Journal of Agricultural and Resource Economics 22(2):208–221

Agriculture to Instream Water Transfers under Uncertain Water Availability: A Case Study of the Deschutes River, Oregon

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Prior appropriations of river flows (primarily to agriculture) have greatly reduced flow in many Oregon streams, causing major changes in stream ecosystems. This study focuses on trade-offs between instream and agricultural uses for the two largest irrigation districts in Oregon's Deschutes River basin. Both short- and long-term water lease strategies are examined, as are requirements now in place that water leases be accompanied by fallowing land formerly served by the leased water. The low-cost strategies combine canal lining with reductions in farmer's per acre water use. Short-term leases are less costly than long-term leases.

Key words: instream flow, irrigation, parametric programming, stochastic programming with recourse, water market

Introduction

The prior appropriations doctrine governs water use in the western United States. Under this law, landowners can claim the right to divert a specified amount of water onto their land, as long as the water is put to a "beneficial" use. Historically, instream water uses were not recognized as a beneficial use and did not have water right status. As out-of-stream diversions have increased, there has been a notable change in the ecosystems of many streams in the West. In an attempt to stop further damage to these ecosystems, several western states passed legislation declaring instream flows a beneficial use. Consequently, states can now claim unallocated water for instream use (Livingston and Miller; McKinney and Taylor).

Legal recognition that instream flows are a beneficial use will not, by itself, solve the problems in many western streams. Some streams are fully appropriated, so instream rights can be used only in high water years. New storage facilities that could supply water for instream rights are generally not feasible, because most cost-effective sites have been developed.

The legal and economic implications of creating beneficial instream use has received extensive attention in the literature (Thompson; Anderson; Daubert and Young; Ward; Loomis; Griffin and Hsu). If new supplies are not developed, the remaining method to provide greater instream flows is to transfer water from existing uses to instream use. Currently, transfers have high transaction costs, such as identifying potential buyers and sellers, as well as legal fees to validate and transfer an existing water right. Because

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This material is based on work supported by the Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture, under Agreement #95-01794. Manuscript #11124 of the Oregon Agricultural Experiment Station.

transfers are so rare and the uncertainty about the process and benefits so great, most water rights holders have little reason to consider selling or leasing their water rights. A formal market to transfer water, along with the legal structure to support such transfers, would be a major step toward facilitating water use transfers to improve stream habitat.

Agriculture uses nearly 90% of the water consumed in the western United States (Rosen and Sexton). Irrigating low-value and surplus crops, while trying to develop new and usually expensive water supplies, is an inefficient use of resources (Colby). Reducing irrigated acreage is often less costly than developing new supplies (Young). Although agriculture could provide water to meet new demands, such transfers are voluntary. Analyzing agriculture's potential to participate in a water market requires estimating the value of water in agricultural production and comparing it to a market price. Profit-maximizing irrigators will lease their water when it is more valuable in the market than in crop production. A water market can motivate farmers to adopt technologies that reduce water loss, making more water available for other uses.

Low instream flow during various times of the year is a major concern in the Deschutes River basin of central Oregon. The major irrigation districts divert water near Bend, resulting in very low river flow between Bend and Lake Billy Chinook (Bureau of Reclamation). Low summer flow results in higher water temperatures and an increase in predator species (Calvillo). The irrigation districts hold sufficient water rights to dry up the river during the summer, but they have agreed to leave a nominal amount of water [about 30 cubic feet per second (cfs)] in the river during irrigation season. Most of this stretch of the Deschutes River has been designated a wild and scenic waterway by the state. The flow recommended to meet recreational, fish, and wildlife needs in wild and scenic waterways is 250 cfs (80,000 acre-feet) throughout the year (Oregon Water Resources Department).

Buyers of water for instream use can seek one-year (short-term) or multiyear (long-term) contracts. Farmers might respond differently to these contracts if water supplies were uncertain. Water supplies in the Deschutes basin depend on winter snow pack in the nearby Cascade Mountains. Most reservoirs in the basin store spring runoff until it is needed for irrigation, with only a small buffer to protect against drought. Snow pack has varied considerably, resulting in substantial variability in irrigation water, particularly for irrigators holding more junior rights. If a water market were created to transfer water for instream uses, how might current water users react? Would it be preferable for a farmer to fallow acreage and lease the corresponding water rights for instream use, or to invest in water-saving technologies and farm with a reduced water supply? The profitability of capital investments to reduce farm water use is reduced because water savings generated are not needed in abundant water years. Under such circumstances, are short-term water-saving strategies, such as fallowing land in water-short years, preferable to capital investments? How much compensation should farmers seek for short-term and long-term leases?

Complicating the farm decisions is the role of irrigation districts supplying water to farms. The districts have large (up to 50%) delivery losses from operating unlined canals over lava rock and porous soils. Canal lining is one method to reduce these losses and recover water for instream use. However, uncertain water supplies and costs make lining a less than clear choice to save water. Given the uncertainty of supplies and the need to keep more water instream, should the districts encourage farmers to adopt water-saving practices and permit them to sell conserved water or conserve water through canal lining?

