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RISING ENERGY PRICES, WATER DEMAND BY PERI-URBAN AGRICULTURE, AND IMPLICATIONS FOR URBAN WATER SUPPLY: THE TUCSON CASE

by

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INTRODUCTION

The research reported here estimates the impact of rising energy prices on farm profits and irrigation water use in Avra Valley, a peri-urban,[1] irrigated region adjacent to Tucson, Arizona. Estimates of the demand for water by Avra Valley farms are used to draw implications about the supply of water for Tucson's municipal needs.

The provision of water demanded by municipal users at "reasonable" prices has long been a problem of the city of Tucson. Tucson is the largest city in the U.S. to meet its water needs entirely from underground sources, and the stock of underground water, built up over thousands of years, is being depleted faster than replenished in both the Tucson Basin and adjacent Avra Valley. In areas within the Tucson Basin and Avra Valley, groundwater declines have exceeded 100 feet in the past 30 years (Matlock and Davis, Matlock and Morin). The water problem has recently been highlighted in Tucson by increasing water rates and political turmoil associated with water rate increases.

Tucson's water is pumped from underground aquifers of the Tucson Basin and Avra Valley. But other important users of the underground water, the copper mines and irrigated agriculture, also compete for this scarce resource. Pumpage in the Tucson Basin in 1975 for municipal/domestic, industry/mines, and agricultural users was 97,300, 62,000 and 110,100 acre feet respectively (Barr and Pingry, p. 5). Irrigated farmland in the Avra Valley, approximately 15,000 acres, pumps approximately 60,000 acre feet per year.

The law governing the extraction and use of underground water appears to permit water historically used in Avra Valley agriculture to be pumped and diverted for Tucson's municipal use, but with restrictions. Municipal diversions are not to exceed 50 percent of the historical annual average amount of groundwater pumped for crop irrigation. If more than this amount is pumped for export to Tucson, it is held that the neighboring farmland may suffer damages because of increased pumping depth, and that the city may be liable (though this possibility has not been established with certainty). Since 1972, the city has purchased 12,000 acres of land in the Avra Valley at a purchase cost of $9 million to provide water to the city.

Rising energy prices may affect farm profits in the Avra Valley and thereby the supply of water available for Tucson's use in at least two ways. First, the demand for land and water for irrigated farming is affected by farm profits. If farm profits are expected to decrease for several years, the number of farms available for sale will increase, and the price of land fall below what it would be with high farm profits. Such a situation, while unfavorable to farming, is favorable for municipal needs. Second, the law which governs the extraction and use of groundwater may be altered in view of changing economic conditions. Historically, agricultural interests have had considerable impact on the formation of water law, and pressed for legislation and court rulings which favor agriculture. The Jarvis I, Jarvis II and Jarvis III court cases are clear examples of this agricultural interest in water rights in the Tucson area (Fleming). The connection between farming profitability and the press

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1. Peri-urban agriculture refers to farming which occurs on the perimeter or periphery of an urban area. The Avra Valley, as defined here, is bounded on the North by Marana Airpark, on the South by Ajo Way, on the East by the Tucson Mountains, and on the West by the Tucson Compressor Station.

for water rights which favor agriculture is not clear cut. However, our hypothesis is that should farming become unprofitable even without further groundwater drawdown, there will be less incentive for farmers to press for water rights which favor farming.

Rising energy prices will affect farm profits by increasing the cost of pumping a given amount of water, and by increasing the price of nitrogen fertilizer which requires substantial energy inputs in its manufacture. Farms in the Avra Valley may adjust to these rising prices by decreasing the amount of water pumped and fertilizer used per acre on each crop, shifting the mix of crops grown, or, in the long run, ceasing to operate as an irrigated farm. These adjustments will affect the demand for irrigation water in the Avra Valley. In the research reported here, a static linear programming (LP) model and water-fertilizer production functions relating crop yield to various levels of these inputs are used to account for farm adjustments, including changes in water demanded. Adjustments are estimated as the price of electricity in the LP-production function model is increased from 25 to 200 percent above the price of electricity in 1976.

