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Evaluating Benefits and Costs of Changes in Water Quality

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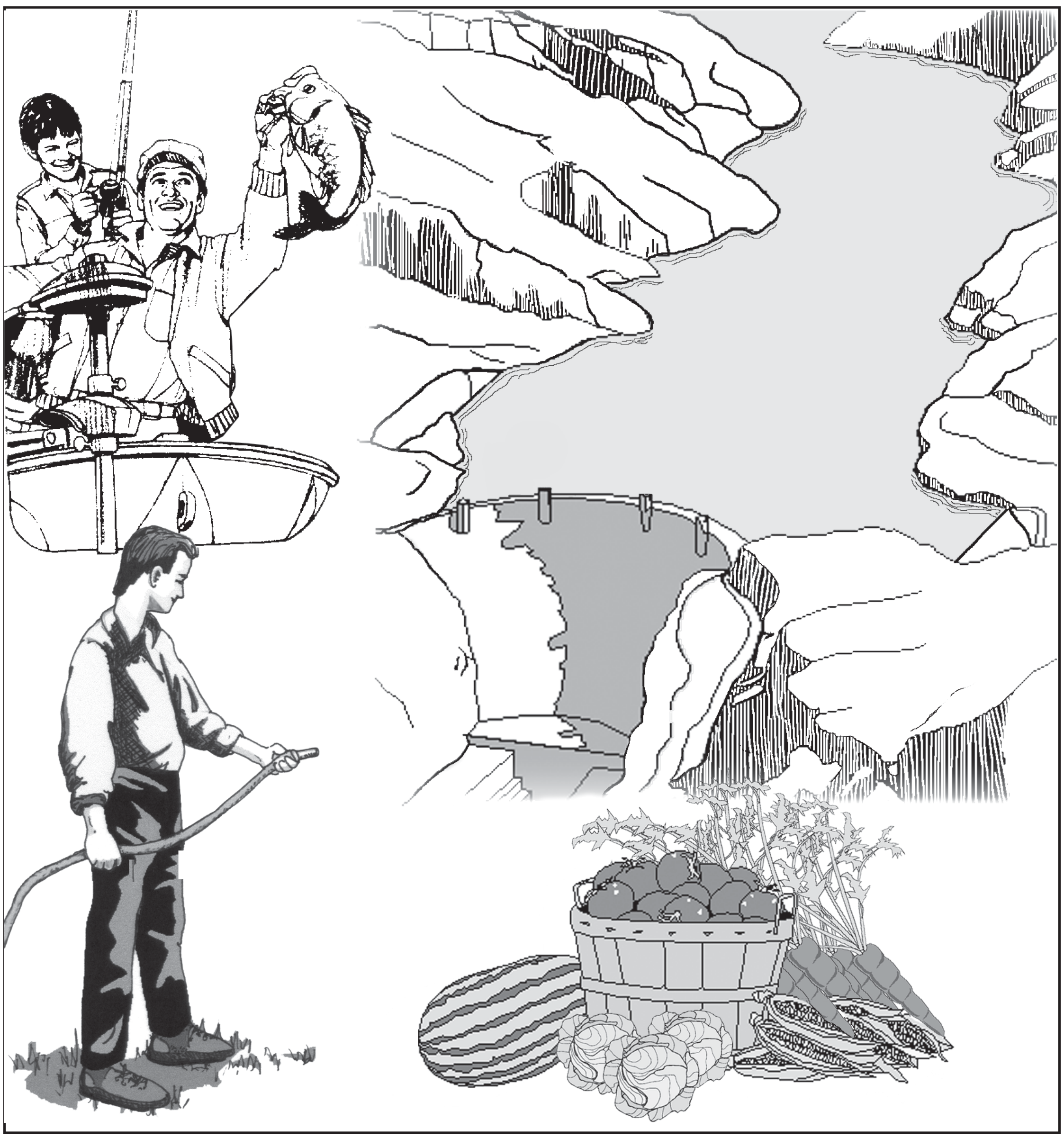

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Abstract

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Water quality affects a variety of uses, such as municipal water consumption and recreation. Changes in water quality can influence the benefits water users receive. The problem is how to define water quality for specific uses. It is not possible to come up with one formal definition of water quality that fits all water uses. There are many parameters that influence water quality and that affect benefits to water users. This paper examines six water quality parameters and their influence on six water uses. The water quality parameters are clarity, quantity, salinity, total suspended solids, temperature, and dissolved oxygen. Changes in these parameters are evaluated to determine values for municipal, agricultural, recreational, industrial, hydropower, and nonmarket uses of water. Various techniques can be used to estimate nonmarket values for changes in water quality, such as the travel cost method, the contingent valuation method, and the hedonic property method. The data collected on changes in water quantity per acre-foot and its effect on recreationists' benefits were analyzed by using multiple regression in a meta-analysis. Results from the regression were used to analyze changes in consumer surplus for particular activities and uses for an additional acre-foot of water. Information in tables is included to provide empirical evidence as to how certain water quality parameters affect a particular use. The tables provide values from previous studies and the valuation techniques used in each study. From these values, we find mean values of changes in water quality and how this change monetarily affects the use in question.

Keywords: Dissolved oxygen, instream flow, nonmarket values, recreation, salinity, water clarity, meta-analysis.

Contents

Introduction

Many activities in our national forests can affect water quality, resulting in a change in water quality to downstream users. Management strategies can decrease or improve water quality for downstream users. Changes in benefits to producers and consumers resulting from a change in quality of national forest water can be measured. One purpose of this paper is to define uses of water and the parameters necessary for the definition of water quality depending on the particular use. Once the parameters are defined, changes in benefits can be evaluated as water quality changes. The various methods that can be used to estimate changes in benefits from a change in water quality are discussed and related to each of the uses.

National forest land is the largest single source of water in the United States and contributes water of high quality. According to one estimate, the calculated marginal value of water from all national forest lands equals at least $3.7 billion per year, with the Pacific Northwest contributing an estimated $950 million (USDA Forest Service 2000). Water withdrawals to offstream uses, including farms, industry, and homes, have increased over tenfold in the 20th century. Streamflows have dropped, while demands for instream water have increased for water-based recreation and protection of water quality (Brown 1999).

Valuation

The concept of commensurability entails measuring all market and nonmarket values from the same conceptual framework. Market and nonmarket valuation of water depends on how the water is used, e.g., for recreation, for industry, and so on. Willingness-to-pay as a measure of benefits is the most fundamental measure of economic value, whether it is market, nonmarket use value, or even nonmarket "nonuse" value, such as existence value. Consumer and producer surplus are measures of benefits, and can be quantified by willingness-to-pay or willingness-to-accept of consumers and producers, respectively. Consumers may pay less than the maximum they are willing to pay for a good; therefore we measure the consumers' benefit (consumers' surplus) for a particular good as the total willingness-to-pay minus the actual cost. Producer surplus is similar in concept to consumer surplus. Producer surplus is the benefit to the producer above the cost of production. Producer surplus is often referred to as net revenue, or profit. Theoretically, producers are willing to supply the first few units of a good at a price above the cost of producing the good but less than the market price. The net revenue, or profit, is a measure of the producers' benefit from receiving the same market price on all units sold, even the first few, which they would supply for less.

Market goods are products that are produced and sold in a formal market, such as bottled water, in which prices reflect the interaction of supply and demand. The marginal value of a market good to a consumer is the price, and it measures the willingness-to-pay for one more unit. This is reflected in the demand curve, also known as the marginal benefit curve. The marginal benefit curve shows the added benefit, or value, of each additional unit consumed. Owing to the property of diminishing marginal utility, the marginal benefit curve is downward sloping because benefits increase at a decreasing rate as one consumes more of a particular good in a given period.

Estimation of both consumer and producer surplus requires estimation of a demand and supply schedule. A demand schedule shows the relation between price and quantity demanded. In figure 1, the demand curve (D) is also the marginal benefit (MB) curve. The downward slope means that for every additional unit consumed, the marginal benefit of consumption of each additional unit of (Q) diminishes. The total value of consumption is the area under the marginal benefit curve up to Qm. If the price of the good is Pm, the consumer demands Qm amount of the good. By deriving the demand curve, we can

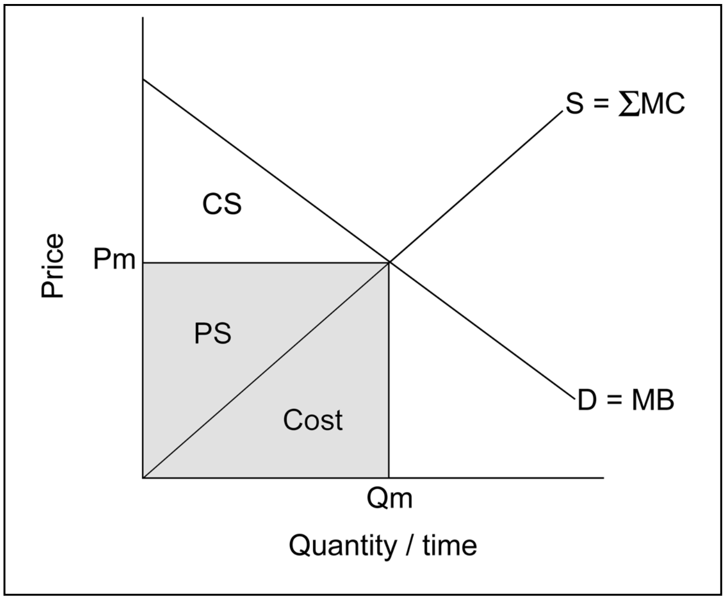

Figure 1—Producers' and consumers' surplus.

measure the gross benefits, and depending on the actual cost of the good, we can calculate the consumers' surplus. A supply schedule shows the relation between price and quantity supplied. If a good has price Pm, the producer supplies quantity Qm of that good. The supply curve is the sum of the marginal costs (åMC) of producing the good. The marginal cost curve is upward sloping because as more of a good is produced in a given period, the cost of producing the additional units increases. The total cost to the producer is the area under the marginal cost curve up to Qm.