Using water-saving technologies to help rehabilitate river ecosystems seems contrary to recommendations from other reseachers. Huffaker and Whittlesey, for example, argue that canal lining and new irrigation technologies create the illusion of water conservation, when in reality they do not alter the water supply in a river basin. This argument applies to the Deschutes River basin. Almost all water leached into the aquifer eventually returns to the Deschutes River before it discharges into the Columbia River. But the issue in the Deschutes basin is not one of total supply, but where the supply is located. Spring recharge occurs well below the low flow area, so provides no benefit to the ecosystem in that area. In short, any decision that results in less water diverted during low flow benefits the instream habitat.

In this article, we use a stochastic programming with recourse model to evaluate the potential impact of a water market when water supplies are uncertain. Issues to be addressed include (*a*) How much water can be bid away from agriculture in the study area at different market prices? (*b*) Which of the two water districts considered is a better low-cost water source for the market? (*c*) What might farmers do to free up water for lease in a market? (*d*) How cost effective is canal lining compared to changes in farm irrigation technologies? and (*e*) How does water flow uncertainty cause results to differ from certain water delivery?

Study Area

Several irrigation districts use Deschutes River water, but most are small and primarily serve hobby farmers. Two districts, North Unit and Central Oregon, serve almost 70% of the irrigated acreage in the area and provide water for almost all commercial farms in the Deschutes basin. Crops produced in these districts include garlic seed, carrot seed, bluegrass seed, peppermint oil, wheat, alfalfa hay, grass hay, grain hay, and pasture. The North Unit Irrigation District (NUID) has the most junior instream water rights for Deschutes River irrigation water and generally must rely on its storage water rights to serve 59,000 acres. NUID farm water deliveries have averaged just over two acre-feet per acre since 1986. The Central Oregon Irrigation District (COID) distributes water to 10,000 acres of commercial irrigated agriculture and 35,000 acres of smaller, hobby farms. COID has senior instream water rights as well as storage water rights. The more senior rights held by COID irrigators account for greater water deliveries than NUID irrigators receive. Water deliveries to COID rights holders average about four acre-feet per acre, or twice NUID deliveries. Water in both districts is priced at a flat, per acre rate. In above average water years, NUID farmers may purchase water above their two acre-feet base allotment at a higher per acre-foot price.

Method

Returns to land and water rights (Π) when water can be traded is represented as

$$\Pi = LR + WS, \tag{1}$$

where *LR* is land rent and *WS* represents returns generated by the sale of water for nonagricultural uses. On the highly productive, irrigated soils in the Deschutes basin, land rents for about \$100 per acre. Lower-quality soils can rent for half this amount. Because rainfall in the area averages about 10 inches per year, land without water can only be used for low-production livestock forage, which generates almost no positive return. Consequently, both *LR* and *WS* can be treated as the total value of water rights to the landowner.

Long-run returns to the farm operator (*RF*) can be calculated as

$$(2) \quad RF = \sum_{c} \sum_{p} \sum_{t} Q_{cpt}[[YLD_{cpt}(W_{cpt})P_c] - RL_{cpt} - MC_{cpt} - FC_{cpt} - RM_c] - LR,$$

where Q_{cpt} is the acres planted to the *c*th crop using the *p*th permanent irrigation technology and *t*th temporary irrigation technology. YLD_{cpt} is the per acre crop yield function, which is influenced by the quantity of water (W_{cpt}) applied. P_c is crop price, RL_{cpt} is the return to labor, MC_{cpt} represents material (e.g., fertilizer, seed) and harvest production costs, FC_{cpt} is the fixed costs of production, and RM_c is the return to risk and management. If farms in the study area are operating in long-run equilibrium, economic profits (*RF*) will tend toward zero.

Solving for land rent yields

$$(3) \quad LR = \sum_{c} \sum_{p} \sum_{t} Q_{cpt}[[YLD_{cpt}(W_{cpt})P_c] - RL_{cpt} - MC_{cpt} - FC_{cpt} - RM_c].$$

Estimates for P_c, RL_{cpt}, MC_{cpt}, and FC_{cpt} are commonly reported in enterprise budgets. Returns to risk and management are much more difficult to estimate. These costs must also be considered if one is to estimate water value as reflected in land rents. To estimate returns to risk and management, we identified a typical crop rotation in each irrigation district. We used current enterprise budgets and land rents in the study area to estimate *RM*. These costs were calculated as a percentage of the rotation's gross receipts. The resulting percentages were used to estimate returns to risk and management for each crop considered within each irrigation district. This approach has the added advantage of partially calibrating the cost data if enterprise budgets fail to correctly represent production costs.

Long-Run Water-Saving Strategies

The major irrigation technologies used in the study area are furrow and sprinkler irrigation. Farmers have additional irrigation technologies that can be adopted to improve efficiency. The current and alternative technologies are outlined in table 2. All technologies require an initial capital investment and save water every year, whether the extra water is needed or not. Furrow irrigation involves applying water to individual, parallel, evenly spaced furrows or trenches in a sloped field. Gated pipe or syphon tubes can be used to furrow irrigate. A pumpback system collects runoff and reuses the water. Surge furrow uses an automated valve to apply water intermittently. Sideroll sprinklers are a linear, raised sprinkler system. Center pivots are another sprinkler technology more efficient than sideroll. Laser leveling allows more uniform water distribution by eliminating high and low points on a field. Flood is the most inefficient irrigation technology and is only used to irrigate pasture in the COID.

