Benefits of Increased Streamflow: 
The Case of the John Day River Steelhead Fishery

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Conflicts between instream water uses such as fish production and traditional out-of-stream uses are an important water resource issue. One criterion for evaluating the merits of alternative water allocations is economic efficiency. This study uses an integrated approach to measure the recreational steelhead fishery benefits of incremental streamflow changes in the John Day River in Oregon. The analysis combines a steelhead fishery production model with a contingent valuation assessment of changes in fishing quality to obtain estimates of the marginal value of water in producing fishing quality. The results suggest that increased summer flows to enhance fishing have a marginal value of about $2.40 acre-foot. When expressed in terms of water actually consumed, the value may be up to 10 times higher. These values are sensitive to the location of flow alterations in the river, potential downstream uses and number of anglers in the fishery.

INTRODUCTION

Most contemporary water resource issues involve allocations of water among competing uses. In the Pacific Northwest, one such use is minimum streamflow for anadromous fish production. Increases in streamflow are viewed as one means of meeting judicially and legislatively mandated improvements in fish production as compensation for losses suffered due to hydroelectric projects. Any increase in allocations to instream use, however, imply conflicts with current or future off-stream uses.

One criterion for evaluating the merits of these alternative water allocations is economic efficiency [U.S. Water Resources Council, 1979]. By comparing net economic benefits, policy makers can assess the social gains and losses of current and future water allocations. Unfortunately, information to implement the economic efficiency criterion is often lacking when dealing with water allocations involving nonmarketed public goods. The value of instream water is a case in point. Until recently, few studies explicitly considered the relationship between streamflow and fishery productivity (and hence the quality of the recreational fishery) [Ward, 1987]. The theoretical validity, strengths and limitations of each procedure are well-documented [see Young and Gray, 1972; Gibbons, 1986]. This lack of a common measure of economic value across all water uses contributes to potential misallocations of water.

OBJECTIVES

The overall objective of this analysis is to evaluate the recreational fishing benefits of incremental streamflow changes using biologic and economic assessment methods. Specifically, the study provides estimates of the marginal value of water with respect to the production of an important game fish, the steelhead trout (Salmo gairdneri). The empirical focus is on realistic portrayal of the relationship between streamflow, fishery production, and sport fishing quality during the critical summer flow period for the John Day River of north central Oregon. The interdisciplinary methodology employed here consists of two tasks: (1) quantification of the relationship between streamflow and fishery productivity (and hence the quality of the recreational fishery) and (2) valuation of incremental changes in the quality of the steelhead recreational fishery using nonmarket valuation techniques. Combining the results of these two tasks provides an estimate of the marginal value of summer streamflow in "producing" recreational steelhead angling. These values can then be compared with the value of that water in off-stream uses to assess the economic efficiency of such allocations. While the methodology is generalizable, the empirical results have specific policy implications for Pacific Northwest water allocations that affect anadromous fish production, particularly within the Columbia River system.

BACKGROUND

Economists have developed several methodologies to circumvent the lack of market data for public goods. These methodologies either indirectly impute a price to the good in question, as illustrated by the travel cost method [Bockstael et al., 1985], or directly query consumers as to their willingness to pay for stated levels of a nonmarketed good, as in the contingent valuation method (CV) [see Cummings et al., 1986; Mitchell and Carson, 1987]. The theoretical validity, strengths and limitations of each procedure are well-documented. Applications of these methodologies include studies of the economic benefits attached to water-based recreation, such as the valuation of salmon sport fishing [Sorhus et al., 1981], waterfowl hunting [Hammack and Brown, 1974; Bishop and Heberlein, 1979], and recreational boating [Sellar et al., 1986].

The total value of a recreational experience elicited in such studies, however, is rarely attributable to one input, such as fish catch or streamflow. As a result, the majority of extant studies are not directly applicable for valuing instream flow, though a subset of this literature attempts to link streamflow levels to recreation benefits (see Gibbons [1986] and Loomis [1987] for a survey and summary of the existing streamflow-economic benefits literature). Of these studies, only a few have explicitly considered the relationship between streamflow and the resultant benefits to anglers: Daubert and Young [1981], Ward [1987], and Walsh et al. [1980] are notable examples.
Acknowledged weaknesses of these latter studies involve specification of the relationship between streamflow, fishery productivity, and the resultant quality of the sport fishery. For example, the biological model employed by Daubert and Young [1981] only provides information on potential, as opposed to actual, catch rates under alternative flow levels. As a consequence, anglers questioned in the CV portion of the study were asked to reveal their willingness to pay for potential catch rates. In general, however, anglers' experiences are limited to actual catch rates.

