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ECONOMIC VALUATION OF FRESHWATER ECOSYSTEM SERVICES IN THE UNITED STATES: 1971–1997

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Abstract. The purpose of this paper is to provide ecologists and resource managers with a sense of where the economic science of ecosystem valuation has come from and where it might go in the future. To accomplish this, the paper provides a comprehensive synthesis of peer-reviewed economic data on surface freshwater ecosystems in the United States and examines major accomplishments and gaps in the literature. Economic value has been assigned to nonmarket goods and services provided by surface freshwater systems in the United States by 30 published, refereed articles in the scientific literature from 1971 to 1997. These studies have used variations of three approaches for a quantitative assessment of economic value: travel cost methods, hedonic pricing methods, and contingent valuation methods. To determine the economic value of nonmarket ecosystem goods and services, each method focuses on a different aspect of social benefit associated with lakes, streams, rivers, and wetlands. Valuation methodologies work from different underlying assumptions while possessing unique limitations and uncertainties. Dollar benefit estimates derived for nonmarket freshwater ecosystem goods and services from these studies tend to be specific to a particular method, ecosystem, and socioeconomic circumstance. Creative interdisciplinary research is needed on the quantitative measurement of surface freshwater ecosystem goods and service values, the relation of these values to key limnological variates, and communication of limnological insights to the public and social scientists in ways that facilitate and improve future management and research.

Key words: economics; freshwater ecosystems; lake; nonmarket ecosystem services; river; wetland.

INTRODUCTION

Surface freshwaters such as lakes, rivers, wetlands, and streams provide many diverse goods and services to human society. These include both market goods and services like drinking water as well as nonmarket goods and services such as biodiversity (Gleick 1993, Naiman et al. 1995, Postel and Carpenter 1997). Many of the goods and services that may be provided by surface freshwaters in the United States today are not bought or sold and thus, have no readily observable price tag. Any economic value attached to these goods or services must be estimated using a surrogate for the observable behaviors witnessed in the marketplace. Available methods for the quantitative valuation of surface freshwater ecosystems require expertise from both social and natural sciences, are still evolving, imprecise, and controversial (Anderson and Bishop 1986, Freeman 1993, Diamond and Hausman 1994, Pourtney 1994, Bingham et. al. 1995).

An ecosystem service, by definition, contains all ''the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life'' (Daily 1997). In addition to the production of marketable goods, therefore, freshwater ecosystems may provide functions such as nutrient recycling and renewal as well as conferring aesthetic and cultural benefits to humans (Costanza et al. 1997). These myriad goods and services may be divided into two categories: (1) the provision of direct market goods or services such as drinking water, transportation, electricity generation, pollution disposal, and irrigation; and (2) the provision of nonmarket goods or services which include things like biodiversity, support for terrestrial and estuarine ecosystems, habitat for plant and animal life, and the satisfaction people derive from knowing that a lake or river ecosystem exists. By estimating the economic value of ecosystem goods and services not traded in the marketplace, social costs or benefits that otherwise would remain hidden or unappreciated are thus revealed. For this reason, ecologists, social scientists, and environmental managers are increasingly interested in assessing nonmarket ecosystem goods and services (Dorfman and Dorfman 1993, Freeman 1993, Costanza et al. 1997, Daily 1997).

Unfortunately, empirical data on nonmarket values for freshwater ecosystems remain scattered throughout the scientific literature and often appear uneven in quality (Costanza et al. 1997, Postel and Carpenter 1997). Despite uncertainty in the estimation of nonmarket val-

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ues for surface freshwater ecosystem services, a comprehensive analysis of extant literature may provide useful insight. Such an exercise provides ecologists with a sense of where the science of ecosystem valuation has come from, and where it might go in the future. To accomplish this goal, we synthesized peer-reviewed economic data on surface freshwater ecosystems in the United States, delineated a few examples from the literature for extended discussion, and examined major accomplishments and gaps in the published literature.

Methods

All data presented here were obtained from studies that were published between 1971 and 1997. They deal explicitly with nonmarket surface freshwater ecosystem goods and services in the United States. We do not review available data for market-related freshwater ecosystem goods and services such as drinking water, freight transportation, pollutant disposal, sport fisheries, and wildlife habitat, as these have been reviewed elsewhere (Covich 1993, Postel and Carpenter 1997). Only peer-reviewed journal articles were included in this review.

The literature search involved an intensive review of databases on the World Wide Web and CD-Rom files located at the University of Wisconsin, Madison, Wisconsin, USA. In total, seven databases were searched: *Agricola*, *EconLit*, *JSTOR*, *Environmental Periodicals Bibliography*, *Social Sciences Index/Abstracts*, *Sociofile,* and *Water Resources Abstracts.* Several keywords—*economic value, economics, contingent valuation, travel cost, hedonic, valuation, water, freshwater, lake, river, wetland,* and *ecosystem service*—were combined in various patterns to elicit studies that might be relevant to surface freshwater ecosystem valuation. This search yielded over a hundred citations. Each article was located and reviewed by the authors. Most (>70%) were rejected because they were not peer reviewed, did not explicitly address freshwater ecosystem services, or dealt with resources for which markets exist. Finally, analyses of environmental economics volumes and the bibliographies of selected studies were reviewed to ensure that relevant studies were not left out (Freeman 1993, Carson et al. 1994).