Short-Run Water-Saving Strategies

Farmers in the study area can use irrigation scheduling, alternate furrow, alternating furrow, and deficit irrigation to reduce water use in any year. Irrigation scheduling involves monitoring the soil water content and crop water use to ensure that water application matches crop needs. Alternate furrow means irrigating every other furrow throughout the season, so water never flows down half the furrows. With alternating furrow, every other furrow is irrigated during an irrigation set. The furrows not irrigated in one irrigation set are irrigated in the following set.

Deficit irrigation involves applying less water than needed to get maximum yields. A computer algorithm, based on a conceptual model by Warrick and Yates, was used to estimate the relationship between water application and crop yield (Connor). This model uses irrigation system efficiency and deep percolation to influence yield as a function of applied water. Specifically, it estimates the percent of a crop's maximum yield in response to water application. The results are entered as the quadratic function:

$$PY_{cpt} = B0_{cpt} + B1_{cpt}W_{cpt} + B2_{cpt}\,(W_{cpt})^2, \tag{4}$$

where PY_{cpt} represents percent of maximum crop yield, and W_{cpt} is the associated water application (in inches). PY_{cpt} is then used to calculate yield:

$$YLD_{cpt} = PY_{cpt}MY_{c'}, \tag{5}$$

where MY_c is the maximum potential crop yield.

Mathematical Programming Model

Parametric mathematical programming is commonly used to estimate price-quantity relationships when market data do not exist (see Kehmeier et al. as an example). The influence of uncertain water supplies on farmers' willingness to lease water necessitated using a mathematical programming model that could incorporate RHS risk. The model also had to allow for sequential decisions made by farmers; decisions made about long-term water conservation investments and long-term leases. Once the water supply becomes known, short-term water-saving strategies may be used to balance supply and demand in drought years. This situation can best be modeled using a stochastic programming with recourse (SPR) approach.

SPR is used when modeling sequential decisions intermingled with risky events. The method contains elements of mathematical programming, decision tree analysis and stochastic dynamic programming. Like decision tree analysis, SPR identifies an optimal "first decision" by considering the possible outcomes, their probabilities of occurrence, and subsequent decisions that can be made to rectify or capitalize on an earlier decision. Decisions at any step in the process can be constrained as in any mathematical programming model. McCarl and Spreen term SPR " . . . perhaps the most satisfying of [all] risk models" (p. 14–42).

The general model formulation is

$$\max Z = \sum_y \sum_c \sum_p \sum_t \rho_y Q_{ycpt}[[YLD_{cpty}(W_{cpty}) - VC_{cpty}(W_{cpty})] - OC_{cpt}] + \sum_y \rho_y[WS_yWP - EW_yPP] \tag{6}$$

Table 1. Historical Water Deliveries by Irrigation District

Year	North Unit Irrigation District (NUID)	Central Oregon Irrigation District (COID)
	(acre-feet/acre)	
1986	2.75	4.63
1987	2.75	4.42
1988	2.25	4.25
1989	2.75	4.25
1990	2.25	4.25
1991	1.85	4.06
1992	1.30	3.81
1993	2.75	3.81
1994	1.70	4.25
1995	1.60	4.01

subject to

$$(7)\qquad \sum_c \sum_p \sum_t Q_{ycpt} \leq TA_y \ \forall y,$$

$$(8)\qquad \sum_c \sum_p \sum_t W_{cpty} + WS_y \leq TWA_y \ \forall y,$$

$$(9)\qquad \sum_c \sum_p \sum_t W_{cpty} - WP_y + WS_y \leq FRA_y \ \forall y, \quad \text{and}$$

$$(10)\qquad \sum_t \sum_c Q_{ycpt} - \sum_t \sum_c Q_{xcpt} = 0 \ \forall p; \quad y = 1, \ldots, Y-1; \quad x = 2, \ldots, Y.$$

The objective function (6) maximizes returns to land given y possible irrigation water deliveries for each irrigation district and ρ_y probability that the y delivery occurs. Table 1 is a summary of water deliveries in each district over the last decade. These historical deliveries are considered representative of long-term supplies. The probability of delivery y occurring was calculated as the total years of delivery y divided by the number of years reported in table 1 (ten). VC_{cpty} represents all costs in (3) that vary with yield and OC_{cpt} represents all other production costs. To facilitate solution of the model, YLD_{cpty} was linearized using 5% water application increments.

Water sales (WS_y multiplied by WP) represent additional returns to the land. When NUID farmers purchase additional water, they pay the incremental purchase price (PP) times the quantity purchased (EW_y). The EW_y variable is bounded at zero in the COID model. Land used to produce all crops under all combinations of permanent and temporary irrigation technologies was limited in (7) to be less than total farm acreage. Farm size was set at 500 acres for the NUID farm and 300 acres for COID. Both sizes were thought by extension agents to be typical of commercial farms in the districts.

