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WATER CONSERVATION OPPORTUNITIES IN PACIFIC NORTHWEST IRRIGATED AGRICULTURE: A WATER RIGHTS MARKET APPROACH

by

Jack E. Houston, Jr. and Norman K. Whittlesey*

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*The authors are Assistant Professor, Department of Agricultural Economics, University of Georgia and Professor, Department of Agricultural Economics, Washington State University, respectively.

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ABSTRACT

Opportunities exist for conservation of water and electricity used in Pacific Northwest irrigation. A mathematical programming model was developed to estimate agricultural responses to water and energy conservation policies. The potential of a water market for exchanges between agriculture and the hydropower sector is considered for increasing regional energy production.

Water Conservation Opportunities in Pacific Northwest

Irrigated Agriculture -- A Water Rights Market Approach

Irrigated agriculture is the largest single consumer of water in the Pacific Northwest (PNW). It is also a major consumer of electrical energy in Washington, Oregon, and Idaho, currently using some five percent of the region's electrical power [Northwest Power Planning Council (NPPC)]. With over two-thirds of PNW electrical power dependent on hydroelectrical generation, agriculture imposes another major impact on power supplies by diverting water from the Columbia River system. The hydropower losses to this water use are of concern to water and energy management agencies in the PNW. Rapid growth in the regional economy over the last two decades has intensified competition among the multiple instream and consumptive uses of Columbia River Basin (CRB) water--hydropower, irrigation, fisheries, navigation, recreation.

Irrigated agriculture is an important sector in the regional economy and has grown rapidly during the past 20 years. There are 8.3 million irrigated acres which produce over 65 percent of the regional direct farm income. Over one-half of this land is irrigated by pressurized systems (69 percent in Washington), requiring some six million megawatt hours of electricity for lifting water, delivering water, and pressurizing irrigation systems. Over 4.9 million acres are irrigated from surface sources which have a direct relationship with hydroelectric generation, withdrawing an estimated 20.7 million acre-feet of water annually [Houston].

Diversions for irrigation above Grand Coulee Dam on the Columbia River or American Falls Dam on the Snake River have much greater opportunity costs for hydropower production than withdrawals lower in the system.[1/] Assuming a replacement cost of 40 mills per KWH for thermal generation, one acre-foot of water diverted and consumed above Grand Coulee Dam (1167 ft. cumulative head) displaces 1015 KWH of potential hydrogeneration with a value of $40.60. One acre foot of water diverted from above McNary Dam (316 ft. cumulative head) has an opportunity value for hydropower production of $11.00.

Return flows of Columbia River surface water withdrawn or diverted for irrigation in most production areas reenter the river system within the same reach (i.e., above the same hydroelectric dam) as withdrawals. In these areas hydropower losses are based on consumptive use, evapotranspiration requirements and losses to deep percolation not returned to produce hydroelectricity at downstream units. In other areas such as the Columbia Basin Project, Owyhee, and Neely-Milner, however, return flows reenter the system one or more reaches downstream from withdrawals. In these production areas, hydropower losses incurred by return flows bypassing generation units are added to the consumptive use losses above. Thus, the impact of irrigation on hydropower production is determined by the location of water diversions from the hydropower system.

National legislation in the form of the Pacific Northwest Power Planning and Conservation Act (P.L. 96-501) was passed in December, 1980, establishing energy conservation as a major goal. The Pacific Northwest Power Plan prescribes that the irrigation sector reduce electricity demand by 30 percent by the end of the 1980's through adoption of more

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[1/] One acre foot of water dropped through one foot of head is capable of generating 0.87 kilowatt hour (KWH) of electricity.

energy-efficient delivery and application systems and water scheduling. The Plan further states, "In a region that produces most of its electricity from hydropower at a generation cost of only 4/10 of a cent per KWH, every effort must be made to take maximum advantage of the hydropower system consistent with the goal of protection, mitigation and enhancement of fish and wildlife." (NPPC) The linkage between agricultural water conservation in the Columbia-Snake River system and hydropower production is an important factor to consider in meeting the stated conservation goals. There is also a strong relationship between the amount of water and the amount of energy used in the irrigation sector. An integrated approach acknowledging these linkages and the impacts of related water and energy policies appears desirable for all parties concerned--the irrigated agriculture sector, regional water and energy management agencies, and the general public.

