# INCREASING STREAMFLOW TO SUSTAIN SALMON AND OTHER NATIVE FISH IN THE PACIFIC NORTHWEST

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*According to biologists, increasing streamflows is among the measures necessary to protect salmon and other native fish in the Pacific Northwest. Yet our understanding of the costs and most cost-effective approaches is hampered by lack of comparative experience. This article attempts to address both of these issues. The analysis finds that the costs of streamflow augmentation may be modest, between \$1 and \$10 per capita per year for the region. Apart from large-scale actions on the Snake and Columbia Rivers, we find that streamflow augmentation will require decentralized approaches, and their cost-effective implementation will require localized scientific information, constant monitoring, and hands-on management to acquire water through purchases, leases, and contingent contracts when and where appropriate.* (*JEL* Q22, Q25)

## I. INTRODUCTION

To restore and protect the populations of wild salmon and other native fish in the Pacific Northwest—including measures called for under the Endangered Species Act—it is widely recognized by biologists and policy makers alike that significant changes will be required throughout the region.

In the case of salmon, the seven native species in the northwestern United States have disappeared from about 40% of their historic breeding ranges during this century (National Academy of Sciences, 1996), and the size of the remaining wild stocks has been severely reduced. According to Nehlsen et al. (1991), 214 stocks are at high to moderate risk of extinction. In addition, annual returns of salmon to the Columbia River basin have decreased from an estimated 12–16 million fish before the 1930s to 2.5 million fish in the 1980s, including those produced in hatcheries. Although catch rates in some commercial fisheries have not declined significantly, most runs that appear plentiful today are composed largely of fish produced in hatcheries. Depletion of native salmon has led to extended restrictions and outright bans on recreational and commercial fishing for several species, and several stocks of salmon have been designated as endangered or threatened under the provisions of the federal Endangered Species Act, as have freshwater fish, including shortnose suckers (*Chasmistes brevirostris*) and Lost River suckers (*Deltistes luxatus*) in Upper Klamath Lake.

The decline of salmon and native freshwater fish in the Pacific Northwest has resulted from numerous interacting activities, such as agriculture, forestry, grazing, industrial activities, urbanization, dams, interactions between wild and hatchery species, and fishing. Salmon are particularly vulnerable to this wide range of human influences because of their anadromous life cycle, whereby they spawn in fresh water, migrate to the sea, and return to their natal streams several years later to reproduce and subsequently die. For example, the hundreds of small and large dams that have been built on rivers throughout the Pacific Northwest have greatly reduced wild runs due to their effects on migration, the quantity and timing of water flows, velocity, water chemistry, and water temperatures (National Academy of Sciences, 1996).

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*Support for this research came from the Center for Watershed and Community Health, Mark O. Hatfield School of Government, Portland State University.

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Contemporary Economic Policy
(ISSN 1074-3529)
Vol. 20, No. 4, October 2002, 366–380

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A range of efforts to reverse the decline in the populations of salmon and other native fish are being taken (or considered) at local, state, and federal levels. These efforts include tightening of harvest restrictions, modifications of dams and dam operations, and changes in the role of hatcheries in fishery management. They also include actions to protect the freshwater habitats of salmon and other native fish, such as riparian habitat protection and restoration and streamflow augmentation (see National Academy of Sciences, 1996).

Streamflow is a key factor affecting the quality of salmon's freshwater habitat. Although the benefits to salmon for a specific increase in streamflows are difficult to assess precisely, biologists point to substantial scientific evidence that reductions in flows have contributed to the decline in salmon stocks throughout the region. Thus, a critical issue in the current policy setting will be how to maintain adequate streamflows to protect existing freshwater habitats and restore those that have been degraded.

Interventions aimed at increasing streamflow to protect fish represent a new challenge to policy makers and resource managers, one for which little comparative or historical evidence exists as a basis for judging the costs or likely effectiveness of alternative approaches. Two distinct kinds of actions are at issue, one involving large-scale mainstem augmentation on the Snake and Columbia Rivers, the other involving much smaller tributary augmentation projects throughout the region. Because agriculture is the principal source of surface water diversions, accounting for about 80% of the total for the region, any efforts to augment streamflow will necessarily concentrate on reducing irrigation withdrawals—whether from thousands of upstream water users in the case of large-scale augmentation or from a handful of water users in a small basin. In both cases, the costs of augmenting streamflows to protect fish will depend importantly on their impact on irrigated agriculture.

In addition to the paucity of information on cost, little is known about how best to achieve the desired goals cost-effectively. Commonly held views include the notion that the costs of increasing streamflows will be extremely high, that the problem could be ameliorated by encouraging greater irrigation efficiency, or that improvements would result from promoting freer water markets. Indeed, some estimates of the value of water in irrigated agriculture in Washington state are as high as $100 to $200 per acre-foot, or even higher (Gibbons, 1986; U.S. Army Corps of Engineers, 1999). In the case of the U.S. Army Corps of Engineers study of the costs of removing four Lower Snake River dams, the lost irrigation is estimated using an assessed value method at $134 million for 37,000 irrigated acres. Given an average application of 2 acre-feet/acre, the implied annualized value using a 6% discount rate is $109/acre-foot (U.S. Army Corps of Engineers, 1999).

The scientific and economic issues surrounding the protection and restoration of salmon and other fish in the Pacific Northwest is the subject of a large and far-ranging literature (see National Academy of Sciences, 1996, for a survey). Considerable attention has been focused on the cost and likely effectiveness of large-scale changes involving hydropower operations on the Snake and Columbia Rivers (see for example Huppert, 1999). The present analysis attempts to contribute to that body of literature by shedding light on the question of the expected cost of streamflow augmentation, and on the kinds of approaches that are most likely to be cost-effective. The question of whether the costs will ultimately fall on farmers or taxpayers is certainly intertwined with questions of cost, cost-effectiveness, and public or political support for action. These issues will ultimately be addressed through legal and political processes at the local, regional, and national levels, and the current analysis does not attempt to predict the eventual outcome of those processes.

