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# Electric Rate Structures for Irrigation: A Tool for Energy Conservation

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# ELECTRIC RATE STRUCTURES FOR IRRIGATION
# A TOOL FOR ENERGY-CONSERVATION?[1]

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## EXECUTIVE SUMMARY
## PRICE POLICY CONCLUSIONS

The major objective of the research performed under this WAPA Conservation and Renewable Energy contract is to determine if electric rate structures can be used to provide incentives to irrigators to make more efficient and/or reduced use of electric power. A companion objective is to examine possibilities for electric rate structures to provide incentive for irrigators to use more electric energy for pumping irrigation water.

The impacts of changes in both the **level** and the **form** of electric rate charges for irrigation on quantities and efficiencies of energy use are examined in the research. The four **form components** involve annual (monthly) minimum charges, monthly demand charges, energy (kWh) charges, and load management controls.

The major policy conclusions emerging from the study are as follows.

1. Policies to change the **level** of charges for energy (kWh) are likely to impact both the quantities and efficiencies of electricity used by irrigators in energizing their pumps. The higher the energy charge, the greater the energy conservation, i.e., the less the energy use and the higher the efficiency of energy use. The possibility for impacts on efficiency of energy use depends, however, on irrigators having access to alternative irrigation water distribution technologies and/or alternative irrigated crops.

2. Policies to change the **form** of electric rate charges for irrigation cannot, in general, be expected to induce hypothesized patterns of energy use. The tested relationships include the following:

- Determining if one-at-a-time increases in the individual electric rate component charges and/or increasing energy block rates provide incentive for irrigators to conserve energy; and

- Determining if one-at-a-time decreases in the individual electric rate component charges and/or declining energy block rates provide incentive for irrigators to use more electric power to energize their irrigation pumps.

3. In designing load management control programs, an REC is well-advised under most conditions to realistically resign itself to the fact that its irrigators will not be able to afford to follow load management controls when their irrigated crops encounter yield reducing moisture stress. The value of the yield loss from load control power interruptions to irrigation systems with moisture-short irrigated crops is simply too great to be counterbalanced by any level of incentive that can be economically justified by most RECs. Allowing for voluntary irrigator withdrawal from load management controls is, therefore, an essential feature of workable programs to conserve energy at times of peak kW demands (unless irrigators have substantially over-sized pumping capacities).

# ELECTRIC RATE STRUCTURES FOR IRRIGATION
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## INTRODUCTION

In economic terms, energy conservation involves a redistribution of energy resources from the present to the future. "Efficiency" is perhaps the most common indicator of energy conservation. Energy conservation is also commonly viewed to be reflected by reduced rather than expanded levels of energy resource use.

Particularly with the impetus of the "energy crisis" in the 1970s, U.S. leadership has placed special priority on the wise use of the nation's energy resources. "Wise" energy use involves both making efficient use of energy resources and being conscious of restricting total energy use so that the energy needs of future generations are not imperiled.

At the same time, the U.S. electric power utility industry is currently faced with a problem of excess generation capacity. This circumstance provides motivation for electric power distributors to promote increased sales of electricity.

The research on electric rate structures for irrigation reported herein was undertaken within this overall context. The dominant objective of the research is to determine if electric rate structures can be used to provide incentive to irrigators to make more efficient and/or reduced use of electric power. A companion objective is to examine possibilities for electric rate structures to provide incentive for irrigators to use more electric energy for pumping irrigation water.

## IRRIGATION ENERGY ENVIRONMENT

Rural electric cooperatives (RECs) in the U.S., the primary clients for this research, number about 925. Of these, somewhat less than one-half are in the WAPA service area. These cooperatives serve about 140,000 irrigators nationally. In 1984, 4.7 million megawatt hours (mWhs) of electricity were sold by RECs to irrigators in the U.S., with about two-thirds of these power sales within the WAPA service area.

South Dakota, the site for this research, has 33 RECs. Total power sales by these 33 RECs in the 1980's is in the range of 1.7 to 1.8 million mWhs annually. Of the total power sales, about 5% is for irrigation water pumping. Nearly 80% of South Dakota's irrigation pumps are energized by electricity.

Four of South Dakota's RECs were selected for special study in this research: the Clay-Union and Union RECs in the southeast, the Cherry-Todd REC which serves irrigators in south central South Dakota (and north central Nebraska), and the Cam-Wal REC along the Missouri River in north central South Dakota (Appendix 1).

Relative to South Dakota's 33 RECs, three of the four case study RECs are below-average in size, as reflected by total consumers and total mWh sales (Appendix 2). The exception is the Cherry-Todd REC which ranks ninth in both regards. Irrigation, however, is of above-average importance in each of the four case study RECs. For example, in terms of total mWh sales for irrigation, the Cherry-Todd and Cam-Wal RECs rank second and third and the Clay-Union and Union RECs rank 14th and 15th among the 33.

"Consumer-densities" differ considerably among the four case study RECs. The approximate 2.6 consumers per mile for the Clay-Union and Union RECs places these two cooperatives in the top four in the state. At the other extreme, the Cam-Wal REC with 1.0 consumer per mile ranks 30th.

Groundwater is the exclusive or dominant irrigation water source in the study sites for three of the four case study RECs (Appendices 3 and 4). The exception is the Cam-Wal REC, in which water is pumped from the Missouri River. Common pumping lifts range from 25 ft in the Clay-Union and Union REC service areas to 150 ft to 300 ft in the Cam-Wal REC service area.

Center pivot systems are found in all four REC service areas, with some low pressure systems being in all except the Cam-Wal REC study areas. Gated pipe units are also in the Union REC study area. Other descriptive information on the irrigation-agricultural production environments in the case study REC study sites is shown in Appendix 4.

## OVERVIEW OF THE RESEARCH

The energy conservation technology examined in this research is the **structure of electric rates** used by retail distributors of electric power--most commonly RECs--to irrigators. That structure consists of both the **level** and the **form** of electric rate charges. For irrigation, the four most common **"form" components** are:

- **Annual or monthly minimum** "facilities" charges, based on pump horsepower (HP) or kilowatt (KW) demand, that are used to compensate an REC electric power supplier for its "fixed" investment in distribution and general plant;

- **Monthly demand** charges, based on monthly average or peak kW demand, that represent an REC's payment to its wholesale supplier for the suppliers electric-power generation and transmission facilities;

- **Energy** charges, based on kilowatt hour (kWh) consumption, that represent the payment for the resources used in generating electricity; and

- **Load management** controls, that represent mechanisms for moderating short-term fluctuations in kW demand.

The basic underlying proposition of the research is that changes in the level and/or the form of electric rate charges for irrigation can be used to provide incentive to irrigators for conserving or expanding electric power use in the pumping of irrigation water.

Most of the research was structured around two guiding sets of hypotheses. The first set of hypotheses dealing with energy conservation is as follows:

i. Increased energy (kWh) charges provide incentive for reduced levels and increased efficiencies of electric power use in pumping irrigation water;

ii. A one-at-a-time increase in the individual electric rate charge components provides incentive for decreased levels and increased efficiencies of electric power use in pumping irrigation water; and

iii. Increasing energy (kWh) block rates provide incentive for reduced levels and increased efficiencies of electric power use in pumping irrigation water.

