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Water, Energy, and Farm Production

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April 1996

Prepared for the U.S. Department of Energy
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Abstract

Electric utility rate deregulation can have disproportionate impacts on water-intensive crops, which have historically relied upon pressurized irrigation technologies and surface water resources. Based on a case study of agricultural growers in southern California, the paper models the impacts of utility rates considered in the Western Area Power Administration's Sierra Nevada Customer Service Region. The study was performed as part of the 2004 Power Marketing Program *Draft* Environmental Impact Statement. The empirical results reflect linear-programming estimates of the income transfers from growers to energy providers based on county-wide coverage of 13 junior and senior irrigation districts and short-run production possibilities of 11 irrigated crops. Transfers of income from growers to energy suppliers occur through their losses in producer surplus.

1.0 Introduction

The farm sector is affected by changes in the costs of energy used in both the distribution and application of irrigation water. This cost relationship between energy and water resources has come to the fore in recent policy deliberations concerning the deregulation of utility rate structures in the western states, particularly California and the Pacific Northwest states. In these regions of the country, changes in electric utility pricing arrangements can affect a variety of farm production decisions, including the use of water and irrigation technologies. Moreover, the resulting changes in these farm production decisions can have important spillover effects on both urban and environmental water users. Against this backdrop, the paper examines whether utility rate deregulation provides sufficient economic incentives to use more energy-efficient irrigation methods or to grow less water-intensive crops.

On an empirical basis, important results have been shown for the effects of irrigation technology on water application and crop production, e.g., Caswell and Zilberman (1985 and 1986) and Vaux et al. (1990). Beyond these considerations, the role of energy costs in determining production practices remains an open question, particularly the extent to which electric utility prices affect groundwater pumping, the conveyance of surface water, and the use of pressurized irrigation systems. Based on a case study of agricultural growers in Kern County, California, this paper constructs an optimization model of actual irrigated farming operations to examine the sensitivity of the farm sector to changes in utility rates.

Section 2 provides background information on crop production, prices and revenues, and the use of land and water resources in the study region. Section 3 describes a linear programming (LP) model of irrigated farming for the region and its sensitivity to the regional pricing of energy and water resources. The LP model is based on the criterion of maximizing net returns from multi-crop

production under alternative methods of irrigation (or processes of production). Section 4 ends the paper with a discussion of the policy implications of the model concerning to crop production patterns and the pricing of energy-water resources.

2.0 Study Region

Kern County, California, is situated in the San Joaquin Valley of Southern California, near Bakersfield. In 1993, Kern County crops had a combined market value of \$1.91 billion. The production of these crops involved 800,100 acres of land, of which 696,000 acres are situated above useable groundwater (Kern, 1995). Agricultural water requirements in the County reached 2.35 million acre-feet (MAF), of which 0.86 MAF were pumped from groundwater (Kern, 1995). The remaining water supplies came from surface water deliveries to the County, including: 1.22 MAF from the State Water Project (SWP); 0.65 MAF from the Kern River; and 0.49 MAF from the Central Valley Project (CVP). Farmers applied nearly 2.2 MAF of water to 11 key crops. Table 1 provides information on the production levels of these crops, their prices and revenues, and the use of land-water resources in their production.

Table 1. Irrigated Farming in Kern County, California—1993

Crop Type	Quantity (tons)	Price (ton)	Revenue	Land (acres)	Water (acre-feet)
Citrus	541,760	\$343	\$185,695,000	34,835	117,568
Grapes	718,500	\$552	\$396,394,000	73,719	253,225
Cotton	182,750	\$1,430	\$261,455,000	277,488	922,646
Alfalfa Hay	604,000	\$101	\$60,963,000	78,568	337,842
Wheat	106,000	\$108	\$11,464,000	44,447	75,560
Barley	42,400	\$97	\$4,107,000	22,664	40,909
Tomatoes	136,600	\$82	\$11,112,000	5,025	17,588
Sugar Beets	335,000	\$37	\$12,244,000	9,779	31,537
Almonds	49,400	\$3,860	\$190,630,000	71,574	224,742
Pistachios	36,800	\$2,683	\$98,745,000	19,713	61,899
Carrots	1,510,000	\$76	\$114,988,000	45,290	126,812
TOTAL	---	---	\$1.35 billion	683,102	2,210,328

Source of information: besides water, the reported values are from the Kern County Agricultural Crop Report for 1993. The water values were calculated on the basis of the model used in the present study.

