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LOWER CRAB CREEK DAM AND RESERVOIR PROPOSAL: A STUDY OF ANADROMOUS FISH BENEFITS

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1 Introduction

In 2007 the Washington Department of Ecology (WDOE) and the U.S. Bureau of Reclamation (USBR) published a study comparing four site options for an off-channel storage reservoir (WDOE and USBR 2007). The reservoir would be supplied by water diverted from the Columbia River at Priest Rapids. The study identifies the Lower Crab Creek Basin as the best site for this project, hereafter referred to as the Lower Crab Creek Proposal. One of the main purposes of this project is to store water in anticipation of a need to protect fisheries through instream flow augmentation. Section 90.90.020 of the Revised Code of Washington mandates that one-third of active storage be available for this use; the remaining two-thirds must be available for out-of-stream uses such as irrigation and municipal uses. Given this mandated surface water allocation, WDOE would determine the timing of water releases.[1] The anadromous fish benefits of the Lower Crab Creek Proposal will depend on the strategic timing of these releases in accordance with biological and economic principles. This paper seeks to provide a useful economic analysis of the marginal benefits for anadromous fish of an incremental change in streamflow in the Columbia River.

Benefit-cost analysis is a central component of economic decision-making.

[1]The legislature reads, "One-third of active storage shall be available to augment instream flows and shall be managed by the department of ecology. The timing of releases of this water shall be determined by the department of ecology, in cooperation with the department of fish and wildlife and fisheries comanagers, to maximize benefits to salmon and steelhead populations."

The potential of a new off-channel storage project to protect fisheries is controversial from both an environmental and an economic perspective. Ideally, policy-makers would weigh the true benefits against the true costs of a proposed project to decide if it should be undertaken. These costs and benefits would account for all of the economic effects of an environmental change. However, it is incredibly difficult to make an accurate benefit-cost analysis of the non-market goods and services that flow from environmental resources. WDOE (2007) notes the challenge of placing a dollar value on the benefits of the Lower Crab Creek Proposal with respect to flow augmentation for fisheries, and the Appraisal Evaluation does not conduct a thorough economic analysis of this aspect of the proposal.[2] Biological and ecological models lie outside the scope of this paper, but a thorough mathematical and theoretical analysis will consider the economic impact of the flow augmentation goal of the Lower Crab Creek Proposal. Section 2 gives background information about anadromous fish in the Columbia River. Sections 3 and 4 discuss the mathematical framework and economic theory for determining marginal benefits. Section 5 presents related empirical results and Section 6 concludes.

2 Background Information

Less than one percent of all fish in the world are anadromous (NOAA); however, these fish play an important role in the culture and economy of

[2] If the proposal were approved, the final environmental impact statement for the project would include a complete benefit-cost analysis.

the Pacific Northwest. The anadromous fish native to the Columbia River are Pacific salmon and steelhead trout *(Salmo gairdneri)*. The native Pacific salmon species are chinook *(Oncorhynchus tshawytscha)*, sockeye *(O. nerka)*, coho *(O. kisutch)*, and chum *(O. keta)*. Salmon have significant cultural importance to Native American tribes, and they provide income through commercial fishing and tourism. However, runs of anadromous fish in the Columbia River have been declining over time; some species, including certain Pacific salmon species, are now considered endangered or threatened (USFWS).

Anadromous fish hatch in freshwater and then migrate to saltwater for most of their lives. During this migration they descend with their heads facing upstream, allowing the current to carry them down to the sea, where they turn to swim for the first time. After spending one to five years living in the ocean, anadromous fish migrate back upstream to their freshwater birthplaces to mate. They subsist only on their stored fat energy while swimming up the river. All Pacific salmon species and most steelhead die after mating at the end of this long journey (Netboy 1980).

Anadromous fish benefits, defined more rigorously in Section 3, are related to stock size, which depends on the quality of the riparian habitat. Determinants of habitat quality include: the quantity of food supply, particularly from wetlands; elements of water quality, such as temperature, turbidity and salinity; the conditions of spawning areas; and the level of instream flow in the Columbia River (Couto 1997). The level of instream flow during migration periods is a key determinant of anadromous fish survival. A weak current or obstacles such as dams would increase the mortality rate during migration. By law, one-third of stored water must be available to augment instream flow (WSL 2008). This paper will consider instream flow in the Columbia River as the main determinant of riparian habitat quality for anadromous fish.