In a competitive equilibrium, Qm of the good is produced at price Pm. The consumer surplus (CS) is the amount the consumer is willing to pay less what they actually pay for the good. The producer surplus (PS) is the net benefit to the producer for supplying the good. The producer charges price Pm per unit for the good. Total revenue to the producer is the entire shaded region. The cost to the producer is the area under the marginal cost curve up to Qm. The net revenue to the producer is the producer surplus (PS). The total benefit to society is the producers' surplus plus the consumers' surplus.

The value of a market good can be measured nonmarginally by calculating total value. By deriving both the demand and supply curves, we can find the consumer and producer surplus. Total consumer surplus added to total producer surplus gives total net value. Total net value will be much larger than marginal value, or price, because marginal value just measures willingness-to-pay for the last unit consumed.

In many cities, a change in quality of the input water does not affect the price, quality, or quantity of drinking water for consumers. Rather, it affects the cost of maintaining acceptable water quality. The benefit change is measured by the change in producer benefit, or producer surplus, given an improvement in the quality of the input. Freeman (1979) shows that a change in input quality affects the marginal cost of production, given that the change in environmental quality affects only the producer and output price does not change. If it is assumed that the price and quantity of water are fixed, benefit of improved water quality comes in the form of decreased cost of production, which benefits the producers in the form of profits.

Nonmarket Valuation Techniques

Nonmarket values are estimated to assess goods and services that are not bought or sold in a formal market. Nonmarket values include nonuse values, such as the value that individuals obtain from knowing that a species exists or that a river is healthy even though they do not have any intent to visit the place in the future. Valuation of water resources and water quality improvements can use either market or nonmarket techniques, or some combination of both. The methods used will differ by water use.

Contingent valuation is used to estimate values people place on changes in a natural resource in the context of a hypothetical market, through the use of surveys. People's total willingness-to-pay for increases or decreases in a natural resource can include current personal use values, possible future use values (option values), and future generation use values (bequest values) (Jordan and Elnagheeb 1993). Total willingness-to-pay also can include existence values, which involve gains people obtain from the good for various reasons other than their personal use (Mitchell and Carson 1989). Contingent valuation methods use these simulated (hypothetical) markets to identify values similar to actual markets (Loomis and Walsh 1997). A respondent is faced with a survey or questionnaire that supplies a variety of information, including detail about the good. The current state of the resource is described, and a description of the improvement is provided. The respondent is asked a willingness-to-pay question regarding an improvement. A method of payment, such as a tax or an increase in a bill, is clearly stated in the survey so respondents are aware of how they would pay for the improvement.

The goal of contingent valuation is to induce people to reveal their willingness-to-pay for the provision of a nonmarket good such as environmental quality (Ribaudo and Hellerstein 1992). With information provided by the respondents, a change in welfare can be estimated for a change in water quality. For example, a contingent valuation survey can ask respondents what would be the largest sum they would be willing to pay to install and maintain equipment to ensure their drinking water is of particular quality. The aggregate willingness-to-pay can serve as an estimate of benefits to consumers from improvements in drinking water quality (Jordan and Elnagheeb 1993).

The travel cost method can be used to measure the value of water quality based on people's actual recreation trip behavior. A demand curve is estimated based on out-of-pocket expenses such as traveling to a recreation site. The travel cost method allows the derivation of a demand curve for particular recreational sites based on expenditures and time cost of travel for a cross section of users. The demand curve is typically generated by regressing the number of visits to the site against travel cost and other exogenous variables. Higher travel costs lead to fewer visits, other things being equal (Ribaudo and Hellerstein 1992). In figure 2, the number of trips demanded is Q. As costs per trip increase, the demand for recreation to the site will approach zero.

Two main categories of travel costs are transportation and travel time. Transportation costs include out-of-pocket expenditures such as gas, food, entrance fees, and any other costs incurred traveling to the site and back. Such things as car insurance or durable equipment used in the recreational activity are not included because these costs have to be paid even if the trip was not taken. The second main type of cost, travel time, is accounted for in the demand function by using time directly as a variable (hours spent traveling) or by using hours times a fraction of the wage rate. Time spent traveling to the recreation site is an opportunity cost, and the wage rate is used as a proxy for time (opportunity) cost. Time cost is then incorporated into the model to derive the demand function. As travel time or transportation costs increase, the number of trips to the site will decrease.

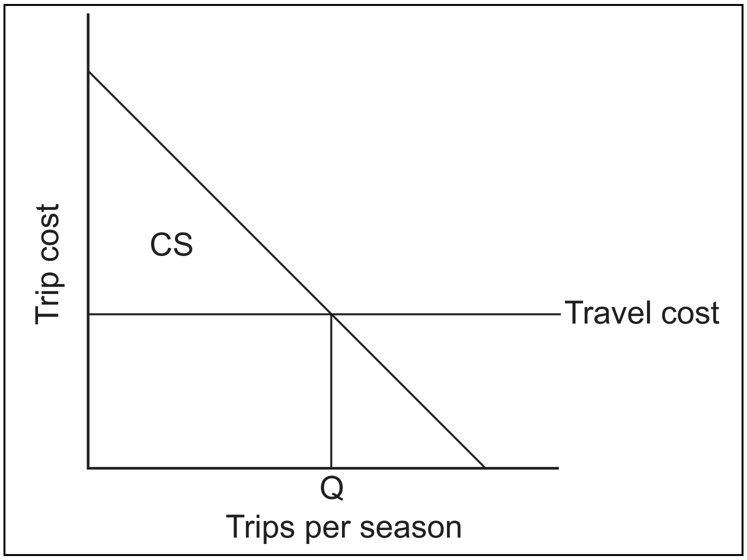

Figure 2—Travel cost method demand curve and consumer surplus.

To compare visitation at sites with varying water quality, data are pooled on visitation from several sites that differ in water quality but are similar in other attributes, such as activities performed and quality of facilities. The per capita demand for visits to the different recreation sites, taking into account the transportation costs and travel time, is compared to assess the changes in trips per year as water quality improves. The demand curves are overlaid to measure the changes in benefits with changes in water quality. In figure 3, demand for recreation at two sites is compared. Line D_1 is the demand curve for a site with poor water quality, and D_2 is the demand curve for a site with higher water quality. With a constant travel cost (TC), the number of trips increases from T_1 to T_2. The shaded region is the change in consumer surplus with a change in water quality at similar sites.

Hedonic pricing techniques have been used in various applications to estimate prices of nonmarket amenities that may be capitalized in the price of a housing unit (Michael and others 1996). These nonmarket amenities include a variety of attributes, such as earthquake risk and water quality. Hedonic property models have been applied to measure the effects of water quality on property prices. Differences in property values can be used to measure benefits from higher water quality or changes in water quality. To obtain a demand curve for water quality improvements from the hedonic technique, it is necessary to use the hedonic technique with multiple markets. The utility derived from portions of a river that vary from poor to good water quality, owing to local patterns of dischargers, can be compared. Benefits obtained from improvements in water quality can then be estimated. Necessary information includes property values, structural and locational characteristics, and appropriate measures of water quality.

It has been estimated that a decrease in water quality significantly depresses property prices surrounding a lake or river. Changes in the quality of water are likely to affect the enjoyment of households owning property on or near the shoreline (Freeman 1979). The value of the property reveals information about the benefits property owners receive from water quality improvements. However, as Freeman states, property values derived from analysis of housing costs reflect benefits to property owners, but not to others. For some water bodies, nonresident use is substantial. Regardless of the limitations,

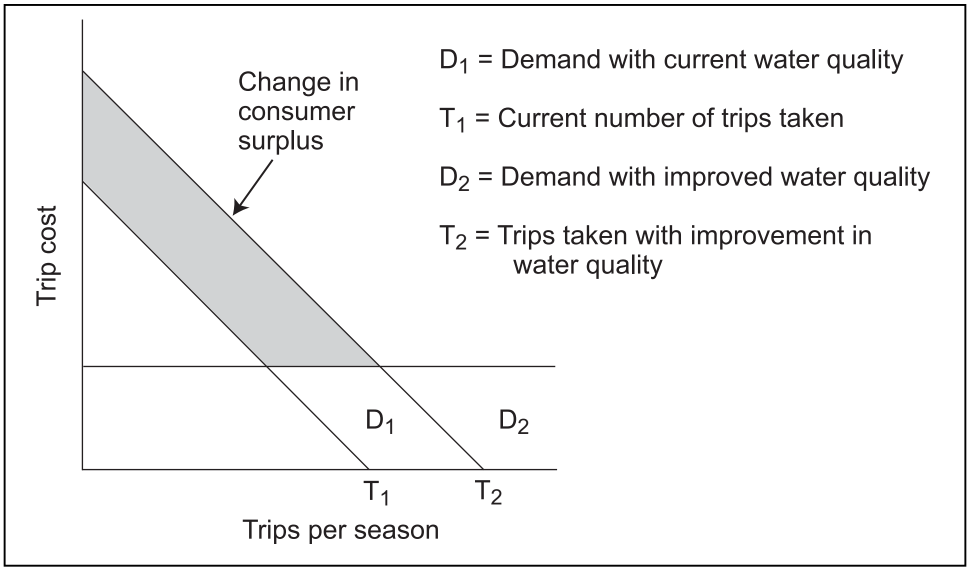

Figure 3—Demand curves for sites with varying water quality.

the hedonic method is important because it has in many instances been a good estimator of the benefits obtained from improvements in water quality by local residents living adjacent to or near a particular water body.