The remainder of this article is divided into three sections. The next section estimates the cost of increasing streamflows; section III discusses the potential benefits of increased stream flows for salmon; and section IV appraises the policy and management alternatives given the unique characteristics of the situation being examined.

## II. THE COST OF INCREASING STREAMFLOW

Because increased streamflows will come primarily from irrigated agriculture, the cost of increasing streamflow is derived from the opportunity cost of water in agricultural use.

If competitive water markets existed, then the value of water for irrigation could be easily inferred from the prices at which farmers buy and sell it. Unfortunately, water rights transactions between farmers are rare. This is due in part to the U.S. prior appropriations system, combined with many states' restrictions on the transfer of water rights, which hinder the reallocation of water through the sale or transfer of water rights between locations and uses. Although there are serious ongoing efforts in many Western states to overcome these obstacles in ways that will introduce more flexibility and efficiency in water allocation, progress has been slow. Moreover, in some parts of the region where water rights transfers have few restrictions, transfers may be impractical or impossible between distant basins or in the absence of conveyance infrastructure.

Estimating the cost of increasing streamflows must therefore be based on indirect evidence and estimations of the value of water in irrigated agriculture. All such evidence is tentative due to possible biases in estimation, highly site-specific values, or estimation techniques with very wide margins of error. Given this lack of reliability for any one estimate, the approach taken here will be to draw on estimates from several independent sources or techniques. In the event that these estimates match, our confidence in the reliability of the estimated value will be strengthened. The kinds of estimates considered include direct evidence based on actual water leasing and sales, indirect evidence based on land markets where land purchases confer water rights with ownership, and estimates from economic models.

### *A. Estimates from Actual Water Leases and Sales*

Despite legal and other obstacles to active water markets among farmers, the acquisition of water rights for instream uses emerged in the early 1990s with purchases by federal and state agencies, such as purchases and leases by the Bureau of Reclamation. In the Columbia River Basin, more than 2.3 million acre-feet of water were acquired from 1990 to 1998 by the Bureau of Reclamation for instream uses (Landry, 1998); their leases from Idaho water banks have grown dramatically during the 1990s (Simon, 1998). Concurrently the Oregon Water Trust pioneered the purchase of water rights by nonprofit organizations seeking to improve streamflows for fish and recreation. There is now also a Washington Water Trust, and a pilot project in the state of Washington's Department of Ecology. In addition, organizations such as Environmental Defense and the Nature Conservancy have also begun to participate in water acquisitions for instream uses in the western United States.

Because these sales are voluntary transactions by farmers, it is reasonable to assume that the prices are equal to or greater than the value of the water to the farmer—although the price paid may exceed the value of the water to the farmer if the contracting process was not competitive (e.g., few potential sellers). In Table 1, we summarize the available data from both the Oregon and Washington Water Trusts. Looking at the data from Oregon, we see that the average (annualized) value of water based on purchases of water rights is $9 per acre-foot, which is lower than the average of $23/acre-foot for one-year leases. This higher cost for one-year leases is to be expected because a single-year contract leaves the farmer and his equipment idle for a single year; whereas when the transaction is permanent, the farmer's equipment may be sold, thereby reducing or eliminating these capital costs. The transaction prices from Washington are significantly higher, averaging $57/acre-foot. This difference probably reflects purchases of water rights in popular recreational areas (e.g., on the Teanaway River) where vacation or hobby farms have recently pushed land and water rights prices above their agricultural values.

### *B. Estimates from Surrogate Land Market*

Although markets for water are rare, there are markets for farmland and the water rights that often go with land ownership. The implicit price of irrigation water can be revealed using hedonic analysis of farm property sales, where the sale price of irrigated farm property can be disaggregated to reveal the incremental price attributable to the land component or water component of the transaction. This approach has an advantage over analytical estimations based on economic models because it is based on actual transactions. An excellent example of this

