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## I. Introduction

Irrigation is a rapidly growing component of Minnesota agriculture. Irrigated land in Minnesota increased from about 1,500 acres in 1941 to 20,000 acres in the early 1960's to about 44,000 acres in 1970. Spurred on in part by very dry years in the mid 1970's farmers expanded irrigation rapidly until in 1982 more than 315,000 acres or 1.6% of harvested land was irrigated (Census of Agriculture, 1982). About 2,100 farms had at least some irrigated land in 1982. This was 2.3% of all farms; while in 1969 about .5% of all farms had at least some irrigated acreage (Census of Agriculture, 1982).

Irrigation consumes a large amount of water in the state. The Water Planning Board estimated that in 1976 irrigation consumed 26.7% of water used and that by 1990 irrigation would account for 46% of all water consumed in Minnesota (Water Resources Research Center, 1980, pp. 23, 33).

Currently most irrigation occurs in central Minnesota to the northwest of Minneapolis and in Dakota county to the southeast of St. Paul. Twelve counties in these areas accounted for almost three fourths of Minnesota's irrigated acreage in 1982. Corn led the crops in irrigated acreage in 1982 with 54%. Soybeans were second with 13%, followed by hay crops with about 7% and potatoes with 6%. The remaining 20% of irrigated land was devoted to a variety of enterprises such as small grains, vegetables, dry edible beans, sugar beets, orchards, and nurseries.

The relative importance of irrigation to Minnesota depends on one's viewpoint. Irrigation is obviously important to those farmers who have invested in irrigation systems as well as to the communities where irrigated agriculture is concentrated. Because of the large proportion of water consumption going to irrigation, most water users in the state are at least indirectly affected by future trends in irrigation water use. Consequently, other consumers in the state as well as irrigators would benefit from increasing irrigation efficiency.

### *Problem Statement*

Increased irrigation efficiency can provide social and individual benefits by freeing additional water for other uses, increasing production from irrigated agriculture, and raising net returns from irrigated enterprises. Increasing producer efficiency of water use is not always synonymous with increasing social efficiency. For example, social efficiency requires use of water to the point where its expected marginal return equals its marginal social cost. However, a risk averse producer might wish to use more than the socially optimal amount of water to insure against loss from abnormally dry conditions. This study does not focus on these possible conflicts; rather, the focus is on information which enables better irrigation scheduling and on pumping restrictions, both of which could increase the efficiency of resource use in irrigation and make both producers and society better off.

Irrigators' objectives with respect to irrigated enterprises may include increasing expected returns and reducing the variability of returns. They are usually somewhat uncertain about the optimal timing and amount of irrigation application needed to attain these objectives. Technological developments which improve our ability: 1. to estimate the amount of plant available water in the soil; and, 2. to predict future weather conditions affecting crop water demand may reduce this uncertainty and improve scheduling. The enhanced scheduling may allocate water more precisely in accordance with crop needs, increasing irrigation efficiency and improving irrigators' distributions of net returns. The question asked in this study concerns how much such information is worth to irrigators. The irrigator's attitudes toward risk may affect the value of information, especially if information makes the distribution of returns less variable.

Those supplying resources to irrigators are also interested in increasing the use efficiency of these resources. This is true of utility companies which supply electrical power for pumping irrigation water.[1] Many utility companies have attempted to even out demand on their generating capacity, and thus use it more efficiently, by shutting off power to irrigators for selected hours of the day. In return for cooperating with this type of load management program, irrigators are given a discount on their electricity charge. Both irrigators and utility companies are interested in the amount of incentives which must be offered to irrigators so that the pumping restrictions caused by load management do not make them worse off. Very likely, the discount required depends on the soil water-holding capacity, the pumping capacity of the irrigation system, and characteristics of the irrigator, such as risk aversion and amount of attention devoted to scheduling management.

*Objectives*

The objectives of the research presented here are:

1. To develop a methodology for evaluating the effects of better information for scheduling irrigation as well as the effects of limitations on the amount of water which can be pumped per day. This methodology should account for the important characteristics of the economic environment, the farm, and decisionmakers which might affect how changes in irrigation efficiency are viewed. These characteristics would include random output prices, nonirrigated enterprises, and nonneutral producer risk preferences.
2. To determine how the value of information is affected by quality of information and by producer risk aversion.
3. To show the effects of pumping restrictions on net returns and irrigator expected utility.