Equation (8) ensures that total water used on all crops under all technologies for each diversion outcome (W_{cpty}) plus water sold in diversion year y is less than total water available to the farm in diversion year y (TWA_y). Equation (9) calculates the amount of additional water purchased by NUID farmers. Constraint (10) ensures that total acreage in a permanent irrigation technology is held constant across all possible delivery outcomes.

Table 2. Efficiency and Cost Assumptions for Irrigation Systems

System	Estimated Efficiency[a] (% water applied)	Deep Percolation[b] (% water applied)	Fixed Cost ($/ acre)	Labor (hours/ set/ acre)
Furrow, syphon tubes (Base tech.)	50.0	25.0	2.16	0.25
Furrow, gated pipe	50.0	22.5	9.41	0.25
Furrow, pumpback	70.0	30.0	8.17	0.05
Alternate furrow, syphon tubes	60.0	22.5	1.08	0.17
Alternate furrow, gated pipe	60.0	22.5	8.33	0.17
Alternate furrow, pumpback	75.0	25.0	8.17	0.05
Alternating furrow, syphon tubes	60.0	22.5	1.08	0.17
Alternating furrow, gated pipe	60.0	22.5	8.33	0.17
Alternating furrow, pumpback	75.0	25.0	8.17	0.10
Surge furrow	70.0	17.5	12.95	0.02
Surge furrow, pumpback	80.0	20.0	20.20	0.02
Sideroll sprinkler (Base tech.)	70.0	20.0	54.00	0.50
Center pivot	80.0	10.0	35.00	0.01
Flood (Base tech.)	20.0	45.0	negligible	0.09
Laser leveling, furrow[c]	55.0	22.5	15.66	0.50
Laser leveling, sideroll sprinkler[c]	72.5	17.5	25.25	0.25
Irrigation scheduling	↑ 10.0 (for each option)	↓ 5.0 (for each option)	1.86	negligible

[a] Efficiency is the percent water applied available for plant uptake. Source: Martin, Gilley, and Skaggs; USDA Soil Conservation Service and Montana State University Extension Service; Bernardo et al.; Shock, Barnum, and Mitchell; Miller and Shock; Henggeler, Sweeten, and Keese; Merriam and Keller; Mitchell, Light, and Page; Mitchell and Stevenson.

[b] Based on Whittlesey, McNeal, and Obersinner and Brown.

[c] Laser leveling is only allowed in combination with furrow-syphon tubes and sideroll sprinkler systems.

Constraints (6) through (10) represent the model in its most general form, which allows for nonuniform leasing of water. If the same amount of water is to be leased each year, reflecting a long-term lease arrangement, the variable WS_y must be collapsed to the single variable WS. When water supply is treated as certain, equations (8) and (9) are reduced from y equations to one equation each and the probability coefficient (ρ_y) is dropped.

Additional constraints were added to link crop establishment and production activities, as well as to prevent crop mixes that had long-term fertility and (or) disease problems. Garlic and carrot seed acreages were limited to 40 and 20 acres based on contract availability. Fifteen percent of COID land was required to be used for pasture or idle acreage, recognizing farms in this district typically have this proportion of poor quality land.

Results and Analysis

Description of Scenarios

Three leasing and irrigation management scenarios were analyzed for each irrigation district. The first, Base, allows only the irrigation systems that are widely used in the area (furrow and sideroll). Any water lease must be attached to idled land. The second, Alltech, allows farmers to adopt any of the feasible irrigation technology and crop rotation combinations, but requires acreage be fallowed. The third, Conserve, allows participation in Oregon's water conservation program which relaxes lease and fallow requirements. Conserve allows sale of water obtained by adopting water saving technologies.

Unlike the first two scenarios, Oregon's water conservation program involves adopting water-conserving technologies recognized as qualifying conservation practices and having the right to transfer some of the unused water. Without this program, the "use it or lose it" feature of the prior appropriations doctrine would require forfeiting conserved water to the state. All systems, except furrow and sideroll, were considered qualifying practices. Oregon's water conservation program does not require land to be fallowed in order to lease water. The exact portion of conserved water allocated to the state is determined on an individual basis, but the standard set under the law is 25%. Conserved water is the quantity of water diverted for production under the baseline systems, less the amount diverted after adopting a water-conserving technology. The state's portion is automatically left instream, reducing the quantity of water to be returned for instream use. An irrigator using Oregon's conservation program could sell or lease more water than someone not involved in the program.

Each scenario represents a way to free water to lease for instream flows. Each scenario, with varying water values in the lease market, illustrates how irrigators might react in their crop rotations and irrigation management. Initially, the models were solved without a water market. Water had no value other than for crop production, with varied and uniform leases representing short- and long-term agreements. The models were then reformulated and resolved by increasing water price $5/acre-foot over the previous formulation until reaching a price of $225/acre-foot.