**TABLE 1**
Recent Water Rights Transactions to Augment Streamflows

| | Current Use | Contract Type | Consumptive Use (acre-feet/year) | Price Paid ($) | Cost/acre-foot[a] ($) |
|---|---|---|---|---|---|
| Oregon locations | | | | | |
| Rogue River, Sucker Creek | Fallow | purchase | 67.80 | 8,800 | 7.79 |
| Rogue River, Sucker Creek | Fallow | purchase | 107.62 | 13,627 | 7.60 |
| Rogue River, Sucker Creek | Fallow | purchase | 57.47 | 8,138 | 8.50 |
| Deschutes River, Squaw Creek | Pasture | purchase | 417.19 | 42,900 | 6.17 |
| Deschutes River, Squaw Creek | Pasture | purchase | 308.08 | 44,352 | 8.64 |
| Deschutes River, Squaw Creek | Pasture | purchase | 48.14 | 7,425 | 9.25 |
| Deschutes River, Squaw Creek | Pasture | purchase | 8.46 | 870 | 6.17 |
| Deschutes River, Squaw Creek | Pasture | purchase | 96.27 | 13,860 | 8.64 |
| Rogue River Little Butte Creek | Hay | purchase | 173.95 | 20,000 | 6.90 |
| Hood River, Fifteenmile Creek | Wheat | purchase | 71.76 | 26,307 | 22.00 |
| | | | | | Average: 9.16 |
| Deschutes River, Buck Hollow Creek | Hay | one-year lease | 196.80 | 6,630 | 33.69 |
| Deschutes River, Buck Hollow Creek | Hay | one-year lease | 196.80 | 6,630 | 33.69 |
| Deschutes River, Buck Hollow Creek | Hay | one-year lease | 196.80 | 6,630 | 33.69 |
| Grande Ronde River, Crow Creek | Hay | one-year lease | 194.00 | 1,600 | 8.25 |
| Umatilla River, E. Birch Creek | Hay | one-year lease | 238.50 | 2,500 | 10.48 |
| Deschutes River, Trout Creek | Hay | one-year lease | 1135.50 | 23,843 | 21.00 |
| Deschutes River, Trout Creek | Hay | one-year lease | 270.00 | 4,680 | 17.33 |
| John Day River, Hay Creek | Hay | one-year lease | 248.80 | 14,500 | 58.28 |
| Rogue River, S.F. Little Butte Creek | NA | one-year lease | 83.34 | 1,438 | 17.25 |
| Deschutes River, Buck Hollow Creek | Hay | one-year lease | 196.80 | 6,630 | 33.69 |
| Grande Ronde River, Crow Creek | Hay | one-year lease | 197.70 | 5,272 | 26.67 |
| Deschutes River, Tygh Creek | Pasture | one-year lease | 94.50 | 945 | 10.00 |
| Rogue River, S.F. Little Butte Creek | NA | one-year lease | 83.34 | 1,438 | 17.25 |
| Grande Ronde River, Crow Creek | Hay | one-year lease | 197.70 | 5,136 | 25.98 |
| Deschutes River, Tygh Creek | Pasture | one-year lease | 94.50 | 945 | 10.00 |
| Rogue River, S.F. Little Butte Creek | NA | one-year lease | 83.34 | 1,438 | 17.25 |
| Umatilla River, Couse Creek | Wheat/Pea | one-year lease | 1065.9 | 23,800 | 22.33 |
| Deschutes River, Buck Hollow Creek | Hay | one-year lease | 196.80 | 5,000 | 25.41 |
| Grande Ronde River, Crow Creek | Hay | one-year lease | 197.70 | 5,136 | 25.98 |
| Rogue River, S.F. Little Butte Creek | NA | one-year lease | 83.34 | 1,438 | 17.25 |
| Umatilla River, Couse Creek | Wheat/Pea | one-year lease | 1065.9 | 23,800 | 22.33 |
| Umatilla River, Couse Creek | Wheat/Pea | one-year lease | 1065.9 | 23,800 | 22.33 |
| | | | | | Average: 23.19 |
| Washington locations | | | | | |
| Teanaway River, Kittitas County | NA | purchase | 302 | 300,000 | 59.60 |
| Teanaway River, Kittitas County | NA | purchase | 121 | 160,000 | 79.34 |
| Big Creek, Kittitas County | NA | purchase | 113 | 150,000 | 79.65 |
| Methow River, Chelan County | NA | one-year lease | 2 | 100 | 50.00 |
| Walla Walla River | NA | purchase | 2 | 1,800 | 54.00 |
| Yakima River (pending) | NA | purchase | 2.25 | 1,000 | 26.67 |
| Yakima River (pending) | NA | purchase | 2.25 | 2,000 | 53.33 |
| | | | | | Average: 57.51 |

*Source:* Oregon data from Oregon Water Trust; Washington data from Washington Water Trust.
[a] Assumes a 6% discount rate to compute annualized cost of permanent acquisitions.

kind of study exists for Mahleur County in eastern Oregon, where the value of water was estimated based on sales of farm land (Faux and Perry, 1999). Using data on land sales for 225 properties, the authors found that land prices varied depending on both the water rights and the soil class. Their analysis inferred that the value of water per acre-foot per year ranged from $9 for land in the lowest soil class to $19 for the median soil class and $44 for the highest soil class.

The most striking observation at this point is the similarity in these estimates to the actual transactions of the Oregon Water

Trust. The $9 estimate for the lowest soil class is identical to the average value for purchased water rights by the Oregon Water Trust. Because we expect the Oregon Water Trust to look for bargains, we would not expect their costs to be at the high end of the range. However, if costs are higher for one-year leases or if the Oregon Water Trust is not able to always find the lowest priced water, we would expect to see prices above the low end of the distribution. Indeed, the inferred value of $19 for the median soil class based on the surrogate market estimate is close to the average one-year lease price of $23 by the Oregon Water Trust.

### *C. Estimates from Economic Models*

Economic analyses can employ a number of different indirect techniques to estimate the value of water. However, estimating the agricultural value of water in a precise way is a complicated task given the site-specific nature of the soils, hydrology, uses, timing, regulation, rights, and incentives surrounding agricultural water diversions. For example, differences in the water-holding capacity of different soil types alone varies by a factor of 4, and the number of irrigations per season for major crops varies from 4 irrigations in the case of field corn on loam soils, to 10 irrigations for dry beans on sandy loam, to 51 irrigations for late potatoes on sand. Agroclimatic differences like these represent one of the reasons why the revenues generated from irrigation water use vary greatly across farms. Differences across locations in the revenues generated from water use are also affected by U.S. and state water laws and the prior appropriations system, which protects water rights based on a "first in time, first in right" basis. These water laws, combined with the state-level restrictions on water transfers, also contribute to differences in the value of water used on different parcels of land. Nevertheless, estimation methods, such as farm budget analysis, production function estimation, or detailed programming models, are widely used to produce estimates of the incremental value of water.

One approach is to represent the kinds of changes that farmers could be expected to make when water supplies are constrained and evaluate the changes in costs and revenues that would result. The analyst is sometimes required to decide the kinds of substitutions that would be made by the farmer, such as (1) converting from one irrigated crop to another, (2) converting from an irrigated crop to a dry land crop, (3) or removing some land from production. These adjustments are realistic to the extent that many farmers know how to make do with less water because in many regions—and especially for junior water rights holders—they are sometimes faced with water shortages in low-flow years.

Alternative estimation procedures that can be expected to exaggerate the costs of reducing irrigation water come from estimates based on the average value of water in irrigation or estimates based on deficit irrigation scenarios in which irrigation water is curtailed unexpectedly (so that plants have insufficient water to grow normally). Estimates of the average value of water in Washington (in adjusted 2000 dollars) range from $20/acre-foot for hops and alfalfa to $62/acre-foot for corn, $104/acre-foot for wheat, $156/acre-foot for pears, and $172/acre-foot apples (Gibbons, 1986). Estimates based on a 10% irrigation deficit range from $120/acre-foot for wheat to $565/acre-foot for potatoes in Washington (Gibbons, 1986).

