region	v_0 ($/af)	β	Proportion of Non-Colorado River Water Used $x_n/(x_n + x_0)$	Average Water Benefit $\overline{v}$ ($/af)	Marginal Value at Full Use p_0 ($/af)	Price Elasticity of Demand**
Western Colorado	–16.3	–0.75	0.000	30.6	12.2	–0.57
Colorado Front Range	–10.8	–1.24	0.873		13.4	–0.45
Wyoming	–23.6	–0.53	0.000	14.2	12.5	–0.65
Utah	–23.6	–0.53	0.000	37.8	12.5	–0.65
New Mexico	–16.3	0.75	0.000	51.2	12.2	–0.57
San Juan-Chama Export	–16.3	–0.75	0.800		12.2	–0.57
Nevajo IIP	57.8	0.93	0.000	51.2	53.9	–14.77
CAP	46.0	0.59	0.725		27.1	–2.44
Colorado River Indian Tribe	32.9	0.44	0.000	36.3	14.5	–1.79
Yuma	83.2	0.24	0.100		20.0	–1.32
California	–29.5	–0.92	0.000	39.4	27.2	–0.52

*Use of parameters v_0, β, x_n, x_0, $\overline{v}$ and p_0 in the total benefit function is described in the text.

**If non-Colorado River supplies are available, this elasticity holds only at full water delivery.

Routt and Moffitt Counties in Colorado (Yampa and White Rivers) and Uintah and Duchesne Counties in Utah (Green and Duchesne Rivers); by Howe and Ahrens (1988) for the Yampa and White Rivers and the Green River above the Colorado; and by Oamek (1990) for this entire "Northern region" (his "PA 82"). Weighted averages (based on consumptive use) are used to aggregate sub-regional estimates of Howe and Ahrens (1988) and of Gollehon *et al.* (1981) to the regional level, while estimates from Anderson (1973) and Oamek (1990) are used directly.

Colorado Front Range. Irrigated production on Colorado's eastern plains makes use of transmountain water exports from the Colorado River Basin. Demand for agricultural water was estimated from a minor revision of the model of northern Colorado agricultural production presented in Michelsen (1989). Crop flexibility constraints were modified in order to allow estimates of damages from up to 50 percent reductions in water use.

California. Estimates from a programming model developed by Booker and Young (1991) are used as the basis for water demand functions for California users of Colorado River Basin water. This model focused on irrigated production in the Imperial Valley, the major user of Colorado River water in southern California.

Arizona. Water demand functions for three distinct users in Arizona (Yuma, Colorado River Indian Reservation, and Central Arizona) were derived from the farm-level programming results obtained by Peacock (unpublished manuscript, Dept. of Agricultural and Resource Economics, University of Arizona, 1993). Two representative farms in the Yuma region were modeled, one with field crops only and one with both field and vegetable crops. A third representative farm, growing mostly cotton, was modeled using the enterprise budget given in Wilson (1992).

Net benefit functions were derived from point estimates of benefits in each of the three models. A portfolio of the three farms which best matched county acreages (minimized the sum of squared deviations from estimated crop acreages) of cotton, wheat, alfalfa, and vegetables was then constructed. A programming model of water allocation within each region was developed to estimate regional benefits from water use. Effective markets within regions were assumed, allowing reallocations among the three farm types when diversions were less than 100 percent. The resulting regional net benefit point estimates were then re-estimated to give a continuous function representing regional benefits.

Municipal Demand Functions

Municipal demand estimates were derived for major southwestern cities, including Phoenix/Tucson, Denver/Front Range, Salt Lake City, Las Vegas, Albuquerque, and the Metropolitan Water District (MWD) service area in southern California. A single cross-sectional study of seasonal household water demand (Griffin and Chang, 1991) was used as the basis for deriving the set of unique but methodologically consistent benefit functions for each municipal region. The approach was based on the observation that the proportion of outdoor to indoor uses varies across regions as a result of climate differences and socioeconomic factors. Summer and winter elasticities of -0.41 and -0.30 reported by Griffin and Chang (1991) for their generalized Cobb-Douglas estimate were used. Following Howe (1982), these are converted to indoor and outdoor elasticity estimates of -0.30 and -0.58. For example, using this procedure with data on indoor and outdoor use in Phoenix and Tucson gives average annual elasticities of -0.43 and -0.39, respectively. These are similar to the range of average elasticities (-0.27 to -0.70) reported in several studies by Billings and Agthe (1980) and Martin and Kulakowski (1991) for Tucson, and Planning and Management Consultants (1986) for Phoenix, as well as the range reported in the numerous other studies on this topic. Municipal demand functions were then estimated using the *average* water prices and use levels for 1985. Table 2 summarizes marginal and total benefit function estimates for Basin municipal uses.