The water resources for crop irrigation are coordinated through the Kern County Water Agency and managed by the local irrigation districts (see Figure 1).^(a) The average price and quantity of surface water deliveries to growers varies considerably within the county, depending on the local irrigation district (see Table 2). In principle, water prices are set by irrigation districts to recover capital and operating expenses of pumping plants and canals involved in the conveyance of surface water. Payments to electric and gas utilities for energy used in water transport are an important element in operating costs of pumping plants in each district and, thus, figure into the price of delivered surface water to irrigators. Irrigators are sensitive to rate deregulation in that they would potentially experience a welfare loss in moving from subsidized rates towards free-market rates.

Figure 1. Local Irrigation Districts in Kern County

(a) The Kern County Water Agency was created by the California Legislature in July 1961. The Agency was granted the primary power to acquire and contract for water supplies for Kern County. Working with other water entities, its primary focus is to coordinate the management of water supplies for Kern County, with particular emphasis on State Water Project supplies.

Table 2. County Water Deliveries and Average Prices By Major Irrigation Districts

District	Water Deliveries (AF)	Average Price (per AF)
Kern Delta WD	229,363	\$25
Arvin-Edison WSD	206,354	\$80
Semitropic WSD	202,000	\$43
Buena Vista WSD	186,665	\$40
North Kern WSD	160,572	\$50
Wheeler Ridge-Maricopa WSD	146,514	\$121
Delano-Earlmart	140,611	\$40
Shafter-Wasco	93,635	\$27
Berrenda Mesa WD	90,764	\$130
Belridge WSD	89,678	\$85
Lost Hills WD	84,812	\$75
Henry Miller WD	54,066	\$46
Kern-Tulare/Rag Gulch	40,000	\$95
TOTAL	1.725 MAF	\$61.00 (weighted average)

Sources of information: The data were compiled from telephone surveys undertaken in June 1995. Irrigation districts supplying less than 15,000 acre-feet are not reported (nor is the Cowello irrigation district due to lack of price information).

However, agricultural growers are sensitive not only to changes in utility rate policies that may influence district water prices, but also the effects of these policies on energy costs associated with groundwater pumping and the pressurization of irrigation systems. This distinction is complicated by the existence of rate differentials among irrigation districts and between irrigation districts and farms. The following section presents a short-run optimization model of the farm sector in which farmers respond to changes in utility rates based on their impact on the energy costs of pumping groundwater and pressurizing irrigation systems.

3.0 Model Formulation

The institutional background described above suggests that the sensitivity of growers to rate deregulation will depend on the value marginal product of water and the energy-efficiency of irrigation technologies. The gains in revenue from the application of water to a crop using a single method of irrigation reflect the value of the gains in crop production, i.e., the value marginal product of water, VMP^w . This monetary value varies directly with the market price of the crop. More generally, a multi-crop farmer ($i=1,2,3,\dots,\text{etc.}$) having alternative methods of irrigation ($j=1,2,3,\dots,\text{etc.}$) would be concerned with numerous VMP functions say, VMP_{ij}^w , each one measuring the gains in farm revenues obtained from applying water to the i th crop using the j th method of irrigation. Meanwhile, the farmers' marginal irrigation costs, MC_{ij}^w , vary with the cost of obtaining an acre-foot of water (either from private wells or irrigation districts) and the cost of applying the water through an irrigation system.

Figure 2 shows the farmers' optimal water application decision for a specific crop and irrigation technology, namely, the quantity of water W^0 at which the additional gains in revenue equal the additional irrigation costs, $VMP_{ij}^w = MC_{ij}^w$. Parametrically, a price increase in energy from P_e^0 to P_e^1 would increase marginal irrigation costs to the farmer, either because water becomes more costly to pump, or more costly to use pressurized methods of irrigation. Either way, these increases in irrigation costs induce farmers to reduce their optimal (profit-maximizing) quantity of water application from W^0 to W^1 . For any given crop, this reduction in water use tends to result in fewer irrigated acres and, consequently, a decline in crop production. It follows that for any given method of irrigation, the supply of agricultural crops is sensitive to the cost conditions faced by farmers.

Figure 2. Farmers' Water Use Decision

The extent to which increases in energy prices will induce farmers to change irrigation practices and water use depends critically on the market value of the affected crops. The most immediate response of profit-seeking farms is to reduce water use on the relatively lower valued crops. Moreover, the magnitude of this response will depend on the irrigation technologies that are available to the farms. For example, citrus orchards may have multiple irrigation methods in place which enable them to economize on energy use, e.g., the application of well water using flood irrigation as opposed to surface water using pressurized sprinklers. Accordingly, one would expect the impacts of higher energy costs on the supply of any given crop will vary according to its market value and the technological substitutions that are available to its producers.

