The Derived Demand for Irrigation Scheduling Services

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Scientific irrigation scheduling is a technique for systematically determining the proper date and quantity of each irrigation in individual fields. This technique is presently being used by government agencies and private companies in the Western United States to assist farmers in planning irrigations. This paper presents the results of a case study of the regional economic effects of scheduling in the A & B District in Idaho. The analysis indicated that substantial reductions in total water use resulted from implementation of the service. However, the acreage of scheduled irrigation activity was found to be sensitive to the cost of the service and the cost of irrigation water.

In recent years a new approach to irrigation has emerged in which a computer is used, in combination with trained personnel working in the field, to determine the appropriate timing and amount of each irrigation for individual fields. The computer is used to model soil moisture conditions and forecast the required date and amount of upcoming irrigations. Field personnel interpret the computer outputs, periodically check soil moisture in the fields, and advise the farmer on his irrigation schedule. This scheduling procedure is based upon principles of soil science, agronomy, meterology, and engineering and is often referred to as scientific irrigation scheduling. It was originally developed by Dr. Marvin Jensen [1975] of the U.S. Agricultural Research Service between 1968 and 1971; was modified and developed by the Water and Power Resources Service (WPRS), the Soil Conservation Service, and others [Gear, *et al.*; Buchheim and Ploss]; and is now being supplied as a commercial service to farmers throughout the Western United States.

It is generally held that the potential benefits of an irrigation scheduling service (ISS) may include:

a. Reduced water use, with attendant reductions in drainage problems and reduced salinity of downstream flows,
b. Increased crop yields,
c. Reduced production costs for water, fertilizer and pesticides, and
d. Improved farm operating efficiencies due to the ability to plan irrigations well ahead of time.

In practice, however, these benefits are often disputed. Given the legislative mandate (Public Law 92-500) to control nonpoint sources of pollution from irrigated agriculture through the imposition of "Best Management Practices," considerable attention has been focused on irrigation scheduling as a potential control measure. Against this back-

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ground, then, the specific objectives of this research were to:

a. Develop a method of assessing the regional environmental and economic benefits and costs of an irrigation scheduling service,
b. Apply that method to a case study for the purposes of evaluating the method and developing some perspective on the factors which affect the benefits and costs of a scheduling service.

Only those results pertaining to the economics of scheduling services are reported in this paper.

Study Area and Data

The analysis was conducted in the context of a case study involving the A & B Irrigation District, 76,800 acres located on the Snake River in Southern Idaho. An irrigation scheduling service has been in use there for ten-years. The principal reasons for choosing the A & B District are: first, the area is relatively homogenous in physical characteristics, and second, substantial data and research have been compiled by various agencies in the area. The district is supplied with water pumped both from the Snake River and from wells, with a lift of approximately 200 feet in either case. One important characteristic of farmers in the A & B District is that their irrigation operations are relatively efficient for gravity systems in Southern Idaho. It was estimated in this study that distribution system losses account for approximately 10 percent of water delivered to the farm while surface runoff and deep percolation account for 39 percent of water applied to the fields. During the ten-year period from 1958 to 1968, annual district deliveries averaged 3.18 acre feet per acre which was considerably less than the 4.1 and 5.09 acre feet per acre in two adjacent districts.

Between 1964 and 1968, six typical farms in the A & B District encompassing approximately 600 acres participated in a U.S. Bureau of Reclamation (USBR) study of irrigation water use [USBR]. An exhaustive data collection program was conducted in each field during each of those years. The data included climatic variables, soil conditions, and agronomic and irrigation practices. In an earlier interagency study conducted from 1958 to 1963, 40 farms covering 4,340 acres were evaluated for irrigation water use and efficiency. Data collected on those 40 farms included water deliveries, runoff, weather data, and crop yields. However, the data collection effort during the 40-farm study was neither as comprehensive nor as complete as that of the six-farm study.

