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The Effects of Water Rights and Irrigation Technology on Streamflow Augmentation Cost in the Snake River Basin

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Three species of salmon in the Snake River Basin have been listed as endangered. Recovery efforts for these fish include attempts to obtain increased quantities of water during smolt migration periods to improve habitat in the lower basin. Agriculture is the dominant user of surface flows in this region. This study investigates farmer cost of a contingent water contract requiring the agricultural release of stored irrigation supplies in low flow years during critical flow periods. Results show that contingent contracts can provide substantial quantities of water at a relatively modest cost without significantly affecting the agricultural base of the area.

Key words: contingent water contracts, irrigation technology, streamflow augmentation, water rights

Introduction

Many salmon stocks, once abundant in the Columbia and Snake Rivers, are now extinct (Peterson, Hamilton, and Whittlesey). In 1993, the National Marine Fisheries Service (NMFS) listed Snake River sockeye and chinook salmon as endangered under the Endangered Species Act (ESA). This reduction in the overall stock level and specie variety has coincided with the development of a variety of multipurpose water projects within the Snake River Basin over the last century. The earliest projects were designed primarily to facilitate irrigated agriculture, but later projects paid more attention to flood control and hydropower objectives (Clairbon). These projects have severely altered the quantity and timing of Snake River flows, contributing to salmon population declines (Sims and Ossiender 1991).

Hydroelectric dams have lowered streamflow velocities so that smolt migration from Idaho to the Pacific Ocean that once took 7–14 days now takes as long as 40 days (Wernstedt, Hyman, and Paulsen). The slower travel exposes smolts to dangers of disorientation, predation, and diseases, in addition to the physical dangers of passing through each of eight large hydropower dams (Hamilton and Whittlesey 1992). Sims and Ossiender (1992a, b) found that increased stream velocity during smolt migration (April through June) could increase smolt survival and the number of returning adults.

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Despite the current uncertainty about how much fisheries benefit from increasing streamflows, both the NMFS (through its recovery plan for Snake River salmon) and the Northwest Power Planning Council (NPPC 1994, 1995) recommend that minimum flow targets be established and maintained for smolt migration periods. Currently, up to 1.19 million acre-feet (MAF) of water from nonagricultural sources is "budgeted" for Snake River releases between 15 April and 15 June to aid salmon migration. However, these additional supplies have been insufficient to generate desired flows in the lower river during critical fish migration periods (Ewbank).

Alternative water sources must be found before a successful recovery program can be implemented. The U.S. Army Corp of Engineers is now investigating the possibility of additional flow augmentation polices for the lower Snake River. A promising water supply source is the substantial amount of agricultural water stored upstream in the Snake River Basin. About five MAF of Snake River flow is stored in reservoirs each spring and subsequently released for irrigation use later in the summer, mainly as a supplemental supply to stream diversions. Most of the upstream irrigation storage reservoirs were built when irrigation technology was relatively unsophisticated and maximum attainable irrigation efficiency was quite low, often below 25%. Generally, sufficient storage was built to serve project lands at these low efficiencies. With improved irrigation technology, per acre diversions have declined and storage capacity often exceeds the diversion needs of acreage with storage rights. Subsequently, the upper Snake River water bank was created to encourage leasing of unused storage water to other agricultural users or for instream uses. The main value of the unused storage water to current right holders is insurance against future drought.

Today, the water bank, along with normal irrigation storage, is being considered as a source of water to supplement river flows for salmon migration during years of drought. However, Idaho law contains a major impediment to using bank water to augment streamflows:

> Storage space . . . that is evacuated to supply water for nonconsumptive uses . . . shall be the last space to fill in the reservoir from which the space was originally assigned . . . in the ensuing year (Sims and Ossiender 1991, Chap. 5, p. 10).

This provision is intended to assure that water sellers (rather than nonparticipant third parties) bear the risk of future water shortage when reservoirs fail to refill due to nonagricultural water sales (Peterson, Hamilton, and Whittlesey). This risk could be an important determinant of farmer willingness to enter into a contingent water contract designed to augment streamflow levels in low flow years.

Previous Research

Several researchers have proposed that water markets be used to improve efficiency of resource use or meet instream flow requirements in the Columbia/Snake River Basin. Gardner, representing the Idaho governor's office, states:

> Water markets for rights or perpetual permits, or even for annual rentals where exchanges can be freely made, provide a solution to our allocation problems. . . . Both economic efficiency and distributional equity would be well served by allocating free transfers of . . . consumptive use (p. 25).

Whittlesey, Hamilton, and Halverson; and Hamilton, Whittlesey, and Halverson first proposed a contingent water market to move Snake River water from irrigation to hydropower. Halverson showed that such a market might also be applicable to the Columbia Basin Project of Washington State. Hamilton, Reading, and Whittlesey extended previous work, focusing on the potential of contingent water markets to benefit lower Snake River fish passage. Additional research by Peterson, Hamilton, and Whittlesey; Sommers; and Huppert, Fluharty, and Kenney has suggested that salmon recovery in the Snake River Basin could be enhanced by limiting irrigation diversions in low streamflow years to improve fishery habitat while leaving the long-term agricultural production base intact. Today, contingent water contracts are being seriously considered as a salmon recovery tool, but additional information on potential risks to farming, management issues, and political acceptance of such contracts is needed (Middaugh).

Study Purpose and Area

This study extends previous research by focusing on the influence of water right seniority and irrigation technology on the minimum compensation required to induce a risk-neutral farmer to contingently contract for release of stored irrigation water to augment streamflows for fisheries habitat. The water broker is assumed to be the designated representative of public interests for protection of salmon habitat. It is anticipated that the broker would work with and for the NPPC, NMFS, and the Bonneville Power Administration (BPA).