AVRA VALLEY FARMING

The Avra Valley, situated on the northwest side of the Tucson Mountains, contained approximately 15,000 crop acres at the time of the study. The climate is hot and dry and provides favorable growing conditions for cotton, wheat, sorghum, and barley.

Farm size in the Avra Valley is fairly large. Figures from Kelso, Martin and Mack for Pima County were assumed to be representative of the distribution of farm size in the Avra Valley (Table 1).

Table 1. Avra Valley Farm Sizes and Numbers

Farm Size Class	I	II	III
Range (acres)	30-520	520-960	960
Average Acres	303	722	2639
% of Farm in Class	48	26	26
# Farms	8	4	4

Well lift depths in Avra Valley range from about 200 to 600 feet, with an average pumping lift of 358 feet (Hathorn). A shallow lift depth of 258 feet and a deep lift depth of 458 feet are also used in the study. Pumping costs are important; for the two principle crops of cotton and wheat, the 1976 costs of electricity for pumping averaged 18 and 25 percent, respectively, of total variable costs (computed from Hathorn and Armstrong).

Energy costs for pumping vary not only by crop and lift depth, but also by type of energy used and by farm size. Recent shortages of natural gas have made it attractive for farmers to switch to electricity as a power source. Therefore, pumping costs associated with an electric power source are utilized in this study. Stults found appreciable differences in the efficiency of water use among three farm-size classes. Small farms have greater water losses than large farms. Water use per cropped acre as a percentage of mean water used, was estimated by Stults to be 108.5, 104.0, and 95.5 percent for Class I, II, and III farms respectively. Differences in efficiency occur because large farms tend to have a larger proportion of their ditches lined with concrete, management expertise may increase as farm size increases, and larger farms are usually leveled to a more optimum grade, thereby increasing irrigation efficiency. These figures, reflecting differences in pumping cost by farm size, are incorporated into the study.

Anhydrous ammonia, the most common source of nitrogen fertilizer utilized in Avra Valley, is an important input affected by rising natural gas prices. The 1976 costs of anhydrous ammonia for the two principle crops of cotton and wheat were 11 and 24 percent respectively of total variable costs (computed from Hathorn and Armstrong). Information from the USDA (Paul) suggests that for each one percent increase in the price of natural gas, the price of anhydrous ammonia will increase by 0.4 percent. In this study, predictions of the price of anhydrous ammonia are made with possible natural gas price increases of 25, 50, 100 and 200 percent.

METHOD

Production function analysis and static linear programming are used to estimate the impact of rising energy prices on farm profits, cropping patterns and irrigation water used in the Avra Valley.

Statistical production functions developed by Heady and Hexem for various crops in Arizona are used to determine the profit maximizing amount of water and nitrogen to apply per acre to each crop as energy prices are arbitrarily increased up to 200 percent above 1976 energy prices. The profit maximizing amount of water and nitrogen to apply per acre are found by determining the amount of these inputs which equate the price of each input to the value of the output produced by the last unit of the input (where the marginal value product from the input equals its price).[2] The price of water is the average cost of pumping an acre foot of water, and varies with well depth, the price of energy, and the irrigation efficiency of different farm sizes. Well depth and farm size are accounted for in the analysis by computing the profit-maximizing amount of water for each of 9 representative farms. Each farm represents one of three farm sizes and one of three well depths, as previously described. Profit maximizing levels of input use are computed for each representative farm for each of the 5 hypothetical energy price levels.

The optimum water-nitrogen levels and output estimated by the production functions, plus variable costs and crop returns from Hathorn and Armstrong, are then used in static linear programming models. The linear programming (LP) models provide a means to estimate the profit maximizing combination of crops to produce on each of the 9 representative farms, given certain constraints and subject to prices assumed for electricity. Constraints include farm acreage and the amount of Pima and Upland cotton which can be grown on each farm. Since cotton is the most profitable crop grown in Avra Valley, a cotton constraint is included to prevent all cotton solutions to the model. It is assumed such solutions would be unreasonable in view of farmers' desire to avoid risk. The cotton constraint is based on the proportion of irrigated land planted to cotton in 1966.[3] In that year, the government made payments to farmers for land taken out of cotton production--thus providing a means of avoiding the risk of low cotton prices. Constraints by farm size are given in Table 2.

