Modeling Agricultural Water Markets for Hydropower Production in the Pacific Northwest

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

More than two-thirds of Pacific Northwest electricity is produced from hydropower on the Columbia River system. Irrigated agriculture in the region has a large impact on power supplies by diverting water that could be used for hydropower and using electricity for pumping the water. This paper examines the potential for water markets that would permit sales of water from agriculture to the hydropower sector for energy production. It is shown that both farmers and energy consumers could be made better off by adopting water markets to reallocate water among these competing uses.

Key words: hydropower, irrigated agriculture, water market.

Pacific Northwest agriculture expanded rapidly during the last two decades, largely through growth in irrigated production. Over 65% of direct regional farm income is now produced on approximately 8.3 million irrigated acres in Idaho, Oregon, and Washington. Much of the growth of irrigated agriculture and other sectors of the regional economy which has occurred in the last twenty years has been influenced by the availability of relatively inexpensive hydropower-produced electricity. Because more than two-thirds of Pacific Northwest (PNW) electricity is supplied from hydropower, irrigated agriculture imposes a major impact on power supplies by diverting water from the Columbia River system while also using electricity for pumping water.

Over 6 million megawatt hours of electricity, about 5% of the region's electrical power, are used annually in pumping irrigation water (Northwest Power Planning Council). This energy demand, coupled with the withdrawal of an estimated 20.7 million acre-feet of water from Columbia River sources to irrigate over 4.9 million acres, is a concern for water and energy management policies in the PNW (Houston). The Columbia River system is a bountiful multiple-purpose resource, but growth in irrigated agriculture and hydropower demand has intensified competition among all instream and consumptive users.

Energy policy planning in the PNW recognizes the role of irrigated agriculture in the electrical energy conservation program of the Pacific Northwest Power Plan (PNPP) as enacted by the U.S. Congress in 1980. The PNPP expects the irrigation sector, through the adoption of more energy-efficient delivery and application systems, water scheduling, and deficit irrigation, to reduce power consumption 30% by the end of the 1980s. The PNPP discussed the value of the hydropower generation losses generally due to irrigation water diversions, but no explicit consideration of the linkage between firm and nonfirm hydropower production and irrigation water conservation in the Columbia River system was reported.[1]

This article reports selected results from a study which developed an integrated approach emphasizing the linkages between agriculture

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This study was financed by the Water Research Center and the College of Agriculture and Home Economics, Washington State University.

Washington State University College of Agriculture and Home Economics Scientific Paper No. 7567.

[1] Firm electrical energy in the PNW is that level of energy production which can be guaranteed even in the lowest river flow conditions on record, or "critical year" flows. Non-firm energy is that amount produced by the hydroelectric system above firm energy levels, when water supplies are above critical year supply levels.

Western Journal of Agricultural Economics, 11(2): 221–231

and hydropower. Various pricing and rationing schemes for water conservation and reallocation in PNW irrigated agriculture were examined in this study for the purpose of increasing potential hydropower production. Water markets to facilitate water exchanges between agriculture and hydropower sectors were considered under several alternative scenarios affecting the value of power and potential adjustments in agriculture to restricted water supplies. The suggested water reallocation is, in part, guided by proposals and conditions for water rights markets set forth by Bromley; Ditwiler (1968, 1970); Howitt, Mann, and Vaux; LaVeen and Stavins; and others. Intraregional effects of agricultural water markets, changes in energy or water pricing policies, water and energy rationing schemes, and agricultural production policies were assessed. Primary attention was given to the interactions of the irrigation and hydropower sectors through their mutual need for water and the energy requirements of agriculture.

Water Policy Considerations

Pacific Northwest policy makers confront two important issues in the water and energy resource sectors: (*a*) how best to allocate water resources among competing uses including appropriate institutions, and (*b*) how to measure improvements derived from changes in allocations and institutions. While optimal social welfare decisions are dependent on value judgments within an ethical system, a more limiting assumption is pursued in this study framework: that social welfare is an aggregate of individual utilities satisfying conditions of efficient resource use (normally associated with pareto optimality) and of equitable distribution.