Two contingent water-contracting scenarios are analyzed: the first based on farmers selling portions of *excess stored water* modeled after the existing water bank structure, and the second based on selling portions of *total stored water*. Excess stored water is defined as that portion of total stored water surplus to expected irrigation requirements for the current growing season, and total stored water is the quantity of water available to the right holder for all uses within a growing season. Under each contract, a farmer commits to release a specific percentage of stored water when downstream flow levels drop below the critical threshold level in each low flow year of the contract period. The cost of releasing water under an excess stored water contract is incurred in subsequent years, whereas the cost of releasing water under a total stored water agreement may be felt in both the current year and future years.

The percentage of stored water committed to the contract, along with rainfall in subsequent years, determines whether irrigation storage refills in the following or subsequent seasons. Releasing stored water for salmon habitat in low flow years increases the probability of incurring an on-farm irrigation water shortage in the current and/or future years. This is different from the stream diversion contingent market contracts analyzed by Hamilton, Whittlesey, and Halverson that would reduce current-year crop production. They did not consider effects of releasing stored water on future years' income.

The Snake River Basin provides the empirical setting for this analysis. The Snake River is the largest tributary of the Columbia River, draining 108,500 square miles, 42% of the Snake/Columbia Basin, and contributes 20% of Columbia River flows. Average annual upper Snake River agricultural diversions exceed 16 MAF, of which up to 5 MAF are stored water diversions, and are used to irrigate about 4 million acres, with 8–10 MAF eventually becoming return flow to the river. Approximately 56% of the irrigated acres in the upper basin use gravity application systems. About two-thirds (68%) of the sprinkler systems are side-roll, followed by center pivot at 29%.

Snow melt and precipitation occur primarily in March to early June. Based on seasonal water supply projections in March, reservoirs are managed to be as full as possible in early to mid-June. It is assumed that by March, farmers have sufficient information to estimate June storage levels and available inflows over the following irrigation season. Given this information and expected crop irrigation requirements, farmers can project how much water can be released to augment April/June streamflows under an *excess* water contract without jeopardizing current season irrigation needs. Future water shortages may occur if subsequent water years are below normal and vacated storage capacity does not refill—particularly likely for junior right holders. Under the alternative contract, a specified percentage of *total* storage available in early June is released to augment flows in low flow years. The total storage contract can create on-farm irrigation water shortages in both the current and subsequent years. The entire contracted percentage is released in each low flow year. The amount of stored water committed under either contract (up to 100%), in combination with stochastic streamflows, determines the probability and severity of a water shortage in the release year and subsequent years.

Contingent contracts of this type do not guarantee a specific quantity of stored reserves will be released for instream flow augmentation in each low flow year; instead, they specify what percentage of defined reserves will be released. Quantities cannot be guaranteed since they are dependent on stochastic reservoir inflows. Refill priority right and irrigation technology will affect stored releases. Storage always refills in the order of priority right. Hence, senior right holders generally will incur less risk of future shortage than junior right holders for similar contracts. Because farms with senior refill priorities have their vacated storage refilled before farms with lower refill priorities, they generally will have higher stored reserves available for contract release in low flow years. Moreover, farms using more efficient irrigation technologies generally will have higher storage levels than farms using less efficient technologies because smaller quantities of stored supplies are required for irrigation diversion per irrigated acre. Historical changes in irrigation technology have not affected individual farm refill priority or quantity of storage rights.

Modeling Procedure

A simulation model was constructed to estimate expected farm-level water supply shortages and net income losses due to contract participation for the three dominant irrigation technologies in the basin. Representative farms were constructed for each irrigation technology using average cropping patterns and yields to represent existing agriculture in the upper Snake River Basin. These three irrigation technologies, which comprise more than 98% of all irrigated basin acreage, are (*a*) rill, (*b*) side-roll, and (*c*) center pivot. Three levels of appropriative rights for stored water (A, B, and C) were defined for each representative farm, with farm A holding the most senior right and farm C the most junior. The farm cost of contracting to release 25%, 50%, 75%, and

Table 1. Baseline Values of Net Farm Income, Crop Mix, and Water Use for the Representative Farms with Unrestricted Water Supplies

Item	Unit	Irrigation System		
		Rill	Side-Roll	Center Pivot
Net Income	$/acre	171	182	212
Irrigated Crop Acreage:				
Pasture	%	14	12	0
Sugarbeets	%	5	2	4
Dry beans	%	3	2	0
Corn	%	3	0	10
Winter wheat	%	32	45	47
Alfalfa	%	32	27	25
Potatoes	%	11	12	14
Water Use	inches/acre	76.38	38.57	30.20
Net Irrigation Requirement (NIR)	inches/acre	24.97	24.91	25.27
Irrigation Efficiency	%	32.69	64.58	83.67

100% of defined stored water reserves in low streamflow years under both the excess and total stored water contractual arrangements is estimated for each contracting level. A 10-year contract period is assumed. Per acre changes in net present value of farm returns over the life of the contract are used to measure expected contract cost.

The baseline data for each representative farm are presented in table 1. Under full water supply, rill irrigated farms annually average $171 per acre net income above variable cost. Gross margins are $182 and $212 per acre, respectively, for side-roll and center pivot farms. The higher gross margins associated with the sprinkler systems are mainly due to a higher value crop mix. Because sprinkler systems require more capital investment, the long-run net income advantage of sprinkler systems is less than indicated by gross margin values. Despite differences in irrigation efficiency and irrigated crop mix, the net irrigation requirement for each representative farm is nearly equal.

As shown in figure 1, the analytic structure consists of three linked models: (*a*) a probability model, (*b*) a hydrology model, and (*c*) an economic model. For simplification, the flowchart is drawn for a single year and a specific contract level.

Probability Model

The probability model simulates upper Snake River monthly flow levels in year *t*, and determines if late spring flows in the lower Snake River are below the target level. The entire contract commitment is released when downstream flows are below the specified target level.