A related difficulty of existing streamflow-benefit studies pertains to the timing of benefits. Milhous [1983] notes that the flow of benefits calculated by Daubert and Young [1981] was assumed to occur concurrently with streamflow. This ignores the dynamic nature of the streamflow-fishery productivity relationship; i.e., by altering current flows, future benefits may also be affected. This is particularly true for anadromous fish, such as steelhead, where recreational benefits typically accrue at locations temporally and/or spatially removed from the site of primary production. Ward [1987], in acknowledging this same weakness in his study, concludes that "important work linking the time path of both streamflows and the resultant catchable fish density needs to be conducted . . . ." [Ward, 1987, p. 383].

**Valuation Framework**

Assessing the economic value of incremental changes in streamflow involves a multistep procedure, starting with an understanding of how changes in physical and hydrological conditions of the stream affect fish production. Changes in fishery productivity, in turn, need to be linked to items valued by anglers, such as changes in fishing quality. The first task is thus to quantify relationships between streamflow changes and steelhead production. The next task is to assign values to improvements in fishing quality arising from an increase in fish populations. Combining the outputs from each task provides a measure of the value of incremental changes in streamflow in producing recreational fishing success.

This multistage bioeconomic framework is common to much of resource economics (see, for example, Freeman [1979]). Economic valuation is based on the premise that the individual's autonomous preferences, as revealed by his behavior, reflects the value attached to particular items or activities. Consumers select and consume certain mixes and levels of recreational activity because those combinations provide greatest enjoyment given time and budget constraints. They are thus "willing to pay" a proportion of individual time and income endowments for each activity. This willingness to pay can be measured from observed behavior (market data). For public goods, the lack of orderly markets requires use of methods based either on travel cost as a proxy for the price of the experience or on willingness to pay provided by direct questioning of consumers.

The theoretically correct measures of willingness to pay (WTP) for increments in fishing quality or willingness to accept (WTA) compensation for decrements in fishing quality are the Hicksian compensating measures [Hicks, 1943]. Of the four measures proposed by Hicks [1943], the two of interest here are compensating variation and compensating surplus. Each represents income adjustments that maintain the individual at some initial utility level. In this study, value measures in the form of Hicksian compensating variation, designated as WTPc, will be used to assign economic value to increments in fishery productivity. Detailed discussions of these and other welfare issues are provided elsewhere (see, for example, Brookshire et al. [1980]).

Once obtained, WTPc estimates can then be used to assess the marginal value of the resource or environmental change in question. For water or any other input allocation decision, interest is on the value of that input in each use at the margin. Economic efficiency is greatest when the marginal value of water is equated across all uses, i.e., no greater level of socially valued outputs could be achieved by reallocating water to other uses. To test whether efficiency gains are possible with alternative allocations requires knowledge on the current values of water across uses. Once obtained, these estimates can be compared with other uses of water (e.g., agricultural irrigation) to determine first, the possibility of gains from reallocations and second, the magnitude of those gains.

**Application to the John Day Steelhead Fishery**

The empirical setting for this study is the John Day River of north central Oregon, a major tributary of the Columbia River. The John Day River basin encompasses 8010 square miles (mi²; 1 mi² = 2.590 Km²) in north central Oregon, ranging in elevation from 150 feet (1 foot = 30.48 cm) above sea level at the mouth of the John Day River to 9038 feet on Strawberry Mountain. The basin supports the largest runs of wild spring chinook salmon (Oncorhynchus tsawytscha) and summer steelhead in eastern Oregon (Oregon Department of Fish and Wildlife, unpublished report, 1985a). Decreases in summer flows due to riparian damage, coupled with the basin's semiarid climate, exacerbate potential conflicts between instream and out-of-stream water users during the critical summer flow period. The basin's economy, largely centered around crop and livestock production, heightens the need for reliable data on the value of instream water. This combination of hydrologic, limnologic, and economic conditions led to the basin's recent selection as the first river basin in Oregon to undergo a comprehensive water management plan.

