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A METHODOLOGY FOR EVALUATION OF ALTERNATIVE
ELECTRIC IRRIGATION RATE STRUCTURES

by

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ABSTRACT

A mixed integer linear programming model is being developed to evaluate the effects of alternative electric rate structures on revenues to electric suppliers-distributors, returns to irrigators, and current and prospective demands for energy and water for irrigation. The model incorporates minimum, demand, and KWH charges for simultaneous analysis.

A METHODOLOGY FOR EVALUATION OF ALTERNATIVE ELECTRIC IRRIGATION RATE STRUCTURES

INTRODUCTION

Rural Electric Cooperatives (REC's) and United States farmers are currently experiencing a great deal of financial stress. The general mood in Washington, D.C. toward the continued provision of concessional loans to the revolving fund of the Rural Electrification Administration is rather unfavorable. Electricity rates paid by farmers have continued to rise in the 1980's (by over 30% between 1981 and 1984), whereas the prices of alternative fossil-fuel energy sources have dropped considerably (USDA, 1985). The U.S. electric generation capacity has been over-extended; possible means of expanding demand so as to "soak up" excess production capacity are being actively explored (Gardner and Young, 1984). Farmer financial vitality is suffering as commodity prices and land values continue to decline (Drabenstott and Duncan, 1985). These circumstances have prompted REC's in South Dakota to explore new electric rate structures (involving both the level and the form of prices) offering greater prospects of meeting the joint needs of themselves and their various client groups including irrigators.

The research reported in this paper is being undertaken to explore the implications of alternative electric rate structures for irrigation to the three main concerned sets of actors -- electric supplier-distributors, electric-consuming irrigators, and the general public. The implications concern electric supplier-distributor revenues, irrigator revenues, electric power sales, efficiencies of energy and water use, and prospective demands for electricity and water by irrigators. The electric rate structure features examined are different levels of charges; varying combinations of up-front, fixed, and variable energy charges; declining, constant, and increasing block structures; and load management strategies. Particular emphasis is being placed on determining complementarities and trade-offs in the implications of different rate structures to each of the three

main concerned set of actors. The insights gained through this research should be of direct use to REC's as they consider types of rate structures, in these difficult times, most suited to their specific circumstances.

Irrigation Environment in South Dakota

Agricultural producers in South Dakota are relative newcomers in adopting irrigation. There were less than 150,000 irrigated acres in the state in 1970. However, during the 1970's irrigated acreage increased 130% in South Dakota compared to a 30% increase in the United States as a whole (Taylor, 1983). In total, South Dakota now has more than 400,000 irrigated acres of which about 80% are privately developed. This paper focuses exclusively on privately-developed irrigation.

Almost all irrigation water in South Dakota is lifted by pump, and over 85% is distributed under pump pressure by sprinklers (Irrigation Survey, 1982). In 1982, about 70% of water distribution systems in South Dakota were center pivot, reflecting the concurrent increase in irrigation within the state and the availability of new center pivot technology in the prior decade. In 1983, 5% of all center pivot systems were low-pressure -- a technology which reduces the energy requirements for irrigation (Sloggett, 1985). About 80% of all irrigation systems in the state are powered by electricity, up from about 35% in the early 1970's (Taylor, 1984).

Approximately 57% of irrigation water is obtained from groundwater sources. The lift required for onfarm pumping from groundwater sources has increased from 70 feet in 1974 to 120 feet in 1983, thereby increasing energy requirements (Sloggett, 1985).

The variable costs of irrigation are closely allied with the cost of energy needed to power irrigation pumps. The focal point of this research is on electricity as a power source. Due to increased electricity prices and increased acres irrigated, the total cost of electricity for onfarm pumped irrigation in the state rose from \$700 to \$9300 thousand dollars between 1974 and 1983 (Sloggett, 1985).

Research Objective

The objective of the research is to estimate the impact of alternative electric rate structures on 1) the future potential demand for irrigation water, 2) the efficiency of irrigation water use, 3) the level of farm income earned by irrigators, and 4) revenues to electric supplier-distributors.

To carry out the objective, a model is being developed to estimate the impact of alternative electric rate structures on the optimal production plans for representative farms. Development and composition of the model are reported herein.