Thermal Energy Demand Functions

Water is used for cooling water in thermal electric generation throughout the Southwest. A single benefit function for cooling water at thermal electric power generating facilities was re-estimated from data on costs of alternative cooling technologies presented in Booker and Young (1991). Actual long-run benefits may tend to be overestimated using this approach, given the possible availability of local ground water for use in cooling. The avoided cost approach may underestimate short-run damages from water shortages, however, given the necessary capital investments for use of water conserving cooling technologies. The estimated benefit function for cooling water use is $V(x)= x_0 v_0 (x/x_0)^{\beta}$, where $v_0 = \$222/\text{af}$, $\beta = -.070$, and $0 < x \leq x_0$. The benefit function implies a marginal water value of $155/af and price elasticity of demand equal to -0.59 at full delivery.

TABLE 2. Estimated Municipal Benefit Functions,* Elasticities,** and Marginal Water Values at Full Delivery for Each Use (1992 dollars).

Agricultural Region	v_0 ($/af)	β	Proportion of Non-Colorado River Water Used $x_n/(x_n + x_0)$	Marginal Value at Full Use p_0 ($/af)	Price Elasticity of Demand
Denver	–373	–1.22	0.602	455.1	–0.45
Central Utah Project	–369	–1.23	0.884	453.9	–0.45
Albuquerque	–298	–1.61	0.495	479.8	–0.38
Las Vegas	–318	–1.27	0.050	403.9	–0.44
Central Arizona	–277	–1.31	0.626	362.9	–0.43
MWD (South California)	–211	–1.63	0.608	343.9	–0.38

*Use of parameters v_0, β, x_n, x_0, and p_0 in the total benefit function is described in the text.

**Because non-Colorado River supplies are available, elasticities given are at full water delivery.

Consumptive Use Depletion Requests

Full economic demand functions for consumptive use of Colorado River water are found using the demand estimates presented above together with USBR (1991) depletion data. The USBR data set gives the legal entitlements for consumptive use and is used to define a "full" delivery depletion schedule for each Basin use. This is the only source for spatially disaggregated estimates of Basin depletions, and it is the starting point for the consumptive use inputs in the modeling of drought impacts by Harding *et al.* (1995), Booker (1995), Henderson and Lord (1995), and Sangoyomi and Harding (1995), all reported in this issue.

The actual depletion schedule used in these studies modifies the USBR schedule by holding agricultural depletions constant at 1992 levels and shifting the Central Arizona Project (CAP) schedule back six years (from 1992 to 1986) to reflect recent low deliveries. CAP deliveries in excess of 1,248 thousand acre-feet (kaf) per year (surplus deliveries) are not included because there is little evidence of demand for these deliveries (Wilson, 1992). The Las Vegas depletion schedule is allowed to increase with population, irrespective of Nevada's limited Colorado River Compact entitlement. The total adjusted increase in depletion schedules for the period 1992 to 2030 is approximately 10.5 percent (1,350 kaf). Synthetic fuel development accounts for 233 kaf of new depletions. The annual growth rate in depletions is less than 1 percent, in contrast to U.S. Bureau of the Census (1990) projections of population growth of 1.2, 1.8, and 0.9 percent annually from 1990 to 2010 for California, Arizona, and Colorado, respectively.

Derivation of Total Benefit Functions

Estimation of total (direct) economic benefit functions for consumptive uses requires scaling demand functions to the level (scheduled depletion x_0) of each use, treatment of alternative water supplies, and use of additional data where demand functions are not defined for very low use levels. If the (inverse) demand function given in Equation (1) holds for $0 < x \le x_0$ (and the price elasticity is not inelastic), then the total benefit V(x) of water use x is found directly by integration of Equation (1), giving

$$V(x) = x_0 v_0 (x/x_0)^{\beta} \qquad (2)$$

where $v_0 = p_0 / (\alpha + 1)$ and $\beta = \alpha + 1$. Equation (2) is typically an oversimplification, however. First, most water users (particularly municipal and energy) have available an alternative water supply source (e.g., ground water). For simplicity, it is assumed that this alternative source is the inframarginal source and that a fixed amount is always utilized. Second, for agricultural water uses, Equation (2) holds only for $x/x_0 \ge 50$ percent of total requests because of limitations in the underlying data. In this case, additional data is needed to complete the integration.

Adjustment for Non-Colorado River Water. If a particular use has water available from a non-Colorado River source, then Equation (2) describes not the benefit from Colorado River use, but instead the benefit from all use. This is shown in Figure 1 where (a) shows the total benefit function V(x) from all sources; the solid line in Figure 1 is a total benefit function for Colorado River use alone, assuming that other supplies are inframarginal. It is desirable to set the total benefit $V_c(x')$ from use of Colorado River water x′ to zero for x′ = 0, as shown in Figure 1(b). Mathematically, the benefit $V_c(x')$ from use of Colorado River water x′ is then given by

$$V_c(x') = (x_n + x_0)\, v_0\, [((x_n + x')/(x_n + x_0))^\beta - (x_n/(x_n + x_0))^\beta] \qquad (3)$$

where x_n is the consumptive use of non-Colorado River water which serves as the inframarginal supply and x_0 is the maximum use (the depletion schedule) for Colorado River water. Note that the total benefit from Colorado River use $V_c(x_0)$ is now implicit in Equation (3) and is given by $V(x_0 + x_n) - V(x_n)$. The demand for Colorado River water is more elastic than the demand from all sources and is non-constant.