**A Fishery Production Model**

The quality of a salmon or steelhead fishery depends, in part, on the number of fish returning to spawn. These populations, in turn, are influenced by numerous environmental conditions throughout their life cycles. The influence of ocean conditions and streamflow on the survival of salmon (Oncorhynchus sp.) have been extensively studied [see Anderson and Wilen, 1985; Nickelson, 1986; Peterman, 1981]. Our interest is limited to assessing the effect of increased or decreased streamflow on the quality of the John Day steelhead sport fishery. The approach selected utilized time series data to estimate a fishery production model, following the procedure found in the work by Anderson and Wilen [1985].

For steelhead, the number of adult fish entering the John Day River in year $t$, $N_t$, can be represented as a function of parental stock size, $P_{t-n}$, where $t-n$ indicates the year the parental stock spawned, environmental conditions affecting survival, $E$, and fishing pressure, $FP$:  

\[ N_t = f(P_{t-n}, E, FP) \]  

A stock-recruitment model is required to express this relationship in a format amenable to statistical estimation. Stock-recruitment models express recruitment as a function of parental stocks and generally include explanatory variables measuring density-dependent and density-independent mortality.
Two commonly employed models are the Ricker [1975] and the Beverton and Holt [1957]. The Ricker model is employed here.

The Ricker stock-recruitment model expresses the relationship between the number of recruits (progeny) and the size of the parental stock (the spawners) as

\[
N_t = R_t \cdot e^{-\beta \cdot E_t} (2)
\]

where

- \( R \) number of recruits to the fishery;
- \( P \) size of parental stock;
- \( \alpha \) a dimensionless parameter;
- \( \beta \) a parameter with dimensions of \( 1/\text{P} \) that relates stock density to mortality.

Since the interest here is on the number of adults returning to spawn \( N_t \), as opposed to the original number of recruits \( R_t \), it is necessary to expand expression (2) to account for the mortality occurring between the spawning of the parental stock and the return of their offspring in 5 years. (Steelhead in the John Day typically spend 2 years in freshwater as juveniles, 2 years in the marine environment, and 1 year in migration between each environment.) Accounting for mortality, \( N_t \) can be related to \( R_{t-5} \) as

\[
N_t = R_{t-5} \prod_{i=1}^{n} (1 - m_i) \quad 0 \leq m_i \leq 1 (3)
\]

where \( m_i \) is the conditional mortality rate associated with the \( i \)th environmental factor and \( 1 - m_i \) is the corresponding conditional survival rate. Each conditional survival rate is assumed to take the functional form \( \exp[\beta \times E_i] \). Substituting this into (3) and combining with (2) yields

\[
N_t = a \cdot P_{t-5} \cdot e^{-\beta \sum_{i=1}^{n} E_i} \cdot \exp \left[ \sum_{i=1}^{n} (\beta_i \times E_i) \right] v_t (4)
\]

where \( v_t \) is a random error term. Specifying the error term as a multiplicative lognormal distribution is in keeping with the assumed multiplicative nature of mortality (see Peterman [1981] for further explanation and empirical support). By taking the natural logs of both sides this expression can be converted to a linear form and the parameters estimated via linear regression methods:

\[
\ln N_t = \ln \alpha + \alpha' \ln P_{t-5} - \beta \sum_{i=1}^{n} E_i + T (\beta_i \times E_i) + \ln v_t (5)
\]

where the \( \beta_i \) are a measure of the mortality attributable to the \( i \)th environmental factor. Note that a coefficient on \( \ln P_{t-5} \) has been included to increase model flexibility.

**Data**

Ideally, annual data on adult escapement for various reaches of the John Day should be used to estimate (5). Lack of a time series of such observations requires an alternate approach. As noted by Ricker [1975], fishing success is often related to stock level as

\[
C/E = qN (6)
\]

where \( C \) is catch, \( E \) is effort, and \( q \) is known as the “catchability” coefficient. Catch statistics are available from creel surveys conducted annually in the John Day Basin (Errol Claire, unpublished data, Oregon Department of Fish and Wildlife, 1987) and offer an index of stock level. The index for returning stock \( N_t \) was defined as steelhead caught per 100 hours of fishing in year \( t \). Use of this index provides the critical link with the economic valuation results to be discussed subsequently, which are based on fishing quality as opposed to stock levels.

A second index of stock levels used in the analysis is redd counts. (A redd is the spawning nest dug out by the female steelhead.) Redd counts are available starting in 1959 [Johnson, 1988]. The number of redds per mile, lagged 5 years, was included in the final model as a measure of parental stock, \( P_{t-5} \).