## II. A Conceptual Model for Evaluating Irrigation Efficiency

Consider the computation of net income for a farming operation producing both irrigated and nonirrigated crops. Before-tax-accrual net farm income is calculated in this analysis because it is assumed to be more relevant to decision-maker utility than other measures of income that could be used. Before-tax net farm income (BTNI) is calculated as:

$$(1) \qquad BTNI = (DY + IY)^{*}P + OFI - IC - YC - OC - PC$$

This analysis assumes the crop mix and the acreage of each irrigated crop is fixed. Thus DY and IY represent output (yield per acre times number of acres) of nonirrigated and irrigated crops, respectively. P is a vector of corn, soybean, and rye prices. The remaining terms are off-farm income (OFI), irrigation variable costs including electricity, lubrication and repairs (IC), yield-related costs including hauling, drying and storage (YC), overhead costs (OC), and production costs which are unaffected by the level of irrigation (PC).

Although BTNI is subject to uncertainty, irrigators can significantly affect the distribution of BTNI through their irrigation scheduling decisions. These decisions about the timing and amount of water to apply will likely be affected by the amount of soil water and weather information available as well as pumping restrictions. The model developed here shows how the effects on irrigators of changing irrigation scheduling strategies can be quantified. This model is used to value information or quantify the losses imposed by pumping restrictions.

The decision maker's utility is assumed to be a function of the distribution of BTNI. Before information is acquired or pumping restrictions are imposed, a BTNI distribution labeled G(X) is obtained. After the information is acquired or pumping restrictions are imposed, a distribution F(X) is obtained. The gain to the irrigator from better information (or loss from the imposed pumping restrictions) is the constant amount V which must be added to (or subtracted from) each element of F(X) in order to make the expected utility of F(X) equal to the expected utility of G(X).

If risk neutrality is assumed, the effects of better information or pumping restrictions can be quantified as the difference in per acre expected net returns on irrigated crops before and after the restrictions are imposed or information is acquired. Net returns (NR) can be calculated using only those costs and returns affected by changes in irrigation scheduling as shown in (2)

$$(2) \qquad NR = P^{*}Y - IC - YC$$

where P represents a vector of corn and soybean prices and Y a vector of irrigated corn and soybean yields. Rye is not included as it is not an irrigated crop.

When risk preferences are nonneutral, the amount V is derived by comparing F(X) with G(X) using generalized stochastic dominance (GSD) (Meyer 1977a). This method compares BTNI distributions and determines how much one scheduling strategy is preferred to another for groups of producers whose coefficients of absolute risk aversion lie within specified bounds over the range of outcomes evaluated. The advantage of the approach is that a specific utility function need not be assumed; rather, the analysis can be applied to as large (small) a group as desired by expanding (reducing) the absolute risk aversion interval.

In the case of information evaluation, the GSD method provides a lower bound on the estimated value of information; information may be worth more than this to some but not all decisionmakers characterized by absolute risk aversion coefficients in the specified interval. This lower bound is that amount by which each element of a BTNI distribution generated with information can be lowered (or, stated another way, the amount the distribution can be shifted to the left) before it no longer dominates a BTNI distribution generated without information. The first step in calculating the value is to select a decision rule i for scheduling irrigation and to calculate the value of information $V_i$ using this rule. This is done by finding an amount $V_i$ such that inequalities (3) and (4) are satisfied:

$$(3) \qquad \int_0^1 (G(X) - F_i(X - V_i))U'(X)dX > 0$$

$$(4) \qquad \int_0^1 (G(X) - F_i(X - V_i - Y))U'(X)dX \leq 0$$

X represents BTNI; $F_i$ and G are cumulative BTNI distributions generated with and without information, respectively; U is a von Neuman Morgenstern utility function; $V_i$ is the value of information which generates $F_i$ using decision rule i; and Y is a small positive amount. The restriction is imposed that the agent's absolute risk aversion coefficients lie between specified upper and lower boundaries $r_2(X)$ and $r_1(X)$, as shown in (5):

$$(5) \qquad r_2(X) \geq -U''(X)/U'(X) \geq r_1(X)$$

The value of information depends on how it is used. An accurate measure of the value of the information is only obtained if the decision rule used maximizes the value. An attempt is made to maximize the value of a given level of information by searching over a series of possible decision rules and choosing the one which maximizes the value as shown in (6):

$$(6) \qquad V_i^* = \max(V_i : i = 1 \ldots n)$$

where n is the number of decision rules evaluated for a given level of information. In the no-information case, there is no search of decision rules. The no-information strategy, to be described later, was derived in consultation with experts familiar with local irrigation practices and is intended to reflect irrigation scheduling based on very little soil water or weather information. Thus, G, the distribution of BTNI derived with no information, is not subscripted.

