AN ANALYSIS OF IRRIGATION STRATEGIES UNDER INCREASING ELECTRICITY COSTS AND DECLINING GROUNDWATER LEVELS

R. Mann
J.J. Jacobs
D.R. Franklin
J. Oster

August 1985
WWRC-85-32

Completion Report
(Project 2-92284)

Submitted to

Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

Submitted by

Roger Mann
James J. Jacobs
Douglas R. Franklin
Jeanette Oster
Agricultural Economics
University of Wyoming

AN ANALYSIS OF IRRIGATION STRATEGIES UNDER INCREASING ELECTRICITY COSTS AND DECLINING GROUNDWATER LEVELS

I. Introduction

In recent years, irrigators in Laramie County, Wyoming have faced a difficult combination of factors. Increasing electricity costs, low crop prices and declining groundwater levels have served to reduce the profitability of crops produced using center pivot irrigation systems. Such economic pressure provides an incentive for irrigators to consider alternative management strategies which may improve the economic returns from center pivot irrigation systems. Similarly, because groundwater levels are declining, strategies can be considered to lengthen the physical and/or economic life of the aquifer.

The purpose of this report is to provide an economic analysis of various management strategies for center pivot irrigated farms in Laramie County, Wyoming. The study uses a model of a typical farm using center pivot irrigation to assess the impact of alternative strategies on returns to land and management. An evapotranspiration/yield model and a pump-cost model simulate yields and pumping costs for the representative farm. The results from these two simulation models are used as inputs for a linear programming model which determines the optimal crop mix and associated returns under alternative irrigation strategies. The management strategies considered in this study are:

1) Converting from high to low pressure center pivot systems;
2) Increasing pump and application efficiencies;
3) Participation in a load control program;

4) Potato farms;

5) Voluntary restrictions of water use of 10% or more; and

6) Restricting the amount of water pumped from the aquifer through a government imposed restriction policy.

Results of the analysis indicate that the most promising strategies with respect to the profitability of center pivot irrigation are:

1) Conversion of center pivot systems from high pressure to low pressure;

2) Improving pump and/or application efficiencies;

3) Participation in the direct load control program;

4) Potato farming; and

5) A non-restriction policy on water pumped from the aquifer.

Section two of the study provides a brief review of previous work on irrigation pumping from the Wyoming Ogallala Aquifer as well as an update on trends in irrigated farming. A discussion of the limitations of previous work is given in section three. Section four outlines the mathematical models and methods used in the analysis. Finally, section five presents the results for the various management strategies considered.

II. Review of Past Work and Update on Trends in Irrigated Farming

Lindemer (1983) investigated the economics of high and low pressure center pivots under declining ground water tables and increasing electricity costs to the year 2002. Linear programs of high and low pressure center pivot farms for the above conditions were used to estimate optimal cropping patterns and farm income under constant water application rates and constant pump and application efficiencies.

Results from that study suggest the fate of center pivot irrigation under increasing electricity prices and declining ground water levels. Returns to land and management for the case farm decline and the optimal crop mix changes such that land is gradually converted to dryland wheat production. For the grain-forage case farm, alfalfa and feed barley are the first crops converted to dryland wheat followed by corn silage, irrigated wheat and dry beans. Conversion to low pressure pivots and/or increased crop prices only slow this trend. Only under optimistic assumptions, i.e., a 2% annual increase in the real price of electricity and/or higher than expected crop prices, does the projected profitability of crops produced under center pivot irrigation remain positive through the year 2002.

Lindemer also reviewed much of the literature on the impact of decreasing groundwater tables on irrigated agriculture in the central Great Plains. Results of previous studies suggest that the economic abandonment of groundwater reserves should occur before the physical exhaustion of the aquifer. Thus, declining groundwater levels and/or increased energy costs (the majority of studies reviewed assumed constant relative prices and production costs and constant technology) would serve to make irrigation on a typical grain-forage farm unprofitable before the use of groundwater for irrigation depletes the aquifer.

Long-term economic predictions, however, are complicated by uncertainties associated with technological innovation, fuel costs, and crop prices. The assumption of constant technology for instance, may severly bias the prediction that irrigation, because of economic factors, will cease before water is depleted. In fact, in some studies, where crop prices were assumed to increase faster than production costs due to technological advances, results indicated increases in irrigated acreage and net returns, even with increasing electricity prices and declining groundwater levels (Warren, Mapp, Kletke, Ray and Want, 1981). Thus, results from various studies done assessing the economic impact on farming of a declining groundwater level are contingent on the assumptions made about future circumstances. In turn, the credibility of results depends upon one's view of the reality of the assumptions.

Since Lindemer (1983) completed his work, the short-run outlook for irrigated agriculture in southeastern Wyoming has improved slightly in two regards. First, above normal precipitation in 1983 and 1984 has allowed irrigators to pump less water thereby removing some economic pressure through reduced pumping costs. Continued low crop prices, however, have kept irrigators in a financially tenuous situation.

Second, electricity price projections have changed considerably. In the early 1980's, Tri-State Generation and Transmission Association (T.S.G.T.A.), the wholesale power supplier for the region, projected an annual increase in real electricity rates of 11.2% from 1982 to 1987 (Lindemer, 1983). However, during this same time, the combination of the rate of increase in electricity demand declining because of price increases and the construction of new generating facilities has left Tri-State with excess generating capacity. Since 1980 electricity rate increases have been continually revised downward. As recently as April 1985, projected increases in kwh charges were as low as 0-2% through 1998 and there has been discussion of a one-cent discount per kilowatt hour for irrigation customers via a pass-on-rate by T.S.G.T.A.

At the same time, the national agricultural situation has deteriorated in recent years due to a variety of circumstances. Inflation in the early to middle 1970's increased production costs substantially. Increases in energy costs outpaced general inflation over this period and since a major part of center pivot irrigation costs are associated with energy use, production costs for these irrigators have increased more relative to other producers. Also, crop prices in real terms have increased little, if at all, in the last ten years (U.S. Agricultural Statistics, 1983). The Russian grain embargo of 1976 allowed countries competing with the U.S. to improve their markets overseas. These factors, along with the strengthening of the U.S. dollar in recent years, have resulted in exports of some U.S. grains never reaching previous levels.

The value of agricultural land is closely tied to the profitability of the crops grown on that land. With low crop prices, high interest rates and increasing production costs in recent years, profitability has been reduced and land prices have fallen in some areas. This reduces the ability of farmers to borrow against the value of their land and contributes to the financial problems facing farmers.

However, there are factors which should tend to improve the outlook for farms in southeastern Wyoming. The state of Wyoming and the federal government have shown some inclination to farm refinancing. Low interest money is being made available to farmers and ranchers. For example, the federal government has recently indicated that terms on Farmer's Home Administration loans may be relaxed in the near future. Another possibility is a shift in crops produced. The construction of a new Anheuser-Busch brewery in Fort Collins, Colorado may provide a possibility for increased production of malt barley by farmers in southeastern Wyoming.

The outlook for irrigated agriculture in the Great Plains could be improved by higher crop prices and/or lower production costs. However, the same factors which would improve profitability for irrigators might also increase the rate of depletion of the groundwater reserve. This increase could occur through marginal lands being brought into irrigated crop production and less incentive for water conservation practices. With low crop prices and/or higher fuel costs, water conservation practices would be encouraged and more land would convert to dryland uses sooner, thereby reducing depletion rates. The consequence of these circumstances is of course, reduced profitability. Because prices and costs of production are mostly determined by circumstances beyond an individual's control, it appears the most promising option to ameliorate the difficulties irrigators face is technological innovation in crop production and/or irrigation methods. Irrigators, particularly in southeastern Wyoming, must find some means to improve profitability which would not, at the same time, lead to further declines in the groundwater table.

III. Limitations of Past Work

Lindemer clearly states the limitations of his assumptions in conducting the economic analysis of groundwater irrigation. Some of his assumptions are:

1) technologies existing in 1982 will prevail until the year 2002;

2) public policies and programs relating to groundwater or the electrical supplier will remain unchanged during the period of analysis, 1982 to 2002;

3) the size of the farm unit remains the same over time and certain restrictions on cropping patterns apply;

4) as the cost of irrigation increases, acreages which become unprofitable to irrigate revert to dryland wheat production;

5) water application per acre for a given crop remains the same as pumping costs increase;

6) application efficiency is the same for high and low pressure systems, and no improvement in application efficiency is considered;

7) no improvement in pumping efficiency is considered; and

8) no new crops are introduced.

Most of these assumptions tend to make the situation appear worse than what is likely to result. For example, the first assumption is certainly not likely to hold true. Technological innovation may occur through new, more profitable crops and improvements in application and pumping efficiencies. With increasing pumping costs, the incentive to develop and adopt profitable new technologies should increase.

Assumption (2) also involves much uncertainty. In the last ten years, electric companies have taken action to develop new rate structures and programs to reduce peak load problems and consequently electricity costs. Groundwater policies are by no means invariant, although trying to determine what changes in policy are advisable, equitable or likely is extremely difficult and controversial.

Assumptions (3), (4) and (8) also seem unrealistic when considering a period of twenty years or more for analysis. Restrictions on crop acreages and rotations used in Lindemer's model may be representative of today's farm, but it is doubtful that these restrictions would hold in the future. New crops are constantly being investigated in an agronomic and economic sense for dryland and irrigated agriculture which may affect cropping patterns by the year 2000. Research in the genetics of nitrogen fixation and water use and yield response may have important consequences for crop production in the future.

Assumptions 1,2,3,4,5 and 8 are also used in this study. While these assumptions can be criticized as limiting, it must also be pointed out that in order to assess a situation simplifications must be made so as to make a model workable. It would be extremely difficult to try to incorporate into a model the impact a change in technology would have on a farmer's economic situation. On the one hand, it could help to reduce costs significantly. On the other hand, it could serve to depress crop prices as a consequence of increasing yields. Even if technology did reduce production costs without adversely affecting crop prices, other factors such as interest rates or the conditions of overseas markets may harm the agricultural sector. Trying to account for all possible elements affecting farmers in the next twenty years would likely make a model unwieldly. Thus, given these considerations, the above assumptions do not seem overly restrictive. Also, in this analysis, crop prices, non-electrical production costs and yields are assumed to be constant over time.

IV. Methodology

The farm model has several components consisting of both simulation and a linear programming model. The component which considers irrigation strategies and resulting crop yields is a simulation model of crop evapotranspiration and yield. Through the amount of water applied, this model feeds into a pump cost simulation which also considers depth to water, price of electricity, pump and application efficiency and other pump characteristics. Results from the simulation model are used in the linear programming model (L.P.) which determines the optimal crop mix under alternative irrigation strategies through consideration of costs and revenues. Variations of the L.P. model were run to take into consideration conversion to low pressure, pump and application efficiencies, potato farming, and a government imposed water restriction policy.

A. Crop Evapotranspiration-Yield Simulation

Due to its complexity, the crop evapotranspiration model is detailed in Appendix 1. In the evapotranspiration/yield model, potential evapotranspiration (ETP) is estimated using the "Blaney-Criddle" method. ETP is a function of daily mean temperature, daily proportion of annual daylight hours and a crop coefficient. The crop coefficient is a factor to account for the variation in crop requirements when estimating potential evapotranspiration (See Appendix 1, Table 5). The model estimates evapotranspiration on a daily basis and subtracts it from estimated soil moisture. Soil moisture is increased through effective irrigation and effective precipitation. If soil moisture is depleted below an allowable fraction of field capacity, actual evapotranspiration (ETA) falls below potential evapotranspiration and yields are decreased.

B. Pump Cost Simulation

The pump cost simulation is based on the PUMP COST program on AGNET (1984). The PUMP COST program calculates fixed and operating costs of center pivot irrigation. The data for calculating operating costs can be drawn directly from the output form of the program. Fixed costs, estimated from the simulation model, change only slightly as pumping pressure and depth to water vary.

The PUMP COST equations are contained within the crop evapotranspiration FORTRAN model. The PUMP COST calculation allows for varying the type of system (high versus low pressure), depth to water, application and pump efficiencies and amount of water applied. The PUMP COST simulation is outlined in Table 1. Irrigation costs include fixed costs, variable non-electrical costs, electricity costs and a demand charge. Required data to calculate pumping costs are gallons per minute (GPM), pressure in pounds per square inch (PSI), depth to water in feet, pump and application efficiencies, inches of water applied, price of electricity (¢/KWH) and the demand charge per horsepower (hp).

Table 1. Outline of PUMP COST Simulation.

```
  FT = (2.31 * PSI) + DP
  HP = FT * GPM/(3960 * PE)
GPMA = GPM * AE
  EL = HP/1.34
HPAF = 325900/(GPMA * 60)
```

KWHA = .0833 * HPAF * EL
WHP = FT * GPM/3960
HTO = HPAF * .0833 * SUMW * AP
VC = (WHP * HTO * 4/4000) + [HP * .62 + ($AP^{.5}$) * .08 * HTO]
+ [(.02 * HTO * 15) + (.5 * AP * 5)] + (3.0 * HTO * KWC/.88)/4
ELU = 31.25 * KWHA * SUMW
FC = [BC + (BC * .015 * (DP - 110)/10) - (BC * .045 *
(80 - PSI)/35)] * 31.25
TC = FC + VC + (ELU * KWC) + (CNCT * HP)/4

Variable Definitions

FT = feed of head
PSI = pump pressure, pounds/square inch
DP = depth to water, feet
HP = required horsepower
GPM = gallons per minute
PE = pump efficiency, $0 \leq PE \leq 1$
GPMA = gallons per minute applied
AE = application efficiency, $0 \leq AE \leq 1$
EL = kw load required
HPAF = hours per acre foot applied
KWHA = kwh required per acre inch
WHP = water horsepower
HTO = hours of operation for the pivot
SUMW = acre inches of water applied per acre
VC = variable costs of operation excluding electricity and demand charge, per ¼ pivot
AP = acres in the pivot
KWC = cost charged per kilowatt-hour in cents
ELU = electricity use per quarter pivot, kwh, 31.25 = 125/4
FC = fixed cost per quarter pivot
BC = base fixed cost at 110 feet to water, 80 PSI, 75% pump and 80% application efficiency, per acre
TC = total cost of irrigation per quarter pivot
CNCT = demand charge per horsepower

A change in variable costs associated with different pump and application efficiencies is incorporated into the analysis through the PUMP COST program. An increase in application efficiency decreases the amount of water pumped, which in turn affects pumping and other variable costs. The optimal irrigation amount decreases and each irrigation is reduced by the ratio of the application efficiencies. For example, if the irrigation efficiency increases from .80 to .85, the amount of each irrigation is reduced by a factor of 0.941 (.8 ÷ .85). Because of the reduction in water applied, variable costs are reduced through a decrease in the amount of time required to run the system. The reduction in water applied associated with an improvement in application efficiency would reduce the rate of groundwater decline slightly but that is not taken into consideration in this analysis. Similarly, an increase in pumping efficiency reduces variable pumping costs through the hp requirement and subsequent kilowatt-hours required per acre inch applied. Also, changing from high to low pressure pivots affects the cost of pumping through the hp required and thus, electricity consumed per acre-inch applied. The reduction in costs associated with a conversion from high to low pressure is calculated through the pump-cost simulation.

In the simulation, fixed costs are increased slightly according to increases in total head caused by pumping pressure (PSI) and feet of lift. For each 10 foot increase in feet of lift over 110 feet, fixed costs are increased by 1.5%. For the change from high to low pressure pivots (80 to 45 PSI), fixed costs are reduced by 4.5%. The reduction in fixed costs due to a one inch reduction in water applied amounts to less than one-half of one percent for applications above 16 acre inches and is ignored in the simulation. This is consistent with results from the AGNET PUMP COST program.

C. Linear Programming Model

Using the output from the pump cost and evapotranspiration simulations, the linear programming model determines the optimal crop mix and associated returns. An objective function expresses net returns from all crops as a function of their production costs per acre, acres in production, crop prices, quantity of crop sold and irrigation expenses. The L.P. determines the maximum net return under a set of linear constraints on cropping patterns and acreages. The constraints are on total acreage available, total acreage for individual crops and crop rotations.

The objective function is

$$(1) \quad N = \sum_{c=1}^{C} P_c Q_c - \sum_{c=1}^{C} K_c L_c - RE - SD$$

where N is net returns to land and management, P_c is price of crop c, Q_c is quantity of crop c sold, K_c is cost per land unit of producing crop c, L_c is units of land in crop c, R and E are electricity price and quantity, and S and D are demand charge per land area and quantity of land, respectively. Thus, K_c excludes electricity and demand charge costs, but includes other fixed and variable irrigation costs.

Q_c is designated by the equation

$$(2) \quad Q_c = Y_c L_c$$

where Y_c is yield per quarter pivot. Crop yield is determined by the evapotranspiration model and the units of measurement vary by crop.

K_c, the cost per land unit of producing crop c, accounts for non-irrigation production costs. Because these costs are not affected by changes in pump and application efficiencies, changes in depth to water, or conversion from high to low pressure, they remain constant throughout the analysis. Non-irrigation production costs are determined by the crop budget program on AGNET (1984).

L_c, E, and D are determined by the linear program. The combination of crops produced which maximizes the objective function will determine the quantity of land and electricity used. The prices of the crops produced and electricity used (P_c, R, S) are determined outside the simulation models and are input directly into the L.P.

In the linear program all land is in units of quarter pivots (31.25 acres). A full pivot of 125 acres allows for some non-irrigable land, primarily due to corners and an access road to the center of the pivot. The grain-forage farm unit is assumed to contain land for four center pivots. Actual land on the farm exceeds 500 acres because of margin lands surrounding the pivot. Consequently, land available for dryland wheat production is increased by a factor of 1.28 to account for the fact that farmers would use this land on the margin for dryland wheat production. A separate L.P. allows for potato farming. This is done because the structure and size of potato farms differ substantially from the grain-forage farm.

The linear constraints imposed on the objective function are on total acreage available, total acreage for individual crops and on crop rotations. As stated above, irrigated acreage on the farm is limited to 500 acres (four quarter pivots). As prices for some crops can vary extensively from year to year, producers tend to grow several crops to reduce risk. To account for this risk element, bean acreage for the 500 acre farm is restricted to be less than or equal to 94 acres in this analysis.

Since feed barley is grown solely as a nurse crop for alfalfa, a rotation constraint places a requirement for barley acreage relative to alfalfa. A four year rotation is used in this analysis. Also, initial runs of the L.P. model indicated that dry beans was often the most profitable irrigated crop for the grain-forage case farm with the remaining land in dryland wheat. This is unreasonable in that beans must be rotated with other crops to avoid disease problems. Thus, another rotation is defined which requires that dry beans be followed by corn silage or irrigated wheat after two years, or that beans be followed by a four year alfalfa-barley rotation. Dryland wheat is forced to enter the solution in whole pivots or 160 acre units (125 x 1.28).

D. Prices, Costs, Yields and Irrigation Amounts Used in Analysis

Prices used in the analysis are provided in Table 2 along with some other price scenarios for crops grown in southeastern Wyoming. The 1973-82 adjusted

Table 2. Various Estimated Prices for Crops Grown in Southeastern Wyoming.

	Used by Lindemer (1983)[a]	1973-82 Average[b]	1982 Actual[b]	L.P. Breakeven[c]	1973-82 Adjusted Ave.[d]	Price Used[f]
Alfalfa (ton)	67.26	53.45	53.50	50.43	54.36	61.00
Feed Barley (bushel)	2.64	2.60	3.30	4.14	2.64	2.64
Dry Beans (cwt)	24.20	19.60	11.00	18.23	20.42	20.42
Corn Silage (ton)	20.29	16.04	16.05	16.93	16.31	18.30
Irrigated Wheat (bushel)	3.77	3.29	3.25	3.46	3.29	3.29
Dryland Wheat (bushel)	3.77	3.29	3.25	3.28	3.29	3.29
Potatoes[e]	5.86	4.42	3.90	2.81	4.60	4.60

a/ Lindemer expected price scenario.
b/ Data from Wyoming Agricultural Statistics.
c/ For the low pressure base scenario with 1984 irrigation costs, management and land costs are not included.
d/ 1982 price received index (PRI) divided by mean 1973 to 1982 PRI, times 1973 to 1982 mean actual price received. PRI from U.S. Ag Statistics, 1983, p. 592 for food grains, feed and hay, and potatoes and beans.
e/ Grown on owned land.
f/ Prices used in this analysis.

average prices were used for all crops except alfalfa and corn silage. The prices used for alfalfa and corn silage are the 1979-83 average prices for these crops. The 1982 and ten-year average prices in comparison to breakeven prices show that, except for potatoes, irrigation can be a very marginal business under current crop prices.[1]

Non-irrigation production costs are estimated with the Crop Budget program on AGNET (1984). A breakdown of estimated costs is provided in Table 3. These costs do not include interest on land or a management charge.

Crop yields used in this analysis were based on yields reported in crop enterprise budgets prepared by the Wyoming Agricultural Extension Service

---

1/ The L.P. scenario used to estimate the breakeven prices is Scenario 4 in Table 6, page 18.

Table 3. Non-irrigation Production Costs.

	Per Acre						
			Machinery				
	Labor[a] Hours	$ [b] Materials	$ [c] Operat.	$Deprec., Fixed	Other[d]	1982 Total	1984 Total[e]
Dryland Wheat[f]	.784	26.34	30.26	36.52	9.86	107.29	111.60
Corn Silage	2.854	90.96	70.54	66.08	26.08	269.36	280.17
Irrigated Wheat	1.955	62.04	34.09	35.83	17.00	159.71	166.12
Feed Barley[g]	2.774	116.69	41.81	44.34	25.67	243.77	253.55
Alfalfa	3.479	42.37	41.34	49.43	15.26	167.53	174.25
Dry Beans	3.348	128.2	46.24	51.71	27.89	272.45	283.38
Potatoes	3.32	298.54	92.62	84.02	58.07	551.51	573.57

a/ Labor valued at $5.50 per hour
b/ Chemicals, seed, custom services, twine, fertilizer.
c/ Fuel, lube, repair, maintenance.
d/ Primarily interest, tax and overhead.
e/ Allows 4% inflation total from 1982 to 1984.
f/ Cost per two-year rotation.
g/ Includes alfalfa establishment cost.

(Agee, 1979 & 1981). They are alfalfa; 5.5 tons/acre, barley; 80 bu/acre, irrigated wheat; 70 bu/acre, corn silage; 22 tons/acre, and dry beans; 20 cwt per acre. These yields are assumed to be the maximum attainable yields for these crops.

Scheduled irrigations for the various crops, assuming an 85% application efficiency, are given in Table 4. These irrigation dates and amounts were determined by the Crop Evapotranspiration Model (Appendix 1) and are for the maximum crop yields listed above. The final irrigations were reduced so that no extra water remained in the soil at season's end yet yields were at a maximum. For alfalfa, irrigations were scheduled such that the soil was filled to capacity after each cutting. Appendix 1 details how irrigation amounts and schedules affect yields. In the fall, winter wheat and alfalfa receive 3 and 7.5 inches respectively. This allows the soil profile to be filled with moisture to the root depth of the crop in the spring.

