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Salmon Recovery in the Columbia River Basin: Analysis of Measures Affecting Agriculture

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Abstract *The effects of salmon recovery measures on the Northwest agricultural sector are evaluated. Relevant recovery measures, such as: modified timing for dam releases, reservoir drawdown, and flow augmentation in the Columbia River basin, on the regional agricultural sector are evaluated. Combined, these measures would increase power rates, grain transportation costs, and irrigation water costs and reduce the supply of water to irrigators. We quantify these input cost and quantity changes and combine them into seven recovery scenarios for analysis. Results suggest that drawdown and/or minor reductions in irrigation water diversions would reduce producers' profits by less than 1% of baseline levels. However, the most extreme scenario—a long drawdown period combined with a large reduction in irrigation diversions—would reduce producers' profits by $35 million (2.5%) annually. That effect is magnified at the local level; of the $35 million decline in annual profits, more than $27 million occur in southern Idaho and eastern Oregon. The federal government would bear these costs if it acquires water via voluntary transactions.*

Key words Barge transportation cost, Columbia-Snake River, electricity rate, Endangered Species Act, field-crop production, flow augmentation, irrigation diversions, recovery measures, salmon.

Introduction

Conflicts have emerged over the impact of historic patterns of water use on riverine systems throughout the world. These conflicts are particularly acute in the western United States, where a century of river development for hydroelectric production,

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agricultural and urban water supplies, and flood control has eroded the ecological integrity of many of these systems. The decline in native fisheries, manifested by the listing of sixty-eight western fish species as threatened or endangered under the federal Endangered Species Act, reflects the degree of ecological stress on western waterways (Moore, Mulville, and Weinberg 1996). Anadromous fish, by virtue of their complex life cycles and the long distances traveled along inland waterways, are particularly vulnerable to the cumulative impacts of watershed development. As a consequence of the broad geographic scope of salmon habitat, efforts to protect these species increasingly conflict with existing land and water uses within the watersheds. This tension is clearly evident in the Pacific Northwest's Columbia-Snake River basin (figure 1).

The Columbia-Snake River basin has been widely acclaimed as one of the world's most productive salmon fisheries. Indeed, salmon is a critical resource for the Pacific Northwest, both as an important river and marine fishery, and as an enduring symbol of the rich natural heritage of the region. However, the natural system has been vastly altered by decades of land and water development, and regional rivers are now tightly regulated to meet hydropower, navigation, flood control, and agricultural and municipal water demands. This multi-faceted development has completely blocked hundreds of miles of upstream salmon habitat, seriously degraded the remaining inland habitat, and created a virtual gauntlet of slack-water reservoirs, dams, and power turbines through which migrating smolts must navigate on their journey to the sea. As a consequence, salmon and steelhead populations are declin-

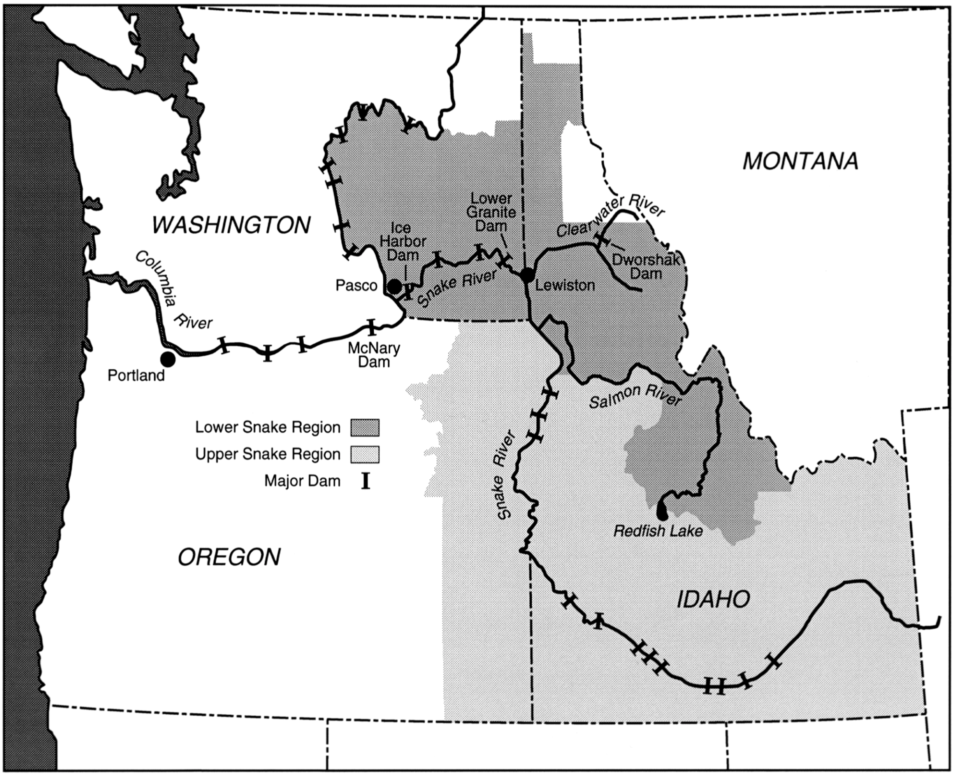

Figure 1. Columbia-Snake River Basin
Source: United States Department of Agriculture, Economic Research Service.

ing across the region, with a number of runs already extinct and others in serious decline. A major restoration effort is now underway to protect salmon runs at risk of extinction and to rebuild a sustainable native salmon fishery. Central to the recovery effort is the need to recreate, to the extent practicable, essential functions of the predevelopment, free-flowing Columbia-Snake river system.

Agriculture is among the major competing sectors relying on water, power, and transportation services from the Columbia-Snake River system. In particular, irrigated crop production is extensively developed in the Pacific Northwest: Idaho, Oregon, and Washington contain more than 6.5 million acres of irrigated land, or 13% of U.S. irrigated area (U.S. Department of Commerce 1994). Agricultural production has contributed to the declining health of freshwater and marine ecosystems through loss and degradation of habitat due to land conversion, as well as through the sector's heavy reliance on water supplies and regulated flows in the Columbia-Snake River system. Measures to restore regional salmon runs could significantly affect the agricultural sector, reducing production and revenues and impacting rural communities dependent on agriculture-related activities. The challenge for policy makers is to achieve ecosystem restoration goals for salmon recovery while minimizing costs to agriculture and other sectors of the regional economy.

This paper presents an analysis of changes in profit from agricultural production under alternative salmon recovery measures. Policy scenarios focus on alternative strategies to increase flow velocities in the Columbia-Snake system, thereby reducing smolt mortality in downstream migrations. Flow velocities can be increased by increasing the volume of water moving downstream (termed flow augmentation) or by reducing the amount of water stored in reservoirs, thereby reducing the size of slow-moving reservoir pools (reservoir drawdown). These measures, which may well yield the greatest benefits to salmon populations, also will likely impose the greatest costs on agriculture.

The next section describes the policy setting for salmon recovery and highlights previous economic analysis of alternative salmon recovery measures. We then provide an overview of agriculture in the Pacific Northwest and the manner in which alternative river management regimes might be reflected in the agricultural sector. The fourth section describes our estimates of the parameter adjustments, in terms of input prices and availability, that would accompany alternative configurations of recovery measures; develops the recovery scenarios analyzed; and describes the empirical model applied in the research. The fifth section presents the results from the empirical analysis of seven recovery scenarios. Results describe the effect of alternative river management regimes on field-crop production, profit, and resource use in agriculture. Underlying uncertainty regarding the volume of water necessary to meet flow-augmentation objectives motivates sensitivity analysis with respect to related assumptions. A section including the results of the sensitivity analysis follows the results from the scenario analysis. A final section draws conclusions of the research.

Policy Setting and Previous Research

Populations of salmon and steelhead in the Columbia and Snake Rivers have fallen to roughly 20% of their peak level of 10–16 million spawning adults per year (Blumm and Simrin 1991). Wild and naturally spawning salmon are at 2% of historic levels. Habitat degradation due to hydropower development, irrigation diversions, and land-use activities has had a major impact on the fishery. Since the 1930s, thirty-six major dams have been built in the Columbia River basin. Hydroelectric dams on the Columbia and Snake Rivers are the foundation of the Pacific Northwest power generating system, providing over 60% of the region's firm power supply.

The dams and their reservoirs, as well as upstream river diversions, have substantially altered the volume and timing of river flows. In turn, the flow alterations have significantly increased travel time for juvenile fish migrating to the ocean, a primary factor in reduced survival rates (National Research Council 1996, p. 243). Since 1991, three Snake River salmon stocks and four Columbia and Snake River steelhead populations have been listed as threatened or endangered under the federal Endangered Species Act (ESA).[1] Another forty-seven salmonid stocks may be at high to moderate risk of extinction in the Columbia River basin (Nehlsen, Williams, and Lichatowich 1991).

Regional efforts to rebuild the salmon fishery began in the early 1980s. The Pacific Northwest Electric Power Planning and Conservation Act (1980) mandated a proactive program for restoring the Columbia River basin salmon fishery. The Act created the Northwest Power Planning Council (Council) to develop and administer a program that balances fish and wildlife with traditional uses of the Columbia River and related land resources (including power production, flood control, agriculture, navigation, water supply, recreation, land development, and fishing).[2] The Council's Columbia River Basin Fish and Wildlife Program includes a general goal of doubling salmon and steelhead runs without loss of biological diversity (Northwest Power Planning Council 1994, sec. 4, p. 1).