In a complex economy, few policies can unambiguously induce changes in a pareto-optimal manner. One measure of social gains or losses generated through a policy change or reallocation of resources is Marshall's concept of consumers' surplus and the analogous producers' surplus as utilized by Samuelson; Enke; Duloy and Norton; and others. That is, consumers potentially gain utility when the price they pay for a consumption good is less than they would be willing to pay. This gain may be measured as

$$(1) \qquad \Delta CS = \int_{p^0}^{p^1} Q(p)\, dp = \int_0^{q^1} \{P(q) - p^1\}\, dq - \int_0^{q^0} \{P(q) - p^0\}\, dq,$$

where quantity demanded (q) is a function of price $Q(p)$ and q^1 and p^1 are the equilibrium values of quantity and price. Restrictive assumptions of equal and constant marginal utility of money for all consumers and negligible income effects from the change are necessary. Deviations from the first may be relatively minor if all consumers are approximately equally affected, such as in access to electrical power. The second assumption involves a partial equilibrium approach whereby effects of changes in the sector under study are relatively small compared to the total economy.

Changes in producers' surplus may be measured as

$$(2) \qquad \Delta PS = \int_0^{q^1} \{p^1 - C(q)\}\, dq - \int_0^{q^0} \{p^0 - C(q)\}\, dq,$$

where quantity supplied (q) is a function of cost $C(q)$. Thus, for any equiproportional shift in the cost (supply) curves as a result of policy changes, producers' surplus is sensitive to the elasticity of demand for commodities produced.

Total consumers' plus producers' surplus change in the irrigated agriculture sector becomes the measure of potential net benefits to be gained through any reallocation of water resources. Water allocation decisions can be compared under various policies to the current base allocation at approximate commodity market prices. Such changes demonstrate impacts in a partial equilibrium framework, while potential distributional effects among producers and consumers in different areas or under differing irrigation patterns can be traced. The net benefits changes are measures of efficiency gains that are necessary but not sufficient to describe welfare improvements.

Most present water rights in the PNW are appropriated rights, extended by public institutions conditional on beneficial usage, chronological attainment, and availability. The water right is forfeited if not put to beneficial use within a specified time period. Willful or negligent waste of such water is unlawful, though the terms with relation to conserved water are vague.[2] Methods for transfer of water rights are not specified, but at least the states of Idaho and Washington now have legislation that enables the development of markets for water exchange.

This paper examines potential policies that would allow water to be sold from agriculture for hydropower production. The impacts on agricultural production and gains in net farm income become the primary measures of desirability for policy alternatives. Since farmers now own the water (rights) in question, it follows that no water sales would occur unless agriculture could be made better off by the exchange.

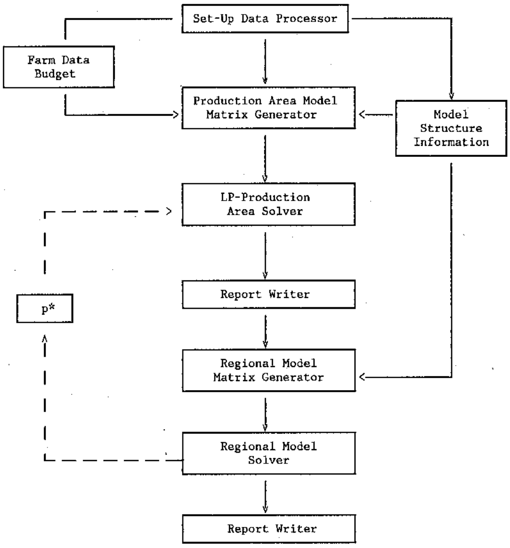

Figure 1. Two-level modeling process

Modeling Irrigation Water Conservation

The framework for studying the efficiency of water and energy conservation policies requires a capability for modeling changes in technology, input prices, output demands, and resource availability. McCarl and Spreen lauded the features of mathematical modeling and its richness in demonstrating changes in the economic environment. Duloy and Norton incorporated Samuelson-Enke type net social payoff to simulate competitive market equilibrium at endogenous quantities and prices. This approach has many proponents in policy modeling, attesting its theoretical consistency for partial analysis (Bisschop et al.; McCarl; Spreen and Takayama; Takayama and Judge; Kutcher and Norton; Norton and Schiefer).