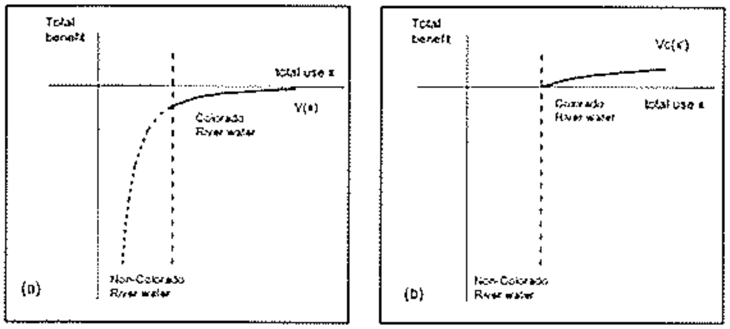

Figure 1. Benefit Function V(x) When Demand is Inelastic for Consumptive Use x from All Sources (a). In (b), $V_c(x')$ is the Benefit Function for Colorado Water Only.

Use of Average Water Use Benefits. It is useful to have an estimate of the total benefit from Colorado River water where (economically feasible) alternatives are not available. Because the agricultural benefit functions given in Table 1 hold only for $x/x_0 \geq 50$ percent, total benefit functions cannot be found solely from Equation (2). For agricultural users, the average benefit of water use $\bar{v}$ in \$/af is available, however. The total benefit $V_a(x)$ of use x can then be expressed as

$$V_a(x) = x_0\bar{v} - x_0 p_0 \int_x^{x_0} (x'/x_0)^\alpha \, dx' \qquad (4)$$

where $x_0\, \bar{v}$ is the total benefit at full requests x_0, and the integral gives the loss suffered by the irrigator from deliveries below x_0. Evaluating the integral gives

$$V_a(x) = x_0\, (v_0\, (x/x_0)^\beta + \bar{v} - v_0) \qquad (5)$$

The marginal benefit functions (Equation 2) and elasticities are not altered by addition of the constant $x_0\, (\bar{v} - v_0)$ to Equation (3).

RECREATION DEMAND

Water-based recreation is an important part of many Westerners' leisure activities, and water-related recreation opportunities draw visitors and tourism dollars to the western United States. Instream flows are vital in preserving fish and wildlife habitat in the arid West and in endangered species restoration. As diversions of water for offstream irrigation and for industrial and residential deliveries have increased, flow levels on many stream systems have decreased to the detriment of instream water uses. The droughts of the 1980s focused further attention on the negative effects of depleted streams and lake levels for recreation, fish, and wildlife.

Measuring Economic Impacts of Instream Flow Protection

Policy makers can make more informed decisions about stream and reservoir management and water allocation if they know the economic benefits provided by a stream system for various activities such as angling and whitewater rafting. Information on the effects of specific changes in water levels also is desirable when considering the economic impacts of drought-induced changes in stream flows and reservoir levels. Since there is limited direct-market evidence on willingness to pay for water-based recreational opportunities and for fish and wildlife preservation, a variety of valuation approaches have been applied to estimate the value of water for these purposes. Marginal benefit functions for recreation can be estimated using information on recreationists' expenditures to travel to and enjoy a water-based recreation site by using the travel costs method (TCM). Alternatively, data can be elicited from recreationists regarding their willingness to pay for recreational use of a river at differing flow levels by using the contingent valuation methods (CVM). The TCM has been used for decades to infer the value that visitors to a recreation area put on the site. The CVM has been refined and applied widely during the past decade to estimate benefits associated with site use and changes in site quality, including changes in flow levels. CVM also is used to measure willingness to pay for preservation that is not associated with actual use of an area. These non-use values arise as people experience benefits from preserving a site or a species that are not associated with a visit to the site or with viewing the species. Estimation of non-use values, which may be quite large, is outside the scope of this research (see Brookshire *et al.*, 1986; Cummings *et al.*, 1986; and Sanders *et al.*, 1990; for discussions of CVM and non-use values). Cummings and Harrison (1995) discuss the components of non-use values.

Reservoir Recreation Benefits

Although water-based recreation resources provide substantial non-market benefits to users, reservoir recreation has received little attention relative to other water uses. Reservoir operations have been primarily aimed at meeting water demands for consumptive uses and power generation, and few studies have attempted to assess the impacts of reservoir level fluctuations on water-based recreation opportunities.