A contingent water contract motivated by fish habitat needs will require contract deliveries when flows in the lower river fall below target levels for the 15 April–15 June smolt migration period. Thus, contract release conditions must be clearly established so the probability of contract-required deliveries and expected cost can be determined

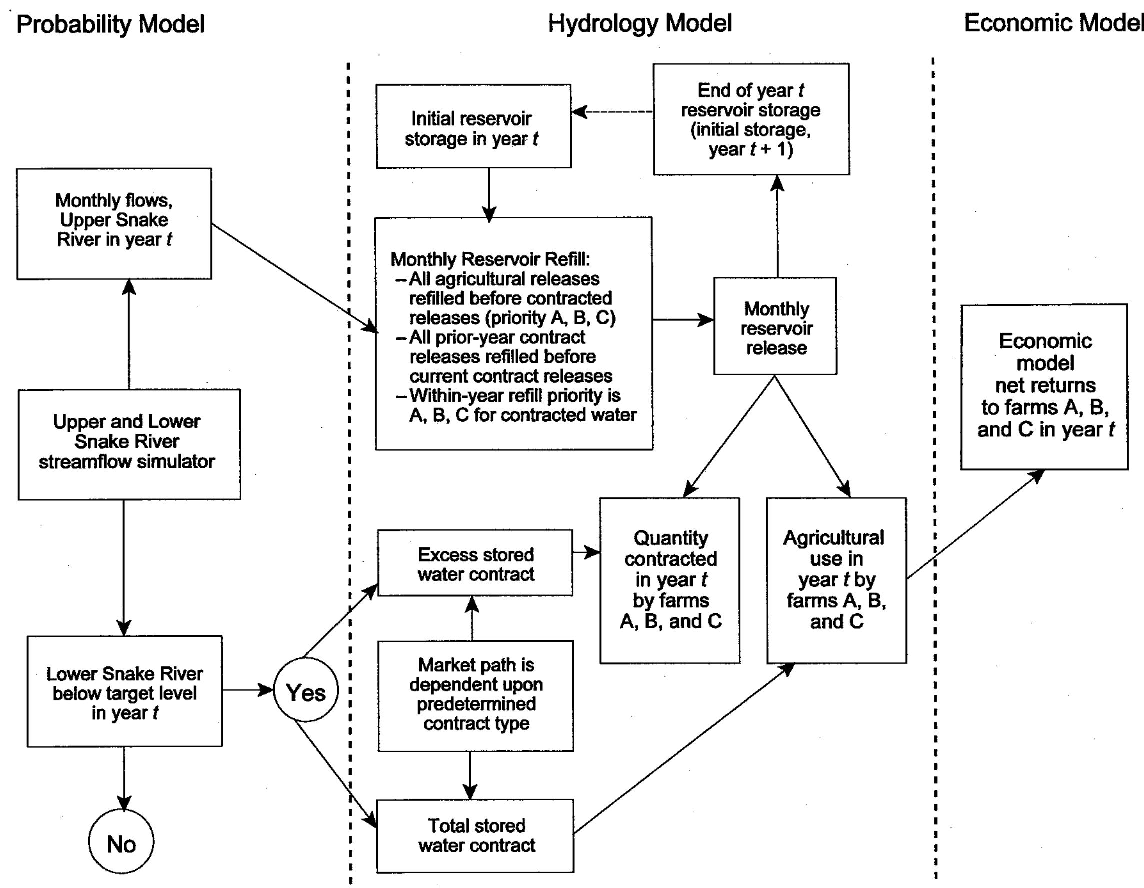

Figure 1. Flowchart of water contract simulation procedure for a given contract rate in year *t*

Table 2. Historic Relationship Between Upper Snake River Flow Level and Probability that Flow Level at Lower Granite Dam Is < 85 Kcfs Target Level

Upper Snake River Average Flow Level, April–June, 1929–88 (Kcfs)	Probability that Lower Snake River Flow < 85 Kcfs
00.00–11.24	0.8
11.24–12.44	0.7
12.44–14.47	0.3
14.47–16.04	0.1
16.04–18.59	0.0
18.59–25.00	0.0

by the owners of storage capacity. In this study, contracted water is released in years when the spring flow level falls below the NPPC minimum monthly average flow target of 85 thousand cubic feet per second (Kcfs) at Lower Granite Dam. Based on historical data for the period 1929–88, the average flow level was below the 85 Kcfs target in 32% of the years—meaning that, on average, contracting farmers would be expected to deliver stored water about three years out of 10.

Despite the apparent existence of cyclical weather patterns, a variety of ARIMA-based statistical tests on the annual streamflow data failed to detect the presence of a statistically significant serial correlation pattern in upper river flows. Hence, each 10-year sequence for upper Snake River streamflow levels, which determines the quantity of water available for reservoir refill each year, was produced by randomly drawing flows (with replacement) from the historic record.

The correlation between upper Snake River flows where the irrigation is located and the lower river flow levels where the salmon migration habitat is located is positive, but not perfect, as shown in table 2. Here the empirical cumulative density function for the three-month average flow level for April through June in the upper Snake River for the years 1929–88 is divided into six intervals. Each interval contains one-sixth (10) of the historic outcomes. The probability of observing a downstream spring flow level below the 85 Kcfs flow target level when the upper flow level is less than 11.24 Kcfs is 0.8. As seen in table 2, the probability that lower river flows are below the target level falls sharply as the spring flow level in the upper river increases. A contract release year is determined when the drawn upstream flow level is associated with a low flow year in the lower Snake River. A drawn 10-year upper Snake River flow sequence, in combination with the information on which years are low flow years on the lower Snake River, provides the hydrology model with the necessary information to simulate the effect of contract participation on on-farm water supplies for one 10-year contract. Given the stochastic nature of streamflow supplies, each 10-year upstream flow sequence with associated contract deliveries was randomly replicated 250 times to derive the expected cost of contract participation.