The second set of hypotheses involving potentially increased energy (kWh) sales deals with essentially the opposite types of relationships from those for energy conservation. In addition to these two sets of hypotheses, the possibilities for using irrigator load management controls to conserve energy at times of peak kW demand are also examined in the study.

The hypotheses are tested through an examination of the behavior of managers of hypothetical farms designed to represent "typical" irrigator clients served by the four case study RECs. A linear programming model was developed to (1) portray as fully as possible the technical, institutional, and economic features associated with each representative farm and (2) determine the most profitable use of farm resources for each commodity price, leveraging, electric rate structure, and pumping lift situation examined.

The managers of the representative farms are presupposed to be able to make short-term farm enterprise and irrigation adjustments, as well as long-term changes in their irrigation technologies, in response to pre-season declared changes in electric rate structures for irrigation by REC electric power suppliers. The farm enterprise and irrigation technology adjustments considered in the overall study are the use or non-use of two already-present electric power, high pressure center pivots; the conversion of the already-present center pivots to low pressure and/or diesel power; the purchase of new irrigation systems for use on dryland; water distribution by center pivot sprinklers or gated pipe, surface-irrigation, gravity flows; the irrigation of crops with greater or lesser irrigation requirements than corn; full versus partial irrigation rates; and the renting of additional irrigated and/or non-irrigated land. A full range of these potential adjustments applies to the Clay-Union and Union REC representative farms. Soil and topography constraints make infeasible certain of these potential adjustments on the representative farms for the other two case study RECs.

The reference point in the linear programming analysis of the representative farms is the 1985 electric rate structure for irrigation in the respective RECs. Annual (or monthly) minimum charges are common to the electric rate structures for all four RECs. Monthly demand charges are used by all except the Cherry-Todd REC. The types of energy block rate charges for the RECs are as follows:

- Two-step declining for Clay-Union and Union;

- Single-step for Cherry-Todd; and

- Three-step declining for Cam-Wal.

In addition, the Clay-Union and Union RECs have a load management control option. Since an examination of the incentives for irrigators to participate in a load management control program doesn't lend itself to linear programming analysis, this aspect of the study was evaluated via simple budgeting procedures.

Most profitable "baseline solutions" were determined for each representative farm with its actual electric rate structure for 1985 under situations of different commodity prices (e.g., 1985 government grain commodity program, 1985 free market, 1980 free market) and different approaches to financing new irrigation equipment (namely, with debt-capital versus with owner, equity-capital). Most profitable solutions were then determined with certain modifications in the level and form of the various electric rate structure components. These modifications include:

- Successive 1 cent per kWh increases in energy (kWh) prices--beginning with 1 cent per kWh and going up until the use of electric power to pump irrigation water just became uneconomic--to test the **increased level** of energy charge hypothesis;

- A one-a-time doubling in the individual electric rate charge components to test the increased **modified form** electric rate charge component hypothesis;

- A 75% reduction in the individual electric rate charge components to test the decreased **modified form** electric rate charge component hypothesis;

- Three step-declining (rather than single-step, two-step declining, and a more gradual three-step declining) block rates to test the declining **modified form** block rate hypothesis; and

- Three-step increasing (the "mirror-images" of the respective three-step declining) block rates to test the increasing **modified form** block rate hypothesis.

The hypotheses are tested through comparisons among pertinent solutions in the amounts and efficiencies of energy used in pumping irrigation water. A conventional engineering definition of "efficiency" is used, namely, the value of added crop production from irrigation per kWh used in pumping the irrigation water.

## RESULTS OF ANALYSIS

The results of testing the energy use and efficiency hypotheses are reported in Appendices 5 to 9 in this report and in various figures in the reports of research findings from the overall study of electric rate structures for irrigation under the following titles, **The Impacts of Alternative Electric Rate Structures for Irrigation,**

**Clay-Union and Union RECs,** Research Rep 87-2, May 1987;

**Cherry-Todd REC,** Research Rep 87-3, July 1987; and

**Cam-Wal REC,** Research Rep 87-4, August 1987.

These research reports are published by and available from the SDSU Economics Department. In the text that follows, these reports are referenced by report number (namely, 87-2, 87-3, and 87-4).

Summaries of the hypothesis testing results on the impacts of changed electric rate structures on (1) total kWh use and (2) the efficiency of using electricity in pumping irrigation water are shown in Tables 1 and 2, respectively. The row entries are organized according to the hypotheses involving changes in the **level** of energy charges and the **four types of changes** in the **form** of electric rate charges. The column headings show the total number of times that each category of hypothesis is tested in the study and the outcomes of the hypothesis testing. The hypothesis testing is intuitive, not statistical.

### Increases in the level of the energy charge

To test the hypotheses involving increased levels of energy charges, derived demand functions for electricity to energize irrigation pumps were estimated for each REC representative farm. The 1985 electric rate structures used by the respective RECs are used in this analysis, with one exception. To simplify the interpretation of analytic results, electric rate structures with single- rather than multiple-step kWh energy charges are assumed.

A total of 38 demand functions were estimated in the study (see Figures 3 and 4 in Reports 87-2 and 87-4 and Figure 2 in Report 87-3). In all 38 instances, the results show a clear indication of less energy use with higher energy (kWh) charges, thus confirming the hypothesized relationship. Less electricity is used at higher electricity prices as a result of irrigators shifting from energy-intensive (e.g., high pressure water distribution) to energy-extensive (low pressure and gated pipe water distribution) irrigation technologies, reducing the scale of irrigated production, substituting diesel fuel for electric power, and shifting from irrigator water-intensive (e.g., alfalfa) to irrigator water-extensive (e.g., soybeans) crops.

Since only one irrigation technology is feasible in the Cam-Wal REC study area (namely, high pressure center pivot water distribution) and only one irrigated crop (corn grain) is assumed to be raised there, the efficiency of electric power use in irrigation is identical in each of the most profitable solutions determined for the Cam-Wal REC representative farms. The efficiencies associated with different segments (points) on the six common derived demand functions for the other three REC representative farms are shown in Appendices 5-7.

The results of testing the efficiency hypothesis for these 18 derived demand functions are summarized in Table 2. The hypothesized inverse relationship between level and efficiency of energy use is confirmed in 16 of the 18 (89%) tested incidences. In two instances (Panel "f" in each of Appendices 5 and 6), however, no clear relationship between the level and efficiency of energy use is shown.

Thus, the results of analysis show strong evidence for increased **levels** of energy (kWh) charges providing incentive for irrigators to conserve energy use in pumping irrigation water. As will soon become clear, however, the evidence is weak for changes in the **form** of electric rate charges to induce irrigators to modify their electric power use according to hypothesized patterns.

**One-at-a-time increases in the individual electric rate component charges**

The impacts on the amount and efficiency of energy (kWh) use of one-at-a-time increases in the individual electric rate components charges were determined for each REC representative farm. In this analysis, the 1985 annual (monthly) minimum, monthly demand, and energy (kWh) charges for each REC are each doubled--but only one-at-a-time in separate runs of the model for each representative farm with all other prices and technological coefficients held the same.