Physical Analytical Subsystem

The analytical system employed for this research is composed of a physical analytical subsystem and a regional economic model (Figure 1). The physical analytical subsystem estimates crop yields, irrigation water use and frequency, and salt and sediment loads of return flows on a per acre basis. This information is used in the regional economic model to estimate changes in regional farm income, water use, scheduled acres, and the amount and quality of irrigation return flows that could result from the use of an irrigation scheduling service. Since this paper focuses on an economic evaluation of the adoption of irrigation scheduling services under alternative implementation strategies, only a brief description of those models relevant for the estimation of water use and crop production relationships will be presented. For a detailed description of the models comprising the physical analytical system see English, *et al.*

Water use and crop production coefficients under irrigation scheduling were estimated from a two-stage simulation process. The first stage involves the interaction of soil moisture and irrigation models in order to simulate moisture stress and seasonal evapotranspiration. The soil moisture model estimates evapotranspiration and soil moisture for each crop by calculating soil moisture budgets for the active root zone and a lower zone into which the root system will eventually move. The soil moisture content, S_{ijt}, expressed as a

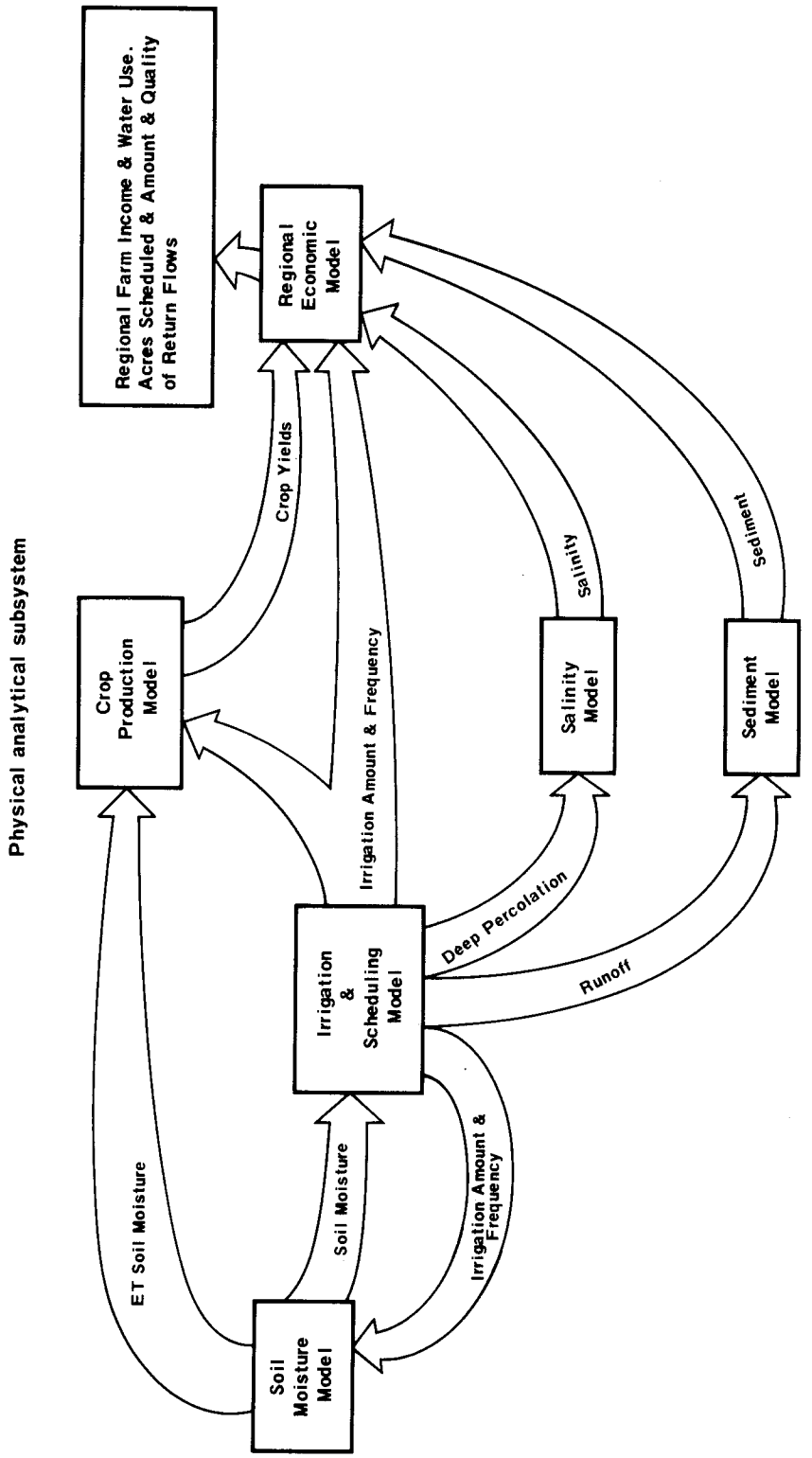

Figure 1. Irrigation Scheduling Analytical System.

percent by volume in field i for crop j at time t is given by:

$$(1) \quad S_{ijt} = s(RZ_{jt}, m_i, \sum_t ET_{ijt}, DP_{it})$$

where:

RZ_{jt} is active root zone depth for crop j at time t.

m_i is soil moisture holding capacity in field i.

$\sum_t ET_{ijt}$ is cumulative evapotranspiration in field i for crop j at time t.

DP_{it} is deep percolation in field i at time t.

Evapotranspiration and percolation, primary determinants of soil moisture, are dependent upon the size of the active root zone. This dynamic area is explained as:

$$(2) \quad RZ_{jt} = r(RZ_{max}, k_{ijt})$$

where:

RZ_{max} is the estimated maximum depth for the active root zone.