Hydrology Model

The hydrology simulation model developed by Frasier, Whittlesey, and Hamilton (FWH) uses the information on upper Snake River monthly flows and contract year status to simulate monthly reservoir refill by storage right priority, the quantity of contract water released, the monthly quantity of water diverted for irrigation by each farm, and the reservoir storage level at the end of the year. The FWH model allows the user to specify a typical farming region and establish water right priorities for farms within the region. Additionally, the model allows the user to (*a*) specify irrigation efficiencies, (*b*) control the portion of applied water lost to evaporation or phreatophytes, (*c*) control the fraction of applied water constituting return flow, and (*d*) control the share of return flows via surface drain or deep percolation. This model assumes three equal-sized representative farms, denoted as A, B, and C, with similar irrigation technology and having storage water rights with seniority in the order ABC. The model uses the water rights structure, along with monthly information on storage inflows and outflows and crop water demand, to estimate the quantity of irrigation water diverted by each farm and return flow quantities.

The hydrology model assumes that in any given month, each farm will divert the full net irrigation requirement (NIR) to satisfy baseline crop demand to the limit of available stored water supplies. When stored supplies are less than irrigation requirements, an on-farm water shortage occurs. Consistent with legal statutes designed to avoid third-party effects, the simulation model completely refills all agricultural release in accordance with the specified refill priority before any contingently contracted flow releases are refilled. Moreover, contract water released in a prior year is refilled before contract water released in the current or subsequent years in accordance with the seniority structure existing at the time of the release. End-of-year reservoir storage is initial reservoir storage in the subsequent simulation year.

Baseline irrigation storage capacity is assumed to be 6.38 acre-feet per acre (AF/A) for acreage with storage rights. This per acre storage quantity equals the per acre seasonal quantity of water applied by a low-efficiency (rill) irrigated farm, and is consistent with original (and current) per acre storage capacity of farms in the region. Storage refill potential is such that under rill irrigation and in absence of a contingent water contract, priority farms A and B never experience water shortages, while farm C incurs a minor water shortage about one year in 10. Farms using sprinkler technology always have sufficient irrigation water supplies under baseline conditions.

Economic Model

The economic model is a mathematical programming model that allows farmers to change crop mix and irrigation strategies in response to contract-caused water shortages.

Farmer Response to Water Shortage. Annual choices available to irrigation management include deficit irrigation, reducing irrigated acreage, and/or changing the crop mix. The production cost and yield adjustments for "water deficit" irrigation used methods developed by Willis. Yields are linearly interpolated between expected yield at full NIR and expected yield at the maximum allowed deficit level for irrigation levels falling between the two irrigation levels. Yield-dependent production costs are proportionately reduced when yields are decreased due to deficit irrigation. Crop budgets and price/income data used in the analysis reflect the conditions of 1993. Annual net farm income was maximized subject to restrictions on land, crop rotation, and monthly water supply. Perennial crop budgets were developed assuming sufficient water is available to preserve the crop stand through its normal life. Individual farms cannot shift irrigation technology because the research objective is to measure the agricultural cost of market participation for farms with specific technologies and priority water rights under a 10-year market contract. It is acknowledged, however, that such contingent water contracts could eventually stimulate additional shifts in irrigation technology.

Under baseline conditions, rill irrigated farm C has a water shortage 8% of the time, receiving on average 98.2% of full water supplies over 250 replications of a 10-year period. These water shortages reduce expected average annual net income $0.62 below the $171 per acre return of farms A and B. Side-roll and center pivot farms A, B, and C never experience water shortages in the baseline.

Net Income Effects of Contract Participation. Contract participation leads to farm income losses when stored water releases impose irrigation water shortages in either the current or future years. The economic model calculates the participating farmer's decrease in net income each year. As the simulation proceeds through time, annual accounts are maintained on the quantity of contract releases, severity of on-farm water shortage, and net income loss. Farmer cost depends upon the percentage of stored water committed to the contract, the frequency of contract releases, and streamflow conditions in subsequent years. The yearly contract-caused net income losses over the 10-year contract period are then chronologically arranged and discounted, using a 4% real discount rate, into a per acre net present value (NPV) estimate of contract cost. This process is replicated 250 times for each contract scenario, and the 250 NPV estimates are subsequently averaged to derive expected contract cost per irrigated acre for each farm. The expected average annual cost per irrigated acre to a participating farmer is derived by converting the average NPV estimates into annualized equivalent values. An annualized equivalent cost value incurred in each contract year and discounted by the appropriate rate of interest (4% real rate) will exactly equal the NPV contract cost estimate.

Results and Analysis

Excess Stored Water Contracts

We first consider an excess water contract where a farmer agrees to release some pre-specified percentage of stored water not needed for irrigation in the current year. If the storage does not adequately refill, on-farm water shortages may occur in future years. The excess water contract assumes the full contract commitment is released in each low flow year.

Rill Irrigation. Water supply shortages from contract participation are reported in table 3 for rill irrigated farms. Senior priority right farm A is excluded from table 3 since it does not incur a water shortage at any contract participation level. The seniority of farm A's refill right assures that all water released under contract will be refilled before it is needed on-farm. The fact that farm A incurs no farm income losses could change if storage refill rules were modified, or if farm A were to release water while

Table 3. Average Percentage of Baseline Water Supplies Received by Rill Irrigated Farms B and C Under Four Excess Stored Water Contract Specifications

Percentage of Excess Stored Water Contingently Contracted	Farm B			Farm C[a]		
	Avg.[b]	Min.[c]	SD[d]	Avg.[b]	Min.[c]	SD[d]
25%	100.0	100.0	0.0	99.8	76.4	7.8
50%	99.8	98.4	0.5	99.4	72.2	8.4
75%	99.6	96.5	1.6	99.1	68.1	8.9
100%	99.1	94.1	2.8	98.7	63.1	9.5

Note: Farm A experiences no water supply shortage at any excess stored water contract level, and so is not represented here.
[a] Average supplies for farm C are reported relative to average baseline condition and not full water supply. Under baseline condition, farm C receives 98.2% of full water supply in an average year.
[b] Average water supply over 250 replications of a 10-year contract period.
[c] Minimum values are single-year minimum supplies expressed as a percentage of full water supply for each 10-year contract period, averaged over 250 replications.
[d] Standard deviation of farm water supply over 250 simulations of a 10-year contract period.

farms B and/or C choose not to participate. In the latter case, farm A would lose its priority right for refill of the portion of storage sold for nonagricultural use, while farms B and/or C would not be so affected. This alternative is not evaluated here.