The method used for the evaluation of pumping restrictions is slightly different. The difference arises because the questions being asked are not the same in the two cases. When evaluating information the question is, "How much can be deducted from each element of a distribution generated with information and still leave the irrigator better off than if he had no information?" In the case of pumping restrictions the question is, "How much must be added to each element of a net returns distribution generated with pumping restrictions to make the irrigator at least as well off as when pumping capacity is unrestricted?" This answer is approximated by an amount V such that inequalities (7) and (8) are simultaneously satisfied:

$$(7) \qquad \int_0^1 (F_j(X) - G_i(X + V))U'(X)dX \geq 0$$

$$(8) \qquad \int_0^1 (F_j(X) - G_i(X + V - Y))U'(X)dX < 0$$

In this case, F and G refer to cumulative BTNI distributions generated without and with pumping restrictions, respectively. The subscripts j and i refer to decision rules for initiating irrigation which stochastically dominate any other decision rule investigated for the unrestricted and restricted pumping scenarios, respectively. After the best decision rule under no load management, j, and the best rule under load management, i, are found, distributions derived from these two strategies are compared and used to solve iteratively for the required compensation, V. In constrast to equations (3) and (4), V is added to X because the goal is to find how much must be paid to make every irrigator whose risk preferences are within the specified intervel at least as well off with pumping restrictions. The amount, V, represents an upper limit on the required discount and may exceed the amount required for some agents in the specified interval.

A conceptual model has been described for comparing scheduling strategies for irrigators with nonneutral risk preferences. The model is used to evaluate the impact of better information or pumping restrictions on irrigator utility. The next section describes the empirical methods for implementing the model.

## III. Empirical Methods

### *The Representative Farm*

A representative crop farm with irrigated and unirrigated enterprises is constructed to reflect conditions in southwestern Minnesota.[3] The farm consists of 320 acres of sandy, low water-holding capacity soils and 320 acres of fine-textured soils. On the 320 acres of sandy soils are two center pivots each capable of irrigating 130 acres. A corn-soybean rotation is followed on the irrigated and unirrigated land with the exception of the unirrigated sandy soils which are planted to rye. The breakdown of land by use is as follows:

| | |
|---|---|
| 150 | acres unirrigated corn |
| 150 | acres unirrigated soybeans |
| 130 | acres irrigated corn |
| 130 | acres irrigated soybeans |
| 50 | acres unirrigated rye |
| 30 | acres roadway and farmstead |
| Total 640 | acres |

The two center pivots owned by the farm[4] are each capable of pumping 800 gpm at 50 psi pressure. In the case where pumping capacity is varied to test the effects of pumping restrictions, a 600 gpm system is also included in the analysis. With 800 gpm capacity, the system can apply .75 of an inch of effective[5] water to 130 acres over a three-day period with allowance for 2.5 hours of down time each day.

A debt-asset ratio of 20% for depreciable assets and 15% for real estate is assumed. This compares with a national real estate debt-asset ratio of 13% in 1982 (Melichar).[6]

Total overhead costs (OC) for machinery, land, irrigation equipment, and other miscellaneous expenses sum to $77,068.64. Crop production expenses (PC) assumed to be unaffected by level of irrigation or yield total $49,511.60. Thus, total expenses to be incurred regardless of yield or irrigation amount come to $126,580.24. These are not all cash expenses because depreciation is included.

Variable irrigation costs (VC) are imposed for electricity, repair, and lubrication and total $1.94 per effective acre inch applied in addition to a monthly demand charge[7] of $6.25 per kw for each month in which the system operates one day or more. An energy charge of $.04 per kwh is used. The system is assumed to have a peak demand of 47.4 kw.

Yield-related costs (YC) consist of charges for grain drying, hauling, and storage. Drying costs for corn are set at $.20 per bushel, while variable hauling costs for corn, soybeans, and rye are $.047, $.06, and $.047 per bushel, respectively. Storage costs are $.03 per month per bushel. Corn, soybeans, and rye are assumed to be stored five, four, and three months, respectively.[8] Total yield-related costs per bushel for corn, soybeans, and rye are $.397, $.18, and $.137, respectively.

Distributions of output prices were generated based on five-year price projections made by the Minnesota Agricultural Extension Service in 1983. These price projections, which took into consideration per capita demand and production costs of the commodity, were used as the long run forecast prices. Random deviations from the forecast price, which reflect year-to-year price variability, are also required. These deviations were obtained from series of statewide season average prices between 1958 and 1982 for each commodity (corn, soybeans, and rye) inflated to 1983 levels. A constant was subtracted from each price in the historical series so that its mean equaled the 1983 price forecast by the Minnesota Agricultural Extension Service. The purpose of the adjustment was to provide a distribution of prices with mean equal to the five-year price forecast and with variability based on an historical series of prices. These adjusted historical price distributions were used to generate 11 random price vectors, with each vector containing a corn, soybean, and rye price. The vectors were generated following a procedure developed by King, which considers correlations among prices of different crops.[9] Eleven random price vectors were generated and are shown in Table 1.