A hybrid hedonic travel cost method was developed by Brown and Mendelsohn (1984) that combines hedonic procedures with the travel cost method. The hybrid method consists of a two-step process. First, the price individuals from each origin zone (zones that are developed to distinguish the distance that individuals travel to the site) must pay to obtain each characteristic of the experience or recreational activity is estimated (Loomis and Walsh 1997). Separate regressions are then run for each of the zones. The quantity of characteristics and recreation activities are independent variables (Brown and Mendelsohn 1984).

Random utility models are a type of travel cost method that models the probability of choosing a particular recreation site on any given recreation choice period (e.g., weekend). Predictions are based on the relative utility of each site compared to the others. Both location (i.e., distance or travel cost) and quality are factored into these probabilities (Alexander 1995).

Contingent behavior is a hybrid system between the travel cost and the contingent value methods. Contingent behavior determines how visits to recreation sites change with quality attributes. The method was designed to measure recreational values for a hypothetical change, such as dam removal resulting in provision of river recreation opportunities, in areas where river recreation is not currently occurring (Loomis 1999). Contingent behavior analysis is also useful in situations where recreational activity is already occurring, as the travel cost method can be used to assess current activity, and a contingent behavior analysis can be developed in conjunction with the travel cost analysis to assess a hypothetical change. For example, a contingent behavior survey could be distributed to households within the region of a recreational facility, questioning willingness to pay to visit the water source to recreate if water quality improved. The survey would ask how many times a year they would visit, and gather information on travel time and transportation costs.

Water Quality Parameters

The six water uses examined in this paper are municipal, industrial, hydropower, recreation, agricultural, and passive use, or instream flow. The U.S. Geological Survey (USGS) has estimated the Nation's water use since 1950, from groundwater, fresh surface water, and saline surface water. Brown (1999) chose six water use categories from the USGS data to report national water demand: (1) livestock; (2) domestic and public; (3) industrial, commercial, and mining; (4) thermoelectric; (5) irrigation; and (6) hydroelectric power. We chose the former categories as they more closely follow the valuation literature.

As there are many different uses of water, it is not possible to come up with a single definition of water quality. Each water use has optimal water quality requirements that are often unique. For example, municipal water, used for drinking and bathing, requires low sediment levels. Water quality requirements for instream recreation depend on the activity. Boating does not require a low sediment level, but swimming does. People who engage in rafting are more concerned with water quantity. Fish require particular temperatures, and water quantity is important for recreational fishing. Water quality is measured by using some combination of water quality parameters. The parameters of water quality we will discuss are total suspended solids, dissolved oxygen, temperature, salinity, clarity, and quantity.

We will define each of the water quality parameters and discuss the importance of each one. We will then relate the parameters to the individual water uses. This discussion will enable us to discuss how to value water quality improvements.

Total Suspended Solids

Water with a low amount of suspended solids is important to many water uses. Although amount of total suspended solids is important for recreational uses, the degree of importance depends on the activity. For instance, swimming requires a low amount of suspended solids, whereas many of the rivers famous for whitewater rafting such as the Colorado River, have a high sediment load. This does not mean that the level of total suspended solids is not important in rafting; it is just less important than for swimming.

Total suspended solids is measured as dry weight of particulates. Both organic and inorganic materials contribute to total suspended solids. Suspended solids can affect the aquatic environment and its organisms by damaging macroinvertebrate communities through deposition, by reducing the abundance of food for fish, by directly affecting fish growth and resistance to disease, and by reducing the areas available for spawning and interfering with fish egg and larval development (Hach Company 2001). Furthermore, the deposition of organic matter can remove dissolved oxygen, an important element in high-quality water. A major source of total suspended solids in natural waters is runoff from urban and agricultural areas.

Dissolved Oxygen

Dissolved oxygen, gaseous oxygen (O_2) dissolved in an aqueous solution, is an important indicator of water quality. Oxygen is necessary to all aerobic forms of life, which provide stream purification. Dissolved oxygen is critical for fish and other water inhabitants. Generally, waters with dissolved oxygen concentrations of 5.0 milligrams per liter (mg/L) (equivalent to 5 parts per million (ppm))[1] or higher can support a well-balanced, healthy biological community. Some species, however, cannot tolerate even

[1] One milligram per liter is the same as one part per million for water solutions when the specific gravity of the solution is the same as pure water under standard conditions. This is assumed to apply to low-concentration solutions.

slight depletion, and when concentrations fall below critical levels, the result is often a complete alteration of the community structure. The consequences of changes in dissolved oxygen frequently have both ecological and economic significance. As dissolved oxygen drops below 5.0 mg/L, aquatic life is put under stress. The lower the concentration of oxygen, the greater the stress. Oxygen levels that remain below 1 to 2 mg/L for a few hours can kill many fish. Note, however, that some systems with “good” water quality exhibit naturally low dissolved oxygen concentrations (e.g., wetlands) (Hach Company 2001).

Nonmarket values and activities are dependent on adequate oxygen. Nonuse values, such as habitat quality, and use values, such as fishing, are uses of water for which dissolved oxygen is an important parameter. A change in dissolved oxygen could cause a decrease in fish catch, decreasing the quality of a fishing experience.

Temperature

Water temperature is very important to many water uses. It affects chemical interactions and reactivity in the water column. Temperature also affects biological activity; many aquatic organisms have strict temperature requirements. The temperature of water in entire watersheds may become elevated by steam-electric generating plants and other industries that use water to cool industrial processes (Gibbons 1986). If the heated water is discharged back into the stream, it disrupts the aquatic ecosystem, and damages fish habitat and wildlife. This practice is prohibited by the 1977 Clean Water Act and therefore is no longer seen as a threat to ecosystems. Cost of cooling the water before disposal was about $10 per acre-foot in a study by Young and Gray (1972). Forest activities that can affect water temperature include overstory removal, enhancement of riparian vegetation, and revegetation activities. Removal of riparian vegetation is commonly believed to increase water temperature, but in particular circumstances can allow for water temperature reductions. Activities that change stream configuration also can affect water temperature, such as structures or vegetation that reduce channel width and increase channel depth and water velocity.

Salinity

A river most often increases in salinity by flowing over salt deposits or picking up nonpoint agricultural runoff high in salt content. Removing salts from watersheds is an expensive process. Almost all water uses are adversely affected by salinity. It is estimated that every 1-ppm increase in salinity causes $230,000 worth of damage for agricultural, municipal, and industrial users (Gibbons 1986) in reduced crop yields and damaged appliances and industrial machinery (Kleinman and Brown 1980). Thus, the benefit of decreasing water salinity may outweigh the cost.

Water Clarity

Water clarity is not generally termed pollution, so the importance of water clarity in benefit measurement has to do primarily with aesthetics. Water clarity also determines the depth of light penetration and thereby the structure of habitats at various depths. Water clarity has both nonmarket and recreational use values.

Water Quantity

The quantity of water is important in many water uses, such as healthy habitats and recreation opportunities. Water quantity can either be too high or too low depending on the use. Water quantity is often a contributing factor to all the parameters of water quality previously mentioned. For example, as the quantity of water decreases, temperature may increase. On the other hand, as water quantity increases, salinity levels can decrease per unit of water. Aside from the relations of other parameters to water quantity, quantity alone is important to many uses. Daubert and others (1979) reported a quadratic relation between water quantity and fishing benefits. They studied the value of fishing, shoreline recreation, and whitewater activities in the Cache la Poudre River, Colorado, during summer 1978. At moderate flows, recreational fishing value was higher than at higher flows. This may not be the case in boating, where value may increase with increasing flows up to a point.

Water Uses

Municipal Water Use

Consumption of water for municipal purposes is less than 10 percent of total water consumption in the United States, although it is often perceived as the most vital or important water use. Municipal water demands are usually described in three categories: residential, public, and "other" uses. Residential water is used, for example, for watering lawns, bathing, drinking, and cooking. Public water use includes firefighting and maintenance of public buildings and grounds. Other uses of municipal water are commercial and industrial water consumption by the general public, such as in restaurants and stores (Gibbons 1986).

There are many factors that influence the demand for water for municipal purposes. Increases in population, temperature, and income increase demand, whereas increases in water prices will decrease the quantity demanded. There are a few instances where this may not be the case. For example, an increase in population density and the related decrease in open space may actually offset each other for municipal water demand (Gibbons 1986).

Municipal water prices do not represent the value of instream water because municipal water prices include retrieval, storage, and transportation costs (Gibbons 1986). The marginal value of water depends on water availability as well as demand. For example, southern California has high water demand as well as limited supply. The value of an additional unit of water for most consumers is likely to be positive and large. On the other hand, in water-rich areas, such as western Oregon, the value of additional water would probably be lower than in southern California.

Producers of municipal water require high-quality input water in their production process. Without adequate quality and supply of water, benefits will be diminished. Municipal water suppliers are most concerned with quantity, salinity, and total suspended solids.

If there is not enough water to support a municipality, producers may have to look elsewhere for further supplies. This is an expensive, as well as controversial issue. To measure the benefits to producers of adequate water supply or water conservation, we can estimate the expense of finding and obtaining water elsewhere. The decrease in marginal costs could be estimated to find the increase in producer surplus from the savings in production costs from additional local water supplies or conservation.

Salinity is important to producers as well. Salt damages the equipment used in retrieving, treating, and transporting water to households. The effect is an increase in the production costs owing to equipment replacement. The benefits to producers of decreased salinity accrues as decreased production costs. The source of salinity is often nonpoint agricultural runoff. It has been estimated that two-thirds of the average salt load in the upper Colorado River is from natural point and natural nonpoint sources (Spofford and others 1980). Removing salts is an expensive process. The damage salinity causes to municipal producers is sometimes far greater than the cost of keeping salt out of rivers by better agricultural management practices.