With 25% of excess stored water committed to the contingent contract, farm B has no future water shortages and farm C has only minute shortages. Farm C averages 99.8% of baseline water supplies (98% of full water supply) under a 25% contract, with the worst year average in each 10-year contract averaging 77.8% of baseline water supply (76.4% of full water supply). However, when compared with the no-contract baseline situation where shortages are routine, single minimum year supplies average 95% of the baseline minimum average value over a 10-year period. The contract creates water shortages for farm B only when at least 50% of excess stored water is contracted for release in low flow years. Under the maximum 100% contract, farm B averages 99.1% of full water supply over the contract and incurs minor water deficits in only 6% of the years. Under the same contract, farm C averages 98.7% of baseline water supply (96.9% of full water supply) over the contract period.

Per acre NPV losses for farms B and C are presented in table 4. At the 100% contract level, NPV losses for farm B average $2.10 per acre, and a maximum NPV loss of $12.31 is incurred in one contract simulation. Average NPV losses for farm C range from $0.93 per acre for a 25% contract to $3.96 per acre for a 100% contract. At the 100% contract level, farm C has a maximum NPV loss of $23.45 per acre in one simulation. Perhaps the most useful information for a farmer considering contract participation is that annualized equivalent values of NPV losses average less than $1 per irrigated acre for all rill farms under the 100% contract. The small cost is a consequence of the contract design which assures water releases never exceed current-year stored surpluses. Hence, contract cost is from subsequent-year income losses due to incomplete reservoir refill.

The average quantity of water released in a delivery year is shown in table 5. Farms with senior water rights release more water than those with lower priority water rights

Table 4. Net Present Value and Annualized Equivalent Cost of Irrigation Water Reallocated to Instream Use for Rill Irrigated Farms B and C Under an Excess Stored Water Contract ($/acre)

Contract Level		Farm B				Farm C			
		Avg.	Max.[a]	Min.[a]	SD[b]	Avg.	Max.[a]	Min.[a]	SD[b]
25%:	Net Present Value[c]	0.00	0.00	0.00	0.00	0.93	4.63	0.17	2.54
	Annualized Cost[d]	0.00	0.00	0.00		0.11	0.55	0.02	
50%:	Net Present Value[c]	0.17	1.51	0.00	0.46	1.86	9.28	0.42	2.70
	Annualized Cost[d]	0.02	0.18	0.00		0.22	1.10	0.05	
75%:	Net Present Value[c]	0.67	4.13	0.00	1.06	2.70	15.60	0.76	3.88
	Annualized Cost[d]	0.08	0.49	0.00		0.32	1.85	0.09	
100%:	Net Present Value[c]	2.10	12.31	0.00	2.00	3.96	23.45	0.84	4.70
	Annualized Cost[d]	0.25	1.46	0.00		0.47	2.78	0.10	

Note: Farm A experiences no income loss at any excess stored water contract level, and so is not represented here.
[a] Maximum (minimum) present value cost of one 10-year contract simulation in 250 contract replications.
[b] Standard deviation of average present value net income loss for a 10-year contract period.
[c] Net present value for 10-year contract cost averaged over 250 replications using a 4% discount rate.
[d] Annualized equivalent cost is calculated using a 4% discount rate.

Table 5. Excess Stored Water Released in Low Flow Years for Alternative Participation Levels: Rill Irrigated Farms (acre-feet/acre)

Contract Level	Farm A				Farm B				Farm C			
	Avg.	Max.[a]	Min.[a]	SD[b]	Avg.	Max.[a]	Min.[a]	SD[b]	Avg.	Max.[a]	Min.[a]	SD[b]
25%	1.03	1.10	0.87	0.13	0.67	1.01	0.45	0.22	0.35	0.70	0.13	0.25
50%	1.89	2.20	0.92	0.51	1.21	2.01	0.38	0.54	0.65	1.34	0.07	0.50
75%	2.61	3.30	0.78	1.08	1.65	2.97	0.26	0.94	0.91	2.01	0.05	0.76
100%	3.22	4.41	0.45	1.70	2.05	3.93	0.18	1.36	1.13	2.67	0.03	1.05

Note: Water volumes correspond to average stored supplies released in a contract-triggered low flow year (32% of all years are low flow years).
[a] Maximum (minimum) values are single-year maximums (minimums) for each 10-year contract period, averaged over 250 contract replications.
[b] Standard deviation of average release in a low flow year over 250 simulations of a 10-year contract period.

Table 6. Percentage of Baseline Water Supplies Received by Side-Roll Irrigated Farms B and C Under 75% and 100% Excess Stored Water Contracts

	Farm B			Farm C		
Contract Level	Avg.[a]	Min.[b]	SD[c]	Avg.[a]	Min.[b]	SD[c]
75%	100.0	100.0	0.00	99.9	99.8	0.02
100%	99.9	99.5	0.14	99.5	92.1	2.50

Note: Farm A experiences no water supply shortage at any excess stored water contract level, and so is not represented here. Farms B and C experience no water supply shortage at the 25% and 50% contract levels.
[a] Average water supply, expressed as a percentage of full water supply, over 250 replications of a 10-year contract period.
[b] Minimum values are single-year minimum supplies expressed as a percentage of full water supply for each 10-year contract period, averaged over 250 replications.
[c] Standard deviation of farm water supply over 250 simulations of a 10-year contract period.

at each participation level. Average releases range from 3.22 AF/A for farm A to 1.13 AF/A for farm C under a 100% contract. There is considerable variation in the quantity released by each farm. For example, at the 100% contract level, the maximum single-year quantity released by farm A in a 10-year contract period averages 4.41 AF/A, but the minimum quantity released averages only 0.45 AF/A. Average single-year maximums and minimums for the quantity released by farm C are less, averaging 2.67 AF/A and 0.03 AF/A, respectively, and are attributable to the lower refill priority. That is, priority of refill affects the amount of surplus water available over time.