Off-farm income was set at $3,000 per year. The next section completes the description of the components of equation (1) by showing how yields are simulated based on variable weather, crop varieties, soil water-holding capacities, and irrigation decisions.

*Crop Growth and Yield Simulation*

A plant growth simulator developed by Hill and Hanks (1978; also Hill et al., 1979) is used to predict corn and soybean growth and yield as a function of moisture stress. The model computes daily soil water balances based on inputs in the form of rainfall and irrigation and extractions due to surface evaporation, plant transpiration, and deep percolation. Daily potential evapotranspiration (the amount of water which could be given off by the plant if soil water were not limiting) is calculated using daily temperatures and solar radiation. Actual daily plant transpiration is equal to or less than potential transpiration depending on daily soil water balances. Corn phenological development is based on daily average temperatures while soybean development depends on temperature and daylength. Yield is a function of the ratios of cumulative actual and potential transpiration for selected growth stages.

The model was validated with soil water, crop, and yield data from several experimental and farm sites in Minnesota. The model did a reasonably good job of predicting crop development based on the few phenological observations available. Soil water levels predicted by the model were also fairly close to actual readings in most cases for the low water-holding capacity soils of concern in this study. However, comparison of actual and predicted yields showed that the model has a tendency to underestimate the affects of moisture stress on yields in Minnesota.

To deal with the yield prediction problem, variations of the corn and soybean yield prediction equations specified by Hill and Hanks were statistically estimated using weather, irrigation, and yield data from several Minnesota sites. The estimated equation for corn is (t statistics are in parentheses):

$$(9) \qquad Y_c = \underset{(78.6)}{155.6} * (T/Tp)^{\underset{(10.6)}{2.61}}$$

$Y_c$ refers to estimated corn yield in bushels per acre; T is cumulative daily actual plant transpiration estimated by the Hill model for the tassel, silk, dough, and early dent stages; and Tp is cumulative daily potential transpiration for these stages. The R-squared value for the equation is .81. The estimated equation for soybeans is:

$$(10) \qquad Y_s = \underset{(50.6)}{49.6} * (T/Tp)^{\underset{(4.34)}{1.067}} * SYF$$

$Y_s$ is estimated soybean yield; T and Tp are cumulative actual and potential plant transpiration for the beginning pod fill, end flowering, and physiological maturity stages; and SYF refers to soybean yield factor.[11] The R-squared value for the estimated equation is .79.

Table 1. Corn, Soybean, and Rye Prices Used to Generate Income Distributions[a]

| | Crop Price | |
|---|---|---|
| Corn | Soybeans | Rye |
| | (dollars per bushel) | |
| 3.33 | 7.96 | 2.78 |
| 3.33 | 7.87 | 2.88 |
| 2.51 | 6.43 | 2.52 |
| 2.23 | 5.61 | 2.52 |
| 2.48 | 6.85 | 2.45 |
| 3.31 | 7.95 | 2.74 |
| 2.60 | 6.86 | 2.47 |
| 2.74 | 7.77 | 2.55 |
| 2.52 | 6.54 | 2.61 |
| 2.72 | 6.10 | 2.62 |
| 2.62 | 6.78 | 2.48 |

[a] Prices are based on expected corn and soybean prices of $2.90 and $6.85, respectively, projected by the Minnesota Agricultural Extension Service. Price deviations were randomly generated from distributions of statewide seasonal average prices observed for 1958-1982. Prices reflect a discount for transportation differential between southwest Minnesota and Minneapolis. The discount used is $.25 for corn and rye and $.175 for soybeans. Local hauling, drying, and storage costs were not deducted from the output price.

This version of the Hill model is used to simulate yield as a function of variable weather and irrigation application decisions. Weather variability is introduced by using daily weather data for 1973-1984 from the Lamberton Experiment Station. Each year of weather is assumed to be an independent, equally likely event. Estimates of unirrigated corn and soybean yields corresponding to each year of weather data were obtained from Lamberton Experiment Station fertility and varietal trial results which were most appropriate for the cultural practices on the farm being modeled. Rye yield estimates were obtained from average yields reported by the Minnesota Agricultural Statistics Reporting Service for the Southwest District. Each year of weather data is used with irrigation data to generate estimates of T, Tp, and yields. Each set of yield estimates is used with each random output price vector to generate a net income for the net income distribution.

### *Soil Types Used in the Study*

The types of soils used for irrigation in Minnesota vary. The *Irrigation Guide for Minnesota* (U.S. Department of Agriculture) lists 11 soil groups suitable for irrigation. These groups were ranked by available water-holding capacity (AWC) and a group near the lower end (Group 8) and one near the middle (Group 11) were selected. They have AWC's of 3.1 and 4.3 inches, respectively, in a three-foot profile. The 3.1 inch AWC is used to evaluate information while both the 3.1 and 4.3 inch AWC soils are used to evaluate pumping restrictions.