The optimization problem of the farm sector is structured in an 11 crop ($i = 1, 2, \dots, 11$) LP model. The 11 crops under consideration generated nearly \$1.35 billion in farm revenue in 1993, involving

almost 700,000 acres of land—89 percent of the total irrigated farmland in the County (Kern, 1993). These crops are sold at competitive market prices, p_i , and specified on a per-ton basis. Growers are price-takers and maximize profits by applying variable amounts of land-water resources under a variety of irrigation technologies ($j=1, 2, \dots, n$).

Let the double-subscripted variable, Q_{ij} , reflect the quantity of crop i produced under irrigation method j . The short-run production possibilities of growers are represented by linear and homogeneous production functions.^(a) The quantity of crop i produced under irrigation method j varies in proportion to the amounts of land and water resources being applied, subject to the additional restriction that these two resources are applied in fixed proportion to one another. For example, water quantity W_{ij} would support an output of $Q_{ij} = W_{ij}/\alpha_{ij}$ tons of oranges, provided that land is available in the appropriate amounts to achieve this output level. Conversely, land quantity L_{ij} would support an output of $Q_{ij} = L_{ij}/\beta_{ij}$ tons of oranges, assuming that water is available in the appropriate amounts to achieve this output level. Accordingly, the constant α_{ij}/β_{ij} denotes the requisite water-to-land ratio in the production of crop i under irrigation method j measured in acre-feet of water required per acre of land.

Because the model assumes that the production of each crop involves constant input ratios (which vary by crop and method of irrigation), the amount of land in each crop must also be allowed to change to reflect optimal changes in water use and cropping patterns.^(b) The short-run profit maximization

(a) Notationally, the underlying production function for crop i and irrigation method j is expressed as $Q_{ij} = \min(W_{ij}/\alpha_{ij}, L_{ij}/\beta_{ij})$, reflecting the amount of the crop that can be produced with minimum quantities of water and land.

(b) By assumption, land-water resources are applied in fixed proportions in the production of all crops. Consequently, as water use changes from its initial level, land use must change in equal proportion, i.e., $d(L/W)=0$.

across all farm activities is attained by the application of water across irrigated crops in order of diminishing marginal profitability. Table 3 shows the percent of irrigated crop acreage covered by existing irrigation systems in the region of interest, including:

- drip
- flood
- furrow
- border
- wheel line sprinklers
- hand move sprinklers
- hose drag sprinklers
- permanent set sprinklers.

Each of these irrigation methods reflects a specific water-application efficiency and cost. Growers have incentives to rely on those irrigation methods which generate the highest quasi-rent per acre. For instance, sprinkler irrigation requires higher pressurization than drip. Traditional irrigation methods,

Table 3. Irrigated Crop Acreage by Irrigation Method and Water Source (in Percent)

Water Source/ Crop/Method of Irrigation	Drip		Flood		Furrow		Border		Wheel Line		Hand Move		Hose Drag		Perm Set	
	S	G	S	G	S	G	S	G	S	G	S	G	S	G	S	G
S=Surface G=Ground																
Citrus	.10	.15	-	-	-	-	-	-	-	-	-	-	-	-	.35	.40
Grapes	.05	.05	-	-	.45	.20	-	-	-	-	-	-	-	-	.10	.15
Cotton	-	-	-	-	.45	.30	-	-	.10	.15	-	-	-	-	-	-
Alfalfa	-	-	.20	.60	-	-	-	-	.15	.05	-	-	-	-	-	-
Wheat	-	-	-	-	.30	.20	-	-	.25	.25	-	-	-	-	-	-
Barley	-	-	-	-	.31	.30	-	-	.19	.20	-	-	-	-	-	-
Tomatoes	-	-	-	-	.60	.40	-	-	-	-	-	-	-	-	-	-
Sugar Beets	-	-	-	-	.45	.30	-	-	.10	.15	-	-	-	-	-	-
Almonds	-	-	-	-	-	-	.85	-	-	-	-	-	.10	.05	-	-
Carrots	-	-	-	-	-	-	-	-	-	-	.72	.28	-	-	-	-
Pistachios	-	-	-	-	-	-	.85	-	-	-	-	-	.10	.05	-	-

Source of information: "Agricultural Water Use and Costs in California," Bulletin 1896, Division of Agricultural Sciences University of California, July 1980, Tables A.7 and A.8, pgs. 30-34.

such as flood and furrow, do not require pressurization at all. Consequently, the application cost per unit of water is relatively higher for a sprinkler system than for flood or furrow systems.^(a)