One detailed model that represents farm-level adjustments among crops and between alternative land uses was developed to estimate the costs of augmenting streamflows by reducing irrigation diversions in the Upper Snake River Basin (U.S. Department of Agriculture, 1996). The study considers adjustments in 5 million irrigated acres in southern Idaho and east-central Oregon. The main crops affected are alfalfa hay, wheat, other hay, other small grains, dry beans, and sugar beets. The estimates are indicative both of the value of water for farming in these regions and of how the costs of augmenting streamflows rises with increases in the size of the reductions in irrigation diversions. The study found that the costs per acre-foot of water were $20 for a 14% reduction in baseline water diversions, $24 for a 20% reduction, and $29 for a 29% reduction. If the model accurately reflects the choices faced by farmers, these estimates should correspond to a one-time lease arrangement in which farmers will expect to return to normal farming practices the following year. Once again, these estimated values closely match the actual prices paid by the Oregon Water Trust for one-year leases and from the hedonic pricing estimates for the medium soil class.

A second study that looked at the potential for water markets in the Central Oregon Water District on the Deschutes River produced similar estimates for leasing portions of water allotments. Cost per acre-foot was estimated to range from $5 to $25 for acquisitions of water of up to 30,000 acre-feet (Turner and Perry, 1997).

Thus, our meta-analysis based on evidence from three independent approaches provides surprisingly consistent estimates of the value of water in irrigated agriculture. We have yet to consider, however, one additional aspect of water purchases to augment streamflow that may affect our estimate of the social cost of these transactions—the use of contingent contracts or interruptible water markets.

### *D. Contingent Contracts*

Acquisition of water to increase streamflows in all years will frequently be unnecessary if the benefits to salmon come from maintaining a minimum streamflow during critical months, and if the critical minimum is currently being achieved in some and perhaps most years. This situation exists for many rivers in the region, where the critical issue is maintaining streamflow above specific levels in low-flow years (and during the lowest-flow months) because of the effect of streamflow on water temperatures (and other factors) that can be lethal to fish (Hamilton et al., 1989).

Providing additional streamflows in those critical years will be less costly than providing additional water in all years (including years when streamflow may already be adequate). Given both the desirability and the lower cost of augmenting streamflow only in low-flow years, so-called contingent contracts have been proposed and even attempted whereby farmers agree to apply less water to their fields in low-flow years in exchange for a payment. This mechanism has great potential for reducing the cost of protecting populations of salmon and other fish, especially where portions of available water could be acquired on a contingent basis. For example, in the Snake River basin, contingent water contracts that required farmers to release stored water supplies (stored in reservoirs) in low-flow years during periods critical to smolt migration could provide substantial quantities of water at a modest cost and without significantly affecting the agricultural base in the area. Willis et al. (1998) estimate that the costs for contracts covering 50% of total stored water would range from $0/acre-foot for farms with efficient irrigation technologies (so that their reserves exceed their requirements) to no more than $3.91/acre-foot for surface irrigators. Even for contracts covering 100% of total stored reserves, cost estimates were quite low, ranging from $3 to $14 per acre-foot.

In locations where stored water reserves are not available, low-cost contracts of this kind may not be feasible; however, in other circumstances they may be feasible. For example, in Mahleur County, Oregon, the hedonic analysis for junior water rights holders suggest that interruptible water rights may not be costly in areas where high-value crops (e.g., onions and potatoes) cannot be grown every year on the same parcel of land because of soilborne disease problems. These high-value crops are rotated with low-value crops, such as hay or wheat, on portions of land each year. When water is in short supply (or if a contingent contract were in force), these low-profit crops could either be deficit irrigated or not planted at all to conserve water for the other fields with cash crops (Faux and Perry, 1999). The evidence from Mahleur County suggests that uncertain water supplies of this kind do not impose significant costs on farmers. Thus, these two cases represent examples of situations in which contingent arrangements for protecting streamflows during low-flow years may be achieved at an even lower cost than the $9 to $25 range estimated above.

### *E. Region-Wide Cost Estimates*

An important question on the minds of irrigators, the public, and politicians is how costly it would be to improve streamflows across the region. The evidence compiled here suggests that a program to increase and maintain minimum streamflows aimed at restoring fish populations could be relatively inexpensive if low-cost opportunities are taken advantage of, especially when the circumstances make contingent contracts

**TABLE 2**
Estimated Cost to Increase Streamflow in Specific Northwest River Basins

| Basin and Proposed Action | Cost per Acre-Foot ($) | Total Cost | |
|---|---|---|---|
| | | **In Dollars ($)** | **As Percent of Net Farm Income in the Affected Region** |
| Upper Snake River[a] | | | |
| +1.13 million acre-feet (maf) annually | 26 | 28 m | 6.0 |
| +2 maf from stored water contracts in driest 25% of years | 0 to 3 | 2 m | 0.50 |
| +1.8 maf from irrigation “interruption markets” 15% of years, max. 50% reduced diversion | −1 to +1 | ±1.8 m | ±0.45 |
| John Day River above North Fork[b] | | | |
| August streamflow raised from 20 cfs to 60 cfs annually by: | | | |
| • Taking land out of production | 0 to 40 | 6,000–25,000 | 1.2–5.0 |
| • Improved irrigation technology | 14 to 27 | 8,700–16,700 | 1.7–3.3 |
| • Cropping substitution | 10 to 20 | 6,000–12,400 | 1.2–2.5 |
| Walla Walla River Basin[c] | | | |
| Combinations of restricted diversions, storage, lining, and water markets to meet June stream flow goal of 75 cfs 95% of the time | NA | 142,000–200,000 | 1.2–2.3 |
| Deschutes River Basin[d] | | | |
| +30,000 acre-feet to raise summer stream flow from 30 cfs to 250 cfs by: | | | |
| • fixed annual water lease contracts | 5–25 | 375,000 | 3.60 |
| • variable water lease contracts | 5–15 | 225,000 | 2.20 |

[a] From USDA (1996), Willis et al. (1998), and Hamilton and Whittlesey (1992).
[b] Based on Faux and Perry (1999), Oregon Water Trust data, USDA (1996), and K. Delano, Soil and Water Conservation Office, John Day, OR (personal communication, July 2000).
[c] From Willis and Whittlesey (1998).
[d] Based on Turner and Perry (1997).

appropriate or where ancillary benefits are possible (discussed later). In some locations, however, such as those with fruit orchards or other high-value crops, or for large increases in streamflows, the costs may be substantially higher.