### *Soil Water and Weather Information Scenarios*

Irrigation strategies based on various combinations of three levels of soil water and three levels of weather information are compared with a "naive" strategy, which might be used by an irrigator with very little information. The naive strategy was developed by consulting with several experts familiar with Minnesota scheduling practices.[12] Details of the strategy are presented in Table 2.

Three levels of soil water information included are: 1. knowledge revealed by using the Checkbook method (Werner); 2. knowledge of actual soil moisture with an error not to exceed plus or minus .3 of an inch; and, 3. perfect knowledge of current soil moisture.

The Checkbook method involves recording the crop emergence date and estimating soil moisture at the beginning of the irrigation season. Daily maximum temperatures, irrigation applications, and rainfall are also recorded. Daily crop water use is estimated based on maximum air temperature, crop type, and number of weeks since crop emergence. Daily soil water balances are calculated by subtracting daily use and adding rainfall or irrigation.

Irrigators are also advised to make periodic checks of actual soil moisture as a way to correct Checkbook estimates (Werner). Weekly corrections for the 3.1 inch soil are simulated by rounding the soil water level projected by the Hill model to the nearest of the following levels: 3.0, 2.4, 1.8, 1.2, 0.6, and 0.0 inches. The rounded figure becomes the new Checkbook estimate. This is a way of approximating how a farmer might update soil water estimates each week based on the feel and appearance of the soil.

With intermediate soil water knowledge, actual soil water levels predicted by the model plus or minus an error term are used as soil water estimates. The errors are assumed to be uniformly and randomly distributed and constrained to not exceed 10% of soil AWC.

Limits are placed on the amount of error which can be made with the Checkbook method or intermediate soil water information. When the soil is saturated, soil water estimates are adjusted to the correct level. For corn if the soil has been at or below 50% of AWC (the level at which stress begins in the Hill model) for at least three days, the readings are corrected if necessary. These constraints are imposed to reflect observations a farmer could make by walking through the field.

With perfect soil water information, the daily soil water balance calculated by the Hill model is used as the soil water estimate for scheduling. Although perfect soil water knowledge is unattainable with current technology, the scenario is included to show the increased return from technology developed to achieve such accuracy and provides a benchmark for evaluating the efficiency of other soil water information levels.

Table 2. Description of the Naive Irrigation Scheduling Strategy for Corn and Soybeans

| Crop | Stage of Growth | Scheduling Strategy |
|---|---|---|
| Corn | planting--emergence | 1" applic. at planting only during very dry conditions |
| | emergence--ten leaf | no irrig. |
| | ten leaf--tassel | low frequency irrig[a] |
| | tassel--silk | high frequency irrig[b] |
| | silk--dough | high frequency irrig. |
| | dough--beginning dent | low frequency irrig. |
| | beginning dent--maturity | no irrig. |
| Soybeans | planting--emergence | 1" applic. at planting only during very dry conditions |
| | emergence--beginning flower | no irrig. |
| | beginning flower--beginning pod fill | high frequency irrig. |
| | beginning pod fill--end flower | high frequency irrig. |
| | end flower--maturity | low freq. irrig. 1st three weeks of period only |

[a] Low frequency irrigation assumes .75 of an inch effective water is applied every five days unless rainfall during previous three days exceeded .5 of an inch. If rainfall exceeded .5 of an inch, irrigation is postponed one day and the criterion is checked again the following day.

[b] High frequency irrigation assumes .25 of an inch daily crop water use. Rainfall offsets crop water use or recharges soil. When soil is .75 of an inch depleted, .75 of an inch effective water is applied.

Three levels of future weather knowledge are evaluated: 1) no knowledge, in which case irrigation decisions are based solely on current soil water levels; 2) no knowledge of future precipitation but perfect knowledge of potential transpiration (Tp) for the next three days; and 3) perfect knowledge of Tp and rainfall amounts for the next three days. In the crop model, potential transpiration is determined by crop stage of growth, solar radiation, and temperature. Thus, knowledge of Tp presumes knowledge of these variables.

Six combinations of soil water and weather information are evaluated:

1. Checkbook soil water--no weather
2. Intermediate soil water--no weather
3. Intermediate soil water--future Tp, no rainfall
4. Perfect soil water--no weather
5. Perfect soil water--future Tp, no rainfall
6. Perfect soil water--perfect weather

These scenarios are compared with the benchmark or naive strategy.