Results

The literature review yielded a total of 30 studies. Results from these 30 studies were then sorted by method, content, and empirical data. On this basis, each study was classified under one of the three primary methods: travel cost method (TCM), hedonic pricing (HP), or contingent valuation (CV), or any combination thereof (some studies appear in more than one table). Benefit estimates were then tabulated in Tables 2–4. To ensure comparability of all dollar values, the results of each study were converted from their original dollar metric to their equivalent in 1997 dollars using the Bureau of Labor Statistics, Consumer Price Index for all urban consumers in the United States (Bureau of Labor Statistics 1997).

Nonmarket goods and the economic concept of value

When discussing empirical results from the freshwater ecosystem valuation literature, one first needs to be clear on what the economic concept of value actually means. The term ''value'' as it is employed in this review has its conceptual foundation in neoclassical economics (Anderson and Bishop 1986, Freeman 1993). In this restricted sense, value is defined by economic behavior in the context of supply and demand for variable goods and services. If we assume that individuals are the best judges for making the trade-offs that are most valuable to them, value can be reflected in two theoretically commensurate empirical measures. First, there is the amount of money people are willing to pay for specific improvements in a good or service, ''willingness to pay'' (WTP). Second, there is the minimum amount an individual would need to be compensated to accept a specific degradation in a good or service, ''willingness to accept compensation'' (WAC) (Bishop et al. 1983). Simply put, economic value is the amount of money a person is willing to give up in order to get a thing, or the amount of money required to give up that thing. To date in the literature of environmental economics, WTP has been the dominant measure of value. It is important to note however, that WTP is not always actually expressed; it is not restricted to what we actually observe from people's transactions in the market. Instead, ''it expresses how much people would be willing to pay for a given good or service, whether or not they actually do so'' (Goulder and Kennedy 1997).

A central concern in the discipline of economics is one of making trade-offs; allocating scarce resources among all of society's members. If society wished to make the most of its endowment of surface freshwater resources, for example, it should be possible to compare the value of what society's members receive from any improvement in a given freshwater ecosystem with the values of what its members give up to degrade the same system. The prevailing approach to this type of assessment is cost-benefit analysis (Ableson 1979, Kneese 1984). Cost-benefit analysis has a long and controversial history (Hufschmidt et. al. 1983, Kneese 1984). One reason for controversy is that cost-benefit analysis is characterized by a strictly utilitarian decision-making structure: i.e., ''defining the project, identifying impacts which are economically relevant, physically quantifying impacts as benefits or costs'' and then, ''calculating a summary monetary valuation'' (Hanley and Spash 1993). The key issue for cost-benefit analysis has traditionally come down to the question of what to count in terms of economic relevance to society.

However, the underlying utilitarian logic of econom-

TABLE 1. Typology of benefits associated with freshwater ecosystems for purposes of economic valuation (adapted from Mitchell and Carson 1989).

Benefit class	Benefit category	Benefit subcategory
Use	In-stream	Recreational (fishing, swimming, boating)
		Commercial (transportation)
	Withdrawal	Municipal (drinking water)
		Agriculture (irrigation)
		Commercial (electricity)
	Aesthetic	Enhanced near-water recreation (hiking, picnicking, photography)
	Ecosystem	Enhanced recreation support (wildlife viewing, hunting)
		Other ecosystem services
Nonuse	Vicarious consumption	Significant others (family)
		Diffuse others (American public)
	Stewardship	Inherent (remote wetlands)
		Bequest (future generations)
	Option	Individual risk-aversion

ics does not rule out substantial sacrifices to protect and maintain essential ecosystem goods or services. Rather, such logic demands only that a value be assigned to a given environmental asset ''insofar as we humans take satisfaction from doing so'' (Goulder and Kennedy 1997). In short, economic theory does not restrict the concept of value to direct consumption by humans (i.e. ''use'' value); ''nonuse'' values also exist. Resource values that are independent of people's current consumption of an environmental resource are variously termed ''nonuse,'' or ''passive-use'' values (Krutilla 1967, Freeman 1993). The basic idea is that significant positive values exist because individuals can value the mere presence of a surface freshwater ecosystem, or improvements to it, even if they do not make specific use of that resource. The ''total'' value of a given good or service includes both of these distinct domains: the sum of both use value and nonuse value (Anderson and Bishop 1986, Sanders et. al 1990).