The water rights in these two districts originally were set to accommodate loss from open, unlined canals. These losses were not viewed as a nonbeneficial use of water. Today, it could be argued that, with technological innovations, this seepage is an inefficient use of water and canals should be lined to eliminate it. More water could then be left in the river to help fish and wildlife environments by reducing water temperature. Model results were compared to the cost and amount of water gained by lining district canals as an alternative to obtaining water from commercial agriculture. The canal supply curves represent the water saved by lining or piping portions of the COID and NUID main canals and laterals.

The basic programming model selects the optimum crop mix, acreage, irrigation strategy, and water application for each representative farm, given the historical pattern of water deliveries within the irrigation district serving this farm. Water supply curves generated for annual uniform and variable leasing illustrate the minimum lease price irrigators are willing to lease their water. Each point on the supply curve is the profit maximizing combination of the total water leased annually for commercial agriculture in both districts. The crops produced, acreages, and irrigation technologies for the three scenarios are identified separately for each district.

Uniform Purchase

Figure 1 illustrates the water supply curves for a uniform, or long-term, water lease. Below $70/acre-foot, all water leased under Alltech, Base, and Conserve comes only

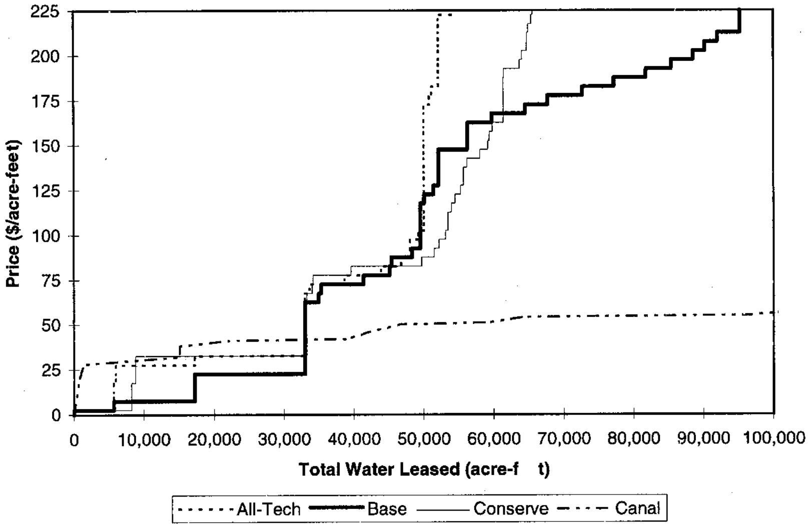

Figure 1. Uniform lease results for uncertainty analysis

from COID. This stems from two key factors, water availability and the crop values in each district. COID has the greater annual water allotment and produces lower-value crops than NUID.

The Base supply curve illustrates irrigator supply without adopting any new water-conserving practices. Water price is generally elastic from $0 to $25/acre-foot. Over 30,000 acre-feet could be purchased at $25/acre-foot, which would be over one-third of the amount needed to increase instream water sufficient to support recreation, fish, and wildlife. With so few water-conserving options, the presence of a water market causes the model to suggest that pasture, alfalfa, and grass hay not be produced. Grain hay also leaves the solution once the price reaches $25/acre-foot.

Under Alltech and Conserve, more technologies to conserve water are available. Some reduce production costs for the farmer. Water is more valuable to the farmer using Alltech or Conserve and it costs more to bid water away from agriculture. The crop rotation and irrigation strategies are nearly identical under Alltech and Conserve. Minor differences occur in crop acreage and some irrigation scheduling practices at $20/acre-foot and higher with the conservation programs in the lowest water year. COID irrigators receive about 4 acre-feet annually to irrigate crops that require 1.4 to 3 acre-feet. After accounting for irrigation system efficiency, sufficient water is available to meet crop requirements and the conservation program is not needed. Leasing the irrigator's portion of conserved water causes all COID land to be fallowed and all water leased at $75/acre-foot. With Alltech, this occurred at $70/acre-foot. Because irrigation deliveries are fairly uniform, deficit irrigation is never considered as a way to conserve water.

The NUID uniform purchase results show no water leased under Base at less than $60/acre-foot. When lease prices are below $60/acre-foot, all possible crops except peppermint oil are produced and bluegrass is the dominant crop. As water rises from $60 to $120/acre-foot, the model frees up water for lease by deficit irrigating wheat, bluegrass, and garlic in low water years. When water price is more than $120/acre-foot, wheat acreage begins to decrease and fallow acreage increases.