Total suspended solids are important to municipal water producers. Total suspended solids are directly related to the treatment procedures that the supplier must use to ensure safety. Ribaudo and Hellerstein (1992) describe the process of treating source water for multiple uses by conventional methods such as filtration and disinfection. Water with low levels of total suspended solids may be treated by filtration, which eliminates the need for other treatments such as sedimentation. Cost savings for municipal water producers when water has low total suspended solids accrue from the reduced need for expensive and involved water treatment. Low turbidity levels also simplify the disinfection process, thus making it less costly.

Agriculture is the major source of sediment in many parts of the country. Soil conservation has a direct link to sediment load. Changes in municipal water production costs induced by changes in sedimentation are a measure of the welfare effects accrued by producers. It is simpler to estimate the benefits to producers than to consumers because changes in producer surplus are measured by changes in production costs or profits. Ribaudo and Hellerstein (1992) state that inputs and outputs of the water production process are generally priced in the market, and it is generally assumed that the production process is efficient.

Consumers of municipal water supplies are most concerned with four parameters of water quality: salinity, total suspended solids, water quantity, and clarity. Irrigation of farmland has been shown to be a factor in salinity in the Colorado River basin, and elsewhere. High salinity can damage water-using appliances and pipes, increase the use of detergents, and deteriorate clothing and other textiles (Ribaudo and Hellerstein 1992). The benefits to consumers of decreased salinity come in the form of decreased costs of replacing appliances, pipes, clothing, and so on.

A common approach in the literature to estimate benefits to consumers from a decrease in salinity is to estimate physical damage in terms of expected appliance lifetimes, assuming that the household would be willing to pay up to the economic value of those physical damages to avoid them (d'Arge and Eubanks 1978). The method uses regression equations that relate appliance lifespan to salinity.

Total suspended solids create many of the same effects as salinity; however, total suspended solids are also related to health and safety of the public. Many outbreaks of infectious diseases have been traced to contaminants in municipal water supplies. A low amount of total suspended solids in the public water supply is an important nonmarket benefit of improved water quality.

Directly estimating household demand or expenditure functions for water quality is generally not possible, as households cannot directly purchase water of varying quality (Ribaudo and Hellerstein 1992). It is still important to measure the benefits consumers gain from knowing their water is of high quality and is treated with the best available technology to ensure safety. To measure the benefits of increased drinking water quality, we look at people's willingness to pay for improvements in water quality. The contingent valuation method can be used to measure willingness to pay for improvements in water quality. Contingent valuation is a flexible tool as it allows the measurement of benefits of changes in an environmental good not traded in a formal market (Jordan and Elnagheeb 1993). To examine the benefit of improving residential water quality, a contingent valuation survey would describe the current state of water quality and then create a hypothetical situation of an improvement in water quality. The description should be realistic and precise enough to give the respondent adequate information on which to base a valuation (Loomis and Walsh 1997).

Table 1 summarizes two studies, each using the hedonic property method, concerning changes in property prices near water bodies given a change in water clarity. The studies examined the change in property price for each foot of lake frontage given a 1-foot improvement in water clarity. In addition to these studies, Feather (1992) found changes in the parcel price of land resulting from decreases in water clarity, by using the hedonic method in Orange County, Florida. The value is unique for each situation, such as location and current clarity.

Scarcity of water increases its marginal value. However, when water quantity is adequate to satisfy demand, total benefits to consumers increase. Table 2 summarizes three studies concerning water values to municipal water users given a change in water quantity. Values were found for a 10-percent reduction in quantity supplied and were expressed in terms of dollars per acre-foot. The range of values demonstrates the importance of clearly defining what is being valued. In these cases, water quantity changes for general municipal use, for lawns, and for indoor domestic use had very different values.

Table 1—Increase in property value per foot of lake frontage for 1-foot improvement in water clarity

Citation	Valuation method	Location	Value
			1998 U.S. dollars
Michael and others 1996	Hedonic	China Lake, Maine	28.00
Michael and others 1996	Hedonic	Cobbossee Lake, Maine	16.37
Michael and others 1996	Hedonic	Long Lake, Maine	17.53
Steinnes 1992	Hedonic	Northern Minnesota	2.34

Table 2—Value of water for municipal use

Citation	Valuation method	Location	Value per acre-foot	Type of value
			1998 U.S. dollars	
Danielson 1977	Value of a 10-percent quantity reduction	South Atlantic Gulf	41.02	Summer
Danielson 1977	Value of a 10-percent quantity reduction	South Atlantic Gulf	41.02	Winter
Young 1973	Value of a 10-percent quantity reduction	Lower Colorado	351.08	Summer
Young 1973	Value of a 10-percent quantity reduction	Lower Colorado	54.32	Winter
Young and Gray 1972	Indeterminate	Unspecified	359.17	Domestic lawn watering
Young and Gray 1972	Indeterminate	Unspecified	653.21	Indoor domestic use

Table 3—Value for municipal water use of water quality improvement

Citation	Location	Annual household value per 1 mg/L[a] improvement	Cost and benefit
		1998 U.S. dollars	
Kleinman and Brown 1980	Colorado River, CO	0.0469	Mean cost from previous studies, decrease in salinity and total suspended solids
Ragan and others 1993	Arkansas River watershed, CO	.0533	Benefit from a decrease in salinity from 500 mg/L to 200 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0365	Benefit from a decrease in salinity from 1,000 mg/L to 200 mg/L
Ragan and others 1 993	Arkansas River watershed, CO	.0280	Benefit from a decrease in salinity from 1,500 mg/L to 200 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0235	Benefit from a decrease in salinity from 2,000 mg/L to 200 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0193	Benefit from a decrease in salinity from 3,000 mg/L to 200 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0177	Benefit from a decrease in salinity from 4,000 mg/L to 200 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0264	Benefit from a decrease in salinity from 1,000 mg/L to 500 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0176	Benefit from a decrease in salinity from 2,000 mg/L to 500 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.0152	Benefit from a decrease in salinity from 3,000 mg/L to 500 mg/L
Ragan and others 1993	Arkansas River watershed, CO	.1480	Benefit from a decrease in salinity from 4,000 mg/L to 500 mg/L

[a] Milligrams per liter.

Table 3 provides information from Kleinman and Brown (1980) and Ragan and others (1993) concerning total suspended solids and salinity in municipal water uses. Both studies used a cost savings valuation method to assess the impact of salinity and total suspended solids on municipal users. Salinity and total suspended solids were combined because they cause similar damages, such as to appliances and clothes. Ragan and others (1993) outline annual benefits to households for a decrease in salinity to 200 mg/L or 500 mg/L. The study results show that the marginal value for each milligram per liter decrease is less for higher initial salinity.

Agricultural Water Use

Water quality affects agricultural uses of water in many ways. Agriculture is also a source of water quality issues. Runoff and return flows from irrigated fields carry dissolved salts leached from the soil. As river flow is diverted for irrigation, the concentration of total dissolved solids increases, reducing the productivity of the water for agriculture (Freeman 1979). Irrigation of land is a primary water use by agricultural producers, and without proper water quality, decreased crop production and disease may result. There are various ways benefits gained from an improvement in water quality for agricultural purposes can be measured, both to consumers and producers.

To the extent that water quality affects agricultural productivity, it can affect the cost of production for a variety of goods and services (Freeman 1979). Water quality is a factor in the production function of an agricultural good. To measure the benefits gained from a water quality improvement, changes in market variables involved in production of the good are evaluated. Benefits from a change in water quality are felt in two ways: through changes in price to consumers, and through changes in the incomes received by owners of inputs used in the production of the good (Freeman 1979).

Salinity, total suspended solids, available water quantity, and water temperature are the water parameters agricultural producers are most concerned with. The measurement of benefits to agricultural producers is similar to that of producers of municipal water. The significant difference is that quantity can change; for municipal water, output quantity remained constant, so consumer surplus did not change and the cost of production changed only producer benefits.

Producer benefits are measured through changes in rents received for factors of production. As an example, say that the producer of organic tomatoes is a single farmer, a price taker in the output market. If there is an improvement in water quality and only the farm benefits, then the price of tomatoes is independent of water quality. Because we already know that the quality of water used as an input in the production of tomatoes affects the marginal cost of production, we can conclude that an improvement in the water quality will cause the marginal cost curve for the farmer to shift down, from marginal cost (MC) MC_1 to MC_2 in figure 4. The price of tomatoes is Px. At MC_1, the farmer produced quantity Q_1. With lower costs, the farmer will now produce quantity Q_2 tomatoes. The producer benefit is the entire shaded region of the graph under the

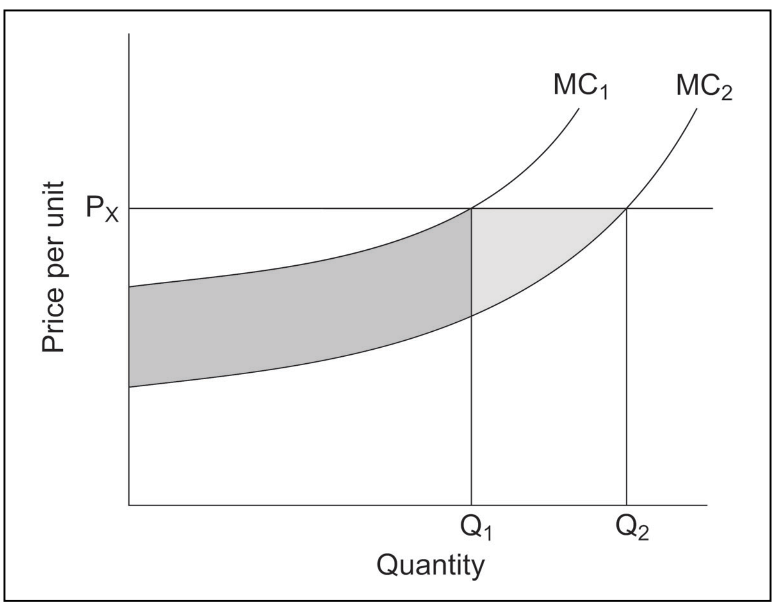

Figure 4—Producer benefit from a shift in marginal cost of production with a fixed price input.

constant price Px. The dark area is the benefit from the reduction of costs to produce the original amount of tomatoes, Q_1. The lighter-shaded area represents the benefits received from the inframarginal rent on the increase in output. Inframarginal rent is a term used to describe the producer surplus earned on all units of production but the last one.