The results of this analysis on the quantities of electric power used in energizing irrigation pumps are shown in the second tier of panels in Figures 7 and 8 in Reports 87-2 and 87-4 and in Figure 4 in Report 87-3. In testing the hypothesis of reduced energy use with increased electric rate component charges, comparisons are made in the kWh of electricity used for pumping irrigation water one-at-a-time between the solutions with doubled component charges and the respective baseline solutions.

The results of the 28 tests of this hypothesis shown in Table 1 reveal a 57% confirmation rate. In 32% of the instances, however, no impact of increased component charges on energy use is shown; and in 11% of the instances, contradictory outcomes are obtained. Among the individual electric rate charge components, the hypothesis is confirmed most strongly for the monthly demand charge and least strongly for the annual (monthly) minimum charge.

The efficiencies of energy use associated with the just-reported solutions are shown in Appendix 8. The results of testing the hypotheses are summarized in Table 2. The hypothesized direct relationship between level of electric rate charge component and level of efficiency is confirmed for 63% of the tested instances; no relationship is shown for 37% of the tested instances.

Thus, the evidence for increased electric rate component charges providing incentive for irrigators to conserve energy in pumping irrigation water is somewhat positive. It is considerably weaker, however, than for increased levels of energy (kWh) charges.

**One-at-a-time decreases in the individual electric rate component charges**

This analysis is directly analogous to that just described, except that the individual electric rate component charges are reduced 75% rather than doubled. The results of this analysis are shown in the same figures and tables as referenced above.

The results of the 28 tests of an inverse relationship between reduced component charges and level of energy use show only an 18% confirmation rate. Contradictory evidence is obtained in 11% of the tested instances, and no relationship is shown in 71% of the cases. The outcomes of testing the hypothesis of an inverse relationship between reduced electric rate charge components and electric use efficiencies are little different from those for the level of energy use.

Thus, the decreased electric rate component charge-energy disconservation hypothesis largely fails to be confirmed. This outcome reflects the indirect effects on farm organization induced by the modified electric ate structures more than counterbalancing the direct effects otherwise expected to take place with everything else the same.

**More steeply declining energy block rate charges**

The hypothesized inverse relationship between more steeply declining energy block rate charges and energy conservation was tested through comparisons in total energy use and energy use efficiency for solutions with three-step declining energy block rate charges versus with the respective actual 1985 REC energy block rate charges. In each three-step model tested, the first-step block rate charge is arbitrarily set at 90% above the middle-step charge and the third-step rate at 90% below the middle-step charge (Table 7 in Report 87-2; Table 5 in Report 87-3; Table 8 in Report 87-4).

For each REC with a multiple-step energy block rate in 1985, the three-step modified block rate is more steeply graduated than that in 1985. For all except the Cam-Wal REC, the modified block rates tested involve more steps than the 1985 block rates.

The results of this analysis on the quantities of electric power used in energizing irrigation pumps are shown in Figures 9 and 10 in Reports 87-2 and 87-4 and in Figure 5 in Report 87-3. The results of the 20 tests of the more steeply declining energy block rate charge-energy disconservation hypothesis shown in Table 1 reveal a 20% confirmation rate, a 15% contradiction rate, and a 65% incidence of no impacts on energy use of more steeply declining energy block rate charges.

The corresponding efficiencies of energy use are shown in Appendix 9. A summary of the hypotheses testing results is shown in Table 2. In 33% of the tested incidences, the hypothesis is confirmed. In 67% of the cases, more steeply declining energy block rates have no impact on energy use efficiency.

Thus, the evidence for a confirmation of the more steeply declining energy block rate charge-energy disconservation hypothesis is very limited. In some cases, the hypothesis is contradicted. In the vast majority of instances, the modified block rate structure fails to provide adequate incentive for any change in the quantity or efficiency of electric power use for energizing irrigation pumps.

**Increasing energy block rate charges**

The three-step increasing energy block rate charges tested are the "mirror-images" of those just described--in that the first- and third-step charges in the respective models are simply interchanged. The findings from this analysis are shown in the same figures ad tables as above.

The general nature of results of testing the increasing energy block rate-energy conservation hypothesis are essentially the same as for the just-described declining energy block rate-energy disconservation hypothesis. Any differences in the outcomes are for an even greater failure of confirmation of the increasing energy block rate hypothesis.

Thus, the results of the study show a clear contrast between using the **level** versus the **form** of an electric rate structure to provide incentive to irrigators for either greater energy conservation or expanded energy use. Changes in the **level** of energy charges are clearly shown to provide such incentives to irrigators. Changes in the **form** of electric rate charges, on the other hand, largely fail to effectively provide such incentives.

**Load management controls**

Load management controls are used to conserve energy at times of peak kW demands. The degree to which irrigation pumping energy can be conserved at such times depends on the response of irrigators to the incentives for load control provided by their retail electric power distributors.

In this section of the study, an economic analysis of the Clay-Union and Union REC load management control programs for irrigators was undertaken.

The highlights of this analysis are presented below (for greater details, see Report 87-2). Based on the results of that analysis, strategies for designing potentially effective and economically attractive load management control programs for irrigators are indicated.

The Clay-Union and Union REC load management control option provides for the waiving of monthly demand charges during those billing months in which irrigators agree to 5 pm to 9 pm electric power interruptions to their irrigation systems. During 1985, power interruptions were made every day. During 1986, power interruptions were made only on those days and at those hours between 5 pm and 9 pm when the RECs actually experienced a peaking in their power demand. The Clay-Union and Union REC load management control program provides the option to irrigators to withdraw from load management controls at any time they should choose to do so. If irrigators opt out of load control, they must pay the monthly demand charge that otherwise would be waived to them.

Irrigators not electing to follow the load management option in 1985 and 1986 were entitled to a 1.1 cent per kilowatt hour (kWh) credit on all irrigation pumping energy used. This credit arose from a discount by the Basin Electric Power Cooperative on the electric power used for irrigation.

The analysis of the load management control program involves determining (1) the net electric power related benefits to irrigators from following load controls and, (2) based on this, the maximum crop yield losses that irrigators could afford to sustain from following load controls. The possibility of yield losses arises whenever load control power interruptions occur at a time when irrigated crops are experiencing moisture stress.

The gross electric power benefits derived by Clay-Union and Union REC irrigators are represented by the waived monthly demand charges. The electric power related costs of following load management are represented most explicitly by the value of the foregone Basin credit. Less tangible, but nevertheless important, costs to irrigators from following load management are represented by the amounts of time, degrees of inconvience, and levels of anxiety/displeasure associated with (1) learning about and coping with the "uncertainties" of load management and (2) personally reactivating irrigation systems following each load management control power interruption to the systems.

Taking into account the gross benefits and only the foregone Basin credit costs of following load management reveals a great sensitivity of irrigator incomes to yield losses from load management irrigation system power interruptions. For example, if Clay-Union and Union REC irrigators were required to determine in advance of the irrigation season whether they would follow load controls and were to have no option to later in the season reverse their decision, they could afford to sustain a maximum all-season crop yield loss of only 2% to 7%. Under these conditions, only irrigators with substantially over-sized pumping capacities and/or willingness to incur considerable risk could reasonably be expected to participate in such a load management program.