Table 4. Irrigation Applications for Maximum Yield: Low Pressure Base Scenario[a]

Winter Wheat

Starting Date	Inches Applied
4/30[b]	4.20
5/28	2.80
total	7.00
+3.0[c]	10.00

Alfalfa

Starting Date	Inches Applied
6/11	7.44
6/16	.81
7/19	4.97
total	13.22
+7.5[c]	20.72

Barley

Starting Date	Inches Applied
5/19	2.24
5/31	2.33
6/11	2.61
6/23	3.08
7/12	.33
total	10.59

Bean

Starting Date	Inches Applied
6/14	1.16
6/22	1.39
6/29	1.49
7/6	1.71
7/13	1.85
7/21	2.17
7/31	1.93
total	11.70

Potato

Starting Date	Inches Applied
6/18-6/25	1.99
7/1-7/15	4.59
7/19	1.09
7/23	1.14
7/27	1.18
7/31	1.21
8/4	1.53
8/9	1.54
8/14	1.52
8/20	1.77
8/27	1.96
9/5	2.00
total	21.53

Corn Silage

Starting Date	Inches Applied
6/13	3.12
7/2	3.87
7/19	4.43
8/9	3.41
total	14.83

[a] See also Table 10, Appendix 1.

[b] April 30.

[c] Fall irrigations

The interrelationship between crop yields, production costs, and crop prices is extremely complex. The economics of irrigation in the future may depend on increased yield due to technological innovation. Appendix 2 summarizes a method for estimating expected yield increases for crops in Laramie County and the United States as a whole. However, because of the uncertainty involved and to be conservative, crop yields are held constant in this analysis.

Depth to water is assumed to increase by 15 feet over 10 years or 1.5 feet per year. It should be noted that conversions to dryland agriculture imply a reduced rate of decline in the groundwater level. However, a preliminary analysis indicated that the economic impact of a reduced rate of decline (i.e. 1 ft vs. 1.5 ft) would be minimal. Thus, reduced rates of decline in the groundwater table stemming from conversion to dryland agriculture were ignored in this analysis.

The cost of electricity increases at 2 and 4% in varying scenarios of the analysis. These increases are considered to be realistic and pessimistic, respectively. In some cases the analysis also considers the optimistic possibility of no increase in electricity prices. A 1984 price of .045 per kilowatt hour and $18.00 per rated horsepower per year is used in the analysis. Table 5 provides projections of electricity prices and depth to water in 1984, 1994 and 2004.

Table 5. Future Projections of Energy Costs, Depth to Water and Maximum Yields for Southeastern Wyoming Crops.

Year	Feet to Water	¢/kwh electricity increasing		Demand charge $/hp	
		2%/year	4%/year	2%/year	4%/year
1984	110	4.50	4.50	18.00	18.00
1994	125	5.485[a/]	6.661	21.942[b/]	26.644
2004	140	6.687	9.860	26.747	39.44

a/ 4.5×1.02^{10}

b/ 18.00×1.02^{10}

V. Results

A. High Vs. Low Pressure Pivots

Results of the simulation and L.P. analysis for high pressure and low pressure center pivots are provided in Tables 6 & 7. Table 6 presents a comparison of high and low pressure pivots for successive years under the optimistic assumption of constant electricity prices. Table 7 provides a similar comparison for a 2 and 4% annual increase in electricity costs.

Scenarios 1-8 show the economic desirability of low pressure pivots in the face of higher electricity costs due to a declining groundwater table. Returns in the low pressure scenarios are more than double those for the high pressure system. Also, results indicate that a low-pressure pivot maintains the life of irrigated farming through at least the year 2004 while a majority of acreage converts to dryland wheat production by that same year using a high pressure system. The difference in future income between high and low pressure returns, if discounted to obtain present values, would indicate how much money could be invested today to finance the conversion to low pressure pivots.

Table 6 also displays results from the model assuming a 2.5 foot decline in the groundwater table. Even at this rate of decline, the crop mix remains the same for a low pressure pivot. If electricity prices remain constant, results suggest that increasing costs of pumping due to decreasing water levels in wells should not, to any large degree, adversely affect irrigated agriculture by 2004. Thus, declining groundwater levels in themselves do not appear to be a significant threat to irrigated farming in southeastern Wyoming.

In Table 7, scenarios 9-18 also indicate the economic advantage of a low pressure pivot with increasing electricity prices, although increases in electricity costs threaten the viability of irrigated farming for both high and low pressure systems. The results show that even with a 2% annual

Table 6. Results of Linear Programming Model for High and Low Pressure Center Pivots Assuming Constant Electricity Prices*

Scenario Number	Year	Depth to Water	Electricity costs ¢ per kwh	Electricity costs $ per hp	$ Max. Return	Acres in crops: bean	alfalfa	feed barley	corn silage	dryland wheat
HIGH PRESSURE										
1	1984	110	4.5	18.00**	4,800.57	83	333	83	0	0
2	1994	125	4.5	18.00	2,996.59	83	333	83	0	0
3	2004	140	4.5	18.00	2,740.08	94	0	0	47	460
LOW PRESSURE										
4	1984	110	4.5	18.00	12,960.72	83	333	83	0	0
5	1994	125	4.5	18.00	11,156.74	83	333	83	0	0
6	2004	140	4.5	18.00	9,352.86	83	333	83	0	0
LOW PRESSURE - 2.5 FT DECLINE										
7	1994	135	4.5	18.00	9,953.59	83	333	83	0	0
8	2004	160	4.5	18.00	6,948.14	83	333	83	0	0

* Application efficiency = .85, pump efficiency = .65

** Participation in direct load control assumed (see Direct Load Control Section)

Table 7. Results of Linear Programming Model for High and Low Pressure Center Pivots Assuming Two and Four Percent Increases in Electricity Costs.*

Scenario Number	Year	Depth to Water	Electricity costs ¢ per kwh	Electricity costs $ per hp	$ Max. Return	Acres in crops: bean	alfalfa	feed barley	corn silage	dryland wheat
HIGH PRESSURE										
9	1984	110	4.5	18.00	4800.57	83	333	83	0	0
			2% Increase							
10	1994	125	5.49	21.94	1572.96	83	0	0	42	480
11	2004	140	6.69	26.74	83.20	0	0	0	0	640
			4% Increase							
12	1994	125	6.66	26.64	137.81	83	0	0	42	480
13	2004	140	9.86	39.44	83.20	0	0	0	0	640
LOW PRESSURE										
14	1984	110	4.5	18.00	12,960.72	83	333	83	0	0
			2% Increase							
15	1994	125	5.49	21.94	6598.28	83	333	83	0	0
16	2004	140	6.69	26.74	1946.92	83	0	0	42	480
			4% Increase							
17	1994	125	6.66	26.74	2538.13	83	0	0	42	480
18	2004	140	9.86	39.44	83.20	0	0	0	0	640

* Applications Efficiency = .85
Pump Efficiency = .65

increase in electricity costs, by 1994 most of the acreage converts to dryland wheat production and returns decline substantially with the use of high pressure pivots. Increased profitability through the use of low pressure center pivot systems is better able to absorb the higher electricity costs. However, even with low pressure, the results indicate that irrigated farming would almost cease by 2004 with a 2% annual increase in electricity costs.

The results, then, lend support to the findings of Lindemer (1983). While his analysis used a higher crop price scenario and therefore indicated a longer life for irrigated farming with a 2% increase in electricity costs, the same general trend for irrigated farming is found in both analyses. Only under optimistic assumptions regarding electricity and crop prices can irrigators in southeastern Wyoming tolerate declining groundwater levels. If more severe conditions are assumed, cessation of irrigated farming appears inevitable. Nonetheless, increased profitability through use of low pressure center pivot systems is able to extend the life of irrigated farming beyond the time predicted with the use of high pressure systems.

B. Improving Pump and Application Efficiencies

The impacts on net returns from improvements in pump and/or application efficiencies are shown in Table 8. An increase in application efficiency decreases the amount of water pumped which, in turn, affects pumping costs. As a consequence, variable costs are reduced via a decrease in the amount of time required to run the system. Similarly, an increase in pumping efficiency reduces variable pumping costs through the horsepower requirement and subsequent kilowatt hours required per acre inch applied.

Scenarios 19-22 show the effects of increasing pump and application efficiencies at a constant groundwater level. The economic advantage of such improvements is clearly indicated through the increase in net returns.

Table 8. Results of Linear Programming Model for Low Pressure Pivots With Changes in Pump and Application Efficiencies.

Scenario Number	Year	Depth to Water	Electricity Costs		Efficiencies		$ Max. Return	acres in crops				
			¢ per kwh	$ per hp	pump	application		bean	alfalfa	feed barley	corn silage	dryland wheat
19	1984	110	4.5	18.00	.60	.80	9,964.36	83	333	83	0	0
20	1984	110	4.5	18.00	.65	.80	11,609.12	83	333	83	0	0
21	1984	110	4.5	18.00	.70	.80	13,018.67	83	333	83	0	0
22	1984	110	4.5	18.00	.70	.85	14,309.45	83	333	83	0	0
2% Increase in Electricity Prices												
23	1994	125	5.49	21.94	.60	.80	3,194.48	94	97	24	34	320
24	1994	125	5.49	21.94	.70	.80	6,775.70	83	333	83	0	0
25	1994	125	5.49	21.94	.70	.85	8,321.24	83	333	83	0	0
26	2004	140	6.69	26.74	.60	.80	1,000.47	83	0	0	42	480
27	2004	140	6.69	26.74	.70	.80	2,063.08	83	0	0	42	480
28	2004	140	6.69	26.74	.70	.85	2,437.77	83	0	0	42	480
4% Increase in Electricity Prices												
29	1994	125	6.69	26.74	.60	.80	1,576.95	83	0	0	42	480
30	1994	125	6.69	26.74	.70	.80	2,574.29	83	0	0	42	480
31	1994	125	6.69	26.74	.70	.85	3,129.49	83	333	83	0	0
32	2004	140	9.86	39.44	.60	.80	83.20	0	0	0	0	640
33	2004	140	9.86	39.44	.70	.80	83.20	0	0	0	0	640
34	2004	140	9.86	39.44	.70	.85	83.20	0	0	0	0	640

Of more interest, however, is the benefit from improved pump and application efficiencies in the face of declining groundwater levels and increasing electricity costs. Consideration of these factors is displayed in Scenarios 23-34. The cases considered are for a 2% and 4% annual increase in electricity prices.

A comparison of Scenarios 23-25 shows the economic benefit in 1994 of improving pump and application efficiencies with a 2% increase in electricity prices. Scenario 23 displays the outcome of the L.P. assuming no change in pump and application efficiencies from 1984. If the pump and application efficiencies were .60 and .80 in 1984 and remained so in 1994, net returns would decline by 69% due to increases in electricity costs. Increasing the pump and application efficiencies by 10% and 5% respectively, mitigates this reduction resulting in only a 16% decline in net returns. Scenarios 26-28 show results for the same type analysis for the year 2004. However, although net returns are improved through increases in pump and application efficiencies, the majority of land converts to dryland wheat by 2004, due to increased electricity costs.

In the case where electricity prices were increased 4% annually, the most significant affect can be seen in Scenarios 29-31 for the year 1994. Improving pump and application efficiencies results in the farm remaining in full irrigated crop production and in turn, net returns increase 50% from what they would have been if efficiency levels remained the same as in 1984. By 2004, changes in pump and application efficiencies become irrelevant with a 4% increase in electricity prices as this increase, coupled with a 140 foot depth to water, causes complete conversion to dryland wheat production.

Of course, increased returns from improvements in pump and application efficiencies would have to be compared with the cost of attaining the improved

In addition to showing the improvements in profitability from converting from high to low pressure pivots and improving pump and application efficiencies, the results indicate that the optimal crop mix is 333 acres of alfalfa, 83 acres of feed barley and 83 acres of dry beans. This mix changes as electricity prices increase but for most scenarios it was found to generate the highest return. Thus, if conversion to low pressure has already taken place or pump and application efficiencies have been improved, the analysis suggests that irrigators may be able to improve their financial situation by increasing alfalfa acreage if existing alfalfa acreage is less than 70% of irrigated acreage.

Also, in Appendix 3 a demand equation for electricity for irrigation in Laramie County was estimated. The results indicated that both in the short and long run, electricity demand appears to be inelastic. The short-run elasticity of demand with respect to kwh price was estimated to be -.25. The long-run elasticity with respect to kwh price was estimated to be -.29.

Up to this time, irrigators may have been unresponsive to changes in electricity prices because, given the prices charged in the last ten to twenty years, the value of the marginal product of yield produced continued to exceed the marginal pumping cost of producing that yield. However, as is pointed out in the appendix, if decreasing groundwater levels and low crop prices continue in the future, irrigators may become more sensitive to increases in electricity prices than the demand function estimated in Appendix 4 indicates. The results from the L.P. for net returns in Tables 7 and 8 seem to portend such a change.

C. Load Control Program

1. Introduction

Load control refers to a program where irrigators turn off or allow utilities to turn off irrigation pumps and thereby receive a reduction in demand charges. Direct load control allows the utility to turn off irrigation pumps, often by some form of remote control. The irrigator normally saves under this system via a decrease in the per horsepower (hp) demand charge paid and occasionally through a reduced price per kilowatt-hour. Some utilities, such as Rural Electric, use a voluntary turn off system whereby the irrigators agree when a pump is to be turned off (see Appendix 3). Load control is a common means of reducing power and irrigation costs. One author notes that "savings in purchased power cost is sufficient to recover the cost of a load management system within two years" for some utilities (Arthur D. Little, Inc., 1978).

Since Tri-State Generation and Transmission Association (T.S.G.T.A.) charges Rural Electric a demand charge, there is incentive to promote load controls. In 1983, Rural Electric attempted a direct remote load control system. However, the attempt failed because some of the equipment failed to operate (personal communication, Rural Electric). In 1984, Rural Electric has opted for a one-day voluntary turn-off system which allows participating farmers to pay an $18.00 per rated hp demand charge, while non-participants pay $18.00 per rated hp up to 25 hp and $33.29 per rated hp for that above 25 hp.[2/]

For the Rural Electric Co, savings from the voluntary turn-off system arise from a decrease in load on the system at any point in time and a decrease in the demand charge paid to T.S.G.T.A. T.S.G.T.A. charged $12.77 per kilowatt of load on a monthly basis in 1984. System load is measured by T.S.G.T.A. once a month over a 30-minute period, corresponding to the heaviest demand period of the month. Rural Electric has an irrigation load of about 22,000 kw in the summer months. If 1/7 of this load is reduced by the one-day

---

2/ The 1985 rate is $19.26 and $33.29, respectively.

voluntary turn-off during the week of heaviest demand, the system load is reduced by 3143 watts [(1/7)(22,000)] for a savings of $40,134 per month. These savings are passed on to participating irrigators in the form of the reduced demand charge ($18.00 versus $28.19 for a 75 hp motor).

2. Load Control Analysis

For the individual irrigator, the economics of load control involve two components. The first component is the value of reductions in yield that may follow from timing and/or reduced amount of water applications because of load control. Second is the savings in energy costs associated with the load control program.

The potential yield reduction due to load control can be estimated with the crop evapotranspiration model. This method has been used before (Bosch et al., 1984) to determine the economic feasibility of participation in a direct load control program on corn.

Irrigation schedules and amounts which resulted in the estimated maximum yields were provided in Table 4, (Page 16). A load control program would reduce yields when the time between irrigation dates is limited such that the quantity of water needed to produce maximum yields cannot be applied.

Table 9 presents results from an analysis of a load control program in which the irrigator agrees to shut off his irrigation system for a specified number of non-consecutive days. For each crop, the first day of the shut off occurs two days after the first application date and the shut off is in effect for 24 hours. For winter wheat, the 4.20 inches of irrigation can be applied in 11.7 days (a pivot operating at 850 gallons per minute on 125 acres would apply .36 acre inches per day). As long as the irrigation of 4.20 inches starts on 4/30, soil moisture will be above the proportion depletion allowance, actual evapotranspiration will equal potential evapotranspiration, and future

Table 9. Analysis of Load Control and Available Irrigation Times.

Date[a/] Application Started	Inches Applied	No. Days[b/] Needed to Apply	No. Days Available to Apply[c/] No Load Control	1-Day Off	2-Days Off	3-Days Off
Maximum Yield Strategy						
Winter Wheat						
4/30	4.20	11.67	28	24	20	16
5/28	2.80	7.70	53	45	37	30
Alfalfa[d/]						
6/11	7.44	20.67	45	39	32	25
6/16	.81	2.25	33	28	23	19
7/19	4.97	13.80	65	56	47	38
Barley						
5/19	2.24	6.20	12	9	7	6*
5/31	2.33	6.47	11	10	9	7
6/11	2.61	7.25	12	10	8	6*
6/23	3.08	8.56	19	16	13	11
7/12	.33	.92	28	24	21	17
Bean						
6/14	1.16	3.22	8	7	5	4
6/22	1.39	3.86	5	4	3*	2*
6/27	1.49	4.14	9	8	6	5
7/6	1.71	4.75	7	6	5	4*
7/13	1.85	5.14	8	7	6	4*
7/21	2.17	6.03	10	8	7	6*
7/31	1.93	5.36	32	28	23	18
Potato						
6/18-6/25	1.99	5.53	13	11	9	7
7/1-7/15	4.59	12.75	18	15	12	10
7/19	1.09	3.03	4	4	4	3*
7/23	1.14	3.17	4	3*	2*	2*
7/27	1.18	3.28	4	3*	3*	2*
7/31	1.21	3.36	4	4	3*	2*
8/4	1.53	4.25	5	4*	3*	3*
8/9	1.54	4.28	5	4*	4*	3*
8/14	1.52	4.20	6	6	5	4*
8/20	1.77	4.92	7	6	5	4*
8/27	1.96	5.40	8	6	5*	4*
9/5	2.00	5.56	16	14	11	9
Corn						
6/13	3.12	8.67	18	16	13	10
7/2	3.87	10.75	17	14	11	9*
7/19	4.43	12.30	21	17	14	11*
8/9	3.41	9.47	30	26	22	18

a/ The timing for no yield reduction from Table 4. 4/30 = April 30.

b/ The pivot can apply .36 acre inches per 24 hours.

c/ The number of days between irrigations less the number of days turned off. An asterisk denotes an irrigation in which not enough time is available to apply the amount of water, and yield reduction will occur unless compensating irrigations are made.

d/ The irrigation schedule filling soil to capacity after the first cutting allows for first irrigation to start on May 2.

irrigation timing and quantities for maximum yields will not be altered. The number of days available to apply without a load control program is the difference between the "dates applied" in the first column. As long as the number of days available exceeds the "number of days needed to apply," the irrigator is able to keep up with crop water needs and yields are not affected.

Under load control, the amount of time available to apply water is decreased according to how often the pump must be turned off. If the number of days available is less than the number of days needed, only the amount of water determined by the number of days available times .36 inches can be applied. Therefore, water applied does not meet water requirements, and yields will be reduced. In Table 9, an asterisk denotes periods in which crop water needs cannot be met.

Table 9 indicates that alfalfa and irrigated wheat would be able to tolerate a three-day per week load control program with no yield reduction in a year of average precipitation. Corn and beans might suffer some yield loss under a two-day week load control program, while potatoes might suffer some yield loss even under a one-day per week control program.

Potatoes are most sensitive to the load control program primarily due to a low tolerance for soil water deficits. Even with no load control, it may be difficult to irrigate potatoes to keep up with water needs in a year of below average precipitation.

Alternative irrigation strategies for the load control programs estimated to have problems meeting crop water needs are summarized in Table 10. If a soil water deficit occurs under a load control program, later irrigations may be increased or earlier irrigations may be added in order to compensate. If an irrigation deficit is found under load control, some of the deficit can be avoided by keeping the soil filled to capacity right up to the deficit period. At most, these irrigations can be increased up to the number of days available to apply from Table 9.

Table 10. Altered Timing and Quantity of Irrigations Under Load Control

Barley: Date Application Started	Barley: Inches Applied 3 days off	Bean: Date Application Started	Bean: Inches Applied 2 days off	Bean: Inches Applied 3 days off
5/13	.98	6/14	1.16	1.16
5/19	1.02	6/18	.37	.47
5/31	2.37	6/22	1.02	.62
6/11	2.03	6/29	1.49	1.69
6/23	3.08	7/4	.01	.40
7/12	.33	7/6	1.70	1.36
total	9.82	7/13	1.85	1.36
		7/21	2.17	2.03
		7/31	1.93	2.64
		total	11.70	11.79

Potato: Date Application Started	Potato: Inches Applied 1 day off	Potato: Inches Applied 2 days off	Potato: Inches Applied 3 days off	Corn: Date Application Started	Corn: Inches Applied 2 days off	Corn: Inches Applied 3 days off
6/18-6/25	1.99	1.99	1.99	6/13	3.12	3.12
7/1-7/15	4.59	4.59	4.59	6/26	.14	.84
7/19	1.09	1.09	1.02	7/2	3.73	3.05
7/21	.27	.27	.27	7/19	4.43	3.72
7/23	1.03	.69	.69	8/9	3.41	3.41
7/27	1.03	1.03	.69	total	14.83	14.14
7/31	1.21	1.02	.68			
8/3	1.53	1.27	1.27			
8/5	.18	0	0			
8/9	1.36	1.36	1.02			
8/14	1.52	1.69	1.35			
8/20	1.82	1.68	1.34			
8/27	1.96	1.66	1.33			
9/5	2.00	2.67	3.32			
total	21.58	21.01	19.56			

The crop evapotranspiration model is used to evaluate the effect of the altered irrigation strategies on crop yield (Table 11). For corn under the two-day off strategy and potatoes under the one-day off strategy, compensating irrigations are adequate so that yields are not reduced.

Table 11. Estimated Yield Per Acre Under Load Control[a/]

	No Load Control	1 Day Off	2 Days Off	3 Days Off
Wheat (bu)	70	70	70	70
Alfalfa (ton)	5.5	5.5	5.5	5.5
Barley (bu)	80	80	80	78.39
Potato (cwt)	250	250	245.81	229.98
Corn Silage (ton)	22	22	22	20.31
Dry Bean (cwt)	20	20	20	20

a/ From crop evapotranspiration-yield model.

For the irrigator, the economics of participating in a load control program depends on the value of any reduction in yields versus cost savings due to reductions in the demand charge. A partial budgeting approach is used to determine how much the Rural Electric Company would have to reduce the demand charge to provide irrigators with the incentive to participate in the program.

Estimates of the value of yield reductions under alternative load control programs are given in Table 12. The values were obtained by multiplying the yield difference between no load control and the load control program by the respective crop prices.

As the irrigation quantities applied under load control are reduced from the optimal quantities of Table 4, some savings accrue in variable irrigation expenses. Table 13 provides these dollar figures for the base scenario for low pressure systems. Any reductions in variable harvest and fertilizer costs are not included. Since maximum yields are attained by all crops under

Table 12. Value of Yield Reductions Per Acre Under Alternative Load Controls Using 1972 to 1983 Average Adjusted Crop Prices[a]

	$ Per Acre		
	1 Day Off	2 Days Off	3 Days Off
Wheat	0	0	0
Alfalfa	0	0	0
Barley	0	0	4.25
Potato	0	19.27	92.09
Corn Silage	0	0	30.92
Dry Bean	0	0	0

a/ Price of wheat, alfalfa, barley, potato, corn silage and bean is $3.29, $61.00, $2.64, $4.60, $18.30 and $20.42 per unit, respectively.

Table 13. Savings in Variable Costs Under Altered Irrigation Strategies[a]

	$ Per Acre		
	1 Day Off	2 Days Off	3 Days Off
Wheat	0	0	0
Alfalfa	0	0	0
Barley	0	0	1.28
Corn Silage	0	0	4.39
Dry Bean	0	0	0

a/ Based on $.04499/kwh.

one-day off load control (Table 11), participation should be economical in normal years. In years of poor precipitation or high temperatures, potato growers might find participation to be non-economic.