For this study a mathematical programming model was developed to estimate agricultural production, commodity price effects, and resource use impacts for several water and energy policy alternatives (Houston; Houston and Whittlesey). This was a modified Dantzig-Wolfe decomposition type model that retained significant detail in the irrigated production responses to policy changes while also providing aggregated results for commodity price effects and water market impacts on hydropower production.

The schematic process of this two-level model is shown in figure 1. In the first level, detailed budgets were developed for as many as thirteen crops under four different irrigation systems in each of seventy-nine surface or ground-water-irrigated production areas throughout the PNW. Each area represented a hydrologic subdivision, grouping common sources of soil and climatic characteristics. Not all crops or irrigation systems appeared in each production area.

A linear programming model was constructed for each area, representing its special resource and activity characteristics. Production area net farm returns to land, water, and management (*MAXNFRPP*) were maximized at preseason expected commodity prices. Under the water market scenario, the value of water for producing hydroelectric power was parametrically varied, and that which was sold was credited to net farm returns. Locational value of hydropower losses of water were accounted for through the cumulative head at the point of diversion, the proportion of water consumed, and the return flow characteristics of each area as noted in Whittlesey et al.[3]

Diversions of water for irrigation in the upper reaches of the Columbia or Snake rivers have much greater hydropower opportunity costs than withdrawals lower in the system.

[2] Water conservation in irrigated agriculture is defined as any reduction in consumptive use through increases in the efficiency of water use or through reduced crop production.

[3] Cumulative head at each point of diversion is the total height through which water would drop at the dam listed and all downstream generating facilities to produce hydroelectricity.