Use of Basin reservoirs is believed to be a declining function of reservoir content or area. Little empirical work has been done in this area, however. One study by Ward and Fiore (1987) of visitation to New Mexico reservoir sites used the square root of reservoir area as an explanatory variable for observed differences in visitation at different reservoirs. No attempt was made to examine the impact of changes in reservoir levels over time with changes in visitation, however. Simple models of Colorado River Basin visitation data for 1980-1992 did not provide a basis for adopting any specific functional relationship, perhaps because of inadequate representation of substitute sites or because of limited reservoir fluctuations over a time period of increasing demand for recreational opportunities (and changes in reporting procedures). We have assumed, for purposes of this study, that visitation at each Basin site declines as the square root of the volume of each reservoir but that use benefits for each visitor are unchanged as reservoir level changes.

Annual visitation to seven Colorado River Basin reservoirs is estimated at 17 million visitor days, based on data provided by the Glen Canyon National Recreation Area (Gediman, personal communication, 1993) and the Lake Mead National Recreation Area (Warner, personal communication, 1993) and supplemented by the Upper Colorado River Commission (1992). Visitors typically engage in boating, fishing, and swimming. The economic benefits received by visitors to Basin reservoirs were estimated using existing studies of use values at specific Basin reservoirs supplemented by a literature summary (Walsh *et al.*, 1988). An average visitor day value for each reservoir was developed using separately calculated values for fishing and all other uses. The average recreational value per visitor day at each reservoir was then found as the weighted sum (weights based on data from Gediman and Warner) of values from each activity. Data sources and recreation visitor day values at Basin reservoirs are summarized in Table 3. In many cases alternative estimates of visitor day values are available for specific sites [e.g., Johnson and Walsh (1987) for Blue Mesa reservoir] which give similar values per visitor day to those reported here. In all cases the final estimated values are similar to the averages reported by Walsh *et al.* (1988).

Free Flowing Reach Recreational Benefits

Recreational use for fishing, boating, and hiking on free flowing reaches (defined here as those not impounded by reservoirs) of the Colorado River mainstem and tributaries also provides economic benefits to users. Because comprehensive data on the dependence of use levels and economic benefits to users on river flows is limited, this study only provides benefit estimates for use between Glen Canyon Dam and Lake Mead.

Recreation below Glen Canyon Dam is dominated by day users rafting and fishing in the relatively calm reach 15 miles below the dam and above the Lees Ferry boat launch, and by multi-day whitewater rafting trips through the Grand Canyon. A study commissioned by the Department of Interior (Bishop *et al.*, 1989) as a part of the Glen Canyon Environmental Studies (a multi-agency study effort providing information on the impacts of Glen Canyon Dam operations) indicates that benefits generated by whitewater rafting and fishing (day use) are significantly influenced by river flow levels. The study used the CVM and found that benefits per fishing day reach their peak of $51/visitor day at a constant flow level near 10,000 cubic feet per second (cfs) and that fluctuations in flows (which occur when peaking hydropower is generated) cause a decrease in fishing benefits. For comparison, Richards and Wood (1985) found fishing benefits at Lees Ferry of $170/visitor day in a TCM study. Fluctuations in flow levels also have a negative impact on benefits experienced by whitewater rafters, with relatively high steady flows (around 30,000 cfs) generating maximum benefits of $122/visitor day for whitewater boaters. Using the findings of Bishop *et al.* (1989) quadratic equations with total benefits V (in $/visitor day) expressed as a function of river flows Q (in kaf/year) were fit to the point estimates of use values:

TABLE 3. Annual Economic Benefits of Flatwater Recreation at Basin Reservoirs (1992 dollars).

Reservoir	Visitation (million/year)	Fishing ($/day)	Weight	Other ($/day)	Weight	Total ($/day)
Flaming Gorge	1.65	12.04[1]	0.5	21.21[2]	0.5	16.63
Curecanti Unit	0.78	29.22[3]	0.4	21.21[2]	0.6	24.41
Navajo	0.59	29.22[3]	0.4	21.21[2]	0.6	24.41
Powell	3.20	29.22[3]	0.2	24.21[4]	0.8	25.21
Mead	6.76	30.17[5]	0.2	36.16[6]	0.8	34.96
Mohave	2.05	30.17[5]	0.2	36.16[6]	0.8	34.96
Havasu	1.99	30.17[5]	0.2	36.16[6]	0.8	34.96

[1] Oster *et al.* (1989).

[2] Average of picnicking and swimming values (Rocky Mountains and Southwest) reported by Walsh *et al.* (1988) (Table 4).

[3] Average of flatwater fishing values reported by Gordon (1970), Sorg *et al.* (1985), and Ward and Fiore (1987).

[4] Average of motorized boating values for California given by Wade *et al.* (1988) and picnicking and swimming values reported by Walsh *et al.* (1988).

[5] Value for general anglers at Lake Mead reported by Martin *et al.* (1982).