k_{ijt} is a measure of relative evapotranspirational demand for crop j in field i at time t.[1]

This equation describes a model developed by Jensen that relates root zone size to the crop growth stage [Jensen, 1979].

In turn, deep percolation in field i at time t is of the form:

$$(3) \quad DP_{it} = h(S_{ijt}, RZ_{jt}, C_i, sd_i)$$

where:

C_i is the conductivity of soil comprising field i.

sd_i is the depth of the soil profile in field i.

This empirical model of soil drainage rates is based upon work by Nielsen, *et al.* It was calibrated for local soils using data supplied by Jensen [1976].

[1]This variable is more commonly known as a crop coefficient. It serves as an index for the growth and development of the crop.

The calculation of evapotranspiration also follows methods proposed by Jensen, *et al.* The basic relationship may be generally expressed as:

$$(4) \quad ET_{ijt} = n(S_{ijt}, k_{ijt}, W_t, d_t, \ell_{it}, \alpha_t, \gamma_t)$$

where:

W_t is average wind velocity during time t.

d_t is average mean daily temperature during time t.

ℓ_{it} is soil surface moisture conditions of field i at time t.

α_t is average solar radiation during time t.

γ_t is relative humidity at time t.

Procedurally then, when the calculated soil moisture budget reaches a crop-specific critical level, the required water diversion is determined by the irrigation model:

$$(5) \quad q_{ijt} = f(f_{it}, S_{ijt}, e)$$

where:

q_{ijt} is irigation water to be diverted.

f_{it} is nominal field capacity in the root zone.

e is the overall efficiency of irrigation including all losses.

These models were then interacted through time to simulate the crop season.

The second stage in the estimation of crop production coefficients under irrigation scheduling is comprised of the crop production model. This model is based upon Stewart, *et al.*, Stewart and Hagan, and Downey; however, the model itself is empirical. The crop production model may be generally represented as:

$$(6) \quad Y_{ij} = V(\sum ET_{ijt}, ETd_{ij}, smt_i, \sum q_{ijt}, P, I_{ij})$$

where:

Y_{ij} is the yield per acre of crop j in field i.

ETd_{ij} is the evaporanspirational deficit suffered by crop j in field i.

smt_i is average soil moisture tension in field i.