The Lower Crab Creek Proposal could provide anadromous fish benefits if instream flows are well-managed. Richter (2007) lays out strategies for operating dams in order to restore natural flows. His study suggests that because the mechanics of river flow control have been established, humans should be able to manage shocks to riparian ecosystems and protect fish runs. For the purposes of the Lower Crab Creek Proposal, Richter's (2007) study implies that if surface water is available, then it is feasible to augment instream flow during critical migration periods.

3 Mathematical Framework

Anadromous fish benefits will be defined by Equation (1), where total benefit is the sum of the marginal value of fish multiplied by the quantity of fish, a function of stock size, across all uses. Total benefit will depend on a number of other variables that affect stock size and fish value. Recall that some of these variables are instream flow, food supply, water quality, and spawning areas. Because the Lower Crab Creek Proposal identifies streamflow augmentation as a primary goal of the project, this paper will seek to isolate the anadromous fish benefits due to changes in instream flow. Thus, marginal benefit equals the partial derivative of the fish benefit function with respect to instream flow, as in shown Equation (2), where f is instream flow, MV_i is the marginal value of use i, and $q_i[s(f)]$ is the quantity of fish as a function of stock size, s, which depends on instream flow.

$$B = \sum_{i=1}^{n} MV_i \cdot q_i[s(f)] \tag{1}$$

$$MB = \frac{\partial}{\partial f} \sum_{i=1}^{n} MV_i \cdot q_i[s(f)] \tag{2}$$

An accurate measurement of benefits requires an introduction to the concept of total economic value and to some of the valuation methods for each component i of anadromous fish-related total economic value. In addition to discussing marginal value, Section 4 will consider the theoretical relationship between the quantity of fish q and the stock size s. To estimate marginal benefits as the partial derivative of benefits with respect to instream flow, we turn to empirical evidence.

4 Economic Theory

4.1 Total economic value

Environmental resource valuation requires a unique conceptual framework because natural resources and environmental goods and services typically do not flow through markets. The fundamental assumption of environmental resource valuation is that economic value is measured within an anthropocentric framework. In other words, the value of a resource depends on the level of human benefits derived from that resource. The measurement of such benefits depends on the concept of total economic value. Environmental economists divide total economic value into three components: use value, option value, and non-use value. The sum of these three components is equal to total willingness to pay.

$$\text{TWP} = \text{Use Value} + \text{Option Value} + \text{Non-use Value}$$

Use values include current and expected future use values associated with the stock and flows of a natural resource in present value terms. Use values of anadromous fish include the value of commercial fisheries, the value of anadromous fish-related recreation, and the value of anadromous fish for ecosystem enrichment. Option value is the value of preserving a resource now to maintain the option of a potential future use. One type of option value is bequest value, which is the value of the satisfaction derived from preserving a resource for future generations to use. One might expect the bequest value of anadromous fish in the Pacific Northwest to be high due to the cultural importance of salmon. Existence value, the only type of non-use value, is the value of preserving a resource with no intention of using it now or in the future.

4.2 Valuation methods

Some components of total economic value appear in markets and are easy to measure; others require particular valuation estimation methods because they never explicitly take on a monetary value. In the case of anadromous fish in the Columbia River, estimating the value of commercial fisheries requires knowledge of the market, whereas measuring recreational use value and existence value requires valuation techniques such as the travel cost method and contingent valuation.

Suppose we want to determine the value of a privately-owned, profit-maximizing commercial fishery that operates within a perfectly competitive market. The annual value of a fishery is the difference between its total revenue and total cost, which is rent. The fishery's total value V is equal to the present value stream of annual rent. This is represented by

$$V = \sum_{t=0}^{\infty} \frac{p \cdot h_t(e_t, s_t) - c \cdot e_t}{(1+r)^t} \tag{3}$$

where p is price per unit of harvest, h is harvest, e is fishing effort, s is stock size, c is cost per unit of effort, and r is the discount rate. It may be difficult to acquire all the information, such as the true discount rate, to accurately estimate V, but this method of valuing a perfectly competitive, privately-owned, profit-maximizing fishery is theoretically simple. This method appears again in a later discussion about the relevance of stock size.

The travel cost method is a type of indirect revealed preference method that is often used to determine the recreational use value of a site. The travel cost method assumes that the value of a recreation site is reflected in recreationists' willingness to pay to get to the site, so the method uses information about travel costs to estimate a demand curve for trips to the recreation site. The total economic benefit of the site is equal to consumer surplus, the area under the demand curve (King and Mazzotta 2000).

Douglas and Johnson (1993) review studies of instream flow valuation that use variations of the travel cost method, including the zonal variant and the individual travel cost approach. Estimating the benefit of a change in instream flow using only the travel cost method requires an enormous amount of data, as shown by Loomis and Cooper (1990). Although the travel cost method has the advantage of using revealed preference data, most studies couple the travel cost method with contingent valuation to estimate the benefit of a change in instream flow.