The Endangered Species Act (ESA) (1973) defines a reactive approach of recovering species "balanced on the brink of extinction." Formal ESA listings for the Columbia-Snake River salmon and steelhead populations triggered formation of a recovery program for these stocks by the National Marine Fisheries Service (NMFS), the agency responsible for implementing the ESA for anadromous fish species. Recovery measures are being developed in the species' formal recovery plan (U.S. Department of Commerce 1995b) and through interagency consultation on activities of federal agencies operating in the Columbia River basin (U.S. Department of Commerce 1995a and 1998). Although a final recovery plan for the listed salmon species has not yet been released, the agency has issued a biological opinion that governs operation of the Columbia River system for the 1994–98 period (U.S. Department of Commerce 1995a). A supplemental biological opinion, developed to incorporate the needs of the newly listed steelhead populations, as well as to revisit measures in place to protect the Snake River salmon, continues, in full, the components of the 1995 NMFS opinion (U.S. Department of Commerce 1998). Many salmon recovery measures identified under the ESA overlap with those in the Council's 1994 Fish and Wildlife Program.

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[1] The term "stock" describes "the fish that spawn in a particular river system (or portion of it) at a particular season and that do not interbreed to any substantial degree with any group spawning in a different place, or in the same place at a different season" (Nehlsen, Williams, and Lichatowich 1991, p. 7). The term "evolutionarily significant units" (ESUs) is used by the National Marine Fisheries Service (NMFS) to designate "species" status for individual stocks under the Endangered Species Act. The NMFS formally listed the Snake River sockeye salmon as endangered on December 20, 1991, and the Snake River spring-/summer-run chinook salmon and fall-run chinook salmon as threatened on May 22, 1992. (The two chinook salmon runs were converted from threatened to endangered under an emergency interim rule issued August 18, 1994, but on January 12, 1998, NMFS withdrew the proposal to reclassify the species as endangered, so they are currently listed as threatened.) In addition, four ESUs of Columbia River Basin steelhead were either listed or proposed for listing in the past two years: on August 18, 1997, NMFS listed the Snake River ESU as threatened and the Upper-Columbia River ESU as endangered; on February 26, 1998, NMFS proposed listing the Middle-Columbia ESU as a threatened species; and on March 19, 1998, the Lower-Columbia River ESU was listed as threatened.

[2] The Council is an interstate, regional governing body, with members appointed by the governors of Idaho, Montana, Oregon, and Washington. The Northwest states, Native American tribes, and four federal agencies with various responsibilities for Columbia River management—the Corps of Engineers, Bonneville Power Administration, Bureau of Reclamation, and Federal Energy Regulatory Commission—share responsibility for implementing the Council's fish and wildlife program.

Policy Recommendations for River Flow Management

We limit our attention to recovery measures likely to affect the agricultural sector; namely, those intended to reduce travel time of juvenile salmon (smolts) migrating to the Pacific Ocean. Other types of recovery measures—such as those designed to address the impacts of fish harvesting (including commercial, recreational, and subsistence harvests) and hatchery operations—are unlikely to affect agricultural crop production and, consequently, are beyond the scope of this research.[3]

The NMFS and the Council largely agree in their approaches to improving in-river salmon migration, although the final specification of these recovery measures has not yet been determined. In 1992, the Council established a benchmark quantity—0.427 million-acre feet (maf) (one acre-foot equals 1.234 x $10^3 m^3$)—of flow augmentation per year from the upper Snake River basin and requested that an additional 1 maf or more be acquired by 1996 (Northwest Power Planning Council 1992). Responsibility for acquiring the initial quantity was assigned equally to Bonneville Power Administration (BPA) and the Bureau of Reclamation (Reclamation), while responsibility for the additional water went unassigned.[4] The Council maintained these quantities in its 1994 program, while specifying that BPA and Reclamation would share the cost of acquiring the additional water, but extended the deadline for its acquisition to 1998. The Council recommended acquisition of water through voluntary transfers, other nonstructural measures, or structural measures (*e.g.*, possible construction of three new storage projects in the upper Snake River basin).

The NMFS followed the Council's general approach to flow augmentation, although with three significant modifications (U.S. Department of Commerce 1995a). First, NMFS assigned responsibility for acquiring water solely to Reclamation, thus appearing to relieve BPA of financial and operational responsibility for the task. Second, the NMFS proposal retained the Council's recommendation for the minimum quantity of water to be obtained (0.427 maf), but abandoned the explicit quantity goal for the amount of supplemental water needed, opting instead to require Reclamation to acquire additional water "if necessary to contribute to survival and recovery of listed stocks" (U.S. Department of Commerce 1995a, p. 100). Third, NMFS specified that, in acquiring water, Reclamation should rely exclusively on voluntary transactions with willing sellers. Reclamation formally agreed to these terms in the ESA interagency consultation between NMFS and Reclamation (U.S. Department of the Interior 1995).

Simultaneously, NMFS established a set of minimum-flow objectives for the Snake River at Lower Granite Dam, and for the Columbia River at McNary Dam.[5]

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[3] Three points qualify the statements on scope of study. First, our study focuses on input availability and cost increases for field-crop production. While salmon habitat improvements may affect livestock grazing on public lands, analysis of this issue is available elsewhere (Haynes, Bolon, and Hormaechea 1992) and, thus, are not analyzed here. Second, unscreened and improperly screened water diversions cause juvenile salmon mortality, and are to be corrected as part of the ESA recovery plan (U.S. Department of Commerce 1995b, p. V-2-69). While screening diversions may impose costs on agriculture, it probably will not affect crop production. An estimate of the costs and regional economic impacts of improved diversion screens is available in Aillery, *et al.* (1996). Third, the analysis does not address potential water-quality impacts attributable to nutrient and pesticide discharge from agricultural fields. While agriculture has been recognized as a source of the loadings (Greene, Ebbert, and Munn 1994), salmon recovery measures have centered largely on adjustments in water-flow regimes.

[4] BPA is the entity that markets electricity produced from the fourteen federal dams on the Columbia and Snake Rivers, while Reclamation is the primary wholesaler of irrigation water in the region.

[5] The 1998 steelhead listings also prompted NMFS to suggest a flow objective for the Columbia River above its confluence with the Snake River (at Priest Rapids). While no additional flow augmentation is expected to be required to meet this additional requirement, NMFS did renew its call for additional study of the viability of providing an additional one maf from the upper Snake River basin generally, and from reduced irrigation diversions in particular (U.S. Department of Commerce 1998).

The flow objectives vary by season and water-year conditions. The Snake River flow objectives range from 85,000 to 100,000 cubic feet per second (U.S. Department of Commerce 1995b, ch. 5, sec. 2, pp. 22–23). Hamilton and Whittlesey (1996) estimate that, on average, using NMFS data, the flow velocity targets will require flow augmentation of 1.08 to 3.15 maf per year. The higher number reflects a scenario in which the flow objectives must be met on a monthly-average basis. An intermediate scenario, which allows for some flexibility by meeting objectives on a seasonal-average basis, would require acquiring 1.95 maf. The lower estimate of 1.08 maf arises from a scenario that attempts to meet the objectives on a seasonal-average basis but imposes a cap of 2 maf on the quantity of water acquired in any given year.

Despite uncertainty over the final numerical goal for flow augmentation levels, Reclamation has been purchasing water in the upper Snake River basin since 1993 (Simon 1998). More than 57,500 acre-feet in permanent water rights and an average of 267,000 acre-feet in annual leases from the Idaho Water Bank have been procured through voluntary transactions (Simon 1998).[6] Combined, these purchases total roughly 75% of the interim goal for flow augmentation of 0.427 maf.

A similar pattern of Council and NMFS activity holds in developing a plan for drawdown of the four lower Snake River reservoirs. In 1992, the Council specified reservoir drawdown as an important element of improving in-river salmon migration (Northwest Power Planning Council 1992), and requested that drawdown at the four sites be implemented by April 1995. The Council's 1994 program refined the approach by making full implementation conditional on an experimentation stage. The NMFS also promotes the approach of experimenting with reservoir drawdown prior to long-term adoption (U.S. Department of Commerce 1995b). Data from experimental drawdowns at Lower Granite Dam will be evaluated before making a final decision. If the biological evidence supports the recovery measure, drawdown of the four lower Snake River reservoirs will be implemented beginning in the year 2000 (U.S. Department of Commerce 1995a, pp. 116–18).[7] A major regional effort involving federal, state, tribal, and local interests—the Drawdown Regional Economic Workgroup (DREW)—has formed to assess the range of impacts associated with management alternatives for the lower Snake-River dams (U.S. Army Corps of Engineers 1997). However, their recommendations will not be released until at least this year.

Previous Economic Studies

Two broad studies and numerous narrower ones evaluate alternatives for implementing the ESA. One study, by Huppert and Fluharty (1996), prepared in compliance with an ESA requirement that costs be estimated for formally designated recovery measures, provides cost estimates for recovery measures proposed by NMFS. Cost estimates for flow augmentation measures are based on Hamilton and Whittlesey (1996). That study examines costs associated with meeting flow-velocity objectives under various assumptions about the baseline hydrologic data set and the period

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[6] Reclamation paid an average price of $95 per acre-foot to acquire 57,518 acre-feet of permanent water rights (Simon 1998, p. 3). Annual lease prices for temporary water use rights are determined administratively by managers of the Idaho water bank. They were set at $5.90 per acre-foot in 1993; $8.45 per acre-foot in 1994 and 1995; and $10.50 per acre-foot in 1996 (Simon 1998, p. 4).