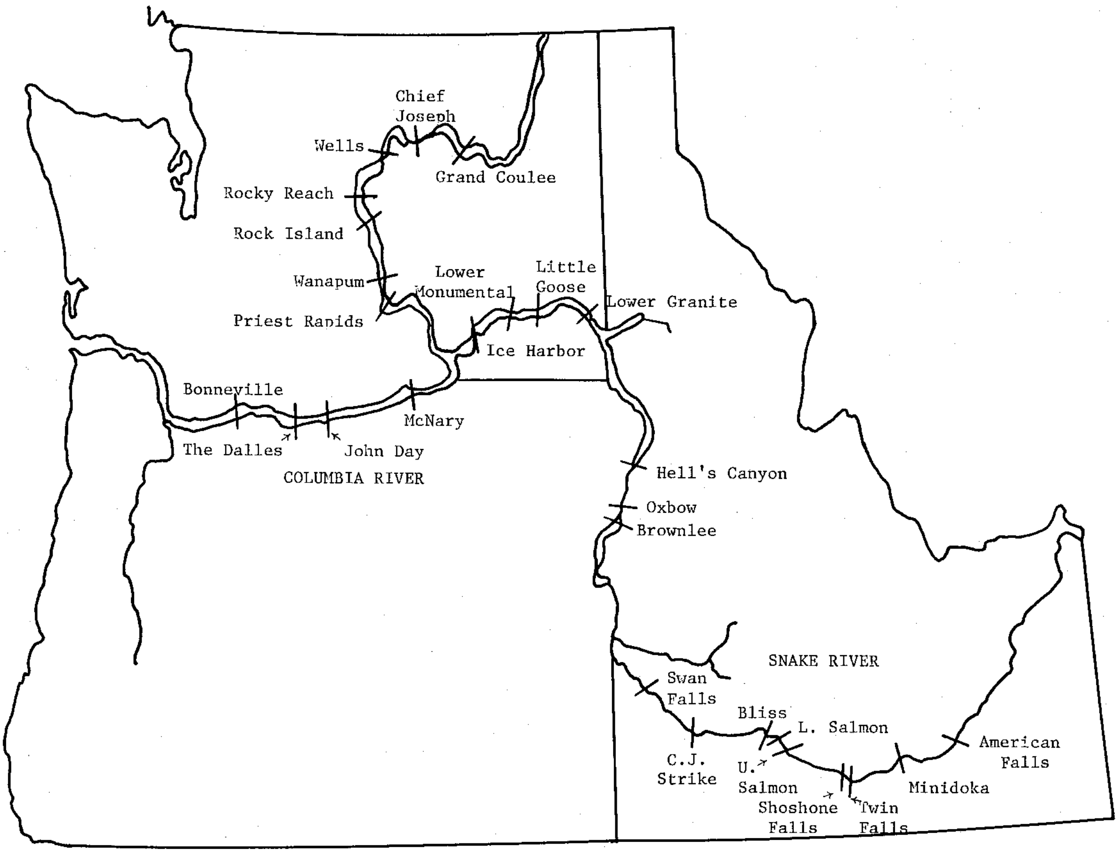

Figure 2. Hydroelectric sites on the mainstream Columbia-Snake River system

An acre-foot of water diverted and consumed above American Falls Dam in southern Idaho, for example, has the potential to produce 1,822 KWH of electricity, while above McNary Dam along the Oregon-Washington border only 275 KWH would be produced. The relative locations of dams in the Columbia River Basin are shown in figure 2. Return flows of water diverted for irrigation in most production areas will reenter the river system within the same reach (i.e., above the same hydroelectric generating dam) as diversions. Hydropower losses in such areas are based on crop consumptive use plus losses to evaporation or deep percolation which are not returned to produce hydroelectricity at downstream units. In some important irrigation areas, however, return flows reenter the system one or more reaches downstream from diversion points. Hydropower losses incurred in those production areas are a function of both levels of diversion and consumptive use (Whittlesey et al.).

Each production area linear programming model recognized the special characteristics of water diversion, delivery, and application systems existing in that area. Water use interacted with irrigation labor, irrigation electricity, and the sale value of water for hydropower to provide production area output responses to alternative water management policies.

Two sets of flexibility constraints to limit crop production were operable in each production area model. The first set affected the limits within which crops could be shifted among existing irrigation systems. In the long-run results reported herein, the total acreage under each irrigation system could vary within the physical limits imposed by each producing area and the acreage of individual crops under each irrigation system could range from zero to 130% of 1982 baseline conditions.

Flexibility constraints were also included for all crops in each production area to conform with agronomic capabilities and aggregate crop production feasible within each area and to restrict output of regionally price-responsive crops (potatoes, apples, and alfalfa) within an aggregate output range consistent with regional markets.[4] In the long run, the acreage of individual crops could range from 75% to 120% of 1982 actual acreages. Short-run model conditions were more restrictive on total crop production and the acreage within an irrigation system. Production responses induced from water and energy price changes were thus consistent with the opportunity to market water when that would enhance net farm income.

Rotation activities were not considered to be a good alternative to the use of flexibility constraints. On individual irrigated farms, the choice of crop mixes is not normally dictated by required sequencing of particular crops. Instead, the capacity of the irrigation system to deliver water, the farmer's managerial experience, the local climate, and market opportunities largely determine what is produced on an individual farm. At the production area level it is the climate and market constraints which are primarily responsible for the choice of crops. Hence, the flexibility constraint approach was considered to be preferable to the use of rotation activities or constraint sets. In no case was the acreage of rotation-sensitive crops, such as potatoes, allowed to violate any agronomic constraints within a production area.

To conserve water through deficit irrigation, water production response functions were used in modeling four major crops—wheat, field corn, alfalfa, and pasture. Other crops were assumed to be irrigated for maximum normal yield. Consumptive water requirements for each production area were taken from James et al. Wheat and field corn water response functions were modeled at several water-yield index point estimates from generalized quadratic forms (Kloster and Whittlesey; Hexem, Heady, and Caglar) and unpublished experimental results in Washington. Adjustments were made for normal yields and net irrigation requirements in each production area. Decrements of 10%, 20%, and 50% of applied water were used to model the water response functions, with dryland grain being the only nonirrigated activity. These yield response functions adjusted water application rates to maximize economic returns as water values or availability changed.

To operate the regional aggregate model, estimates of water and energy use, agricultural output, and potential hydropower production from conserved water in each production area model were then input as extremum value points (fig. 1). The combination of water and energy resource use and outputs for each solution to a production area model became a composite activity in the regional model, as it would in an interactive decomposition model. Sets of activities in the regional model were then constrained for use according to the policies under which they were generated, to maintain a consistency between the production area models and the regional model. For example, each production area model would be solved under a similar set of water values for a given water market policy. The set of solutions for each production area model would form a like number of activities in the regional model for determining the aggregate response to that same policy. Similar features were employed in Bisschop et al. and in McCarl.