This integration of conservation approaches provides additional provocation and possibilities for a water rights market, generally in the vein of proposals and conditions set forth by Bromley, Ditwiler, Howitt et al., LeVeen and Stavins, and others. A precondition for the establishment of a workable water rights market is that the rights to water use are clearly defined and transferable. Though many institutional constraints on transfers presently exist, Ditwiler suggested that existing regional irrigation districts in most cases have rights approximating those necessary for a workable water market if such powers as annexation and consolidation of territories are considered. Conserved water within a district which has a higher value in an alternate use inside or outside the district could be transferred with the district acting as the broker or transporter, or both. The objective of this paper is to outline potential irrigation water conservation alternatives and assess their regional water and energy market impacts using a multi-level mathematical programming model developed by the authors.

Modeling the Water Rights Policy for Conservation

A two-level mathematical programming model was developed to simulate the decision-making processes and predict the responses of PNW irrigators confronted with alternative water and energy policies, including the water rights market approach described above. This conditional normative method can accurately model production and price impacts of the aggregate irrigated agriculture sector. The first stage of the model divides the irrigated areas of Washington, Oregon and Idaho into 45 specific geographic production areas. Further subdivision to distinguish between groundwater and surface water sources and some specialized farm types results in 79 production area models. Each of these production area models contains detailed information about water source, irrigated acreage, crop alternatives, irrigation systems, pump lift, energy use, and hydropower tradeoff for surface water diversion.

The first stage production area models are used to estimate farm level reaction to water and energy resource management policies. For example, a water market that would allow the exchange of water between agriculture and hydropower uses can be evaluated at alternative values of hydropower. Hydropower loss coefficients reflect the reach diversion, consumption, and return flow characteristics of each production area. The amount of water conserved in agriculture and offered to the market can be estimated while obtaining information about other resource use impacts and changes in agricultural output.

The estimates of water and energy use, agricultural output, and potential hydropower production from the production area models (stage one) are then used as input in creating the second stage model. This second stage model, maximizing the Samuelson-Enke type of net social payoff, aggregates resource use impacts and evaluates the market price effects of changes in agricultural production due to a particular policy or resource management plan. Prices of crops responsive to changes in PNW irrigated farm production--potatoes, fruits represented by apples, and forage crops--are modeled endogenously using the Duloy and Norton method. Prices of other representative crops are assumed infinitely elastic within the relevant range of irrigated production in this region.

The product values obtained at the second level of optimization are returned to the first level models for adjustment of reactions to the policy or management plan. This iterative process continues until a market equilibrium effect is achieved in a manner similar to the Dantzig-Wolfe decomposition principle. Competitive equilibrium through the maximization of net social benefits and the tracking of net farm revenue provide comparative information on the implications for resources, production, income, and market price impacts of alternative water management policies.

The results reported in this paper focus upon the potential sale of water from agriculture to the hydropower sector based upon the opportunity cost of hydropower production. In this instance, the value of the potential hydropower production of water was parametrically varied from zero to 40 mills per KWH.

Responses to water policy and price changes in the short-run versus the long-run are distinguished by assumed abilities to replace or modify irrigation water delivery systems and/or irrigation application systems in the long-run only. Irrigation system replacement also restricted the allocation of crops to each respective system.

In the short-run model results reported here, no change in technology is assumed, nor is replacement of irrigation systems necessary. Irrigators were assumed to have full water transfer rights and would sell or receive compensation for water diverted from agriculture to the energy sector at the opportunity value applicable within each area.

Selected Production Area Results

The results at the production area level demonstrate the wide locational differences in conservation response to water market values and the large potential for conservation of water, even in the short-run. Allowing the sale of water between agriculture and hydropower provides that, as the value of water for hydropower increases, net returns to agriculture can be improved by reducing agricultural water consumption and selling the conserved water for energy production. Relative increases in agricultural income appear, as expected, to be greatest in the upriver production areas of Southern Idaho and Central Washington where the opportunity value of water in hydropower production is largest.

Table 1 shows the percentage increases in net returns to land and water as the hydropower value is raised from zero to 20 and then to 40 mills per kilowatt hour (m/KWH). Ferry/Stevens and the Columbia Basin Project areas, which divert water above Grand Coulee Dam, show quite substantial changes in net returns, as do the Boise, West Side and Neely/Milner areas of Southern Idaho. Changes in net returns due to sales of conserved water in the lower stretches of the Columbia River System, such as Big Bend East and the Deschutes areas, are relatively minor.