An analysis of selective month-by-month load control program participation shows that the maximum yield loss that a Clay-Union or Union

REC irrigator could afford in any one month is only 1.8%. These findings result in a rather clear conclusion.

If a load management control program is designed so as to permit irrigators to opt out of load controls on demand, as is currently the case with the Clay-Union and Union RECs, irrigators would be well advised to enter and remain in the program as long as their irrigated crops are not under yield reducing moisture stress. For every month that they do so, they can avail themselves of the waived monthly demand charges for their load controlled irrigation systems.

If such moisture stress conditions should arise, however, and the REC is experiencing a peaking of power demand, irrigators should immediately opt out of load controls. They should do so because it is unrealistic to manage irrigation water so as to avoid a minimum level of moisture stress leading to anything less than a 1.8% yield loss during a particular month. By breaking their meter seal and continuing to pump irrigation water, irrigators can mitigate the economically damaging yield losses that otherwise would result from load control power interruptions to their irrigation systems.

Table 1. The results of testing the hypotheses on the impacts of changes in the level and form of electric rate structures on total kWh use for pumping irrigation water.

| | Total number of times tested | Hypothesis confirmed | | No impact | | Hypothesis contradicted | |
|---|---|---|---|---|---|---|---|
| | | Number | Percent | Number | Percent | Number | Percent |
| Changes in the level of the energy charge | 38 | 38 | 100.0 | 0 | 0 | 0 | 0 |
| Changes in the form of the electric rate charges | | | | | | | |
| One-at-a-time doubling in the individual electric rate charge components | | | | | | | |
| Annual (monthly) minimum | 10 | 4 | 40.0 | 5 | 50.0 | 1 | 10.0 |
| Monthly demand | 8 | 6 | 75.0 | 1 | 12.5 | 1 | 12.5 |
| Energy (kWh) charge | 10 | 6 | 60.0 | 3 | 30.0 | 1 | 10.0 |
| Sub-total | ( 28) | (16) | (57.1) | ( 9) | (32.2) | ( 3) | (10.7) |
| One-at-a-time 75% reduction in the individual electric rate charge components | | | | | | | |
| Annual (monthly) minimum | 10 | 1 | 10.0 | 8 | 80.0 | 1 | 10.0 |
| Monthly demand | 8 | 4 | 50.0 | 3 | 37.5 | 1 | 12.5 |
| Energy (kWh) charge | 10 | 0 | 0 | 9 | 90.0 | 1 | 10.0 |
| Sub-total | ( 28) | ( 5) | ( 17.9) | (20) | (71.4) | ( 3) | (10.7) |
| More steeply declining energy block rates | 20 | 4 | 20.0 | 13 | 65.0 | 3 | 15.0 |
| Three-step increasing energy block rates | 20 | 4 | 20.0 | 12 | 60.0 | 4 | 20.0 |
| Sub-total for changes in the form of electric rate charges | 96 | 29 | 30.2 | 54 | 56.3 | 13 | 13.5 |
| Grand Total | 134 | 67 | 50.0 | 54 | 40.3 | 13 | 9.7 |

Table 2. The results of testing the hypotheses on the impacts of changes in the level and form of electric rate structures on the efficiency of using electricity to pump irrigation water.

| | Total number of times tested | Hypothesis confirmed | | No impact | | Hypothesis contradicted | |
|---|---|---|---|---|---|---|---|
| | | Number | Percent | Number | Percent | Number | Percent |
| Changes in the level of the energy charge | 18 | 16 | 88.9 | 2 | 11.1 | 0 | 0 |
| Changes in the form of the electric rate charges | | | | | | | |
| One-at-a-time doubling in the individual electric rate charge components | | | | | | | |
| Annual (monthly) minimum | 6 | 4 | 66.7 | 2 | 33.3 | 0 | 0 |
| Monthly demand | 4 | 3 | 75.0 | 1 | 25.0 | 0 | 0 |
| Energy (kWh) charge | 6 | 3 | 50.0 | 3 | 50.0 | 0 | 0 |
| Sub-total | (16) | (10) | (62.5) | ( 6) | (37.5) | (0) | (0) |
| One-at-a-time 75% reduction in the individual electric rate charge components | | | | | | | |
| Annual (monthly) minimum | 7 | 2 | 33.3 | 4 | 66.7 | 0 | 0 |
| Monthly demand | 4 | 1 | 25.0 | 3 | 75.0 | 0 | 0 |
| Energy (kWh) charge | 6 | 0 | 0 | 6 | 100.0 | 0 | 0 |
| Sub-total | (16) | ( 3) | (18.7) | (13) | (81.3) | (0) | (0) |
| More steeply declining energy block rates | 12 | 4 | 33.3 | 8 | 66.7 | 0 | 0 |
| Three-step increasing energy block rates | 12 | 4 | 33.3 | 7 | 58.4 | 1 | 8.3 |
| Sub-total for changes in the form of electric rate charges | 56 | 21 | 37.5 | 34 | 60.7 | 1 | 1.8 |
| Grand total | 74 | 37 | 50.0 | 36 | 48.7 | 1 | 1.3 |

Appendix

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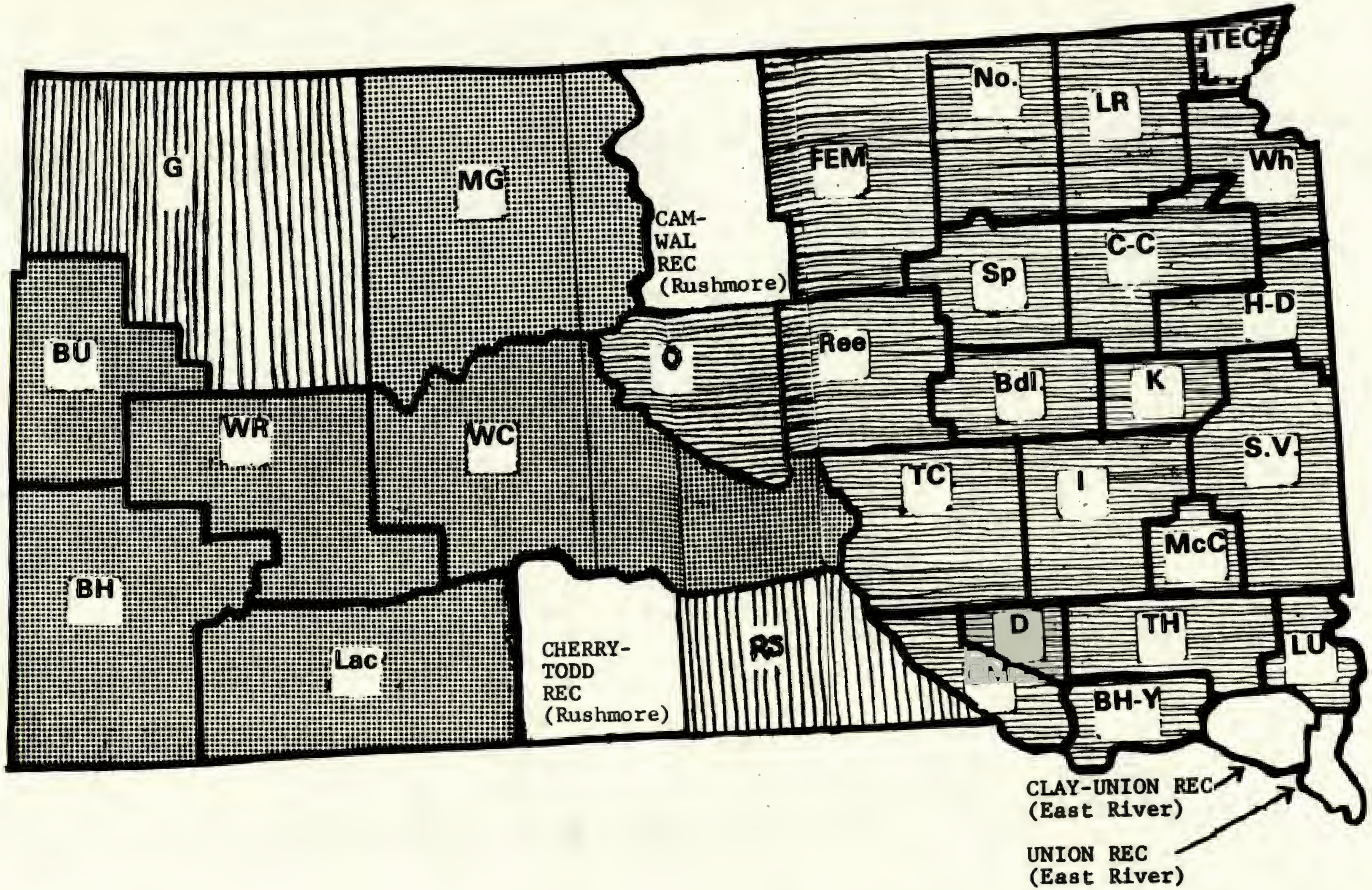
Appendix 1. The four case study South Dakota rural electric cooperatives: Clay-Union, Union, Cherry-Todd, and Cam-Wal.