[7] Drawdown of two Columbia River reservoirs (John Day and McNary) have also been discussed, but Congressional authorization (and appropriations) are necessary before formal evaluations can be conducted.

over which the standard must be met. Consequently, it provides valuable information about the implications of fluctuations in natural water supplies. However, Hamilton and Whittlesey (1996) assume that water is made available only by fallowing land, including both permanent land retirement and intermittent disruptions facilitated by interruptible water transfer contracts in which farmers agree to forgo agricultural production in dry years. In contrast, although our analysis is for average water-year conditions, we consider the potential for water conservation due to substitution among irrigated crops, as well as such extensive margin adjustments as shifts from irrigated to dryland production.

A second major study was prepared in support of the Columbia River System Operation Review (SOR)—a regional planning effort that was initiated in 1990 by federal agencies responsible for Columbia River operations, including BPA, Reclamation, and the Corps of Engineers. An SOR Environmental Impact Statement (EIS) analyzes river-management strategies from several perspectives, including economic effects (Columbia River SOR Interagency Team 1995a, b, and c). Reservoir drawdown below the minimum level necessary to maintain normal operations at the dams is incorporated into two of the thirteen alternatives analyzed in the SOR, but was not an element of the SOR-agencies' preferred alternative. However, the preferred alternative does call for continued study of the feasibility of reservoir drawdown below minimum operating pool levels. Flow augmentation from reduced agricultural water diversions in the upper Snake River basin is not examined in the SOR study.

An independent study by Paulsen and Wernstedt (1995) conducts a cost-effectiveness analysis of actions to maintain seventy-nine salmon and steelhead stocks in the Columbia River basin. Their study focuses on the role of hatcheries and barge transport of smolts, among other measures, for preserving salmon. Numerous other studies focus on narrower questions, such as barge transportation costs (*e.g.*, Hamilton, Martin, and Casavant 1992), reduced access to grazing in national forests to protect spawning habitat (*e.g.*, Haynes, Bolon, and Hormaechea 1992), and changes in benefits to the recreation industry associated with reservoir drawdown (*e.g.*, Cameron, *et al.* 1996), among others. However, none of these studies address the package of measures affecting river flow or their overall effect on the agricultural sector. This is the question to which we now turn.

Agriculture in the Pacific Northwest

The total value of agricultural production in the Pacific Northwest (Washington, Oregon, and Idaho) was an estimated $9.1 billion in 1992, including $5.4 billion for crop sales and $3.7 billion for sales of livestock, poultry, and related products (table 1).[8] Cropland in the Pacific Northwest totaled 19.3 million acres that year, including 11.8 million harvested acres. Wheat and other grains are produced primarily for export, with the majority of production shipped by barge or rail to port facilities in Portland, Oregon. Alfalfa and other hay crops are produced to meet local livestock demands. Higher-valued specialty crops, such as potatoes, sugar beets, fruits, and other vegetables, are a significant source of revenue for area farmers, despite comparatively small acreages. Regional production of potatoes accounted for almost one-half of U.S. potato production, with regional shares of national production also significant for barley, sugar beets, and wheat.

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[8] Data in this section are from the *1992 Census of Agriculture* (U.S. Department of Commerce 1994), unless otherwise noted.

Table 1
Characteristics of Agriculture in the Pacific Northwest, 1992

	Regional Totals	Share of National Totals
Acreage:	*1,000 Acres*	*Percent*
Land in farms	46,804	5.0
Total cropland	19,339	4.4
Harvested cropland	11,784	4.0
Pastureland	27,542	5.4
Irrigated land	6,523	13.2
Value:	*$ Million*	
Agricultural production	9,079	5.6
Crops sold	5,396	7.2
Livestock sold	3,683	4.2
Production:		
Grain crops	*Million Bushels*	
Wheat	262	11.9
Barley	77	19.4
Corn	24	0.3
Other crops	*Million Tons*	
Hay	8.34	6.6
Irish potatoes	10.18	49.6
Sugar beets	5.36	18.4
Livestock	*1,000 Head*	
Beef cows	1,506	4.6
Milk cows	524	5.5
Sheep and lambs	804	7.5
Hogs and pigs	181	0.3

Source: 1992 Census of Agriculture (U.S. Department of Commerce 1994).

Large supplies of relatively inexpensive surface water are available through extensive development of the Columbia-Snake River system. Irrigation was practiced on 6.5 million acres in 1992, representing 55% of regional harvested cropland. Idaho ranks fourth among U.S. states in irrigated agricultural land, while Oregon ranks ninth and Washington tenth. Virtually all production of potatoes, sugar beets, dry beans, and corn is irrigated.

Agriculture accounted for over 95% of total water consumption in the Northwest in 1990.[9] Water consumption in irrigated agriculture was estimated at 13.1 maf in 1990, including 6.8 maf in Idaho, 3.4 maf in Oregon, and 2.9 maf in Washington (Solley, Pierce, and Perlman 1993). Surface water diversions accounted for 75% of agricultural water supplies, with the balance supplied by ground water. In the upper Snake River basin of southern Idaho and eastern Oregon (figure 1)—the region tar-

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[9] Hydropower production utilizes large volumes of water in the Columbia River system, yet does not "consume" water according to U.S. Geological Survey definitions (see Solley, Pierce, and Perlman 1993).

geted for reduced irrigation diversions to meet instream flow objectives—Reclamation provides roughly 60% of the surface water used for irrigation in southern Idaho, supplying over 1.35 million acres of cropland, and approximately one-third of the surface water used for irrigation in eastern Oregon, serving over 170,000 irrigated acres.

Improving in-river salmon migration through flow augmentation in the upper Snake River and drawdown at four dams on the lower Snake River in southeastern Washington would have the greatest effect on agriculture of the proposed recovery measures. Flow augmentation would directly reduce the water supply of irrigators operating in the upper Snake River basin. Reservoir drawdown would impose three input-cost increases on the agricultural sector: power rate increases for irrigators, primarily in Washington and Oregon, due to restricted hydroelectric production; grain transportation cost increases due to disruption of barge operations along the lower Snake River; and irrigation water cost increases due to higher pump-lifts for irrigators pumping directly from the affected reservoir pools. A third measure, already in place, modifies the timing of releases to favor fish populations, rather than maximizing the value of that water for electricity production, and thus may also increase power rates. The potential effect of these measures on agricultural profit and production are important pieces of economic information for salmon recovery planning and ESA implementation.

Framework for Assessing the Effects of Salmon Recovery Efforts on Northwest Agriculture

The primary question motivating this research involves the effect of federal efforts to restore endangered Snake River salmon on the Pacific Northwest's agricultural sector. To address this question, we first estimate potential adjustments in agricultural input costs and irrigation-water availability associated with recovery measures under consideration. Next, we identify an economic model to simulate farmers' responses under each policy scenario. We then define seven "recovery scenarios" involving various combinations and degrees of the different salmon recovery measures.

Parameter Adjustments for Salmon Recovery Measures

Increased river-flow velocity to improve in-river migration conditions for juvenile salmon may be achieved through reshaping the water budget (altering the timing of streamflows by revising operations of dams in the Columbia and Snake River basin), flow augmentation from the upper Snake River basin, drawdown of the lower Snake River reservoirs, or various combinations of the three methods.

Core management measures. A core set of river management measures are already set for implementation, including water budget modifications, structural adjustments to dams, and flow augmentation from the Dworshak Reservoir on the Clearwater River in Idaho. These measures will reduce both the quantity of power produced and its value. The quantity of power produced falls because less water will flow through power generating turbines due to intentional spill (bypass of turbines), and because lower reservoir depths imply lower hydraulic heads and, thus, less energy produced. The decline in value occurs because timing reservoir releases to coincide with salmon migrations shifts power production from high-demand winter months to seasons in which electricity is less valuable per unit. We estimate that BPA customers will face a 4% increase in wholesale power rates as a consequence of these measures.[10] No other agricultural input costs are expected to change under the core measures.

BPA power rate increases would have varying impacts on retail rates charged to irrigators across the Northwest. The largest impacts would occur in regions of Washington and Oregon, where many utilities set retail rates based on BPA's rate structure. In contrast, most irrigators in Idaho are largely insulated from BPA's rate policy because Idaho Power Company provides their electricity. Similarly, much of the Columbia Basin Project in Washington is supplied by utilities whose retail prices are not directly affected by BPA rate adjustments. Under a 4% increase in BPA wholesale rates, for example, average retail rate increases would range from a low of 0.5% in Idaho, to 1.6% in Washington, and 1.9% in Oregon.[11]

Flow augmentation. As described previously, Reclamation agreed to the NMFS directive to acquire 0.427 maf of flow augmentation. An additional 1 maf—for a total of 1.427 maf—has commonly been discussed as a targeted quantity. Of these quantities, approximately 0.3 maf are available from uncontracted storage space in southern Idaho and the Idaho Water Bank (Huppert, Fluharty, and Kenney 1992, p. 3–50). Subtracting the 0.3 maf in available water from the target quantities leaves a range of 0.127 to 1.127 maf of flow augmentation to be secured in the upper Snake River basin. These two levels—0.127 maf and 1.127 maf—serve as the principal flow targets examined in the study.