Use of separate indices to measure stock levels in (5) (for \( N_t \) and \( P_{t-5} \)) offers several advantages. First, use of separate indices to measure parental and returning stocks minimizes correlated errors between periods \( t - 5 \) and \( t \). Second, using the creel survey index as a measure of parental stock would necessitate accounting for fishing pressure during the sport fishing season. Use of the redd count index bypasses this difficulty.

A hypothesis of this analysis is that increases in summer flow lagged 5 years (\( S_{t-5} \)) increase fish production. Increased flow will reduce stream temperatures and increase habitat area. Currently, summer stream temperatures in the upper 70s and lower 80s (°F) have been measured on some stream reaches within the basin [U.S. Bureau of Reclamation, 1985], well above the optimal range for steelhead of 45° to 58° F. However, other factors also influence steelhead survival. A priori, their effects are summarized as follows.

1. Spring streamflow, lagged 5 years, \( (SP_{t-4}) \) is assumed to be a negative factor in that high flows may scour spawning beds and destroy newly laid eggs [Shephard and Withler, 1958].

2. Winter flow, lagged 4 years, \( (W_{t-4}) \) is positive in that higher streamflows reduce the probability of ice-ups and might also be indicative of warmer temperatures.

3. Spring flow, lagged 4 years, \( (SP_{t-4}) \) is negative, as in \( SP_{t-5} \).

4. Marine productivity, \( U_{t-1} + U_{t-2} \) is positive as improved marine productivity increases fish survival and hence the number of returning spawners. Ocean upwelling as defined by Nickelson [1986] is employed as a proxy for measuring marine productivity. It is the sum of the monthly upwelling volumes (in cubic meters per second per 100/m²) for March through September. The sum of the upwelling indices 1 and 2 years prior to return of the parental stock was employed. This variable exhibited a strong correlation with marine survival indices derived from other steelhead stocks [see Johnson, 1988].

5. Migration route influences (i.e., dams on the Columbia River) increase both upstream and downstream mortality. For this latter effect, a dummy variable was employed to account for the construction of the John Daly Dam in 1968. To accommodate the hypothesized life cycle, a 3-year lag is employed in specifying this variable.

All flow data are from the United States Geological Survey (various years) which maintains several stream gauges within the John Day Basin. Since 40% of John Day steelhead are produced in the North Fork and 25% in the Middle Fork, streamflow measurements at Monument, on the North Fork below the confluence of the Middle Fork, were used to construct all flow variables. Spring flow (April–June) was defined as the average flow, expressed in cubic feet per second (1 ft³ = 0.028 m³). Summer (July–September) and winter
(January–March) flow variables were similarly constructed. All data are reproduced in the work by Johnson [1988].

**Results**

The model estimated was specified as

\[ \ln N_t = \alpha + \beta_0 (P_{t-5}) + \beta_1 (SP_{t-5}) + \beta_2SU_{t-5} + \beta_3W_{t-4} + \beta_4SP_{t-4} + \beta_5(U_{t-1} + U_{t-2}) + \beta_6D3 \]

(7)

where each variable corresponds to definitions above. Equation (7) was estimated with data from 1964 to 1983 using ordinary least squares (OLS) via the SHAZAM statistical package [White, 1978].

OLS estimation results are presented in Table 1. The results of this estimation are statistically significant (\( p = 0.05 \)). These coefficients are used to construct streamflow-angler success elasticities, which provide a means of combining the fishery model results with the CV results to be presented subsequently. These elasticities are defined as

\[ e_i = \frac{\%\delta HRSFISH}{\%\delta FLOW_i} = \beta_i \times FLOW_i \]

(8)

where \( \beta_i \) is the coefficient on the \( i \)th streamflow variable, FLOW, and HRSFISH is the catch rate in hours per steelhead. Table 1 reports these values for each of the streamflow periods, as calculated at mean values. The interpretation is straightforward. Spring streamflow, for example, if increased 1% will lead to a 1.15% reduction in angler success four years later and a 1.58% reduction in angler success the fifth year. Summer flow, in contrast, if increased 1%, will increase angler success 5 years later by 0.88%.

Two caveats must be attached to the above streamflow-angler success elasticities. As used in the model, the flow variables measure the average flow over 3-month periods. This ignores critical periods during these months when an increment in flow is more productive (or destructive, for spring flows) when compared to increments in other periods. Whether this makes a difference from a management standpoint depends on the ability to accurately identify critical periods and to what degree managers can “target” additional flows to occur in these periods. The more accurate the identification and targeting, the more the magnitudes of the above elasticities should be increased. Along the same lines, the fishery production model presented in (7) does not allow for threshold effects. Spring flows, for example, may have no adverse effect on fishery productivity until a critical flow level is reached. The elasticities are thus most accurate for average flow levels. Estimated elasticities for higher or lower flows should be used with caution. Identification of critical flow levels and periods is an important future research issue.