Both use and nonuse benefits of freshwater ecosystem goods or services have been categorized (Table 1). Use benefits consist of all the direct and indirect ways in which a given individual expects to make use of a freshwater resource. Important nonuse benefits (e.g., vicarious consumption, stewardship, and future option) are called ''existence values'' which capture the notion that an individual does not have to visit a surface freshwater ecosystem or use its resources to gain personal utility from it (Krutilla 1967). A related idea developed in the economics literature is that of ''option value,'' or the premium that people are willing to pay to preserve an environmental amenity because exploitation now would foreclose an option of using the ecosystem for another purpose in the future (Desvouges et al. 1987).

Hence, a fundamental problem with estimating social demand for many goods and services associated with surface freshwaters is that markets for them do not exist. There are no obvious behavioral trails, market purchases, or similar evidence to provide information about values (National Oceanic and Atmospheric Association 1993). Attempting to overcome the nonmarket ''valuation problem,'' economists and other policy-oriented social scientists have developed techniques for measuring the value of environmental goods and services (Anderson and Bishop 1986, Mitchell and Carson 1989, and Freeman 1993). These methods differ greatly in data needs and in underlying assumptions about economic agents and biophysical environments (Mitchell and Carson 1989). We encountered three approaches most commonly used for freshwater valuation: travel cost, hedonic pricing, and contingent valuation (Anderson and Bishop 1986, Mendelsohn 1987).

The economic literature focuses on estimates of ''marginal value,'' i.e., the change in value resulting from a specified change an ecosystem service (Dixon et al. 1994, Goulder and Kennedy 1997). Consequently, the marginal values reported below are specific to particular ecological changes in particular ecosystems. Numerous texts show how marginal values are used in cost-benefit examples for decision making; for aquatic examples see Dixon et al. (1994) and Carpenter et al. (1999).

The travel cost method

The travel cost method (TCM) is one approach used in the literature to place a value on freshwater quality changes via observed consumption in related markets (Dixon et al. 1994). Benefit estimates from valuation studies using the TCM are presented in Table 2. To estimate the value nonmarket benefits associated with freshwater services, proxy consumption costs—i.e., gas mileage costs, entry fees, on-site expenditures and outlays on recreational equipment—are substituted for the market price of the environmental good or service in question. In most applications of TCM, each visit by an individual or a household to a recreation site is treated as a transaction in which the cost of traveling is incurred in return for access to the site. Thus, people are assumed to react to increasing travel costs the same way they would react to an admission fee; the more it costs to get to the site, the less frequently the site will be used. In short, ''people will make repeated trips to the site until the marginal value of the last trip is just worth what they have to pay to get there'' (Mendelson and Markstrom 1988).

In the literature on the nonmarket goods and services of freshwater ecosystems, TCM has been used primarily to estimate the value of water quality changes at recreation sites (Bouwes and Schneider 1979, Ribaudo et al. 1984, Smith and Desvouges 1986). In this procedure, a site quality index (e.g., water clarity, dissolved oxygen, fish stocks, etc.) is taken as a predictor

TABLE 2. Benefits measured by the travel cost method (TCM).

Study and publication date	Freshwater ecosystem type	Good(s) being valued	Sample units	Unit specific benefit (1997 dollars)	Aggregate benefits (1997 dollars)
Bouwes and Schneider (1979)	Lake	Recreational trips to Pike Lake, Wisconsin, as a result of change in water quality measured by Uttormark's Lake Condition Index (LCI)	Visitors to Pike Lake who traveled there for the purpose of recreation	Total mean annual consumer surplus, $85,721	Annual value of the benefit stream, $\$730 \times 10^3$
Bowker et al. (1996)	River	Improved river water quality and more guided whitewater rafting on the Chatooga and Nantahala rivers in South and North Carolina	Visitors who participated in commercial whitewater rafting on the Chatooga and Nantahala rivers in 1993	Maximum per trip consumer surplus: Chatooga River, $292; Nantahala River, $195	Not available
Burt and Brewer (1971)	Lake and reservoir	Increased levels of water quality and increased surface area of new reservoirs proposed by the Army Corps of Engineers on a system of three lakes near St. Louis, Missouri	Random selection of all households in the state of Missouri	Not available	Annual net benefit, $\$25 \times 10^6$
Cameron et al. (1996)	Reservoir and river	Reservoir and river water levels; summer-month (May, June, July, and August) trips to federal water bodies located within the Columbia River Basin if water levels changed	Three sample populations: (1) all residents of the Pacific Northwest; (2) households located within counties adjacent to the river basin; (3) recreationists visiting the basin	Range of individual per month consumer surplus: $16 (minimum) at Lake Koocanusa to $125 (maximum) at Lake Roosevelt	Not available
Smith and Desvouges (1986) and Smith et al. (1986)	Reservoir and river	Recreational demand as a result of specified change in water quality (boatable to swimming): the comparison considers three water quality changes at 13 recreation sites along the Monangahela River in southwestern Pennsylvania	Households in the five counties that comprise the Pennsylvania portion of the Monangahela River Basin	Annual benefit per household: (1) loss of boatable, $6 (2) boat to fish, $13 (3) boat to swim, $51	Not available
Ribaudo and Epp (1984)	Lake	Increased levels of ambient water quality in St. Albans Bay, Vermont	Current and former users of St. Albans Bay and surrounding areas	Surplus per trip: current users, $189 former users, $149	Aggregate per season, $\$827 \times 10^3$
Sanders et al. (1991)	River	Changes in recreational user days of 11 Colorado rivers under program to specify protection under the Wild and Scenic Rivers Act	All households in the state of Colorado who might be recreationists on the lakes	Individual consumer surplus per day, $27.62	Not available
Young and Shortle (1989)	Lake	Recreational benefits associated with water quality improvements in St. Albans Bay, Vermont	All recreationists on St. Albans Bay, Lake Champlain	Not available	Aggregate per season, $\$599 \times 10^3$