[6] Motorized boating values on Lake Havasu given by Wade *et al.* (1988).

$$V_{\text{fishing}}(Q) = 23.6 + 5.76 \times 10^{-3}\,Q - 2.69 \times 10^{-7}\,Q^2 \qquad (6)$$

$$V_{\text{rafting}}(Q) = -\,12.3 + 11.4 \times 10^{-3}\,Q - 2.41 \times 10^{-7}\,Q^2 \qquad (7)$$

R^2 for Equations (6) and (7) were 0.99 and 0.98, respectively. Total benefits in each activity are found by multiplying the per visitor day benefits by 15,000 and 169,000 annual visitor days for day use fishing and multi-day rafting, respectively.

The focus on this single reach (located mostly within Grand Canyon National Park) likely results in a serious underestimation of the total instream use values in free flowing reaches. For example, visitor days on the single reach for which we estimate benefits total about 175,000 annually, while data provided by Rosene (Bureau of Land Management, Upper Colorado River District Office, Kremmling, personal communication, 1993) and Von Koch (Bureau of Land Management, Moab District Office, personal communication, 1993) identify over 130,000 visitor days on raft trips in the Westwater, Desolation Canyon, San Juan River, and Upper Colorado River reaches, half as part of multi-day trips. Day trips to raft Westwater Canyon on the Colorado River mainstem are valued at over $200 per trip by using TCM (Bowes and Loomis, 1980). Fishing and shoreline uses are also important throughout the region. For example, an individual's willingness to pay ranges up to $60/day [estimated by Daubert and Young (1981) using CVM] for fishing on the Cache la Poudre, an eastern Colorado mountain river affected by Basin water exports. Flow levels are important: anglers' and shoreline users' aggregate marginal benefits from additional flows range from $23 and $6/af, respectively, at relatively low flow, but are negative at high flow levels. Because such data on the relationship between instream flows and recreation values in Basin reaches is very limited, however, no further benefit functions are developed.

HYDROPOWER

Instream flows, largely from reservoir storage, produce hydroelectric power at a number of Basin dams. Estimates of the marginal value of generated hydropower were prepared based on the avoided cost of alternative thermal energy production. Hydropower production occurs during base and peak load periods, displacing base load (primarily coal and nuclear) facilities and peak load (primarily gas turbine) facilities, respectively. Because the cost of peaking production is typically significantly greater than for base load production, hydropower plants are often operated to maximize total production during peak periods.

Hydropower production in the Lower Basin during peak load periods is largely constrained by plant capacities. The physical effect of marginal decreases in water flow is then dominantly a decrease in base load production, with peaking production unchanged. The marginal value of Lower Basin hydropower is conservatively valued at the avoided cost of base load production at thermal facilities.

Upper Basin hydropower production is modeled after the preferred alternative given in the 1995 Final

Environmental Impact Statement on operation of Glen Canyon Dam (U.S. Bureau of Reclamation, 1995). Under the "Modified Low Fluctuating Flow Alternative," base and peaking releases are effectively constrained by a maximum allowable daily flow fluctuation. Marginal reductions in total flow thus reduce both base and peaking production. Because base and peaking periods are roughly equal in length (Harpman *et al.*, 1994), Glen Canyon hydropower can be valued at the mean avoided cost of base and peaking period alternatives. Other Upper Basin hydropower is valued similarly.

Generation costs for base and peaking periods for each Basin are taken from Booker and Young (1991). Only operations and maintenance costs were used given the presence of substantial underutilized thermal capacity serving the market for Basin hydropower. As an approximation to modeling operation of generation and transmission through a complex, interconnected grid in replacing hydropower generation (U.S. Department of Energy, 1994), the most costly 50 percent of total installed capacity serving the Upper and Lower Basins was used as the basis for these avoided cost calculations. Costs of operating Basin hydropower facilities were not determined, though they are both small (e.g., maintenance costs for investor-owned utilities reported by U.S. Department of Energy (1992) are 2.8 mills/kwh) and to some extent independent of the total level of hydropower production (and hence do not contribute to marginal costs). Net marginal benefits of hydropower production based on avoided cost and operating expenses were estimated at 52.4 and 46.9 mills/kwh for the Upper and Lower Basins, respectively.

Net benefits in units of instream flow (i.e., \$/af) are found by calculating total energy production using

$$E = k\,h\,Q\,\eta \qquad (8)$$

where h is the hydropower head (in feet), k is a constant 1.02353 kwh/af/foot of head, Q is the total instream flow (excluding spills, in af), and η is the system efficiency for electric generation. Efficiency was estimated at 0.9 for all Basin reservoirs, while the hydropower head depends directly on reservoir conditions. Table 4 gives the net marginal benefits of instream flows estimated under the typical Basin conditions characterizing the first nine years of a particular drought sequence (Booker, 1995).