Table 2 summarizes estimates of the cost of achieving a desired streamflow goal for four streamflow augmentation activities in different river systems in the region: the Snake River, the John Day River, the Walla Walla River, and the Deschutes River. Based on the rivers, methods, and contractual arrangements represented by these four dissimilar situations, the estimated cost of streamflow augmentation varies between $1 and $25 per acre-foot. To place these estimates in perspective, the annual total cost of each proposed action is compared to the net farm income for all irrigated acres in each of the four regions. This calculation involves the consumptive use of water per acre (typically between 1.5 to 3 acre-feet), net farm income per irrigated acre, and the average annual reduction in consumptive use of water per irrigated acre that would be required to achieve the desired streamflow goal (a fraction of an acre-foot per acre). These calculations reveal that costs range from 0.5% to 4% of net farm income among irrigated enterprises in the four regions.

The kinds of increases in streamflow and minimum streamflow targets evaluated in these four studies range from very large-scale augmentation schemes on the Snake River to a small-scale plan for ensuring August streamflows of 60 cubic feet per second (cfs). Each site appears to have been chosen for study because minimum streamflow was a problem.

To the extent that these four proposed interventions are representative of the range of settings and kinds of actions needed to restore adequate streamflow, these estimates should be indicative of the costs that might be required to achieve similar goals region-wide. Indeed, they may overstate the average level of stream augmentation needed across irrigated watersheds if they were selected for study because they represent basins with severe streamflow problems. Estimating the cost of augmenting streamflow for all the tributaries and main stems in the region is beyond the scope of the current study, so a rough estimation is offered here based on the evidence cited. We make the assumption that the average cost of streamflow augmentation region-wide will be similar to the average for these four cases (which include both large- and small-scale augmentation actions). With this assumption, we estimate the total cost for the region as a whole and for each state based on total irrigated acres and net farm income per acre ($310 in Washington, $230 in Oregon, and $190 in Idaho). Using costs as a percent of net farm income from Table 2, the estimates range from $2.2 million in Oregon (if cost is assumed to be 0.5% of net farm income) to $26 million in Idaho (when the cost is assumed to be 4% of net farm income). If these costs were born by the region's taxpayers, they would amount to only a tiny fraction of personal income, ranging from 3/1000 of a percent to 1/40 of 1% or between about $1 and $10 per person per year (see Table 3).

These figures are comparable to estimates related to large-scale modifications of the Columbia River basin. Aillery et al. (1999) estimate the costs to agriculture for salmon recovery to be between 1.0% and 2.5% of farm profits (or $14–35 million); Huppert (1999) estimates the reductions in net farm income to be somewhat higher, at $52.6 million.

## III. THE BENEFITS OF INCREASED STREAMFLOWS ON FISH

The costs of streamflow augmentation will ultimately need to be compared to expected benefits. Substantial evidence suggests that protecting and improving freshwater habitats for fish populations has a high social value. For example, several studies for Western and Southwestern states have estimated the value of increasing streamflow for fishing and other recreational uses from $16 to $86 per acre-foot, and for the economic value of improved streamflows to enhance salmon populations in northern California from $33 to $53 per acre-foot (Colby, 1989).

The benefits of increased streamflows will depend on both the value to society of increasing fish populations and its effectiveness on increasing fish populations. Despite decades of study, the quantitative relationships between fish populations and streamflow have been among the most elusive and controversial scientific debates. Large variations in fish population occur for a wide variety of reasons, making it extremely difficult to isolate and identify a cause-and-effect relationship. Attempts to identify these relationships on the main stems of the Snake and Columbia Rivers have been disappointing, although for smaller dewatered tributaries where fish populations have declined dramatically or disappeared, the benefits of maintaining minimum streamflow may be more apparent.

The effect on the populations of salmon and other fishes of augmenting streamflows will vary by species, location, and with the timing of these changes due to differences in the potential benefits for protecting eggs, juvenile, and adult fish. Augmenting streamflows at the wrong time in the wrong place could actually be harmful to salmon or have no effect.

In some cases, increased streamflow can be harmful to salmon—for example, if high water levels enable spawners to lay eggs in gravel that will be dry in later months. Ensuring adequate stream velocity for the outmigration of smolts is also considered crucial.

One key factor affecting the survival of salmon in their freshwater habitats is water temperature, which can affect salmon directly by reaching lethal levels or indirectly by reducing reproductive rates or offspring survival. Higher stream temperatures can also lead to a greater prevalence of bacteria, reduced resistance to these bacteria among fishes, and lower levels of dissolved oxygen. In general, coldwater species such as salmon confront increased stress levels, greater susceptibility to disease, and increased competition with warm water species (Beschta et al.,

**TABLE 3**
Estimated Cost of Streamflow Augmentation in the Pacific Northwest

| When Cost as a Percent of Net Farm Income is: | Oregon | Washington | Idaho | Entire Region |
|---|---|---|---|---|
| Annual cost | | | | |
| 0.50 | $2,241,050 | $2,642,789 | $3,318,810 | $8,202,648 |
| 1 | $4,482,100 | $5,285,578 | $6,637,620 | $16,405,297 |
| 2 | $8,964,199 | $10,571,155 | $13,275,239 | $32,810,594 |
| 4 | $17,928,399 | $21,142,310 | $26,550,478 | $65,621,187 |
| As % of state personal income | | | | |
| 0.50 | 0.003% | 0.002% | 0.012% | 0.003% |
| 1 | 0.005% | 0.003% | 0.024% | 0.006% |
| 2 | 0.011% | 0.006% | 0.049% | 0.012% |
| 4 | 0.021% | 0.013% | 0.098% | 0.024% |
| Dollars per person per year | | | | |
| 0.50 | $0.68 | $0.46 | $2.70 | $1.19 |
| 1 | $1.37 | $0.93 | $5.39 | $2.37 |
| 2 | $2.73 | $1.86 | $10.78 | $4.74 |
| 4 | $5.46 | $3.72 | $21.57 | $9.48 |

*Source:* Estimates of cost as percent of net farm income derived from information in Table 2.