If irrigation strategies in the NUID are expanded to include the entire range of tech-

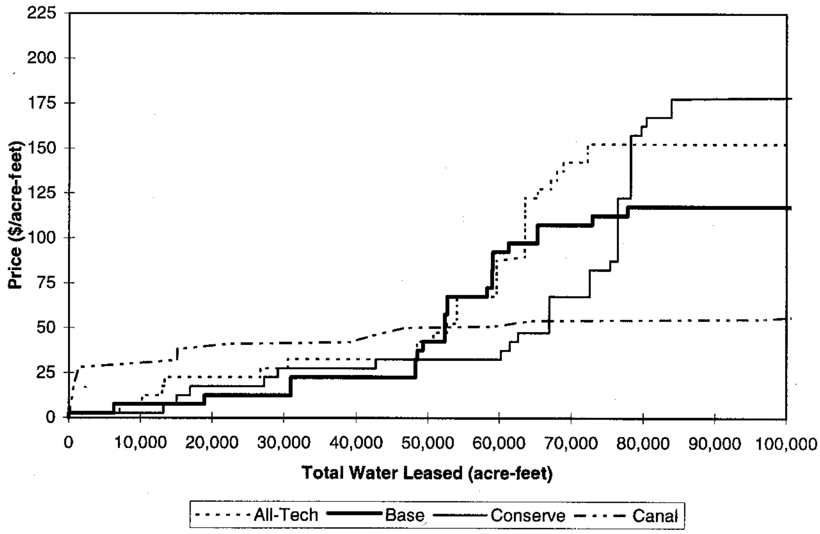

Figure 2. Nonuniform lease results for uncertainty analysis

nologies, water is usually supplied to the lease market at a higher price because it becomes more profitable to adopt irrigation technologies than simply fallow land or deficit irrigate crops. Surge flow irrigation is adopted on all acreage, with irrigation scheduling used on some crops. Water saved from the surge flow technology is used to produce more wheat and to reduce the severity of deficit irrigation in drought years.

The Alltech and Conserve results are quite similar. Conserve has a more lenient lease option in which a portion of "conserved water" can be leased without fallowing land. It increases the off-farm water supply over most price ranges. Because farmers cannot keep all their water savings, however, they fallow more land and deficit irrigate to produce their crops. A pumpback system also becomes economical under Conserve, although only at relatively high (+$145/acre-foot) water prices.

Lining canals to reduce delivery losses is another source of water. The supply curve for canal lining in both districts is also shown in figure 1. This option can provide a great deal of water to a water market in a narrow price range. More than enough water to meet the 80,000 acre-feet requirement for fish, wildlife, and recreation could be obtained for $60/acre-foot. Most of the 80,000 acre-feet saved from lining canals would come from COID.

Nonuniform Purchase

Annual lease agreements between farmers and instream users allow irrigators to decide how to use their water each season. Figure 2 illustrates the average annual water supply for short-term lease agreements from both COID and NUID. The crops produced and irrigation strategies followed are very similar to the long-term leases, but more water could be supplied for instream use at a lower price than before. Farmers could lease excess water in high water years at a low price, because sufficient water would be available to also produce a good crop.

Short- and long-term leases in COID result in very similar water supplies to a lease market, but all three scenarios show a slight increase in the amount of water leased with short-term leases. The most water available to lease increases from about 38,000 acre-feet with long-term leases to 42,000 acre-feet with short-term leases because the maximum water leased is no longer limited to 3.81 acre-feet per acre, the level in the lowest water year.

The NUID Base results reveal that water is not leased in the shortest water year until the lease price reaches $140/acre-foot. The initial lease price decreases as available water increases within a year. More NUID irrigators would participate in Oregon's conservation program than COID irrigators. High lease prices are required before all NUID land would be fallowed and all water leased because highly valued specialty seed crops are produced in the district.

Of course, canal lining represents an investment that conserves water regardless of the water supply in the Deschutes basin. Consequently, the supply curve for canal lining is the same for both short-term and long-term leases. With the short-term leases, however, the lower cost of buying water from farmers makes canal lining less profitable.

Certainty in Water Supply

This study emphasizes the need to consider an uncertain water supply when evaluating a water market to meet instream needs. Analyzing production decisions assuming constant, average, water availability ignores the possibility that irrigators would change practices to accommodate a single, low water year. Taking the average water diverted at NUID and COID farms and resolving the models with this water availability results in an increased willingness for agricultural users to supply water to the water market at a given price.

Eliminating the uncertainty of a low or high water year is more apparent in NUID than in COID because variability in water supply has been much greater in NUID than COID. The COID model results for a certain water supply are quite similar to an uncertain supply. In NUID, the uniform lease results are limited by the minimum water year in which only 1.3 acre-feet are available. Using a certain, average water availability of two acre-feet per year increases the minimum amount of water that can be leased each year and shifts the supply curves down and to the right (fig. 3). Crop and irrigation management are basically the same, but relaxing the lease limit increases the amount of water leased. Failure to consider uncertainty results in an overestimate of water supplied.

Summary

Low flows caused by irrigation diversions in the Deschutes River of central Oregon affect water quality in several stretches of the river. In low flow areas, water temperature and other factors are detrimental to fish habitat. The irrigation districts hold water rights to divert more water than the current flow, but have agreed to leave a nominal amount of water (30 cfs) in the river during the irrigation season. The river flow recommended for state scenic waterways to support recreation, fish, and wildlife requires 80,000 acre-feet (250 cfs) during the irrigation season.