The reduction in demand charge necessary to provide the incentive for irrigators to participate in a load control program is provided in Table 14. Each non-zero figure is the value of yield loss less variable cost savings per acre, times 125 acres divided by 76.6 hp (low pressure pump). A 76.6 hp motor under low pressure is equivalent to about 57.1 kilowatts (kw). Each day of turn off results in a 1/7 reduction in load or 8.1 kw. This in turn results in a savings to Rural Electric of $12.77 per kw which is $103.43 per month per

Table 14. Reduction in Demand Charge Necessary to Provide Incentive for Load Control Program Participation

	$ Per Horsepower		
	1 Day Off	2 Days Off	3 Days Off
Wheat	0	0	0
Alfalfa	0	0	0
Barley	0	0	4.84
Corn Silage	0	0	43.29
Dry Bean	0	0	0

pivot or $1.36 per month per hp. As the irrigation season extends about six months, maximum reduction in the demand charge per hp should equal $8.16 (6 x $1.36).

The analysis suggests that the current voluntary load control program offered by rural Electric may provide irrigators unjustifiable savings, especially since irrigators would sometimes turn off their pivots regardless of the load control program. Savings that could be passed on to irrigators would depend on the dispersion of these turn offs over a week and consequent measured kwh of demand by T.S.G.T.A. Also, the six month irrigation season is probably too long to calculate reductions in the demand charge. Crop seasons vary from about 110 days (beans) to about seven months (alfalfa).

An alternative way to assess the effect of participation in a load control program is to compare net incomes for the individual irrigator between participation and nonparticipation. Table 15 presents results from the L.P. for such a comparison. As mentioned before, the demand charge for the non-participant is $18.00 per rated hp for the first 25 hp used and $33.29 per rated hp for hp in excess of 25. The demand charge for a participant is $18.00 per rated hp for each hp used.

A comparison of the results indicates the economic advantage of the load control program. While the crop mix remains the same in both cases, returns

Table 15. Results of Linear Programming Model for Participation and Non-Participation in Voluntary Loan Control Program.*

Scenario Number	Year	Depth to Water	Demand Charge 1st 25 hp	Demand Charge Excess 25hp	$ Max. Return	acres in crops: bean	alfalfa	feed barley	corn silage	dryland wheat
PARTICIPATION										
25	1984	110	18.00	18.00	12,960.72	83	333	83	0	0
26	1994	125	18.00	18.00	11,156.74	83	333	83	0	0
27	2004	140	18.00	18.00	9,352.86	83	333	83	0	0
NON-PARTICIPATION										
28	1984	110	18.00	33.29	10,460.11	83	333	83	0	0
29	1994	125	18.00	33.29	8,472.27	83	333	83	0	0
30	2004	140	18,00	33.29	6,482.94	83	333	83	0	0

*For a low pressure center pivot system

decline at a faster rate for farmers not participating in the load control program. By 2004 returns are $6,482.94 for non-participants compared to $9,647.74 for participants, a 34% savings. In 1984, the savings are $2,776 or 21%. The savings are a consequence of reduced demand charge due to the one-day turn-off through the load control program.

In the final analysis, the best load control programs offered by a utility should be based on the rate structure charged the utility by the wholesale supplier, implementation costs, potential savings and customer response. If peak load problems suggest particular programs which may account for substantial cost savings, the utility should then estimate implementation costs and probase maturation rates through close consultation with irrigators. Nonetheless, given the current structure of Rural Electric's load control program and current conditions for farmers, results from this analysis suggest that participation in a load control program with at least one day per week turn-off should be economical for producers. For wheat and alfalfa, up to three days off per week might be economical for participants. For barley and corn-silage, two days might be acceptable.

3. Current Rate Structure

It should be noted that Rural Electric, the retail supplier of electricity for Laramie County has recently received a one-cent discount per kwh from T.S.G.T.A. This discount is being passed directly on to irrigators making the kwh charge 3.5 cents rather than 4.5 cents as of May, 1985.

In order to receive the discount, it is required that Rural Electric not offer a reduction in the demand charge through a load control program and thus for the year beginning May, 1985 Rural Electric has discontinued its load control program. Since the new rate structure is being implemented on a trial basis, the above analysis on load control is not entirely obsolete. If it is not economically feasible for Rural Electric to reduce the kwh charge a load control program may reappear in the future.

Table 16 provides results of the L.P. when considering the new rate structure. In passing on the one-cent discount to customers, Rural Electric did increase the demand charge from $18.00 to $21.50.[3/] Since no load control program is offered however, this charge is for all horsepower used.

The results indicate the economic advantage of the new rate structure. Scenario 4 (Table 6, pg. 19) shows net returns for a farmer participating in the load control program in 1984. As can be seen, however, lowering the kwh rate one cent and increasing the demand charge $3.50 serves to reduce pumping costs even further than the load control program. A comparison of Scenarios 5-6 and Scenarios 32-33 shows that this holds true for subsequent years. In 1984 returns are 15% higher with the new rate structure. Returns are 15% higher in 1994 and in 2004 they are 19% higher.

In Table 6 an analysis was done assuming no increase in electricity prices. Results indicated that by 2004 the farm remained in full production although returns declined by 28%. Given the reality of a reduction in the kwh charge, the assumption of constant electricity prices does not appear to be overly optimistic. If that holds true, this study would predict that most farmers in southeastern Wyoming should be able to survive for at least the next twenty years even with a declining groundwater table.

It must be remembered, however, that net return figures in this study are returns to land and management. No allowance has been made for debt in the analysis. Consequently, conclusions drawn about the viability of irrigated production are contingent on an irrigator's debt position. While certain

---

3/ The 1985 rate was $19.26. However, the 1984 rate of $18.00 was used as a basis of analysis in this study.

Table 16. Results of Linear Programming Model Considering Change in kwh Charge, May 1985.

Scenario	Year	Depth to Water	Electricity Costs $ Per kwh	Electricity Costs $ per hp	$ Max Return	Acres in Crops Bean	Acres in Crops Alfalfa	Acres in Crops Feed Barley	Acres in Crops Corn Silage	Acres in Crops Dryland Wheat
4	1984	110	.045	$18.00	12,960.72	83	333	83	0	0
5	1994	125	.045	18.00	11,156.74	83	333	83	0	0
6	2004	140	.045	18.00	9,352.86	83	333	83	0	0
31	1984	110	.035	$21.50	15,193.29	83	333	83	0	0
32	1994	125	.035	21.50	13,532.82	83	333	83	0	0
33	2004	140	.035	21.50	11,872.27	83	333	83	0	0

management strategies may increase profitability, the improvement may still not be sufficient to cover land interest charges or other debt obligations. In this analysis, predictions concerning how long an irrigator can stay in production are based on the assumption that the irrigator owns his land in full.

D. Potato Farm Analysis

The potato case farm varies from the grain-forage farm in several ways. A primary difference is in size, with the potato farm having six center pivots instead of four.

With the grain-forage farm it was necessary to define a dry bean rotation since dry beans was the most profitable crop. From the breakeven prices of Table 2, potatoes appear to be very profitable. Consequently, a rotation is included which allows potatoes to be grown on the same ground once every three years. Potatoes are sensitive to disease so this rotation reflects real conditions.

Table 17 provides results of the analysis of low-pressure pivot scenarios for the potato case farm. The model "chooses" to grow dry beans to the maximum of 94 acres and irrigated wheat in the rotation with potatoes in all scenarios. Even at a 6% annual increase in energy prices, potato farming continues to be profitable in 2004.

Scenarios 37 and 38 allow for a 10% reduction in irrigation water applied. Two ways of making the 10% reduction were tried. In Scenario 37 the 10% reduction was made during the first growth stage of the crops (see Appendix 1, Table 5). Any irrigation amounts from Table 4 (Page 16) falling within the first growth stage of a crop would be reduced by 10%. Similarly, in Scenario 38, the 10% reduction was made during the last growth stage of the crops.

Table 17. Results of Linear Programming Model for Potato Farm; 1973-82 Average Adjusted Prices, Low Pressure Pivots

Scenario Number	Year	Depth to Water	Elec. Costs ¢ per kwh	Elec. Costs $ per hp	Efficiencies pump	Efficiencies application	$ Max Return	Acres in Crops Potato	Acres in Crops Dry Beans	Acres in Crops Irrig. Wheat	
34	1984	110	4.5	18.00	70	85	112,458.17	250	94	406	
35	1984	110	4.5	18.00	70	80	110,491.08	250	94	406	
36	1984	110	4.5	18.00	60	80	105,856.06	250	94	406	
37	1984	110	4.5	18.00	70	85	47,811.38	250	94	406	10% first
38	1984	110	4.5	18.00	70	85	90,393.81	250	94	406	10% last
39	1994	125	5.48	21.94	70	85	103,379.14	250	94	406	
40	1994	125	6.66	26.64	70	85	95,684.92	250	94	406	
41	1994	125	8.06	32.24	70	85	86,490.82	250	94	406	
42	2004	140	6.69	26.75	70	85	92,006.81	250	94	406	
43	2004	140	9.86	39.44	70	85	69,882.66	250	94	406	
44	2004	140	14.43	57.73	70	85	37,990.07	250	94	406	

Between the two approaches, results indicate that reducing water by 10% during the last growth stage resulted in the least reduction in net returns. However, in both cases returns are significantly reduced from levels when full irrigation amounts are applied. This suggests that timely irrigations are important in producing potatoes.

The apparent profitability of potatoes does not reflect the intensity of management needed on this crop. As stated earlier, production costs do not include management and land interest charges which are particularly important with regard to potatoes. Potato farmers may be utilizing marketing and packaging skills and production information and experience that is not reflected in the estimated production costs. However, the farmer who can produce and market potatoes should have a significant advantage over farmers growing other crops.

E. Predicted vs. Actual Crop Mix

It is interesting and informative to make some comparisons between the results of this analysis and actual crop acreages and returns for farms in Laramie County. Although predicted returns to land and management vary according to different conditions assumed, the suggested crop mix remained consistent for most of the scenarios considered. Apparently, the profitability of alfalfa was large enough to withstand increasing costs due to increases in depth to water and electricity prices. For nearly all scenarios, the results indicate that the most economical crop mix is one where 70% of the irrigated land is in alfalfa. The other two predominant crops were feed barley and dry beans, however, feed barley appears because it serves as a nurse crop for alfalfa. In 1984, returns to land and management with this crop mix were predicted to be $12,960.72 (see Table 6, Scenario 4, Page 19).

A review of the mix of crops grown in Laramie County for the last ten years indicates a different distribution than the one predicted in this analysis. Table 18 shows the proportion of total irrigated acreage for the various crops produced in Laramie County. Historically, alfalfa has accounted for only 44% of the total crop mix for the area. Interestingly though, it constitutes the largest proportion of irrigated acreage for the area, a fact that lends support to the results in this study.

Table 18. Proportion of Total Irrigated Acreage Devoted to Production of Various Crops in Laramie County, WY, 1974-1983.

	1983	1982	1981	1980	1979
All Wheat	8.1	14.6	14.7	16.2	15.9
Barley	20.8	22.4	27.6	23.3	20.0
Oats	14.5	9.6	11.3	13.0	13.2
Dry Beans	6.6	9.0	10.2	9.0	11.8
Sugar Beets	.004	1.1	1.7	2.0	2.3
Corn	6.1	2.3	.003	.008	.004
Alfalfa	43.4	40.8	34.0	35.6	36.3

	1978	1977	1976	1975	1974	Ten Yr Average
All Wheat	13.1	9.3	14.8	14.7	6.8	12.8
Barley	17.8	19.1	20.7	17.6	20.0	20.9
Oats	10.3	12.8	4.7	3.5	4.6	9.8
Dry Beans	10.3	3.5	3.5	3.5	9.2	7.7
Sugar Beets	1.4	.008	4.6	6.6	5.4	2.5
Corn	4.7	2.3	1.2	1.2	1.1	1.9
Alfalfa	42.2	52.0	50.3	52.8	52.7	44.0

Using the historical figures on the percent of irrigated land devoted to the various crops, an estimate of returns can be made using the L.P. model. The program would restrict the crop mix to that shown by historical data. For the prices and costs of production assumed in this analysis, a farmer having a crop mix of 44% alfalfa, 21% feed barley, 23% winter wheat,[4/] and 12% dry beans, returns are estimated by the L.P. to be $2591.85, which is only 20% of the estimated returns of the crop mix where 70% alfalfa is grown.

This estimate may be biased downward by the fact that statistics used for actual crop data were county averages which include acreage for both surface irrigation and center pivot irrigation. Crop acreage irrigated with center pivot sprinkler systems, however, may have higher proportions of the more intensively managed crops such as alfalfa and dry beans than the county averages indicate. Because these crops also have higher than average returns per acre, actual returns are likely to be higher than the estimated figure of $2,591.85. Nonetheless, there is a substantial difference between the net return based on the predicted crop mix from this analysis and the net return based on the average crop mix for Laramie County.

Such a difference suggests that for some farmers profitability could be improved through increased production of alfalfa and dry beans or perhaps introduction of new crops with higher profitability. Given the possibility of a new Anheuser-Busch brewery being built near Fort Collins, malt barley may be a potentially profitable crop. Also, Table 2 (Page 14) indicates that for both feed barley and winter wheat, the actual price is below the break-even

---

4/ Because oats was not a crop considered in this study, its proportion of total acreage was combined with winter wheat. While their respective prices may differ it seems reasonable to assume their water requirements are comparable. Because oats tend to be a less profitable crop than winter wheat, combining the two in the linear program would overstate the estimated return figure and thus, if anything, would make irrigators' financial situation appear better than it actually is.

price and thus any acreage of these crops grown is realizing a negative net return. Unless prices improve for these two crops in the near future, it might be wise for the producer to consider an alternative nurse crop for alfalfa if feed barley is being used as well as a substitute crop for wheat.

In addition, consideration must be given to the dynamic element of crop production. While the model suggests that for the individual farmer planting 70% of irrigated land in alfalfa would optimize returns, the collective impact from all farms in the area may serve to depress the price of alfalfa and in turn, decrease its profitability. Under these circumstances, a new crop mix could result and accordingly, a new level of returns. As stated earlier, the results of this study are contingent on the assumption of constant relative prices for crops. If demand/supply conditions alter this assumption, it follows that results are likely to change.

Table 19 presents results from a simplistic analysis which takes into account changes in the price of alfalfa that may come about due to supply conditions by 1994, assuming alfalfa acreage is increased as prescribed by this analysis. Ideally, a statistical relationship between quantity and price should be estimated. However, the complexity of such an estimate is beyond the scope of this study. Instead, the price of alfalfa was arbitrarily lowered to the estimated breakeven price, $50.34 (Table 2, Page 14) and also to a price halfway between the current price and the breakeven price, $55.67.

Not surprisingly, at the breakeven price no alfalfa is grown. The same holds for the price of $55.67, even with no increase in electricity prices. Also, returns decrease substantially with these two reductions in price.

Equally significant is the resulting crop mix when reductions in the price of alfalfa are considered. The results show, with only a 9% decrease in the price of alfalfa (i.e. $55.67), and with zero percent increase in

Table 19. Results of Linear Programming Model For Alternative Alfalfa Prices.

Scenario Number	Year	Price of Alfalfa	% Electricity Cost Increase	$ Max Return	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
45	1994	$50.34	0%	4562.39	83	0		42	480
46	1994	$55.67	0%	4562.39	83	0		42	480
47	1994	$50.34	2%	3624.56	83	0		42	480
48	1994	$55.67	2%	3624.56	83	0		42	480

electricity prices, by 1994 the predominant crop grown will be dryland wheat. Thus is appears that supply and demand conditions would mitigate the prescribed increase of alfalfa in this study. Although dry beans and corn silage do enter as profitable crops, earlier results suggest that further increases in electricity costs due either to declining groundwater levels or increases in electricity prices threaten the viability of these crops also. Such sensitivity to changes in crop prices indicates the tenuous position many farmers are in.

Demand and supply conditions notwithstanding, the results of this study suggest that profitability would be improved through increased production of alfalfa. While it may not be feasible for all farmers to increase their alfalfa acreage, for those who can, the change may help to lessen the burden of the impact of declining groundwater levels.

F. Water Restriction Policy

1. Introduction

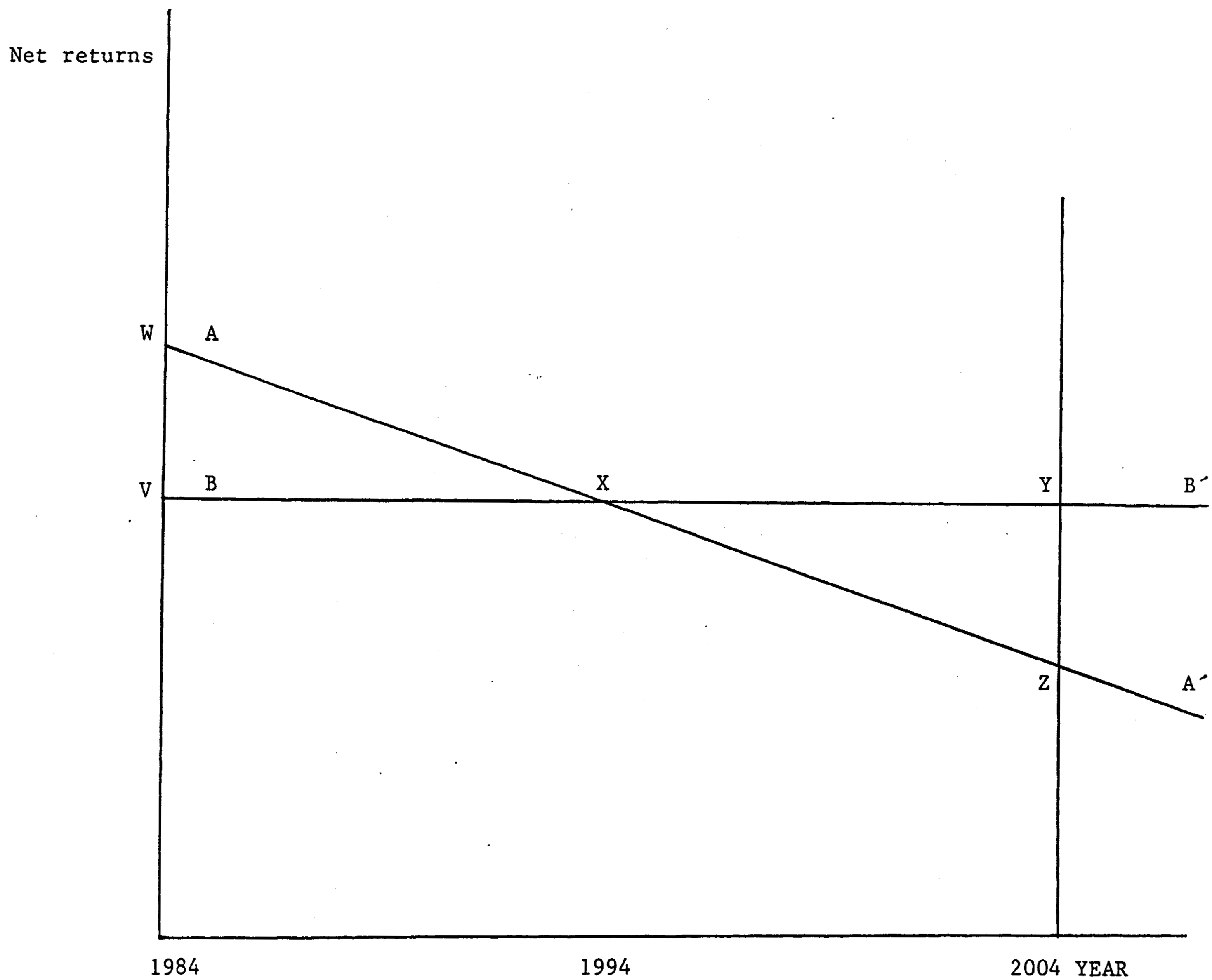
Groundwater has generally been classified as a "common pool resource." A common pool resource is characterized by a number of individuals having access to a resource but no one having the right to exclude another from the use of it. The problem arising with a common pool resource is that the collective action of people using the resource can result in the resource being depleted too rapidly. There is no incentive for one person to refrain from using the resource because others will continue to use it. As a result, the resource may not be available for use in the future. Thus, common property resources tend to discourage individuals from conserving a resource for future use as there is no guarantee to the individual that foregoing use of the resource will result in availability of the resource in the future.

In the case of groundwater reserves in Laramie County, the collective action of individual irrigators has resulted in groundwater withdrawals exceeding recharge of the aquifer. As a consequence, the groundwater level in different areas of the county is declining at a rate of 1-4 ft per year. As stated earlier, a declining groundwater level has placed added economic pressure on farmers by raising the costs of pumping water for irrigation. Increasing well depths coupled with increases in electricity prices have threatened the viability of irrigated farming in the area. In considering this situation, the state engineer's office does have the authority to impose a water restriction policy. The goal of such a policy might be to restrict water use so that the quantity of water withdrawn would equal recharge rates. This should insure the availability of groundwater in the future and in turn, may help extend the life of irrigated farming in the area.

What is of interest from an economic standpoint is how such a restriction would affect farm income, both individually and for the area. When water is restricted a trade-off between present and future income takes place. Under a restriction policy, farmers forego some amount of water use so that water will be available further into the future than would be the case if water was not restricted. Restricting the amount of water used usually has two effects on net income. Initially, income would decline if the value of the reduction in yield from using less water is greater than the savings in pumping costs. However, in later years, revenue under a restriction policy is likely to be greater than income generated in the absence of a restriction policy due to increased groundwater levels lowering pumping costs. The question is then, will the revenue gained under a restriction policy be greater than revenue sacrificed? Figure 1 displays this question graphically.

In Figure 1, Line AA' represents a net income stream for an irrigator in the absence of a restriction policy. As well depths decline pumping costs

Figure 1.



increase over time. If all other factors remain constant, income steadily declines. Line BB' represents a net income stream when water is restricted so that recharge equals withdrawal. Due to a constant depth to water, all other factors remaining the same, pumping costs do not change and thus income would not change. As can be seen, at some point (X) increases in pumping costs due to a declining groundwater level cause a greater reduction in income than does the loss in yield from applying less water under a restriction policy.

Graphically, the question becomes, is triangle XYZ (revenue gained with a restriction policy) greater than triangle WXV (revenue sacrificed with a restriction policy). To answer this question, the net present value (NPV) of each income stream must be calculated and compared. If the NPV of the income stream with a restriction policy is larger than the income stream without a restriction policy, the revenue gained in future years is greater than income foregone in the early years and vice versa.

In this section, two alternative ways of restricting water are discussed and an economic analysis of these policies is conducted. The NPV of an income stream is affected by both the discount rate used and the time period considered. Consequently, the analysis will assess the impact of the restriction policies for three discount rates and for twenty and forty-year time horizons.[5/] The analysis will use the net income for the representative case farm modeled in this study as a proxy for income to the entire area.

5/ The discount rate should be equivalent to the rate of interest an individual could borrow or lend funds at. Relative prices and non-electricial costs have been assumed constant in this study and thus inflation rates are assumed to average out over time. Consequently, the discount rates used in this analysis are intended to reflect real rates of interest in the future. The before-tax real rate of interest for agriculture for the last twenty years has been estimated at 3% (see Holland, 1984). Thus rates of 2% 4% and 6% are used in this analysis to account for any potential fluctuation.

Thus, if the NPV of returns for the representative farm is greater under the restriction policy versus no public policy, government action is deemed beneficial. As mentioned before, for returns to be greater under the restriction policy, savings in electricity costs arising from a reduction in the quantity of water pumped and a constant groundwater level would have to outweigh the value of additional yield obtained by applying larger irrigation amounts in the absence of a restriction policy.

