Procedures in Estimating Benefits of Water Quality Change

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Wisconsin water resource managers have determined that the water quality in Pike Lake is deteriorating rapidly. The source of this problem resides with the fact that storm sewers empty directly into the lake, delivering large nutrient loads. The impending decline can be prevented by the construction of a storm sewer diversion project. This undertaking can be accomplished for a fixed cost of \$175,000—operation and maintenance costs are considered negligible. The question being asked by the resource manager is whether the benefits to be derived from preserving the present high level of water quality will justify the project cost.

Although the foregoing is hypothetical, the problem is typical of those confronting today's decision makers. What insight can economics bring to bear on issues such as these? The purpose of this paper is to address such an issue by presenting a method for estimating, *ex ante*, the benefits of water quality change by (*a*) presenting the theoretical basis for the empirical analysis, (*b*) establishing the relationship between an objective measurement of water quality utilized by water resource experts and the subjective ratings of lake users, (*c*) presenting a model including recreators' ratings of water quality, and (*d*) synthesizing these components by advancing a method which is applied to the possible decision-making situation described above.

The Theoretical Model

Consistent with the notation used by Mäler, an individual's utility is represented as a function of consumption activities, C, and environmental services, Y:

$$U = U(C,Y). \tag{1}$$

By assuming weak complementarity, i.e., those situations where the consumption of a private good is a necessary prerequisite of the enjoyment of a given environmental quality, it is possible to derive the benefits (costs) of a quality change in a public good from information on the demand for the private good. Embodied in this notion of weak complementarity is the assumption that there are no option values, or that if the demand for some private good is zero, then so is the marginal willingness to pay for some environmental quality. An example is the case of water-related recreation, the use of which is influenced by the level of water quality. Those who do not use the lake are then assumed to be indifferent to water quality changes.

It can now be shown that this condition will allow estimation of the demand price for the environmental service, e.g., recreation visits (V). When the quality of water is WQ_O, the income-compensated demand curve for recreation visits is D_0 as in figure 1. At the price P_O, the consumer demands V_O trips and has consumer surplus ABC. If the quality of water improves to WQ_1 it is assumed to increase the marginal utility per trip, thus shifting the demand to D_1. The new consumer surplus is the triangle DEC.[1] The question to be answered is how much is the consumer willing to pay for this change?

Calculation of the benefits associated with a change in water quality as represented by willingness to pay can proceed in three steps. (*a*) A change in price from P_0 to P_1: given the demand curve D_0, the individual must be compensated by the corresponding consumer surplus ABC so as not to be made worse off by the price change. (*b*) A change in WQ: given the assumption of weak complementarity, the consumer's utility is unaffected and thus there is no need for compensation. (*c*) A change in price back to P_O: the consumer is willing to pay the new consumer surplus as represented by the area DEC. The net result is the difference between the consumer surplus before and after the water quality change. In other words, the consumer would be willing to pay $BADE$ for a change in water quality. The first step in making such a determination is the estimation of the demand curve for recreation, as measured by trips (V), including a shift variable which is a function of water quality.

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[1] Although the assumptions required to use consumer surplus often appear restrictive, Willig has demonstrated that this need not necessarily be the case. He states that in those instances where the consumer's income elasticity is in the range of ± 1.0, and "if the surplus area under the demand curve between the old and new prices is 5 percent of income (or less), then the compensating variation is within 2 percent of the measured consumer's surplus" (p. 590). Both of these conditions are realistic for the case at hand.