At the farm level, expenditures on irrigation reflect the costs of delivered water from irrigation districts and the costs of its application, both of which depend on utility pricing: irrigation districts make payments to utilities for energy consumed in the course of pumping and pressurizing surface water prior to delivery to farms; farms pay utilities for energy consumed in pumping groundwater and pressurizing irrigation systems. Thus, to facilitate the parametric analysis of alternative energy price regimes, it is convenient to express the LP objective function as the difference between total net crop returns and energy-related production costs:

$$\Pi = \sum_s [\sum_i \sum_j (NR_{ij}^s \times L_{ij}^s) - P_c^f \times KWH^f - P_c^d \times KWH^d] \quad (1)$$

Net returns per acre of crop i under irrigation method j are denoted by NR_{ij}^s , where the superscript s defines the water source, i.e., surface water ($s=1$) or groundwater ($s=2$). The total net returns from crop i are defined by the product of net returns per acre and the total number of acres in crop i under irrigation method j and water source s , i.e., $NR_{ij}^s \times L_{ij}^s$. The energy-related costs are represented by the terms $P_c^f \times KWH^f$ and $P_c^d \times KWH^d$, reflecting energy used by farms (f) and irrigation districts (d) to pump water and pressurize irrigation systems. (The appendix at the end of the paper provides additional description of the objective function).

(a) Modern irrigation pumps have peak pump efficiencies in the range of 75 to 82 percent. In the absence of data detailing the distribution of pump types and efficiencies in Kern County, a relatively lower value of 60 percent was assumed. Note that Caswell and Zilberman (1985) have described various technological efficiencies for flood irrigation (60 percent), sprinkler irrigation (85 percent) and drip irrigation (95 percent) based on a maximum index value of 100%.

Profit maximization is achieved by solving for the optimal amount of land resources applied across crops i , irrigation methods j , and water sources s - hence, the triple summation of net returns. The LP constraint set used in deriving optimal land allocations is represented by expressions (2) through (6) and discussed below:

$$AW_{ij}^s \times L_{ij}^s \leq WS \quad (2)$$

$$\sum_{i=1}^{11} \sum_{j=1}^8 \sum_{s=1}^2 AW_{ij}^s \times L_{ij}^s \leq WS \quad (3)$$

$$\sum_{i=1} \sum_{j=1} \sum_{s=1} KWH_{ij}^f \times L_{ij}^s - KWH^f = 0 \quad (4)$$

$$\sum_{i=1} \sum_{j=1} KWH_{ij}^d \times L_{ij}^s - KWH^d = 0 \quad (5)$$

$$L_{ij}^s, KWH^f, KWH^d \geq 0 \quad (6)$$

Crop-specific water constraints are defined by (2). Each acre of land is assumed to require AW_{ij} acre-feet of irrigation water. Accordingly, the sum of land in crop i under irrigation method j is constrained to not exceed the baseline water use level, WS_{ij}^s . These baseline water-use levels act as upper-bound constraints on the optimal L_{ij}^s values for the various crops.^(a) Meanwhile, the global water constraint across all crops is defined by (3) and acts as an upper-bound constraint on the maximum amount of water available for application.

Equation (4) reflects on-farm energy used for irrigation of crops, reflecting two potential components: the energy requirements of pressurized irrigation systems and groundwater pumping. In the LP model specification, land in crop i under irrigation method j is assumed to have specific energy requirements. Consequently, total farm energy consumption refers to the amount of energy required per acre

(a) For purely technical reasons, the minimum boundary constraints are set to ensure that water use in crop i under technology j assumes only non-negative values. Meanwhile, the maximum boundary constraints reflect the possibility that irrigated acreage cannot increase due to limitations placed on surface water allocations. In 1993, for instance, irrigated acreage did not significantly increase, despite the increased availability of surface water due to lateness in the allocation of SWP water to irrigators.

multiplied by the quantity of acreage in the various crops under all methods of irrigation, i.e., the sum of products $KWH_{ij}^{fs} \times L_{ij}^s$ across all i , j , and s . Note that equation (4) aggregates on-farm irrigation energy consumption, KWH^f , which in turn enters the objective function in the form of on-farm variable energy costs, i.e., $P_e^f \times KWH^f$.

Equation (5) reflects the energy requirements of irrigation districts in delivering surface water to farms. As defined in (5), energy use by irrigation districts is the product of the various per-acre energy requirements and the amount of irrigated farmland receiving surface water deliveries from irrigation districts, i.e., $KWH_{ij}^d \times L_{ij}^1$, for all i and j . Similar to equation (4), the energy used by irrigation districts enters the objective function in the form of irrigation-district energy costs, i.e., $P_e^d \times KWH^d$. Finally, constraints (6) reflect non-negativity conditions imposed on the decision variables L_{ij}^s and the amounts of energy used by farms and irrigation districts in Kern County, i.e., KWH^f and KWH^d .