### *Pumping Restrictions*

Some utility companies may wish to implement load management programs whereby the amount of time the pump can be operated each day for irrigation is limited. In this study, four load management scenarios are analyzed: 1) no constraints on pumping; 2) a five-hour shutoff, four days per week (20 hours weekly); 3) a seven-hour shutoff, four days per week (28 hours weekly); and 4) an eight-hour shutoff, seven days per week (56 hours weekly). The five and seven-hour shutoffs are being considered by at least one utility company in Minnesota. The eight-hour restriction is designed to simulate a very severe power curtailment.

### *Modeling Irrigation Decisions*

The season for irrigating corn begins three days before the ten-leaf stage is reached and ends after reaching the beginning dent stage. These dates normally correspond to the period from late June to late August. The soybean irrigation season begins three days before the flowering stage and ends with physiological maturity. This period usually lasts from early July to early September. The included growth stages are those in which crop moisture stress results in yield reductions according to the Hill model. In addition, irrigation at planting occurs in years of very dry planting conditions.

Several levels of soil and weather information are being considered. However, regardless of how much information the irrigator has, he/she must still make a decision whether or not to irrigate on any given day based on the available information. To get a true measure of the value of better information or the effect of pumping restrictions, one must optimize the choice of decision rule for the level of information and available pumping capacity.

The decision rule focuses on current or future soil water depletion levels at which irrigation is "triggered". For example, when intermediate soil water and future Tp information is available, the decision rule is geared to the depletion level to which soil water will fall over the next three days based on the available information and given that no irrigation occurs. When only current soil water information is available, decisions are tied to current soil water depletion estimates based on the available information. For each level of information or pumping restriction, possible depletion levels at which to trigger irrigation are searched at five percentage point intervals. The depletion which yields the stochastically dominant distribution of net returns for a given pumping scenario or level of information is then used as the decision rule when comparing that information or pumping scenario with others. An exception to this is irrigation based on the naive strategy, i.e., the benchmark information level. In that case, only the strategy shown in Table 2 is evaluated.

### *Producer Risk Preferences*

The method for comparing distributions generated with varying levels of information or pumping restrictions requires specification of upper and lower bounds on producers' coefficients of absolute risk aversion. Meyer (1977b) showed the theoretical basis for determining bounds on a producer's absolute risk aversion coefficient based on the producer's choice of outcome distributions. King and Robison described a practical interview procedure for obtaining estimates of these bounds.

Wilson estimated Minnesota swine producers' risk aversion coefficients using Meyer's criterion. He reviewed several previous attempts to elicit utility functions from farmers and determined the risk aversion coefficients implied by the functions. For example, Lin, Dean, and Moore elicited utility functions from operators of six large farms in California which implied risk aversion coefficients of -.0001 to .0006 at an average annual net income of $100,000. Knowles elicited utility functions from four southwest Minnesota farmers. Evaluating these functions at $20,000 and $100,000 produced risk aversion coefficients between 0 and .0003. Based on his survey of previous studies, Wilson hypothesized that the majority of swine producers interviewed would have risk aversion coefficients within a range of -.0003 to .0003. His results showed that absolute risk aversion coefficients of 69% of the swine producers with identifiable risk attitudes fell within an interval of -.0002 to .0003. He stated, "The results substantiate the hypothesis that the majority of the producers fall within a relatively narrow band in risk aversion space" (p. 86). Additionally, a small group (11%) fell in a band ranging to extreme risk preference (-.0002, -∞) and another small group (13%) fell in an interval ranging to extreme risk aversion (.0003, + ∞).

Risk preferences are included in this analysis by calculating the value of information for several risk aversion intervals. Wilson's results provide a guide to specifying relevant intervals which reflect the distribution of producers' absolute risk aversion coefficients. Large intervals are used for extreme ranges of risk aversion where Wilson found a small frequency of producers. The interval -.001 to -.0002 is chosen to represent the extreme risk preferrer. The .0003 to .0015 interval is selected to represent extreme risk averters.

The -.0002 to .0003 risk aversion interval where Wilson found most producers in his sample, is subdivided into three approximately equal intervals: -.0002 to -.00005, -.00005 to .0001, and .0001 to .0003. This set of five intervals is used to test the sensitivity of the value of information to the level of producer risk aversion. Comparison of net income distributions for varying levels of risk aversion is done using a FORTRAN program, SDRF, written by King.

## IV. The Value of Information in Increasing Irrigation Efficiency

### *Effects of Information on Net Income, Yields, and Water Use*

The impact of information is measured in terms of how it affects the distribution of BTNI defined in (2). The previous section discussed how random weather and output prices, information levels, and irrigation strategies are combined to generate distributions of BTNI.