We assume that additional water for flow augmentation would be acquired through reductions in irrigation diversions. An underlying physical relationship, discussed below, translates irrigation diversion reductions into flow augmentation. In general, a given level of flow augmentation requires a higher level of diversion reduction because some portion of those diversions returns to the river through surface runoff and underground return flow. In our analysis, augmenting Snake River flows by 0.127 maf and 1.127 maf requires irrigation diversion reductions of 0.239 maf and 2.125 maf, respectively.[12] The two levels of reductions represent estimated declines of 2% and 20% in on-farm water applications for field-crop production in the upper Snake River basin. This specification implies that all water for flow augmentation is made available by reducing water consumption (and associated nonrecoverable losses). The reductions are apportioned between southern Idaho and eastern Or-

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[10] These rate changes are based on the assumption that reduced BPA power revenues would be passed on to consumers in the form of higher rates. However, the past few years have seen rapid change in the electricity industry as it adjusts to deregulation and falling natural gas prices, and it now appears that BPA may lose market share if it passes the increased costs on to rate payers. Consequently, BPA rates may not change in response to salmon recovery measures; the costs would be absorbed by BPA (Columbia River SOR Interagency Team 1995c). In that case, our estimates could overstate the direct cost to farmers, but would provide a proxy for the cost to the power sector generally, and are useful for comparison with other studies. This is the same approach used in the SOR EIS.

[11] Wholesale power rate increases were adjusted under a two-step process to estimate effective retail rate increases by sub-state area. First, wholesale-retail conversion rates were calculated based on wholesale rates paid by utilities and average retail rates charged to irrigators, weighted by irrigation power use across utilities within the BPA service area. Second, retail rate increases were adjusted to reflect the share of regional irrigation power use affected by BPA rate increases. Power cost adjustments were further modified to reflect the effect of reservoir drawdown on pumping costs for out-of-pool irrigators. See Aillery, *et al.*, 1996, Appendix A, for more detail.

[12] These values are based on an assumption that 100% of water not consumptively used or lost to off-farm evaporation returns to the river as return flow. The implications of relaxing that assumption are addressed in the section on the relationship between diversion reductions and flow augmentation.

egon—irrigators in Washington will not be affected by this policy—and by type of water supply (Reclamation and private).[13]

Reservoir drawdown. Cost increases from drawing down the four lower Snake River reservoirs separate into "low" and "high" levels based on drawdown durations of two months (April 16 to June 15) and 4.5 months (April 16 to August 31), respectively. The 2-month drawdown would assist the listed sockeye and steelhead populations, which migrate in spring, while the 4.5-month drawdown would assist both the spring and summer migrants.

Segments of the Northwest agricultural sector would face higher BPA power rates and grain transportation costs under drawdown. We estimate that a 2-month reservoir drawdown would increase wholesale rates by 4%, in addition to the 4% power rate increase associated with the core salmon recovery measures. The total rate increase predicted for scenarios involving the low-impact drawdown and core management measures is thus 8%. Power rate increases associated with a 4.5-month drawdown are estimated to increase by another 4% to 12%. Wholesale rate increases are translated into retail rate increases of 0.5% to 5.6%, depending on the state and scenario, and are in a similar range as SOR estimates of average regional BPA retail rate increases of –1.0% to 4.0% (Columbia River SOR Interagency Team 1995a, ch. 4, pp. 180–81). In addition, drawdown would increase the pump-lift, and thus the water costs, for those irrigators pumping out of Ice Harbor Reservoir.

Reservoir drawdown would also interrupt barge operations along the navigable portion of the Snake River (from Lewiston, Idaho, to the river's confluence with the Columbia River near Pasco, Washington). Grain typically conveyed during these months would need to be shipped earlier, later, or by alternative transportation mode. Producers in eastern Washington and northern Idaho rely heavily on Snake River barges to transport export-bound grain, and thus would stand to be the most affected by reservoir drawdown.

Seasonal disruptions in barge transportation are difficult to incorporate in a model of annual production. Consequently, we model transportation cost increases as an increase in average cost per unit of grain output. That is, estimated seasonal transportation cost increases are weighted by the percentage of grain shipped at higher cost during drawdown months to obtain an average annual increase in grain transportation costs.[14] Under the 2-month drawdown, the average (low-level) transportation cost increases for annual grain shipments (expressed in cents per bushel) are estimated to be 2.30 for wheat and 0.16 for barley for northern Idaho, and 0.04

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[13] Irrigation diversion reductions are apportioned across the upper Snake River basin using a four-step procedure. First, we assume that 50% of augmented flow comes from Reclamation water supplies. This reflects the Council's original recommendation that Reclamation be responsible for 50% of flow augmentation. Second, Reclamation diversion reductions are apportioned across the southern Idaho study area (90%) and the eastern Oregon study area (10%) based on their proportionate shares of baseline Reclamation diversions. Third, reductions in private diversions are set equal to Reclamation diversion reductions, by state. Fourth, reductions in private diversions are distributed proportionately based on on-farm and off-farm sources, by state. Because Reclamation-served irrigators use less total water than privately served irrigators, they must reduce water use proportionally more than privately served irrigators to meet their 50% requirement. For example, to meet the 1.127 maf target, Reclamation-served irrigators reduce on-farm water use by almost 27%, compared to 15% for privately-served irrigators.

[14] Transportation costs arise from a shift from barges to trucks or rail as an alternative means for transporting grain during a drawdown. Estimated costs reflect assumptions about the least-cost option for alternative transport modes. A third option, capacity adjustments for grain elevators, is not included in the cost calculations. For the 2-month drawdown period, we assume that railcars transport 100% of the grain formerly moved by barge through the lower Snake River. For the 4.5-month drawdown, we assume that railcars transport 50% and trucks transport 50% of the grain formerly barged. See Aillery, *et al.*, 1996, Appendix B, for more detail on cost change derivations.

for wheat and 0.32 for barley in eastern Washington. Under the 4.5 month drawdown, the (high-level) cost increases are 6.08 for wheat and 1.43 for barley in northern Idaho and 0.92 for wheat and 1.17 for barley in eastern Washington.

Economic Model of the Agricultural Sector

The model used for the empirical analysis is a multi-output economic model of Northwest field-crop production (Schaible 1997). Subregional heterogeneity in agronomic conditions and resource costs and availability is captured, to a degree, by using “modeling subareas” (MSAs) as the unit of analysis. State and hydrologic boundaries, defined on the basis of county-line approximations of major watershed divisions, are used to identify nine MSAs for the study area: three in Idaho, four in Oregon, and two in Washington. Land and water resources are identified by MSA for as many as nine field crops, with irrigated and dryland production activities separated by crop. Irrigated land and water resources within an MSA are further disaggregated by water source; *i.e,* by whether water is supplied by the Bureau of Reclamation or by private water sources. Privately supplied water is further separated into surface and ground water sources.

The model assumes that agricultural producers maximize profit for the farm when allocating their land and water resources, taking output and variable input prices as given.[15] The model evaluates the economics of farm-level resource decisions using a multistage, programming-based, system estimation procedure that adopts the duality concepts of multi-output production theory (*e.g.*, Lau 1976; Chambers and Just 1989; Squires 1987) and the behavioral cost-adjustment concepts of disequilibrium theory (*e.g.*, Hanoch and Rothschild 1978; Morrison 1985; Varian 1984). Both theoretical concepts are required to allow the model to endogenously specify crop-specific cost functions that incorporate opportunity costs associated with observed allocations of land and water resources.

Five assumptions of agricultural production guide the representation of multi-output farm production in this model: (1) inputs are allocated to specific crop production activities; (2) production is technically nonjoint so that input allocations uniquely determine crop-specific output levels; (3) farm-level land and water resources are fixed, allocatable inputs; (4) producers allocate land and water endowments to maximize producer returns while explicitly accounting for opportunity costs of fixed, allocatable inputs; and (5) farm-level substitution possibilities exist. That is, the producer may substitute land and water resources to reduce acreage of water-intensive crops, substitute ground water for surface water, substitute dryland production for irrigated production, and reduce irrigated crop output. The model is calibrated to average water-year conditions; model data reflect observed resource use for a mid-1980s environment, so the western drought conditions of the latter 1980s and the early 1990s did not affect the estimated cost-function coefficients.

The complete model, specified as a quadratic optimization problem, is solved using a three-stage process. Stage one specifies MSA-level field-crop production using a crop-specific, restricted profit-function approach. Stage two involves estimating a “restricted-equilibrium” version of the model by incorporating shadow values on land resources by MSA (acquired from stage one) within crop-specific cost functions. Stage three provides a test of model reliability. That is, it applies Takayama and Judge’s (1971) Reducibility Theorem to evaluate the estimated cost-function pa-

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[15] In this context, profit represents farmers’ revenues from crop production less actual variable- and fixed-input costs and estimated opportunity costs associated with resource allocations.

rameters by examining how well the linearized version of the stage-two model mirrors observed subregional land and water resource allocations. Scenario and sensitivity runs involve changes in cost and resource supply parameters.

Data for model parameters are acquired from several secondary sources. Cost and return data for the Pacific Northwest are defined for ninety-three irrigated and thirty-four dryland field-crop production activities. Yields for irrigated crops are based on linearly homogeneous (output per unit land), quadratic water-yield functions. In addition to applied water, the yield functions incorporate qualitative variables for farm-level water management and irrigation technology options, and variables to capture physical and structural characteristics, such as weather, climate, farm structure, and soil quality. A composite intercept term combines all nonirrigation water application information. Modeled dryland production levels were consistent with observed dryland yields for each subregion.