Legend:

REC's served by East River Electric Power Cooperative

REC's served by Rushmore Electric Power Cooperative

REC's who are members of Basin Electric Power Cooperative

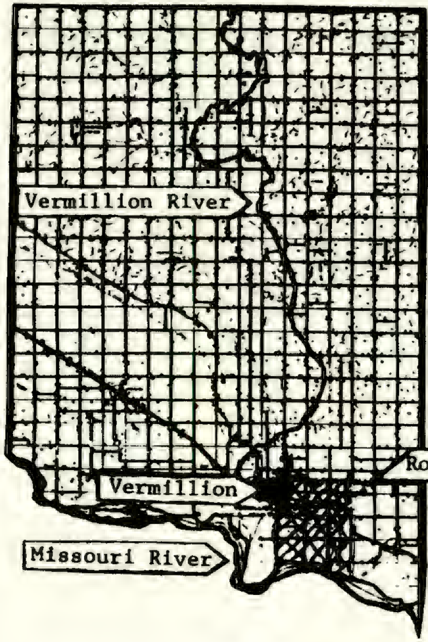
REC's where study sites are located

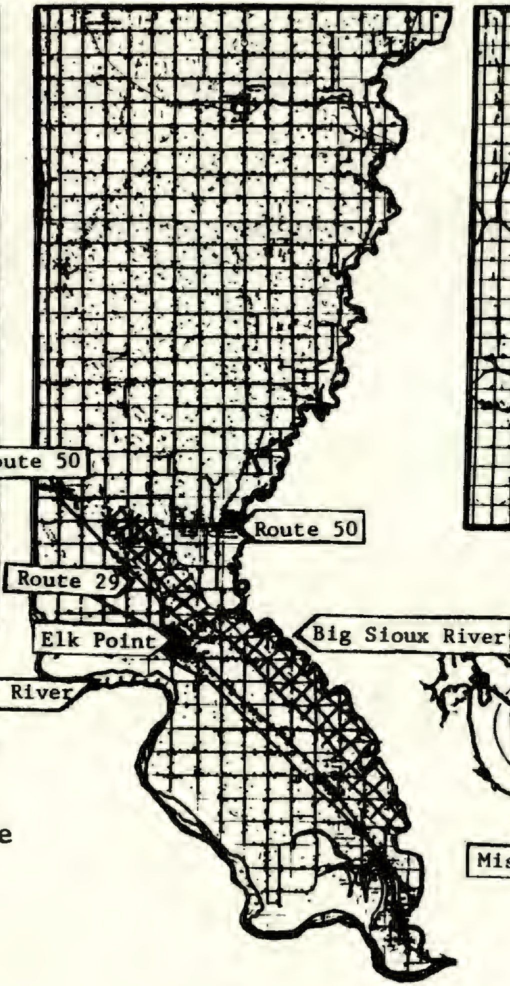
Appendix 2. Selected irrigation sales statistics, four case study RECs, 1984.[a]

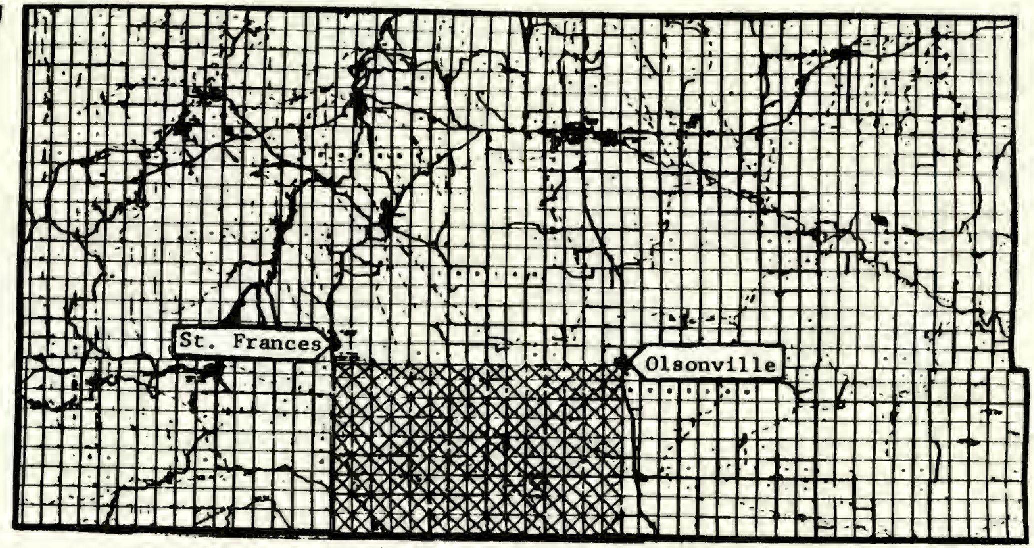
| | Rural electric cooperative | | | |
|---|---|---|---|---|
| | Clay-Union | Union | Cherry-Todd | Cam-Wal |
| **Number of consumers served** | | | | |
| Total | | | | |
| Number | 2,790 | 1,120 | 3,729 | 2,063 |
| Rank | 18 | 30 | 9 | 22 |
| Irrigation | | | | |
| Number | 87 | 144 | 203 | 143 |
| Rank | 11 | 7 | 2 | 8 |
| Irrigation relative to total | | | | |
| Percentage | 3.1% | 12.9% | 5.4% | 6.9% |
| Rank | 10 | 2 | 7 | 6 |
| **Megawatt hour sales** | | | | |
| Total | | | | |
| Megawatt hours | 46,008 | 15,727 | 60,942 | 39,080 |
| Rank | 21 | 32 | 9 | 23 |
| Irrigation | | | | |
| Megawatt hours | 1,475 | 1,381 | 11,682 | 7,188 |
| Rank | 14 | 15 | 2 | 3 |
| Irrigation relative to total | | | | |
| Percentage | 3.2 | 8.8 | 19.2 | 18.4 |
| Rank | 11 | 8 | 2 | 3 |
| **Consumers per mile** | | | | |
| Number | 2.65 | 2.59 | 1.85 | 1.03 |
| Rank | 3 | 4 | 14 | 30 |

[a]The rankings are relative to the total number (namely, 33) of South Dakota rural electric cooperatives.