of the actual observed consumption behavior, for example, as numbers of visits, distances traveled, or costs incurred. The number of visits to site *j* by individual *i*, V_{ij}, is used to fit the following equation:

$$V_{ij} = f(C_{ij}, Q_j, M_i)$$

where C_{ij} is the travel cost of person *i* to site *j*, Q_j is the quality index of the site, and M_i is the person's income. It is assumed that *V* will be directly related to *Q*; as quality rises, *V* will rise. This regression equation forms the basis for calculations of the marginal dollar value of the environmental quality of the site (Dixon et al. 1994).

A dominant theme of peer-reviewed studies using TCM is a focus on recreational demand as a proxy measure for nonmarket demand of the water quality or water level of lakes, reservoirs, and rivers (Table 2). This approach represents the oldest and perhaps the most straightforward approach to handling a set of heterogeneous goods and services associated with surface freshwater ecosystems.

One early TCM study addressed the benefits of a proposed storm sewer diversion project for Pike Lake in southeastern Wisconsin (Bouwes and Schneider 1979). A Lake Condition Index (Uttormark and Wall 1975) was used to summarize key water quality variates (Secchi disk transparency, hypolimnetic oxygen, primary producer biomass, and risk of fish winterkill) that were related by regression to subjective public perceptions of lake quality. This regression was used to incorporate ecological measures of water quality into an economic model of demand for recreational services of Pike Lake. Bouwes and Schneider (1979) estimated a potential loss of U.S. $85 700 per year if Pike Lake's water quality continued to deteriorate. In light of these benefits, and the costs of the planned sewer diversion, the authors concluded that ''it would be a wise decision for the water resource manager to recommend the project'' (Bouwes and Schneider 1979).

More recently, Smith and his colleagues measured the recreational demand associated with three different specified water quality improvements in the Monongahela River basin, Pennsylvania (Smith and Desvousges 1986 and Smith et al. 1986). The simple travel cost model that turned out to be the best predictor of recreational demand was based on the recreation behavior reported by 69 survey respondents who used one or more of the 13 recreational sites along the river. The authors used records of respondents' use and travel costs and the variation in mean dissolved oxygen across the 13 sites to estimate the pooled demand curve for a simple travel cost model. The model was subjected to three different scenarios that involved hypothetical changes in the water quality at each site to estimate the value of water quality changes at these 13 recreational sites. The three scenarios were: (1) avoid a decrease in available boatable area due to degradation of water quality conditions on the river; (2) improve water quality from the current classification of ''boatable'' to ''fishable''; and (3) improve conditions from the current ''boatable'' to ''swimmable'' condition. Using this model, the estimated WTP for each water quality change was as follows: approximately U.S. $6 per trip to avoid further degradation of the 13 sites; U.S. $13 per trip to improve water quality from its present boatable state to fishable state; and U.S. $51 per trip to improve water quality from boatable to swimmable.

The hedonic method

Hedonic pricing (HP) places value on ecosystem goods and services by estimating a statistical relationship between the attributes of the surface freshwater system and the price of a good for which a market actually exists. The hedonic model assumes market goods (e.g., houses) have values influenced, in part, by characteristics of neighboring ecosystems. The observable market for such goods is then assumed to be motivated by an implicit, unobserved market for underlying characteristics, including ecosystem services. In short, instead of prices of goods, the researcher using the HP method looks for prices of underlying ecosystem attributes; instead of demand for goods, there is a demand for attributes. For example, in many HP estimates of freshwater ecosystem goods and services, the price of lakeshore property is related to indices of water quality such as water clarity. Michael et al. (1996) summarize the underlying logic of this type of model:

> If consumers have a choice in the quantity and quality of the characteristics of a market good [lake-front property], and an environmental good is a characteristic of the market good, then the implicit price of a nonmarket characteristic, such as water quality, can be observed through consumers' purchases in the market. If two lakefront properties are exactly the same and only differ by the level of water quality for their respective lakes, the price differential between the two properties is the implicit price paid for the property on the lake with the higher water quality.