1987). Some evidence suggests that mortality of salmon smolts from predator fish also rises significantly at higher water temperatures; low streamflows can reduce the available area for spawning or leave eggs dry that were laid when water levels were higher. In the case of the Snake and Columbia Rivers, low streamflow is believed to raise the mortality of ocean-bound juvenile salmon as they move slowly through the ponds created by a series of dams.

The relationship between low streamflows and high water temperature is generally more pronounced during summer months when air temperatures and exposure to sunlight are highest. However, the contribution of additional streamflows to improved salmon habitat can vary greatly from location to location, month to month, and year to year for a given river.

The benefits of increased streamflows may also depend on the presence of complementary conditions that also affect habitat quality and stream temperature, such as riparian vegetation (Wu et al., 2000b). Among other factors, the effect of increased streamflows on salmon survival will depend on how water temperature will be affected and whether water temperatures are currently close to the threshold levels in which survival and reproduction are seriously threatened. If water temperatures are well above these threshold levels, then lowering water temperatures by one or two degrees will have no impact on salmon survival. Similarly, if water temperatures are well below these threshold levels, additional water may also have no impact on salmon populations (Wu et al., 2000a).

It is therefore essential that the benefit side of the equation be carefully considered at the same time as the cost side. Buying low-priced water at the wrong time in the wrong place may appear to be a bargain, but if it has no positive effect on salmon it will represent a cost without a benefit. Publicly funded programs that seek to increase streamflows in an across-the-board fashion, or programs that seek to spread funds evenly across jurisdictions due to political equity considerations, may produce outcomes in which a majority of actions were futile because water temperatures were either too low or too high to have the desired effect or where conditions other than flow in a given stream were more limiting factors on salmon survival.

Aside from direct benefits to fish, there may be important ancillary benefits to augmenting streamflow. Such added benefits could lower the net social cost of protecting salmon habitat. One type of ancillary benefit may arise when improved irrigation efficiency is introduced to increase streamflow. If inefficient irrigation and large return flows are responsible for bringing chemical- and fertilizer-laden water back into the stream, improved irrigation efficiency may improve water quality even if it cannot be assumed to actually increase water quantity. If improved irrigation efficiency both lowers water diversions and reduces the contaminated return flows, then the two effects will be complementary: The increased streamflow will also dilute the (lower) levels of pollution even further.

Another potentially valuable ancillary benefit of augmenting streamflows is the generation of hydroelectric power. Combining the idea of a contingent market with that of ancillary benefits, water in the upper Snake River basin could be shifted from irrigation to streamflow to assist passage of migrating juvenile salmon during periods of droughts. The cost of diverting water away from Idaho farmers is estimated to be about $2.50/acre-foot. However, the additional power that could be produced with such a water market has been estimated to be between $5 and $6.59/acre-foot (Hamilton and Whittlesey, 1992). Changes in the price of power will affect these estimates, and the very high prices paid (temporarily) for electricity in the region in 2001 due to the California power crisis suggest that these ancillary benefits may, at times, be greater than the agricultural value of the water.

However, depending on the existing practices it is possible that augmenting streamflow to protect fish could actually reduce the value of hydropower if the timing, location, and return flows from irrigation occur when and where electricity prices and generation capacity are higher than for the stream augmentation regime. Hydropower benefits (or costs) may also be relevant to smaller irrigated basins, such as in the Klamath basin.

## IV. IMPLEMENTATION OPTIONS AND ISSUES

Augmenting streamflow would appear to be an important component of a comprehensive strategy to maintain and restore fish populations that will also need to consider such actions as riparian habitat improvements, harvest restrictions, dam breaching, and drawdown. An important question for each component is this: What is the most cost-effective implementation strategy? This question would be easier to answer in the case of streamflow augmentation if comparative or historical case studies were available on which to base an evaluation, but they are not. Two centralized approaches that are frequently mentioned as possible solutions are (1) programs that promote irrigation efficiency, and (2) facilitation of more efficient water markets. Unfortunately, neither of these interventions can be expected to improve streamflows and fish habitat. Indeed, each has the potential to produce negative effects on fish. Both of these centralized approaches are evaluated; this is followed by some evidence and observations about the kind of approach that would appear to be necessary.

### *A. Irrigation Efficiency Improvements*

Irrigation efficiency is defined as the ratio of the amount of water actually consumed by the crop to the total amount of water diverted (from surface or ground water) for irrigation. Depending on the irrigation technology being used, a farmer may need to apply twice as much water to a field as is required by the plants being grown. The quantity of water that is not consumed by the plant will flow back to the stream, percolate down into the ground, or evaporate. It is generally assumed that water that percolates into the subsoil will eventually find its way back into the stream, but this may take hours, days, or years, depending on the soils, geology, and the distance to the stream. The benefits to fish of changes in irrigation diversions vary greatly depending on what is assumed about the amount and timing of changes in these return flows.

Evaporation will vary as well, depending on temperatures and humidity, but is often assumed to account for no more than 10% or 15% of the water applied.

In the Northwest, the most common irrigation system used is surface irrigation (also called flood or furrow irrigation), which is the least efficient, with irrigation efficiencies between 32% and 57% depending on the crop. A wide range of improvements in technology and management can raise irrigation efficiency. Changes in labor use can reduce runoff losses and raise irrigation efficiency by 5%; pump-back and gated pipes can further raise irrigation efficiency to between 52% and 77%. Automatic multiset systems can do even better, achieving irrigation efficiencies from 77% to 92%. Sprinkler system irrigation efficiencies range from 60% to 75%. Conveyance efficiencies (typically canals for transporting water) of 70% to 80% are common in the Northwest; some are as low as 20% for unlined canals. Overall efficiencies including conveyance and irrigation average less than 50% and in some cases less than 20% (Butcher et al., 1988).

Although irrigation efficiency is an important factor affecting streamflows, it has sometimes been assumed that promoting improved irrigation efficiency in agriculture will result in less water being diverted from the stream and, hence, more water left for fish or other uses. Consistent with this perception, several Western states have passed legislation encouraging farmers to invest in improved on-farm irrigation technology (Huffaker and Whittlesey, 2000). The reality is more complicated, however, because improved irrigation efficiency will also reduce return flows.