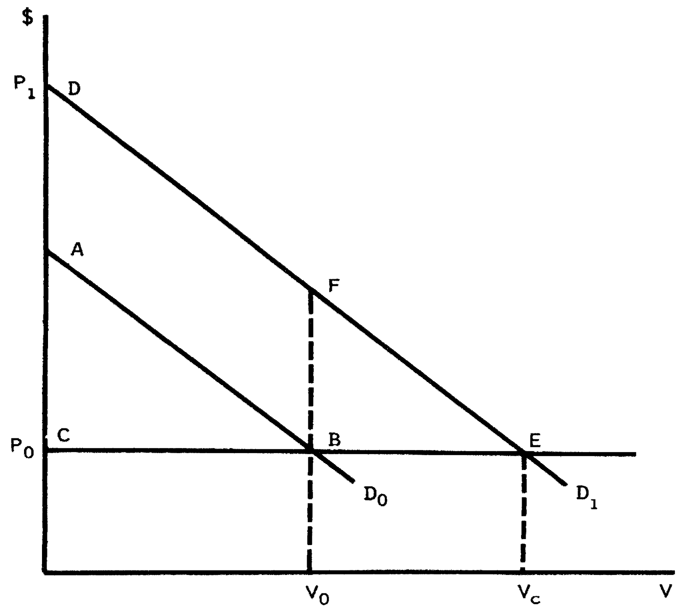

Figure 1. Benefits under complementarity conditions

Hotelling pioneered the travel-cost method for evaluating a recreational resource, and further refinements were provided by Trice and Wood, and Clawson. This approach is well documented, so no elaboration is required. The willingness-to-pay technique, a conceptually similar method credited to Davis, directly estimates consumer surplus through an interview procedure. Both of these methods have been applied to evaluating the total recreational resource, but not in assessing the value of a resource attribute such as water quality.

Some of the previous efforts to estimate the effect of a change in water quality on value of recreation resources have concentrated on the estimation of those benefits that would be attributable to the change in one or more of the physical parameters that contribute to the quality of water, e.g., recreation benefits increase as the dissolved oxygen concentration level rises (Kneese and Bower, Davis). Stevens hypothesized that the quality of the recreation experience (fishing) is a function of angling success per unit of effort, which reflects water quality. Reiling, Gibbs, and Stoevener employed use-intensity factors for swimming, fishing, and water skiing as a proxy for water quality. In the latter case, the indices were subjective estimates, by Forest Service and Environmental Protection Agency employees, of the amount the lakes were used for various activities. The major shortcoming in these research efforts is that the techniques do not contain a systematic relationship between the subjective index used as a proxy for water quality and physically measurable water quality parameters. Perhaps more important, these indices do not reflect recreators' perceptions of water quality.

Objective and Subjective Water Quality Relationship

Ultimately, the existence or nonexistence of benefits emanating from a water quality change are determined by whether an improvement is perceived by the affected water user. Thus, to estimate adequately the benefits associated with water quality changes, it is necessary to predict how lake users perceive water quality. However, water resource experts do not deal with the subjective form of rating as would the typical recreator, but in more objective, measurable terms such as turbidity, dissolved oxygen, and BOD in parts per million, etc. It is therefore necessary to determine if there exists a relationship between the more objective water quality measurements as utilized by the scientists and the subjective rating of water quality as perceived by the lake users.

To ascertain the existence of the relationship, it was necessary to seek out a water quality index that would be readily amenable to testing. The choice was Uttormark's Lake Condition Index (LCI) which was recently developed to classify all Wisconsin lakes larger than 100 acres, providing a system to facilitate resource decision making. One of the main considerations in developing the LCI was to produce an inexpensive lake classification system. Thus, the existing availability of data greatly influenced the choice of parameters used to classify lakes. The lake water quality parameters used to evaluate the lakes are dissolved oxygen in the hypolimnion, secchi disk transparency, fish winterkill, and the extent of macrophyte or algae growths. Penalty points are assigned to these parameters, depending upon the degree to which they exhibit undesirable symptoms of water quality, and then added to produce the relevant LCI. The possible range is zero to twenty-three points, with these amounts representing the finest and poorest levels of water quality, respectively. The resulting classification system was tested by comparisons with other more data intensive studies, the relative ranking of lakes to that of area resource managers, and consistency in ranking when lake information generated from other studies was used with the LCI method—in each instance the LCI compared favorably. For purposes of this study, the LCI bears three advantages over other indices: (*a*) it provides a simple scaler for lake classification, much like what could be expected of the average lake user; (*b*) it has been used to rate all Wisconsin lakes in excess of 100 acres; and (*c*) it is relatively simple.

Data used to test the relationship between subjective and objective water quality rating were obtained by on-site interviews at eight southeastern Wisconsin lakes. In addition to the standard cost, time, and demographic questions, respondents were asked perceptual questions regarding water quality of that particular survey lake. Specifically, recreators were asked to rate the lake water quality on a zero to twenty-three scale, such as that employed by the LCI. The effectiveness of the LCI in predicting the public's perception of water quality was tested by regressing the average rating ($\bar{R}$) of all recreators for each lake on the corresponding LCI for that lake. The results of this analysis were encouraging, yielding the working equation

$$(2) \qquad \ln \bar{R} = 1.948 + \underset{(3.37)}{.0364}\ \text{LCI},$$

where the values in parentheses are computed t-values, the sample size was 7 and the R^2 .694. Equation (2) will be utilized within the resource evaluation model below to predict the changes in recreators' perceptions of water quality.