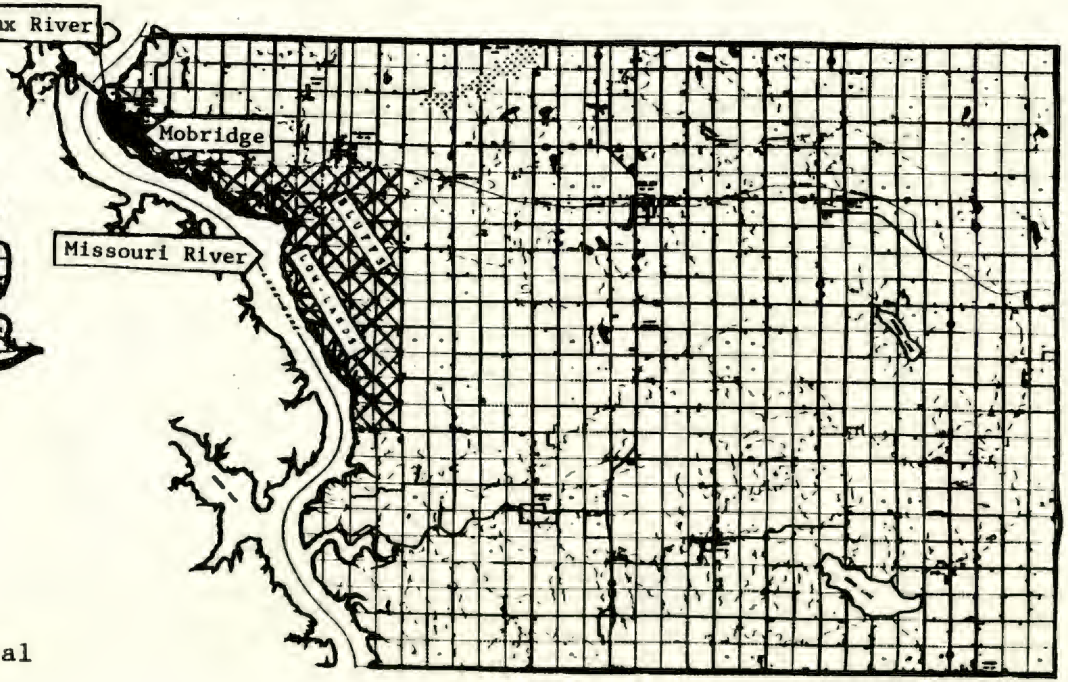
Source: 1984 Annual Statistical Report, Rural Electric Borrowers, Washington, D.C.: Rural Electric Administration, U.S. Dept of Agric, 1985, pp 144-151.




c. Todd County for the Cherry-Todd REC




a. Clay County for the Clay-Union REC (above)

b. Union County for the Union REC (right)

Legend:

Study sites

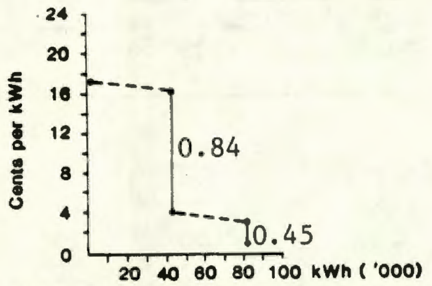
d. Walworth county for the Cam-Wal REC

Appendix 3. The REC study sites within which typical irrigated farms and ranches were identified.

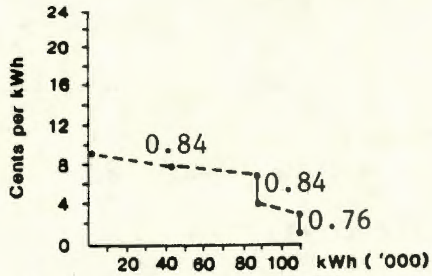
Appendix 4. Selected features of the irrigation-agricultural production environments in the four case study REC study sites.

| | Rural electric cooperative | | | |
|---|---|---|---|---|
| | Clay-Union | Union | Cherry-Todd | Cam-Wal |
| Irrigation water sources | | | | |
| Ground water (GW), surface water (SW) | GW | Mainly GW<br>Some SW | GW | SW |
| Common pumping lift (feet) | 25 | 25 | 130 | 150 low-lands<br>300 bluffs |
| Irrigation water distribution | | | | |
| Center pivot[a] | | | | |
| High pressure | yes | yes | yes | yes |
| Low pressure | yes | yes | yes | no |
| Gated pipe | no | yes | no | no |
| Typical May-September seasonal precipitation (inches) | 11-17 | 11-17 | 10-15 | 8-14 |
| Average growing degree days | 3,425 | 3,425 | 3,090 | 2,924 |
| Dominant soil | Light loam | Heavy clay | Light loam over sandstone | Heavy clay |
| Topography | Nearly level | Level | Nearly level | Moderately sloping |
| Most common farm enterprises | | | | |
| Corn | yes | yes | yes | yes |
| Alfalfa | yes | no | yes | yes |
| Soybeans | yes | yes | no | no |
| Smallgrains | no | no | no | yes |
| Hog farrowing and finishing | yes | no | no | no |
| Beef cow-calf and calf wintering | no | no | yes | yes |

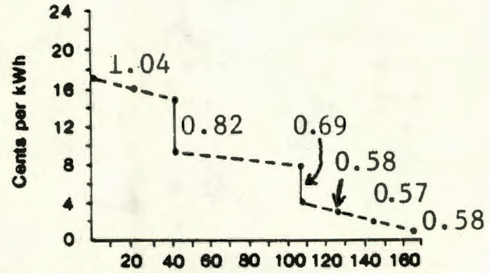
[a]Typical "high" and "low" pressure water distribution pressures are 65 to 85 pounds per square inch (psi) and 25 to 35 psi, respectively.