CONVEYANCE COSTS

Marginal conveyance costs are dominated by the energy costs of pumping lifts required to deliver Basin water to southern California municipal uses, Central Arizona, and several smaller users. Energy costs are estimated by the marginal costs of Basin electrical energy production. Following the approach to valuing hydropower production, the operation and maintenance cost of thermal sources is used to value energy usage. Again, the most costly 50 percent of installed capacity is used as the appropriate measure of marginal costs. Flow-related maintenance expenses estimated for hydropower production are utilized for non-energy marginal operation and maintenance costs. Such expenses would result primarily from maintenance of pump motors and turbines. Valuing conveyance costs from such a national economic perspective gives marginal costs for pumping of water for agricultural uses ranging from \$10/af for Navajo Indian Irrigation Project users to \$87/af for CAP. Municipal conveyance costs were estimated at \$107/af for MWD users and an average \$123/af for CAP users.

TABLE 4. Annual Economic Benefits of Instream Use at Basin Dams and Reservoirs. Year 1 of severe and sustained drought simulation (Booker, 1995) (1992 dollars).

Dam and Reservoir	Hydropower Benefits		Recreation Benefits	
	Total ($ million)	Marginal ($/af)	Total ($ million)	Marginal (annual $ per af of storage)
Flaming Gorge	18	19.8	23	8.7
Curecanti Unit*	109	45.2	17	19.5
Navajo	24	17.0	12	10.0
Glen Canyon Dam/Lake Powell	223	26.3	71	3.7
Hoover Dam/Lake Mead	201	23.6	199	10.4
Davis Dam/Lake Mohave	46	5.8	72	39.6
Parker Dam/Lake Havasu	23	3.3	70	112.4

*Composite of Morrow Point, Blue Mesa, and Crystal Dams.

SALINITY DAMAGES

Colorado River salinity first became a major issue when irrigation return flows from the Wellton-Mohawk division of the Gila Project in Arizona resulted in water deliveries to Mexico with concentrations as high as 2,700 mg/l (Miller *et al.*, 1986). Construction of a drainage canal to the Gulf of California reduced concentrations in Mexican deliveries to near those used by Arizona and California irrigators, but drainage water could no longer be included in the 1.515 million acre-feet delivered annually to Mexico. Salinity in Colorado River water is believed to cause substantial damage to United States municipal and agricultural water users as well. Indeed, with the recent completion of the Central Arizona Project delivering municipal supplies to Phoenix and Tucson, an additional 2.5 million water users are now potentially affected by Colorado River salinity.

Damage estimates are problematic, however, given the differing composition of mineral constituents at different locations and the long time period over which damages are believed to occur. One set of damage estimates presented by Booker and Young (1991) is used here to provide an estimate of salinity damages to municipal and agricultural users. Constant marginal damages over time are assumed. The municipal damage estimate is based on the single household damage estimate of $0.26 per mg/l (1989 dollars) given in Booker and Young (1991). Assuming two households per acre-foot of water use, damages are $0.558/mg/l/af expressed in 1992 dollars. Municipal damages are assumed for Las Vegas, CAP (municipal), and MWD users. Agricultural damages are based on producer income differences in linear programming models of Imperial Valley (California) agriculture at 800 mg/l and 1100 mg/l salinity (Booker and Young, 1991). Salinity damages from full water deliveries to 50 percent reductions are within 10 percent of the average value of $0.0378/mg/l/af (1992 dollars). The latter is used to estimate damages to agricultural water users in Arizona and California.

While these damage estimates are typical of those used by other researchers, they should be regarded as preliminary. For example, the municipal damage estimate suggests damages of $130/af from use of Colorado River water based on salinity concentrations of 675 mg/l in Colorado River water and 415 mg/l in an alternative supply. Coupled with high conveyance costs for some uses, this suggests small net marginal benefits from Colorado River water use in several cases. The recent negative public reaction to introduction of Colorado River water in Tucson supports this view, as does the reluctance of central Arizona farmers to use CAP water. Nevertheless, unabated efforts to secure additional Colorado River supplies by southern California and southern Nevada suggest that water providers will accept salinity damages when they lack alternative cost effective water sources.

CONCLUSION

The economic benefit and cost estimates for offstream and instream water use provided in this article encompass all major water uses in the southwestern United States. The estimates provide a basis for policy decisions affecting southwestern United States water users and for policies governing the Colorado River, which currently are the subject of intense political negotiations and debate. In providing benefit estimates across a wide variety of competing uses, the inevitable tradeoffs in allocating water resources across the Southwest are clarified. The economic impacts of drought reported by Booker (1995) and Henderson and Lord (1995) elsewhere in this issue explicitly address tradeoffs exacerbated by the presence of drought.

Despite our focus on the dominant economic impacts of regional water use, these benefit estimates do not include non-use values. Hence significant environmental values not based on direct resource use (e.g., protection of endangered species) are not addressed. Second, indirect economic impacts of water use are not considered. Total regional economic impacts could thus significantly exceed the direct economic impacts calculated based on our benefit estimates. Finally, benefit estimates in every offstream and instream use contain large uncertainties and are subject to continued refinement as additional data becomes available. Nonetheless, the estimates given here are based on detailed research covering the value of water in both offstream and instream uses, and they provide a reasonable starting point for reconciling the competing needs of these alternative water uses.