Assume a farmer diverts 400 acre-feet with an irrigation efficiency of 40%. This means that his consumptive use is 160 acre-feet, and assuming 10% is irretrievably lost to evaporation or deep percolation, we can expect that 200 acre-feet end up as return flow into the river. What happens if this farmer adopts improved irrigation technology that raises irrigation efficiency to 70%, if the stream diversion is lowered from 400 to 350 acre-feet? On the face of it, this would appear to be good for salmon because it leaves an additional 50 acre-feet in the stream. With a higher irrigation efficiency, however, the consumptive use is now 245 acre-feet, and with 10% (35 acre-feet) still irretrievably lost, the return flow is only 70 acre-feet. Adding 70 acre-feet to the 50 that is no longer diverted, implies a lower streamflow of 120 instead of the 200 that occurred before the adoption of the new technology. In general it is quite possible that investment in irrigation efficiency can substantially reduce streamflows, depending on what changes the farmer may make in farming practices and depending on how other irrigators downstream may respond to changes in the availability of streamflows at different times.

It is also important to recognize that improved irrigation efficiency does not necessarily mean more economic efficiency or higher net revenues. It may be that for some crops, especially low-value crops, the cost of improved irrigation technology is high compared to the increased revenues that it will generate for the farmer (for example, if it enabled him to increase yields or switch to a higher value crop). There are two essential points to be made here. First, a technology that raises irrigation efficiency may not raise economic efficiency; it may lower profits for the farmer if the cost of the technology outweighs the gains to the farmer. Second, neither promoting irrigation efficiency nor promoting economic efficiency will necessarily improve the streamflow situation for fish, especially in settings where surface water is already overappropriated via existing senior and junior rights holders.

Although an increase in irrigation efficiency cannot be assumed to increase streamflows, streamflow could be increased in this way if the reduction in water diversion is greater than the reduction in return flow resulting from the increased irrigation efficiency. Arrangements could certainly be made with a particular irrigator to ensure that streamflow increases, in which case we want to evaluate the cost of increasing streamflows in this manner. The costs of improved irrigation efficiency will be primarily the capital costs of the new irrigation technology and associated maintenance costs. The benefits to the farmer may include labor savings, energy savings, and the elimination of costs associated with previous irrigation technology (e.g., earth-moving equipment used in flood irrigation). Bear in mind that for this to be attractive to the farmer, the benefits must outweigh the costs. In this case, however, the potential reduction in the amount of water diverted for consumptive use will not represent a benefit to the farmer because he or she does not generally pay a fee per unit of water used, and thus will not generally benefit directly from leaving the water instream.

To estimate the cost of increasing streamflows by improving irrigation efficiency, we need to know the net irrigation requirements for the crops grown (a crop's consumptive use minus the water naturally supplied by rainfall). For crops in the Northwest these range widely. For example, in central Washington the range is estimated to be 15–29 acre-inches per acre. Taking a value of 24 acre-inches per acre, we can calculate that for surface irrigation with an irrigation efficiency of 50%, 4 acre-feet of applied water are required to achieve the 2 acre-feet requirement. Adoption of sprinkler irrigation (with an irrigation efficiency of 75%) could lower the necessary applied water by 1.33 acre-feet. The annualized cost of the investment for sprinklers ranges from $300 to $600 per acre in Oregon.[1] For a 6% interest rate, this translates into annualized costs of $18–26 per year, or $9–$13 per acre-foot per year. Other factors may affect these costs, such as accompanying changes in energy use, labor, and so on; estimates will differ for other kinds of irrigation investments. For example, an economic analysis of alternative irrigation systems in Kittitas Valley, Washington (Hoffman and Willett, 1999), compares grated pipe irrigation with wheel-line, center pivot, and linear move techniques. Comparing the costs of these technologies with the improved irrigation efficiencies, the cost per acre-foot of "saved" water ranges from $40 for center pivot to $61 for linear move. As a means of increasing streamflows, therefore, these estimates suggest that promoting improved irrigation efficiency will be less attractive than alternatives discussed above.

Once again, however, one cannot assume that farmers will divert less water when irrigation efficiency improves; they may change the crops they grow or other practices so that the amount of water applied stays the same but the consumptive use increases. Indeed, low irrigation efficiency may be good for fish because return flow is wasted water for the farmer, but it mostly represents water that ends up back in the stream either on the surface or through aquifers delayed by hours, months, or perhaps years depending on the soils and geology. If return flows occur over a period of months, much of the water returns to the stream in seasons when achieving minimum streamflow is not critical. In this situation, reducing irrigation diversions when streamflows are critical to salmon survival and reproduction will have a larger positive impact because the concurrent reduction in return flows will be slight, making the net effect on streamflow larger. Even though the total annual streamflows may be unaffected in this case, the seasonal distribution of flows will be improved by increasing flows in months that benefit salmon most, while reducing flows during other, noncritical months.

### *B. Promoting Water Markets*

With regard to water markets, simply eliminating the impediments in the current system of irrigation water rights so that water right holders may freely buy and sell water in markets is unlikely to directly benefit salmon. These changes would promote economic efficiency and a reallocation of water such that water that is currently in low-value uses could be sold to farmers with potential higher value uses. Although this would improve economic efficiency of water use, it would not necessarily result in more water left in stream. Indeed, in the absence of other changes in the rules governing water allocation, freer water markets could be expected to broaden the range of valuable uses of water in agriculture, thereby leaving less water in streams.

### *C. Needing a Broker*

To achieve the desired increases in streamflows in a cost-effective way, an approach is needed that takes account of (1) the benefits to salmon and other fishes of increases in streamflows across different times, locations, and for a range of scenarios for fluctuations in year-to-year conditions; (2) the presence or absence of confounding or complementary ancillary factors, which may raise or lower the expected benefits from a specific streamflow increase; and (3) differences in the marginal cost of reduced irrigation diversions for different rivers, times of the year, and under a variety of lease, purchase, and contingent contracts. If offers to lease, purchase, or contract for water are proposed to farmers, we can generally assume that farmers will only accept such offers when the value of water to them is less than the price offered. From the other side of the transaction, however, no similarly self-interested agent exists who will lease water from farmers only when its streamflow value exceeds the price demanded.