**Economic Valuation Procedure**

The contingent valuation procedure was used in this study for two reasons. First, our focus is on estimating benefits for improvements above the current angler success level. This is motivated by the Northwest Power Planning Council’s stated objective of doubling the Columbia River’s fish runs and Oregon Department of Fish and Wildlife goal of increasing average John Day steelhead production from the current escapement level of 15,000 adults to 23,000 (Oregon Department of Fish and Wildlife unpublished report, 1985). The hypothetical structural of the CV questionnaire allows these unobserved quality levels to be valued. Second, the John Day steelhead fishery is not composed of one distinct angling area. This effectively ruled out use of the travel cost method. A third methodology, the household production function approach, was not used due to potential empirical estimation difficulties [see Bockstael and McConnell, 1981].

**Survey Design**

The survey used here involved personal interviews with John Day anglers to collect information on current and past visitation rates to the John Day as well as socioeconomic data such as age, education, and income. The main body of the survey was devoted to measuring the angler’s compensating variation (WTPc) values for stated increments in fishing quality. To elicit WTPc, the angler was first given information on the average success rate on the John Day River in each of the previous 5 years. These data came from creel surveys conducted annually by the Oregon Department of Fish and Wildlife (ODFW) and the Oregon State Police [Johnson, 1987]. Given this information, the respondent was then asked to state his own catch rate on the John Day in an average year. This gave a base level of fishing quality at which to construct the contingent market. The respondent was then told that there were three postulated increases in the number of steelhead in the river: 33, 67, and 100% above the average level. Under each of these improvement levels, identified as improvement A, B and C, respectively, the respondent was asked to state his new catch rate on the John Day in an average year. This made a difference from a management standpoint depending on the ability to accurately identify critical periods and to what degree managers can “target” additional flows to occur in these periods. The more accurate the identification and targeting, the more the magnitudes of the above elasticities should be increased. Along the same lines, the fishery production model presented in (7) does not allow for threshold effects. Spring flows, for example, may have no adverse effect on fishery productivity until a critical flow level is reached. The elasticities are thus most accurate for average flow levels. Estimated elasticities for higher or lower flows should be used with caution. Identification of critical flow levels and periods is an important future research issue.

**TABLE 1. Estimated Ricker Model of John Day Summer Steelhead, 1964–1983, Dependent Variable ln (Nt)**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimated Coefficients</th>
<th>Standardized Coefficient</th>
<th>Elasticity at Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.737</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.125)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pt-5</td>
<td>-0.166</td>
<td>-0.804</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.125)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln (Pt-5)</td>
<td>1.292</td>
<td>0.751</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.12)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sp-5</td>
<td>0.000586*</td>
<td>-1.066</td>
<td>-1.581</td>
</tr>
<tr>
<td></td>
<td>(0.00049)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sp-4</td>
<td>0.00322*</td>
<td>0.694</td>
<td>0.882</td>
</tr>
<tr>
<td></td>
<td>(0.00168)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wt-4</td>
<td>0.000327†</td>
<td>0.504</td>
<td>0.515</td>
</tr>
<tr>
<td></td>
<td>(0.000142)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sp-4</td>
<td>-0.000411*</td>
<td>-0.786</td>
<td>-1.15</td>
</tr>
<tr>
<td></td>
<td>(0.000135)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dt-3</td>
<td>-0.504*</td>
<td>-0.460</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.168)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ut-1 + Ut-2</td>
<td>0.00102*</td>
<td>0.429</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>(0.00337)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observations = 20 (1964–1983); adjusted R squared = 0.72. Elasticities at other flow levels can be calculated as the product of the coefficient and the flow level in question. Standard errors are presented in parenthesis.