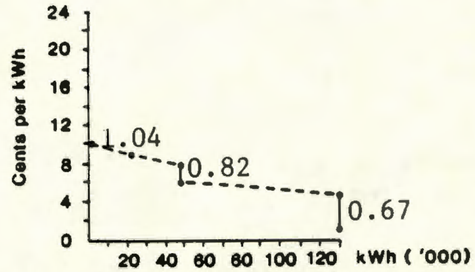

a. Debt-financing, 1985 commodity prices, with AM and MD charges



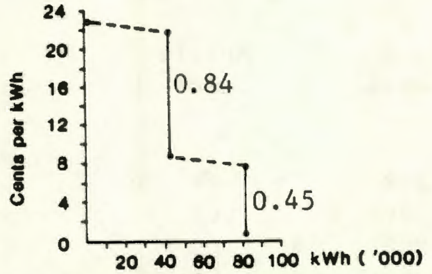

b. Equity-financing, 1985 commodity prices, with AM and MD charges



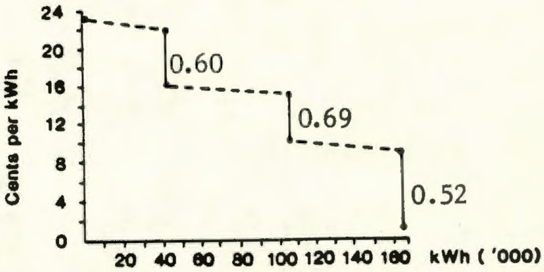

c. Debt-financing, 1980 crop prices, with AM and MD charges




d. Equity-financing, 1980 crop prices, with AM and MD charges



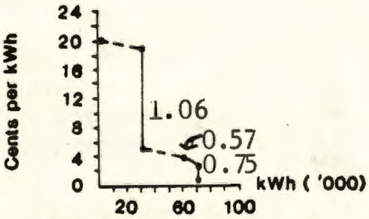

e. Debt-financing, 1985 commodity prices, without AM and MD charges



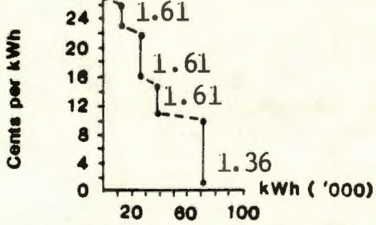

f. Debt-financing, 1980 crop prices, without AM and MD charges

Note: In the above panel titles, (a) AM = annual minimum and MD = monthly demand at the 1985 baseline rates and (b) "debt-financing" and "equity-financing" mean irrigators who finance new irrigation equipment with debt- and equity-capital, respectively.

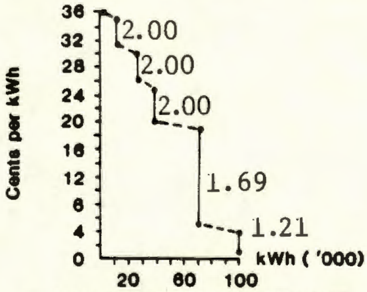
Appendix 5. Efficiencies of electric power use in pumping irrigation water, derived price demand functions, Clay-Union REC representative farm.



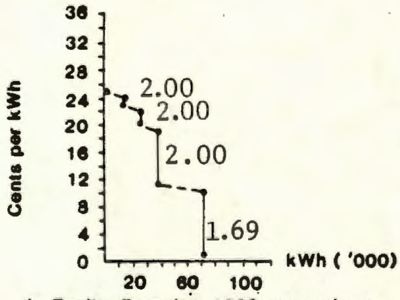

a. Debt-financing, 1985 commodity prices, with AM and MD charges



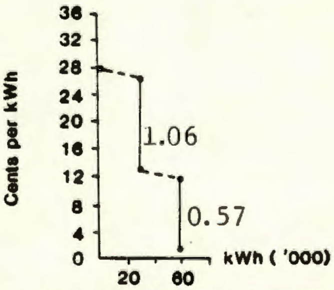

b. Equity-financing, 1985 commodity prices, with AM and MD charges



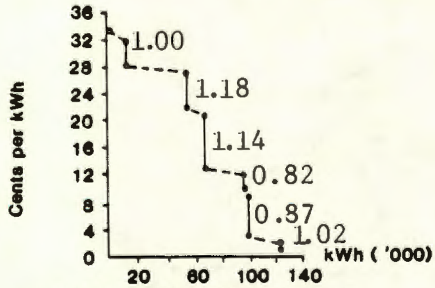

c. Debt-financing, 1980 crop prices, with AM and MD charges




d. Equity-financing, 1980 crop prices, with AM and MD charges



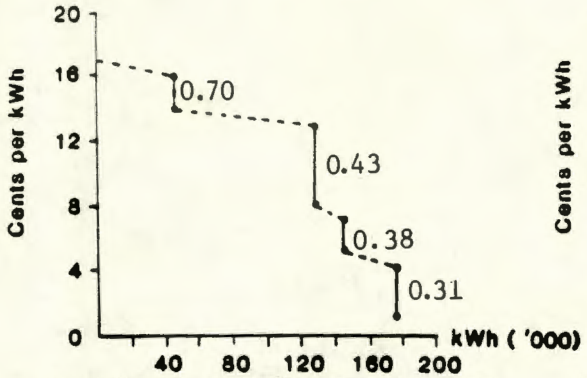

e. Debt-financing, 1985 commodity prices, without AM and MD charges



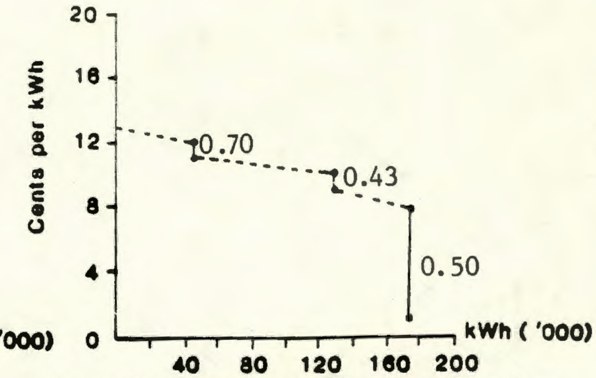

f. Debt-financing, 1980 crop prices, without AM and MD charges

Note: In the above panel titles, (a) AM = annual minimum and MD = monthly demand at the 1985 baseline rates and (b) "debt-financing" and "equity-financing" mean irrigators who finance new irrigation equipment with debt- and equity-capital, respectively.

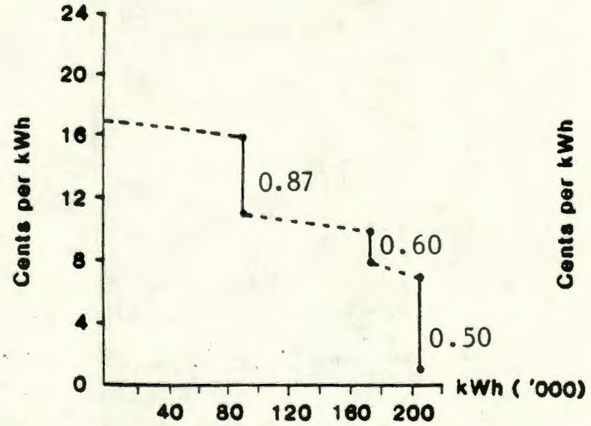
Appendix 6. Efficiencies of electric power use in pumping irrigation water, derived price demand functions, Union REC representative farm.