In essence, the fish need a broker. They need an agent to search for the best deals, to find those transactions with the highest benefit per dollar spent. Such a broker will need to identify which rivers will benefit most

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[1] K. Delano, Soil and Water Conservation Office, John Day, OR personal communication.

from streamflow increases and how much additional water is optimal (in which months, years, and reaches). In addition, the cost to agriculture of augmenting flows for each location and time must be compared to the benefits so that scarce resources can be allocated to streams, months, and years where the fish-benefit per dollar spent is highest. Success will involve assembling detailed scientific and economic information and finding creative arrangements, agreements, and contracts that take advantage of settings where currently low-value water uses coincide with high potential benefits to salmon and other fishes.

Achievement of satisfactory results at low cost will necessarily require innovative individuals and organizations to act on behalf of salmon. A hands-off or across-the-board approach will necessarily produce higher costs and lower benefits than a hands-on approach, which will look for best buys on behalf of salmon. Some experience with these kinds of efforts has been developed in the past few years by organizations such as the Oregon Water Trust and the U.S. Bureau of Reclamation.

A decade of experience by the U.S. Bureau of Reclamation has been evaluated by Simon (1998) to assess the efficiency and transaction costs for alternative mechanisms for acquisition of water, including bilateral bargaining, standing offers or posted prices, and auctions. He finds that competitive acquisition procedures are unlikely to be successful unless many conditions are met, procedures that will not evolve by themselves, but that need an institutional structure established by the public sector. In some locations where significant acquisitions are required, Simon proposes auction-type experiments or flexible posted prices as possibilities. For settings in which acquisitions and offer prices will vary locally and seasonally, bilateral negotiations, with their higher transaction costs, are likely to be necessary. However, with the possibility of long-term contingent contracts with triggers based on predicted flows or reservoir levels, transaction costs may be significantly reduced.

The Oregon Water Trust has an impressive record as the first nonprofit organization to initiate purchases of irrigation water rights for in-stream uses in the region. Indeed, the bulk of existing evidence on market transactions for in-stream water purchases, listed in Table 1, comes from the Oregon Water Trust. Its lead is now being followed by the Washington Water Trust and the Washington State Department of Ecology.

## V. CONCLUDING COMMENTS

Based on data from market transactions for water, and for farmland with water rights, as well as numerous economics studies, the costs of increasing streamflows by reducing irrigation diversions are estimated to range between \$9 and \$25 per acre-foot of water. In the context of a broadly based regional program to restore and maintain healthy fish populations, these values translate into annual total costs of between 0.5% and 4.0% of the net farm income for all irrigated farms in the region, or between \$1 and \$10 per person. If some of these costs were paid with federal funds, the costs to residents of the region would be lower.

A central question affecting both the costs and the effectiveness of any program to increase streamflow is how such changes would be implemented. In this regard there is misunderstanding regarding the effects that either improved irrigation technology or active water markets would have. In the case of irrigation technology, innovations at the farm level may be an important part of a program to increase streamflows, but adoption of advanced irrigation technologies will not achieve the desired result by itself. In fact, raising irrigation efficiency could actually lead to a reduction in streamflows. In the case of water markets, a more efficient allocation of water for on-farm uses could be expected to increase (rather than decrease) diversions, reduce return flows, and raise the cost of programs that buy water for streamflow augmentation purposes.

A threat to the potential success of government programs aimed at achieving these goals comes from competing interests and political pressures. Pressures to spread funds evenly across congressional districts or to allocate funds based on criteria other than maximizing the benefit to fish would severely diminish the effectiveness of the program. Evidence of how such pressures to spread funds to achieve political equity can be wasteful are found in other federal programs aimed at improving riparian habitats (see Wu et al., 2000b). This evidence highlights the caution that inappropriate approaches to increase streamflows may prove highly costly or ineffective. Thus, policy makers must guard against approaches such as across-the-board water rights cutbacks or purchases, or subsidies for adoption of improved irrigation efficiency: if those actions are not carefully chosen and implemented they may not result in increased streamflows in the locations and times where they will benefit salmon most.

Nevertheless, government policies and initiatives will be needed for any comprehensive program. Several observations can be made about specific directions these might take, which could contribute to their success. First, there is a clear need for additional biological information and data analysis to determine just how much water is needed in which streams, during which months, and in which years. One such program involves compiling information on the health and potential for improvements at the subbasin level by the Oregon Water Resources Department. State and local water authorities need to monitor water diversions and changes in consumptive use if streamflow protections are put in place. The allocation or reallocation of water and water rights needs to focus on actual consumptive use, rather than on statutory rights or diversions, to avoid changes that may appear to be increasing streamflows when in fact they do not (Huffaker and Whittlesey, 2000).

Second, though it should be noted that facilitating water markets will not directly address streamflow problems, the exchange of water among farmers could be beneficial in several ways. Markets would promote the efficient distribution of water and raise the average (and total) value of water use in agriculture, which would in turn be beneficial to farm incomes. Thus, in the face of long-term or across-the-board reductions in irrigation water rights, improvements in the allocative efficiency of water would help maintain average profits among irrigated farms. Additionally, a well-developed market for irrigation water might help create the institutional mechanisms and information needed to facilitate water contracts for instream use.

Third, to lower the costs of increasing streamflows, the ease with which ancillary benefits, such as hydropower generation, could be taken advantage of needs enhancement. Accomplishment of this will likely require legislation to remove hindrances from water transfers, especially between Idaho irrigators and in-stream uses.

Finally, it should be recognized that irrigators are among those in the region who want to protect salmon and other fish in-stream. This is evidenced by a significant number of voluntary water rights contributions that have been made to the Oregon Water Trust. Giving recognition to farm enterprises that made voluntary contributions or that have participated in other stream enhancement projects will likely encourage participation in these efforts.

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