The price paid to irrigation districts for water recovers the capital and operating expenses of pumping plants, specifically, the energy used to pump the water to the irrigator. For example, pumping stations in the Arvin-Edison district used 113,695,222 KWH of wholesale energy at a total cost of \$3.67 million (1993 dollars).^(a) These costs were recovered from growers via water pricing. At the same time, energy costs of growers included retail energy used for groundwater pumping and irrigation. The following section considers the sensitivity of growers to changes in the energy costs of irrigation districts and growers.

(a) The Arvin-Edison Water Storage District pumped 522,517 AF of water to 97,000 acres of irrigated crops—approximately 14 percent of the irrigated land in the study region (Arvin-Edison Water Storage District Water Resource Management Program, March 1995, pg. 1). Pumping stations in this district used 113,695,222 KWH at a cost of nearly \$3.7 million (Arvin-Edison Water Storage District, 1993 Pumping Plant Power Summary).

4.0 Policy Analysis

The present analysis concerns the transfer of income from growers to energy suppliers as a result of rate deregulation within the Western Area Power Administration's Sierra Nevada Region (Western Sierra Nevada). The focal point in the analysis is the effects on agricultural profits that would result from elimination of subsidized power rates to large-scale irrigation district customers (e.g., Arvin-Edison).

Existing power contracts between Western Sierra Nevada and large-scale irrigation district customers specify the amounts of capacity and energy that Western Sierra Nevada agrees to offer for the long-term (greater than 12 months). The contracts are written at rates (approximately 5 cents per kilowatt hour) that are significantly below wholesale free-market rates (approximately 10 cents per kilowatt hour). Correspondingly, the rates paid by growers for retail power used for groundwater pumping and system pressurization (approximately 15 cents per kilowatt hour), are substantially higher than those for the Western Sierra Nevada Region. Rate deregulation and competitive market forces would reduce these rate differentials by eliminating subsidies and promoting open access to alternative sources of power. Based on the model presented in Section 4, the impact of rate deregulation would be passed on to growers in the form of changes in water prices and irrigation costs.

The sensitivity analysis considers the impact of paying a five-cent increment per kilowatt hour: from a baseline of 5 cents under the No-Action Alternative, to 10 cents under selected environmental impact statement (EIS) alternatives. According to data made available by the R.W. Beck engineering firm,

this rate increment brackets all of the potential electricity rates confronting Western-Sacramento agricultural customers in Kern County under the various EIS alternatives being studied.^(a)

The impacts of the five cent rate escalation are reported in Tables 5, 6 and 7 under two alternative surface water levels: the first involves the availability of 2.25 million acre-feet of water for crop irrigation, i.e., an average year; the other involves the availability of only 1 million acre-feet, i.e., a drought year. Altogether, these scenarios encompass the range of water-supply conditions faced by Kern County irrigators over the last decade and the range of rate changes implied under the EIS alternatives. A summary of the results of the sensitivity analysis are reported in Table 8 and suggest that potential rate changes tend to have significantly greater impacts if accompanied by a dry year as opposed to an average year.

In Table 5, the results of the LP analysis suggest that a five-cent increase in Western-Sacramento energy rates during an average year of surface water availability would decrease farm profits from \$324 million to \$297 million (a change of -8.3 percent). Meanwhile, if the rate increase occurred during a dry year, farm profits would decrease from \$324 million to \$266 million (a change of -17.9 percent). Note that the impacts on profits are substantially larger when the increase in rates is accompanied by dry conditions. In this case, the level of farm profits is reduced by some \$58 million. Based on the analytical model used in the present study, cotton, alfalfa hay, wheat, sugar beets, carrots, and almonds are the crops whose profits are sensitive to changes in Western-Sacramento energy rates and water availability.

(a) The 2004 Power Marketing Program Draft Environmental Impact Statement, Western Area Power Administration Sierra Nevada Customer Service Region, March 4, 1996.