*Significance at 0.02 level.
†Significance at 0.05 level.
TABLE 2. WTP and Mean Expected Catch Rate Summary

<table>
<thead>
<tr>
<th>Stock Level</th>
<th>Mean Expected Catch Rate, hours per steelhead</th>
<th>Mean Bid 1986 dollars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current</td>
<td>9.3</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>7.1</td>
<td>WTPc(A) = $8.58</td>
</tr>
<tr>
<td>B</td>
<td>5.0</td>
<td>WTPc(B) = $11.11</td>
</tr>
<tr>
<td>C</td>
<td>2.9</td>
<td>WTPc(C) = $13.59</td>
</tr>
</tbody>
</table>

Mean bids were calculated as the average of the 62 usable surveys.

on payments for additional improvements, i.e., B and C. After the CV questionnaire was pretested on the Alsea River, Oregon salmon fishing in August and September 1985, it was administered in person to 67 steelhead anglers during the 1986/1987 steelhead fishing season. Five anglers declined to be interviewed, resulting in an acceptance rate of 93%. Of the 67 surveys, five were deemed unusable due to key questions which remained unanswered, leaving 62 usable for analysis.

Analysis of Survey Data

The individual CV responses were used to estimate an aggregate bid function for potential improvements in steelhead production. Such a function is based on a concept presented in the work by Bradford [1970] and further developed in the work by Brookshire et al. [1980]. The curve is obtained by first calculating mean bids and quality levels to arrive at a mean individual curve. Mean bids and catch rates are presented in Table 2 and graphically shown in Figure 1. The mean bid curve was fitted to a quadratic functional form:

\[ WTPc = 0.27 + 4.12\Delta HRSFISH - 0.32(\Delta HRSFISH)^2 \]  
(9)

(base = 9.3 hours per steelhead), where \( \Delta HRSFISH \) is the improvement in the success rate from the base level of 9.3 hours/steelhead. An improvement in fishing quality is indicated by reductions in HRSFISH. Values in parentheses are standard errors. The current success level was included as an observation (i.e., \( WTPc = 0, \Delta HRS = 0 \)). The adjusted \( R^2 \) is approximately 0.95.

The total number of anglers in a given year is needed to convert the mean individual bid function into an aggregate bid function. This number is approximated from several sources. By dividing the average total annual angler hours (derived from creel surveys and ODFW catch estimates) by the average hours per angler, an estimate of total anglers per season can be derived. From the survey responses average hours per angler per day was 6.8 hours. Average days of 5.7 per angler per season was estimated via a weighting procedure to account for the likelihood of being sampled. On the basis of these values, the estimated number of anglers each year is 888 anglers with a standard deviation of 300. An increase in success rates may be accompanied by an increase in angling effort, resulting in higher aggregate benefits than would otherwise be calculated by assuming a fixed number of anglers. Alternatively, this increase in effort may also lead to congestion, lowering individual benefits [Anderson, 1980]. Using standard statistical tests, the null hypothesis that annual catch is a linearly homogeneous function of the catch rate could not be rejected. Thus fishing pressure on the John Day does not appear to increase with increases in success rates, given the catch rate levels used in the analysis.

The aggregate bid function for fishing improvements can now be represented as

\[ AGG. \ WTPc = 240 + 3.660\Delta HRSFISH - 280(\Delta HRSFISH)^2 \]  
(10)

(base = 9.3 hours per steelhead), which is (9) multiplied by the annual user rate, 888 anglers. This aggregate bid function represents the benefits accruing only to current users of the resource. Any existence, option, or bequest value held by nonusers is not represented in these values.

To integrate the CV results with the fishery production model requires that the \( \Delta HRSFISH \) variable employed in both the economic and biologic analyses to be of comparable units. This is accomplished via an adjustment factor, calculated as the average expected catch rate from the CV survey (9.3 hours/steelhead) divided by the average observed catch rate from the creel surveys (17 hours/steelhead). Equation (10) is thus changed to

\[ AGG. \ WTPc = 240 + 2,002\Delta HRSFISH - 84(\Delta HRSFISH)^2 \]  
(11)

(base = 9.3 hours per steelhead). This equation is then combined with the fishery production model estimated in the previous section to derive the marginal value of instream water.

The WTPc estimates for fishing quality captured in (9) can be used to measure the value of an additional steelhead caught. From the survey the average angler catches 4.2 steelhead in a season. An additional steelhead implies a success rate equal to 7.5 hours/steelhead compared with 9.3 hours currently. From (9) the willingness to pay for this increased fishing quality is $6.65. Hence the typical value of an additional sport-caught steelhead is $6.65 under current catch conditions. This WTPc estimate for an additional steelhead, while close to some recent estimates [e.g., Samples and Bishop, 1985; Cameron and James, 1987] is in contrast to the much higher values currently used for policy analysis (see, for example, Scott et al. [1987]). These latter values, however, are typically average, rather than marginal values.