2. Implementation

a. Restriction on Pumping

The first restriction policy analyzed is one that has been discussed by the state engineer's office. With this policy, restrictions on groundwater used would be based on the priority date of a well. Specifically, farmers whose priority date for a well was after 1980 would have to reduce water use by 30%; farmers with wells having a priority date between 1970 and 1980 would have water use restricted by 20%; irrigation wells established between 1960 and 1970 would be restricted by 10%; and farmers having wells with priority dates before 1960 would face no restriction on water use. Based on current water usage, this policy should reduce groundwater use such that recharge rates would be approximately equal to withdrawal rates.[6/]

6/ A U.S. Geological Survey estimated that between 1971 and 1977 discharge from the Ogallala Aquifer exceeded recharge by approximately 20% (Crist, 1980). Due to the difficulty of measuring groundwater it has been emphasized this is a rough estimate. The proposed restriction policy would result in approximately a 14% reduction in water use (i.e. if water use were 100 acre feet for each well priority group, imposition of a restriction policy would result in water use of 100 + .9(100) + .8(100) + .70(100) = 340 acre feet versus 400 acre feet in the absence of a restriction policy, about a 14% reduction). No recent study has been done updating the 1971-77 estimate. Because there has been a significant reduction in wells established since 1980, it is likely that the percentage difference between recharge and discharge has not changed substantially. Thus, the reduction resulting from the restriction policy seems to be a fair approximation of the amount necessary to equalize recharge and withdrawal rates.

If water is restricted, the farmer has several options to meet the restriction requirements. The first option is to use less water on all irrigated crop acreage. The second option is to take some amount of land out of production and use optimal irrigation amounts on the land remaining in production. A third option would be to use some combination of less water and land. As an example, suppose a farmer was using 1000 acre feet of water on 200 acres of land, which is equivalent to 5 acre feet per acre. If he was forced to restrict water use by 20%, he could either irrigate all 200 acres with 800 acre feet of water (4 acre feet per acre), or, he could irrigate 160 acres with the 800 acre feet of water (5 acre feet per acre), or some combination in between with both reduced land and water could be used to meet the restriction requirements.

With the first option, the farmer will likely face reduced yields as a result of using less water on all acreage. With the second option, maximum yields would be maintained but on only 80% of the land. The third option should result in higher yields per acre than the first option but on a smaller amount of land. Which option is chosen depends on which results in the smallest loss in net returns.

L.P. runs were made placing restrictions on water use, on land, and combinations thereof for the 500 acre case farm.[7/] A comparison was then made to see which resulted in the highest return. Table 20 presents results from the L.P. for the three restriction amounts, i.e. 10%, 20%, and 30%.

As can be seen from the table, when water was reduced on all crop acreage, two approaches were used. One way was to reduce water by a certain

---

7/ Due to limitations of the Linear Program, no combination of a reduction in land and water was considered for the 10% reduction in water.

Table 20. Various Strategies For a Percentage Reduction in Water.

% Reduction	Strategy for Reduction Water reduced equally among all application amounts	Water reduced during least affected growth stage	Reduction in land-full water	Restrict Land 10% Restrict water 10%	Restrict Land 10% Restrict water 24%	Restrict Land 20% Restrict water 12%
10%	Returns=$9539.01 Barley - 83 Beans - 83 Alfalfa-333	Returns-$7704.92 Barley - 83 Beans - 83 Alfalfa-333	Returns=$11,351.04 Barley - 73 Beans - 73 Alfalfa-292			
20%	Returns=$3766.09 Barley - 83 Beans - 83 Alfalfa-333	Returns=$2029.11 Barley - 83 Beans - 83 Alfalfa-333	Returns=$9741.35 Barley - 50 Bean - 94 Corn - 21 Alfalfa-208	Returns=$8346.63 Barley - 73 Bean - 73 Alfalfa-292		
30%	Returns= $83.20 Dryland wheat = 640	Returns= $83.20 Dryland wheat = 640	Returns= $8131.65 Barley - 38 Bean - 94 Corn - 28 Alfalfa-153		Returns=$1015.65 Barley - 73 Bean - 73 Alfalfa-292	Returns=$8097.84 Barley - 63 Bean - 63 Alfalfa-250

percentage amount and distribute the reduction equally among all irrigation amounts. The second approach taken was to make the entire percentage reduction during the growth stage of the crops that affected yields least (see Appendix 1, Table 4). For example, referring back to Table 4 (page 16), the optimal irrigation amount for wheat was ten inches. A 10% reduction in water would be one inch. Either each of the three application amounts could be reduced by one-third of one or, because wheat yields are least sensitive to reductions in water between the plant and vegetative stages, all of the one inch could be deducted from the first application amount.[8/]

A comparison of the two approaches to reducing water on all the existing irrigated acreage indicates returns are highest when the reduction is distributed equally among all application amounts. Apparently making the entire reduction during the least affected growth state reduced yields more than distributing the reduction equally among all application amounts. However, if water is to be reduced, results show the farmer would be better off by taking the respective amount of land out of production. Thus, losses due to reduced yields by applying less water on all acreage, or through some combination of reducing water and reducing acreage, were greater than losses due to a reduction of yields from taking the appropriate percentage of land

---

8/ In reality, it is unlikely that an irrigator would make the entire reduction on water during one stage of plant growth. Due to the limitations of the model, however, the approach was the best approximation to an irrigator's attempt to reduce water at the least sensitive time.

out of production.[9/] The economic analysis of the proposed restriction policies then, is based on the assumption that farmers will reduce their irrigated acreage to meet water restriction requirements.

In addition to determining which means of reducing water is best under a restriction policy, the results suggest that, in the absence of a restriction policy, the farmer would be better off to apply full irrigation amounts rather than reduce water to try to save money through lower pumping costs. The 1984 returns for the case farm when full irrigation amounts were applied were $12,960.72 (see Table 6, Scenario 4, pg. 19). This means that, based upon prices and yield response functions used in this study, the reduction in water decreased returns because of lower yields more than it reduced pumping costs because of less water used. Thus, if a water restriction policy is not implemented, this analysis suggests that voluntary reductions in water of 10% or more would not help maintain profitability for the farm unit, at least in the short run.

b. Calculating Net Income

In assessing the impact of the water restriction policy on the income of individual producers and the area, the analysis continues to use the 500 acre case farm. L.P. runs were made for the farm restricting land by 10%, 20%, and

---

[9/] Because the linear program is designed to take half-pivots out of production (i.e. 62.5 acres) when irrigated land is reduced in some manner, an exact 10%, 20% and 30% reduction is not possible. Thus, in the analysis, a 10% reduction is approximated by taking one half-pivot out of production which is really a 12.5% reduction in land (62.5/500). Similarly, the 20% reduction is approximated by taking two half-pivots out, a 25% reduction in actuality. The 30% reduction is represented by taking three half-pivots out of production which is really a 37.5% reduction. Also, the assumption is made that when a half-pivot is taken out of irrigated production it is put into dryland wheat production. Thus, any returns calculated for a restriction on water will include revenue generated from dryland wheat acreage.

30%. Table 21 presents the net income figures for the years 1984-2004 when these restrictions are imposed. The income figures were calculated for electricity price increases of 0%, 2% and 4%.

The figures in Table 21 then represent income streams of farmers when forced to restrict water by a certain amount. The column where a constant depth to water is assumed represents the income stream for the farm whose well priority date was before 1960 and therefore faces no restriction on water. He benefits from the constant groundwater level resulting from the water restriction policy.

As can be seen from Table 21, when the restriction policy is imposed, and no increases in electricity prices are assumed, farmers' incomes remain constant from year to year. As discussed before, this is due to the constant groundwater level resulting from the restriction policy. When increases in electricity prices are assumed, income figures for the restriction amounts decline each year by the respective increases in pumping costs.

Thus, in 1985, assuming no increase in electricity prices, net returns for a farmer facing a 10% restriction on water would decline by 11%. Net returns for farmers having to restrict water by 20% would decline by 24% and farmers facing a 30% restriction would experience a 36% decline in net returns. For a 2% and 4% increase in electricity prices returns decline by approximately the same percentage amounts in 1985.

Table 22 displays the NPV of income streams for the respective restriction amounts considering electricity price increases of 0%, 2%, and 4%. As stated earlier, to determine whether a restriction policy should be implemented, it is the net present value of the income stream that is of interest. The NPV figures for the restriction amounts in Table 22 are for the income streams in the last four columns of Table 21. For comparison, the NPV

Table 21. Net Income Figures of 500 Acre Farm for Various Restrictions on Water Use, 1984-2004, No Increase in Electricity Prices.

Year	No Restriction-Depth to Water Declines At 1.5 ft/yr	No Restriction-Constant Depth to Water	10% Restriction	20% Restriction	30% Restriction
1984	12,960.72	12,960.72	11,351.04	9741.35	8131.65
1985	12,779.16	12,960.72	11,351.04	9741.35	8131.65
1986	12,599.25	12,960.72	11,351.04	9741.35	8131.65
1987	12,419.38	12,960.72	11,351.04	9741.35	8131.65
1988	12,239.42	12,960.72	11,351.04	9741.35	8131.65
1989	12,057.93	12,960.72	11,351.04	9741.35	8131.65
1990	11,878.05	12,960.72	11,351.04	9741.35	8131.65
1991	11,698.06	12,960.72	11,351.04	9741.35	8131.65
1992	11,516.61	12,960.72	11,351.04	9741.35	8131.65
1993	11,336.70	12,960.72	11,351.04	9741.35	8131.65
1994	11,156.74	12,960.72	11,351.04	9741.35	8131.65
1995	10,975.26	12,960.72	11,351.04	9741.35	8131.65
1996	10,795.40	12,960.72	11,351.04	9741.35	8131.65
1997	10,615.39	12,960.72	11,351.04	9741.35	8131.65
1998	10,435.54	12,960.72	11,351.04	9741.35	8131.65
1999	10,254.05	12,960.72	11,351.04	9741.35	8131.65
2000	10,074.09	12,960.72	11,351.04	9741.35	8131.65
2001	9894.18	12,960.72	11,351.04	9741.35	8131.65
2002	9712.73	12,960.72	11,351.04	9741.35	8131.65
2003	9532.74	12,960.72	11,351.04	9741.35	8131.65
2004	9352.86	12,960.72	11,351.04	9741.35	8131.65

Table 21 Continued - 2% Increase in Electricity Prices

Year	No Restriction- Depth to Water Declines At 1.5 ft/yr	No Restriction- Constant Depth to Water	10% Restriction	20% Restriction	30% Restriction
1984	12,960.72	12,960.72	11,351.04	9,741.35	8,131.65
1985	12,384.83	12,568.22	11,007.06	9,447.00	7,547.37
1986	11,801.91	12,174.11	10,662.74	9,151.40	6,963.17
1987	11,180.64	11,746.22	10,228.34	8,830.50	6,378.97
1988	10,585.07	11,349.02	9,940.79	8,532.50	5,794.77
1989	9,979.30	10,948.51	9,590.34	8,232.20	5,210.57
1990	9,333.03	10,514.21	9,210.33	7,906.50	4,626.37
1991	8,643.94	10,042.94	8,797.97	7,553.00	4,042.17
1992	7,982.57	9,605.45	8,415.20	7,224.90	3,457.97
1993	7,277.96	9,132.45	8,001.30	6,870.10	2,873.77
1994	6,598.28	8,688.55	7,612.90	6,537.20	2,289.56
1995	5,874.94	8,209.29	7,193.50	6,177.70	2,067.91
1996	5,107.38	7,696.09	6,744.50	5,792.80	1,846.23
1997	4,368.09	7,213.50	6,322.20	5,430.90	1,624.55
1998	3,580.98	6,694.04	5,867.70	5,041.30	1,402.87
1999	2,787.16	6,174.45	5,413.10	4,651.60	1,181.19
2000	1,980.16	5,648.49	4,952.80	4,257.10	959.51
2001	1,164.93	5,124.10	4,494.00	3,863.90	737.83
2002	302.23	4,561.17	4,001.40	3,441.60	516.15
2003	83.20	3,998.19	3,508.80	3,019.40	294.47
2004	83.20	3,428.72	3,010.50	2,592.30	72.80

Table 21 Continued - 4% Increase in Electricity Prices

Year	No Restriction- Depth to Water Declines At 1.5 ft/yr	No Restriction- Constant Depth to Water	10% Restriction	20% Restriction	30% Restriction
1984	12,960.72	12,960.72	11,351.04	9,741.35	8,131.65
1985	11,918.48	12,041.26	10,532.08	9,055.34	7,547.37
1986	10,876.22	11,129.88	9,714.15	8,369.36	6,963.17
1987	9,833.96	10,214.50	8,896.22	7,683.88	6,378.97
1988	8,791.69	9,299.12	8,078.29	6,997.40	5,794.77
1989	7,749.44	8,383.74	7,260.36	6,311.42	5,210.77
1990	6,707.18	7,468.36	6,442.43	5,625.44	4,626.37
1991	5,664.91	6,552.98	5,624.50	4,939.46	4,042.17
1992	4,622.65	5,637.60	4,806.51	4,253.48	3,457.97
1993	3,580.39	4,722.22	3,988.64	3,567.50	2,873.77
1994	2,538.13	3,806.83	3,170.71	2,881.52	2,289.56
1995	2,292.61	3,434.44	2,860.90	2,599.59	2,067.91
1996	2,047.12	3,062.08	2,551.11	2,317.68	1,846.23
1997	1,801.63	2,689.72	2,241.32	2,035.77	1,624.55
1998	1,556.14	2,317.36	1,931.53	1,753.86	1,402.87
1999	1,310.65	1,945.00	1,621.74	1,471.95	1,181.19
2000	1,065.16	1,572.64	1,311.95	1,190.04	959.51
2001	879.67	1,200.28	1,002.16	908.13	737.83
2002	83.20	827.92	692.37	626.22	516.15
2003	83.20	455.56	382.58	344.31	294.47
2004	83.20	83.20	72.80	62.40	52.00

Table 22. Net Present Value of Returns for 500 Acre Farm Under Water Restriction Policy Based on Well Priority Dates, 1984-2004.

			NPV of Net Returns				
Scenario	Discount Rate	% Increase in Electricity Prices	No Restriction-Constant Depth to Water	10% Restriction	20% Restriction	30% Restriction	No Restriction Policy-Depth to Water Declines at 1.5 ft/yr
49	2%	0	211,971.89	184,589.29	157,206.49	129,824.20	192,005.40
50	4%	0	174,813.42	152,231.02	129,648.42	107,065.62	160,113.60
51	6%	0	146,588.87	127,652.47	108,715.97	89,779.32	135,669.10
52	2%	2%	141,913.99	123,288.29	104,662.59	68,341.48	117,098.70
53	4%	2%	121,654.52	105,716.82	89,778.88	58,093.23	103,313.70
54	6%	2%	105,668.97	91,847.35	78,025.70	52,054.49	91,986.00
55	2%	4%	90,726.23	79,502.95	68,398.47	51,615.50	81,984.74
56	4%	4%	82,663.52	71,908.91	61,839.42	46,647.86	74,604.14
57	6%	4%	74,694.28	65,449.07	56,265.39	42,440.34	68,285.88

figures of income streams for the 500 acre farm in the absence of a restriction policy are also presented in Table 22. These NPV figures are for the income streams associated with the first column of Table 21.

A comparison of the NPV figures for a restriction policy and those for a non-restriction policy indicates that, in most cases, farmers with wells established after 1960 (i.e. farmers required to restrict water use) would be better off financially without a restriction on water. Exceptions to this conclusion are for the farmer facing a 10% restriction on water and an electricity price increase of 2% annually. In this case, the farmer would be better off financially under a restriction policy with discount rates of 2% and 4% (see Scenarios 52 & 53). A farmer with a well established before 1960 faces no restriction on water and thus benefits in all cases under the restriction policy given the criterion of greater NPV.

In reality, however, actual restrictions on water are not likely to be as straightforward as indicated above. In fact, an irrigator could face all four options under the restriction policy. It is possible for one farmer to have a number of different wells, each with a different priority date. Consequently, he would face different restrictions on water on different parts of his land. The income figures in Table 21 are for a 500 acre farm with all the irrigated land being in one of the four categories of restrictions on water use. In actuality, a farmer's income stream may be some combination of each of the income streams in Table 21 when a restriction policy is imposed. Because of differences in the size of farm units and restriction combinations faced by irrigators, the percentage decline in returns listed above are perhaps better indications of the impact of the restriction policy on income per acre rather than on overall income streams for individual farmers.

Since it is likely that an irrigator would face some combination of restriction amounts, it would be more meaningful to calculate a NPV income figure for a "composite" farm. This income figure is calculated by taking a weighted average of the NPV income figures in Table 22 based on the amount of acreage irrigated under the specified well priority dates. Data from the state engineer's office indicate that 23% of the irrigated land in the water control area in Laramie County is irrigated by wells established before 1960; 16.5% is irrigated by wells established between 1960 and 1970; 60% is irrigated by wells established between 1970 and 1980; and less than .5% is irrigated by wells established after 1980[10/] Thus, according to the structure of the restriction policy, the majority of irrigated land in the county would face a 20% restriction on water. Because the 500 acre farm modeled in this study is intended to be a representative farm for Laramie County it seems appropriate to use the county acreage figures as a basis for the configuration of the composite farm.

An example will help to demonstrate how a NPV income figure for the composite farm is calculated. The calculation of the NPV of income with a 2% discount rate and no increase in electricity prices is as follows (see Scenario 49, Table 22):

(3) .23(211,971.89) + .17(184,589.29) + .60(157,706.49) = $174,457.48

As stated earlier, 23 percent of the irrigated land is irrigated by wells established before 1960; 17 percent is irrigated by wells established between 1960 and 1970; and 60 percent is irrigated by wells established between 1970

10/ The water control area constitutes 95% of irrigated acreage in Laramie County and therefore serves as a good approximation of the distribution of wells in the county. Also, the decrease in wells established is due to the imposition of a moratorium on additional groundwater development with large capacity wells by the Wyoming State Board of Control. Finally, because wells established after 1980 constitute such a small percentage of total wells, restrictions on these wells are subsequently ignored in the analysis.

and 1980. As before, these income figures would then be compared to the NPV of the income stream over the same period when there is no restriction on water use. These comparisons will be discussed in detail in the following section.

Because implementing the restriction policy would not be a costless operation, allowances were made for potential expenses of the program. The expenses were $30,000 per year for salary and travel expenses for an individual employed to monitor the program, and $200 for a meter for each well. Given the fact there are approximately 50,000 irrigated acres in the control area, these expenses combined were estimated to be about $1 per acre per year. Consequently, for the representative farm with a restriction policy, $500 was deducted from the annual net income before computing the net present value figures in Table 22.

Finally, because the water restriction policy would be implemented on a county-wide basis it is also necessary to consider the impact of the policy on income for the area. However, because the 500 acre farm modeled in this study is intended to represent a typical farm in Laramie County and, because the data on well priority dates is for the water control area in the county, the weighted income figures calculated for the 500 acre composite farm can also serve as proxies for income for the control area.

Since the composite 500 acre farm provides an estimate of the net return per acre for the control area, an income figure for the area could be approximated by multiplying per acre income by the number of irrigated acres in the control area. However, in determining if the NPV of income for the area is greater with a restriction policy, it would make no difference whether the income figures for the 500 acre composite farm are used or whether a converted income figure for the area is used. The income figure calculated for the area would only be a multiple of the individual farm's income and thus would not alter the relationship between income streams with and without a restriction policy. As a consequence, in the remainder of the study the income figures for the 500 acre composite farm will be used as proxies for income for the Laramie County Grounwater Control Area when a restriction policy is imposed. Thus, if NPV income figures for the 500 acre farm are greater under a restriction policy, the same would hold for area income and vice versa.

3. Results

Table 23 compares the net present value of returns between a water restriction policy and no restriction policy. The NPV figures for the restriction policy are the income figures for the composite 500 acre farm as discussed in the previous section. Given the criterion of greatest NPV, the results indicate that farmers irrigating with center pivot irrigation systems in southeastern Wyoming would be better off if water was not restricted. The net present value of income streams for all cases considered was greater when irrigators were allowed to determine the quantity of water used.

Table 24 presents the respective crop mixes for a restriction vs. no restriction policy considering 0%, 2% and 4% increases in electricity prices. As electricity prices increase, it would be expected that the restriction policy would appear more attractive due to the potential savings in electricity costs from a constant depth to water. However, whether this is the case or not depends on the crop mix.

Referring again to Table 23, it can be seen that with a 2% increase in electricity prices, the difference between the income streams for a restriction policy versus no restriction policy narrows considerably. This can be attributed to the fact that, with a 2% increase in electricity prices,

Table 23. Comparison of NPV of Returns For 500 Acre Composite Farm Between Water Restriction Policy Based on Well Priority Dates and No Water Restriction Policy, 1984-2004.

Scenario	Discount Rate	% Increase in Electricity Rates	Restriction	No Restriction
58	2%	0	$174,457.58	$192,005.40
59	4%	0	$143,875.40	$160,113.60
60	6%	0	$120,645.93	$135,669.10
61	2%	2%	$116,396.80	$117,098.70
62	4%	2%	$99,819.66	$103,313.70
63	6%	2%	$86,733.30	$91,986.00
64	2%	4%	$66,916.00	$81,984.74
65	4%	4%	$61,188.19	$74,604.14
66	6%	4%	$56,183.22	$68,285.88

Table 24. Crop Acreage For the 500 Acre Composite Farm With and Without a Restriction Policy.

0% Increase in Electricity Prices

Year	Restriction					No Restriction				
	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
1984	69	276	69	0	0	83	333	83	0	0
1994	69	276	69	0	0	83	333	83	0	0
2004	69	276	69	0	0	83	333	83	0	0

2% Increase in Electricity Prices

Year	Restriction					No Restriction				
	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
1984	69	276	69	0	0	83	333	83	0	0
1994	69	276	69	0	0	83	333	83	0	0
2004	69	276	69	0	0	0	0	0	0	640

4% Increase in Electricity Prices

Year	Restriction					No Restriction				
	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat	Bean	Alfalfa	Feed Barley	Corn Silage	Dryland Wheat
1984	69	276	69	0	0	83	333	83	0	0
1994	69	276	69	0	0	83	0	0	42	480
2004	0	0	0	0	520	0	0	0	0	640

a farmer facing a 1.5 ft decline in well depth is forced to convert to dryland wheat production by the year 2004. However, under a restriction policy, a constant depth to water helps to offset the increases in electricity costs and the farmer remains in full irrigated production.

If this situation continued with a 4% increase in electricity costs, the water restriction policy could have resulted in a higher NPV of returns than a no restriction policy. As can be seen from Table 24, however, a 4% increase in electricity prices causes the farmer to convert to dryland wheat in both cases and therefore the margin between income streams widens for these scenarios. Thus, the results in Table 23 indicate that savings in electricity costs arising from a reduction in the quantity of water pumped and a constant groundwater level under the restriction policy did not outweigh the value of additional yield obtained by applying optimal irrigation amounts in the absence of a restriction on water.

As mentioned earlier, the NPV of an income stream is affected by both the discount rate used and the time period considered. Thus, it is possible that if either one of these factors were changed the results presented above could change also.

Because a water restriction policy is intended to extend the life of irrigated farming beyond the point predicted when water is not restricted, one would expect the restriction policy to appear more attractive at lower discount rates. The benefit of maintaining income longer under a restriction policy is undermined by higher discount rates eroding the value of income in later years. However, the results of the analysis showed that even at a discount rate of 2% the NPV of returns was greater without a restriction on water. Consequently, for the restriction policy to merit implementation in the twenty year time frame, a discount rate of less than 2% would have to be assumed, which may not be realistic.

Similarly, if water use is restricted, and electricity prices do not increase, income for the farmer(s) would remain at some constant level throughout the time period considered. This is due to the fact that with a restriction policy, the groundwater level does not decline, therefore the cost of pumping does not change. Thus, ceterus paribus, the farmer would grow the same crop mix in subsequent years that maximized returns in the initial year. Given this situation, it could be argued that the time period considered in this analysis should be longer thereby increasing the potential benefits resulting from the restriction policy.