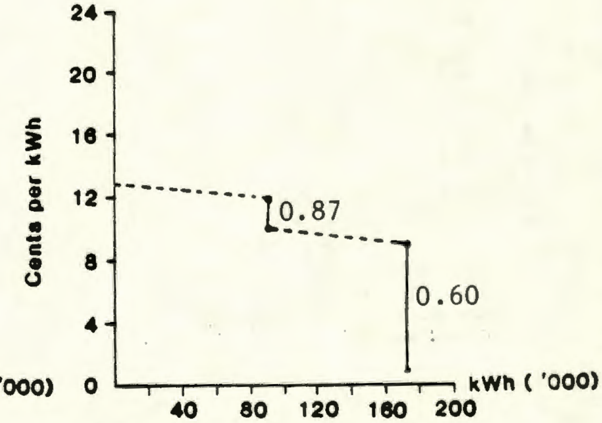

a. Debt-financing, 1985 commodity prices, with the AM charge



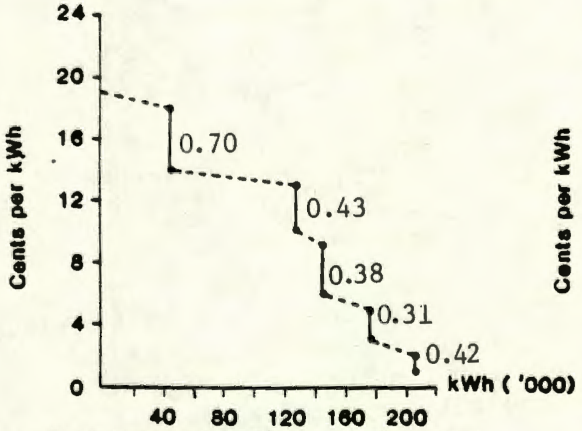

b. Equity-financing, 1985 commodity prices, with the AM charge



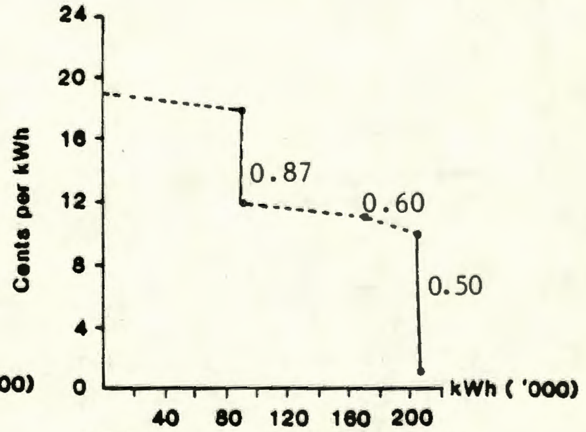

c. Debt-financing, 1980 crop prices, with the AM charge




d. Equity-financing, 1980 crop prices, with the AM charge




e. Debt-financing, 1985 commodity prices, without the AM charge




f. Debt-financing, 1980 crop prices, without the AM charge

Note: In the above panel titles, (a) AM = annual minimum and MD = monthly demand at the 1985 baseline rates and (b) "debt-financing" and "equity-financing" mean irrigators who finance new irrigation equipment with debt- and equity-capital, respectively.

Appendix 7. Efficiencies of electric power use in pumping irrigation water, derived price demand functions, Cherry-Todd REC representative farm.

Appendix 8. Impacts of one-at-a-time increased and decreased annual minimum, monthly demand, and energy electric rate charges on the efficiency of electric power use in pumping irrigation water; irrigators with debt- versus equity-financed new irrigation equipment; 1985 commodity prices; Clay-Union, Union, and Cherry-Todd REC representative farms.

| REC and type of rate structure | Efficiency of electric power use ($ per kWh) | |
|---|---|---|
| | Debt-financing irrigator | Equity-financing irrigator |
| Clay-Union REC | | |
| 1985 baseline (B/L) electric rate charges | .45 | .76 |
| One-at-a-time doubling of the B/L charge | | |
| Annual minimum (average kW) | .84 | .84 |
| Monthly demand (peak kW) | .84 | .84 |
| Energy (kWh) | .84 | .84 |
| One-at-a-time 75% reduction of the B/L charge | | |
| Annual minimum (average kW) | .45 | .76 |
| Monthly demand (peak kW) | .45 | .76 |
| Energy (kWh) | .45 | .76 |
| Union REC | | |
| 1985 baseline (B/L) electric rate charges | .75 | 1.37 |
| One-at-a-time doubling of the B/L charge | | |
| Annual minimum (nameplate HP) | 1.06 | 1.36 |
| Monthly demand (peak kW) | 1.06 | 1.36 |
| Energy (kWh) | .75 | 1.36 |
| One-at-a-time 75% reduction of the B/L charge | | |
| Annual minimum (nameplate HP) | .88 | 1.36 |
| Monthly demand (peak kW) | .88 | 1.36 |
| Energy (kWh) | .75 | 1.36 |
| Cherry-Todd REC[a] | | |
| 1985 baseline (B/L) electric rate charges | .31 | .50 |
| One-at-a-time doubling of the B/L charge | | |
| Annual minimum (HP) | .38 | .50 |
| Energy charge (kWh) | .38 | .50 |
| One-at-a-time 75% reduction of the B/L charge | | |
| Annual minimum (HP) | .31 | .50 |
| Energy charge (kWh) | .31 | .50 |

[a]The Cherry-Todd REC electric rate structure for irrigation contains no provision for a monthly demand charge.

Appendix 9. Impacts of differently configured energy (kWh) block rate charges on the efficiency of electric power use in pumping irrigation water; irrigators with debt- versus equity-financed new irrigation equipment; 1985 commodity prices; Clay-Union, Union, and Cherry-Todd REC representative farms.[a]

| REC and type of energy (kWh) block rate | Efficiency of electric power use ($ per kWh) | |
|---|---|---|
| | Debt-financing irrigator | Equity-financing irrigator |
| Clay-Union REC | | |
| 1985 baseline electric rate charges (a two-step block rate) | .45 | .76 |
| Three-step declining block rate | | |
| 1985 AM and MD charges | .45 | .76 |
| Zero AM and MD charges | .45 | .50 |
| Three-step increasing block rate | | |
| 1985 AM and MD charges | .45 | .76 |
| Zero AM and MD charges | .84 | .68 |
| Union REC | | |
| 1985 baseline electric rate charges (a two-step block rate) | .75 | 1.37 |
| Three-step declining block rate | | |
| 1985 AM and MD charges | .75 | 1.36 |
| Zero AM and MD charges | .57 | .98 |
| Three-step increasing block rate | | |
| 1985 AM and MD charges | .75 | 1.36 |
| Zero AM and MD charges | 1.31 | 1.36 |
| Cherry-Todd REC | | |
| 1985 baseline electric rate charges (a single-step block rate) | .31 | .50 |
| Three-step declining block rate | | |
| 1985 AM charge | .31 | .50 |
| Zero AM charge | .31 | .42 |
| Three-step increasing block rate | | |
| 1985 AM charge | .42 | .50 |
| Zero AM charge | .42 | .50 |

[a]In the description of the energy block rates, AM = annual minimum and MD = monthly demand.