Contingent valuation is a stated preference method that uses a survey to determine willingness to pay for a hypothetical change in environmental quality. The survey asks either an open-ended valuation question (e.g., how much would you pay per year for an annual increase in instream flow of 20%?) or a referendum-type valuation question (e.g., would you pay $20 per year for an annual increase in instream flow of 20%?). A survey that uses a referendum-type question may offer follow-up amounts to more accurately estimate a respondents' willingness to pay. A contingent valuation study also asks for demographic information and preferences, which may be used in econometric analysis to control for exogenous variables. Contingent valuation is a versatile and inexpensive means of estimating non-market benefits, but the results are often controversial: studies may contain biases inherent to the technique and the nature of the survey. Nevertheless, it is a widely accepted method for estimating components of total economic value and is, in fact, the only method for estimating existence value (King and Mazzotta 2000).

4.3 Stock size and comparative statics

An incremental change in instream flow at Lower Crab Creek will affect the stock of anadromous fish in the Columbia River. Quantifying this effect requires a biological model. An example of this approach will be considered in the empirical section. However, we can say a few things about the economic implications of variations in anadromous fish stock size.

Total benefit depends on the quantity of the good or service derived from the stock of anadromous fish for each component of total economic value. For example, a large stock size will yield more opportunities for recreation than a small stock size, so the benefit due to recreation will increase with stock size. Similarly, we would expect a reduced stock size to adversely affect commercial fisheries, thereby reducing the rental component of total economic value. It is important to note that stock size may influence non-use benefit differently because existence value does not stem from an intention of ever using a discrete quantity of the resource. It does not make sense to define the quantity of existence as a smooth, continuous function. Rather, quantity may take a value of one or zero depending on whether or not the species exists.

$$q(s) = \begin{cases} 1 & \text{if } s > 0 \\ 0 & \text{if } s = 0 \end{cases} \tag{4}$$

The marginal benefit function for existence probably does reflect diminishing marginal benefits from increases in stock size. Empirical methods should reflect this as well, even though the simple mathematical model cannot explain variation in existence benefits due to changes in stock size.

Commercial fishing is one use that does depend on stock size very explicitly. A simple model of static efficiency demonstrates the relevance of stock size for fishery benefits. Consider a private fishery that operates in a perfectly competitive market with no externalities. Assume a discount rate of zero, constant input and output prices, and a negligible critical stock size.[3] The fishery chooses to maximize its profit over time. Because the model assumes zero discounting, the profit maximization problem simplifies to maximizing profit in one time period. Recall that annual rent equals total revenue minus total cost. Assuming constant fish prices and constant input costs,

$$R_t = \pi_t = \bar{p} \cdot h_t(e_t, s_t) - \bar{c} \cdot e_t \tag{5}$$

gives profit in a single time period, where the fish harvest (h) is a function of effort (e) and stock size (s). If t is one year, then R_t is the annual value of the fishery, or rent. Rent is maximized where the slope of the total revenue curve equals the slope of the total cost curve, as shown in Figure 1. The fisher is maximizing sustained yield over time with a discount rate of zero, so this point is called the static efficient sustained yield. A dynamic efficient sustained yield model relaxes the assumption that the discount rate is zero. Assuming a positive discount rate, future profits will be less valuable, so harvest effort will increase in the present, depleting the stock to a lower sustained level over time.

[3] The critical stock size is the smallest biologically sustainable stock size. The growth rate at this point is zero and will become negative if the stock size decreases at all, leading to extinction by biological forces. On the other hand, if the stock size increases at all, biological forces will increase the stock to a stable size.

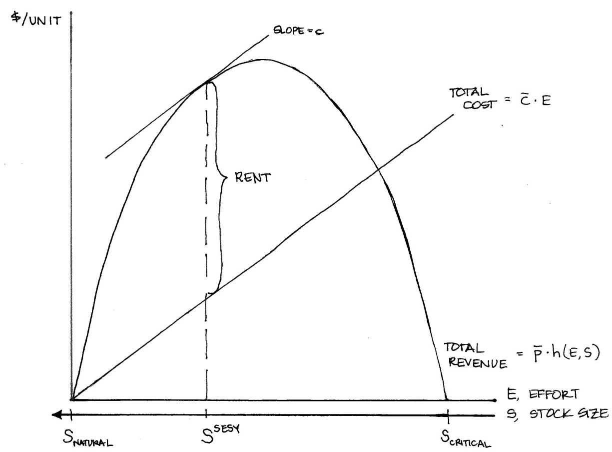

Figure 1: An illustration of static efficient sustained yield for a competitive fishery.