Value of Water in the Production of Fishing Quality

A value function for incremental changes in streamflow can be obtained by combining the streamflow-angler success elas-

![Fig. 1. WTP versus success rate (hours per steelhead).](image-url)
tivities (equation (8)) with the results from the CV analysis (equation (11)). By multiplying (8) through by $\%\Delta FLOW_i$ and rearranging, one obtains

$$\Delta HRSFISH = \beta_i \times \Delta FLOW_i \times HRSFISH \quad (12)$$

Combining with (11), adjusting for the percentage of steelhead produced in the North Fork of the John Day and letting $HRSFISH$ equal the current average angler success rate (of 17 hours/steelhead) results in

$$AGG. WTPc = 156 + 22,122(\beta_i \times \Delta FLOW_i) - 15,780\beta_i^2 \times \Delta FLOW_i^2 \quad (13)$$

(base = 17 hours per steelhead). The marginal benefits function is derived by taking the first derivative of (13) with respect to $\Delta FLOW_i$:

$$MARG. VAL. WATER = 22,122 \times \beta_i - 31,560\beta_i^2 \times \Delta FLOW_i \quad (14)$$

(base = 17 hours per steelhead). Equation (14) is used to calculate the marginal value of instream water for steelhead enhancement. These marginal values of water for summer, spring, and winter streamflow in the production of steelhead fishing 5 years after the flow's occurrence, are presented in Table 3, first column. As is evident from the table, the values for increased summer flow are positive and considerably greater than other periods. In absolute terms, however, the value of an incremental change in summer flow of $0.53/acre-foot$ (1 acre-foot = 1233 m$^3$) appears quite modest. These flow values are directly affected by the relatively small numbers of anglers fishing the John Day River.

As noted earlier, recreational benefits may accrue at locations far removed from the primary point of production. Many John Day-reared steelhead are caught outside the basin in the Columbia River sport and Indian gillnet fisheries. The U.S. Bureau of Reclamation [1985] assumes that 1.5 John Day steelhead are caught in these other fisheries per escaping John Day steelhead. Using this estimate and assuming the marginal value per additional sport caught steelhead of $6.65$ can be transferred to these other fisheries, a more complete account of the marginal value of instream water can be obtained:

$$MARG. VAL. WATER = 22,122 \times \beta_i - 31,560\beta_i^2 \times \Delta FLOW_i \quad (14)$$

A reasonable assumption is that the streamflow-angler success

$$\Delta FISH CATCH \times MARG. VAL. FISH$$

$$= \Delta ESCAPEMENT \times 115 \times $6.65$$

$$= ([\beta_i \times \Delta FLOW_i \times ESCAPEMENT \times 1.5 \times 0.65] \times $6.65$$

$$= \beta_i \times \Delta FLOW_i \times $97,256 \quad (15)$$

A reasonable assumption is that the streamflow-angler success弹性们 from (8) can also be interpreted as streamflow-escapement elasticities. Equation (15) can then be rewritten as

$$MARG. VAL. WATER = \beta_i \times \Delta FLOW_i \times ESCAPEMENT \times 1.5 \times 0.65 \times $6.65 = \beta_i \times \Delta FLOW_i \times $97,256 \quad (16)$$

where $ESCAPEMENT$ has been assumed to be 15,000 (Oregon Department of Fish and Wildlife, unpublished report, 1988a). Results are presented in Table 3, second column. The resultant summer flow value increases approximately fourfold, to $2.36/acre-foot$. The second column calculation demonstrates that the value of instream water is sensitive not only to the estimated number of anglers but also to what benefits are included in the measurement. Excluding out-of-basin benefits leads to an undervaluation of John Day River streamflow.

**Implications and Conclusions**

The above analysis provides an estimate of use values for an increment of water in the production of recreational steelhead fishing within the John Day River. Including some out-of-basin benefits, the value of an additional acre-foot of water in the production of recreational steelhead fishing is $2.36$ in 1987 dollars. A complete analysis of the efficiency of water use, however, requires measures of the value of water in both in-stream and off-stream uses. For example, other fish species in the river, such as resident trout, chinook salmon, and warm water species, would benefit from an improvement in streamflow patterns. While this study focuses only on the value in one instream use, recreational steelhead fishing, some evidence is available on the most important out-of-stream use within the Basin, agriculture.