Crop-specific production costs for most crop technologies are obtained primarily from the Irrigation Production Data System (IPDS). This system provides cost data for all crops, except dry beans, potatoes, and sugar beets. Production cost data for non-IPDS crops are obtained primarily from state farm-level budget reports. Commodity prices are calculated as exogenous expected market prices, using a geometric-lag analysis of state-level season average prices for the period 1968–83, and adjusted by a weighted-average farm program payment. Season-average crop prices are acquired from USDA's National Agricultural Statistics Service. Weighted-average deficiency payments are included to more accurately reflect farm-level returns to land and water, and relative profitability across crops. Deficiency payment adjustments are calculated using farm program data from USDA's Farm Services Agency. See Schaible (1997) for a formal development of the conceptual model, and Schaible, *et al.* (1995) for more information on the parameterization.

As with any simulation model of a region of this size, a number of assumptions in model specification generalize farm-level heterogeneity and variability in annual or local economic conditions. The level of aggregation used is assumed sufficient to capture broad regional adjustments in producer profit and resource use due to changes in the input supply and cost parameters considered. However, it precludes examination of impacts across various subsets of irrigators—for example, by farm size, technology class, and pump lift. Moreover, the modeling subunit likely masks smaller-scale variations in geoclimatic conditions within MSAs, possibly resulting in an overestimate of the actual substitution to dryland production that could occur. However, the model structure moderates any potential to over (or under) state such cropland adjustments by incorporating opportunity costs associated with land allocation decisions that are based, in part, on geoclimatic conditions and rotational considerations. Other potential model limitations include exogenous output and input prices and fixed irrigation coefficients. Relaxing these assumptions is not likely to cause qualitative changes in our results. Nevertheless, possible under- or overestimates of costs due to model assumptions are discussed in the results section, where appropriate.

Study Scenarios

Although flow augmentation and reservoir drawdown have generated considerable attention in the policy process, significant uncertainty underlies whether and to what extent the two measures will be implemented. To address this uncertainty, we construct a set of seven scenarios that reflect the options for implementing the two measures, in concert or in isolation, for a range of levels (table 2). The core management measures, with their estimated 4% increase in wholesale power rates, are included in

Table 2

Salmon Recovery Scenarios: Input Cost Increases and Resource Use Restrictions

		Recovery Measure Effects		
Scenario	Recovery Measure	Wholesale Power Rate Increase (Pacific Northwest)[1] (percent)	Reduced Irrigation Diversions (Upper Snake River Basin)[2] (million acre-feet)	Grain Transportation Cost Increase (Lower Snake River Basin)[3] (¢/bushel)
1	Core management measures[4]	4%	0	0
2	Flow augmentation (low flow)	4%	0.127	0
3	Flow augmentation (high flow)	8%	1.127	0
4	Reservoir drawdown (2 month)	8%	0	0.04 – 2.30
5	Reservoir drawdown (4.5 month)	12%	0	0.92 – 6.08
6	Flow augmentation (low flow) and Reservoir drawdown (2 month)	8%	0.127	0.04 – 2.30
7	Flow augmentation (high flow) and Reservoir drawdown (4.5 month)	12%	1.127	0.92 – 6.08

[1] Wholesale power rate increases translate into retail power rate increases that vary geographically, depending on the extent to which an area is affected by BPA pricing policies and differing wholesale-retail conversion rates.

[2] An estimated 0.239 and 2.125 million acre-feet of irrigation diversion reductions are needed to achieve the 0.127 and 1.127 million acre-feet flow augmentation objectives, respectively.

[3] Grain transportation costs vary by area and by type of grain (wheat or barley). For example, the lower value in the range is for wheat in eastern Washington, while the upper end of the range is for wheat in northern Idaho. Cost increases for barley in the two regions fall between those levels.

[4] The core measures underlying Scenario 1 reflect a set of Columbia and Snake River management measures already set for implementation. The 4% wholesale power rate increase caused by these measures is incorporated into all scenarios.

every scenario. The scenarios span the range of probable combinations and specifications of the various measures under consideration or targeted for future analysis. They do not, however, guarantee equivalent environmental benefits and consequently do not create a framework for cost-efficiency analysis. Rather, the scenarios are designed to provide estimates of the potential agricultural-sector impacts of alternative policy combinations.

Scenario 1 is limited to the 4% increase in BPA wholesale power rates associated with the core management measures. Scenarios 2 and 3 add impacts of irrigation diversion reductions in the upper Snake River basin. Scenario 2 includes the 4% power rate increase plus 0.127 maf of flow augmentation from irrigation reductions. Scenario 3 increases the power rate change to 8% and includes a high-level for flow augmentation (1.127 maf).

Scenarios 4 and 5 focus on the impacts of reservoir drawdown. Scenario 4 incorporates the 8% power rate increase (for the core management measures and a 2-month drawdown) and the grain transportation cost increases estimated for the 2-

month reservoir drawdown option. Scenario 5 represents the core management measures and the 4.5-month reservoir drawdown by including the upper estimates for increases in wholesale power rates (12%) and grain transportation costs.

The final category of scenarios reflects effects of both reservoir drawdown and flow augmentation, in addition to the core management measures. Scenario 6 corresponds to an 8% power rate increase and low-level adjustments for both irrigation diversion reductions and grain transportation costs. Scenario 7 represents a "high-cost" scenario, with high-level adjustments for all three sets of parameters.

Results

Modeling results include changes in producer profit and allocations of land and water resources among crop-specific production activities under the seven recovery scenarios. Values of those variables for nine MSAs in the Pacific Northwest are aggregated to the regional level for reporting purposes. However, aggregate results mask substantial variation at sub-regional levels. Results presented for individual states and for the upper Snake River basin provide context for considering regional heterogeneity where local impacts may be significant.[16]

Producer Profits

Profits (producer surplus) from field-crop production serve as the primary basis for comparison across the salmon recovery scenarios. Baseline profits in the model total $1.278 billion for the Northwest ($527 million for Idaho, $237 million for Oregon, and $514 million for Washington). Estimated changes in profits relative to the baseline level provide a measure of the impact of salmon recovery measures.[17]

The two reservoir drawdown alternatives (Scenarios 4 and 5) are estimated to have relatively minor effects on the Northwest agricultural sector for the range of adjustments evaluated. Scenarios involving drawdown reduce profits by less than 1% of baseline levels (figure 2). The estimates range from $3.8 million for a 2-month drawdown to $8.9 million for a 4.5-month drawdown. Thus, the results suggest that increases in power rates and grain transportation costs estimated for reservoir drawdown would not significantly affect the region's agricultural economy.[18]

A minor irrigation diversion reduction (Scenario 2) would also have a relatively small effect on profits at the regional level. Scenario 2 would reduce profits by less than $4 million per year, or less than 0.5% of baseline profits. Further, combining cost increases associated with reservoir drawdown and irrigation diversion reductions (Scenario 6) would not markedly change these results.

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[16] Results reported here focus on direct producer impacts. Changes in production activities will have implications for agricultural input and processing industries. See Aillery, *et al.*, 1996, for estimates of the regional impacts associated with those changes.

[17] Comparisons with the baseline indicate the effects of regional efforts to protect ESA-listed salmon. However, NMFS considers both the core measures and 0.427 maf of flow augmentation among current conditions from which the effects of their recovery plan are to be assessed. Comparisons of results for Scenarios 3–7 with those for Scenario 2 thus provide estimates of the effects specific to this narrower definition of NMFS' proposed recovery plan.

[18] The model does not capture potential adjustments in energy demand associated with increased retail power prices. To the extent that such adjustments would occur, costs of salmon recovery measures could be lower than those estimated here. However, evidence suggests that electricity demand in the Pacific Northwest is generally inelastic over marginal price adjustments. Moreover, power costs represent a small portion of farmers' total costs, so response to price adjustments in the range we consider can be expected to be highly muted.

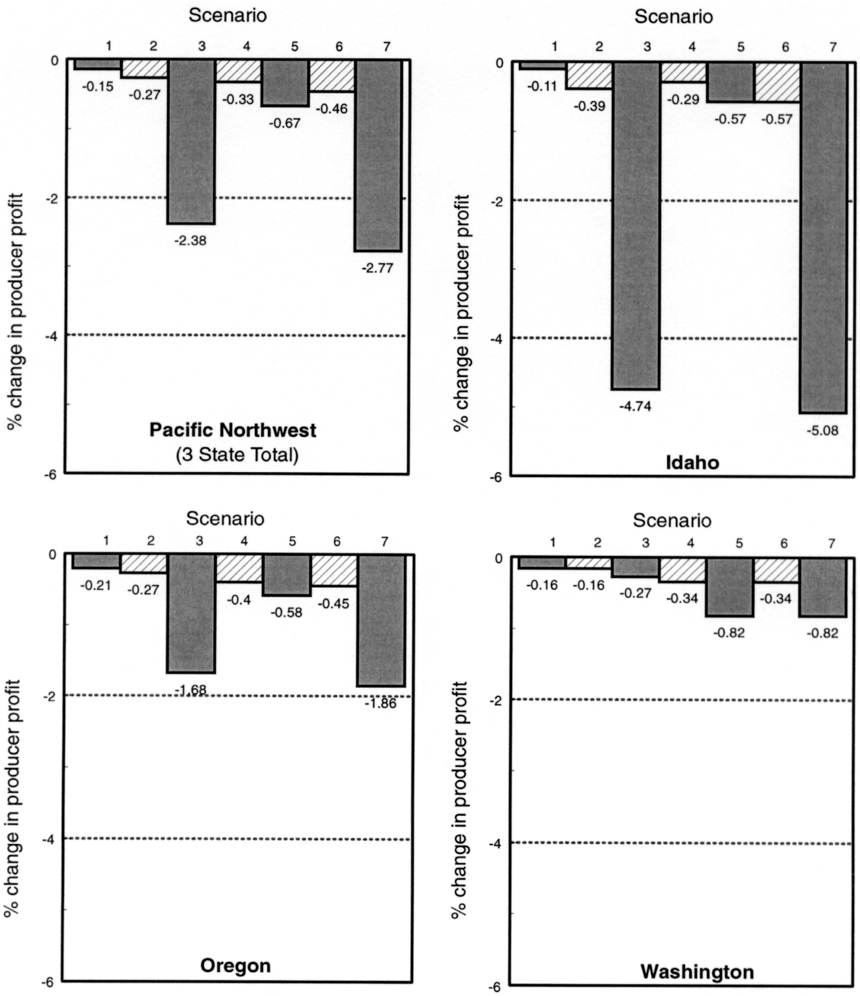

Figure 2. Percentage Change in Producer Profit, by Salmon Recovery Scenario

Note: Baseline producer profit is $1,278 million for the Pacific Northwest and $527, $237, and $514 million for Idaho, Oregon, and Washington, respectively.