By restricting the entry of a convex combination of extreme points from each independent production area and using Samuelson-Enke type maximization of net social payoff, the regional model aggregated resource use impacts and evaluated market price effects for changes in agricultural production under each policy or resource management plan. The regional response of prices for potatoes, apples, and alfalfa to changes in PNW irrigated farm production were modeled endogenously, as in Duloy and Norton. Prices of other representative crops were assumed infinitely elastic within the relevant range of irrigated production in the region and, thus, affected net social benefits only through their relative costs of production.

Product prices (P^*) for apples, potatoes, and alfalfa obtained at the second level of optimization were used to check the consistency of production response originally provided at the first level through an iterative process. Production area reactions to a policy change indicated that the production area models did provide solutions consistent with regional markets for these products. Shadow prices for constraints on the market-sensitive crops were reduced to near zero in the second round of optimization while using the estimated commodity prices (P^*). Further iterations to a gen-

[4] Potatoes were considered as a proxy for all regionally produced fresh and processed vegetables. Similarly, apples were a proxy for all tree fruits, and alfalfa represented other forage crops.

Table 1. Percent Increases in Net Returns from Sales of Agricultural Produce and Water under Alternative Hydropower Values for Selected Production Areas

Surface Water Production Area	River Dam at Diversion	Cumulative Head at Diversion	Present Irrigated Acreage	Increase in Net Returns to Land and Water	
				20 m/KWH	40 m/KWH
		(feet)	(acres)	(%)	
Ferry-Stevens, WA	Grand Coulee	1,167	21,000	6.91	23.32
Columbia Basin, WA	Grand Coulee	1,167	517,900	1.57	10.95
Wenatchee, WA	Wells	658	34,000	.00	.08
Big Bend East, WA	Priest Rapids	393	61,100	.05	.11
Deschutes, OR	The Dalles	142	207,500	.00	.02
John Day, OR	John Day	242	58,800	.01	.05
Weiser, ID	Brownlee	1,312	60,100	6.38	21.62
Boise, ID	Swan Falls	1,336	409,700	1.49	7.01
West Side, ID	Upper Salmon Falls	1,636	538,600	1.72	8.05
Neely-Milner, ID	Minidoka	2,045	172,300	5.88	20.81

eral equilibrium would have been possible but were deemed neither necessary nor efficient for an adequate assessment of water market policies. The concept of a market equilibrium for the price-responsive crops would imply a long-run setting, including a permanence about any given water or energy policy.

Selected Results of Water Market Assessment

The results reported here considered potential sales of water from irrigators to the hydropower sector for increasing electricity production. Opportunity values of water for producing hydropower were parametrically varied from zero to 50 mills per KWH (m/KWH) of equivalent hydrogeneration at the production area level. These values represented the range of values of hydropower generation from conserved water in surplus water flow years (near zero), firm electricity conserved under the Northwest Power Plan (18 m/KWH at 1982 real prices), and new thermal generation for replacement of lost hydropower or for meeting new power demand (40 to 50 m/KWH). These model results are representative of a situation in which water is sold permanently or continuously over time from agriculture for hydropower production. Alternatively, they may be considered as the impact of a single year of interruption during a low flow period if the water sales are to be used to boost power production in the low flow period only. In the latter case, no water sales would occur in periods of average or above average water flow and agricultural production would be unaffected. Selected production area results are presented for comparison of locational impacts and then an aggregate regional situation is discussed.

Production Areas Impacts

Wide locational differences were observed in responses to changing water market values. Some production areas were shown to have substantial opportunities for water exchange with the hydropower sector. Because the sale of water between agriculture and hydropower was voluntary and profit motivated, such exchanges occurred only when net returns to agriculture could be improved by reducing agricultural water consumption and selling the conserved water for energy production. Percentage agricultural income increases are shown in table 1 for selected production areas. The general location of production areas may be discerned by associating the river dam at diversion for each area given in table 1 with those on figure 2. Farm income effects from water sales were greatest in the upriver production areas of southern Idaho and central Washington where the hydropower value of water is largest.