Study Sites

REC's provide much of the electric power for irrigation in the state. Variation among REC's is considerable for the number of irrigators as a percent of total consumers (0-15%), MWH sales to irrigators as percent of total sales (0-40%), irrigation revenues as percent of total revenues (0-50%), and, to a degree, type of rate structure (Lundeen, 1986).

Study sites are being selected on the basis of importance of irrigation to the REC, growth of irrigation within the service area of the REC within the past decade, geographic dispersion throughout the state, and willingness of REC officials to cooperate in the study. For the initial phase of the study, two REC's located in Clay and Union Counties in southeastern South Dakota which fulfilled these criteria were selected.

For subsequent phases, the model will be adapted for two additional geographic areas served by REC's with possible differences in internal financial structure. In addition, sites will be selected on the basis of diversity of soil type, variation in rainfall, potentially profitable crops grown, and source of water. It is expected that at least one additional site will be located near and receive water from the Missouri River. An additional site in the more arid regions of the state west of the Missouri River may also be chosen.

The distinctive real-life circumstances of each REC and study area will be reflected in the model in order to allow an intensive, case-study analysis of each study site. This should permit a clearer view of the institutional constraints inherent in formulating alternative rate structures.

Rate Structures

For all REC's the rate schedules for electricity for irrigation contain some combination of the following three components:

- 1) Charge per measured horsepower -- usually assessed one time at the beginning of the season and based on size of motor
- 2) Demand charges per KW per month -- based upon peak power usage
- 3) Energy charge per KWH -- this may be a flat rate or a declining block rate structure

The rate structures for the REC's chosen for Phase I of this study contain all three components, with a declining block rate structure for the KWH charges. The model incorporates all of these charges and allows for testing alternative rate structures which will be developed to provide approximately similar revenues apportioned differently among the components.

Both REC's also offer load management options whereby irrigators can choose to shut down their systems during periods of peak use. They do not then have to pay a demand charge each month. However, this increases labor requirements as sites must be visited to restart the systems.

DEVELOPMENT OF THE MODEL

Economic studies have been undertaken to estimate the effects of electric rate structures on use of energy and derived demand for water for irrigation. Buller and Nordin (1984) estimated the potential savings due to load management and time-of-use pricing for a representative irrigated farm in southwest Kansas. They projected an annual saving of nearly \$2.5 million for 100 irrigated farms similar to the representative farm.

In a study in Colorado, Gardner and Young (1984) examined the effects of alternative electricity rates and rate structures on water and electric use, revenues to REC's (which are also electricity costs to irrigators), and net returns to farmers. Through use of a linear programming model which optimized returns to land and management, they found that electric rate structures affect the amount of electricity and water used but that a greater impact results from commodity prices. With higher commodity prices, the elasticity of demand for energy and water is considerably lower than with low commodity prices.

The study reported herein complements the above studies geographically, institutionally, and in physical production environments in South Dakota as compared to those in Kansas and Colorado. Gardner and Young's model utilized linear programming in which various types of block rate structures and levels of rates were formulated and the effect upon water and energy use ascertained. The model used in this study extends their model in so far as minimum charges and demand charges are an integral part of the electric cost structure contained within the model. A total rate structure including various levels of minimum and demand charges as well as KWH charges is being examined.

The programming model is described in the next section. In subsequent sections, various components of the model along with specific application to the Phase I study site are detailed.

Programming Model

The model developed in this study uses a mixed integer linear programming algorithm. The mixed integer approach was used because certain activities must enter the solution in their entirety, rather than in fractional amounts as in a strictly linear programming model. It is a short-run, single period model.

The model allows for the selection of different dryland and irrigated crops. If an irrigated crop enters the solution, all electric costs of running the system such as annual minimums, demand charges, and cost per KWH are included. Variable production costs are taken into account for both dryland and irrigated crops.

The columns section of the model is divided into five general subsections (Figure 1). The first subsection contains all the activities associated with the electric charges for irrigation power. The three main activities are the annual minimum, the demand charge, and the cost per KWH. These charges depend on the motor size of the center pivot system and, therefore, differ between high and low pressure systems.