Table 2. Constraints by Farm Size, Acres.

Farm Size	Land Constraints	American-Pima Cotton Constraints	Upland Cotton Constraints
I	303	45	89
II	722	36	213
III	2639	130	776

Crops typically grown in Avra Valley, and those used as alternatives for this study, include American-Pima cotton, Upland cotton, wheat and small amounts of alfalfa, barley and sorghum. Models were run for electricity prices at the 1976 level of $ .02808 per KWH, and prices 25, 50, 100 and 200 percent above that price. (By January 1, 1978, electricity prices were $ .03418 per KWH.) Other data, primarily the costs of production and returns from each crop are based upon 1976 estimates from Hathorn and Armstrong.

RESULTS

The short run effect of increased energy prices on water used for irrigation in the Avra Valley is shown in Table 3. By definition, the short run allows changes to be made in the amount of inputs used per acre and the cropping pattern, but differs from the long run in that entry and exit of farmland from agriculture is not considered.

Table 3 indicates that only after electricity prices have increased to over 100 percent of 1976 levels will water conserved in irrigated agriculture constitute a sizeable portion of Tucson's

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2. Profit maximizing levels of water and nitrogen to apply on each acre will be less than that determined by the production function analysis if there are constraints on the total amount of water and nitrogen which can be applied. No constraints were assumed. If constraints in fact exist, the conclusions of the research are strengthened rather than weakened.

3. Boster and Martin, in their 1977 study (page 20), use this same basis for employing a cotton acreage restriction in their linear programming study of Pinal County farming. They point out that although the restriction may be slightly low in comparison to cotton acreage actually planted in 1976, cotton prices in that year were exceptionally high--and in the long run cotton prices and acreages are expected to be lower.

Table 3. Short Run Irrigation Water Use in Avra Valley.

% Increase in Energy Price	Water Pumped (1000 AF)	Water Conserved[4/] (1000 AF)	Water Conserved as a % of Pumpage in 1975 from the Tucson Basin for Municipal/Domestic Use
Initial	57.3	--	--
25	56.1	1.2	1
50	55.4	1.9	2
100	54.6	2.7	3
200	32.9	24.4	25

municipal/domestic water needs. Water conservation per acre for all crops, as pumping costs increase, is predicted to be relatively small. The statistical production functions upon which this conclusion is based suggest that, in general, water used per acre decreases by less than 10 percent, even at energy price increases of 200 percent.[5/]

Water conservation at high energy prices is caused primarily by a shift out of wheat production on farms with medium to deep lifts. Even this water conservation effect may be overestimated in the short run, however, because the cotton constraint within the model prevents land being diverted from wheat to cotton production--a transition which may occur rather than allowing land to go unused.

In the long run, farmers must not only maximize returns over short run variable input costs (for machinery repairs, fuel and oil, labor, hired service, materials), but also cover the fixed costs of buildings, machinery, irrigation facilities, taxes and management. If returns to land and risk become lower than could be obtained if land were sold and the returns put in other assets of similar risk, land will tend to go out of agricultural production.[6/]

Table 4 shows the returns to land and risk for each farm of a particular size and well lift depth as energy prices are increased up to 200 percent. No appreciation in land values is assumed. Numbers in parentheses are the percentage returns based upon an assumed land selling price of $1000 per acre. Assuming an 8 percent return on an alternative investment, such as currently available on long term bonds, all Class I and Class II farms plus deep lift Class III farms are expected to go out of agricultural production as electricity prices increase by even 25 percent over 1976 levels. Besides these, the large, medium lift depth farms show relatively low long run returns as electricity prices increase 50 percent. At a 100 percent increase in electricity prices, all irrigated farmland shows low or negative long run rates of return.