Flexibility constraints on production area crop acreage generally prevented reducing total irrigated land in any production area more than 25% from the base level. The 25% rule was applied in this policy option to avoid having agricultural production completely elimi-

Table 2. Hydropower Production from Water Sold and Irrigation Electricity Use in GWH at Alternative Hydropower Values for Selected Production Areas

Surface Water Production Area	Hydropower from Conserved Water		Baseline Irrigation Electricity Use	Percent Irrigation Electricity Conserved	
	20 m/KWH	40 m/KWH		20 m/KWH	40 m/KWH
Ferry-Stevens, WA	0	13.51	19.85	12.49	29.37
Columbia Basin, WA	0	603.55	419.46	3.48	3.75
Wenatchee, WA	0	.28	69.60	.45	.47
Big Bend East, WA	.29	.29	59.69	0	0
Deschutes, OR	0	.50	151.98	0	0
John Day, OR	.03	.03	15.93	0	0
Weiser, ID	34.12	48.68	14.92	21.65	51.07
Boise, ID	87.85	215.20	57.82	8.09	72.28
West Side, ID	138.43	272.92	88.04	9.64	49.14
Neely-Milner, ID	138.67	150.01	30.44	52.23	53.61
Regional total	592.00	1,518.00	5,660.00	1.17	3.09

nated in any area. At 30 mills per KWH, the hydropower value of an acre-foot of consumed water is $53 in the Neely-Milner area behind Minidoka Dam, while an acre-foot of water would be worth only $3.70 for power production in the Deschutes area behind the Dalles Dam (Whittlesey et al.; Whittlesey, Hamilton, and Halverson). Therefore, in areas with a high opportunity cost for water, the flexibility constraints did limit the amount of water that could be sold since the value of water in agricultural production was generally less than its opportunity cost in power production. When the flexibility constraints became effective in limiting water sales, it was still possible to gain some additional water conservation through deficit irrigation and, in some areas, more efficient irrigation methods.

Potential hydrogeneration from water sales and associated decreases in electricity use for irrigation are shown for selected production areas in table 2. Significant opportunities for water exchange were demonstrated in southern Idaho areas at power rates as low as 20 mills per KWH.[5] The West Side and Neely-Milner areas, for example, could each sell water having hydrogeneration potential exceeding 138 GWH (10^6 KWH). Nearly 604 GWH of hydropower could be created by water sales from agriculture in the Columbia Basin area at 40 mills per KWH rate, even with the rather strict limitations imposed by the crop acreage flexibility constraints. Boise and West Side areas of southwestern and south central Idaho also demonstrated substantial potential for water sales.

Water was conserved by irrigation through changes in cropping patterns, reduction in irrigated acreage, and deficit irrigation. Modest changes in water consumption could generally be accomplished with only small reductions in the value of agricultural production based upon the research results. Areas facing potential major reductions in agricultural water consumption were those that have relatively low-valued agricultural uses of water, such as pasture and hay, which are highly water-consumptive but provide relatively low net returns per unit of water consumed.

Production areas reducing water consumption would not necessarily be the same as those which reduce electricity use for irrigation pumping. The Columbia Basin area could provide over 600 GWH of potential electricity generation from reduced water consumption with only a slight decrease in electricity demand. Water conservation in this area was largely achieved on lands irrigated by gravity flow systems, while only small changes occurred on sprinkler-irrigated lands. In the peculiar geographic location of the Columbia Basin area, irrigation diversions are from behind Grand Coulee Dam but irrigation returns flows reach the river at McNary Dam pool. Hence, total water diversions, rather than consumed water, determine the impact on hydropower production. In this region some acreages were shifted from gravity flow to sprinkler systems,

[5] The current cost of power to consumers in the Pacific Northwest averages about 35 m/KWH, and the opportunity cost of additions to power supplies through conservation or thermal power production would range from 30 to 50 m/KWH.