Agricultural consumers are concerned with the same water quality parameters that concern producers. Assuming a change in production costs will result in a change in the output price, there will be a change in consumer surplus in addition to the change in producer surplus. As can be seen in figure 5, when demand D_Q is elastic and the marginal cost of production changes from MC_1 to MC_2, the total benefit to both consumers and producers is equal to the net change in the sum of the surpluses, or the entire shaded region. Because most agricultural products are traded in national and international markets, it is rare that a change in water quality in one watershed would have any effect on the price of most agricultural products. The exception would be locally grown and consumed specialty crops (Freeman 1979).

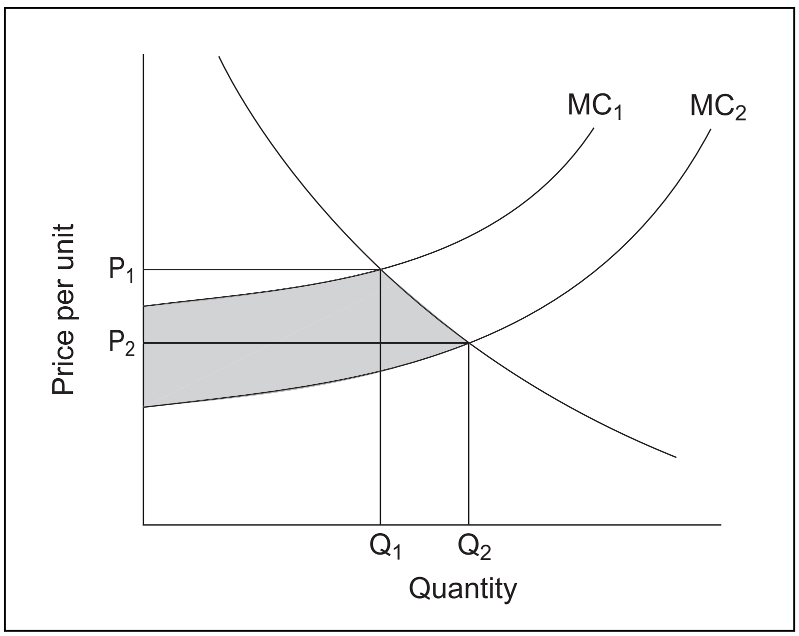

Figure 5—Producer and consumer surplus from a shift in marginal cost of production with elastic demand.

Water quantity is an important concern to agricultural producers. Table 4 summarizes five studies concerning the benefits to agricultural producers given an increase in water. The primary method used is to measure the change in production costs given a 1-acre-foot change in water availability. The study areas were the Pacific Northwest, Idaho, and Montana. Again, the variation in water value emphasizes that value is a function of use.

Table 4—Value of water for agriculture

Citation	Valuation method	Location	Value per acre-foot	Crop
			1998 U.S. dollars	
Aillery and others 1994	Change in production costs	Pacific Northwest	34.36	
Ayer 1983	Change in production costs	Washington	202.94	
Ayer and others 1983	Change in production costs	Idaho	597.77	
Washington State University 1972	Farm crop budget	Yakima River basin, WA	20.46	Cotton
Washington State University 1972	Farm crop budget	Yakima River basin, WA	171.68	Melons
Washington State University 1972	Farm crop budget	Yakima River basin, WA	62.53	Melons
Washington State University 1972	Farm crop budget	Yakima River basin, WA	20.71	Potatoes
Washington State University 1972	Farm crop budget	Yakima River basin, WA	155.76	Safflower
Washington State University 1972	Farm crop budget	Yakima River basin, WA	103.46	Safflower
Duffield and others 1992	Change in production costs	Bitterroot, MT	55.71	
Duffield and others 1992	Change in production costs	Big Hole, MT	26.15	

Figure 6 illustrates changes in benefits to agricultural producers given a change in salinity or total suspended solids, from Kleinman and Brown (1980). They estimate forgone production minus direct variable costs to agricultural producers relying on water in the lower mainstem of the Colorado River. Salinity and suspended solids were combined because of the nature of damages that they cause. There is an increase in damages as the milligrams of suspended solids per liter increases.

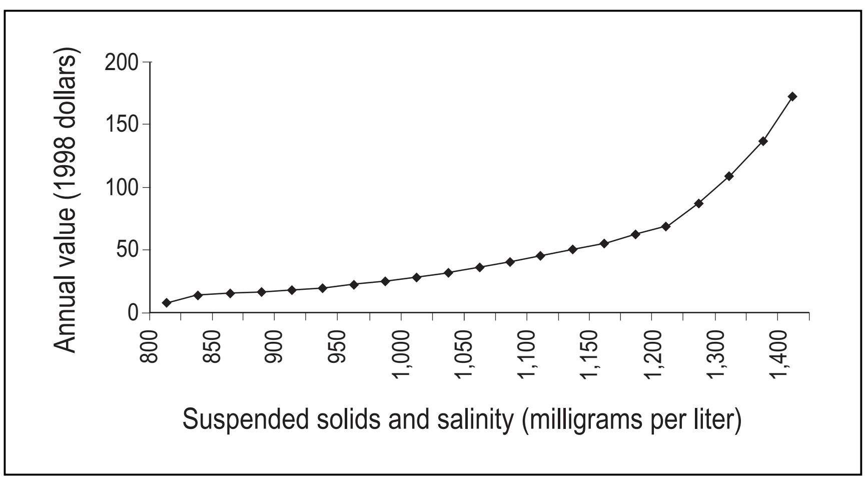

Figure 6—Value of damages to agriculture owing to total suspended solids and salinity.

Recreation Use

The demand for water-based recreation has been increasing as our population expands and the desire for outdoor recreation grows, particularly near urban areas and in national parks and other unique sites. Although some rivers heavily used for recreation, and holding other values as well, have been protected by legislation, there are still many watersheds that have been altered by dams and waterway construction, or pollution.

Water-based recreation is affected by all the water quality parameters that we have discussed. The relative importance of water quality parameters depends on the activity. Swimming requires higher quality water than boating. For waterskiing, users will prefer a site where the sediment is low, but sediment may not be as detrimental for activities such as whitewater rafting, where the main concern is an adequate water supply. Many famous whitewater rivers such as the Colorado have high sediment loads. To calculate the benefits of water quality improvements, we must measure the value of water for the particular recreational activity. There are various ways we can measure the added benefits people receive when the quality of their experience is improved, or when water quality is improved. Although several recreation activities may respond to water quality improvement, the activities are not necessarily homogenous; they may respond differently to changes in water quality.

Dissolved oxygen, total suspended solids, temperature, and water quantity are important water quality parameters for fish and, therefore, fishing. Sutherland (1982) states that the benefits of improved water quality can be defined as net willingness to pay for water quality improvement. Rafters are most concerned with water quantity. Rafters with different skill levels often want different water quantities. The amount of total suspended solids is not as important to rafters as is water quantity; it is also not as important for rafting as for other uses, such as swimming and fishing. Water quality also is important for the many recreational activities associated with water shorelines, such as viewing wildlife and camping. Parameters important to shoreline activities include water clarity, total suspended solids, and water quantity.

We can use the same nonmarket valuation methods to find the benefits of improved water quality for various recreationists, such as shoreline recreationists and rafters, although the results may be quite different. For example, water must have low amounts of total suspended solids to be classified as swimmable. The value of a decrease of total suspended solids may be higher for swimming than for rafting or boating. Daubert and others (1979) conducted a survey to determine the marginal values of different streamflows in the Cache la Poudre River in Colorado for fishing, shoreline recreation, and whitewater activities. Recreationists were asked what they would be willing to pay to have more water. Depending on the activity, marginal values could be positive if more water resulted in higher utility, or negative if more water resulted in decreased utility. The highest marginal value for fishing, $16 (in 1980 dollars) per acre-foot, was found with low flows (50 to 90 cubic feet per second); water value dropped to zero as flows reached 450 to 500 cubic feet per second. For shoreline recreation, the maximum marginal value also occurred at low flows and was $11 per acre-foot, falling to zero at flows of 700 to 750 cubic feet per second. The value for whitewater recreation exhibited constant marginal returns of $6 per acre-foot at the range of flows in the survey.