Table 1. Production Area Increases in Net Farm Returns Under Alternative Hydropower Values.

Production Area (Surface Source)	Cumulative Head at Diverstion (ft.)	Present Irrigated Acreage (Acres)	Percent Change in Net Returns to Land and Water	
			20 m/KWH	40 m/KWH
Ferry Stevens (Wa)	1167	21,700	6.91	23.32
Columbia Basin Project (Wa)	1167	517,900	1.57	10.95
Big Bend East (Wa)	393	61,100	.05	.11
Deschutes (Or)	142	207,500	.00	.02
Boise (Id)	1336	409,700	1.49	7.01
West Side (Id)	1636	583,600	1.72	8.05
Neely, Milner (Id)	2045	172,300	5.88	20.81

The geographic location of irrigation within the region will heavily influence the opportunity to sell water for hydropower uses. A water market would not affect irrigation water use in an area like Deschutes but could significantly induce conservation measures in areas with a large hydropower tradeoff potential for water use.

Potential hydrogeneration from the water conserved in irrigation in these selected production areas and the corresponding decrease in electricity demand for irrigation are shown in Table 2. Even at the conservation value of 20 m/KWH for hydropower production, the southern Idaho areas demonstrate an opportunity for substantial water conservation. The West Side and

Neely/Milner areas, for example, each conserve water with the potential of over 138 GWH (10^6 KWH) hydropower generation. Nearly 604 GWH of hydropower potential has been saved in the Columbia Basin area at the 40 m/KWH rate, the opportunity cost of thermal electricity production. Boise, the West Side, and Neely/Milner areas likewise demonstrate large potential sales of conserved water at the 40-mill level.

Table 2. Hydropower Equivalent of Water Conserved and Electricity Use With Alternative Hydropower Values.

Production Area (Surface Source)	Hydropower Conserved		Electricity Use in Irrigation		
	20 m/KWH	40 m/KWH	0 m/KWH	20 m/KWH	40 m/KWH
	----------GWH--------		--------------GWH--------------		
Ferry, Stevens (Wa)	0	13.31	19.85	17.37	14.02
Columbia Basin Project (Wa)	0	603.55	419.46	404.88	403.64
Big Bend East (Wa)	0.29	0.29	59.69	59.69	59.69
Deschutes (Or)	0	0.50	151.98	151.98	151.98
Boise (Id)	87.85	215.20	57.82	53.15	18.79
West Side (Id)	138.43	272.92	88.04	79.55	44.78
Neely, Milner (Id)	138.67	150.01	30.44	14.54	14.12

The water conserved in irrigation and sold for hydropower production is accomplished through changes in cropping patterns, reductions in irrigated acreage, and deficit irrigation on grain and forage crops. In general, these marginal changes in water consumption were accomplished without significant reductions in the value of agricultural production.

The areas that achieved major reductions in water consumption were those that had high opportunity costs for water and potential for water conservation as represented by low-valued agricultural uses of water. Some areas had significant acreages of pasture and hay, which are large water users with relatively low values per unit of water consumed, although other crops, such as feed grains, were also sacrificed as the opportunity cost of water increased.

It will be noted that the areas that reduced water consumption were not necessarily the same ones that reduced on-farm energy use. The Columbia Basin Project provided over 600 GWH of electricity in increased hydropower production by reducing water consumption. However, this area showed only slight decreases in energy use. In these cases, the water conservation was largely achieved on lands irrigated by gravity flow methods while showing only small changes in water use on sprinkler irrigated lands. In fact, due to the peculiar geographic location of the Columbia Basin project, there was some shifting of relative crop acreage from gravity flow to sprinkler systems in order to reduce water diversion and thereby increase hydropower production. Areas of southern Idaho had changes in both water consumption and electricity use. These areas turned heavily to deficit irrigation on forage crops and, in some cases, actually reduced total irrigated acreage. All irrigated areas were provided with the alternative of dryland grain production, usually on a summer fallow rotation.

Regional Impacts of a Water Market

When the value of water for hydropower use is varied from 0 to 40 m/KWH, the net social benefits and net returns to irrigation both increase. Net social benefits are a measure of net benefits from agricultural production--net returns to agricultural producers plus the value to consumers from lower commodity prices plus the value of water sold for energy production. The net returns to irrigation measure the net value of agricultural commodity sales and sales of, or compensation for, water conserved. Table 3 summarizes these changes, along with water diversion, increased hydropower production, and electricity use at alternative levels of hydropower value.