Information and risk attitudes affect the timing and amount of irrigation water applied, which in turn affect irrigated corn and soybean yields. Yields and irrigation amounts for the information scenarios are summarized in Table 3. Irrigation with the no-information benchmark strategy resulted in average corn and soybean yields of 154.03 and 48.69 bushels, respectively, and an average irrigation application of 8.12 inches. As indicated by equations 8 and 9, no moisture stress would result in estimated yields of 155.6 bushels of corn and 49.6 bushels of soybeans. Thus, for all levels of information and risk aversion, the preferred strategies are those which keep yields close to a maximum. However, better information allows the irrigator to obtain near maximum yields with somewhat less water. In the case of the risk neutral irrigator, average per acre irrigation amounts fall from 7.5 inches for the Checkbook scenario to 6.84 inches for the perfect soil and weather information case.

The results show some tendency for irrigation application amounts to increase with risk aversion reflecting the fact that with more risk aversion the preferred decision rules call for beginning irrigation sooner, i.e., at lower soil water depletion levels. With four of the information scenarios, average irrigation applications are higher for the risk averse intervals than for risk neutrality. However, two exceptions are noted with the most risk seeking interval: the intermediate soil, future Tp and perfect soil, future Tp information scenarios. In these two cases, irrigation applications are higher for the risk seeker than for the risk neutral irrigator. Because the most risk-seeking interval is sensitive to how the irrigation strategy affects the best outcome, it would be desirable to have more years of weather data to further test the relationship between irrigation water use and the most risk-seeking interval.

**Table 3.** Mean Whole-Farm Before-Tax Net Income, Per Acre Irrigated Corn and Soybean Yields, and Per Acre Irrigation Amounts With Various Levels of Information and Risk Aversion[a]

| | Coefficient of Absolute Risk Aversion Interval | | | | | |
|---|---|---|---|---|---|---|
| | Risk Seeking | | Risk Neutral | | Risk Averse | |
| Information Level | -.001 to -.0002 | -.0002 to -.00005 | -.00005 to .0001 | 0.0 to 0.0 | .0001 to .0003 | .0003 to .0015 |
| Checkbook | 47289.00 | 47289.00 | 47289.00 | 47289.00 | 47214.00 | 47214.00 |
| | 154.74 | 154.74 | 154.74 | 154.74 | 155.47 | 155.47 |
| | 48.92 | 48.92 | 48.92 | 48.92 | 49.06 | 49.06 |
| | 7.50 | 7.50 | 7.50 | 7.50 | 8.15 | 8.15 |
| Int Soil no Weath | 47467.00 | 47467.00 | 47642.00 | 47642.00 | 47397.00 | 47397.00 |
| | 154.47 | 154.47 | 155.22 | 155.22 | 155.58 | 155.58 |
| | 48.92 | 48.92 | 49.06 | 49.06 | 49.10 | 49.10 |
| | 7.11 | 7.11 | 7.34 | 7.34 | 7.96 | 7.96 |
| Prf Soil no Weath | 47836.00 | 47836.00 | 47836.00 | 47836.00 | 47688.00 | 47688.00 |
| | 155.40 | 155.40 | 155.40 | 155.40 | 155.58 | 155.58 |
| | 48.94 | 48.94 | 48.94 | 48.94 | 49.05 | 49.05 |
| | 7.10 | 7.10 | 7.10 | 7.10 | 7.40 | 7.40 |
| Int Soil Fut Tp | 47646.00 | 47876.00 | 47923.00 | 47923.00 | 47428.00 | 47428.00 |
| | 155.57 | 155.50 | 155.00 | 155.00 | 155.60 | 155.60 |
| | 49.10 | 49.10 | 49.09 | 49.09 | 49.10 | 49.10 |
| | 7.61 | 7.25 | 7.05 | 7.05 | 7.86 | 7.86 |
| Prf Soil Fut Tp | 47857.00 | 48065.00 | 48065.00 | 48065.00 | 48065.00 | 48065.00 |
| | 155.60 | 155.60 | 155.54 | 155.54 | 155.54 | 155.54 |
| | 49.09 | 49.05 | 49.05 | 49.05 | 49.05 | 49.05 |
| | 7.29 | 7.06 | 7.06 | 7.06 | 7.06 | 7.06 |
| Prf Soil and Weath | 47990.00 | 48146.00 | 48146.00 | 48146.00 | 48146.00 | 48146.00 |
| | 155.57 | 155.44 | 155.44 | 155.44 | 155.44 | 155.44 |
| | 49.08 | 48.99 | 48.99 | 48.99 | 48.99 | 48.99 |
| | 6.84 | 6.84 | 6.84 | 6.84 | 6.84 | 6.84 |

[a] The first line of table entries show net returns to labor, management, and equity capital in 1983 dollars, the second and third lines refer to corn and soybean yields in bushels per acre, and the fourth line refers to average net irrigation application in inches per acre.