Table 5. Profits by Crop (in millions of 1993 dollars)

Crop	5 cents/KWH - No Action		10 cents/KWH - Other	
	Avg. Year (2.25 MAF)	Dry Year (1.0 MAF)	Avg Year (2.25 MAF)	Dry Year (1.0 MAF)
Citrus	55.04	same	53.76	same
Grapes	100.48	same	96.67	same
Cotton	63.31	28.89	50.96	28.89
Alfalfa Hay	5.18	0.00	5.18	0.00
Wheat	0.32	0.00	0.32	0.00
Tomatoes	2.88	same	2.62	same
Sugar Beets	1.32	0.00	0.91	0.00
Almonds	32.52	same	27.37	same
Carrots	4.83	0.00	2.65	0.00
Pistachios	58.18	same	56.76	same
Total	324.06	277.99	297.18	266.08

In Table 6, the results of the LP analysis suggest that a five-cent increase in Western-Sacramento energy rates during an average year reduces only sugar beet production. Thus, under average conditions, all of the other crop production levels remain invariant to a five cent increase in energy costs. The major impacts on production arise as a result of changes in energy rates during a dry year. Under this scenario, the production of cotton is reduced by 66 percent, while the production of various other crops ceases altogether, i.e., alfalfa hay, wheat, sugar beets, and carrots. The elimination of these crops from production reflects their having lower profit margins when compared to the various other crops, whose production remains unaffected by the rate increase. Note how the extra impacts posed by water shortages tend to exacerbate what otherwise would be only a very modest effect on crop production levels.

Table 6. Quantity of Production by Crop

Crop	5 cents/KWH - No Action		10 cents/KWH - Other	
	Avg. Year (2.25 MAF)	Dry Year (1.0 MAF)	Avg Year (2.25 MAF)	Dry Year (1.0 MAF)
Citrus	384,927	same	same	same
Grapes	349,428	same	same	same
Cotton	155,393	53,341	155,393	53,341
Alfalfa Hay	397,868	0	397,868	0
Wheat	24,535	0	24,535	0
Tomatoes	184,320	same	same	same
Sugar Beets	267,064	0	240,358	0
Almonds	58,691	same	same	same
Carrots	1,476,454	0	1,476,454	0
Pistachios	38,637	same	same	same
Quantity Index	100.00	na	99.9	70.6

Note: the quantity index is calculated using base year prices as weights (the Laspeyres index) and changes in the quantities of crops produced due to energy rate changes arising in an average or dry year.

In Table 7, the results of the LP analysis suggest that a five cent increase in Western-Sacramento energy rates would have a very modest impact on agricultural land use during an average year. This impact is reflected by the idling of 978 acres planted in sugar beets and irrigated by wheel line methods using surface water sources. However, note that the impact of energy costs on land use become considerably more significant when accompanied by dry conditions. In this case, the impacts of the rate increase are once again reflected by a large reduction in land planted in cotton (-66 percent) and the idling of all lands planted in alfalfa hay, wheat, sugar beets, and carrots. Again, the removal of this land from irrigated farming reflects their having lower profit margins compared to the various other crops. The production of these relatively higher-valued crops remains profitable under dry conditions and continues the use of land and water resources regardless of the rate increase.

Table 7. Land Use By Crop (in acres)

Crop	5 cents/KWH - No Action		10 cents/KWH - Other	
	Avg. Year (2.25 MAF)	Dry Year (1.0 MAF)	Avg Year (2.25 MAF)	Dry Year (1.0 MAF)
Citrus	34,835	same	same	same
Grapes	73,719	same	same	same
Cotton	277,488	95,252	277,488	95,252
Alfalfa Hay	47,140	0	47,140	0
Wheat	8,889	0	8,889	0
Tomatoes	5,025	same	same	same
Sugar Beets	9,779	0	8,801	0
Almonds	71,574	same	same	same
Carrots	45,290	0	45,290	0
Pistachios	19,713	same	same	same
Total	593,453	300,118	592,475	300,118

5.0 Summary

A summary of impacts described in the foregoing discussion is presented in Table 8. The foregoing analysis has shown that agricultural irrigators in Kern County are an important component in the analysis of potential economic impacts of changes in Western Sierra Nevada electricity rates. Based on the assumptions of the paper, crop supplies vary with the affects of electricity rates on water prices and short-run irrigation cost conditions. The LP analysis of agricultural impacts from changes in Western Sierra Nevada utility rates emphasizes the critical importance of the underlying water supply conditions. These conditions should not be overlooked in when considering the potential impacts of utility-rate policies on growers via their energy, water, and land use decisions.