In practice, most HP analyses use a statistical model to estimate the effect of water quality variates on observed price. For example, the price of a given lakefront house (P_i) might depend on several regressors such as site characteristics S_i (house size, lot size, distance to lake, etc.), neighborhood characteristics N_i (ethnic composition, schools, etc.), and environmental variables Q_i (Secchi disk transparency, fish stocks, etc.). A regression is fit to predict price from these variates:

$$P_i = f(S_i, N_i, Q_i).$$

Given the regression equation, the marginal value of the environmental variate is estimated as dP/dQ.

Valuation studies using the HP method are presented in Table 3. All of these studies use actual housing sale price or appraised housing price as a proxy to estimate

TABLE 3. Benefits measured by hedonic pricing (HP).

Study and publication date	Freshwater ecosystem type	Good(s) being valued	Sample units	Unit specific benefit (1997 U.S. dollars)	Aggregate benefits (1997 U.S. dollars)
Doss and Taff (1996)	Wetland	Implicit price paid for a 10-m increase in house proximity to four different wetland types: (1) open water; (2) scrub–shrub; (3) emergent vegetation; and (4) forested	Households located in Ramsey County, Minnesota, including St. Paul and suburbs	Open water, \$101 scrub–shrub, \$148 emergent vegetation, \$139 forested, \$148	Not available
Epp and Al-Ani (1979)	River and stream	Implicit price increase in property value per one-unit increase in water pH in adjacent streams	Single-family households located in rural Pennsylvania	Increase in mean sales per one-unit increase in pH, \$1439	Not available
Lansford and Jones (1995)	Lake	Implicit prices paid for shoreline property and ''near to the lake'' properties for increasing proximity to the lake	Properties located on or near the Highland Lakes Chain: Lake Travis and Lake Austin, Texas	Sales prices of a 1,500 square foot residence:† Waterfront, \$201, 300 feet from shore,‡ \$127; 1500 feet from shore,‡ \$117	Market value of residential recreational benefits: \$69 $\times 10^6$
Michael et al. (1996)	Lake	Implicit prices paid by lakefront property owners for one-meter increases in summer water clarity	Households located within four Maine lake districts: Auburn, Augusta, Waterville, and northern Maine	Auburn, \$294; Augusta, \$76; Waterville, \$197; northern Maine, \$172	Not available
Steinnes (1992)	Lake	Implicit prices paid for shoreline lots per unit increase in level of water clarity (1-m secchi disk) on 53 freshwater lakes in Minnesota	All appraised lakefront properties on 53 lakes	Increase of a lakeshore lot per unit increase water clarity, \$235	Not available
Young and Shortle (1989)	Lake	Aggregate increase in property values associated with specified water quality improvements in St. Albans Bay, Vermont	All Households located in the vicinity of St. Albans Bay, Vermont	Not available	Increase in property values for St. Albans Bay area, \$1.8 $\times 10^6$

† One square foot is equivalent to 0.093 m^2.
‡ One foot is equivalent to 30.48 cm.

the nonmarket value of lake, river, or wetland ecosystem characteristics.

For example, Steinnes (1992) estimated the contribution of water clarity to lakefront property values in northern Minnesota. This study used the appraised property market values as the market proxy. Property value was then related directly to water quality indicators using regression. Secchi disk transparency proved to be the only freshwater ecosystem variate that was consistently significant in the regressions. A 1-m increase in Secchi disk transparency raised lakeshore prices by an average of U.S. \$235 per lakeshore lot.

In one of the most detailed HP studies of water quality in the literature to date, Michael et al. (1996) examined the relationship between Secchi disk transparency and selling price of >900 properties on 34 lakes in Maine during 1990–1994. Prices were regressed on lot size, number of stories, septic system, neighborhood characteristics, and Secchi disk transparency. A decrease in Secchi disk transparency of 1 m in 10 yr was associated with significant declines in property values, ranging from U.S. \$3000 to \$9000 per lot (up to 22%). The authors found significant empirical support for the argument that, among a group of lakes varying in transparency, property values are lower on lakes with lower water clarity.

The contingent valuation method

The contingent valuation method (CV) attempts to discover nonmarket values of surface freshwater ecosystems by asking people directly for their WTP estimates. Whereas both TCM and HP are used to estimate unobservable environmental values via observable market proxies, CV attempts to measure those values by using social scientific survey techniques (Heberlein 1988, Bishop and Heberlein 1992, NOAA 1993). The typical CV questionnaire presents a scenario of a freshwater ecosystem and a hypothetical market in which the benefits associated with this change might be purchased. Then, the researcher ''questions a random sample from the population of interest about their WTP for the [scenario] described'' (Mullarkey and Bishop 1995: 64). The values revealed by respondents are thus said to be contingent upon hypothetical markets presented in the survey instrument.