The standard deviation of the quantity released increases with the contract participation level. At high percentage rates of participation, the standard deviation is larger for farm A than for farm C, primarily because the senior right holder releases about three times as much water. However, at the lowest participation level, the standard deviation of the released quantity is less for farm A than for farm C because seniority of the refill right nearly guarantees that farm A will be able to release its maximum contract commitment in all low flow years. Regardless of the contract level, the relative variation in the quantity released, as measured by the coefficient of variation, is smaller for farm A than for farm C.

Side-Roll Irrigation. Water supply deficits imposed on side-roll irrigated farms are shown in table 6 for farms B and C. (Farm A incurs no on-farm water deficit at any contract level under side-roll irrigation technology.) The more efficient technology confines farm B contract-related water shortages to the 100% contract. Farm C incurs water supply shortages under both the 75% and 100% contracts. But these shortages are minimal, and farm C averages over 99% of full water supplies at both contract levels, incurring a contract-caused water shortage less than one year in 10.

The annual average quantities of water released by each side-roll farm in a low flow year are shown in table 7. For a 100% contract, average quantities released range from 5.14 AF/A for farm A to 3.84 AF/A for farm C. Generally, three to four times more stored water is delivered under a 100% contract than a 25% contract. Moreover, average releases per acre of irrigated land are greater than for rill irrigated farms due to the more efficient technology and resulting greater excess storage capacity.

Center Pivot Irrigation. With center pivot technology, farms A and B receive full water supplies at all contract levels, and farm C shortages are limited to the 100% contract. Farm C averages 99.7% of full water supply in each contract period and sustains small water deficits in 2% of the years. Annual releases in low flow years are greatest under center pivot technology because it has the highest irrigation efficiency and thus smaller diversion requirements, leading to increased excess stored water supplies relative to the less efficient technologies. Farm A releases an average of 5.41 AF/A in a low flow year compared with 4.23 AF/A for farm C under a 100% contract.

Review of Excess Storage Market. The average acre-foot cost of water released is computed by dividing the annualized equivalent value of NPV by the expected quantity of water released in each contract year (average quantity released in a low flow year multiplied by the probability of a low flow year). Regardless of irrigation technology, no water deficit or net income loss is incurred by farm A at any contract level. Rill irrigated farm B cost is $0.38 per acre-foot of released water under a 100% contract. Rill irrigated farm C encountered the greatest costs, with annualized costs ranging from $0.98 per acre-foot at the 25% level to $1.30 per acre-foot at the 100% level. Farm C contract cost is significantly less with a more efficient irrigation technology. For example, at the 100% contract level, annualized costs are $0.14 and $0.11 per acre-foot for the side-roll and center pivot technologies, respectively. Hence, priority rights and irrigation technologies affect the ability of farms to enter into a contingent water contract. Policy makers should target high priority rights and high efficiency technologies for such contingent markets to obtain the greatest return for water purchases to enhance fish habitat. However, in the end, it may be necessary to deal with all farm types in order to achieve streamflow targets.

Total Stored Water Contract

In this section we examine the effects of a contingent contract wherein farmers would commit 25%, 50%, 75%, or 100% of *total* stored water for flow augmentation when needed in the lower Snake River. A 75% total stored water contract requires the farmer to release 75% of all stored water supplies when triggered by the downstream flow condition. The actual release would range from 0% to 75% of the total storage right, depending upon how full storage reservoirs are when water delivery is mandated. In contrast to an excess stored water contract, a total stored water contract can impose water shortages in both the current and subsequent years. As before, when lower Snake River flows are projected to be below the 85 Kcfs target level, all contracted water is released in an effort to support the target flow level.

Rill Irrigation. Table 8 indicates that contract-caused water shortages are minor at the 25% contract level for rill irrigated farms, but significantly increase at higher contract levels. Water shortages are common under a 100% contract, and farms A, B, and C can expect some water supply deficit 32%, 38%, and 46% of the time, respectively. At this contract level, farms A and B average 86.7% and 83% of baseline water supplies, respectively, compared with only 74% for farm C. Expected minimum single-year farm water supplies in each 10-year contract period are significantly lower, respectively averaging 54.5%, 40.6%, and 18.6% of baseline requirements for farms A, B, and C.

Contract costs are either zero or minimal for all three rill irrigated farms until contract obligations exceed 50% of storage. Under a 100% contract, per acre NPV losses

Table 7. Excess Stored Water Released in Contract Years for Alternative Participation Levels: Side-Roll Irrigated Farms (acre-feet/acre)

	Farm A				Farm B				Farm C			
Contract Level	Avg.	Max.[a]	Min.[a]	SD[b]	Avg.	Max.[a]	Min.[a]	SD[b]	Avg.	Max.[a]	Min.[a]	SD[b]
25%	1.34	1.34	1.34	0.00	1.32	1.34	1.28	0.03	1.20	1.32	1.09	0.11
50%	2.67	2.68	2.66	0.01	2.62	2.68	2.48	0.12	2.32	2.61	1.60	0.32
75%	3.97	4.01	3.71	0.14	3.72	3.91	2.30	0.59	3.10	3.83	0.94	1.01
100%	5.14	5.35	3.43	0.63	4.53	5.15	1.12	1.50	3.84	5.02	0.24	1.90

Note: Statistical results are for contract release years only (approximately 32% of all years).
[a] Maximum (minimum) values are single-year maximums (minimums) for each 10-year contract period, averaged over 250 contract replications.
[b] Standard deviation of average release in a low flow year over 250 simulations of a 10-year contract period.