ACKNOWLEDGMENTS

Much of this work was conducted while the senior author was with the Wyoming Water Resources Center and the Department of Agricultural Economics at the University of Wyoming. The research was supported by grants from the Wyoming Water Resources Center, the U.S. Geological Survey, Department of Interior under Award No. 14-08-0001-G1892, and by the Arizona Agricultural Experiment Station. The authors acknowledge the research assistance provided by Bruce Peacock and Christine Mullahy-Koenig. Robert Young and Ari Michelsen provided important guidance for the project. Helpful comments were received from Jan Matusak of the Metropolitan Water District and two anonymous reviewers.

LITERATURE CITED

Anderson, M. H., 1973. The Demand for Agricultural Water in Utah. Utah Water Research Laboratory, Utah State University, Logan, Utah.

Billings, B. R. and D. E. Agthe, 1980. Price Elasticities for Water: A Case of Increasing Block Rates. Land Economics 56(1):73-84.

Bishop, R., C. Brown, M. Welsh, and K. Boyle, 1989. Grand Canyon, Recreation and Glen Canyon Dam Operations: An Economic Evaluation. Maine Agricultural Experiment Station Publication No. 1368, University of Maine, Orono, Maine.

Booker, J. F., 1995. Hydrologic and Economic Impacts of Drought Under Alternative Policy Responses. Water Resources Bulletin 31(5):889-906.

Booker, J. F. and R. A. Young, 1991. Economic Impacts of Alternative Water Allocations in the Colorado River Basin. Colorado Water Resources Research Institute Completion Report No. 161, Colorado State University, Fort Collins, Colorado.

Bowes, M. D. and J. B. Loomis, 1980. A Note on the Use of Travel Cost Models with Unequal Zonal Populations. Land Economics 56(4):465-470.

Brookshire, D. S., L. S. Eubanks, and C. S. Sorg, 1986. Existence Values and Normative Economics: Implications for Valuing Water Resources. Water Resources Research 22(11):1509-1518.

Brookshire, D. S., M. McKee, and G. Watts, 1993. Draft Economic Analysis of Proposed Critical Habitat Designation in the Colorado River Basin for the Razorback Sucker, Humpback Chub, Colorado Squawfish, and Bonytail. U.S. Fish and Wildlife Service, Utah Field Office, Salt Lake City, Utah.

Cummings, R. G., D. S. Brookshire, and W. D. Schulze, 1986. Valuing Environmental Goods: An Assessment of the Contingent Valuation Method. Rowman and Allanheld, Totowa, New Jersey.

Cummings, R. G. and G. W. Harrison, 1995. The Measurement and Decomposition of Non-use Values: A Critical Review. Environmental and Resource Economics 5(3):225-248.

Daubert, J. T. and R. A. Young, 1981. Recreational Demands for Maintaining Instream Flows. American Journal of Agricultural Economics 63(2):667-767.

Gollehon, Noel R., Robert R. Lansford, and B. J. Creel, 1981. Impacts on Irrigated Agriculture from Energy Development in the Rocky Mountain Region. Southwestern Review of Economics and Management 1(1):61-88.

Gordon, Douglas, 1970. An Economic Analysis of Project Number F18R15 Idaho Sport Fisheries. Idaho Cooperative Fishery Unit, Idaho Dept. of Fish and Game, Boise, Idaho.

Griffin, R. C. and C. Chang, 1991. Seasonality in Community Water Demand. West. J. Agr. Econ. 16(2):207-217.

Harding, Benjamin L., Taiye B. Sangoyomi, and Elizabeth A. Payton, 1995. Impacts of a Severe Sustained Drought on Colorado River Water Resources. Water Resources Bulletin 31(5):815-824.

Harpman, D. A., A. S. Rosekrans, and R. E. Moulton, 1994. Simulating Hourly Hydropower Operations for the Assessment of Environmental and Economic Impact. *In:* Water Policy and Management, D. G. Fontane and H. N. Tuvel (Editors). Proceedings of the 21st Annual Conference, American Society of Civil Engineers.

Henderson, James L. and William B. Lord, 1995. A Gaming Evaluation of Colorado River Drought Management Institutional Options. Water Resources Bulletin 31(5):907-924.

Howe, C. W., 1982. Impact of Price on Residential Water Demand: Some New Insights. Water Resources Research 18(4):713-716.

Howe, C. W. and W. A. Ahrens, 1988. Water Resources of the Upper Colorado River Basin: Problems and Policy Alternatives. *In:* Water and Arid Lands of the Western United States, M. T. El-Ashm and D. C. Gibbons (Editors). Cambridge University Press, New York, New York.

Johnson, D. M. and R. G. Walsh, 1987. Economic Benefits and Costs of the Fish Stocking Program at Blue Mesa Reservoir, Colorado. Colorado Water Resources Research Institute Technical Report No. 49, Colorado State University, Fort Collins, Colorado.