CV remains the subject of heated debate within the nonmarket valuation literature (Hanemann 1994). The main problem is that many economists remain wary of relying on hypothetical transactions to reflect how people would behave in a functioning market (Pourtney 1994). A detailed critique of this problem is beyond the scope of this paper, but we acknowledge that major issues in CV survey design and implementation remain unresolved (Diamond and Hausmann 1994, Hanemann 1994, Pourtney 1994).

Published valuation studies using the CV method tended to address a greater diversity of freshwater issues and a greater range of spatial scales than the TC and HP studies (Table 4). Ecosystem services often included water quality, water levels, river flows, and wetland amenities at various spatial scales ranging from individual lakes or watersheds, to individual states, and to the entire United States.

At the largest spatial scale, for example, Carson and Mitchell (1993) were able to estimate the national benefit of meeting the goal of the Clean Water Act for swimmable water quality in all the nation's freshwater bodies. Using data from a 1983 national probability sample of 813 persons located at 61 sampling points in the contiguous United States, the authors estimated a national mean willingness to pay (WTP) to be $298 per household. The payment vehicle used in this study was annual taxes and higher product prices that would be paid by all households in the United States (Mitchell and Carson 1989). Updating their 1983 data, the authors assert that the total benefits for achieving the national swimmable water quality goal from a baseline of nonboatable water is approximately U.S. $\$5.8 \times 10^{10}$ per year. After comparing this aggregate benefit with the latest reported annual *cost* estimates for water pollution control of approximately U.S. $\$4.6 \times 10^{10}$, Carson and Mitchell conclude that the social benefits of achieving swimmable water quality in the nation's freshwater lakes, rivers, and streams exceeded the costs.

At a smaller, regional scale of analysis, Sutherland and Walsh (1985) considered the value of preserving water quality in the Flathead River Basin, Montana, USA. The CV method was used to estimate the preservation value of environmental quality before actual degradation occurred due to coal mining activity in the region. A usable sample of 171 Montana households was obtained by mail survey during the summer of 1981. The names and addresses were drawn from telephone directories of four major cities and adjacent rural areas of the state, each occurring at varying distances from the study area. Recreation users and nonusers total annual WTP for water quality in the Flathead River Basin was estimated to be an annual mean of U.S. $113. Interestingly, the authors also tested the ''distance-preservation value hypothesis,'' which suggests that preservation value has a negative association with distance from that resource. If supported, this hypothesis would allow researchers to empirically estimate a regional boundary where economic benefits for preservation became zero. Sutherland and Walsh extrapolated mean WTP to the regional population living in the seven states and three Canadian provinces surrounding the Flathead River Basin. They found that households living beyond 1030 km (640 miles) from the Flathead River were not willing to pay anything to preserve water quality in the area. Thus, the aggregate annual preservation value of the Flathead River basin was limited to an estimated U.S. $\$160 \times 10^6$ annually.

CV results have sometimes been extrapolated across spatial scales. For example, Berrens et al. (1996) measured WTP for minimal flows in four rivers in New Mexico and scaled up their results to estimate WTP for all rivers in New Mexico. Sanders et al. (1990) made a similar extrapolation when they extended their WTP for 11 specific rivers to a larger population of 15 rivers. The economic literature discusses spatial issues under the rubric of ''geographical nesting'' that acknowledges the idea that nonmarket goods are often embedded within recognizable geographic boundaries (Carson and Mitchell 1995). Results of the Flathead study, for example, may have a geographic basis. People living outside the Flathead Basin were substantially less interested in the Basin's water quality than those persons directly affected by the coal mine.

DISCUSSION

The literature reviewed here demonstrates the challenges inherent in estimating the economic value of surface freshwater ecosystem goods and services. The diversity of studies suggests that methodological guidelines and standards are still evolving (Mitchell and Carson 1989, Freeman 1993, NOAA 1993). The process of placing an economic value on nonmarket goods and services remains problematic. However, it is evident from this review that within the context of a specific management scenario for a freshwater ecosystem, defensible dollar estimates can be obtained and thereby add to the information base for environmental decision making. These estimates may require considerable creative research and have substantial uncertainties. Despite these limitations, the available data suggest that Americans do indeed attach substantial positive economic values to the myriad nonmarket goods and services their freshwater lakes, rivers, streams, and wetlands provide.

Another interesting finding is that economic analyses in the literature often focus on a specific indicator of water quality. For example, secchi disk transparency (i.e., water clarity), as used by Michael et. al. (1996), is a common indicator of the state of a freshwater ecosystem. Water clarity has the significant advantage of being relatively easy to explain to the public. Another indicator that has been translated into nontechnical language is the frequency of noxious algal blooms (Lathrop et al. 1998). Such indicators compress ecological characteristics into one or a few metrics, which are advantageous for communication but may omit important aspects of ecosystem functioning. The evaluation of ecological indicators has its own extensive literature (e.g., Loeb and Spacie 1994, Rapport and Calow 1995). How such indicators might be used in valuation studies is an important topic for future interdisciplinary research.