Table 8. Percentage of Baseline Water Supplies Received by Rill Irrigated Farms at Each Contract Participation Level Under a Total Stored Water Contract

	Farm A			Farm B			Farm C[a]		
Contract Level	Avg.[b]	Min.[c]	SD[d]	Avg.[b]	Min.[c]	SD[d]	Avg.[b]	Min.[c]	SD[d]
25%	100.0	100.0	0.0	99.9	99.1	0.3	97.1	85.0	11.1
50%	100.0	100.0	0.0	97.7	86.2	5.6	91.5	72.9	16.5
75%	98.4	95.6	2.6	91.9	71.0	13.9	83.8	56.8	23.7
100%	86.7	54.5	21.3	83.0	40.6	26.3	74.0	18.6	34.3

[a] Average supplies for farm C are reported relative to average baseline condition and not full water supply. Under baseline condition, farm C receives 98.2% of full water supply in an average year.
[b] Average water supply over 250 replications of a 10-year contract period.
[c] Minimum values are single-year minimum supplies expressed as a percentage of full water supply for each 10-year contract period, averaged over 250 replications.
[d] Standard deviation of farm water supply over 250 simulations of a 10-year contract period.

average $46 for farm A, $74 for farm B, and $174 for farm C over the 10-year contract, indicating some water required for baseline irrigation needs is released at this contract level.

Stored water releases in a low flow year are generally two to four times greater than under the excess stored water contract. Average releases by rill farm A in a low flow year range from 1.53 AF/A for the 25% contract to 6.09 AF/A for the 100% contract. Corresponding quantities are 1.33 AF/A to 4.78 AF/A for farm C. Farms with senior water rights consistently contribute more water for streamflow augmentation than those holding junior water rights, other factors equal.

Side-Roll Irrigation. Farms employing sprinkler technology are less likely to experience water shortages than farms using rill technology. Side-roll irrigated farms incur no significant water supply shortages under a 25% or 50% contract, and only small shortages at the 75% level. However, under a 100% contract, water shortages are fairly common, with farms A, B, and C averaging 90%, 86%, and 80% of baseline supplies, respectively. Minimum single-year water supplies average 66%, 32%, and 17% of baseline crop requirements for farms A, B, and C, respectively.

Income losses are directly related to these water shortages. Farms A, B, and C incur an expected per acre NPV loss of $40, $67, and $106, respectively, when contracting at the 100% level. These values are slightly less than for the rill irrigated farm because the more efficient technology reduces crop diversion requirements and buffers agricultural exposure to water supply deficits attributable to contract releases.

Water releases are slightly higher than for rill irrigated farms. Under a 25% water contract, each farm releases 1.59 AF/A in a low flow year, but releases vary by right priority at higher contract levels. At the 100% contract level, average releases are 6.31, 5.98, and 5.16 AF/A for farms A, B, and C, respectively. The variation in the quantity released by side-roll farms A and B under a 100% contract is considerably less than that of rill irrigated farms A and B, but the quantity released by farm C fluctuates widely and ranges from zero to 6.37 AF/A. The more efficient technology reduces the variance of the total quantity released by all three side-roll farms in a low flow year relative to the rill irrigated farms.

Center Pivot Irrigation. A more efficient irrigation technology creates more surplus stored water. These increased surpluses reduce the probability of contract-related water shortages. Under a 100% contract, farms A, B, and C annually average 90%, 86%, and 82% of full on-farm water requirements, respectively. Average minimum single-year supplies average only 66% of full supply requirements for farms A and B, and 45% for farm C, but are significantly higher than the corresponding side-roll minimum values. Water deficits are incurred 28%, 30%, and 42% of the time, respectively, by farms A, B, and C under a contingent contract for 100% of stored water.

Contract cost is minimal for all center pivot farms except at the 100% contract level, where per acre NPV losses average $55, $92, and $121, respectively, for farms A, B, and C. These losses are greater than for side-roll irrigated farms because center pivot farms have high-value crops.

Annual quantities of water released in low flow years are similar to those for the side-roll farm. At the 25% contract level, each farm contributes about 1.59 AF/A in a low flow year, and average quantities released under a 100% contract are 6.34, 6.07, and 5.21 AF/A for farms A, B, and C, respectively. The variability in the quantity released by farm C under a 100% contract remains high, ranging from 6.37 to 0.16 AF/A, which is slightly less than for similar farms using either rill or side-roll technologies.

Table 9. Annualized Equivalent Cost per Acre-Foot of Water Released by Upper Snake Irrigated Farms Under a Total Stored Water Contract

	Annualized Cost of Water Released ($/acre-foot)								
	Rill Farm			Side-Roll Farm			Center Pivot Farm		
Contract Level	A	B	C	A	B	C	A	B	C
25%	0.00	0.29	2.22	0.00	0.00	0.00	0.00	0.00	0.00
50%	0.05	1.38	3.91	0.00	0.00	0.03	0.00	0.00	0.00
75%	0.45	2.72	6.84	0.00	0.05	0.90	0.00	0.01	0.34
100%	3.04	5.32	14.54	2.52	4.47	8.19	3.46	6.06	9.23

Note: Annualized equivalent cost per acre-foot of water released is calculated by dividing the annualized per acre cost by the expected annual quantity released per irrigated acre.

Forgone Benefit of Water Sold. Annualized income losses per acre-foot of water released for each total stored water contract are presented in table 9. For a given irrigation technology and contract level, it is less costly for a senior right holder to enter into a contractual agreement than a junior right holder. This occurs because of the refill rules for water storage. Assuming that all storage right owners in a reservoir participate in the same contingent water contract, it is the senior right that will always refill first. Hence, the risk or cost of such participation must be greatest for the junior right holders. Of course, the senior right holders also will be able to furnish greater amounts of water over time to the contract. Per acre-foot cost is higher for center pivot farms A and B than the comparable rill farmer under a 100% contract because of the higher valued crop mix. This is not the case for farm C because the more efficient technology produces fewer and/or less severe water supply shortages than the rill technology, more than offsetting the effect of the higher valued crop mix.