Table 8. Summary of Impacts On Profits, Production and Land Use By Crop (% change over baseline)

	Avg Year (2.25 MAF)			Dry Year (1.0 MAF)		
	Profits	Production	Land Use	Profits	Production	Land Use
Citrus	-\$1.28 mill. (-2.3%)	no change	no change	-\$1.28 mill. (-2.3%)	no change	no change
Grapes	-\$3.81 mill. (-3.8%)	no change	no change	-\$3.81 mill. (-3.8%)	no change	no change
Cotton	-\$12.35 mill. (-19.5%)	no change	no change	-\$34.42 mill. (-54.4%)	-102,052 (-66%)	-182,236 (-66%)
Alfalfa Hay	no change	no change	no change	-\$5.18 mill. (-100%)	-397,868 (-100%)	-47,140 (-100%)
Wheat	no change	no change	no change	-\$0.32 mill. (-100%)	-24,535 (-100%)	-8,889 (-100%)
Tomatoes	-\$0.26 mill. (-9%)	no change	no change	-\$0.26 mill. (-9%)	no change	no change
Sugar Beets	-\$0.41 mill. (-31.1%)	-26,706 (-10%)	-978 (-10%)	-\$1.32 mill. (-100%)	-267,064 (-100%)	-9,779 (-100%)
Almonds	-\$5.15 mill. (-15.8%)	no change	no change	-\$5.15 mill. (-15.8%)	no change	no change
Carrots	-\$2.21 mill. (-45.1%)	no change	no change	-\$4.83 mill. (-100%)	-1,476,454 (-100%)	-45,290 (-100%)
Pistachios	-\$1.42 mill. (-2.4%)	no change	no change	-\$1.42 mill. (-2.4%)	no change	no change
Total	-\$26.63 mill.	<1%	-978 (<1%)	-\$57.73 mill.	-29.4%	-293,335 (-50.5%)

It should also be noted that other events in the political economy may ultimately influence the utility rates analyzed in this paper. Specifically, the California Public Utilities Commission (CPUC) is in the process of restructuring the state electric utility industry (Decision 95-12-063 as modified by Decision 96-010009).^(a) The restructuring is intended to place downward pressure on retail electricity prices by introducing competition and new market mechanisms.^(b) Accordingly, the results of this paper must be reconsidered once these policies see the light of day.

(a) The CPUC's decision was effective on December 20, 1995, and is scheduled for implementation starting January 1, 1998, for the state's regulated utilities.

(b) The Federal Energy Regulatory Commission has published a notice of proposed rulemaking on promoting wholesale competition through open-access nondiscriminatory transmission services by public utilities (RM-95-8-000) (FERC, 1995). The rules would increase access to transmission services for all sellers and buyers involved in interstate commerce, thereby increasing competition in wholesale power markets.

Appendix A — Model Construction

Total profits from the production of crops are defined as revenues ($P_i Q_{ij}$) and the total irrigation and non-irrigation costs:

$$\Pi = \sum_i \sum_j [P_i Q_{ij} - TIC_{ij} - TNIC_i] \quad (7)$$

where TIC_{ij} is the total irrigation costs for crop i under technology j ,

$$TIC_{ij} = [\alpha_{ij} (C_i^w + C_j^a)] L_{ij} \quad (8)$$

Total irrigation costs for crop i under technology j reflect the total acreage of land in crop i under technology j . Per-acre irrigation costs are defined as the sum of the unit application cost of technology j and the unit water cost for crop i , given crop-specific water application rates α_{ij} under each method of irrigation. For any given amount of water applied to crop i under technology j , the quantity of land under production can be calculated by dividing this amount of water by the specific application rate, α_{ij} . Note further that each irrigation method has a specific water application efficiency ϵ and cost C_j^a . The water application costs reflect energy used in irrigation system pressurization:

$$C_j^a = P_j^a + [1.024 \frac{2.31 (PSI_j)}{\epsilon}] P_f^e \quad (9)$$

For convenience, energy used for system pressurization was converted from pounds per square inch PSI_j to feet-of-lift (1 lb/sq. in. = 2.31 Ft of lift). The average sprinkler systems operate at 50 PSI. In contrast, drip irrigation systems operate at only 15 PSI. Accordingly, the pressurization requirements for sprinkler systems convert to approximately 115.5 feet of lift, while those of average drip irrigation systems convert to 34.7 feet of lift. Finally, an average pump efficiency of $\epsilon = .60$ is assumed.^(a)

(a) For a more detailed discussion of pump efficiencies see Ley (1994) and Caswell and Zilberman (1985).

The cost of irrigation water obtained from private wells is distinguished from the cost of irrigation-district water:

$$C_i^w = \begin{cases} [1.024(\frac{H_i}{\epsilon})] P_e^f & GW \\ [1.024(\frac{H_i}{\epsilon})] P_e^d + P_w & SW \end{cases} \quad (10)$$

The top branch of (10) reflects the average groundwater costs to retail power rates. The energy costs of groundwater vary with farm utility rates $P_e^f = \$0.15/\text{kwh}$; average well depth associated with crop i H_i ; and average on-farm pump efficiency $\epsilon = .60$. The model applies the following formula in relating energy use to head and pump efficiency:

$$\text{kwh}/AF = 1.024(\frac{H}{\epsilon}) \quad (11)$$

The bottom branch of (10) reflects average surface water costs relative to energy costs, which involve: the feet of lift between the water source and the irrigator $H = \text{Ft of lift}$; the energy efficiency of pumping stations $\epsilon = .60$; and the electricity rates paid by irrigation districts $P_e^d = \$0.05/\text{kwh}$. Irrigators also pay an average base water fee of $P_w = \$64.50/AF$, which recovers capital depreciation and maintenance of pumping stations.