$\sum_t q_{ijt}$ is the quantity of irrigation water applied.

P is net rainfall.

I_{ij} is the number of irrigations applied to field i to raise crop j.

These soil moisture, irrigation and scheduling, and crop production models were used to estimate yield and water use coefficients for each crop under irrigation scheduling.

The Regional Economic Model

A scheduling service can be made available to farmers either by a private company or a public agency. The public agency may choose to offer such a service for many reasons, such as to promote more efficient water use in order to increase the size of the irrigated area served from a fixed supply of water or to reduce irrigation return flows. The purpose of this analysis is to project the amount of irrigation activity that would be scheduled if a private company or public agency provided the service. Linear programming was used to determine optimal water application rates so as to maximize net returns to land and management under the district cropping pattern that existed in the 1973-75 period. While the relevant decision unit in this analysis is the firm, substantial interest in irrigation scheduling is vested in its impact upon externality production. Since firms are assumed to be profit maximizers, and lacking firm-specific economic information, it is presumed that the maximization of net returns under the aggregate district cropping pattern adequately simulates aggregate grower behavior.

The LP model was optimized for three sets of assumptions. The first solution was constrained to unscheduled operations to estimate the level of returns to producers, resource use, and irrigation return flows assuming a scheduling service did not exist. This solution served as a basis from which other solutions could be compared. The second model configuration required all water applications to be determined by a scheduling service. The difference between the solutions derived in the first and second model configurations served as an estimate of the potential change that could be possible from a scheduling service. The third configuration was not restricted to scheduled or nonscheduled water applications. Therefore, the optimal solution represented the level of scheduling that would probably exist if the service were offered on an elective basis. The cost of the scheduling service and the cost of water were parameterized in the third model configuration to determine the effect on the number of scheduled acres.

Input Data

The USBR information provided a set of data describing water use, crop yields, and irrigation return flows. These data with prices and costs were used to derive the coefficients detailing unscheduled operations in the linear programming model. Three levels of observed irrigation water application rates were defined as low, medium, and high on the basis of observed water use by crop in 443 unscheduled field operations in the A & B District. Ranges for the three levels were determined by ordering these observed application rates and inspecting their distribution. The medium level was defined as the typical rate for that crop plus variations that could be explained by differences in the precision of applying water. Extreme application rates were placed in the high and low classifications.

The 443 observations were taken from the six-farm study (204 cases) and the 40-farm study (239 cases) and included corresponding crop yields. Table 1 contains the specific water application rates and the proportion of cases in each rate. As an example, the range between 25 and 35 acre-inches of applied water was defined as medium water use for barley. Less than 25 acre-inches and more than 35 acre-inches were defined as low and high water use respectively. The average irrigation labor per acre set and the average number of irrigation sets for each crop were estimated from the six-farm study and used

TABLE 1. Definition of Low, Medium and High Water Use for Each Crop (Unscheduled Irrigation Regime) and Proportion of Irrigated Cases in Each Category[a].

Crop	Low	Medium	High
	Acre-inches per acre		
Alfalfa	<35.1 (0.243)	35.1 – 50.0 (0.457)	>50 (0.300)
Barley	<25.03 (0.541)	25.0 – 35.0 (0.360)	>35.0 (0.099)
Beans	<25.0 (0.255)	25.0 – 37.0 (0.568)	>37.0 (0.177)
Peas	<27.0 (0.452)	27.0 – 42.0 (0.474)	>42.0 (0.074)
Potatoes	<30.0 (0.115)	30.0 – 45.0 (0.499)	>45.0 (0.386)
Sugar Beets	<40.1 (0.346)	40.1 – 50.0 (0.414)	>50.0 (0.240)
Wheat	<25.0 (0.544)	25.0 – 35.0 (0.364)	>35.0 (0.092)

[a]The numbers in parentheses represent the proportion of irrigated fields observed with application rates within the indicated class.

to compute the average total irrigation labor per acre by crop for each water application rate.