Table 5—Value of water quality improvements for recreation (decrease in total suspended solids and salinity)

Citation	Valuation method	Location	Value	Water use change
			1998 U.S. dollars	
		Mean increase in benefit per household		
Carson and Mitchell 1993	Contingent valuation	National	104.29	Nonboatable to boatable
Carson and Mitchell 1993	Contingent valuation	National	79.60	Boatable to fishable
Carson and Mitchell 1993	Contingent valuation	National	88.68	Fishable to swimmable
Smith and others 1986	Contingent valuation	Monongahela River, PA	35.65	Loss of area
Smith and others 1986	Travel cost	Monongahela River, PA	6.38	Loss of area
Smith and others 1986	Contingent valuation	Monongahela River, PA	38.31	Boatable to game fishing
Smith and others 1986	Travel cost	Monongahela River, PA	12.95	Boatable to game fishing
Smith and others 1986	Contingent valuation	Monongahela River, PA	56.39	Boatable to swimmable
Smith and others 1986	Travel cost	Monongahela River, PA	52.20	Boatable to swimmable
		Mean annual recreation benefits		
				Activity:
Sutherland 1982	Travel cost	119 counties of ID, OR, and WA	54,630	Swimming
Sutherland 1982	Travel cost	119 counties of ID, OR, and WA	48,957	Camping
Sutherland 1982	Travel cost	119 counties of ID, OR, and WA	98,303	Fishing
Sutherland 1982	Travel cost	119 counties of ID, OR, and WA	66,515	Boating

Table 5 provides information about the increase in benefits to recreationists given an improvement in water quality. Values were estimated by using contingent valuation and travel cost methods. Fishing provided the greatest annual benefits in the Pacific Northwest, whereas camping provided the least, reflecting the importance of water quality to each activity.

Table 6 provides detail from Smith and Desvousges (1986), who estimated recreation values for changes in water quality. The travel cost method was used to find benefits per trip for changes in water quality. The sites were primarily in the Midwest, South, and Southeast. They estimated two values for water quality, one for water suitable for boating and fishing, and one for water suitable for boating and swimming.

Table 7 summarizes nine studies that use the contingent valuation and travel cost methods to assess the benefits to recreationists given an increase in water quantity. Various locations and activities are included in the table to illustrate the variability across sites and activities. The marginal value depends on the site and the activities done at each site.

Table 6—Recreational benefits measured by the travel cost method for a change in dissolved oxygen saturation of 1 percent

Location	Value of improvement per trip	
	Boatable	Fishable
	1998 U.S. dollars	
Arkabutla Lake, MS	4.09	4.59
Lock and Dam 2, Arkansas River navigation system, AR	4.04	4.67
Belton Lake, TX	1.35	1.48
Benbrook Lake, TX	.55	1.00
Blakely Mt. Dam, Lake Ouachita, AR	.47	.53
Canton Lake, OK	.69	.74
Cordell Hull Dam and Reservoir, TN	1.98	2.19
Defray Lake, AR	1.48	1.58
Grapevine Lake, TX	.53	.58
Grenada Lake, MS	2.67	3.03
Hords Creek Lake, TX	.42	.47
Melvern Lakes, KS	.77	.84
Millwood Lake, AR	4.70	5.15
Mississippi River pool 6, MN	.05	.05
New Savannah Bluff Lock and Dam, GA	1.82	2.06
Ozark Lake, AR	.87	.98
Philpott Lake, VA	2.32	2.61
Proctor Lake, TX	.11	.13
Sam Rayburn Dam and Reservoir, TX	1.29	1.42
Sardis Lake, MS	1.27	1.42
Whitney Lake, TX	.95	1.06

Source: Smith and Desvousges 1986.

Water Quantity and Recreation Meta-Analysis

Because there are 17 different value estimates for instream flow values in table 7, it is possible to perform a systematic, quantitative analysis for relations by using meta-analysis. Meta-analysis is a commonly used quantitative reversion technique applied to evaluate results of past studies for patterns or consistency of findings. The studies summarized in table 7 were examined by using meta-analysis to determine what, if any, statistical relation might exist between the value per acre-foot increase, and independent variables that include waterflow, recreational activity, and valuation method used. Results of the regression are outlined in table 8. The functional linear form between the variables resulted in the best t-statistics, and highest explanatory power at 59 percent.

Table 7— Value of water for recreation uses

Citation method	Valuation method	Location	Marginal value per acre-foot	Additional feet per second	Type of activity
			1998 U.S. dollars		
Daubert and Young 1981	Contingent valuation	Poudre River, CO	14.50	100	Fishing
Daubert and Young 1981	Contingent valuation	Poudre River, CO	13.44	100	Rafting
Daubert and Young 1981	Contingent valuation	Poudre River, CO	14.50	100	Shoreline
Walsh and others 1980	Contingent valuation	West Slope Rivers, CO	6.94	1,400	Kayaking
Walsh and others 1980	Contingent valuation	West Slope Rivers, CO	4.50	2,800	Rafting
Walsh and others 1980	Contingent valuation	West Slope Rivers, CO	24.46	1,120	Fishing
Ward 1987	Travel cost	Rio Chama, NM	40.32	1,000	Rafting and fishing
Harpman 1990	Contingent valuation	Taylor River, CO	3.10	40	Fishing
Duffield and others 1992	Contingent valuation	Big Hole, MT	34.12	100	Fishing
Duffield and others 1992	Contingent valuation	Bitterroot, MT	13.44	100	Fishing and shoreline
Johnson and Adams 1988	Contingent valuation	John Day River, OR	3.10	204	Fishing
Loomis and Creel 1992	Travel cost	San Joaquin, CA	90.00	2,000	Fishing and other
Loomis and Creel 1992	Travel cost	Stanislaus, CA	16.54	300	Fishing and other
Loomis and Cooper 1990	Travel cost	North Fork Feather, CA	91.63	20	Fishing
Loomis and Cooper 1990	Travel cost	North Fork Feather, CA	71.29	100	Fishing
Loomis and Cooper 1990	Travel cost	North Fork Feather, CA	57.44	200	Fishing
Loomis and Feldman 1995	Contingent valuation	Snake River, ID	76.00	235	Viewing of falls

Table 8—Linear and double log meta-analysis regression results for marginal benefits from an increase in streamflow[a]

Form	Dependent variable	Constant	Valmethod	Fish	Boat	Linear: CFS[b] Log-log: LNCFS[c]	F-stat	R^2
Linear	VAF[d]	40.88	50.42	-26.53	-35.84	0 .004	4.37	.59
		(2.82)[e]	(3.69)	(-1.56)	(-1.99)	(.48)		
Log-Log	LNVAF[f]	3.13	1.76	-0.84	-1.04	.02	3.30	.52
		(2.90)	(3.28)	(-1.26)	(-1.48)	(.09)		

[a] Number of observations = 17 with 12 degrees of freedom. Studies are outlined in table 7.
[b] CFS = water flow in cubic feet per second.
[c] LNCFS = log of CFS.
[d] VAF = value per acre-foot increase.
[e] Numbers in parentheses are t statistics.
[f] LNVAF = log of VAF.

The estimation resulted in the following equation:

$$VAF = ß_0 + ß_1 valmethod - ß_2 fish - ß_3 boat + ß_4 CFS$$

where VAF is the value per acre-foot increase in 1998 dollars,

valmethod is a dummy variable for the valuation method used where 0 = contingent valuation and 1 = travel cost,

fish is a dummy variable for fishing where fishing = 1 and not fishing = 0,

boat is a dummy variable for boating where boating = 1 and not boating = 0, and

CFS is waterflow in cubic feet per second.

In the log-log equation, LNVAF is the log of the value per acre-foot increase in flow, and LNCFS is the log of waterflow in cubic feet per second.

The overall linear regression does a good job explaining nearly 60 percent of the variation in values for instream flow. The coefficient on valmethod indicates that if the travel cost method was used, then the marginal value per acre-foot increases by $50.42, as compared to a contingent valuation method study. The t-statistic is significant at the 1-percent level. If the activity performed is boating, the marginal value per acre-foot decreases by $35.84. The t-statistic for this variable is significant at the 5-percent level. The variable CFS has a low t-statistic, indicating waterflow is not significant in the model. This suggests that the recreational value of instream flow appears not to be related to the absolute flow level. It may be that relative flow concepts, such as percentage bankfull elevation[2], used in the Walsh and others (1980) analysis is a more meaningful concept when comparing waterflows across rivers and studies. As additional instream flow studies become available, this analysis could be updated to improve the meta-analysis. An improved meta-analysis equation could be used to provide a simple benefit-transfer for providing rough estimates of the value of instream flow on rivers without existing studies.

Industrial Water Use

Industrial water use in the United States accounts for approximately 43 percent of withdrawals and 9 percent of consumption (U.S. Water Resources Council 1978). Industrial water use is water used as an input in a production process, such as cooling, condensation, washing, and moving materials (Gibbons 1986). Water may also be incorporated into products.

Industrial intake water must meet various water quality standards. Industrial users of water are concerned with total suspended solids, salinity, and quantity of water available. Depending on the use, quality standards differ in stringency. If the water is used for human consumption or for boiler feed, quality requirements are the most stringent.

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[2] Bankfull elevation is the elevation of the depositional flat, immediately adjacent to the channel (Leopold 1994). The streamflow most effective in producing and carrying sediment is the flow at bankfull elevation (Verry 2000). Bankfull is that portion of the channelway usually defined by a topographic break, where water would completely fill the channel to the level of the adjacent floodplain. It represents a common reference point for measuring flows (personal communication, April 2002, Dr. Gordon Grant, research hydrologist, USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Lab, 3200 SW Jefferson Way, Corvallis, OR 97331).

High salinity or suspended solids could be detrimental to equipment (Gibbons 1986). The quantity of water available is also important. Many companies have their own wells for general process water supply.

Like some agricultural and municipal water uses, industrial water use can result in water quality degradation. The cooling process carries away waste heat, raising water temperature if discharged back to the water source. Evaporative losses may increase the concentration of salts. Chemical and petroleum refining may introduce organic chemicals and solvents into the effluent (Kleinman and Brown 1980).