The set of feasible water application alternatives faced by farmers assumes a global constraint (expressing an upper-bound limit on water applied to all crops over a one-year period), and crop-specific

constraints imposing min-max restrictions under alternative irrigation methods. These crop-specific water constraints directly affect the min-max amounts of land in any given crop subject to fixed land-to-water proportions:

$$\sum_i \sum_j W_{ij} \leq W^{\max} \quad (12)$$

$$W_{ij}^{\min} < W_{ij} \leq W_{ij}^{\max}$$

All remaining production costs for crop i reflect non-water production expenses incurred by farmers, and expressed as the product of the non-irrigation cost of crop i per acre (C_i^p) and the total acreage of crop i under the relevant technologies:

$$TNIC_i = C_i^p \sum_j L_{ij} \quad (13)$$

Appendix B — LP Tableau

A stylized summary of the LP model structure is shown in Table 4, illustrating production of two crops ($i = 1, 2$) under two irrigation systems ($j = 1, 2$), using either surface or groundwater ($s = 1, 2$). The first three rows of the tableau contain specific i , j , and s values corresponding to the LP specifications described above. The model variables are contained in the row labeled VAR, representing L_{ij}^s , KWH^f , and KWH^d . The coefficients in the objective function are listed in row x , and correspond with expression (8). With the exception of irrigation energy costs, the coefficients appearing in the objective function are specified on a per-acre basis, e.g., NR_{22}^1 represents the per-acre net return to crop 2 under wheel line irrigation using surface water. Meanwhile the two energy cost coefficients represent kilowatt hour costs to farmers and irrigation districts.

Rows 1-11 represent the constraint set. Specifically, rows 1-8 state that each acre of land L_{ij}^s requires AW acre-feet of water and that this product must be less than or equal to baseline water use WS_{ij}^s .

Row 9 of the tableau contains the global water constraint, stating that the sum of individual water uses cannot exceed the sum of baseline water uses WS. When binding, the parametric analysis of this constraint can generate the value marginal product of irrigation water across individual crops and irrigation methods. Otherwise, the constraint is redundant when its right-hand side value is greater than or equal to the sum of the individual WS_{ij}^s values.

Rows 10 and 11 identify on-farm and irrigation district energy uses, which also appear in the objective function in the form of on-farm energy costs. Each KWH_{ij}^{fs} value equals the on-farm energy used to irrigate an acre of crop i under irrigation system j using water source s . No energy is used on farms for activities L_{11}^1 and L_{21}^1 , which entail gravity irrigation in conjunction with surface water deliveries. However, on-farm energy is used under gravity systems that apply groundwater, as reflected by the

Table 4. LP Tableau (2 crops, 2 irrigation systems, 2 source of water)

i=	Crop 1	Crop 1	Crop 1	Crop 1	Crop 2	Crop 2	Crop 2	Crop 2			
j=	Furrow	Furrow	W. Line	W. Line	Furrow	Furrow	W. Line	W. Line			
s=	Surface	Ground	Surface	Ground	Surface	Ground	Surface	Ground			
Var	L	L	L	L	L	L	L	L	KWH	KWH	
Obj	NR	NR	NR	NR	NR	NR	NR	NR	-P	-P	
Row											RHS
1	AW										≤ WS
2		AW									≤ WS
3			AW								≤ WS
4				AW							≤ WS
5					AW						≤ WS
6						AW					≤ WS
7							AW				≤ WS
8								AW			≤ WS
9	AW	AW	AW	AW	AW	AW	AW	AW	AW		≤ WS
10		KWH	KWH	KWH		KWH	KWH	KWH	-1		=0
11	KWH _{ss} ^{d1}		KWH		KWH		KWH			-1	=0

non-zero values for KWH_{11}^{fs} and KWH_{12}^{fs} . Row 11 refers to irrigation district energy use in surface water deliveries. Each KWH_{ij}^{ds} coefficient equals the quantity of energy required by the irrigation district to deliver AW_{ij}^1 acre feet of water. All KWH_{ij}^{d2} coefficients are zero in row 11, as they pertain to groundwater-irrigated acreage. The following section evaluates the sensitivity of growers to various changes in the structure of utility rates.

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