In contrast, a major (uncompensated) irrigation diversion reduction could have a substantial effect on the Northwest agricultural economy. Scenario 3 would reduce profits by almost 2.5%, or more than $30 million per year. Combining irrigation reductions with reservoir drawdown (Scenario 7) increases the impact only slightly; profits decline by roughly 2.8%, or more than $35 million per year.[19] These impacts

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[19] Exogenously specified prices likely are appropriate for many of the scenarios and crops considered, given limited adjustments and relatively small national shares for some crops. However, the prices of several specialty crops (*e.g.*, potatoes and malt barley) may respond to adjustments in production predicted for Scenarios 3 and 7. Production levels for some of these crops are predicted to increase while those for others fall, potentially resulting in offsetting price shifts. Consequently, it is possible that the estimates provided here, over- or, underestimate the cost of responding to recovery measures, or that the potential revenue effects of price increases and decreases would offset each other.

would be concentrated primarily in south-central Idaho and eastern Oregon, where irrigators rely heavily on water from the Snake River system. Profits in the upper Snake river sub-region decline by roughly $28 million, or almost 6%, in scenarios 3 and 7. Thus, that region bears 80% to 90% of the total impact. Likewise, state-level effects would be greatest for Idaho (5% decrease in profits), with lesser effects for Oregon (2% decrease in profits) and Washington (1% decrease in profits) (figure 2). Although large reductions in irrigation diversions may have a significant impact on the farm-sector, the relative reduction in water use exceeds the relative reduction in profits by a fair amount—a 20% decrease in irrigation water use in the upper Snake River subbasin causes a 6% decrease in profits—because decreases in irrigated acreage are concentrated in crops with relatively low profitability, and increases in dryland crop production partially substitute for decreased irrigated production.

As previously noted, irrigation water diversion reductions for flow augmentation likely will be acquired through voluntary transactions as a matter of public policy. The economic-efficiency implications of reduced irrigation-water supplies remain the same, in principle, regardless of whether the water is acquired voluntarily or through cost-effective regulation; that is, producer response would be invariant to whether compensation is paid. However, compensated transfers shift the cost burden from farmers to the federal government.

Crop Production Adjustments

In the model, producers respond to changes in input cost and availability by reallocating land in two ways: changing the mix of irrigated field-crops and adjusting the extensive margin between irrigated and dryland production. Results suggest that alterations in the pattern of cropland use and field-crop output in the Pacific Northwest as a whole would be relatively small for the increases in power rates and grain transportation costs considered. Scenario 1, as well as scenarios based on reservoir drawdown (Scenarios 4 and 5), essentially do not alter cropland use and crop output.

On the other hand, scenarios with irrigation diversion reductions show more substantial adjustments. With flow augmentation of 0.127 maf (Scenarios 2 and 6), output in the three-state region is predicted to decrease for alfalfa (4%), sugar beets (4%), and corn (1%), while output is predicted to increase for other small grains (2%). The cutback in water availability drives a share of irrigated acreage from crops with high water requirements, such as alfalfa and sugar beets, into irrigated crops needing less water, such as barley and oats, or into dryland production of alfalfa, barley, and oats. More than 50,000 irrigated acres (1% of baseline irrigated acres) are converted to dryland production under these two scenarios.

Flow augmentation of 1.127 maf magnifies the pattern of results above. Irrigation water use declines by 20% in Scenarios 3 and 7, causing output to decrease substantially for alfalfa (33%), sugar beets (30%), and corn (5%). Output of other small grains increases by more than 15%, with increases in both irrigated and dryland production of these crops. Wheat production also increases slightly, as some irrigated acreage is converted to dryland wheat production. Northwest production of potatoes, a major irrigated crop in Idaho, declines by less than 1% with the high level of flow augmentation.

Adjustments in cropland use underlie the significant changes in output. If irrigation diversions are reduced by 1.127 maf (Scenarios 3 and 7), an estimated 500,000 acres—nearly 16% of irrigated land in the upper Snake River basin, or 10% overall—are converted to dryland production. The largest absolute declines in irrigated acreage occur for alfalfa (573,000 acres) and sugar beets (43,000 acres). An expansion of irrigated barley and oats (180,000 acres) partially offsets the decline in irrigation of other crops. Most conversion from irrigated to dryland production occurs in alfalfa (218,000 acres), other small grains (138,000 acres), and wheat (119,000 acres). Increased dryland alfalfa acreage offsets a significant share of the decline in irrigated alfalfa acreage. Nevertheless, total alfalfa output declines by 33%, due, in part, to significant differences in yields between irrigated and dryland production.[20] For example, in the model, irrigated alfalfa in southern Idaho yields 4 tons per acre compared to 1.4 tons for dryland alfalfa.

Sensitivity Analysis on Flow Augmentation

Our results suggest that augmenting river flows with irrigation diversion reductions is the one salmon recovery measure capable of significant disruption to the agricultural sector. Specific requirements to reduce diversions are also one of the less certain aspects of recovery plans. Accordingly, we conducted sensitivity analysis with respect to variations in both the level of flow augmentation required and in the hydrologic relationship between irrigation diversions and flow augmentation.

Flow Augmentation Levels

The Council's original flow augmentation targets of 0.127 maf and 1.127 maf provided benchmarks for our scenario-based analysis (discussed above). In this section, we analyze the sensitivity of profits to a range of flow augmentation levels. Nine flow augmentation targets were evaluated, ranging from 0 to 1.6 maf, in increments of 0.4 maf (figure 3).[21] Results suggest that foregone profits—the opportunity cost of supplying water for flow augmentation—increase at an increasing rate as higher levels of irrigation diversion reductions are imposed. For example, flow augmentation of 0.8 maf reduces profits by roughly $17 million. A doubling to 1.6 maf reduces profits by almost $48 million, or roughly three times the prior reduction. The relationship between foregone profits and flow augmentation translates into a supply curve for river flow by calculating the "arc marginal costs" associated with incremental increases in diversion reductions.[22] These arc marginal costs rise from roughly $13 per acre-foot for the first increment of water (0 to 0.4 maf) to about $43 per acre-foot for increasing flow augmentation from 1.2 maf to 1.6 maf. The arc-marginal cost of acquiring 1.127 maf is approximately $33 per acre-foot.

Relationship Between Diversion Reductions and Flow Augmentation

Converting quantities of irrigation diversion reductions into flow augmentation requires that values be assigned to several parameters of the hydrologic and irrigation

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[20] Adjustments in local feed prices and cattle production would likely occur with the sizable reductions of alfalfa production predicted, but ramifications of that possibility are beyond the scope of this analysis.

[21] Results for Scenario 1 serve as the benchmark for this sensitivity analysis. We also conducted sensitivity analysis with flow augmentation levels using two alternative assumptions for levels of power rates and transportation costs based on parameters applied in Scenarios 4 and 7. Profits in the other sensitivity analyses deviated only slightly from those graphed in figure 3.

[22] Arc marginal cost is computed as an arc measure using the set of point estimates of foregone profits for increasing flow augmentation.