Water conserved as land goes out of agricultural production will be substantial. As energy prices increase by 25 percent and Class I, II and some Class III farms go out of irrigated agriculture, water savings are expected to be 45,000 acre feet, or 46 percent of the 97,000 acre feet of groundwater pumped in the Tucson Basin in 1975 to meet municipal/domestic needs (Barr and Pingry). The current, 1978, price of electricity is already 20 percent over the price assumed in the model, and recent estimates by Armstrong indicate that there are only about 10,000 acres of irrigated cropland left in the Avra Valley, down 5,000 acres from the time the study was initiated a year ago. As energy price increases by 50 and 100 percent, and all land is diverted from irrigated agriculture,

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4. Water conserved refers to the difference between irrigation water pumped at 1976 energy prices and water pumped at the hypothesized energy price increase.

5. The statistical production functions used in this study are somewhat crude, but the best available at the time. Current research by USDA researchers located at the University of Arizona attempts to improve our knowledge of crop response to water.

6. In the long run, farms may increase profits and perhaps continue to operate if new energy saving technologies, such as sprinkler irrigation systems, are adopted. For the most part, however, these technologies are very costly and because of uncertainties of product prices and rising input costs, it is here assumed that there will not be a shift to such technologies in the Avra Valley.

Table 4. Estimated Returns[7/] to Land and Risk[8/] with Increasing Energy Prices: No Appreciation in Land Values.

Farm Size	Lift Depth Feet	% Increase in Energy Price 0		25		50		100		200	
		$1000	%	$1000	%	$1000	%	$1000	%	$1000	%
I (303 Ac)	285	10	(3)	3	(1)	0	(0)	-11	(-4)	-28	(-9)
	385	0	(0)	-6	(-2)	-12	(-4)	-24	(-8)	-44	(-15)
	485	-7	(-2)	-4	(-5)	-23	(-8)	-36	(-2)	-51	(-17)
II (722 Ac)	285	57	(8)	46	(7)	34	(5)	12	(2)	-29	(-4)
	385	37	(5)	22	(3)	7	(1)	-20	(-3)	-68	(-9)
	485	19	(3)	2	(0)	-15	(-2)	-49	(-7)	-87	(-12)
III (2639 Ac)	285	337	(13)	316	(12)	260	(10)	182	(7)	41	(2)
	385	263	(10)	212	(8)	162	(6)	66	(3)	-115	(-4)
	485	210	(8)	149	(6)	91	(3)	-25	(-1)	-180	(-7)

some 64 and 72 percent respectively of pumpage from the Tucson Basin for municipal/domestic use is conserved in the Avra Valley.

Land prices in the preceeding estimates are assumed constant. It is likely, however, that land in the Avra Valley will appreciate in value. Land appreciation represents a return to the landowner, and therefore should be taken into account in computing long run returns to land and risk, and in estimates of acreage taken out of agricultural production as energy prices increase. Table 5 gives estimates of the rate of return to land and risk at different energy prices and at 5 and 10 percent rates of land appreciation. It is again assumed that land will be sold and taken out of agricultural production when the rate of return to land and risk is 8% or less. The amounts of water conserved as energy prices increase and land is taken out of agricultural production, given assumed rates of land value appreciation of 5 and 10 percent, are shown in Table 6. Again, the quantities of water conserved are relatively large. At a 50 percent increase in the price of energy and an assumed 10 percent land value appreciation, water conservation is estimated to be 22,600 acre feet, or 23 percent of the water pumped from the Tucson Basin in 1975 for municipal/domestic purposes.

SUMMARY AND CONCLUSIONS

Relatively large amounts of water are expected to be conserved in the Avra Valley as energy prices increase and land is removed from agricultural production. Most water savings will result from long run shifts of land out of irrigated agriculture, rather than as a result of decreases in water application per acre of a particular crop, or changes in crop mix. The amount of water saved will depend upon energy price increases and land value appreciation. As an example of the amount

7. Numbers in parentheses are the percentage returns to land and risk if land prices are assumed to be $1000/acre. Land prices of $1000 per acre are probably conservative. Although few Avra Valley farms are bought and sold for agricultural production, Tucson has recently purchased former farmland for near $1000 per acre, and the mines have purchased former farmland for $2000 per acre (Armstrong). If the price of land is $1,500, the estimates of percentage returns shown above should be divided by 1.5.