In the absence of a restriction policy, a declining groundwater table raises the costs of pumping each year. Again, ceterus paribus, at some point in time the farmer will be forced to abandon irrigation due to the cost of pumping being too high. Furthermore, there would be a time when income under a restriction policy equals income with no restriction. This idea was displayed in Figure 1. After this point in time, annual income under the restriction policy would remain the same while income in the absence of a restriction policy would continue to decline until irrigation ceased. If a time period longer than twenty years was considered, it is possible that the NPV of net returns under a restriction policy would be greater than the income stream under the no policy option.

In extending the time period considered for implementation of a restriction policy to forty years (1984-2024), results do show that, under certain conditions, the NPV of net returns is greater under a restriction policy. Table 25 presents comparisons of the NPV of returns between a water restriction policy and no water restriction policy for the years 1984-2024.

Scenarios 67 and 68 show that when there is no increase in electricity prices, the NPV of returns is greater under a restriction policy for discount rates of 2% and 4%. Also, a restriction policy becomes more beneficial for a

Table 25. Comparison of NPV of Returns For 500 Acre Composite Farm Between Water Restriction Policy Based on Well Priority Dates and No Water Restriction Policy, 1984 - 2024.

Scenario	Discount Rate	$ Increase in Electricity Prices	Restriction	No Restriction
67	2%	0	295,122.45	276,281.00
68	4%	0	210,055.30	207,680.20
69	6%	0	157,837,89	162,481.30
70	2%	2%	121,255.55	118,032.80
71	4%	2%	102,848.38	103,826.20
72	6%	2%	88,647.02	92,274.14
73	2%	4%	72,611.09	87,661.37
74	4%	4%	65,072.83	78,643.85
75	6%	4%	58,841.33	71,222.31

2% discount rate when electricity prices are increasing at 2% annually. These results imply that, for the conditions assumed, income under the restriction policy in later years eventually outweighed the higher incomes from unlimited pumping in the early years.

As was mentioned earlier, higher discount rates operate more powerfully to reduce income in later years. As can be seen in Scenario 69, a discount rate of 6%, with when no increase in electricity prices, makes the water restriction policy less desirable in terms of net returns than a no restriction policy.

Data on income streams for the case farm indicate that with a restriction policy it would take only six additional years beyond 2004 for the farm to convert to dryland wheat production when electricity prices are increasing 2% annually. Table 24 indicated that with no restriction the farm converts to dryland wheat production by 2004. Thus, when the 1984-2004 time period considered is extended 20 years, there would be only six years of additional net revenue that would be greater than income for the farm without a restriction on water, a factor that does not seem likely to change the results significantly. Indeed, as can be seen from Table 25, extending the time period considered only changes the results for a discount rate of 2%.

Because results show that the farm goes out of irrigated production by the year 2004 for both a restriction policy and non-restriction policy when electricity prices are increasing at 4% annually, extending the time period considered would not alter the results as in both cases the farm is in full dryland wheat production by 2004.

To summarize, results indicate that for a time period of 40 years or more, the restriction policy is only beneficial when the relative price of electricity remains constant and discount rates of 2% and 4% are assumed, or if electricity prices are increasing at 2% annually and a 2% discount rate is assumed. Within a 20 year time span, results indicate the farmer, and the area, would be better off without a restriction policy even with increasing electricity prices. Thus, the decision whether to adopt a restriction policy is contingent on the assumptions made about future electricity prices, discount rates, and appropriate time horizons.

4. Caveats

Because of the generalizations made in the above analysis of a water restriction policy, there are some caveats that need to be mentioned to accompany the results presented.

To begin with, there could be some farmers who would be better off under a restriction policy, given the criterion of net returns. For those irrigators with the majority of their land irrigated by wells established before 1960, water would still be unlimited under the restriction policy while at the same time pumping costs would not increase because of a constant groundwater level.

On the other hand, the majority of acreage in the area is irrigated by wells established between 1970 and 1980 and farmers owning these wells would face a 20% restriction on pumping. Consequently, returns for the majority of acreage in the area would decline by approximately 15-25% for the first ten years (see Table 21). Whether farmers would be willing to, or perhaps more importantly could, tolerate these reductions is unpredictable. Despite potential benefits in later years from a restriction policy in a forty-year time frame, it does seem likely that such pressure would motivate some farmers to cease operation.

Similarly, because groundwater levels vary throughout the area, unlimited pumping may not benefit every irrigator in the area as suggested by this analysis. For those irrigators whose well depths are dropping at a rate faster than 1.5 ft per year, unlimited pumping by the irrigators may result in lower returns than would occur under a restriction policy.

Finally, no consideration was given in the analysis to the impact of a restriction policy on those parts of the community whose incomes are significantly dependent on agriculturally generated expenditures. Because there is a positive correlation between farm income and agriculturally related business revenue, cessation of irrigated farming due to increased pumping costs threatens the livelihood of the off-farm business sector. Thus, there could be reasons why the community as a whole might wish to delay final exhaustion of agricultural irrigation in the area via a water restriction policy.

Because of the positive correlation between farm and off-farm income, however, it has been assumed that any potential costs and benefits of a restriction policy for the community would be comparable to those for the farms themselves. Thus, if a water restriction policy was found to make the farmer worse off via lower income streams, the same was assumed for the general business community and vice versa. This does not seem an unreasonable assumption given the fact it was only when a time horizon of 40 years was considered and electricity prices remained constant that a restriction policy was found to have merit. In all other cases a discount rate of 2% or less would have to be assumed in order to justify implementation. While it is generally presumed that the social or community rate of time preference is lower than the private entrepreneurial rate, it seems highly unlikely that the community rate in this situation would be less than 2%. Consequently, it seems there is no economic reason why those parts of the community whose incomes are dependent on agriculturally generated expenditures would be affected any differently by a water restriction policy than the individuals it is imposed upon.

5. Alternative Restriction Policy

As an alternative to the structure of the restriction policy just discussed, it may prove more beneficial to restrict water equally among all irrigators. The goal of the restriction policy is to reduce water use so that the recharge rate approximately equals the withdrawal rate. The restriction policy discussed previously should result in about a 14% reduction in total water use. However, as opposed to using a structure that imposes different restrictions on different irrigators so that water will be reduced by 14%, each irrigator could restrict water use by 14%. This option has the potential to achieve the desired goal of equalizing recharge and withdrawal rates while, at the same time, generating a higher overall income level for the area.

As was pointed out earlier, due to restrictions of the L.P., an exact percentage reduction is not always possible. Because the L.P. only takes half-pivots out of production at a time a 14% reduction in water use is approximated best by taking one half-pivot out of production for each 500 acre farm. In actuality, this is a 12.5% reduction. Also, as was mentioned earlier, the model indicated that it is more profitable to take land out of production than to reduce irrigation amounts when water use is restricted. Thus, in this analysis as in the previous one, land will be taken out of production to achieve the percentage reduction in water use.

Table 26 displays comparisons between a restriction policy and no restriction policy for 1984-2004 when water is restricted equally among all irrigators. The results suggest again that farmers would be better off without a restriction policy. The NPV of returns was greater in most cases when water was not restricted. The exceptions were at 2% and 4% discount rates when electricity prices increased at 2% annually. Under these assumptions, returns were higher when water was restricted. In those cases foregoing water use in the present was compensated for in the future through savings in pumping costs due to maintaining constant groundwater levels.

The figures in parentheses, in Table 26, are the income figures under the restriction policy based on well priority dates. As can be seen, returns are higher when water is restricted equally among all irrigators. Thus, if a restriction policy was imposed it would be more beneficial for the area as a whole to have each irrigator reduce water by the same percentage amount rather than have it reduced contingent on when well rights were established.

Table 26. Comparison of NPV of Returns For 500 Acre Composite Farm Between Water Restriction Policy When Irrigators Reduce Water by Equal Amounts and No Water Restriction Policy, 1984 - 2004.

Scenario	Discount Rate	$ Increase in Electricity Prices	Restriction		No Restriction
76	2%	0	184,589.29	(174,457.58)	192,005.40
77	4%	0	152,231.02	(143,875.40)	160,113.60
78	6%	0	127,652.47	(120,645.93)	135,669.10
79	2%	2%	123,288.39	(116,396.80)	117,098.70
80	4%	2%	105,716.82	(99,819.66)	103,313.70
81	6%	2%	91,847.35	(86,733.30)	91,986.00
82	2%	4%	79,502.95	(66,916.00)	81,984.74
83	4%	4%	71,908.91	(61,188.19)	74,604.14
84	6%	4%	65,449.07	(56,183.22)	68,285.88

Some caution must be exercised in interpreting the results in Table 26. Because the overall percentage reduction for the restriction policy based on well priority dates was a little more than 14% due to the restrictions of the L.P. and the percentage reduction for this restriction policy was a little less than 14%, the comparison made may not be appropriate. However, it is unlikely that a 1% or 2% change in either direction would significantly change income figures. Thus the results seem to be a good approximation of what income figures would be if exact percentages could be calculated.

The results change somewhat when a period of 40 years is considered. Table 27 presents the same comparisons as before but for the period 1984-2024. Results show that the NPV of net returns is greater under a restriction policy for all three discount rates when no increase in electricity prices is assumed. The NPV of returns is also higher under a restriction policy for a 2% discount rate and a 2% increase in electricity prices. The remaining scenarios (scenarios 89-93) indicate that farmers would be better off without a restriction on water usage.

Table 27. Comparison of NPV of Returns for 500 Acre Composite Farm Between Water Restriction Policy When Irrigators Reduce Water by Equal Amounts and No Water Restriction Policy, 1984 - 2024.

Scenario	Discount Rate	% Increase in Electricity Prices	Restriction	No Restriction
85	2%	0	311,694.99 (295,122.45)	276,281.00
86	4%	0	221,903.32 (210,055.30)	207,680.20
87	6%	0	166,774.07 (157,837.89)	162,481.30
88	2%	2%	120,152.19 (121,255.55)	118,032.80
89	4%	2%	102,403.32 (102,848.38)	103,826.20
90	6%	2%	88,623.55 (88,647.02)	92,274.14
91	2%	4%	75,913.85 (72,611.09)	87,661.37
92	4%	4%	68,094.57 (65,072.83)	78,643.85
93	6%	4%	61,626.06 (58,841.33)	71,222.31

Between the two restriction policies the results in Table 27 also suggest that it would be more beneficial to the area to restrict water equally among irrigators if a restriction policy was imposed. Exceptions to this conclusion are Scenarios 88 and 89. However, all three scenarios for a 2% increase in electricity prices show a small difference between returns for the two restriction policies. If these conditions prevailed, then it would make little difference which restriction policy was imposed.

Thus, only if the relative price of electricity remains constant and a time period of 40 years or more is considered, does a restriction policy forcing all irrigators to reduce water by an equal percentage show significant benefits for discount rates of 2%, 4% and 6%. Within a 20 year time span, results indicated the farmer would be better off without a restriction policy. The same holds for a 40 year time horizon when 2% and 4% increases in electricity prices are assumed although the restriction policy was found to be more beneficial for a 2% discount rate when electricity prices increase at 2% annually.

8. Summary

As was stated earlier, the decision whether to adopt a restriction policy or not is contingent on the assumptions made about future electricity prices, discount rates and appropriate time horizons. In this study, results indicate that during the period 1984-2004 irrigators in southeastern Wyoming would be better off without a restriction on water. However, if the assumption of constant electricity prices is made, (something which does not seem unreasonable in light of the recent decrease in the kwh charge by Tri-State), and 40 years or more is regarded as an appropriate time horizon, results suggest that it would benefit farmers to restrict water. Thus, income would be sacrificed presently to have more in the future. Furthermore, if water is restricted so that recharge rates approximately equal withdrawal rates, results indicate it would be more beneficial to the area in terms of income to have all irrigators restrict water equally as opposed to achieving the reduction by the restriction policy based on the priority date of an irrigator's well.

G. Conclusion

The results of this study have indicated some ways in which the profitability of center pivot irrigation might be improved. These are conversion to low-pressure pivots, improvements in pump and application efficiencies, participation in a load control program, and potato production. Strategies considered that were found to make the farmer worse off were voluntary reductions in water use of 10% or more and placing a restriction on water for the entire area. However, if the time frame considered in this study was extended twenty years, under certain conditions, restricting water pumped from the aquifer proved more beneficial to farmers than allowing them to determine the quantity of water used.

Results from the analysis comparing high and low pressure center pivot systems indicated the economic advantage of a low pressure system. Assuming no increase in electricity prices, returns were 63% higher in 1984 using a low pressure pivot rather than a high pressure system. In 1994 they would be 73% higher, and in 2004 they would be 70% higher. If a 2% annual increase in electricity prices is assumed, returns are 76% higher with low pressure versus high pressure in 1994. In 2004, they are 95% higher. In fact, by 2004 a 2% annual increase in electricity prices causes complete conversion to dryland wheat production with a high pressure system. Finally, if electricity prices increase at 4% annually, use of low pressure systems in 1994 improves returns by 97% over those realized with a high pressure system. By 2004 however, the increase in electricity prices causes complete conversion to dryland wheat production with both high and low pressure systems. Thus, there are significant financial benefits from using a low pressure system.

Changes in pump and application efficiencies using a low pressure pivot system were also analyzed. In 1984, a 10% increase in pump efficiency and a 5% increase in application efficiency increased net returns by 30%. When increases in electricity prices are assumed, benefits from improving pump and application efficiencies are even more significant. With a 2% annual increase in electricity prices, a 10% increase in pump efficiency and a 5% increase in application efficiency improved returns by 62% in 1994. In 2004, under these same conditions, returns are 59% greater than they would have been without the improvements in pump and application efficiencies. If a 4% annual increase in electricity prices is assumed, improving pump and application efficiencies by 10% and 5%, respectively, help to improve profitability by 50% in 1994. As in the last analysis though, by 2004 the farm converts completely to dryland wheat production with a 4% annual increase in electricity prices and increasing pump and application efficiencies does not help to improve the situation.

The benefits from converting from high to low pressure center pivots and from improving pump and application efficiencies would have to be compared with the costs of doing so. However, as the results indicate, the benefits from both measures are substantial. Unless individual circumstances differ greatly from those assumed in this analysis, it is highly unlikely that the costs of such changes would outweigh the benefits.

Another means found to improve profitability was participation in the direct load control program. A load control program can provide savings in pump costs if alterations in timing and/or reduced amounts of water applications do not significantly affect crop yields. Results of the analysis indicated an economic benefit to farmers from participation in the Load Control Program. In 1984 returns were 21% higher for participants than for non-participants. In 1994 they were estimated to be 20% higher and in 2004 returns increased by 34% due to participation in the load control program.

Results from the analysis that considered the recent reduction in the kwh charge show even greater benefits than those derived from the load control. Lowering the kwh rate one cent and increasing the demand charge $3.50 per hp, serves to reduce pumping costs even further than what the load control program resulted in. In 1984 returns under the proposed 1985 rate structure would have been 15% higher than returns under the load control program. In 1994 they are 15% higher and in 2004 they are 19% higher.

The economic analysis of the potato farm showed potatoes to be very profitable relative to other crops. Even with a 6% annual increase in energy prices potato farming continues to be profitable in 2004. In 1984, a potato farm growing 250 acres of potatoes, 94 acres of dry beans and 406 acres of irrigated wheat realized almost a six-fold increase in returns per acre over the average grain-forage farm. The apparent profitability of potatoes does not reflect the intensity of management needed in this crop. In this study, production costs do not include management and land interest charges which are particularly important with regard to potatoes. However, the farmer who can produce and market potatoes should have a significant advantage over farmers growing other crops.

Finally, in considering a water restriction policy, the results of this study indicate that during the period of 1984-2004 irrigators in southeastern Wyoming would be better off without a restriction on water. During this time frame, savings in electricity costs arising from a reduction in the quantity of water pumped and a constant groundwater level under the restriction policy did not outweigh the value of additional yield obtained by applying optimal irrigation amounts in the absence of a restriction on water. However, if the assumption of constant electricity prices is made and 40 years or more is regarded as an appropriate time horizon, results suggest that it would benefit farmers to restrict water usage. During this time period the NPV of the income stream would be greater under a restriction policy. Furthermore, if water is restricted so that recharge rates approximately equal withdrawal rates, results indicate it would be more beneficial to the area in terms of income to have all irrigators restrict water by an equal amount as opposed to achieving the reduction by the policy based on well priority dates.

The economic analysis performed here also brings forth a few other notable insights into the situation of irrigators in southeastern Wyoming. First, results for various management strategies considered have indicated the importance of electricity prices in determining the fate of irrigated agriculture in the area. For a low pressure system, operating at 65% pump efficiency and 85% application efficiency, a 2% annual increase in electricity prices causes farm income to decrease 50% by 1994 and 85% by 2004. Also, by 2004, the farm converts to 90% dryland wheat production. With a 4% annual increase in electricity prices, farm income declines by 80% by 1994. By 2004 the farm has totally converted to dryland wheat production.

On the other hand, with no increase in electricity prices, the irrigator remains in full production in 2004 and net income declines by only 28% due to increases in pumping costs from a declining groundwater level. Thus, changes in the groundwater table do not have as significant an impact economically on irrigated agriculture as do changes in electricity prices.

An analysis in Appendix 3 indicated that up to 1984, electricity demand with respect to price was relatively inelastic. However, as is pointed out in the analysis, if decreasing groundwater levels and low crop prices continue in the future, irrigators may become more sensitive to increases in electricity prices than the demand function estimates indicated. The results from the L.P. for certain management strategies considered in this study seem to portend such a change. Particularly if crop prices remain relatively constant, results indicate any further electricity price increases of 2% or more could not long be tolerated by irrigators in southeastern Wyoming.

This result has great import not only for irrigators but also for electric utility companies as well. In recent years utility companies have become concerned about maintaining sales and revenues in light of the effects of declining groundwater levels and higher electricity prices on demand for electricity. The recent decrease in the kwh charge by Tri-State certainly reflects this concern. If continued low crop prices as well as decreasing groundwater levels serve to make demand for electricity more elastic in the future, pricing policies should become an important factor in decisions regarding the solvency of utility companies.

Another factor that became apparent through the analysis was the sensitivity of the crop mix to changes in price. As one section of the study showed, with only a 9% decrease in the price of alfalfa, and with a zero percent increase in electricity prices, by 1994 the predominant crop grown would be dryland wheat. The analysis also showed that for most crops, prevailing prices were either below or slightly above break-even levels (see Table 2, pg. 14). For both feed barley and irrigated wheat the current price (as assumed in this study) is below the break-even price. Prices for dry beans, corn silage and dryland wheat are between less than one percent and 11% larger than break-even prices. Consequently, small decreases in crop prices could have significant adverse effects on irrigated farming.

In assessing alternative ways to restrict water, results indicated the sensitivity of crop yields to reductions in water. When water was restricted by 10% or more, the analysis showed that farmers were made worse off in terms of income. The most profitable option of reducing water by approximately 10% could only generate 88% of the returns when full irrigation amounts were applied. This means that, given prices and yield response functions used in this study, reductions in water decreased returns because of lower yields more than it reduced pumping costs because of less water used. Thus, in the absence of a restriction policy, a farmer would be better off to apply full irrigation amounts rather than reduce water to try to save money through reduced pumping costs, at least for the next twenty years.

Finally, a comparison of the results between management strategies that improved profitability and returns for actual crop acreages grown in Laramie County over the last ten years indicated that profitability could be improved by increasing alfalfa acreage. Apparently, the profitability of alfalfa was large enough to withstand increasing costs due to increases in depth to water and electricity prices. For nearly all scenarios the results indicated that the most economical crop mix is one where 70% of the irrigated land is alfalfa. While it may not be feasible for all farmers to increase their alfalfa acreage, for those who can, the change may help to lessen the burden of the impact of declining groundwater levels.

Farmers might be able to improve net returns by means not considered in this analysis. Other water-conserving crops might become economical to produce and new varieties of crops other than those grown currently could be developed which would be relatively drought-resistant. Operators might also improve returns by varying crop mix in accordance with crop/price variations. The extreme variability of the price of dry beans suggests that farmers could improve average returns by even crude predictions of bean price and consequent variations in planted acreage. Also, the analysis made no attempt to incorporate returns from government farm programs. For some operators, these programs undoubtedly help to increase returns. Finally, the potential for new markets cannot be ignored. As mentioned before, the location of an Anheuser-Busch Brewery in the vicinity of Fort Collins, Colorado could create a substantial demand for malt barley and in turn, result in increased net returns using center pivot irrigation, even in the face of declining groundwater levels.

It must be emphasized that any attempt to predict the future involves a great deal of uncertainty. In particular, any change in crop prices or in technology that would affect pumping costs and/or crop yields could change the results substantially. Even a one-cent decrease in the kwh charge was found to have significant financial benefits for irrigators. Individual operators might find their circumstances to vary substantially from those modeled here and thus, not every farm in the area may behave as predicted. However, if electricity prices do increase as little as 2% annually, as long as as recharge rates are less than extraction rates and the relative prices of crops and inputs remain constant, the long-term forecast is for some abandonment of center pivot irrigation. Under these conditions only the most efficient operators may be able to survive to that time when groundwater pumping will approximately equal natural recharge rates.

References

Agee, Doug E. 1979. "Costs of Producing Crops, Center Pivot Irrigation, Southeastern Wyoming, 1977-78." Division of Agricultural Economics, University of Wyoming, Agricultural Extension Service Bulletin 670.

Agee, Doug E. 1981. "Costs of Producing Crops, Worland Area, Wyoming, 1981-82." Division of Agricultural Economics, University of Wyoming, Agricultural Extension Service Bulletin 644R.

AGNET. 1984. Crop Budget Program.

AGNET. 1984. PUMP COST Program.

Arthur D. Little, Inc. 1978. "Summary of Utility Load Management Problems." E.U.R.D.S. #63, N.A.R.U.C. Palo Alto, California.

Bosch, D.J., V.R. Eidman and E.E. Gill. 1984. "The Effect of Power Interruptions on Net Returns From Irrigated Corn." Presented at the American Agricultural Economic Association Meetings, Cornell University, Ithaca, New York.

Buyok, John. 1979. "Efficiencies of Irrigation Pumping Plants in Southeastern Wyoming." Division of Agricultural Engineering, University of Wyoming. Unpublished Mimeograph, August.

Crist, Marvin. 1980. "Effect of Pumpage on Groundwater Levels as Modeled in Laramie County, Wyoming." U.S. Geological Survey, U.S.Department of Interior, Report #80-1104.

Doorenbos, J.; A.H. Kassam et al. 1979. "Yield Response to Water." FAO Irrigation and Drainage Paper No. 33, Rome.

Guitjens, J.C. 1982. Models of Alfalfa Yield and Evapotranspiration." Journal of the Irrigation and Drainage Division Proceedings of the American Society of Civil Engineers 108, No. IR3 212-222.

Holland, A. Steve. 1984. "Real Interest Rates: What Accounts For Their Recent Rise?" Review of the St. Louis Federal Reserve Bank, 66.

Kearl, Gordon W. 1981. "Average Prices of Cattle and Calves at Billings, Montana 1972-1981." AE 80-13, 1981-R, Division of Agricultural Economics, University of Wyoming, Laramie.

Lindemer, Kevin J. 1983. "Estimated Effects of Declining Groundwater Levels and Increasing Electricity Prices on a Typical Irrigating Farm in Laramie County, Wyoming, 1982 to 2002." M.S. Thesis, Division of Agricultural Economics, university of Wyoming, Laramie.