The John Day Basin has approximately 59,000 irrigated acres (1980 acreage). As is the case with fish production, the value of additional irrigation supplies will vary by location within the Basin. As a result of frequent water shortages in the summer period, current cropping patterns include a high percentage of grain and forage crops. Where climatic and water supply conditions are favorable, more profitable crops such as mint, orchards, potatoes, and sunflowers can be grown. The U.S. Bureau of Reclamation [1985] estimated irrigation benefits from increased water supplies in the Basin to vary from $10$ to $24$ per acre-foot, depending on location and crop alternatives. These values are consistent with estimates from other locations with similar crops and environmental conditions. The lower estimate, based on farm budgets for a representative 320-acre family grain and forage farm, appears most appropriate as a measure of the value of an additional acre-foot of water in agricultural production under current cropping patterns.

Judged against the $10.00/acre-foot estimate for agricultural use, the value of an additional acre-foot of water in the production of recreational fishing does not appear to support any reallocation across uses. These values, however, may be misleading. Ward [1987] notes that water used for recreational purposes may be used later by agriculture at a lower point on the river. In addition, due to losses in transport and application (some of which may return to the river), agriculture does not consume 100% of the water diverted. To increase instream flow by 1 cubic feet per second (cfs) it may be necessary to decrease agriculture diversions by 2 cfs or more. The correct values should thus be for acre-feet of water consumed. Unfortunately, complete hydrologic data for all reaches of the John Day River are unavailable. Furthermore, water values

<table>
<thead>
<tr>
<th>Period</th>
<th>$\beta_i$</th>
<th>Mean Flow Level, cfs</th>
<th>Dollars per acre-foot*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>-0.000586</td>
<td>2700</td>
<td>$0.073 - $0.32</td>
</tr>
<tr>
<td>Summer</td>
<td>0.00432</td>
<td>204</td>
<td>$0.53 - $2.36</td>
</tr>
<tr>
<td>Winter</td>
<td>0.000327</td>
<td>1573</td>
<td>$0.041 - $0.18</td>
</tr>
</tbody>
</table>

*Calculated by assuming a 1 cfs change over a 3-month period. Converted to value per acre-foot by dividing by 178.
within the Basin will vary greatly by location. It is instructive, however, to present some reasonable estimation of use values in consumption. If irrigation consumes half of the total water diverted, agricultural water would be valued at $20/acre-foot consumed. Additions to instream flow would consume far less, say, 10% of the increased flow, raising instream values to over $23. This higher value assumes that the remaining proportion of instream flow is subsequently withdrawn or otherwise put to beneficial use after passing through the juvenile rearing area. If it is instead left instream, then the correct value for instream water reverts to $2.36, reflecting the true opportunity cost of making that water unavailable for alternate uses. Whether transfers of water from agriculture to fishery production are justified on efficiency grounds is thus highly sensitive to the assumed spatial use pattern in each competing use. Further research is needed to define the most productive spawning and rearing reaches of the John Day River Basin, as well as the hydrology of the system.

Finally, it should be noted that the conclusions drawn from this analysis reflect a recent phenomenon within the basin of increasing anadromous fish runs. While the causes of these increases are not fully understood, improved passage conditions at Columbia River dams and increased marine survival are likely causes. Current flow levels appear to be adequate to sustain a viable fishery when riparian habitat and downstream conditions are maintained. The results of this analysis, however, cannot be viewed as supporting less water for fishery production nor do the results imply that no investments should be made in enhancing the steelhead fishery. Some increase in summer streamflow in the upper reaches of the John Day, coupled with riparian habitat management and instream habitat alternatives, may be viable investments.

It should be stressed that benefits reported in this study are due to changes in streamflows, ignoring any benefits arising from habitat improvements. In reality, streamflow, water quality, adjacent riparian cover, the dynamics of the stream, and other ecosystem attributes all combine to "produce" fish. Habitat degradation caused by mining, forestry, agricultural, and range activities in the Basin have led to significant reductions in anadromous fish populations (Oregon Department of Fish and Wildlife, unpublished report, 1985b). The above values assigned to instream water have been estimated under the assumption that the relationship between streamflow and these other inputs remains constant. Given current and future habitat improvement projects planned for the John Day Basin, this assumption is questionable. Further research is needed to quantify the relationship between streamflow, habitat quality, and steelhead production. Such research will be of particular importance in developing least cost strategies of meeting judiciously mandated increases in fish production.

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