8. Returns to land and risk are total farm receipts - total variable costs - fixed costs including a management fee. More specifically:

Total variable costs = costs of machinery repairs, fuel and oil; labor; hired services; and materials (Hathorn and Armstrong).

Fixed costs including management = costs of building depreciation, insurance, repair and interest on investment; concrete ditches depreciation, repair and interest on investment; machinery and equipment depreciation and interest on investment; real estate and personal property taxes (excluding wells); irrigation well and equipment depreciation and interest on investment; and a management fee. Except for the management fee, costs are computed from Boster and inflated to 1976 values using the same price indices used by Boster. The management fee, which is considered to be the opportunity cost of management or the approximate cost of a hired manager, is assumed to be $18,000 based on Armstrong.

Table 5. Estimated Percentage Returns to Land and Risk with Increasing Energy Prices: Land Assumed to Appreciate by 5 and 10 Percent Respectively.[9]

		% Increase in Energy Price									
		0		25		50		100		200	
		Land Value Appreciation -%									
Farm Size	Lift Depth Feet	5	10	5	10	5	10	5	10	5	10
I	285	8%	13%	6%	11%	5%	10%	1%	6%	-4	1
(303 Ac)	385	5	10	3	8	1	6	-3	2	-10	-5
	485	3	8	0	5	-3	2	-7	-2	-12	-7
II	285	13	18	11	16	10	15	7	12	-1	6
(722 Ac)	385	10	15	8	13	6	11	2	7	-4	1
	485	8	13	5	10	3	8	-2	3	-7	-2
III	285	18	23	17	22	15	20	12	17	7	12
(2963 Ac)	835	15	20	13	18	11	16	8	13	1	6
	485	13	18	11	16	8	13	4	9	-2	3

Table 6. Estimated Water Conserved with Increasing Energy Prices: Land Assumed to Appreciate by 5 and 10 Percent Respectively.

	% Increase in Energy Price							
	25		50		100		200	
	% Land Value Appreciation							
	5	10	5	10	5	10	5	10
1000 Ac Feet Water Conserved	34.7	17.2	41	22.6	51.7	35.6	57.3	52.0
Water Conserved as % of Pumpage in 1975 from Tucson Basin for Municipal/ Domestic Use	36	18	42	23	53	37	59	54

of water expected to be conserved, the estimates indicate that if land values appreciate at 10 percent and energy prices increase by 50 percent over their 1976 levels, some 22,600 acre feet of water will be conserved, an amount equal to 23 percent of the amount of water pumped from the Tucson Basin in 1975 to meet municipal/domestic demand.

Increasing energy prices result in long run losses to Avra Valley agriculture. While these losses may harm those in agriculture and closely related industries,[10] Tucson's economic position may be helped. First, there will be more water available. Second, the price which the city must pay

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9. See Table 4 for methods of computation and sources. Land prices assumed to be $1000 per acre. If land prices of $1500 per acre are assumed, the percentage returns are a few percentage points below those shown.

10. The number of people who may temporarily loose employment is relatively small. The total number of workers involved in Avra Valley farming is estimated to be less than 200 people (Armstrong). Even if two people are employed in related industries to service each one employed in agriculture--almost certainly an overestimate--the initial loss of 200 agricultural workers would imply a temporary loss of at most 600 jobs in total. These job losses would likely be absorbed rather easily in the Tucson economy. The Tucson metropolitan population is approaching 1/2 million, and during the next 5 years Tucson is expected to be one of the fastest growing city in the U.S. (Arizona Daily Star).

for farmland, in order to gain control of the underlying water, should be diminished, <u>ceterus paribus</u>, and the quantity of farmland for sale increased. And third, it is hypothesized that with fewer people involved in irrigated agriculture, legal conflicts between competing users will be diminished.

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