Table 3. Regional Response to Increasing Hydropower Values of Conserved Water (1985 Electricity Rates)

Type of Response	Million Units	Hydropower Value (m/KWH) 0	10	20	30	40
Net returns to irrigation[a]	$	1,397	1,396	1,396	1,398	1,408
Value of water sales	$	0	5.50	19.60	48.18	76.24
Net farm income[b]	$	1,397	1,402	1,416	1,446	1,484
Consumer surplus	$	2,692	2,692	2,686	2,670	2,648
Total irrigated acreage	acres	8.076	8.076	8.059	7.987	7.902
Water diversion	ac.-in.	239.66	236.97	230.06	221.42	216.64
Hydroelectric power from water sales	KWH	0	162	592	1,218	1,518
Irrigation electricity use	KWH	5,660	5,638	5,594	5,565	5,485

[a] Net returns to irrigation includes only the value of sales from agricultural commodities.
[b] Net farm income includes the value from crop sales plus the value from water sales.

reducing water diversions but increasing per-acre electricity demand.[6]

Production areas in southern Idaho reduced both water and electricity use as the opportunity value of water increased. These areas relied heavily on deficit irrigation for forage crops (including field corn) and, in some areas, reduced the acreage under irrigation by 10% or more. Most of the acreage reduction was on sprinkler-irrigated lands to decrease pumping energy costs. Electricity demand in the West Side area, for example, would decrease nearly 50%, while water savings could increase electricity production by 273 GWH.

Production areas downstream in the river basin experience relatively low opportunity costs for irrigation water diversions and would be little affected by opportunities to sell water for hydropower production. However, such areas could be substantial beneficiaries from improved commodity prices as upstream regions sold water and reduced agricultural production.

Regional Impacts

The regional model sought a competitive equilibrium solution by maximizing the sum of consumers' and producers' surplus for the irrigated agriculture sector. This approach provides a partial equilibrium solution to questions about social welfare that may be implied by a water market. It is partial in several respects but primarily for excluding the consumer and producer effects of changes in hydropower production. Though these effects were not measured, they are believed to be relatively small, as shown by McCarl and Ross. Nevertheless, there are some important implications to agriculture for the water market options.

A summary of the regional model solution results are shown in table 3. The first line in table 3 reflects the net return to agriculture from the sale of agricultural products. It is notable that as the value of water sold for hydropower and total water sales increase, the net returns to irrigation initially decline and then increase as more water is sold. The first uses of deficit irrigation occur on pasture and grain crops which do not have an assumed price effect from decreased production. As water for irrigation becomes more scarce due to water sales, the production of potatoes, apples, and alfalfa are decreased. The inelastic demand for these crops causes net return to irrigation to rise, despite reduced production. Net farm income is increased even more through the sales of water for hydropower. The distribution of this increased agricultural income is not uniform throughout the region. Producing areas in upper reaches of the river basin would market most of the water and experience a decline in agricultural production, while those lower in the basin would likely produce more of the crops of higher value and capture the gains in producer surplus from increased crop prices.

The value of water sales shows the amount received by farmers for water sales to hydro-

[6] Short-run model solutions did not permit expansion of any irrigation system. Long-run model solutions did allow changes in the proportion of acreage served by each type of irrigation system within a production area. The limits on acreage that could be served by any irrigation system was controlled by factors such as soils, slopes, and field size. These factors varied among production areas.

power. Total Columbia River Basin water diversions would decrease by about 23 million acre-inches, or 10%, at the 40 m/KWH value for power. Sales of this power would produce 1,518 GWH of electricity and be valued at $76.24 million. Farmers conserving and selling water would receive this amount. Adding the net returns to agriculture and the value of water sales provides an estimate of net farm income on irrigated farms in the region. Agriculture is better off with the opportunities of a water market than without an alternative reallocation device.

The regional model objective of maximizing the net social payoff function provides an estimate of the consumer impact from changing levels of agricultural production. Consumer surplus is shown to decrease as the prices of some commodities rise and the overall level of agricultural production declines. In fact, the decline in consumer surplus is considerably greater than the rise in net returns to irrigation (producer surplus) associated with agricultural production only. However, the value of water sales does increase the partial measure of net social payoff as estimated in this model. Little can be said about the general welfare effects of the increased levels of power production. While agriculture is definitely better off, the rest of society experiences a trade-off between the benefits of increased power production and decreased food production.