Crop yields observed in the 443 water use cases were used to estimate yields for each crop for the three levels of unscheduled water use. Crop yields had to be adjusted to reflect technologic changes that have caused gradual increases in productivity since the USBR studies. Crop yields under scheduled water regimes were estimated from the crop production model calibrated for each crop with data from the 204 cases of the six-farm study. The resulting estimates of scheduled crop yields were modestly higher than their unscheduled counterparts for beans, potatoes, and sugar beets. In the remaining cases, scheduled yield estimates were within the range of yields associated with alternative water use rates.

Crop prices used in the analysis were district average prices paid to farmers in the A & B District during the years 1973 through 1975, the most recent data available at the time of the analysis. Water prices were based upon actual District prices during those same years. Production costs per acre for alfalfa, barley, potatoes, sugar beets, and spring wheat were based on variable preharvest costs taken from budgets derived by Kuntz. Harvest costs were adjusted proportionally for the differences between the yield per acre used in the budget and the yield per acre adjusted for trend.

Regional Effects of an Irrigation Scheduling Service

Potential Impacts of a Scheduling Service

Basic economic information was estimated for each irrigation regime under alternative policies (Table 2). The changes in average annual returns to land and management under alternative implementation schemes are described in Table 3. Changes in the annual returns to land and management are attributable to adjustments in the crop and resource use mix and, therefore, productivity

TABLE 2. Estimated Average Annual Results of the Irrigation Scheduling Analysis in the A & B District[a].

Variable	Units	Base No Scheduling	Mandatory Scheduling	Voluntary Scheduling No Charge Per Acre	Voluntary Scheduling $5.00 Per Acre Charge
Returns to Land and Management	$1,000,000	14.118	14.390	14.518	14.456
Irrigation Water:					
Use	1,000 Acre-Feet	216.865	144.013	167.711	205.078
Cost	$ 1,000	841.013	655.767	721.628	838.553
Irrigation Labor:					
Use	1,000 Hours	120.539	86.476	97.625	114.681
Cost	$ 1,000	416.469	298.759	335.807	395.349

[a]These results are averaged from annual estimates for 1973, 74 and 75. The average area irrigated in this period was 65,132 acres.

TABLE 3. Changes In Average Annual Net Returns Per Acre By Policy From the Base Analysis.

Component Change	Mandatory Scheduling	Voluntary Scheduling No Charge Per Acre	Voluntary Scheduling $5.00 Per Acre Charge
	Dollars Per Acre		
Increase in Value of Production	−0.32	3.07	4.83
Decrease in Irrigation Water Cost	2.69	1.83	0.04
Decrease in Irrigation Labor Cost	1.81	1.24	0.32
Increase in Net Returns	4.18	6.14	5.19

differences as well as changes in irrigation costs.[2] The average per acre value of production declines from the unscheduled base analysis under the mandatory scheduling regime since alfalfa yields for the high water use alternative were greater than those estimated to be obtained under scheduling.[3] Under the two voluntary adoption analyses, regional crop production and resource use is completely optimized given the scheduling

[2]Note that this formulation of the linear programming model employs the expected values of yields and prices. The costs of risk management associated with yield and/or price variability are not included.

[3]It should be emphasized that these results are based upon the perfect implementation of recommendations from the ISS. For an assessment of the impact of departures from the schedule see English, *et al*. Consequently, under such stringent conditions, these estimates represent an optimistic upper bound of participation.

service charges. Under fully subsidized voluntary scheduling, an average of 48,230 acres were scheduled annually. Table 4 indicates that the production of beans, potatoes and sugar beets was increased through scheduling when compared against the base analysis. Despite production declines for alfalfa and barley, the average per acre value of production under subsidized scheduling increased by $3.07. When a $5.00 per acre charge for scheduling is levied, however, scheduled acreage declines to 21,550 acres. At this charge level, alfalfa, barley, peas, and sugar beets are no longer scheduled (Table 4).[4] Thus, the bulk of the change in net returns per acre is associated with changes in the value of production; i.e., irrigation-associated cost savings are no longer accruing to the grower.