Comparative statics makes it possible to analyze the effect of a change in stock size, whether due to biological or human forces. Stock size affects total revenue through the harvest function h. A smaller stock size would reduce the harvest and therefore reduce total revenue. The rent would be smaller than the rent in the initial time period, so a reduction in stock size reduces the value of commercial fisheries. A smaller anadromous fish stock size yields a smaller total benefit, which is consistent with the expectation that stock size and total benefit are positively related.

4.4 Surface water allocation

The economic efficiency of the Lower Crab Creek Proposal will depend on how surface water is valued across uses. Consider a simple case in which anadromous fish and agriculture are the only two sources of demand for surface water from the Columbia River and that they are mutually exclusive uses. Suppose additional units of surface water are more valuable for anadromous fish than they are for agriculture. This is reflected by the curves in Figure 2: the marginal net benefit of fish curve (MNB_F) lies above the marginal net benefit of agriculture curve (MNB_A). The aggregate marginal net benefit curve is constructed by adding the horizontal components of MNB_F and MNB_A at each level of marginal net benefits. The economically efficient allocation occurs when each use has the same marginal net benefit. Thus, given a constant supply of surface water S_T, it is efficient to allocate Q_F units of surface water to anadromous fish and Q_A units of surface water to agriculture. If the surface water supply fell to S'_T it would be economically efficient to allocate all of the available water to anadromous fish.

This model of surface water allocation does not account for some important real-world complications. First, there are more than two uses for surface water from the Columbia River. Among these uses are agriculture, municipal, hydropower, and recreation. The model could be extended to include marginal net benefit curves for each of these other uses. The aggregate marginal net benefit curve would account for all of the uses and the economically efficient allocation of surface water would still depend on the relative value of instream flow for each use. Second, the model does not deal the impact of the timing of water flows. Juvenile anadromous fish derive higher marginal net benefits from instream flow during summertime when they are migrating downstream. This is not captured by the static surface

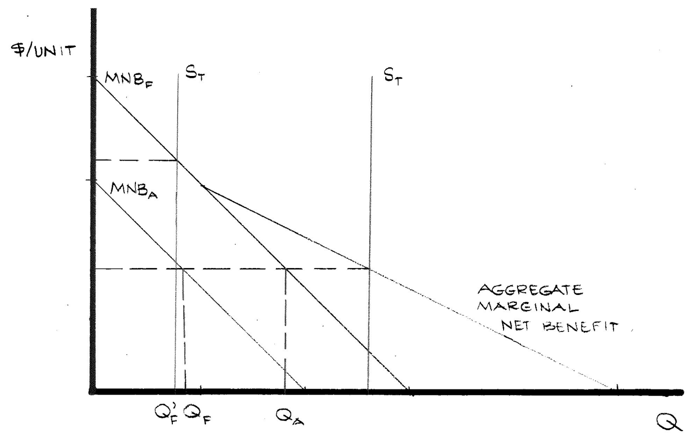

Figure 2: An illustration of efficient surface water allocation between two mutually exclusive uses.

water allocation model. It would be important to specify the season in order to manage surface water allocation efficiently. Finally, the discussion began with the assumption that the MNB$_F$ curve lies above the MNB$_A$ curve. Figure 2 also suggests that these functions are linear. In reality, the marginal net benefits functions are unknown. Estimating these functions requires the conceptual framework of total economic value and estimation techniques for non-market goods.

5 Empirical Evidence

The theory of benefit transfer gives an opportunity to consider empirical evidence without conducting a rigorous field study of anadromous fish in the Columbia River. Benefit transfer uses information from a nonmarket valuation study conducted at one location or during a previous time period to infer the value of an environmental good or service in a different location or time period, as described by Wilson and Hoehn (2006). This allows for benefit estimation without conducting a costly empirical study. However, benefit transfer inherently introduces error when the parameters of the study produce an imperfect transfer. Wilson and Hoehn (2006) discuss current issues related to benefit transfer and survey the relevant literature.

Resource economists use the valuation methods described in Section 4.2 to estimate the benefits of changes in streamflow for particular anadromous fish species. Douglas and Johnson (1993) provide a survey of the literature on this subject. In one such study, Johnson and Adams (1988) estimate recreational fishing benefits due to incremental changes in streamflow in the John Day River. The John Day River, a tributary of the Columbia River that is located in north-central Oregon, and is a long, free-flowing river system with no dams. It provides a spawning habitat and migration route for anadromous fish. The river is a source of irrigation and has multiple recreation uses, including fishing (USDI 2000). The Lower Crab Creek Proposal includes construction of an off-channel reservoir, and the ecology of the river system certainly differs from that of the John Day River; however, among the available literature, this case study appears to be the most suitable choice for a benefit transfer analysis.