The Statistical Model

The general form of the model used to estimate water quality benefits is of the Clawson-Hotelling genre:

$$(3) \qquad V_{ij} = \alpha + \sum_{k=1}^{n} \beta_{ik} X_{ijk} + e_{ij},$$

where V_{ij} is the number of visits by decision-making unit i to lake j, X_{ijk} is the value for the independent variable k for the decision-making unit i at lake j, and e_{ij} is the error term. The primary objective is to produce a statistical demand curve with reliable estimates of the structural parameters—particularly those of the cost variable from which the resource value is derived, and that of the water quality variable which is used to determine the economic significance of a water quality change.

The final estimated demand curve for visits from the regression analysis is

$$(4) \qquad V_O = 43.22 - \underset{(.950)}{.317}\ C + \underset{(2.10)}{.008}\ C^2 - \underset{(2.93)}{5.264} \ln \bar{R} - \underset{(3.63)}{.162}\ T + \underset{(2.81)}{.0003}\ T^2 - \underset{(2.35)}{.321}\ I,$$

where V_O is number of visits for the year, C is total variable cost per trip, $\bar{R}$ is recreator's rating of water quality, T is round-trip time and I is recreator's annual income. For this regression, the sample size was 195 and the R^2 .203. The low t-value on cost may reflect the possibility that time is perhaps a more binding constraint than costs when considering relatively short day trips. The income coefficient carries a negative sign and may suggest that recreators tend to substitute other activities for day trips as income increases. The rating variable proved to be consistent in this and other model specifications, demonstrating a level of significance of approximately 1% or better.

It was realized that other site amenities might contribute to users' perceived ratings; thus, the survey lakes were chosen so that they were as similar as possible except for water quality. That is, the lakes were of similar size, ranging between 400 and 600 acres; location choice was made so that physiographic characteristics would be comparable; and lake sites possessed many of the same amenities deemed desirable by lake day-users, such as lifeguards, boat launching facilities, and beaches.

The data used to estimate the above demand curve are in the form of individual observations rather than the commonly employed zone averages. The justification for this approach lies in the fact that without the inclusion of time in the estimated demand equation, the cost coefficient generally will have too great a magnitude and, hence, an underevaluation of the resource value. However, when zone averages are employed, there exists a high degree of multicollinearity between cost and time; thus, time has been excluded in most evaluation procedures. Estimation procedures based on individual or group observations avoid this problem. However, the resulting R^2 is reduced considerably, even though the t-values on the estimated parameters will be high. For purposes of resource evaluation, concern is more with the level of significance of the individual variable than with the magnitude of the coefficient of determination (Brown and Nawas, p. 249; Gum and Martin, p. 560). In this study it is the cost variable that is used in evaluating the resource and the shifter variable, rating, that is of interest.

Economic Benefits under Current and Alternative Water Quality Conditions

To estimate the resource value under current water quality conditions, a two-step evaluation process, as used by Gum and Martin, was employed. This approach requires applying a derived statistical demand curve to each individual observation, using the recreator's observed cost and visit data to reflect behavior at zero additional site cost. This is then used to estimate an aggregated demand curve for the total recreation experience from which the resource value is estimated.

For example, by introducing a change in costs term, c, into equation (4) the estimate of visits becomes:

$$(5) \qquad V_c = 43.22 - .317\ (C + c) + .008\ (C + c)^2 - 5.264 \ln R - .162\ T + .0003\ T^2 - .321\ I.$$

By subtracting equation (5) from equation (4), the individual decision-making unit's demand curve can now be represented by equation (6),

$$(6) \qquad V_c = V_O - .317\ c + .016\ Cc + .008\ c^2.$$

The evaluation of the resource is accomplished by using equation (6) to estimate an aggregated demand curve. This is done by applying it to the cost and visitation data of each of the representative decision-making units. Costs (c) are increased until the number of trips equals zero or starts to increase.