Table 3. Regional Level Responses to Changes in the Value of Hydropower

Type of Response	Units (10^6)	Hydropower Value (m/KWH) 0	10	20	30	40
Net Social Benefits	$	4097	4101	4110	4123	4140
Net Returns to Irrigation	$	1395	1395	1396	1397	1407
Total Water Diversion	ac.-in.	364	361	352	344	339
Hydroelectric Power From Water Conserved	KWH	360	538	998	1612	1895
Electricity Use	KWH	5791	5761	5680	5654	5579
Total Irrigated Acreage	acres	8.127	8.125	8.078	8.006	7.925

The welfare of agricultural irrigators increases as the opportunity value of water increases and the water market concept is exercised. Through a hydropower value of 30 m/KWH the net returns to agricultural production increased slightly, though total water diversions were decreased by 20 million acre inches. Most of this water was taken from pasture, which now provides a near zero marginal value to water, other forages, and low-valued grain crops. In many cases, it was possible to achieve water conservation through deficit irrigation and reduced yields without affecting irrigated acreage or significantly affecting the net value of farm product sales.

The largest increments of water conservation came after the hydropower value surpassed 20 m/KWH. At the higher opportunity costs for water, it became profitable for farmers to reduce irrigated acreage and turn to other extreme measures to conserve water. The value of agricultural production went up as these measures were taken due to the inelastic demand for some agricultural commodities. This is evidenced by the increasing net returns to irrigation as hydropower values increased.

The water conserved at a hydropower value of 20 m/KWH has a generation potential of 998 GWH. At 40 m/KWH the hydropower potential from water conserved in agriculture is 1895 GWH, with a value of $75.8 million. Additionally, 212 GWH less electricity is demanded for irrigation at the 40 m/KWH value, a 3.7 percent reduction. Total energy saved and produced would be 2107 GWH while actually increasing the value of agricultural production and raising net social benefits from irrigated agriculture by $43 million. For a comparison of these values, a 1200 MW nuclear plant would produce approximately 7500 GWH of electricity per year. The nuclear plant cost would be more than $5 billion and the full cost of electricity produced would exceed 50 m/KWH. Thus, both the agricultural and nonagricultural sectors would gain through the use of a water market such as described here.

Short-run changes in acreages of crops grown are relatively small within the region, total irrigated acreage declining from 8,127,000 acres to 7,925,000 acres, or by 2.5 percent. However, most of these changes occur in the upper CRB areas and are limited to a few crops, primarily alfalfa, pasture, field corn and sugar beets. Flexibility constraints limited the upward adjustments of potato, apple, grape, and hop acreages, while limiting the downward shift from pasture, alfalfa, mint, and sugar beets. Relaxing or removing these constraints would allow additional conservation opportunities in a long-run setting. Some irrigation water conservation occurred through decreased rates of water application on the alfalfa, pasture, field corn, and wheat crops.

Conclusions

It is evident that irrigated agriculture in the PNW can play a major role in future water and energy management policies for the region. The model results described in this paper indicate a significant potential for water and energy conservation in irrigated agriculture. Under the assumption of transferable water rights, the regional social welfare could be increased by allowing the sale of water from agriculture to the nonagricultural sector. Agricultural income could be raised while the region could avoid some of the problems and capital costs of supplying energy through thermal power plants. The increased stream flows from reduced upriver irrigation diversions would also be beneficial to other instream uses of water, such as anadromous fisheries, navigation and recreation.

Our two-level model enabled clear evaluation of locational differences in response to water and energy conservation policies and their potential impacts on income, resource use, production, and market price. Opportunities and impacts of this water market policy fall unevenly on regional irrigators, with upper river surface water irrigating areas being more extensively affected.

Water markets for the described purpose are not now available. Such exchanges may be difficult to initiate and administer. There are many political, legal, institutional, and social barriers to overcome before such markets could be implemented. However, there is ample evidence that the means should be explored. Shadow prices on the lower bounds modeled for several major crops and the opportunities for adopting more efficient irrigation technology give us reason to believe that the long-run opportunities for water conservation in agriculture are greater than those described herein.

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