The average annual per acre reduction in water and irrigation labor costs ranged from $0.36 to $4.50 depending upon the particular implementation policy (Table 3). In aggregate terms, water costs were reduced 22 percent under mandatory scheduling, 14.2 percent under voluntary subsidized scheduling services, and 0.3 percent under a $5.00 per acre scheduling service. These cost reductions belie the reductions in water use accomplished through irrigation scheduling. Water use was reduced 33.6, 22.7, and 5.4 percent under the mandatory, subsidized, and priced alternatives, respectively.[5] The disparity between water cost and use reductions is due to the water pricing schedule of the A & B District, which stipulates a fixed rate for the first three acre-feet of water use. The economic incentive to reduce water use and for the adoption of a scheduling service would be proportionately greater if the unit cost of water varied directly with use.

Voluntary Adoption of a Scheduling Service

The foregoing analysis indicated that the district as a whole would profit from universal irrigation scheduling. However, it should be noted that in some situations a farmer might be better off *not* to use a scheduling service for some crops but instead to adopt one of the three levels of unscheduled water use because it would be more profitable. As an example, the highest profit for alfalfa growers in 1973 was realized with high water use and no scheduling, rather than with scheduling. The most profitable strategy

[4]Under the no-charge implementation policy, alfalfa was scheduled in 1974 and 75, but not in 1973. With a $5.00 per acre charge, alfalfa is not scheduled at all. Sugar beets are scheduled in 1975 under the charge policy, but not in 1973 or 1974.

[5]Note that the water saved under each of the implementation strategies is not explicitly valued in its availability for other uses. To the extent that such opportunities exist, there are further potential benefits associated with the implementation of irrigation scheduling.

TABLE 4. Average Annual Crop Production by Policy[a].

Crop	Units	Base No Scheduling	Mandatory Scheduling	Voluntary Scheduling No Charge Per Acre	Voluntary Scheduling $5.00 Per Acre Charge
Alfalfa	tons	92,423	86,558	88,646	92,423
Barley	bushels	1,385,959	1,378,342	1,378,342	1,385,959
Beans	cwt	105,983	111,309	111,309	111,309
Peas	cwt	42,239	37,425	42,239	42,239
Potatoes	cwt	1,288,035	1,337,890	1,337,890	1,337,890
Sugar Beets	tons	190,370	192,698	192,698	191,822
Spring Wheat	bushels	797,806	773,354	797,806	797,806

[a]Note that crop acreages are constant by policy. Consequently, production changes are due to variations in average yields resulting from changes in the optimal mix of activities.

would depend upon the cost of water and scheduling and the value of any yield differentials. Therefore, the analysis was repeated allowing the LP to select the optimum irrigation regime for each crop given a set of water and scheduling costs.

The cost of scheduling was parametrically varied in the LP model from zero to $5.00 to estimate average annual changes in the number of acres scheduled and the amount of return flows. The cost of scheduling affected the number of acres scheduled differently in each year. However, the composite results from the three-year analysis indicates that an increase in the price of scheduling from zero to $5.00 per acre would reduce the number of scheduled acres from approximately 48,000 acres to 22,000 acres (Figure 2). The general relationship of price to scheduled acres can be captured by estimating the elasticity of demand in order to assess the sensitivity of scheduled acres to cost for specific ranges of the demand function. Elasticities were estimated from the linearized demand function for various scheduling costs. These values are presented in Table 5. At less than $3.00, response is inelastic, but as the cost approaches $5.00, it becomes substantially more elastic. Therefore, if the scheduling service were supplied in the A & B District at current market cost ($5.00 per acre) about 25,000 acres or 38 percent of the total irrigated acreage would be scheduled.