Martin, W. E., F. Bollman, and R. Gum, 1982. Economic Value of Lake Mead Fishery. Fisheries 7(6):20-24.

Martin, W. E. and S. Kulakowski, 1991. Water Price as a Policy Variable in Managing Urban Water Use: Tucson, Arizona. Water Res. Research 27(2):157-166.

Michelsen, A. M., 1989. Economics of Optioning Water Rights for Urban Water Supplies During Drought. Unpublished Ph.D. dissertation, Dept. of Agricultural and Resource Economics, Colorado State University, Fort Collins, Colorado.

Miller, Taylor O., G. D. Weatherford, and J. E. Thorson, 1986. The Salty Colorado. The Conservation Foundation, Washington D.C.

Oamek, G. E., 1990. Economic and Environmental Impacts of Interstate Water Transfers in the Colorado River Basin. Monograph 90-M3, Center for Agricultural and Rural Development, Iowa State University, Ames, Iowa.

Oster, J., D. Taylor, J. Jacobs, and E. Bradley, 1989. Reservoir Eutrophication and Recreational Activity on Flaming Gorge Reservoir, Experiment Station Bulletin No. 908, University of Wyoming College of Agriculture, Laramie, Wyoming.

Planning and Management Consultants, 1986. A Disaggregate Water Use Forecast for the Phoenix Water Service Area. Report to the Phoenix Water and Wastewater Department.

Richards, M. T. and D. B. Wood, 1985. The Economic Value of Sportfishing at Lees Ferry, Arizona. *In:* Riparian Ecosystems and their Management: Reconciling Conflicting Uses. Proceedings of the First North American Riparian Conference. U.S.D.A. Forest Service General Technical Report RM 120, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado.

Sanders, L. D., R. G. Walsh, and J. B. Loomis, 1990. Toward Empirical Estimation of Total Value of Protecting Rivers. Water Resources Research 26(7):1345-1357.

Sangoyomi, Taiye B. and Benjamin L. Harding, 1995. Mitigating Impacts of a Severe Sustained Drought on Colorado River Water Resources. Water Resources Bulletin 31(5):925-938.

Sorg, C. F., J. B. Loomis, D. M. Donnelly, G. L. Peterson, and L. J. Nelson, 1985. Net Economic Value of Cold and Warm Water Fishing in Idaho. U.S. Dept. of Agriculture, Forest Service Resource Bulletin RM-11, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

U.S. Bureau of the Census, 1990. Projections of the Population of States, by Age, Sex, and Race: 1989 to 2010. Current Population Reports, Series P-25, No. 1053, U.S. Government Printing Office, Washington D.C.

U.S. Bureau of Reclamation, 1991. Colorado River Simulation System: Inflow and Demand Input Data. Engineering and Research Center, Denver, Colorado.

U.S. Bureau of Reclamation, 1995. Final Environmental Impact Statement, Operation of Glen Canyon Dam. Colorado River Studies Office, Salt Lake City, Utah.

U.S. Department of Agriculture, Agricultural Statistics Board, 1990. Annual Price Summary, Washington DC.

U.S. Department of Agriculture, Economic Research Service, 1984 and 1991. Economic Indicators of the Farm Sector: State Financial Summary. Washington D.C.

U.S. Department of Agriculture, Economic Research Service, 1992. Agricultural Irrigation and Water Use. Agriculture Information Bulletin Number 638. Washington D.C.

U.S. Department of Energy, 1992. Electric Plant Cost and Power Production Expenses 1990. Energy Information Administration, Washington D.C.

U.S. Department of Energy, 1994. Salt Lake City Area Integrated Projects Electric Power Marketing: Draft Environmental Impact Statement. Western Area Power Authority, Salt Lake City, Utah.

Upper Colorado River Commission, 1992. Forty-Fourth Annual Report. Salt Lake City, Utah.

Wade, W. W., G. M. McCollister, R. J. McCann, and G. M. Johns, 1988. Estimating Recreation Benefits for Instream and Diverted Users of Waterflows of the Sacramento-San Joaquin Rivers Watershed. Presented at W-133 Committee Meeting, Monterey, California.

Walsh, R. G., D. M. Johnson, and J. R. McKean, 1988. Review of Outdoor Recreation Economic Demand Studies with Non-market Benefit Estimates, 1968-1988. Colorado Water Resources Research Institute Technical Report No. 54, Colorado State University, Fort Collins, Colorado.

Ward, Frank and John Fiore, 1987. Managing Recreational Water Resources to Increase Economic Benefits to Anglers in the Arid Southwest. New Mexico Agricultural Experiment Station Research Report 609, New Mexico State University, Las Cruces, New Mexico.

Wilson, Paul N., 1992. An Economic Assessment of Central Arizona Project Agriculture. Report to the Office of the Governor and the Arizona Department of Water Resources, Phoenix.