Mapp, Harry P. and Craig L. Dobbins. 1977. "The Impact of Increased Energy Costs on Water Use and Agricultural Output in the Oklahoma Panhandle." Oklahoma Agricultural Experiment Station, Research Report No. P-755, Oklahoma State University, Stillwater, Oklahoma.

Morgensen, V.O. 1980. "Drought Sensitivity at Various Growth Stages of Barley in Relation to Relative Evapotranspiration and Water Stress." Agronomy Journal 72(6) 1033-1038.

Lloyd Sissons. Rural Electric Co., Pine Bluffs, Wyoming, personal communication.

Short, Doug and L. Sissons. 1984. Rural Electric Company 1984 Irrigation Study. Presented to REC Board of Directors, May 8, 1984.

Tri-State Generation and Transmission Association, Inc. 1984. 1983 Annual Report. James H. McNear, President, Denver, Colorado.

U.S.D.A. U.S. Agricultural Statistics 1983. Washington, D.C.

Warren, John, Harry Mapp, Darrel Kletke, Daryll Ray and Charles Wang. 1981. "Results of the Oklahoma Agricultural and Farm Level Analysis: Six-State High Plans - Ogallala Aquifer Area Study." Department of Agricultural Economics, A.E. No. 8191, Oklahoma State University, Stillwater, Oklahoma.

Westfield, Fred M. 1980. "The Economic Theory of Marginal Cost Pricing and its Application by Electric Utilities in France and Great Britain." E.U.R.D.S. #53, N.A.R.U.C., Palo Alto, California.

Wyoming Agricultural Statistics, 1984, Cheyenne, Wyoming.

Zinc, Richard A. 1980. "Economics of Alternative Enterprise Combinations: Torrington-Wheatland Area, Wyoming." M.S. Thesis, Division of Agricultural Economics, University of Wyoming, Laramie.

APPENDIX 1

A SIMULATION MODEL OF EVAPOTRANSPIRATION, IRRIGATION AND CROP YIELDS FOR SOUTHEASTERN WYOMING

Introduction

Many researchers have developed models of evapotranspiration (ET) for crops. These models have been used to schedule irrigations and have aided in the understanding of crop-water relationships. Often, a measure of potential evapotranspiration (ETP) is used to determine when soil moisture depletion is critical and yields may be affected. An irrigation is then scheduled to fill the soil to capacity.

This work attempts to carry the problem a step further. Estimates of actual evapotranspiration (ETA) under limiting soil moisture are made and published parameters relating ETP versus ETA are used to estimate crop yields.

Methodology

The ET-yield model is summarized below. Potential evapotranspiration (ETP) is estimated using the "Blaney-Criddle" method and is a function of daily mean temperature, daily proportion of annual daylight hours and a crop coefficient. Precipitation and temperature from Pine Bluffs, Wyoming are input as daily historical averages. If soil moisture is depleted below an allowable fraction of field capacity, ETA falls below ETP, and yields are decreased.

Two versions of the model allow for substantially different irrigation strategies. In the first model, an irrigation is made to field capacity the day soil moisture is depleted below the allowable fraction of field capacity for the crop root depth. Actual evapotranspiration is maintained at ETP over the season and maximum yields are attained. In this version, the model determines irrigation timing and quantities needed to produce maximum yields.

In the second version, the timing and quantity of irrigation are input under control of the model user. Actual evapotranspiration may fall below ETP, and yields are decreased relative to the evapotranspiration deficit.

Potential Evapotranspiration

Potential evapotranspiration is estimated by the Blaney-Criddle method. Other methods may be more accurate but the required weather data are not available for southeastern Wyoming. The method is outlined by SCS (1967). Their method of estimating ETP on a monthly basis is expanded to make estimates on a daily basis. Required inputs are mean daily temperature (MDT), daily percent of annual daytime hours (PDH), and a crop coefficient (KC). Daily ETP was estimated using the formula below:

(1) $ETP = [(MDT)(PDH)/100] \times (.0173\ MDT - .314)(KC)$

where ETP is potential evapotranspiration in inches.

In the model, KC, MDT and PDH all change on a daily basis and KC also varies by crop. Graphs of KC provided by SCS (1967, pp. 65-88) were used to develop data on daily KC for the various crops. KC was then regressed against time in days to obtain an equation to estimate daily KC for the simulation. Equations (2) through (7) in Table 1-A were used to estimate a daily KC factor for each crop.

In order to estimate KC over time, it was necessary to convert percent of growing season to day of the season. Estimates of length of the growing season were obtained from Doug Agee (personal communication) and from Trelease et al. (1970) and are provided in Table 2-A.

Similarly, mean temperature, precipitation and percent of annual daylight hours change daily in the simulation. Daily temperature and precipitation data for 1900 to 1973 were obtained from the Pine Bluff's weather station in Laramie County, Wyoming. These daily weather data from Pine Bluffs were

Table 1-A. Equations Estimated for Use in the Evapotranspiration - Yield Model[a]

(2) $$KCWW = 3.5673 + .074238D - .00057822D^2 + .00000118834D^3 - 1.17412\ LOG(D)$$
(1.23) (.036) (.000284) (.0000009) (.616)

$R^2 = .99$ F = 167 DW = 1.64

(3) $$KCSG = 16.57 + .31135D - .00169133D^2 + .0000031825D^3 - 7.10354LOG(D)$$
4.85 (.0796) (.000478) (.00000117) (1.9913)

$R^2 = .99$ F = 110 DW = 1.66

(4) $$KCPO = 68.9487 + .474397D - .00141818D^2 + .0000016339D^3$$
(19.34) (.152) (.00057) (.00000093)

$R^2 = 1.0$ F = 453 DW = 2.15

(5) $$KCCO = 31.05 + .2485D - .00080759D^2 + .00000097431D^3 = 10.451LOG(D)$$
(11.17) (.1054) (.0004514) (.0000008225) (3.91)

$R^2 = .99$ F = 187 DW = 1.71

(6) $$KCBE = 239.377 + 1.93768D - .0073111D^2 + .0000116125D^3 - 80.56LOG(D)$$
(49.95) (.4067) (.001599) (.0000027279) (16.80)

$R^2 = .98$ F = 91 DW = 3.32

(7) $$KCAL = .744216 + .0055225D - .000036631D^2 + .000000049011D^3 + .0313159LOGD$$
(.276152) (.003417) (.0000154) (.0000000272) (.106)

$R^2 = 1.0$ F = 549 DW = 2.84

(8) $$PDH = -70.0039 - 1.24383Y + .00968187Y^2 - .0000432554Y^3 + .000000094011Y^4$$
(6.848) (.0864) (.000547) (.000002175) (.0000000046)

$$- .0000000000786546Y^5 + 31.5483LOG(Y)$$
(.0000000000039655)

$R^2 = 1.0$ F = 73664 DW = .4600

(9) $$MDT = 18.305 - 1.0307Y + .01338Y^2 - .000053245Y^3 + .0000000642Y^4$$
(1.115) (.0416) (.000328) (.00000116) (.00000000145)

$$+ 8.6072Log(Y)$$
(.6105)

$R^2 = .99$ F = 5874 DW = 1.80

(10) $$PREC = .068556 + .0030107Y - .00001217Y^2 + .00000001478^3 - .04371Log(Y)$$
(.01226) (.00024) (.00000109) (.000000001713) (.0055)

$R^2 = .61$ F = 142 DW = 2.12

(11) $$PRECEF = [(.9614 - .009547\ (PREC * 30.5)^{1.9}] * .032787$$
(.0025) (.00011)

$R^2 = .999$ F = 6682 DW = 1.77

Variable Definitions

KCAL = crop coefficient for alfalfa, April 1 to Sept. 20

KCWW = crop coefficient for winter wheat, day 1 = March 1, season March 15 to July 20

D = day, March 1 = 1

KCSG = crop coefficient for spring grains, season April 1 to Aug. 9

KCPO = crop coefficient for potatoes, season May 15 to Sept. 21

KCCO = crop coefficient for corn silage, season May 1 to Sept. 7

KCBE = crop coefficient for dry beans, season May 20 to Sept. 1

PDH = length of day from sunrise to sunset 42° north latitude, estimated with data from March through November

Y = day, January 1 = 1

MDT = mean daily temperature, Pine Bluffs, Wyoming, 1900 to 1973, data from all available days

PREC = mean daily precipitation, Pine Bluffs, Wyoming, 1900 to 1973, data from all available days

PRECEF = the proportion of precipitation which enters the soil profile

---

a/ Crop coefficient data drawn from SCS, (1967) pp. 66-88.

Table 2-A. Crop Parameters Used in the Model.

Crop	Growing Season Start	Growing Season End	Inches Root Growth Per Day	Maximum Root Depth Inches	Initial Root Depth Inches
winter wheat	3/15	7/20	.30	48	18
alfalfa	4/1	9/20	-	72	72
spring grain	4/1	8/9	.384	48	0
potato	5/15	9/21	.35	40	0
corn	5/1	9/7	.50	60	0
bean	5/20	9/1	.37	41.0	0

averaged and regressed against day of the season to obtain equations for the simulation. Estimated equations for daily temperature and precipitation are provided by Equations (9) and (10) in Table 1-A, respectively.

To obtain an estimate of PDH, data on the time of sunrise and sunset for 42° north latitude were drawn from The Astronomical Almanac (1984) on a 4-day basis. These times were converted to hours of daylight on each day and were regressed against day of the year. The resulting equation is provided as Equation (8) in Table 1-A. In the simulation, the estimate of daily hours is divided by 100 times total annual hours to obtain daily percent of annual daylight hours.

Actual Evapotranspiration

Actual evapotranspiration (ETA) depends on root depth, moisture capacity of the soil and the proportion depletion allowance for the given crop. The proportion depletion allowance (PDA) for each crop represents that proportion of soil moisture to root depth that may be depleted before ETA falls below ETP. These coefficients are given in Doorenbos (1979). Since PDA is a function of ETP, the coefficients were regressed against ETP to obtain equations of PDA for each crop group. Estimated equations are given in Table 3-A.

Field capacities of soils were drawn from Borrelli, et al. (1983). Initial root depths and growth per day for the various crops were derived from Jean and Weaver (1924) for a site near Greeley, Colorado and from Borrelli et al. (1983). The data from Jean and Weaver indicated substantially greater root depths than data from Borrelli. Consequently, the data in Table 2-A falls between the two sources.

The formula to determine ETA is:

(12) $ETA = ETP$ if $SW \geq (1 - PDA)(FC)(RD)$ and

(13) $ETA = [SW/(1-PDA)(FC)(RD)]*ETP$ if $SW < (1-PDA)(FC)(RD)$

where SW is soil water to root depth, FC is soil water holding capacity and RD is root depth. These formulas are given in Doorenbos (1979). The segment (FC)(RD) is the water holding capacity of the soil to root depth. ETA equals ETP until the proportion depletion allowance is met, and then falls linearly to zero.

Table 3-A. Equations to Calculate Proportion Depletion Allowance for Crop Groups as a Function of Potential Evapotranspiration.

---

(14) $PDA_1 = .68381 - 2.6277ETP + 3.45621ETP^2$
$\quad(.01468)\quad(.1386)\quad(.2883)$
$R^2 = .996 \quad F = 820 \quad DW = 2.50$

(15) $PDA_3 = .01346 - .31259LOG(ETP)$
$\quad(.015338)\quad(.00937)$
$R^2 = .993 \quad F = 1112 \quad DW = 1.99$

(16) $PDA_4 = 1.122 - 3.30764\ ETP + 3.75296ETP^2$
$\quad(.020)\quad(.1917)\quad(.3988)$
$R^2 = .996 \quad F = 975 \quad DW = 2.39$

Variable Definitions

PDA = allowable water depletion fraction $0 \leq PDA \leq 1$

ETP = potential evapotranspiration in inches per day
1 = potatoes
3 = alfalfa, beans, wheat, grains
4 = corn

Source: Data from Doorenbos (1979), page 28.

Soil Water

Soil water to root depth (SW) is calculated on a daily basis by the model. Excess water over the quantity of SW to root depth is considered to run off or percolate below the root zone and thereby be unavailable to the plant. The equations used to estimate soil water to root depth are:

(17) $SW_d = SW_{d-1} + EPRE_d + EIRR_d - ETA_d$ if $SW_d \leq (RD_d)(FC)$ and

(18) $SW_d = (RD_d)(FC)$ if $SW_{d-1} > (RD_{d-1})(FD)$

where EPRE is effective precipitation, EIRR is effective irrigation and d denotes the day of the simulation. Thus, precipitation and irrigation enter the soil and evapotranspiration leaves unless SW_d is estimated to be over field capacity, in which case soil water is set to maximum available soil water. Irrigation is assumed to be 85% efficient with low pressure center pivots.

Effective precipitation is calculated according to the method in Trelease et al. (1970). The data in that report are used to estimate the proportion of precipitation which is effective as a function of total monthly precipitation using regression (Equation 11, Table 1-A). This function is then used to estimate the proportion of daily precipitation that is effective precipitation. The model allows for initial soil water levels of 75% of capacity to root depth for winter wheat and alfalfa, and one inch of water for the other crops.

Irrigation

In one version of the model, dates and quantity of irrigation water must be specified by the user. In the other version, the model determines irrigation needs endogenously according to

$$(19) \quad IRR_d = [(RD_d)(FC) - SW_d - EPRE_d]*1.18 \quad \text{if } SW_d < (1-PDA_d)(RD_d)(FC)$$

where IRR_d equals depth of irrigation on day d. If Equation (18) holds, e.g. soil water falls below the depletion allowance, an irrigation occurs which fills the soil to capacity. The 1.18 represents an irrigation efficiency of .85(1/.85 = 1.18).

Yield Equations

Many authors have found that yield may be expressed as a function of evapotranspiration. Equations for alfalfa are drawn from Guitjens et al.

(1982). Equations estimated by Morgensen (1980) for barley consider the timing of the evapotranspiration deficits to predict a yield relative to maximum attainable yield. The equations from both authors are given in Table 4-A. The equations express yield of barley as a proportion of maximum yield. This functional form has some advantages over others for extrapolating between locations as ET is expressed as ETA/ETP and some of the problem with equations expressing yield as a function of ETA alone is avoided.

For winter wheat, potatoes, corn and beans the yield response functions are derived from Doorenbos et al. (1979). Their method allows for consideration of the growth stage of the crop as a determinant of the severity of water stress on crop yield. Actual yield is a function of maximum yield, actual and potential evapotranspiration and exogenous yield reduction coefficients associated with the crop growth stage. It was necessary to make an estimate of the timing of the growth stages for use in the simulation. Data provided by Wright (1982) and Teare and Peet (1983) were used to estimate the timing or date of the various growth stages. Table 5-A provides estimates of the dates used in the simulation and the associated yield reduction coefficients.

Graphical Depiction of the Model

The dynamics of the model are best illustrated graphically. The solid line in Figure 1-A shows the management of soil moisture over a growing season to obtain maximum yield, while the dashed line represents soil moisture conditions for the reduced yield scenarios with some simplifying assumptions. With daily ET equalling daily ETP, which are both in excess of daily effective precipitation, soil moisture declines until the proportion depletion allowance is reached. At that point an irrigation occurs which fills the soil profile to capacity.

Table 4-A. Equations from Morgensen (1980) and Guitjens (1982) Used to Estimate Barley and Alfalfa Yield

<u>From Morgensen for Barley</u>

(20) YBA = .118 + .882 * (ETA/ETP)

(21) YBAA = .504 + .494 * (ETA/ETP)

where YBA = The proportion reduction in yield from evapotranspiration deficits occurring before heading.

YBAA = the proportion reduction in yield from evapotranspiration deficits occurring during and after heading.

ETA = actual evapotranspiration during the period

ETP = potential evapotranspiration during the period

<u>From Guitjens for Alfalfa</u>

(22) YF = 1.554 + .111 ETAS

(23) YS = .541 + .163 ETAS

(24) YT = .393 + .146 ETAS

where YF = yield in tons from the first cutting

YS = yield in tons from the second cutting

YT = yield in tons from the third cutting

ETAS = accumulated evapotranspiration in inches during the period between cuttings, or from start of growth to first cutting for YF.

Table 5-A. Growth Stages and Associated Yield Reduction Coefficients.

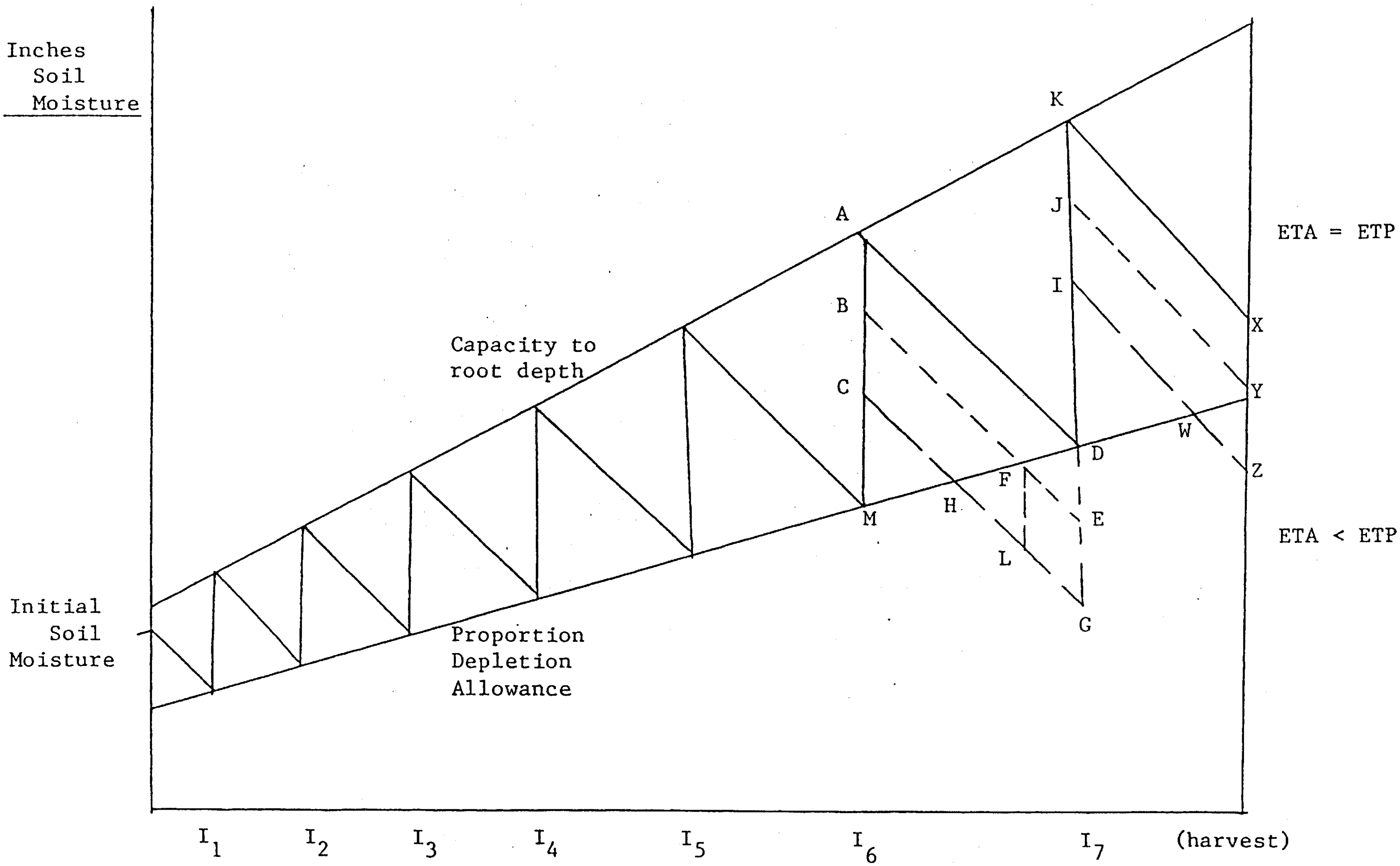
Crop		Growth Stage									
Wheat		Plant Date		Vegetative		Flower		Yield Form		Harvest	
	day[a/]	15		90		121		141		142	
	YRC[b/]		.2		.6		.5				
Potato		Plant Date		Vegetative: Early		Vegetative: Late		Yield Form		Ripen	Harvest
	day	76		112		137		187		206	206
	YRC		.45		.80		.70		.20		
Barley		Plant Date		Before Head		During + After Head		Harvest			
	day	32		116		162		162			
Corn		Plant Date		Vegetative		Flower		Yield Form		Ripen	Harvest
	day	62		132		145		180		191	191
	YRC		.7		.7		.7		.7		
Bean		Plant Date		Vegetative		Flower		Yield Form		Ripen	Harvest
	day	81		127		137		178		185	185
	YRC		.2		1.1		.75		.2		

a/ Day of the simulation on which the growth stages begin, March 1 = day 1.

b/ Yield reduction coefficient, page 39, Doorenbos et al. (1979) for the entire period.

Consider the irrigation which occurs at I_6 in Figure 1-A. To fill the soil profile with moisture requires an effective irrigation amount of AM. What if irrigation is reduced by equal increments resulting in effective irrigations of BM or CM? The soil water deficits with irrigations BM and CM may be represented by areas DEF and HGD, respectively. The improvement of soil water deficits by increasing irrigation from CM to BM is the area HFL plus LFEG, but the improvement from increasing irrigation by another increment to AM is only DEF. Increasing irrigations from CM to BM to AM results in soil water deficits decreasing at a decreasing rate. As a result, benefits from additional irrigation increase at a decreasing rate and decreasing marginal returns to irrigation water is a consequence.

Figure 1-A. Illustration of Irrigation and Soil Water Dynamics.



I_1 to I_7 = irrigation dates

- - - - = reduced irrigation at I_6 from effective amount AM to amount BM

— — = reduced irrigation at I_6 from effective amount AM to amount CM

——— = soil moisture for no reduced yield

Consider again the irrigation strategy for maximum yield. Filling the soil to capacity at time I_7 requires an irrigation of KD. However, there is excess soil moisture of XY at harvest which is not needed and presumably would percolate out of the soil before the next season. This suggests that an irrigation amount of JD at time I_7 would save on energy costs without reducing yields.

Consider what would occur if a reduced irrigation was made early in the season with no increase in later irrigations for compensation. A reduced irrigation at time I_2 would result in five periods of soil moisture deficits before harvest. Reduced irrigation at time I_4 would result in only three soil moisture deficits. Thus, in this simple representation an early reduction in irrigation has the potential to be more damaging. The ET model does compensate for this effect in one way. Below the proportion depletion allowance ETA is less than ETP. This could be represented by flattening out line segment HG, and as a result, the soil moisture deficits would eventually disappear.

Precipitation occurs as discrete events of varying quantities. It could be considered as vertical jumps in the soil moisture profile much like the irrigation events in Figure 1-A. However, precipitation events occurring immediately after irrigation could be entirely lost as soil moisture cannot exceed water holding capacity to root depth. Therefore, it would seem that filling the soil moisture to less than capacity with some consideration of precipitation probabilities might be a more optimal policy. The increased cost associated with a larger number of irrigations would have to be weighed against the benefits of reduced total water applied, assuming that rainfall could be used more effectively.

Results

Predicted and actual climatic variables are shown in Table 6-A. Actual proportion daylight hours and weather variable averages for the period 1941 to 1970 are drawn from SCS (1967) and U.S.D.C. (1982), respectively. Predicted PDH differs from actual PDH by less than 4/10 of 1 percent in every month.

Predicted and actual mean temperature also compare well. The maximum error of 3% occurs in predicting temperature in August. Precipitation is overpredicted in March, April, July, August and September and is underpredicted in May and June. This may be due to the different periods of estimation involved. Over all months, predicted precipitation is 102% of 1941 to 1970 mean levels.