Varying scheduling costs would not affect regional returns to a great extent. The average net return for 1973, 74, and 75 without a scheduling service was $14.118 million or $216.76 per acre. This return was increased relative to the unscheduled regime by a zero cost scheduling service to $14.518 million or $222.90 per acre. An increase in the cost of scheduling to $5.00 per acre would decrease

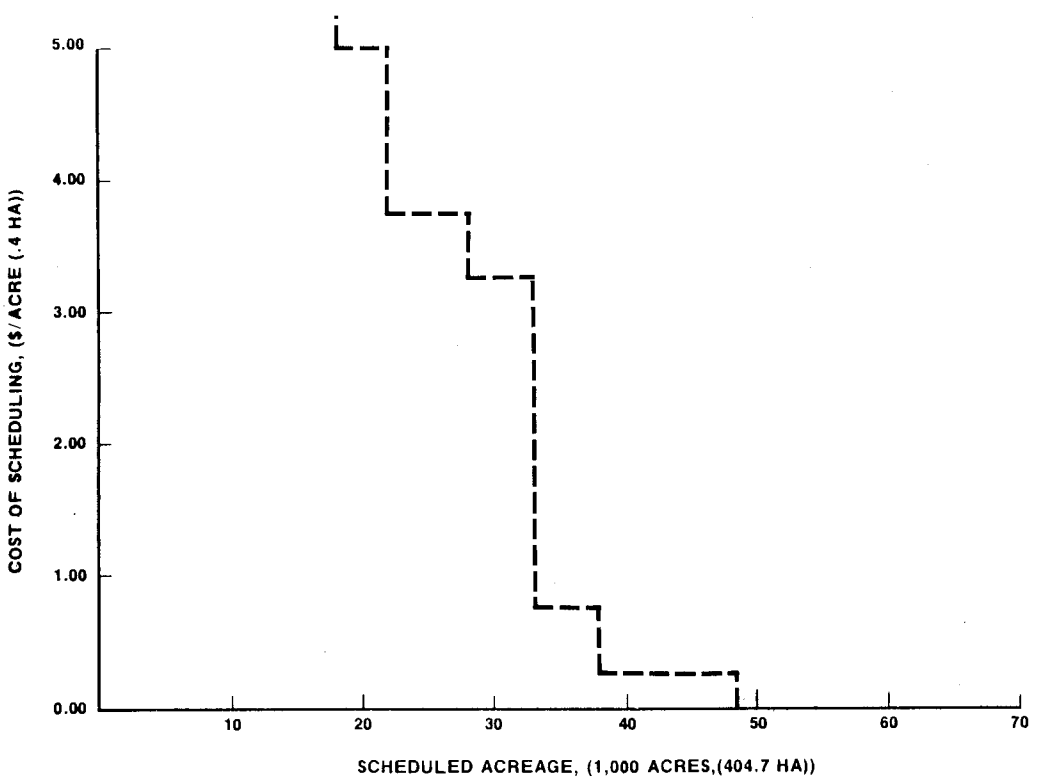

Figure 2. Estimated Scheduled Acreage and Scheduling Cost, A & B District, 1973, 1974 & 1975.

TABLE 5. Estimated Elasticity of Demand for Irrigation Scheduling Services.

Scheduling Cost ($/Acre)	Elasticity of Demand
$1.00	−0.122
2.00	−0.280
3.00	−0.489
4.00	−0.778
5.00	−1.208

average annual returns to $221.95 per acre. As reported earlier, the estimated annual water use in the A & B District without a scheduling service was 216,865 acre-feet and 144,013 acre-feet if a scheduling system was imposed (Table 2). In the case of a voluntary scheduling service charging $5.00 per acre, the estimated average annual water use was 205,078 acre feet. This amount was reduced to about 167,711 acre-feet if the service was offered at no charge (Figure 3).