Johnson and Adams (1988) first develop a biological production model of a steelhead fishery and then use contingent valuation to estimate the economic value of an incremental streamflow change. For the biological production model they develop a time-series model and use ordinary least squares (OLS) to regress the annual adult steelhead population in the John Day River against a number of lagged seasonal streamflow variables. The regression also includes a dummy variable to account for migration route influences, such as the construction of the John Day Dam in 1968. Johnson and Adams (1988) use the statistically significant results of the OLS estimation to construct streamflow-angler success elasticities. One limitation of this model is that the seasonal streamflow variables span three months and therefore do not precisely target critical flow periods. Further biological research could increase the precision of the estimate.

Johnson and Adams (1988) use is contingent valuation to estimate the economic value of an incremental streamflow change. They note that the travel-cost method is not applicable to their study because the steelhead fishery in the John Day River is not limited to a single angling area. This is also true of the recreational fisheries in the Columbia River because incremental streamflow changes at Lower Crab Creek would affect multiple recreational fishing locations along the Columbia River. Johnson and Adams (1988) administered a survey that asked questions about willingness to pay for John Day steelhead fishery improvements. They use the responses to estimate an aggregate bid function for steelhead fishery improvements. They note that this bid function does not account for any option or existence values; thus, we expect this valuation method to give a lower bound for total economic value of the resource.

Johnson and Adams (1988) combine the fishery production model and the bid function to derive the marginal value of instream water for recreational fishing according to the following equation.

$$\text{MARG. VAL. WATER} = \Delta\text{FISH CATCH} \times \text{MARG. VAL. FISH} \quad (6)$$

Their analysis leads to a value of \$2.36 (in 1987 dollars) for an additional acre-foot of water in the production of recreational steelhead fishing. This is significantly lower than an estimated \$10.00 per acre-foot (in 1987 dollars) for agricultural use, as reported by Johnson and Adams (1988). However, Johnson and Adams (1988) note that their estimate does not take into account the non-consumptive property of instream flow allocated to fisheries.[4] In other words, the incremental flow that benefits steelhead production also has value for downstream uses. Re-evaluating these estimates yields evidence that water is actually more valuable to fisheries than it is to agriculture. This discrepancy in estimates changes the economically efficient allocation of surface water. The Revised Code of Washington mandates that one-third of surface water be allocated to fisheries, so this result does not directly affect the benefit-cost analysis. However, it does dictate whether or not the mandated allocation achieves economic efficiency.

Johnson and Adams' (1988) estimate of use value for an increment of water in the production of recreational steelhead fishing in the John Day river is a lower bound on the estimate for the use value of an increment of water in the production of anadromous fisheries in the Columbia River. We expect the

[4] Nor does their model consider potential threshold (cumulative) effects, the importance of which is described by Wu (2000).

actual value to be higher for at least two reasons. First, both steelhead and salmon in the Columbia River enjoy the benefits of an incremental increase in streamflow. Second, the concept of total economic value suggests that many factors are relevant in environmental resource valuation. Recreational use is just one component of the total value of anadromous fish in the Columbia River. An incremental change in streamflow may also affect commercial fishery value and potential future use–option value–of anadromous fish. The benefit transfer sought through this analysis is useful, but further research is necessary to better estimate the true benefit of an incremental change in instream flow for anadromous fish in the Columbia River.

6 Conclusion

This study has presented the economic theory of non-market environmental resource valuation as it applies to measuring anadromous fish benefits in the Columbia River. An accurate benefit estimate requires consideration of the total economic value of the resource, which includes use, option, and non-use values. The travel-cost method and contingent valuation are two methods for determining these values for non-market goods and services. The marginal benefit of an incremental change in streamflow for anadromous fish depends on the biological relationship between fishery productivity and streamflow, as well as the economic value of fish for each of the total economic value components. This study analyzed the economic importance of stock size for recreational and commercial fishery productivity. Although constructing a more extensive biological model was not feasible, the theory of benefit transfer allowed for the presentation of some relevant empirical evidence. An increment of water almost certainly does have economic value for anadromous fish productivity in the Columbia River. The magnitude of anadromous fish benefits of the Lower Crab Creek Proposal will ultimately depend on strategic management of the reserved surface water.

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