Table 7-A provides estimates of ETP for the six crops included in the model. A comparison is provided with results from Trelease et al. (1976) for Pine Bluffs, Wyoming. Their estimates are larger for all crops except potatoes.

Estimated root depths are given in Table 8-A. The alfalfa stand is assumed to be mature with a 6 foot root depth and no further root growth occurring during the season. Soil in the simulation was allowed to hold 2 inches of water per foot of soil, or .1667 inches per inch of soil.

Table 9-A provides simulated values of the proportion depletion allowance (PDA). When ETP is low, crops can tolerate a larger proportion depletion. Potatoes are relatively water sensitive and can tolerate depletions only up to 23% to 54% of field capacity. Corn is relatively drought tolerant as depletions of 59% to 87% can be tolerated. This follows directly from the data provided by Doorenbos (1979).

Table 6-A. Predicted and Actual Climate Variables.

	Predicted (all years)			From Other Sources		
					Pine Bluffs, Wyoming, 1941-1970	
Month	Monthly % Daylight Hours 42°	Inches Precip.	°F Mean Temp.	Monthly % Daylight Hours 42°	Inches Precip.	Mean Temp.
March	8.33	1.36	33.53	8.30	.83	33.40
April	9.02	1.94	44.47	8.99	1.54	44.80
May	10.17	2.33	56.21	10.13	2.88	54.60
June	10.23	2.30	65.33	10.24	3.07	63.70
July	10.37	2.20	69.52	10.35	2.02	71.50
August	9.65	1.85	67.77	9.62	1.64	69.90
Sept.	8.39	1.37	60.45	8.40	1.10	60.00

Table 7-A. Predicted Accumulated Potential Evapotranspiration in Inches.

End of Month	Winter Wheat	Alfalfa	Spring Grains	Potatoes	Corn	Beans
March	.67	.04	0	0	0	0
April	3.22	1.99	.95	0	0	0
May	8.04	6.20	5.16	.79	1.80	.86
June	12.55	12.31	11.68	4.23	5.95	5.25
July	13.69	19.30	16.02	11.34	12.47	12.25
August		25.09	16.27	18.99	18.44	16.91
Sept.		27.78		22.78	19.44	17.00
Trelease[a]	[b]	33.03	19.76	20.41	25.47	18.26

[a] Estimated from Trelease et al. (1970) for Pine Bluffs, Wyoming.

[b] Not available

Table 8-A. Simulated Root Depths (inches).

Month	Winter Wheat	Alfalfa	Spring Grains	Potatoes	Corn	Beans
March 31	23.1	72	0	0	0	0
April 30	32.1	72	11.5	0	0	0
May 31	41.4	72	23.4	5.9	15.5	4.4
June 30	48	72	34.9	16.5	30.5	15.5
July 31	48	72	46.8	27.3	46.0	27.0
August 31	48	72	48	38.1	60	38.5
Sept. 30	48	72	48	40	60	38.8

Table 9-A. Simulated Values of Proportion Depletion Allowance.

Month	Winter Wheat	Alfalfa	Spring Grains	Potatoes	Corn	Beans
March 31	.95	1	0	0	0	0
April 30	.67	.75	.85	0	0	0
May 31	.56	.56	.52	.54	.86	.80
June 30	.71	.48	.50	.33	.64	.50
July 31	1	.49	.91	.23	.48	.50
August 31	1	.60	1	.28	.70	.75
Sept. 30	1	.72	1	.39	.74	.76

For the version of the model which initiates its own irrigations, Table 10-A provides estimates of irrigation timing and amounts which assure that soil moisture is above the PDA for that crop.

Winter wheat and alfalfa start out with initial soil moisture equal to three-quarters of the field capacity to root depth. Both of these crops are estimated to require infrequent but large irrigations. This is because they have roots to start the season and the amount of time for depletion to the proportion depletion allowance is longer than for crops starting with no root systems. For alfalfa, the model does not directly consider changes in water needs due to cuttings.

Table 10-A. Irrigations and Water Budget of Crops Estimated for Southeastern Wyoming.[a]

Winter Wheat

Starting Date[b]	Inches Applied
4/30	4.20
5/28	4.38
subtotal	8.58
x .85[c]	7.29
SWR[d]	-4.00
EPRE[e]	+8.16
IW[f]	+2.25
total	13.70
fall irrig.[g]	2.40
	16.10

Alfalfa

Starting Date	Inches Applied
6/11	7.44
7/19	6.78
subtotal	14.22
x .85	12.08
SWR	-4.07
EPRE	+10.77
IW	+ 9.00
total	27.78
fall irrig.[g]	6.00
	33.78

Barley

Starting Date	Inches Applied
5/19	2.24
5.31	2.33
6/11	2.61
6/23	3.08
7/12	4.40
subtotal	14.66
x .85	12.46
SWR	- 5.77
EPRE	+ 8.59
IW	+ 1.00
total	16.28

Bean

Starting Date	Inches Applied
6/14	1.16
6/22	1.39
6/29	1.49
7/6	1.71
7/13	1.85
7/21	2.17
7/31	2.61
8/21	4.38
subtotal	16.76
x .85	14.25
SWR	- 4.98
EPRE	+ 6.74
IW	+ 1.00
total -	17.00

Potato

Starting Date	Inches Applied
6/18	.96
6/25	1.03
7/1	1.09
7/6	1.05
7/11	1.17
7/15	1.28
7/19	1.09
7/23	1.14
7/27	1.18
7/31	1.21
8/4	1.53
8/8	1.54
8/13	1.52
8/18	1.77
8/24	1.96
8/31	2.58
subtotal	22.10
x .85	18.79
SWR	- 5.01
EPRE	+ 8.02
IW	+ 1.00
total	22.80

Corn Silage

Starting Date	Inches Applied
6/13	3.12
7/2	3.87
7/19	4.43
8/9	5.92
subtotal	17.34
x .85	14.73
SWR	- 4.61
EPRE	+ 8.32
IW	+ 1.00
total	19.45

Footnotes for Table 10-A.

a/ For spring grain, beans, potatoes and corn silage one inch of soil water is available to the roots at planting. Additional soil moisture available at planting and eventually used by the plant may be subtracted. Initial soil moisture of 3/4 field capacity to root depth for winter wheat and alfalfa is assumed.

b/ Since there is not enough time in a day to apply the irrigation, it may carry into later days. 4/30 = April 30.

c/ The efficiency of irrigation is 80%.

d/ SWR is soil water remaining to root depth at harvest.

e/ Effective precipitation during the growing season.

f/ Initial soil water level allowed for.

g/ It is assumed that irrigated winter wheat receives three inches of irrigation in the fall. Alfalfa receives water equal to the initial water level of 9.0 inches, less 3.0 inches of effective winter precipitation, times 1.25 equals 7.5 inches irrigation, 6.0 effective inches.

For the other crops, irrigation amounts increase in proportion to the increasing root depth. The interval between irrigations depends on root depth as well as evapotranspiration due to heat, day length and the crop coefficient.

Beans and potatoes require frequent irrigation. This result is consistent with recommended practices (Seamands, 1982). Both crops have relatively slow root growth and a shallow maximum root depth. With shallower roots, more irrigations are necessary. For potatoes, the low proportion depletion allowance also contributes to a need for frequent irrigations.

At the end of the simulation the model determines the amount of remaining soil water which exists above the proportion depletion allowance. Multiplied by the inverse of irrigation efficiency this would yield the amount of irrigation which was not needed. By subtracting remaining soil water from total effective irrigation and adding in effective precipitation, the total amount of water used is derived which, in this case, equals potential evapotranspiration (Table 7-A). Estimated irrigation of spring-seeded crops may be excessive as any soil water existing at planting time is not considered available to the plant.

For winter wheat, alfalfa and barley the proportion depletion allowance at harvest equals 1. This implies that all remaining soil water for these crops is not needed in the soil at harvest.

The irrigation amounts in Table 9-A cannot realistically be applied by a center pivot system in one day. A system capable of pumping 850 gallons per minute could deliver about 282,742,730 cubic inches per 24 hour day. An irrigated area of 125 acres is about 784,093,880 square inches. Consequently, the pivot can apply a maximum of about .36 acre-inches per day. The initial alfalfa irrigation of 7.44 inches would take 21 days to complete. If the model were to indicate that the next irrigation should occur before 21 days were up, the implication would be that evapotranspiration is greater than irrigation capacity, and loss in yield would be unavoidable unless the irrigation was started earlier.

The irrigation amounts calculated by the evapotranspiration model are based on crop yields reported in crop enterprise budgets prepared by the Wyoming Agricultural Extension Service (Agee, 1979 and 1981). These yields are assumed to be the maximum attainable yields for these crops. As ETA never falls below ETP, yields are maximum. Table 11-A displays the maximum yields assumed for the six crops considered in this study.

For alfalfa, equations supplied by Guitjens et al. (1982) consider yield by cutting to be a function of accumulated evapotranspiration (ETA) during the interval between cuts. The 5.5 total tons/acre is comparable to maximum yields obtained in southeastern Wyoming.

Table 11-A. Estimated Yields Under Optimal Irrigation Strategy.

Per Acre				
Winter Wheat	Barley	Potato	Corn Silage	Dry Beans
70 bushels	80 bushels	250 cwt	22 tons	20 cwt

Estimated yield of alfalfa, equations from Guitjens et al. (1982) Nevada

1st cut :	2.28	tons/acre
2nd cut :	1.61	tons/acre
3rd cut :	1.61	tons/acre
total	5.50	

Cited References

Borrelli, John, K.J. Fornstrom, D.J. Brosz, and R.W. Van Klaveren. 1983. "Irrigation Scheduling The Checkbook Method for Wyoming." B-806 University of Wyoming Agricultural Experiment Station, Laramie.

Doorenbos, J., A.H. Kassam et al. 1979. "Yield Response to Water." FAO Irrigation and Drainage, Paper No. 33, Food and Agriculture Organization of the U.N., Rome.

Guitjens, J.C. 1982. "Models of Alfalfa Yield and Evapotranspiration." Journal of the Irrigation and Drainage Division Proceedings of the American Society of Civil Engineers 108, No. IR3, 212-222.

Jean, Frank C. and J.E. Weaver. 1924. "Root Behavior and Crop Yield Under Irrigation." Carnegie Institution of Washington; Washington, D.C.

Lindemer, Kevin J. 1983. "Estimated Effects of Declining Ground Water Levels and Increasing Electricity Prices on a Typical Irrigating Farm in Laramie County, Wyoming." Master's thesis, Division of Agricultural Economics, University of Wyoming, Laramie.

Mann, Roger. 1984. "The Demand for Electricity for Irrigation in Laramie County, Wyoming." Unpublished document, Division of Agricultural Economics, University of Wyoming, Laramie.

Morgensen, V.O. 1980. "Drought Sensitivity at Various Growth Stages of Barley in Relation to Relative Evapotranspiration and Water Stress." Agronomy Journal 72(6)1033-1038.

National Almanac Office. 1984. The Astronomical Almanac 1984. U.S. Government Printing Office, Washington, D.C.

Seamands, Wesley J. 1982. "Wyoming Crop Recommendations." B-478R Agricultural Extension Service, University of Wyoming, Laramie.

Soil Conservation Service. 1967. "Irrigation Water Requirements." Technical Release Number 21, USDA/SCS, Engineering Division. Revised Sept. 1970, Washington, D.C.

Teare, I.D. and M.M. Peet, editors. 1983. Crop-Water Relations. John Wiley & Sons, New York.

Trelease, Frank J., T.J. Swartz, P.A. Rechard and R.D. Burman. 1970. "Consumptive Use of Irrigation Water in Wyoming." Wyoming Water Planning Report No. 5, Water Resources Series No. 19, Wyoming Water Resources Research Institute, Laramie.

U.S. Department of Commerce. 1982. Climatological Data, Wyoming. Washington, D.C.

Wright, James L. 1982. "New Evapotranspiration Crop Coefficients." Proceedings, A.S.C.E. Vol. 108, No. IR2, March.

APPENDIX 2

ANALYSIS OF CROP YIELD TRENDS IN LARAMIE COUNTY, WYOMING

The viability of center pivot irrigation in the future will be affected by attainable crop yields. If crop yields can be increased to levels above national averages, the financial status of irrigators in Laramie County could be improved.

Lindemer (1983) assumed constant crop yields to the year 2020. However, technological advances and improved management could increase crop yields in the future. This may help offset increased production costs associated with declining groundwater levels. Predicting future yields is complicated because of the uncertainty of technological advances. However, consideration of recent yield trends might indicate the extent to which yields may increase in the future. In this section, yield trend estimates are calculated for both U.S. and Laramie County, Wyoming average yields.

Data

Time series data for the years 1973 to 1982 were drawn from U.S. Agricultural Statistics (1983) and Wyoming Agricultural Statistics (1978, 1983) to obtain U.S. and Laramie County, Wyoming yield data. Precipitation and temperature data for three weather stations in Laramie County--Albin, Archer and Carpenter--are used (WWRC, 1983). Precipitation data are averaged over the three stations and summed over monthly periods. Temperature data are averaged over these same stations by month.

Simple Trend Estimates

Simple regression is employed to estimate U. S. and Laramie County, Wyoming crop yields over the period 1973 to 1982. The equations are provided in Table 1-B. Regressions for U. S. average yields for the specified crops,

Table 1-B. Yield Estimates for Crops: U.S. Average and Laramie County, Wyoming Irrigated Crops, 1973 to 1982.[a]

U.S. Average Yields		R^2 [b]	F [c]
(1) winter wheat	YIE = -19.95 + .69YR	.61	12.29
	(13.64) (.18)		
(2) spring wheat	YIE = -22.38 + .65YR	.39	5.17
	(19.87) (.26)		
(3) barley	YIE = -95.28 + 1.84YR	.90	70.00
	(15.23) (.20)		
(4) all hay	YIE = -.88 + .04YR	.60	11.95
	(.81) (.01)		
(5) dry beans	YIE = -7.99 + .275YR	.59	11.43
	(5.64) (.073)		
(6) potatoes	YIE = -45.55 + 3.97YR	.78	30.00
	(51.15) (.66)		
Laramie County, Wyoming Irrigated Yields			
(7) winter wheat	YIE = -54.98 + 1.19YR	.25	2.73
	(55.70) (.72)		
(8) spr wheat[d]	YIE = -67.38 + 1.37YR	.17	1.46
	(88.12) (1.23)		
(9) barley	YIE = -95.37 + 2.01YR	.28	3.07
	(89.15) (1.15)		
(10) alfalfa hay	YIE = 4.36 - .019YR	.03	.26
	(2.85) (.037)		
(11) other hay	YIE = 1.41 - .004YR	.003	.02
	(2.28) (.029)		
(12) dry beans	YIE = 13.22 + .061YR	.01	.08
	(18.11) (.234)		
(13) oats	YIE = -43.70 + 1.34YR	.15	1.20
	(99.61) (1.28)		

Variable Definitions

YIE = yield per acre in bushels for wheat barley and oats, in tons for hay (2000 lb.), and in hundredweight for dry beans and potatoes (cwt, 100 lbs.).

Table 1-B. (continued)

YR = year, expressed as last two digits of 1973 to 1982.

---

a/ Standard errors are given below each estimated parameter in parentheses.

b/ Equation R^2.

c/ Equation F-statistic. Critical value (N = 10, α = .05) = 5.32.

d/ Spring wheat data is for 1974 to 1982.

except spring wheat, were found to be significant as indicated by the R^2 and F statistics. The equations indicate that, over time, U. S. average crop yields have steadily increased. Wheat yields increased by an average of .65 to .69 bushels per acre per year over the period. Barley yields appear to have been increasing nearly three times as fast. Hay yield increased at a rate of about 80 lbs per acre per year. Potato yield increased at a rate of 397 lbs per acre per year.

The simple regressions for Laramie County, Wyoming yields were not found to be significant however. This may be due, in part, to weather fluctuations in Wyoming which impact average yields. Weather affects yields in many ways other than through water needs of the plant. Winterkill can be damaging to alfalfa, other hays and winter wheat. Hail can be damaging to grain yields. Precipitation at planting time can delay planting and hinder early season field operations.

To account for the impact climatic factors may have on crop yields in Laramie County, multivariate regression analysis is employed. Separating out the effects of such variables as temperature and precipitation in crop yields should provide a better estimate of the time trend in crop yields. Improvements in technology and management practices serve to increase crop yields over time. However, if weather variables have adversely affected crop yields, a simple regression between time and yields may not show the positive correlation between technological and management improvements and yields. By considering the correlation between disturbances in the regression equations, better estimates of parameters are achieved. A Gauss-Newton alternative procedure is employed to obtain maximum likelihood estimates (Hall and Hall, 1980).

Multiple Regression Estimates of Laramie County, Wyoming Crop Yields

Table 2-B provides estimates of the multiple regression equations. Data for the years 1966 to 1982, excluding 1969 and 1974 due to weather data deficiencies, were used in the analysis.

Given water shortages and/or limited surface water supply, groundwater pumping for irrigation is hypothesized to be positively associated with yields. Electricity use per irrigation account for pumping and irrigation conveyance is divided by average rated horsepower to adjust for increasing horsepower of pumps over the period.

Electricity use expressed as kilowatt-hours used per irrigation account in the county per average rated horsepower was found to have an insignificant or negative effect on crop yields. This might be due to the more severe evapotranspirational requirements of crops in years requiring more irrigation. Regardless, the variable is not included in the equations in Table 2-B.

The structure of factors affecting oats and barley yields was found to be the same based on significance of excluded variables. April precipitation may reduce yields on these crops through hindrance of planting operations. June precipitation may be associated with reduced yields through hail, waterlogging or through wind and heavy rain associated with thunderstorms. July temperature is negatively associated with oat and barley yields as expected.

The structure of factors affecting bean yields is found to be much different than that for the spring grains. Hot temperatures in May apparently

Table 2-B. Multivariate Regression Estimates of Irrigated Crop Yields in Laramie County, Wyoming.[a]

	M[b]	SE[c]	DW[d]
(14) OATY = 287.9 - .092YR - 11.82APRP - 5.21JUNP - 2.77JULT	57.1	7.16	2.3
(90.7) (.427) (2.84) (1.86) (1.01)			
(15) BARY = 275.7 + .852YR - 9.12APRP - 4.36JUNP - 3.70JULT	56.1	5.46	2.0
(71.6) (.331) (2.25) (1.47) (.80)			
(16) BEANY = .64 + .18YR + .28JUNT - .29MAYT	16.67	1.22	1.9
(6.48) (.06) (.07) (.08)			
- - - - - - - - - - - - - - - - - - - -			
(17) ALFY = 3.1 + .027YR + .096SEPOCTP - .021DECTM - .032JULT + .033JULSEPP	2.8	.08	2.2
(1.0) (.005) (.023) .007) (.012) (.011)			
(18) OTHY = 2.76 + .010YR + .164SEPOCTP - .030DECTM - .034JULSEPT	1.15	.15	1.3
(1.60) (.008) (.036) (.011) (.026)			
(19) WWY = 75.72 + 1.06YR + 4.52SEPOCTP - .377DECTM + .518MARAPRT - 2.17MAYJULT	36.3	1.67	2.4
(19.57) (.10) (.43) (.138) (.16) (.29)			
- 1.34MARMAYP			
(.27)			

[a] Standard errors are below each estimated parameter in parentheses.

[b] Mean of the dependent variable.

[c] Standard error of the regression.

[d] Equation Durbin-Watson statistic.

Table 2-B. (continued)

Variable Definitions

OATY = oat yield in bushels per acre

YR = year expressed as last two digits of the year (73 to 82)

APRP = $(APP_{al} + APP_{ar} + APP_{ca})/3$

APP = April precipitation in inches

al = data from Albin weather station

ar = data from Archer weather station

ca = data from Carpenter weather station

JUNP = $(JNP_{al} + JNP_{ar} + JNP_{ca})/3$

JNP = June precipitation in inches

JULT = $(JUT_{al} + JUT_{ar} + JUT_{ca})/3$

JUT = July mean monthly temperature °F

BARY = barley yield in bushels per acre

BEANY = dry bean yield in cwt (hundredweight) per acre

JUNT = $(JNT_{al} + JNT_{ar} + JNT_{ca})/3$

JNT = June mean monthly temperature °F

MAYT = $(MAT_{al} + MAT_{ar} + MAT_{ca})/3$

MAT = May mean monthly temperature °F

ALFY = alfalfa yield in tons (2000 lbs) per acre

SEPOCTP = $(SEP_{al} + SEP_{ar} + SEP_{ca})/3 + (OCP_{al} + OCP_{ar} + OCP_{ca})/3$

SEP = September precipitation in inches in the previous year

OCP = October precipitation in inches in the previous year

DECTM = $(DCTM_{al} + DCTM_{ar} + DCTM_{ca})/3$

DCTM = mean monthly minimum temperature in December in °F of the previous year

JULSEPP = $(JUP_{al} + JUP_{ar} + JUP_{ca})/3 + (AUP_{al} + AUP_{ar} + AUP_{ca})/3 + (SEP_{al} + SEP_{ar} + SEP_{ca})/3$

JUP = July precipitation in inches

AUP = August precipitation in inches

SEP = September precipitation in inches

JULSEPT = same as JULSEPP, except for mean monthly temperatures in °F, and divided by three

MARAPRT = same as JULSEPP, except for March to April mean monthly temperatures in °F, and divided by two

MAYJULT = same as JULSEPP, except for May to July mean monthly temperatures in °F, and divided by three

MARMAYP = same as JULSEPP, except for March to May precipitation in inches.

reduce yields, while hot temperatures in June may increase yields. No other significant relationships were found with any other monthly weather variables.

The three equations for alfalfa, other hay and winter wheat show that all three are affected significantly by precipitation in the previous fall and previous December minimum temperature. The effect of previous fall's precipitation is as expected. Insulation from winterkill may be part of the reason for this effect.

The significant negative impact of December minimum temperature is not as expected. One possible reason for the negative sign on this variable is that cold temperatures may cause dormancy and consequent avoidance of later winterkill. Analysis of temperature variables for November through February showed that minimum, mean and maximum winter temperature variables all tend to be negatively associated with yields.

Temperatures in varying summer periods were found to have the expected negative effect on hay and winter wheat yields. July temperature has a significant negative effect on alfalfa yield. May through July temperature has a very significant negative effect on winter wheat yields. The negative effect of July through September temperature on yield of other hay is not significant. Winter wheat yield is positively associated with March to April temperature. This could be due to earlier spring emergence, reduced late winterkill, or both.

Precipitation in July through September is positively related to alfalfa yield. This may be due to a contribution to water needs of the crop, association with cool weather, or some other factors. March through May precipitation is negatively associated with winter wheat yield, perhaps due to rain and wind damage, increased disease incidence or associated cool temperatures.

The multivariate regression equations indicate the potential for crop yields to increase over time if climatic factors did not have adverse impacts. All crops except for oats and other hay show significant positive yield trends in the multivariate analysis. None of the time trends of Laramie County crops are significant in the simple regressions. Table 3-B shows the estimated yield increases for the crops with significant yield trends by expressing the annual yield increase as a percentage of the mean yield. The numbers indicate how much crop yield would increase if the weather variables were held constant. By themselves, the time trends show significant increases in crop yields. These increases would be attributable to technological, agronomic and management improvements.

Table 3-B. Yield Trends of Laramie County, Wyoming Irrigation Crops.

	Increase Per Year	1973-1982 Mean	As a Percent of Mean
irrig. winter wheat (bu)	1.06	37.03	2.9
barley (bu)	.85	60.71	1.4
alfalfa (ton)	.027	2.92	.9
dry beans (cwt)	.18	17.92	1.0
dryland winter wheat (bu)	.63	25.88	2.4

If a longer time period had been considered, weather fluctuations may have averaged out and a significant time trend may have been found with the simple regression. If weather factors are assumed to average out in the future, the estimated time trend should provide a good indication of changes in crop yields over time. Such information may be helpful in determining future revenues from farm production and in turn, provide some guidelines for management decisions.