Our literature review also demonstrates considerable variability among the dollar values derived from different studies that deal with similar surface freshwater ecosystem goods or services. While it is plausible that some of this variability could be explained by differences among the human populations surveyed, ecosystem types evaluated, or specific environmental scenarios considered, the data are too sparse for a meaningful statistical test of such ideas. However, it is possible to evaluate some of the differences among the methods and to interpret implications for ecologists interested in the socioeconomic dimensions of freshwater ecosystems.

Comparison of valuation methodologies

Although there are other approaches to nonmarket ecosystem valuation, the vast majority of studies in the literature employ one or more variations of the three methods we have described. Despite the availability of these methods, however, the estimation of meaningful economic values for all individuals who might potentially benefit from water quality improvements remains a considerable empirical challenge. To capture the ''total economic value'' of a given improvement in freshwater ecosystem, both nonuse and use values must be estimated (Mullarkey and Bishop 1995; see also Table 1). Because each valuation method targets a different aspect of total economic value, its estimation potential tends to be limited to differing aspects of the total environmental service package associated with freshwater ecosystems.

The methods reviewed above differ greatly in both their data needs and in their underlying assumptions about economic agents and biophysical environments. The TCM and HP methods are based on linkages between ecosystem indicators and markets for related private goods and services (Anderson and Bishop 1986). The economic value of the freshwater ecosystem service must be inferred through the application of some model of the relationship between market goods and that service.

In contrast to the related-market methods, the CV method estimates total value through a survey questionnaire, thereby allowing considerable flexibility in the ecological scenarios it can be used to value. But, many scholars remain skeptical about the quality of WTP estimates derived from CV. As this review shows, even when two CV studies examine the same ecological type (i.e., a wetland) the empirical results may vary depending on the context of the ecological asset being valued and how the peculiarities of that asset are communicated to the respondent in the survey instrument (Table 4).

Each of the available methods for measuring the economic value of nonmarket freshwater ecosystem goods and services has important shortcomings. However, perhaps the most important limitation is common to all the methods: as of yet, the American public has a very difficult time attaching economic value to ecosystem services they do not use or perhaps even recognize (Heberlein 1988). Despite this limitation, while some freshwater ecosystem goods and services may not be known well enough by the public to place economic values on now, it is likely that others will become vitally important and highly valuable in the future. Hence, the methodologies reviewed here will be increasingly drawn upon to derive estimates of their true worth to society.

Implications for resource managers and ecologists

Resource managers and ecologists should be aware that nonuse values have been shown to comprise a sizable portion of total economic value associated with freshwater ecosystems. One important conclusion that follows is that if such values are left out of policy analysis, resulting policy will tend to overestimate the role of use values, and underestimate the role of nonuse values. Without efforts to quantify the nonuse benefits associated with freshwater ecosystem goods and services, policy and managerial decisions could potentially be skewed in favor of environmentally degrading practices by neglecting the diffuse social interests that benefit from the many nonuse oriented characteristics of such systems.

Ecology can play a crucial role in bringing concepts like ecosystem services to the foreground of the valuation debate (Costanza et. al. 1997, Daily 1997). Assigning a dollar value to functions of freshwater eco-

TABLE 4. Benefits associated with surface freshwater ecosystem services in the U.S. measured by the contingent valuation method (CVM), 1977 to 1997.