As it is illogical for the number of trips to increase as costs increase, thus, trips are set equal to zero in the latter instance (Gum and Martin). This result is then expanded by the representation rate of that observation. The representation rate or weighting factor is determined by the response rate: the total number of recreators divided by the product of the average number of trips and party size of the sample and the number of observations in the sample. These expanded individual demand curves then are summed horizontally to construct the aggregate demand curve from which the resource value is estimated, e.g., the area under this curve reflects the consumer surplus associated with the resource.[2]

To estimate the annual benefits associated with a change in water quality, i.e., *BADE* in figure 1, it is necessary to determine how a change in water quality will modify recreator's behavior. The change in water quality is reflected in the model so that the initial number of trips is more or less than under previous water quality conditions, i.e., $V^*_O \gtreqless V_O$, where the difference is 5.264 ($\Delta ln\ \tilde{R}$) having been estimated by equation (2). Substituting V^*_O for V_O in equation (6) gives the desired result.

The resulting change in resource value under various levels of water quality can be determined by calculating the difference between the initial resource value and that occurring after the water quality change.

A Water Resource Management Scenario: The Problem and Solution

To perform an *ex ante* analysis of the hypothetical problem we presented our resource manager above it is necessary to (*a*) establish the resource value with current water quality conditions; (*b*) determine the impact on users' perceptions of the potential decline in water quality; and (*c*) estimate the decline in resource value that would be avoided by the project.

To demonstrate the effects on resource evaluation of a change in water quality, it is necessary to determine the number of recreators that utilize the resource with current water quality conditions. The number of individual recreators to visit Pike Lake for the year prior to the survey, 1975, was 168,629. This will be assumed to be an approximation of the number for the current year. This count is considered accurate, as access to the lake is limited to supervised entrances where head counts are taken. It is determined from the survey data that the average number of trips per party during the previous season was 13.9 trips and average party size was 6.15 persons, yielding 1,972 different parties, or approximately 27,400 total group visits at the lake over the course of the year.

With this information and the pertinent individual group information required by equation (6), it is possible to estimate the resource value under current water quality conditions by employing the procedure described above. The results of the computations are presented in table 1, which reflects resource value as $429,038.

The next step in this method requires that we estimate how the expected change in water quality, i.e., ΔLCI = 7, will affect the recreator's perceived rating. This movement will be predicted by the use of equation (2). Repeating the resource evaluation procedure as before, but employing the modified form of (6), i.e., with V^*_O substituted for V_O, it is possible to estimate what the potential loss in benefits would be with deteriorated water quality conditions. These results are also presented in table 1 and the resource value is now $390,074. Thus, the estimated annual benefits, i.e., area *BADE* in figure 1, would be $429,038 − $390,074, or $38,964. This amount, as in most of these recreational analyses, may represent somewhat of an overestimation as substitutes and alternative activities are not accounted for. One possible way to mitigate this would be to determine the lower limit of benefits, thereby constructing a range of possible benefits. Reconsider the case in figure 1, but rather than allowing the recreator to expand the number of trips taken to V_1 we restrain him to V_0, his original number of trips, and calculate the corresponding consumer surplus, *BADF*, thereby not concerning ourselves with substituting one activity with another. Now we have established the range between *BADE* and *BADF*. If the range is narrow, the substitution effect can be considered minor.

The present value of the benefit stream, assuming a modest twenty-year period and 10% discount

Table 1. Resource Value with Alternative Water Quality Conditions

	Present Conditions (LCI = 3)		Expected Conditions (LCI = 10)	
Added Cost per Trip ($)	Total Group Trips	Total Revenue ($)	Total Group Trips	Total Revenue ($)
0	26,996	0	24,383	0
3	25,632	76,896	23,195	69,584
6	24,577	147,461	22,282	133,692
9	23,820	214,379	21,617	194,553
12	21,521	258,247	19,535	234,420
15	21,264	318,957	19,305	289,582
18	13,966	251,392	13,111	236,002
21	0	0	0	0
Consumer Surplus Value		$429,038		$390,074

[2] It is necessary to assume here that the demand functions are aggregates of homogeneous groups of recreators, i.e., similar tastes and preferences, react the same to price changes, etc. (Mäler p. 184). This assumption is mitigated by the use of individual observations (Gum and Martin p. 564).

rate, is $331,740. Given the expected costs and benefits associated with this project, it would appear to be a wise decision for the water resource manager to recommend the project.

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