Changes in marginal costs of production must be estimated to calculate the change in benefits to industrial producers from improvements in water quality. In most cases, if total suspended solids or salinity decreases in the input water, there is a decrease in production costs, for example, by eliminating certain treatments or in longer equipment life. These changes in benefits are measured by deriving a new marginal cost curve given the decrease in production costs. The increase in producer surplus is then measured for production of the same amount of the good, given that the price to the consumer remains constant and only the producers benefit. This is the same method used for agricultural producers given that the price of the good remains constant.

Assuming the price of a good changes with a change in marginal cost of production, we would expect to see an increase in consumer benefits given improvements in water quality. The methods for measuring the increase in consumer surplus are the same as described for agricultural products.

Table 9 summarizes four studies concerning the values of water for industrial uses. Water value was calculated in most of the studies by examining changes in production costs for a particular industry. The values are highly variable between industries. For example, the value per acre-foot of water for the chemicals industry is $99, while the low estimate for the meat packing industry is $637 per acre-foot. The meat packing industry may require more water of higher quality in their production processes than does the chemical industry.

Heintz and others (1976) and Unger (1978) provide estimates of annual damages that industries face because of poor water quality owing to salinity and suspended solids. Heintz and others (1976) estimated total annual damages at $968 million, and Unger (1978) at $1.9 billion, in 1998 dollars. There is little information on benefits for industrial water use owing to the uniqueness of industrial uses, and differences in damage estimates are due to variations in industry uses.

Hydropower Water Uses

Hydropower has been a source of energy for many years, for activities such as the use of water wheels to rotate grindstones for milling wheat, corn, and other grains. In 1980, the United States relied on hydropower from dams for about 12.1 percent of the power consumed in the country. Hydropower is an important method of obtaining energy and has many advantages. One unit of water generates hydropower cumulatively by passing through turbines of many dams along the descent of a river (Gibbons 1986). Hydropower produces less pollution than the extraction and burning of fossil fuels such as coal or natural gas.

Hydropower does have disadvantages. Depending on their construction, dams can eventually silt in or wear out. Dams cause the inundation of vast amounts of land, destruction of fish and wildlife habitat, and the loss of whitewater recreational

Table 9—Values of water for industrial use

Citation	Valuation method	Value per acre-foot	Type of industry
		1998 U.S. dollars	
Young and Gray 1972	Indeterminate	99.77	Chemical industry
Young and Gray 1972	Indeterminate	125.27	Paper manufacturing
Young and Gray 1972	Indeterminate	31.04	Minerals industry
Russell 1970	Change in production costs	146.33	Beet sugar processing
Kollar and others 1976	Change in production costs	259.40	Cotton textile finishing
Kane and Ostantowski 1980	Change in production costs	637.42	Low estimate,meat packing industry
Kane and Ostantowski 1980	Change in production costs	889.07	High estimate, meat packing industry

opportunities (Gibbons 1986). Dams also may cause changes in water temperature. Decreased movement of sediment through the system contributes to loss of habitat and recreational opportunities downstream. These effects are cumulative in a system of dams.

Parameters most important for hydropower production are water quantity and salinity. Salinity affects hydropower production in some of the same ways it affects industrial production. If salinity is too high, penstocks and turbines may deteriorate more quickly. Measurement of benefit from improvements in salinity levels is estimated by determining the increase in equipment lifespans and savings in replacement costs. Water quantity is important in hydropower production. Without an adequate water supply, efficiency is lowered. When valuing water for hydropower, it is important to note that the productivity for hydropower is constant. Each acre-foot of water dropped over a given head (vertical feet) makes the same amount of electricity, so the marginal and average productivities of water in this use are equal. On a specific river, the amount of electricity produced per unit of water is a function of both the average net head on the river and the conversion efficiency of the particular hydropower facility (specifically, the efficiency of the conversion of the energy of falling water into electrical energy) (Gibbons 1986). This relation is fairly standard and can be expressed as 0.87 kilowatt per acre-foot of head (Whittlesey and others 1981).

As water quantity increases in a river, we would expect to see an increase in hydropower production and an increase in revenues. The increase in revenue can be calculated by multiplying the acre-feet of water by 0.87 times the value of a kilowatt-hour. However, there must be a demand for the power when the water is available. At high spring flows, electricity demand for heating and cooling is low, so a lower price may be received.

Consumers of hydropower obtain benefits when water quantity increases. With an increase in waterflow, there is a potential increase in kilowatt-hours produced. This results in a lower marginal cost curve to producers because they are now able to provide more electricity. As demand for electricity is usually inelastic, consumers of electricity obtain benefits from water quantity increases in the form of decreased prices.

Table 10 summarizes information from three studies concerning the values of water for hydropower use. The hydropower industry relies on a large supply of water to provide energy to their customers. The cost savings of hydropower compared to other means of producing electricity were found for different parts of the country by Brown (2000). Alternate costs of firm and peak levels of production were found for other means of providing electricity for certain parts of the country and then compared to the same production level from hydropower by Gibbons (1986). Whittlesey and others (1981) evaluated the opportunity cost of forgone power production owing to agricultural diversions.

Nonmarket and Nonuse Values

Nonmarket values for water include onsite use value and nonuser benefits. Nonuser benefits of water include benefits people obtain without making direct use of water, such as ecological value, preservation benefits, and option or bequest values. These benefits are hard to measure because they are often not linked to observable behavior. Parameters necessary in defining water quality for nonuse benefits may include clarity, quantity, total suspended solids, salinity, dissolved oxygen, and temperature.

Many people receive value from high water clarity because they own or visit land near water bodies and clarity affects aesthetics. Water quality must be sustainable to ensure the environmental quality of particular ecosystems, as high levels of suspended solids or salinity can be harmful to aquatic ecosystems. Spawning areas, food sources, and habitats can be harmed, and there can be direct damage to fish, crustaceans, and other aquatic wildlife (Clark and others 1985). Many upstream activities can cause small changes in water temperature, and results can potentially be devastating. Many aquatic organisms have strict temperature requirements and thus are susceptible to fluctuations in temperature. Dissolved oxygen is extremely important for the survival of many species. If the amount of dissolved oxygen is disrupted, there can be a serious alteration of the aquatic ecosystem. However, some systems are defined as having good water quality even if their dissolved oxygen concentrations are low, such as wetlands; different water bodies have different uses, and acceptable water quality will depend on these uses. Alterations of the parameters can be detrimental to fish and wildlife in many ecosystems.

Water quantity is an important parameter for many habitats. It has been shown that the marginal value of instream flow for fish habitat gradually drops as flows reach a maximum (Brown 1991). Low streamflow can cause concentrations of many pollutants to increase, and cause an increase in water temperature.

Lakefront properties can be viewed as heterogeneous goods; they have many different characteristics and are differentiated from each other by the quality and quantity of these characteristics (Michael and others 1996). When consumers purchase differentiated goods, they are purchasing the characteristics that make up that good (Lancaster 1966). If the quality of any of the characteristics of the goods changes, we would expect the price of the good to change. If the quality of water surrounding lakefront property improves, we expect the price of the property to increase because water quality is a characteristic of the property. The hedonic valuation method allows the measurement of benefits of water quality through the price differences of housing.

Table 10—Values of water for hydropower use

Citation	Valuation method	Location	Value per acre-foot
			1998 U.S. dollars
Brown 1999	Cost savings	Colorado River	17.00
Brown 1999	Cost savings	California	10.68
Brown 1999	Cost savings	Pacific Northwest	8.59
Gibbons 1986	Alternate cost of 18.52 mills per kilowatt-hour[a]	Columbia River, from Grand Coulee Dam to sea level	34.00
Gibbons 1986	Alternate cost of 44.01 mills per kilowatt-hour[b]	Columbia River, from Grand Coulee Dam to sea level	88.00
Gibbons 1986	Alternate cost of 18.52 mills per kilowatt-hour	Snake River, from American Falls to sea level	64.00
Gibbons 1986	Alternate cost of 44.01 mills per kilowatt-hour	Snake River, from American Falls to sea level	160.00
Gibbons 1986	Alternate cost of 18.52 mills per kilowatt-hour	Tennessee River	16.00
Gibbons 1986	Alternate cost of 44.01 mills per kilowatt-hour	Tennessee River	36.00
Gibbons 1986	Alternate cost of 18.52 mills per kilowatt-hour	Colorado River, from Shoshone to the mouth	46.00
Gibbons 1986	Alternate cost of 44.01 mills per kilowatt-hour	Colorado River, from Shoshone to the mouth	114.00
Whittlesey and others 1981	Opportunity cost of forgone power generation	Southeast ID	125.00
Whittlesey and others 1981	Opportunity cost of forgone power generation	Southwest ID	80.00
Whittlesey and others 1981	Opportunity cost of forgone power generation	Lower Columbia River	13.30
Whittlesey and others 1981	Opportunity cost of forgone power generation	Columbia River basin	70.00

[a] The average production expense for a coal-fired steam-electric plant in 1980.
[b] The average production expense for a gas-turbine electric plant in 1980.

Property attributes are also an important nonmarket benefit. Although property owners may not consume the water in a lake or stream, water adjacent to property has aesthetic value and attracts wildlife, which residents enjoy. Property owners receive economic value from water clarity. In a study of lakefront property in Maine by Michael and others (1996), house price per foot of lake frontage was modeled as a function of water clarity at the time the property was purchased, along with other factors such as square footage and number of bedrooms. The study found that estimated increases in selling price of the average lakefront property owing to a 1-meter improvement in water clarity ranged from $34 to $81 per foot of lake frontage, depending on the lake valued. Estimated decreases in the selling price of the average lakefront property owing to a 1-meter reduction in water clarity ranged from $65 to $141 per foot of lake frontage. Estimates of the aggregate property price increase around an entire lake owing to a 1-meter water clarity improvement ranged from $6,528,000 to $9,365,900, whereas estimates of the aggregate price decrease around an entire lake owing to a 1-meter reduction in water clarity were between $12,480,000 and $16,080,700.