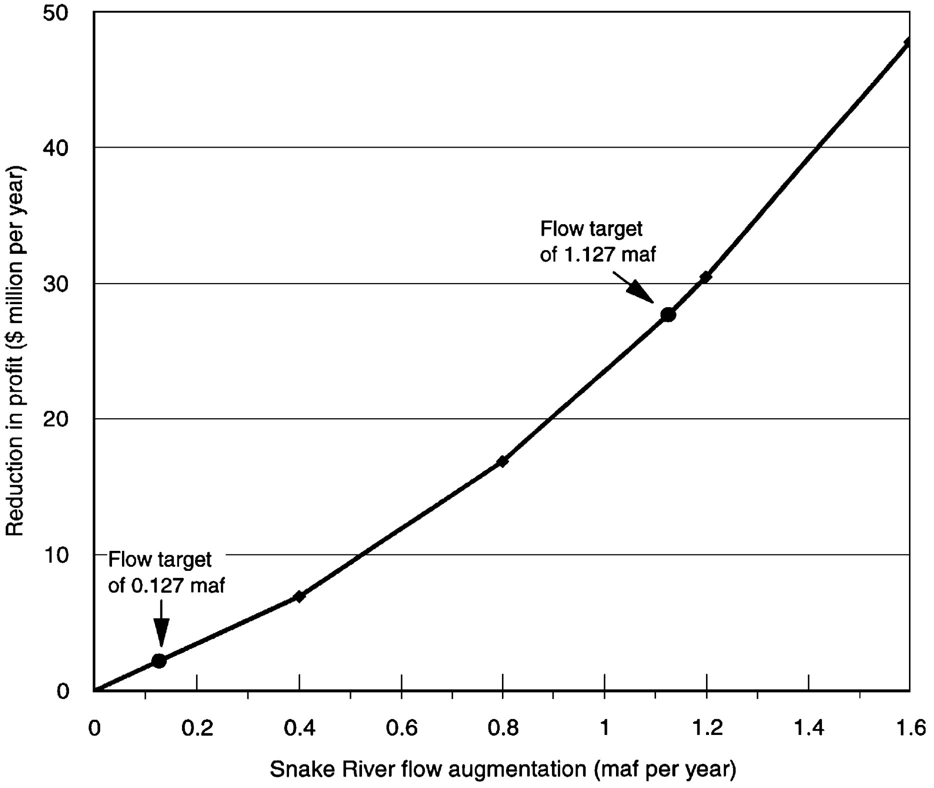

Figure 3. Reduction in Profits in the Upper Snake River Basin Due to Irrigation Diversion Reductions for Flow Augmentation

systems. Irrigation systems consist of water diversion from a river, conveyance to a set of farms, and on-farm distribution and application. Physical quantities of water are accounted for by summing crop consumptive use, evaporation, surface runoff, and deep percolation into aquifers. The latter three quantities can occur at any stage of the system (diversion, conveyance, distribution, and/or application). In this study, values are assigned for off-farm conveyance efficiency, on-farm efficiency, share of loss to evaporation and surface runoff, and return-flow to the river that vary by MSA and water source, while deep percolation is calculated as a residual of those factors. The values for off-farm conveyance efficiency are from Schaible, *et al.* (1995), while remaining values are from Frasier, Whittlesey, and Hamilton (1992). On-farm application efficiency is assumed to be 60%.

In the upper Snake River basin, ground water reserves are physically linked to Snake River flows. Thus, a share of deep percolation losses from conveyance, field application, and drainage eventually re-enter the river channel via ground-water return flow. The return-flow rate through the aquifer to the Snake River is important in computing flow augmentation, yet is not known with certainty (Frasier, Whittlesey, and Hamilton 1992). For the analysis reported above, irrigation diversion reductions consistent with the flow augmentation requirements are calculated based on the assumption that 100% of deep percolation into the aquifer reaches the river each year. This assumption implies that the aquifer is in long-run equilibrium after adjusting to reduced irrigation diversions. In fact, aquifers tend to adjust

Table 3
Effect of Alternative Irrigation Efficiency Assumptions on Estimated Flow Augmentation in the Upper Snake River Basin

Irrigation Efficiency	Base Diversion Reduction to Meet 1.127 maf of Flow Augmentation	Flow Augmentation Given Base Diversion Reduction Under Alternative Return-flow Rates: Return Flow = 100%	Return Flow = 50%	Return Flow = 0%
	(million acre-feet)			
40%	2.812	1.127	1.751	2.375
60%	2.125	1.127	1.583	2.039
80%	1.716	1.127	1.418	1.711

slowly, with stabilization at a long-run equilibrium requiring 50 years or longer (Frasier, Whittlesey, and Hamilton 1992).

The sensitivity of flow augmentation to alternative assumptions about the aquifer return flow rate is presented in figure 4. Consider the upper Snake River flow augmentation target of 1.127 maf per year (while holding other parameter values constant). A reduction in irrigation diversions of 2.125 maf per year is required to achieve the 1.127 maf in flow augmentation, assuming 100% of deep percolation losses re-enter the river as aquifer return flow. In this case, flow augmentation is attributable solely to reductions in crop consumptive use and evaporative losses. Under alternative rates of aquifer return flow, flow augmentation increases for a given diversion reduction. For example, the same diversion reduction of 2.125 maf would yield 1.583 maf in flow augmentation if only 50% of deep percolation reappeared as aquifer return flow, and 2.039 maf in flow augmentation with no aquifer return flow. Therefore, a diversion reduction of 2.125 maf is sufficient to meet the 1.127 maf flow augmentation target under all return-flow assumptions, and deviations from the base assumption of 100% return flow serve to increase Snake River flow above targeted levels.

An alternative perspective is that return flow rates below 100% of deep percolation losses require diversion reductions of less than 2.125 maf, and reduced agricultural sector adjustments, to achieve the 1.127 maf flow augmentation target. For example, with a 50% return flow rate, diversion reductions of only 1.510 maf would be required to achieve the 1.127 maf target. In that case, the cost of attaining the flow augmentation goal would be $17 million, significantly less than the $28 million estimate presented above (for Scenarios 3 and 7). In this sense, the cost estimates presented in the previous section represent an upper-bound for costs of flow augmentation measures.

Examination of alternative aquifer return-flow rates on diversion requirements for achieving a flow-augmentation target illustrates the importance of assumptions about the hydrologic system. Adjustments in parameter values for irrigation and conveyance-system efficiencies can also affect the level of reduction in diversions necessary to meet flow augmentation goals. Table 3 demonstrates the relationship between on-farm irrigation efficiency and flow augmentation under alternative return-flow assumptions.[23] The middle row reproduces the values displayed in figure 4. The first and third rows indicate the sensitivity of those results to our irrigation

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[23] The effect of efficiency improvements also depends on changes in consumptive use, *i.e.*, on whether conserved water is used on the field to achieve higher yields or expand acreage, is diverted by junior water rights holders, or remains in stream. We assume here that it remains in stream.

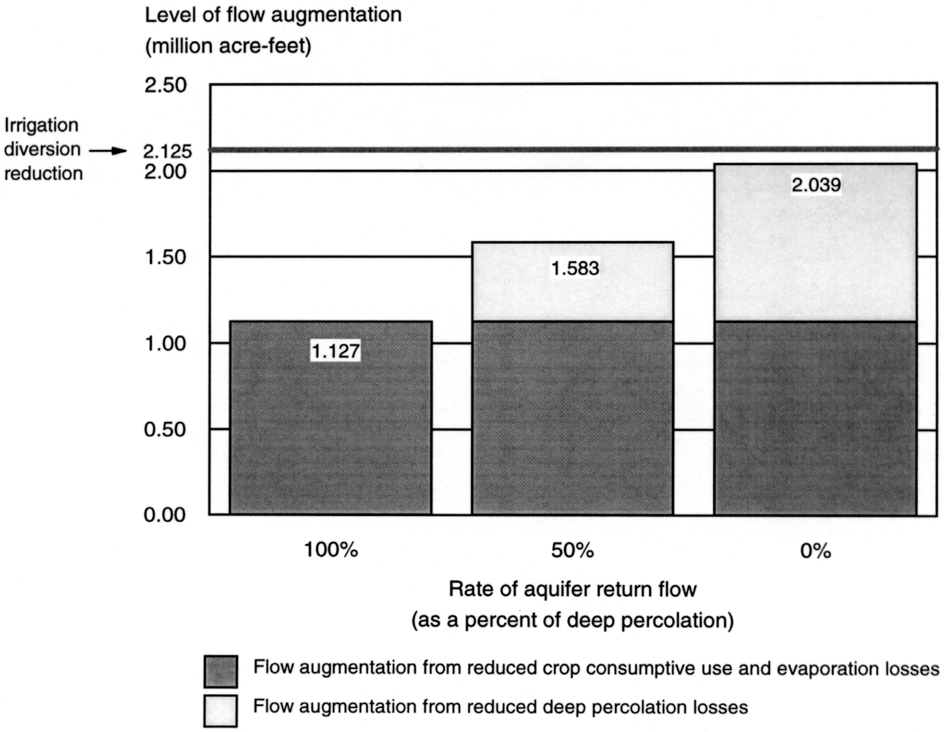

Figure 4. Effect of Alternative Aquifer Return Flow Rates on Flow Augmentation in the Upper Snake River Basin for an Irrigation Diversion Reduction of 2.125 Million Acre-feet

efficiency assumption. The reduction in diversion necessary to meet the 1.127 flow augmentation target would be only 1.716 maf, for an irrigation efficiency of 80%, assuming 100% return-flow. This value contrasts with the 2.125 maf required for a 60% irrigation efficiency used in our analysis.

Similarly, if irrigation efficiency was in fact 40%, rather than 60%, the 2.125 maf reduction in diversions would not provide the desired level of flow augmentation. Instead, diversions must be reduced by 2.812 maf to increase Snake River flows by 1.127 maf (again assuming 100% return-flow). Consequently, our cost estimates for each flow augmentation objective would be too high (low) to the extent that we have under (over) estimated actual irrigation efficiencies. Further, flow augmentation per unit of diversion reduction increases with on-farm irrigation efficiencies. Hence, a lack of symmetry exists in the deviation from our estimates that would be associated with an increase or decrease in irrigation efficiency of 20%; our cost estimates would be off by more if irrigation efficiency was lower than 60% than if it was higher than 60% by an equal amount. However, the influence of irrigation efficiency on flow augmentation declines as return flow declines.