Aggregate Effects

While this investigation was not designed to specifically measure the aggregate streamflow effects of a contingent water contract for irrigation storage in the Snake River Basin, some general conclusions can be gleaned from the analysis. A study by Hamilton and Whittlesey (1996) found that 1–2 million acre-feet of water would be needed in the 13% of wettest years to meet all potential late spring and summer monthly flow targets—which extends beyond the critical two-month salmon migration period of this analysis—without other changes in river operations. In the driest 25% of years, the requirements would increase to 6–10 million acre-feet to meet flow targets in all months of habitat need, which exceeds the basin's reservoir storage capacity. Hence, using stored water supplies to obtain additional water for flow augmentation is only a first step in meeting fish habitat needs.

There are approximately 5 million acre-feet of irrigation storage in the upper Snake River Basin. Of this, approximately 2–3 million acre-feet could be obtained in the manner of this analysis and distributed to improve fish habitat in a timely manner (Hamilton and Whittlesey 1996). Thus, while the contingent water contracts for stored water considered here could make a significant contribution to streamflows, it is not possible to describe a specific measure of benefit that might be obtained in this manner. The net benefit to target flow rates for fish will depend upon the type and extent of other changes in river operations that are undertaken. Environmental impact studies are now underway to evaluate partial and total drawdown of all four lower Snake River reservoirs. With such changes in the lower river, the amount of water needed to meet flow targets is greatly reduced. In fact, permanent removal of the four lower river dams would completely eliminate the need for additional water in that portion of the river.

Conclusions, Limitations, and Future Research

The farm-level costs of two alternative contingent water contracts designed to augment lower Snake River streamflows in low flow years to enhance salmon migration were examined. The source of the contracted water supplies is the upper Snake River reservoir storage system originally built for irrigation. The first water contract considered was largely modeled after the existing upper Snake River water bank, where farmers agree to sell a percentage of stored water that is excess to current-year irrigation needs. The second contract specification calls for farmers to sell a percentage of total stored water. The economic cost of releasing stored water under an excess stored water contract is limited to future years when marketed storage is not refilled before being needed on-farm, whereas releases under a total stored water contract can have an economic cost in both the current year and future years. Both contracts are different from a market that takes only surface supplies from farmers in low flow years and leaves them unaffected by the market release in subsequent years.

Contingent contract cost was estimated by assuming farmers sign 10-year contracts to release a specific portion of their stored water supplies to improve fishery habitat in designated low flow years. Each contract simulation further assumed that all storage owners sell the same percentage, not quantity, of available water in a low flow year while maintaining the same irrigation technology over the 10-year contract period.

Contract cost per acre-foot of water obtained is less under an excess stored water contract than a total stored water contract, but the excess stored water contract provides much less water for fish habitat. The total stored water contract generally contributes two to four times more water for streamflow augmentation at each contract level. Acre-foot water cost increases as the percentage of stored water contracted is increased, particularly for junior appropriators. Farms using more efficient irrigation technologies are less likely to incur water shortages or experience net income losses.

Widespread adoption of stored water contracts might encourage some farmers to adopt a more efficient irrigation technology or alternative crops. Such implementation could induce widespread changes on the basin hydrology. However, relatively few of the rill irrigated farms, currently comprising more than 55% of land irrigated in the region, can easily and quickly adopt a more efficient technology with the associated cropping patterns used in this analysis. Soils, slopes, farm financial condition, field size, and climatic factors individually and collectively constrain the choice of irrigation technology and crop rotation. For example, small field size or irregular-shaped fields can prohibit the efficient adoption of center pivot irrigation. While it is expected that the evolution of irrigation technologies will continue and that future market conditions will influence the mix of crops available to farms, it was beyond the scope of this study to consider the specific effects of long-term contracts for stored water on either technology adoption or crop selection.

Huffaker and Whittlesey note that increased irrigation efficiency can lead to water spreading if water "conserved" through irrigation efficiency increases can be applied to acreage currently not under irrigation. Water spreading, if allowed, will generally increase the marginal value of water to agriculture and the opportunity cost of contract participation. The contract cost estimates for the more sophisticated irrigation technologies do not include this potential opportunity cost because water spreading is prohibited within the study region. Stored water can be applied only to land having stored water rights.

The effects of risk preference on contract cost were not evaluated. In this regard, the expected cost estimates are only baseline values from which market exchange values for water would be negotiated. Other forms of risk are also ignored. For example, changes in absolute and relative crop prices over the duration of the contingent water contract could affect the relative costs of each contract option. Problems of this type could be solved by market contract terms sensitive to changes in crop markets.

Transaction cost was also ignored. However, in this setting, this cost would be minimal and limited to the cost of negotiating the broad-based contracts with the regional agriculture. Most likely, the designated buyer would negotiate with entities such as irrigation districts or ditch service areas rather than individual farmers.

In summary, this study evaluates the effects of irrigation technology and water right priority on contingent contracts for irrigation storage to supplement streamflow for salmon recovery. It is shown that substantial quantities of water could be obtained at relatively modest cost, with a major advantage of being able to use existing storage capacity to shape downstream flows during critical periods and, importantly, without causing the long-term retirement of some exiting irrigated acreage. Knowledge of how irrigation technology and water priority right affect the agricultural cost of releasing stored water supplies provides instream interest groups with a tool for cost-effectively achieving streamflow management goals in an irrigated river basin. While many questions about contract implementation remain unanswered, this study describes a means to increase the flexibility of water allocations in an overappropriated river basin to better meet the needs of environmental concerns.

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