A water market to reallocate water among irrigators and instream use is a way to keep water in the river and alleviate water quality problems. Two farm production models, one for each of the two largest irrigation districts in the Deschutes basin, were developed

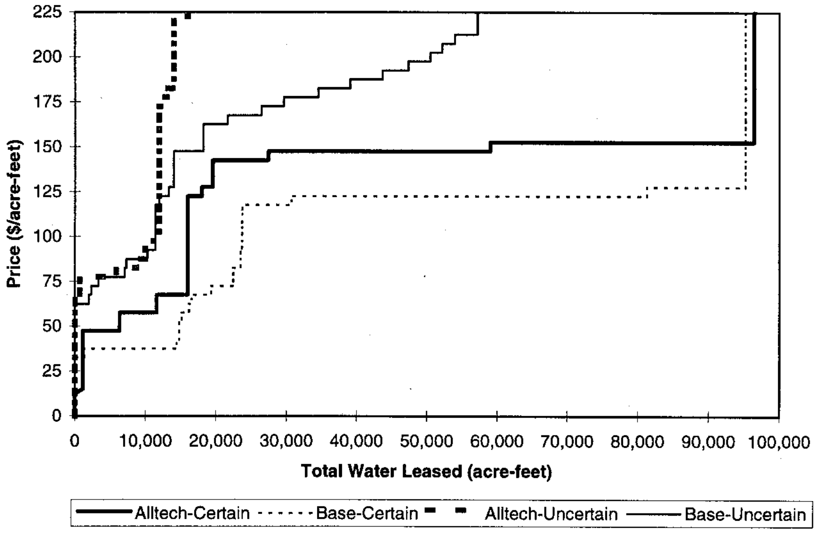

Figure 3. Uniform lease results in NUID with known and unknown water availability

to identify practices irrigators could use to free water for instream use and to estimate the value of water to commercial agriculture, or the minimum compensation needed by irrigators to lease their water. A stochastic programming with recourse model was used to identify optimal management under uncertain water supplies. Changes in farm water management were compared to costs of lining canals in the two districts.

The benefits of market approach to reallocating water was readily apparent in the results. COID was a better source of low-cost water than NUID because it has a greater per acre water endowment and lower-value crops are produced in it. Canal lining was also a relatively inexpensive source of water. When long-term leases were considered, the least-cost strategy was to obtain about half the 80,000 acre-feet by lining canals and the other half by purchasing COID water. A greater proportion of purchases from COID and NUID was the preferred strategy when short-term leases were considered. Of course, this short-term strategy provides additional water only in average-to-wet years. Current minimal stream flows would remain in drought years. Ignoring the uncertainty of water availability, especially in the NUID, results in overestimating the willingness of irrigators to lease their water. Because COID dominates as the water source at low prices, little difference exists between supply curves under certain and uncertain water supplies.

This study indicates that the current irrigation systems used in the region may not be the most economical or efficient. Changing irrigation methods may allow commercial agriculture to supply more water to a water market. Further demonstration experiments of water-conserving technologies will probably be needed in the area before widespread adoption occurs.

Other, smaller irrigation districts in the area provide water to farmers. These districts were ignored in this study because of their size and because they contain mostly hobby farmers. The general belief in the area is that hobby farmers value irrigation water at substantially higher prices than commercial farmers do (Main). This potential source of instream water should also be investigated.

To date, irrigation districts in the area have been reluctant to support more freedom to trade water with other districts or users. The agricultural community fears that trading will lead to a permanent loss of water rights. Farmers worry that the agricultural sector would shrink substantially in some areas if water moved to nonagricultural uses. However, if the state or conservation groups want to increase instream flow, they must purchase some water from irrigation districts. The results here provide some insight about the potential costs of increasing flows for those advocating for more instream flows and also provide farm operators some idea of their water's value.

[*Received February 1996; final revision received March 1997.*]

References

Anderson, R. L. "Conflict between Establishment of Instream Flows and Other Water Uses on Western Streams." *Water Resour. Bull.* 18(1982):61–65.

Bernardo, D. J., N. K. Whittlesey, K. E. Saxton, and D. L. Bassett. "An Irrigation Model for Management of Limited Water Supplies." *W. J. Agr. Econ.* 12(1987):164–73.

Brown, S. County Executive Director, Farm Service Agency, Madras OR. Personal communication, July 1995.

Bureau of Reclamation. "Water Loss Analysis: Upper Deschutes River Basin Water Conservation Project, Oregon; and Oregon Subbasin Conservation Planning, Oregon." Draft rep., Pacific Northwest Region, Boise ID, June 1993.

Calvillo, Y. M. "Bad News Bass." *Oregon's Agricultural Progress* 41(Fall 1995):12–15.

Colby, B. G. "Transactions Costs and Efficiency in Western Allocation." *Amer. J. Agr. Econ.* 72(1990):1184–192.

Connor, J. "Market Water Transactions as a Water Quality Policy: A Case Study of the Malheur River Basin, Oregon." Unpub. Ph.D. diss., Oregon State University, Corvallis, 1995.

Daubert, J. T., and R. A. Young. "Recreational Demands for Maintaining Instream Flows: A Contingent Valuation Approach." *Amer. J. Agr. Econ.* 63(1981):666–76

Griffin, R. C., and S.-H. Hsu. "The Potential for Water Market Efficiency When Instream Flows Have Value." *Amer. J. Agr. Econ.* 75(1993):292–03.