Study and publication date	Freshwater ecosystem type	Good(s) being valued	Sample units	Unit specific benefit (1997 U.S. dollars)	Aggregate benefits (1997 U.S. dollars)
D'Arge and Shogren (1989)	Lake	Per square-foot value of lakeshore property associated with a qualitative increase in water quality from boating/fishing level to a swimming/drinking level†	All residents who own lakefront property on the East and West Lakes of Okoboji, Iowa	Per square foot,† $11	Not available
Berrens et al. (1996)	River	Benefits of maintaining minimum instream flows in one New Mexico River (Middle Rio Grande) vs. all New Mexico rivers	All households in the state of New Mexico	Middle Rio Grande River, $29; all New Mexico rivers, $91	Not available
Boyle et al. (1993)	River	Policies that would result in varying increases in cubic feet per second (cfs) flow of the river for whitewater rafting‡	Commercial and private whitewater boaters	Commercial: @26 000 cfs, ‡ $843; @40 000 cfs, $531. Private: @26 000 cfs, $691; @40 000 cfs, $512	Not available
Carson and Mitchell (1993)	All freshwater bodies in the United States	New federal policies designed to ensure that all water bodies reach at least a swimmable quality level	All household residents of the United States	Swimmable water quality per household, $298	National aggregate benefit, $58 $\times$ 10^{10}
Cordell and Bergstrom (1993)	Lake and reservoir	Four management programs that alter ''full water levels'' in four reservoirs during summer and fall	Recreationists on four reservoirs in western North Carolina	Present, $46; Scenario 1, $57; Scenario 2, $72; Scenario 3, $83	Scenario 1, $4 $\times$ 10^6; Scenario 2: $8 $\times$ 10^6; Scenario 3, $15 $\times$ 10^6
Daubert and Young (1981)	River	Recreational benefits of instream flow at several different levels of cubic feet per second (cfs)‡	Recreationists using the Cache la Poudre River	@500 cfs,‡ $53; @900 cfs, $9	Not available
Desvouges et al. (1987)	River	Mean WTP for improved access to river with improved water quality	River users and nonusers from five-county area around Monongahela River	Users, $139; nonusers, $49	Not available
Duffield et al. (1992)	River	Water quality improvements that would change the quality of recreational trips to the Big Hole and Bitterroot rivers, Montana	Residents and nonresidents who recreate on the Bitterroot and Big Hole Rivers	Bitterroot: residents, $57–$81; others, $103–$125 Big Hole: residents, $99–$143; others, $188–$245	Not available
Gramlich (1977)	River	A yearly tax increase that would guarantee clean up of (1) the Charles River in Massachusetts and (2) every river in the United States, including the Charles River	All households in the greater Boston area	Charles River only, $81; all other rivers, $147	Charles River only, $55 $\times$ 10^6; all other rivers, $4.3 $\times$ 10^9

TABLE 4. Continued.

Study and publication date	Freshwater ecosystem type	Good(s) being valued	Sample units	Unit specific benefit (1997 U.S. dollars)	Aggregate benefits (1997 U.S. dollars)
Greenley et al. (1981)	River	Sales tax targeted for specific water quality improvements that would enhance recreational enjoyment in the South Platte River Basin, Colorado	All households in the South Platte River Basin	Annual total WTP for sales tax per household, \$214	Annual aggregate sales tax value, \$1.1 $\times 10^9$
Henry et al. (1988)	Lake	Specified improvements of water quality on Lake Bemidji, Minnesota	Households in the Lake Bemidji trade area	Improved quality, \$88	Not available
Lant and Tobin (1989)	Wetland	Improved river water quality through the protection of riparian corridors	Residents of three drainage basins: Edwards, Wapsipinicon, and South Skunk	All three drainage basins, \$363	Not available
Pate and Loomis (1997)	Wetland and river	A specific wetland improvement program and river contamination clean-up program	Households in San Joaquin Valley	Wetland restoration, \$216; contamination clean, \$234	Wetland, \$175 $\times 10^6$; contaminate, \$190 $\times 10^6$
Sanders et al. (1990)	River	A special fund to be used exclusively to include 11 Colorado rivers under the protection of the Wild and Scenic Rivers Act	All households in the state of Colorado	Eleven Colorado rivers, \$117	Aggregate present value, \$1.8 $\times 10^9$
Smith and Desvouges (1986)	Reservoir and river	Three water quality changes at 13 recreational sites along the Monangahela River in southwestern Pennsylvania	Residents and recreationists living within a five-county region of southwestern Pennsylvania	Loss of boatable area, \$35; boatable to fishable, \$42; boatable to swimmable, \$55	Not available
Sutherland and Walsh (1985)	River	Protection of water quality in the Flathead River drainage system, Montana	Resident households within 676 km (420 miles) of drainage	Flathead basin residents WTP, \$113	Total value for border states and Canada, \$160 $\times 10^6$

† One square foot is equivalent to 0.093 m^2.
‡ Cubic feet per second: one cubic foot is equivalent to 0.028 m^3.

systems such as cleansing, recycling, and renewal requires a full understanding of the nature of these dynamic processes. Ecological information must therefore be integrated into an economically meaningful framework before a meaningful assessment of value can be made. This is a formidable challenge.

Ecologists and managers should also recognize that most of the valuation estimates presented in this paper are highly site specific. Values hinge, for example, on the details of a particular project, ecosystem features, time frame, spatial scale, and the human population under study. Ecologists are familiar with the problem of scale-specific or site-specific observation, but in some cases theoretical constructs supported by empirical relationships allow ecological data to be extrapolated (Levin 1992). Conversely, little is known about the most appropriate way to extrapolate value estimates for ecosystem goods and services across spatial scales (e.g., from a few lakes, to a statewide region of lakes, to the nation's freshwater lakes).

We conclude with the observation that valuation studies to date have been performed for relatively few freshwater ecosystem goods and services at a limited number of sites in the United States. Hence, our ability to generalize from studies presented in this review is limited. Nevertheless, the results presented in this review do provide valuable insights into the challenges and limitations of ecosystem service valuation as it is currently being practiced. The experiences summarized here should be useful to ecologists, managers, and social scientists as they collaborate to estimate the true value of freshwater ecosystem goods and services.

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