Alfalfa, apples, and potato products would have varying price responses as water values increased. At the highest level of water exchanges, alfalfa prices would rise 8% to 9% over current expected prices. If such conditions continued, this price increase would induce higher production levels and lower levels of water conservation in some areas. Apple prices and acreages remained relatively stable at the regional level. Apple production, however, would tend to increase in areas of higher yields and decrease in others as water values increased.

Agronomic factors limit potato production acreages to approximately those suggested in the aggregate upper bounds modeled here. However, potato prices could fall as much as 25% in regional markets as production is shifted from lower-valued crops within the limits of this analysis. The highly inelastic price response of potatoes would reduce the price sharply for minor acreage increases. These price and acreage shifts would be similar to fluctuations which actually occurred in recent years. Most production areas would produce potatoes at the upper bounds of acreage modeled.

The lower-bound flexibility constraints on crop production did limit the amount of water marketed, particularly at the higher values of power. Hardly any agricultural uses of water can exceed the value provided by hydropower at 40 m/KWH in the upper reaches of the river basin, at least not with current levels of commodity prices. Future investigations of water markets for this purpose must be sensitive to this issue.

These model results are a measure of annual impacts and the presumption that sales of water could be permanent or only in years when water for hydropower was insufficient. However, if an intermittent market were followed in response to the stochastic variations of stream flows, the market costs to agriculture and society would be much smaller than indicated here and the potential benefits much larger.[7] In any case, the results provide a conservative estimate of the economic potential for a water market in the Pacific Northwest. At values of power in the 20–30 m/KWH range, energy produced from hydropower is cheaper than the marginal cost of nearly any other form of additional power. By 1990 it is projected that additions to the electricity production capacity of the PNW will be necessary, and most options for new energy sources will cost more than 40 m/KWH. Total potential electrical energy saved and produced would be approximately 1,693 GWH at 40 m/KWH for hydropower. For comparison, a 1,200 MW nuclear plant would produce approximately 7,500 GWH electricity per year at costs exceeding 50 m/KWH.

The nature of the models used in this study provide a result representing a long-term average. It is as if the water were marketed every year with the same effects on power production and agriculture. In reality, however, the hydropower sector would benefit to a much greater level, and the agricultural production losses would be much lower if water were exchanged only in years of low stream flow, say one year in ten. Under this arrangement, agriculture could be paid a much larger compensation for

[7] The interruptible water market described here would be activated by weather and stream flow conditions, not the whim or desire of the farmer participant. Once a farmer agrees to participate in the market, the timing and amount of water to be sold will be determined by stream flow conditions for hydropower production.

water sold and still leave both parties to the market better off. This concept of an interruptible water market is more thoroughly described in articles by Whittlesey and Houston, McCarl and Ross, and a preliminary publication by Whittlesey, Hamilton, and Halverson.

The two-level model enabled an evaluation of the production and distributional consequences of response to water value changes. Income, resource use, crop production, and market price impacts were estimated for each area of Idaho, Oregon, and Washington, with the higher elevation surface-water irrigated areas incurring particularly significant changes. For a comprehensive presentation of these and other results, see Houston and Whittlesey.

Conclusions

Water and energy resource managers in the PNW must be increasingly cognizant of water conservation opportunities in irrigated agriculture. Model results demonstrate a significant potential for exchanges of water between the two sectors on economic efficiency grounds. Agricultural income would increase, while regional problems of supplying additional firm energy through thermal plants could be diminished or avoided. Increased upriver streamflows would also benefit other instream water uses such as anadromous fisheries and recreation.

Water markets to achieve the reported results are not widely available in the PNW or elsewhere. Political, institutional, and social barriers to such exchanges of water rights still exist. However, Ditwiler (1970) suggested that water districts in the PNW have authority approximating a full water rights market, if powers such as annexation and consolidation of territories are considered. If institutional barriers to water markets are removed, incentives of a market would likely elicit levels of water exchange greater than results suggested here. It is apparent that water markets could raise the social benefit of water now held and used exclusively by agriculture. Though farmers would always enter such markets on a voluntary basis, their own welfare would necessarily be enhanced as the major incentive for their participation.

[*Received December 1985; final revision received August 1986.*]

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