Henggeler, J. C., J. M. Sweeten, and C. W. Keese. "Surge Flow Irrigation." College Station: Texas A&M University, n.d.

Huffaker, R. G., and N. K. Whittlesey. "Agricultural Water Conservation Legislation: Will It Save Water?" *Choices* 10(4th Quart. 1995):24–28.

Kehmeier, P. N., T. M. Quigley, R. G. Taylor, and E. T. Bartlett. "Demand for Forest Service Grazing in Colorado." *J. Range Manage.* 40(1987):560–64.

Livingston, M. L., and T. A. Miller. "A Framework for Analyzing the Impact of Western Instream Water Rights on Choice Domains: Transferability, Externalities, and Consumptive Use." *Land Econ.* 62(1986): 269–77.

Loomis, J. "The Economic Value of Instream Flow: Methodology and Benefit Estimates for Optimum Flows." *J. Environ. Manage.* 24(1987):169–79.

Main, B. South Central Regional Manager, Oregon Water Resource Department, Bend OR. Personal communication, December 1995.

Martin, D. L., J. R. Gilley, and R. W. Skaggs. "Soil Water Balance and Management." In *Managing Nitrogen for Groundwater Quality and Farm Profitability,* eds., R. F. Follett, D. R. Keeney, and R. M. Cruse, pp. 199–235. Madison: Soil Science Society of America, Inc., 1991.

McCarl, B. A., and T. H. Spreen. "Applied Mathematical Programming Using Algebraic Systems." Unpub. MS., n.d.

McKinney, M. J., and J. G. Taylor. "Western State Instream Flow Programs: A Comparative Assessment." Instream Flow Information Pap. No. 18, National Ecology Research Center, Fish and Wildlife Service, U.S. Department of the Interior. *Biological Report* 89(1988):25–46.

Merriam, J. L., and J. Keller. *Farm Irrigation System Evaluation: A Guide for Management.* Logan: Utah State University Press, 1978.

Miller, J., and C. Shock. "The Effects of Surge Irrigation on Onion Yield and Quality, Irrigation Efficiency, and Soil Nitrogen Losses." In *Malheur County Crop Research 1992,* pp. 43–50. Spec. Rep. No. 924, Agr. Exp. Sta., Oregon State University, Corvallis, 1992.

Mitchell, A. R., J. E. Light, and T. Page. "Alternate and Alternating Furrow Irrigation of Peppermint to Minimize Nitrate Leaching." In *Central Oregon Agricultural Research Center Annual Reports, 1990–1992,* pp. 29–36. Spec. Rep. 922., Agr. Exp. Sta., Oregon State University, Corvallis, 1993.

Mitchell, A. R., and K. Stevenson. "Surge Flow and Alternating Furrow Irrigation of Peppermint to Conserve Water." In *Central Oregon Agricultural Research Center Annual Reports, 1993,* pp. 79–87. Spec. Rep. 930, Oregon State University, Corvallis, 1994.

Oregon Water Resources Department. "Deschutes River Scenic Waterway, Metolius Scenic Waterway Flow Needs Assessment." Draft rep., Oregon Water Resources Department, Salem OR, April 1991.

Rosen, M. D., and R. J. Sexton. "Irrigation Districts and Water Markets: An Application of Cooperative Decision-Making Theory." *Land Econ.* 69(1993):39–53.

Shock, C. C., J. M. Barnum, and A. R. Mitchell. "Alternate and Alternating Furrow Irrigation of Small Grain as Low Cost Options to Improve Irrigation Efficiency and Reduce Nitrate Leaching." In *Malheur County Crop Research 1993,* pp. 199–206. Spec. Rep. No. 936, Agr. Exp. Sta., Oregon State University, Corvallis, 1993.

Thompson, R. A. "Statutory Recognition of Instream Flow Preservation: A Proposed Solution for Wyoming." *Land and Water Law Rev.* 17(1982):139–54.

U.S. Department of Agriculture, Soil Conservation Service, and Montana State University Extension Service Staff. "Irrigation Water Management: When and How Much to Irrigate." Montana's guide sheet collection related to agriculture, Bozeman MT, 1989.

Ward, F. A. "Economics of Water Allocation to Instream Uses in a Fully Appropriated River Basin: Evidence from a New Mexico Wild River." *Water Resour. Res.* 23(1987):381–92.

Warrick, A. W., and S. R. Yates. "Crop Yield as Influenced by Irrigation Uniformity." In *Advances in Irrigation,* ed., D. Hillel, pp. 169–80. Orlando: Academic Press, Inc., 1987.

Whittlesey, N. K., B. L. McNeal, and V. F. Obersinner. "Concepts Affecting Irrigation Management." In *Energy and Water Management in Western Irrigated Agriculture,* ed., N. K. Whittlesey, pp. 101–27. Boulder: Westview Press, 1986.

Young, R. "Local and Regional Economic Impacts." In *Water Scarcity: Impacts on Western Agriculture,* eds., E. Englebert and A. Scheurmg, pp. 244–65. Berkeley: University of California Press, 1984.