Improvements in on-farm irrigation efficiency have been identified as a potential means of securing instream flows for salmon recovery. While investments in water-conserving technologies may help reduce farmers' costs of meeting diversion reduction targets, those improvements would be less effective as a means of increasing in-stream flows for salmon in the long-run. Actual water savings will depend on both the volume and timing of return flows from irrigation losses and changes in consumptive use, both on-farm and downstream.

Economic Benefits of Salmon Recovery

Estimates of benefits associated with salmon recovery provide context for the cost estimates described above. This section briefly describes the types of benefits that might be expected and introduces previously published estimates of those benefits. Note, however, that the cost and benefit estimates presented here are not comprehensive, nor are they directly comparable. Our focus on the costs to the agricultural sector precludes a complete accounting of all costs potentially associated with the recovery measures. We do not, for example, estimate the cost to municipal and industrial electric-power users or the costs to recreators negatively affected by reservoir drawdown (see Cameron *et al.* 1996 for a discussion of the latter effect). Moreover, economic benefits from salmon recovery measures will be derived from increased probability of survival for listed species, and, to the extent that recovery measures also increase population numbers for salmon and steelhead not currently listed but sharing habitat. However, scientific uncertainties prevent us from linking the study scenarios to those biological metrics. This further inhibits direct comparison of the costs and benefits.

Potential benefits from salmon recovery efforts include benefits to commercial, recreational, and tribal fishers, as well as those not dependent on consumption-based activities, including, for example, viewing opportunities for the hundreds of thousands of visitors to fish ladders at Columbia and Snake River dams, and existence, option, and bequest values associated with preventing species' extinctions.[24] The central role of salmon in the identity of the Pacific Northwest generally, and for Native American cultural activities in particular, suggests that these nonmarket benefits may be substantial. The total benefit will comprise the sum of all such benefits accruing from salmon recovery. Unfortunately, little empirical evidence exists on the aggregate benefit for Columbia River salmon and steelhead. However, various studies have examined individual components or related benefits.

Increased values to commercial fisheries will accrue only to the extent that efforts to recover the listed species incidentally increases populations for those stocks that are commercially fished. Linking increased survival rates for migrating smolts to the number of returning adults is difficult, but estimates suggest that the recovery measures considered could increase Columbia River commercial and Native American salmon and steelhead harvests by 1% to 8% after several years. Associated increases in net revenues are estimated to be $31,000 to $246,000 per year (Aillery, *et al.* 1996, p. 36).

Three studies use the contingent valuation method (CVM), albeit with three different survey types, to estimate nonmarket benefits for Pacific Northwest salmon. Olsen, Richards, and Scott (1991) provide perhaps the most comprehensive study of nonmarket benefits associated with Columbia River Basin salmon and steelhead. Relying on a questionnaire posing open-ended questions, they estimate regional existence and option values from doubling the size of salmon and steelhead runs in the basin to be $60 million per year. Increased consumer surplus from sport fishing adds another $111 million annually of nonmarket benefits. The total value of $171 million per year exceeds, by a significant margin, even our most extreme estimate of

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[24] See Aillery, *et al.*, (1996), pp. 34–42, for more detail on these types of values, some estimates, and a discussion of difficulties associated with their estimation.

$35 million per year in reduced farmers' profits. Moreover, Olsen, Richards and Scotts' (1991) estimate of existence value, which converts to approximately $17 per fish, is among the most conservative estimates available for large changes in Pacific Northwest fish populations.

In an application of the stated-preference method for eliciting responses, Layton (1995) estimates that households would be willing to pay $2.43 per year for 10 years to increase by 1 the number of salmon stocks remaining after 150 years. This value translates into a willingness to pay of $11–$21 per household per stock preserved, depending on the assumed discount rate.[25] Using the more conservative estimate of $11 implies a regional value of $123 million for recovering the seven listed stocks (or ESU's), applying Olsen, Richards and Scotts' (1991) estimate of 1.6 million regional households. Finally, Loomis (1996) uses a dichotomous choice referendum format to examine willingness to pay for removing two dams on the Elwha River in northwestern Washington. Dam removal is estimated to increase the number of anadromous fish in that relatively small basin by 300,000. His results suggest that benefits to Washington State residents would be $138 million per year for 10 years. Further, he provides an estimate of $6 billion (with a lower bound of $3 billion) for nonmarket benefits to all U.S. households from restoring the Elwha River salmon fishery and ecosystem. These three CVM studies on nonmarket benefits of Pacific Northwest salmon recovery provide some context for the agricultural sector costs estimated in this study.

Summary and Conclusions

Our analysis examines the effects of ESA-related salmon recovery measures on the agricultural sector in the Pacific Northwest. Agriculture in the region relies heavily on river development for irrigation water in the upper Snake River basin, power supplies from hydropower generation, and river barging of grains through the navigable portions of the lower Snake and Columbia Rivers. Two means of improving conditions for downstream, in-river salmon migration—reservoir drawdown along the lower Snake and flow augmentation from the upper Snake—would increase the cost of crop production and distribution and reduce the availability of irrigation water. A set of scenarios is developed to represent the potential range of input cost and quantity changes that regional agricultural producers could face.

We apply a multi-output model of crop production in the Pacific Northwest to analyze seven study scenarios. From the model's baseline conditions, analysis of parametric adjustments contained in the scenarios simulate the effect of salmon recovery measures on profits, crop output, cropland use, and water demand in Northwest agriculture. Several key results emerge. Scenarios involving reservoir drawdown, which would increase power rates and transportation costs, reduce farmers' profits by less than 1% of baseline levels, or $8.9 million per year, for the longest drawdown period evaluated (4.5 months). Scenarios involving a relatively small reduction in irrigation water diversions in the upper Snake River basin would also produce a relatively small reduction in profits at the regional level, or less than $4 million per year. In contrast, scenarios incorporating a relatively large reduction in irrigation water diversions indicate a more substantial effect. In tandem with a longer drawdown period for the lower Snake reservoirs, a major irrigation diversion reduction would reduce profits by almost 2.5% relative to the baseline, or more than

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[25] The lowest value in this range is based on a discount rate of 18%, similar to that charged by credit card companies. At the other extreme, a discount rate of 3% is used, more similar to estimates of a social discount rate.

$35 million per year. Moreover, these impacts are concentrated in the upper Snake River basin, a relatively small portion of the entire Columbia-Snake River basin.

Three additional points are relevant in light of the finding that the largest effects would occur with flow augmentation from the upper Snake River basin. First, results indicate that, in percentage terms, profits would decrease less than water use due to retirement of less productive lands and substitution effects. For example, a 20% decrease in irrigation water use in the upper Snake region would cause a decrease in profits of 6%. While this general relationship is expected, estimates of the magnitude of proportional cost "savings" (smaller reductions) due to farmers' adjustment opportunities are informative given the uncertainty over the final goal for flow augmentation.

Second, an important distinction arises between economic cost and distributional impact. For social benefit-cost analysis, the decrease in profits (or equivalently, producer surplus) measures the economic cost of flow augmentation to the agricultural sector. As a matter of public policy, though, the federal government has chosen to acquire water only through voluntary, compensated transactions. In that case, irrigators in the upper Snake River basin can only benefit from this policy. In addition, institutional reform in Idaho and Oregon may be necessary to implement water markets on the scale of Snake River transfers envisioned, as discussed by Huffaker, Whittlesey, and Wandschneider (1993).

In this context, the results provide an estimate of irrigators' minimum "willingness-to-accept" compensation for reduced water supplies, or, alternatively, the cost to the government of purchasing this water.[26] Of course, purchasing water for that amount requires the government to price discriminate. For example, by acquiring 1.127 maf of flow augmentation by setting a single offer price at $33 per acre-foot, our estimate of the incremental cost of supplying water at that level would be $37.2 million, significantly more than the reduction in profits of $27.6 million (figure 3). Reclamation's adoption of a sealed-bid approach to acquire water would be one way to price discriminate, thereby minimizing public expenditures on upper Snake River flow augmentation (Simon 1998). The cost of purchasing water would be further reduced, and possibly offset completely, if revenues from selling the additional hydropower produced at downstream dams with that water are accounted for. We do not address revenues from hydropower in analytical terms because it is not within the scope of our analysis. However, Hamilton and Whittlesey's (1996) analysis suggests that these benefits may be significant—on the order of $31 million per year for a scenario in which flow augmentation averages 1.08 maf per year.

Third, this analysis is for average water-year conditions. The opportunity costs of flow augmentation will likely increase in dry years. In the driest years, flow targets may not be attainable at all, or could require a near cessation of irrigation diversions. On the other hand, little or no disruptions may occur in extremely wet years. For example, Hamilton and Whittlesey (1996) estimate that for a scenario incorporating NMFS data and recommendations (their most conservative scenario), 2.0 maf or more would be required for 30% of the years to meet seasonal flow targets, but for 35% of the years, the targets could be met without flow augmentation. Our results thus provide a useful benchmark for planning purposes, but clearly do not provide an estimate of the cost to agriculture in any given year.

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[26] Foregone profit would likely serve as a lower-bound estimate for compensation requirements because the producer could attempt to negotiate a more beneficial arrangement. A farmer's perspective may be that, to be compensated fairly, the government should pay a premium for use of the farmer's property right. For example, this premium might account for a positive lifestyle option value or a risk premium associated with uncertainty regarding future water supply conditions and costs associated with a water transfer. As well, a farmer may negotiate strategically with the government for a sizable premium in excess of foregone profit.

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