In order to project yield increases for dryland wheat, Laramie County average dryland wheat yields (YD) are estimated as a function of year (YR) winter precipitation from November to February (NOVFEBP) previous September plus October precipitation (SEPOCTP), mean March temperature in °F (MART), and July precipitation in inches (JULP). As July precipitation is associated with hail, the expected sign is negative. The equation estimated with data from 1964 to 1980 is:

$$(20)\quad YD = \underset{(18.11)}{-39.97} + \underset{(.28)}{.63YR} + \underset{(1.16)}{.91NOVFEBP} + \underset{(.91)}{3.64\,SEPOCTP} + \underset{(.23)}{.45MART} - \underset{(.86)}{2.43JULP}$$

$$R^2 = .85 \qquad F = 9.21 \qquad DW = 1.00$$

Summary

Multivariate estimation of Laramie County irrigated crop yields shows significant yield trends from 1965 to 1982. The effect of most weather variables is as expected, with the exception of winter temperatures which are negatively associated with yields of winter wheat and hay. Electricity use for irrigation was not found to be positively associated with irrigated yields.

Cited References

Crop Reporting Service. Wyoming Agricultural Statistics, Cheyenne, 1978, 1983.

Hall, B.H. and R.E. Hall. 1980. TSP Time Series Processor User's Manual. Computing Center University of Western Ontario, London, Ontario, Canada.

U.S.D.A. 1981. Agricultural Statistics. Prepared under direction of Melvin L. Koehn, ESCS, U.S. Government Printing Office, Washington, D.C.

Wyoming Water Research Center. 1983. Water Resources Data System User's Guide. Revised by Barbara Drury and Anne Travis, Laramie.

APPENDIX 3

THE DEMAND FOR ELECTRICITY FOR IRRIGATION IN LARAMIE COUNTY, WYOMING

Introduction

Numerous authors have investigated irrigation's demand for electricity. Howitt et al. (1980) reviewed some of these studies and the problems involved. Linear programming has often been used to derive electricity demand curves for irrigation because of "the absence of observations over a wide range of prices." Econometric models have been used to estimate residential, commercial and industrial demand for electricity (E.U.R.D.S., 1977). Little if any work has been done with econometric estimation of irrigation demand for electricity. The purpose of this paper is to estimate a demand function for electricity for irrigation using econometric methods.

Laramie County lies in the southeast corner of Wyoming adjacent to Nebraska and Colorado. The climate in Laramie County is cool and dry with the majority of irrigated crop water needs met by irrigation. The primary crops irrigated are alfalfa, spring grains, corn, dry beans and potatoes. The county is served by the Rural Electric Company which also serves small parts of Colorado and Nebraska. Groundwater for irrigation is primarily from the Ogallala aquifer. The climate and soils in the western part of the county are not amenable to crop production.

Data

Data supplied by the Rural Electric Company shows some important historical trends in the area. Table 1-C provides data on electricity use, number of irrigation accounts, average horsepower and price charged per kilowatt-hour (kwh). From 1964 to 1969 there was little change in the number of irrigation accounts in the county. From 1969 to 1977 the number of irrigation accounts increased rapidly due to the acceptance of center pivot irrigation. In 1977 a moratorium was imposed on the drilling of new irrigation wells due to declining groundwater levels. The average rated horsepower increased rapidly over 1969 to 1977 due to requirements of the center pivot systems. Both the number of accounts and average rated horsepower stabilized considerably after the drilling moratorium was imposed.

Table 1-C. Data on Electricity Demand for Irrigation in Laramie County, Wyoming.

	Laramie County		Average Rated Horsepower			
Year	Electricity for Irrigation (Megawatt Hours)	Number of Irrigation Accounts	Total System	Laramie County[a]	Kilowatt Hours per Account per HP	Cost per kwh(¢)
1964[b]	3,404	149		23	993	1.5
65	2,563	148		23	753	1.5
66	3,415	151		23	983	1.5
67	2,684	158		23	739	1.5
68[b]	3,097	153		23	880	1.5
69	4,577	165		25.9	1,071	1.26[c]
70	4,832	177		28.8	948	1.24[c]
71	5,984	184		31.7	1,026	1.22[c]
72	6,229	190	39.0	34.6	948	1.23[c]
73	7,469	213	43.2	39.6	886	1.25[c]
74[b]	11,437	230	47.9	44.5	1,117	1.20[c]
75	14,103	282	54.4	49.5	1,010	1.22[c]
76	18,608	312	60.7	54.5	1,094	1.43[c]
77	19,433	324	61.6	55.4	1,083	1.51[c]
78	20,800	335	61.9	56.6	1,097	1.97
79	17,030	335	63.3	57.8	880	2.675
80	19,295	330	64.7	58.9	993	2.872
81	14,536	331	66.2	60.1	731	3.183
82	13,921	328	67.8	62.0	685	3.41
83[b]	10,864	311	70.7	63.8	548	4.17

a/ Estimated for 1964 through 1981.
b/ Data not used in analysis due to weather data deficiencies.
c/ Due to declining block structure over the period, estimate of average price is based on total electric use. Price may also vary due to rate changes during the season.

The price charged by Rural Electric for electricity actually declined in real terms from 1964 to about 1975. The rapid increase in electricity costs since 1976 has outpaced inflation.

The quantity of electricity demanded by the average irrigator in this study is kwh used per account per rated horsepower per year. As data were not available, it was necessary to make an estimate of rated horsepower for irrigators in Laramie County in order to calculate quantity demanded.

Average rated systemwide horsepower for the Rural Electric Company was made available for the years 1972 to 1983 (Table 1-C). Regression was used to estimate average rated horsepower over time before and after the moratorium on well drilling (Table 2-C). The estimate of average rated horsepower was adjusted downward by a factor of .91 to allow Laramie County irrigators a lower rated horsepower than the system average as indicated by data from 1982 and 1983. An average rated horsepower of 23 was obtained by judgment for the period 1964 to 1968 and is allowed to increase by 2.9 horsepower per year from 1969 to 1972 (Rural Electric Company, personal communication). Weather data were obtained from three weather stations in the county; Albin, Archer and Carpenter. Mean monthly temperature and monthly precipitation data were averaged over these same three weather stations in the analysis.

Methodology

Total electricity use for irrigation in Laramie County depends partially on number of irrigation pumps and the rated horsepower of the motors. For the individual irrigator the price of electricity, the expected price of the product and weather conditions should influence his use of electricity for irrigation.

Increased electricity price per kwh is hypothesized to influence electricity use negatively. A partial adjustment model is used to derive

Table 2-C. Equations to Estimate Average Rated Horsepower and Number of Irrigation Accounts in Laramie County, Wyoming.[a]

	R^2	F	DW
(1) HPE = -355.00 + 5.46 YR (22.51) (.30)	.99	322	1.42
(2) HPL = -38.646 + 1.294 YR (8.17) (.10)	.98	159	1.55
(3) AC = 345.113 - .017 HPC (1.193) (.0015)	.98	130	2.45

Variable Definitions

HPE = average rated horsepower systemwide for 1972 to 1976

YR = year, expressed as last two digits, i.e., 72 to 82

HPL = average rated horsepower systemwide for 1977 to 1982

AC = number of irrigation accounts in Laramie County, Wyoming, 1978 to 1982

HPC = demand charge per horsepower in dollars times estimated average horsepower for Laramie County times 100, all divided by the GNP implicit price deflator (1983 = 100)

[a] Standard deviation is given under each estimated parameter in parentheses.

short run and long run elasticities of demand. The lagged dependent variable is used as an independent variable. The long run demand coefficient is $B^* = B_1/(1-B_2)$ where B_1 is the estimated parameter on price per kwh and B_2 is the estimated parameter on the lagged dependent variable (Nerlove and Addison, 1958).

The equation used to estimate the number of irrigation accounts in Laramie County is shown in Table 2-C. Irrigators must also pay a "demand charge" based on the rated horsepower of their pump. As indicated by the significant coefficient on HPC, this charge may be a deterrent to contracting for seasonal irrigation service.

It can be argued on economic grounds that the "demand charge" should not be included as an independent variable affecting electricity use. This is because, once paid, the "demand charge" is a fixed cost invariant with respect to seasonal electricity use. On the other hand, irrigators may feel that, with higher demand charges, savings must be made by lower electricity use to stay within some allowable irrigation expense. The importance of the demand charge to electricity use is tested for by inclusion of this variable.

Weather is considered to be an important determinant of irrigation levels and consequent electricity use per irrigator per rated horsepower. Precipitation decreases the need for irrigation. Increased temperature should be associated with increased electricity demand through increased evapotranspiration. Weather data were obtained from three weather stations located at Albin, Archer and Carpenter in Laramie County. Mean monthly temperature and monthly precipitation data were averaged over these three weather stations in the analysis.

Increased crop prices are hypothesized to impact electricity use positively. Producers may respond to high crop prices by trying to increase yields through increased irrigation.

Several hypotheses relating the demand for electricity with structural change over time will be tested. There has been some changeover to low-pressure center pivot systems in recent years, and innovations in irrigation scheduling and other technologies should allow irrigators to use less electricity. A dummy variable for the period since the moratorium on well drilling (1978-1982) is used to test the hypothesis that, all else equal, irrigators were using less electricity per account per horsepower from 1978 to 1982.

By multiplying the dummy variable times electricity price, change in response to electricity price can be tested for. With higher electricity prices and increasing production costs from 1978 to 1982, irrigators might have become more responsive to price changes.

During the period 1969 to 1977, irrigators faced a declining block structure in the charge per kwh. Most center pivot irrigators would have easily passed the first block and, at the margin, were paying based on the lower rate associated with the second block. The question arises as to whether the season average price or the marginal second block price is the most important influence on quantity demanded. Price variables are constructed to reflect both the season average and second block price to see which most significantly influences demand.

Results

Weather variables were entered into ordinary least squares regression equation by order of seasonal occurrence in order to determine the amount of variability in electricity use that can be accounted for by successive weather variables.

Table 3-C provides four regression equations using weather data to the end of April, June, August and September, respectively. The equations account for 50, 75, 93 and 98 percent of annual variability in electric use per account per horsepower. This demonstrates the difficulty in predicting electricity use early in the irrigation season when weather cannot be predicted.

Equation (7) is the final demand equation. Crop prices were found to have an insignificant effect on electricity use and thus this variable is not included in Equation 7. Once irrigation is started, irrigators apparently water their crops according to water needs without much consideration of crop price.

Electricity demand is found to be insignificantly related to April temperature after the inclusion of September temperature. May to September

Table 3-C. Estimation of Electricity Demand Equations Showing Contribution of Weather Variables As Irrigation Season Progresses.[a]

		R^2	F	DW
(4)	KWACHP = 1298.36 − 141.44 KWC − .189 HP − 20.13 MAP + 5.08 AT	.50	2.75	
	(447.15) (47.13) (.136) (28.51) (9.54)			
(5)	KWACHP = 118.64 − 86.59 KWC − .222 HP − 27.77 MAP + 11.65 AT	.75	4.61	
	(831.06) (41.16) (.106) (23.35) (9.40)			
	− 34.91 MJP + 16.33 MJT			
	(18.94) (15.60)			
(6)	KWACHP = 2674.25 − 76.68 KWC − .093 HP − 20.56 MAP + 15.75 AT	.93	8.50	
	(2761.30) (30.32) (.083) (16.98) (6.80)			
	− 36.12 MJP + 16.29 MJT + 1056.9 JAP − 38.95 JAT − 75649.7 (JAP/JAT)			
	(16.91) (10.82) (946.6) (40.47) (64804.3)			
(7)	KWACHP = 6032.87 − 75.39 KWC − .14 HP − 30.47 MAP	.98	30.54	2.04
	(1487.51) (17.96) (.04) (8.60)			
	− 11.79 MJP + 24.93 MJT + 2329.9 JAP − 102.6 JAT − 163188 (JAP/JAT)			
	(7.28) (4.88) (545) (22.36) (37327)			
	+ 17.16 ST + .124 $KWACHP_{y-1}$			
	(3.23) (.125)			
	(4.45)			

a/ N = 16, R^2 = equation R^2, F = equation F-statistic, DW = Durbin-Watson Statistic. Estimated standard errors given below each estimated parameter in parentheses.

Table 3-C. (continued)

Variable Definitions

KWACHP = seasonal kilowatt-hours used per account per rated horsepower in Laramie County

KWC = average seasonal price charged per kilowatt-hour, divided by the GNP implicit price deflator (1983 = 100)

HP = average demand charge per irrigator; equals charge per horsepower times average rated horsepower, divided by the GNP implicit price deflator

MAP = $[(MRP_{al} + MRP_{ar} + MRP_{ca})/3] + [(APP_{al} + APP_{ar} + APP_{ca})/3]$

AT = $(APT_{al} + APT_{ar} + APT_{ca})/3$

MJP = $[(MYP_{al} + MYP_{ar} + MYP_{ca})/3] + [(JNP_{al} + JNP_{ar} + JNP_{ca})/3]$

MJT = $[(MYT_{al} + MYT_{ar} + MYT_{ca})/3 + (JNT_{al} + JNT_{ar} + JNT_{ca})/3]/2$

JAP = $[(JLP_{al} + JLP_{ar} + JLP_{ca})/3] + [(AGP_{al} + AGP_{ar} + AGP_{ca})/3]$

JAT = $[(JLT_{al} + JLT_{ar} + JLT_{ca})/3 + (AGT_{al} + AGT_{ar} + AGT_{ca})/3]/2$

ST = $(SPT_{al} + SPT_{ar} + SPT_{ca})/3$

MRP = March precipitation, inches
al = Albin weather station, WY
ar = Archer weather station, WY
ca = Carpenter weather station, WY
APP = April precipitation, inches
APT = April mean temperature, °F
MYP = May precipitation, inches
JNP = June precipitation, inches
MYT = May mean temperature, °F
JNT = June mean temperature, °F
JLP = July precipitation, inches
AGP = August precipitation, inches
JLT = July mean temperature, °F
AGT = August mean temperature, °F
SPT = September mean temperature, °F

mean temperatures are significantly and positively related to electricity use as expected. Precipitation from March to April and July to August are significantly and negatively related to electricity use. The lagged dependent variable is insignificant but is included in Equation 7 to allow for estimation of long run demand elasticity.

Table 4-C provides estimates of electricity use in response to weather variables. Due to the interaction term on July and August precipitation and temperature, response is evaluated at the mean of each; 3.69 inches and 68.94 degrees, respectively. The weather data indicates that the standard deviation of monthly mean temperature is two to five degrees with the lower deviation in the summer months. The standard deviation of monthly

Table 4-C. Estimated Impact of Precipitation and Temperature on Electricity Use and Expense.

Weather Variable	Coefficient[a/] on Variable	As Percent[b/] of Mean	Change in KWH Demand (1983)	Change in Electricity Cost/Account (1983)	Change in Utility Revenues (1983)
MAP	-30.47	-3.3	-595,254	$79.81	$-24,822
MJP	-11.79	-1.3	-233,935	31.37	-9,755
JAP	2329.9	-4.0[e/]	-732,162	98.17	-30,531
MJT	24.93	2.7	494,656	-66.33	20,627
JAT	-102.6	2.4[e/]	438,164	-58.75	18,271
ST	17.16	1.8	340,485	-45.65	14,198
JAP/JAT	-163188				

[a/] From Equation 7, the amount kwh per account per hp changes with a one unit change in the dependent variable.

[b/] The mean is 932.52 kwh per account per hp.

[c/] There were 311 accounts with an average rated horsepower of 63.8 in 1983. Electricity cost was 4.17¢ per kwh in 1983. Expressed as change per inch precipitation or degree F.

[d/] For Laramie County only.

[e/] All estimated responses from here to the right account for the interaction of July and August precipitation and temperature.

precipitation is around one to two inches. Combined with Table 4-C, this indicates that frequent, non-trivial annual variations in electricity demand occur due to variations in weather.

The coefficients on price per kwh, the demand charge and the lagged dependent variable can be used to estimate price elasticities of electricity demand. Average annual kwh use per account per horsepower over the entire period was 932.52. Average adjusted kilowatt hour price and demand charge per account were 3.14 and 489.34, respectively. The short run elasticity of demand with respect to kilowatt-hour price is -(3.14/932.52) X 75.39 = -.25. Short run elasticity with respect to the demand charge is -(439.34/932.52) X .14 = -.07. These inelastic demands indicate that irrigators are fairly unresponsive to price changes. A one percent increase in kilowatt-hour price will bring only a .25 percent reduction in electricity use. As expected, electricity demand is even less responsive to the "demand charge". After being paid, it is a fixed cost for the remainder of the season.

The partial adjustment lag uses the coefficient of adjustment to determine long run elasticity. The coefficient of adjustment equals one less the estimated coefficient on the lagged endogenous variable and is 1 - .124 = .876. The long run price elasticities on kilowatt-hour price and the demand charge are -(3.14/932.52) x (75.39/.876) = -.29 and -(439.34/932.52) x (.14/.876) = -.075, respectively.

These long run elasticities are quite close to the short run elasticities (-.25 and -.07). This suggests that most irrigator response to price change occurs within a year of the price change.

The total quantity of electricity demanded by Laramie County irrigators is

(8) Q_d = (KWH/AC/HP) * AC * HP

where Q_d is quantity demanded, KWH is kilowatt hours, AC is number of accounts and HP is horsepower. From Equations (2) and (3), HP has been rising over time. This increases power costs such that the number of accounts falls. An increase in the demand charge thus decreases demand through KWH/AC/HP and AC. The inelastic response to electricity price indicates that utilities might be able to control revenues by changing variable price. Irrigators may be unresponsive to electricity price because, within current price ranges, the value of the marginal product of yield produced may exceed the marginal cost of producing that incremental yield up to maximum yield.

Equation (7) predicts electricity use quite well over the period used for estimation. The size of the error terms ranges from 0 to 5 percent and exceeds 2% of predicted levels in only 3 out of 16 years. Unfortunately, this is of little help to electric utilities because weather is not known in advance. As a result, estimates of prediction error from Equations (4) to (6) in Table 3-C would be substantially larger.

Hypotheses related to structural change, the demand charge and declining block pricing are tested through equations presented in Table 5-C. Equation (9) excludes the demand charge variable HPC. An F-statistic less than half that for Equation (7) lends support to the hypothesis that the demand charge does influence quantity of electricity consumed. That is consistent with the notion that irrigators may try to compensate for a higher demand charge, a fixed cost, by reducing variable electricity use.

Equation (10) allows for a dummy slope shifter on electricity price for the period 1978 to 1982. The insignificance of the variable KWHDUM and a lower equation F-statistic, relative to Equation (7), indicates that irrigators have not significantly altered their response to electricity price in current years. If anything, the positive sign on KWHDUM indicates that irrigators were less responsive to electricity price from 1978 to 1982 than in previous years.

Table 5-C. Estimation of Electricity Demand Equations with Alternative Functions to Test for Some Hypotheses Related to Electricity Demand Structure.

	Equation	R^2	F
(9)	KWACHP = 5830.9 - 63.69KWC - 26.00MAP	.95	13.18
	(2345.2) (27.73) (13.39)		
	- 17.09MJP + 24.44MJT + 2165.3JAP - 98.66JAT		
	(11.17) (7.69) (857.1) (35.22)		
	- 152575(JAP/JAT) + 14.97ST + .16$KWACHP_{y-1}$		
	(58663) (4.97) (.20)		
(10)	KWACHP = 6113.42 - 87.44KWC + 12.02KWHDUM - .217HP	.99	24.95
	(1574.85) (25.67) (17.26) (.121)		
	- 29.31MAP - 8.87MJP + 26.3MJT + 2387.7JAP		
	(9.24) (8.75) (5.5) (582.1)		
	- 103.02JAT - 167044 (JAP/JAT) + 16.38ST + .08$KWACHP_{y-1}$		
	(23.61) (39799) (3.59) (.15)		
(11)	KWACHP = 6023.94 - 91.02KWC - .24HP + 54.07DUM	.99	29.27
	(1451.5) (22.41) (.10) (48.34)		
	- 27.77MAP - 7.73MJP + 26.6MJT + 2372.4JAP		
	(8.74) (7.98) (4.9) (533.8)		
	- 101.22JAT - 165934 (JAP/JAT) + 16.02ST + .05$KWACHP_{y-1)}$		
	(21.85) (36505) (3.31) (.14)		
(12)	KWACHP = 6727.8 - 57.02KWCA - .106HP - 31.92MAP	.98	30.13
	(1506) (13.7) (.04) (8.70)		
	- 12.28MJP + 26.42MJT + 2614.6JAP - 116.6JAT		
	(7.27) (4.93) (550.1) (22.58)		
	- 182770 (JAP/JAT) + 17.47ST + .21$KWACHP_{y-1}$		
	(37627) (3.26) (.12)		

Table 5-C. (continued)

Variable Definitions
(See Table 3)

KWHDUM = DUM x KWC

DUM = 1 if year is 1978 to 1982, = 0 if year is 1964 to 1977

KWCA = average seasonal price charged per kilowatt-hour for the lowest priced block if declining block was used, divided by the GNP implicit price deflator (1983 = 100)

To test if electricity use was more or less in the period 1978 to 1982 a dummy variable was employed in Equation (11). Although the variable is not significant ($\alpha = .05$), the positive sign on DUM indicates that electricity use per account per horsepower may have increased in the period 1978 to 1982, even with conversion to low-pressure center pivots.

In Equation (12) the electricity price variable is the second block price for the period 1969 to 1977. The slightly larger T-statistic on the price variable in Equation (7) indicates that average price paid over the two blocks is a better indicator of demand than price paid for the second block, although the difference is certainly not significant.

Summary

The results indicate that weather variables can explain a large proportion of variation in demand for electricity for irrigation. Electricity use appears to have been inelastic with respect to electricity prices, and the effect of crop prices on the amount of electricity used is insignificant. With useful long-term weather predictions, utilities might be better able to predict electricity use. This has implications for pricing and production policies of the utility.

Hypotheses that irrigators were more price responsive in the period 1978 to 1982 than in previous years cannot be substantiated. Calculated long run demand elasticities are very close to short run elasticities indicating that most response of irrigators to price changes will occur within a year. Both long and short run elasticities suggest inelastic response to electricity prices.

The insignificance of crop price and the inelastic response to electricity price may not continue in the future. In the past, increasing numbers of irrigation accounts was due largely to strong crop prices, low energy prices and some subsidy for irrigation development. With increasing electricity prices, decreasing groundwater levels and low crop prices, some producers may be forced out of business. This could change the entire structure of response to prices.

Cited References

Economic Report of the President, February 1984.

Electric Utility Rate Design Study. 1977. "Rate Design and Load Control: Issues and Directions." A Report to the National Association of Regulatory Utility Commissioners, Palo Alto, California.

Howitt, Richard E, William D. Watson and Richard M. Adams. 1980. "A Reevaluation of Price Elasticities for Irrigation Water." Water Resources Research, Vol. 16, No. 4, pp. 623-628, August.

Mann, Roger, James J. Jacobs and Douglas R. Franklin. 1984. "An Analysis of Irrigation Strategies, Crop Yield Response and Farm management Under Alternative Electricity Rate Structures and Declining Groundwater Levels." Unpublished manuscript in progress, Division of Agricultural Economics, University of Wyoming, Laramie.

Nerlove, Marc and William Addison. 1958. "Statistical Estimation of Long-run Elasticities of Supply and Demand." Journal of Farm Economics Vol. XL, No. 4, pp. 861-880, November.