The second subsection contains the various conversion options for the two existing electrically-powered high pressure center pivots on the farm. Either center pivot can be converted to low pressure, or converted to diesel with either high or low pressure. This subsection contains the conversion costs and is linked to the third subsection of irrigated crop production activities which are broken down into different levels of irrigation water application (full, two-thirds, and one-third irrigation levels). The link is accomplished in such a manner that if a pivot is converted to low pressure, only low pressure irrigated crop activities (and the corresponding costs and yields) are used with the system. The same link is made between high pressure pivot and crop activities.

The fourth subsection deals with the dryland production activities. These activities account for variable production costs only.

The last subsection consists of crop sales activities and a hog production activity. The crop sales activities and the hog activity are linked to both dryland and irrigated crop production activities. They allow for transferring grain grown on the farm into the hog enterprise or for the various commodities to be sold on the market for cash.

The rows section of the matrix consists of six subsections. The first subsection consists of the objective function of profit maximization. This row considers gross revenue minus all electricity costs (annual minimum, demand, \$/KWH), the annualized value of irrigation system conversion costs, the non-power irrigation operation costs, and both dryland and irrigated crop production costs.

The second subsection consists of transfer rows. These rows are used to link irrigated crop activities to the annual minimum, demand, and cost per KWH charges. For example, if irrigated corn enters the solution, the monthly demand charges and annual minimum will also automatically enter the solution. The cost per KWH will also be activated and will correlate with acres of corn production and irrigation level. Transfer rows also link crop production to crop sales or use in the hog enterprise.

Farm operator and hired labor, in bi-monthly periods, are shown in the third subsection. These rows account for the labor used on the farm during the year in irrigating as well in producing the crops (planting, cultivating, etc.).

The fourth row subsection deals mainly with land and acreage constraints. These rows insure that the model selects crop activities appropriate to the types of irrigation systems that enter the solution. The total amounts of cropland, pastureland, and available rented land are also constrained by these rows.

The pumping rows constrain the model from irrigating more crops than the physical system can handle. Here each system is limited by the amount of water it can pump during a given month.

The sixth and final subsection contains rows to account for operating capital, livestock capital, and cashflow. The values shown in these rows will be used for calculating various financial performance measures.

Representative Farm

The representative farm for the Phase I study contains 700 cropland acres which can be used for either irrigated or dryland farming and/or swine production.

The main crops irrigated in the study region are corn, soybeans, and alfalfa. Union County REC ranks first in soybeans and third in corn among all REC's in South Dakota in number of acres of each crop irrigated within the service area. Union-Clay REC ranks 6th and 11th, respectively (Lundeen, 1986). In the model, irrigation is restricted to the three main crops but dryland production allows for spring wheat and oats in addition.

A farrow-to-finish, two litter hog production system is typical of the region. A maximum of 40 sows is allowed in the model.

Input and output coefficients for various crop production alternatives were obtained from farm management budgets developed by SDSU agricultural economists and plant scientists and from discussions with the study area county agents. After an initial set of coefficients was developed, meetings were held with area irrigators to further refine the coefficients. One-third, two-thirds, and full irrigation options were included in the model; coefficients for less than full irrigation were constructed based upon expected yields and coincidental input use.

In the basic model, two center pivot, high pressure (75 psi.) electrically-powered irrigation systems are assumed to be present. Various alternatives are allowed which include conversion to a low pressure (30 psi.), electric system or to diesel-power with either high or low pressure. The producer may also purchase new high or low pressure electrically-powered or diesel center pivot systems or gated pipe systems. Complete dryland production is another option.

Irrigation Water Requirements

Irrigation water requirements in the Phase I study were determined by examining evapotranspiration (ET) and weather data. ET rates for different crops and rainfall data from the Vermillion weather station were used in a three step process.

First, evapotranspiration (ET) rates were identified. Brosz and Wiersma (1970) have calculated ET rates for corn and alfalfa using the Jensen and Haise method. These ET rates vary depending on planting dates for corn and times of cutting of alfalfa. Using appropriate planting and cutting dates (CLRS, 1980), the ET rates for corn and alfalfa in our study were calculated. ET rates for soybeans were calculated using crop coefficient curves developed by Pair (1969) in conjunction with the base potential evapotranspiration coefficients for alfalfa. The ET rates obtained represent the daily consumptive use for each crop during each week of the growing season. These water requirements were summed to obtain monthly ET values for each crop.