Loomis and others (2000) used contingent valuation to estimate values per acre-foot of water on the Platte River in Colorado at $771. Douglas and Taylor (1999) used contingent valuation to assess several scenarios on the Trinity River in California. They estimated values per acre-foot of water that ranged from $536 to $957. Table 11 illustrates the value of salmon given changes in water quality. It is interesting to note that as the number of salmon assumed to exist in each study goes down, the marginal value per salmon increases, reflecting the increased scarcity.

In table 12, values for water quality for nonusers are outlined from three studies. In each study, survey respondents are valuing improvements in water quality related to salinity, suspended solids, and water quantity.

Table 11—Nonmarket nonuse values of additional salmon owing to an increase in water quality

Citation	Valuation method	Location	Value	Number of salmon
			1998 U.S. dollars	
Loomis 1999	Contingent valuation	Pacific Northwest and California	1,400	1,000,000
Loomis 1999	Contingent valuation	Pacific Northwest and California	10,712	250,000
Olsen and others 1991	Contingent valuation	Pacific Northwest and California	203	2,500,000
Loomis 1996	Contingent valuation	Pacific Northwest	3,325	300,000
Hanemann and others 1991	Contingent valuation	California	232,356	14,900

Table 12—Nonmarket values of water quality (salinity and total suspended solids) and quantity

Citation	Valuation method	Location	Value per household	Notes
			1998 U.S. dollars	
Greenley and others 1981	Contingent valuation	South Platte River basin	95.00	Existence and bequest values of nonrecreationists from Fort Collins
Greenley and others 1981	Contingent valuation	South Platte River basin	99.00	Existence and bequest values of nonrecreationists from Denver Metro and the South Platte basin
Loomis 1987	Contingent valuation	Mono Lake	131.00	Utility bill increase for first level of improvement in lake level, visibility, and bird survival and diversity
Heintz and others 1976	Contingent valuation	Fraser River valley	656.00	Preservation value of salmon

Conclusion

Across the Nation, there are significant challenges to policymakers and decision-makers concerning the allocation of high-quality water to the many uses and users. The challenge is to manage federal lands to provide abundant, clean, high-quality water to sustain a burgeoning population, an agricultural industry, historical salmon runs and populations of other threatened species, and recreational opportunities (USDA Forest Service 2000).

Table 13 is a summary of water values by use and parameter for the studies cited in this paper. Although this is a useful summary of the information we have presented, the variation in value by use outlined in previous tables must be kept in mind. Nonmarket values are not summarized in table 13, as the type of meta-analysis outlined in table 8 is a better way to assess the similarity of nonmarket valuation studies.

The application of water values in particular uses can help in forest planning processes, as well as in policy decisions concerning our national forests. National forest land is the largest single source of water in the United States (USDA Forest Service 2000). The USDA Forest Service can provide information to policymakers, managers, and citizens, and improve their ability to develop options, anticipate consequences and implications, and formulate responsive, informed programs. An understanding of water values can provide information on issues concerning Federal Energy Regulatory Commission (FERC) relicensing, instream flow protection for threatened and endangered species, and water policy responses in the face of climate change.

From the 1940s to the 1960s, 325 hydroelectric projects were licensed and built on U.S. national forests. These facilities have provided power, as well as many recreational opportunities. They also have resulted in significant adverse effects on national forest

Table 13—Summary of mean water values by use and parameter in adjusted 1998 dollars

	Water parameter				
Water use	Clarity	Quantity	Salinity and total suspended solids	Temperature	Dissolved oxygen levels
Municipal	16.06 [a] (n=4) [d]	249.97 [b] (n=6)	0.0656 [c] (n=10)	Not applicable (NA)	NA
Agriculture	NA	131.96 [e] (n=11)	52.04 (n=21)	Negative effect	NA
Recreation	Positive effect	33.8 [f] (n=17)	52.72 [g] (per household; n=9) 67,100.00 (total value; n=4)	Negative or positive effect depending on activity	1.54 [h] (boat and fish, n=21) 1.74 [h] (boat and swim, n=21)
Industrial	NA	313.0 [i] (n=7)	1.43 billion annual damages (n=2)	Negative effect	NA
Hydropower	NA	58.84 [j] (n=15)	Negative effect	NA	NA

[a] Value per foot of lake frontage for 1-foot improvement in water clarity; data from table 1.
[b] Value per acre-foot for municipal use; data from table 2.
[c] Value of water quality for municipal use; data from table 3.
[d] n = number of studies assessed.
[e] Value per acre-foot for agriculture; data from table 4.
[f] Value per acre-foot for recreation; data from table 7.
[g] Value of water quality for recreation use; data from table 5.
[h] Value per recreational trip for an improvement in dissolved oxygen; data from table 6.
[i] Value per acre-foot for industrial use; data from table 9.
[j] Value per acre-foot for hydropower; data from table 10.

resources. Within the next decade, more than half of these projects will come up for relicensing. This relicensing process presents the opportunity for the USDA Forest Service to influence how these projects will operate for the next 30 to 50 years (USDA Forest Service 2000).

With the application of water values to particular uses, particularly many recreational and nonuse values, water values for hydropower can be compared to water values for minimum instream flow and recreation and habitat enhancement. An economic analysis can reflect public values for both hydropower and other concerns in FERC relicensing. Gibbons (1986) provides values for instream water for various purposes. By reducing power production and allowing more waterflow for recreation, we can enhance recreational experiences while still allowing for power production (Loomis and Feldman 1995).

Water values for various uses also can be used to assess the tradeoffs between irrigation and other uses. Water rights, however, were established over a century ago by using the prior appropriation system. In addition, environmental laws such as the 1977 Clean Water Act and the 1973 Endangered Species Act establish standards for water quality. Water quality and quantity are still issues. The Forest Service needs to actively participate in the processes that establish rights and laws for water quality and water rights to secure instream flows sufficient to sustain species populations and recreational opportunities (USDA Forest Service 2000).

The contingent valuation method can provide us with information concerning the value of instream flow for nonmarket purposes. The values can be compared in different settings to assess management options for forest planners, as well as for policymakers to help with assessing multiple uses of a limited resource. As an example, Daubert and Young (1981) used the contingent valuation method to find values for fishing per acre-foot of water in the Poudre River in Colorado. With this information, we could then find agricultural water use values in the river basin, and analyze management strategies that balance water uses with marginal values for both recreationists and farmers.

As there are many hydrologic changes that may accompany global climate change, climate change is another variable that may have many adverse effects on the world's water supply, leading to difficulties in meeting competing water use requirements. Climate change may affect water supply and quality for drinking, irrigation, recreational, commercial, and industrial use, and may affect instream flows that support aquatic ecosystems, recreation, and hydropower. These conditions will present challenges to water managers who must balance increasingly variable water supplies with seasonal water demands that do not coincide with one another.

A further challenge is the growing public and legal demand for water for environmental purposes. The value of leaving water instream to protect endangered species and support habitat is increasing throughout the Nation. There are various policy options that may help meet the demands of water users, including modifying those demands. With data on water values, these policies can look at higher valued uses to help with decisionmaking.

Water price reform may be one strategy used to decrease the inefficient use of water for irrigation and alleviate some of the pressures of excess demand that arise from water shortages. Moss and DeBodisco (1998) state that irrigation water is underpriced, and this is a significant stumbling block to more efficient use. According to Gibbons (1986), a 10-percent reduction in consumptive use by agriculture represents a 50-percent increase in water availability for urban or environmental purposes. Reductions in agricultural use can be achieved in several ways, but most likely through water pricing reforms and incentives for water transfers, either on an individual basis or through formal water markets.

Water banks are public or private institutions that act as water brokers or clearinghouses to match buyers and sellers of water. They facilitate the rapid movement of water from low- to high-value uses. California has had success in coping with drought by developing and implementing a state-run water bank. Owing to continuation of a severe drought, cities and farmers with permanent crops, such as orchards, faced substantial water supply shortfalls. In 1991, Governor Wilson created the California Water Bank. The water bank was designed to meet four essential water needs: municipal and industrial uses, agricultural uses, protection of fish and wildlife, and carryover storage (U.S. Office of Technology Assessment 1993). At the time of establishment, the state of California bought water at $125 per acre-foot, and sold it for $175 per acre-foot, and the buyer paid delivery costs. Of the $50 spread between purchase and sale price, $45 covered losses such as water lost in transit from the source to the buyer. The remaining $5 covered Water Bank administration costs. In part, the purchase price was arrived at by estimating forgone income per acre through an assessment of consumptive water use for crops. This is an example of the way water values can be used to respond to changes in water supply.

Outright purchases of senior water rights for drought protection may impose unwanted costs on the economies of local communities relying on irrigated agriculture, and may not be the most cost-effective solution. Agricultural water rights holders can retain their water rights and have the option to transfer their rights for other uses by instituting water supply option contracts. The exercise of the option transfers water to other uses as needed, while preserving water for agriculture during normal supply years (Michelsen and Young 1993).

Providing cold, clear water of high quality for aquatic organisms and human use is a focus of water management on national forests. With information about water and water quality values for various uses and water quality parameters, we can estimate the marginal values for water with a given change in a water quality parameter. The values reported here can be used to help with reevaluating many policy and management regimes in the face of water scarcity and pollution issues concerning our Nation's water resources.

Metric Equivalents

When you know:	Multiply by:	To find:
Acres	0.405	Hectares
Feet	.305	Meters
Cubic feet	.0283	Cubic meters
Acre-feet	1,233.5	Cubic meters

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