Conclusions

Irrigation scheduling could be an effective tool in irrigation management since the program objective is to keep soil moisture higher than the permanent wilting point and below soil moisture holding capacity with a minimum number of irrigations. This results in a minimum of return flows without reducing acreage or yields. The main problem of course is the ability of each farmer to implement each scheduling order with suffi-

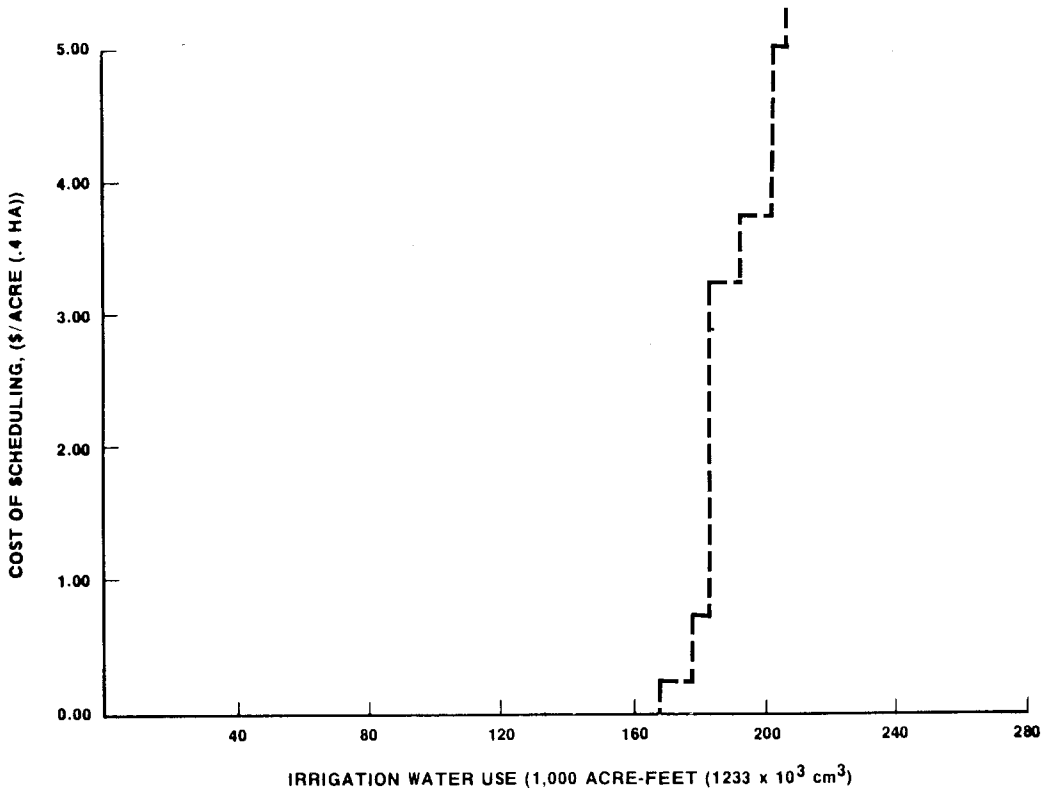

Figure 3. Estimated Water Use and Scheduling Cost, A & B District, 1973, 1974 & 1975.

cient precision. Errors in timing and application amounts can negate most of the crop yield or return flow benefits.

To summarize the effects of the scheduling program, water use resulting from the various scheduling policies in the A & B District were compared with the results of no scheduling service. The results from the regional economic model indicate that scheduling and the degree to which it is implemented has a dramatic effect. Water use was estimated at 216,865 acre-feet without scheduling and 144,013 acre-feet with required scheduling. Water use varied between these amounts for voluntary scheduling with costs ranging from zero to $5.00 per acre.

Scheduling cost proved to be a significant factor in determining the aggregate amount of irrigated acreage that will be scheduled. This is true in the A & B District since irrigation practices normally applied in the District are reasonably efficient, and increasing the charge for scheduling services will make it less profitable than normal irrigation practices.

Many irrigation districts hold water rights in excess of ET and percolation requirements and do not charge farmers on the basis of water use. This promotes inefficient water use and opportunities for large amounts of return flows to be generated. An imposed scheduling service in these areas would have a substantial effect on water use and bypass the more compelx legal and institutional questions involving water pricing and allocation.

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