Step two involved determining monthly effective rainfall, which is primarily a function of plant ET rates (U.S.D.A., 1967). The higher the ET rate, the greater the effective rainfall and vice versa.

The effective rainfall for each month was determined using a table relating mean monthly rainfall and average consumptive use (U.S.D.A., 1967). The effective rainfall values differed for the different crops due to differences in the consumptive use values for the respective crops. An additional probability factor was applied to the effective rainfall values so that they would reflect the water supply expected 80 percent of the time.

Third, irrigation water requirements were determined by subtracting the sum of monthly effective rainfall and carryover moisture (carryover moisture assumed to be 7.0 and 3.5 inches per foot depth of soil at the beginning of the growing season for silty, clay soils and sandy soils, respectively) from monthly ET. If the result was negative, no irrigation water was assumed to be required. A positive

result meant that irrigation water must be applied. The positive amount was divided by system efficiency (90% for center pivots) to obtain gross irrigation water applications needed.

Irrigation Costs

The non-power annual operating costs for the various types of irrigation systems were calculated via AGNET's pump-cost program (Thompson, 1985). The irrigation power costs were handled separately, so that they can be changed in accordance with changes in the various assumed electric rate structures.

The costs of converting from high to low pressure and from electric to diesel power sources and the costs of new irrigation systems were based on Thompson (1985), with appropriate local modifications as indicated by a local irrigation dealer. For the profit equation, these costs were amortized over 15 years at 11.0% [the "average" 15 year Treasury Note rate for 1985 (FRB, 1986)]. For the cash flow equation, these costs were amortized at 13.5% (Melichar, 1985). Amortization periods of two, four, and eight years were assumed for converting electrically powered high pressure systems to low pressure, converting from electric to diesel-powered systems, and investing in new irrigation systems, respectively.

Commodity Prices

Previous research has shown that crop prices were the most important factor affecting farmers' response to electric rate structures, therefore the choice of price levels is critical in any similar analysis (Gardner and Young, 1984).

Production costs were based on 1985 input prices; therefore an initial analysis will incorporate 1985 crop prices in the model. However, as 1985 prices were considerably lower than some previous years, a second set of prices reflecting a ten-year average of 1976-1985 prices was also incorporated into the model.

SUMMARY

REC's and U.S. farmers are experiencing a great deal of financial stress due to a confluence of circumstances involving lower commodity prices and land values, higher electric costs, and excess production capacity. To meet their joint needs, REC's and irrigators have been exploring new electric rate structures.

This research is being undertaken to examine the effects of alternative rate structures on electric supplier-distributor revenues, returns to irrigators, and current and prospective demands for energy and water for irrigation. The focus is on privately-developed irrigation, of which there are now more than 300,000 acres in South Dakota.

A mixed integer linear programming model is being developed to investigate the impact of alternative electric rate structures on the optimal production plans for representative farms in four study sites in South Dakota. The model differs from those used in some previous studies in that all components of a typical REC rate structure (minimum, demand, and KWH charges) can be incorporated and analyzed simultaneously.

The model allows for retention of two high pressure center pivot irrigation systems; expansion for additional similar systems; conversion to low pressure diesel or electric center pivot systems, high pressure diesel center pivot, or gated pipe; or dryland farming.

Production choices and costs were developed from meetings with plant scientists, agricultural engineers, irrigators, and extension agents.

Figure One--Schematic Description of MILP Matrix
 (+,- are sign of coefficient in model)

Colns \ Rows	Row Type	Electric Charges	Pivot Options	Irrigated Crop Production	Dryland Crop Production	Hogs	Crop Sales
Profit	N	(-) (-1)	(-) Annualized	(-) (+) ← KWH Per Acre	(-)	(+)	(+)
Transfer Rows	E			(-) ← Yield Per Acre	(-)	(+) ← Yield Used	(+)
Labor	L			Man Hours Per Acre (+)	(+)	(+)	
Land Constraints	L		Land Supplied -130 -130 -130 -130	+1+1 +1+1 +1+1	Land Used +1+1	+1	
Water Pumping	L	Inches Pumped Per Month (-)		Inches Applied Per Acre (+)			
Financial Concerns	G			(+)	(+)	(+)	(-)

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