The distribution of whole farm net returns (BTNI) depends upon the level of information available for scheduling irrigation as well as random output prices and weather events. Mean BTNI for the no-information benchmark case is $46,332. The data in Table 3 indicate that mean BTNI increases with better information for all levels of absolute risk aversion. For some risk aversion intervals, mean BTNI is less for the intermediate soil water, future Tp information scenario than for perfect soil water information alone. It is difficult to say which of these scenarios represents more information, because one contains better soil water information and the other contains better weather information.

### *Risk Preferences and the Value of Information*

Before-tax information values are derived from the distributions of BTNI generated with different levels of information. They are presented in Table 4 as per-irrigated-acre amounts for easier interpretation. Generally, the results show that more information has greater value. However, perfect information does not seem to offer a high potential payoff relative to the gain obtained by using existing information systems. The results for the risk neutral case are discussed first.

With risk neutrality, the values are obtained by subtracting mean net farm income without information from mean net farm income with information and dividing by the number of irrigated acres (260). The expected return to perfect soil water and weather information is $6.98 per acre. The Checkbook information system yields an expected return of $3.68 per acre or about 53% of the return to perfect information. The perfect soil water information result appears similar to that reported by Dudek *et al.* They found that for surface irrigators in Idaho elasticity of demand for an irrigation scheduling service based on perfect soil water information exceeded one when the price rose to $5.00 per acre.

The finding that weather information generates a small fraction of potential returns to perfect information need not imply that research on ways to produce better weather information would have a low rate of return. The return might be high if it could be applied to many acres, making the per acre cost of producing better weather information low. Also, the return might be higher if the irrigator were forced to irrigate with limited seasonal water supplies.

The results in Table 4 show the value of information to be sensitive to risk preferences. Producers can use the information to generate a more desirable distribution of net returns in terms of their risk attitudes. The value of information to risk averters tends to depend on how much it increases the lowest outcomes, whereas the value to risk seekers tends to depend on how much it increases the highest outcomes. Here, information is more effective in increasing the lowest outcomes of the distribution; therefore, it has a higher value to risk averters than to risk seekers. For example, Checkbook information increases expected returns by $3.68 per acre; however, the most risk-seeking interval would not pay anything for Checkbook information indicating that it does not result in any increase in the very highest outcomes of the distribution. However, individuals in the most risk averse interval could pay $14.40 per acre indicating that Checkbook information is effective in increasing the lowest outcomes of the distribution.

The other information levels show similarly large increases in value with risk aversion. The value to risk seekers is less than to risk neutral or risk averse producers indicating that information produces smaller absolute increases in the highest outcomes of the distribution than in the lowest outcomes. The table shows that two information levels (Checkbook and perfect soil water) have zero value to the most risk-seeking interval. This interval is sensitive to how information affects net returns in the year producing the highest net income. These two information scenarios did not increase the highest net income compared with the no information case. It would be desirable to have more years of weather data to test further the relationship between value of information and the most risk seeking interval.

The way information affects the net income distribution is sensitive to 1976 conditions, a drought year in Minnesota. Whole-farm income tends to be the lowest for 1976 weather conditions because of very low yields from unirrigated crops. Irrigating with the benchmark strategy results in lower irrigated yields for 1976 weather conditions. Somewhat higher yields are obtained by irrigating with information and following the decision rule which makes the best use of that information. More emphasis is placed on the difference in income for 1976 conditions as risk aversion is increased. Not surprisingly, the estimated value of information is reduced considerably by omitting 1976 conditions from the analysis.

**Table 4.** Before-Tax Values[a] of Selected Information Scenarios for Different Levels of Risk Aversion

| | Coefficient of Absolute Risk Aversion Interval | | | | | |
|---|---|---|---|---|---|---|
| | Risk Seeking | | Risk Neutral | | Risk Averse | |
| Information Level | -.001 to -.0002 | -.0002 to -.00005 | -.00005 to .0001 | 0.0 to 0.0 | .0001 to .0003 | .0003 to .0015 |
| Checkbook | 0.00 | 1.00 | 2.40 | 3.68 | 14.40 | 14.40 |
| Int Soil no Weath | 0.50 | 1.40 | 3.00 | 5.04 | 15.00 | 15.00 |
| Prf Soil no Weath | 0.00 | 2.40 | 4.20 | 5.78 | 16.00 | 15.90 |
| Int Soil Fut Tp | 0.10 | 2.40 | 4.40 | 6.12 | 15.70 | 15.70 |
| Prf Soil Fut Tp | 0.40 | 3.00 | 4.90 | 6.66 | 16.50 | 16.50 |
| Prf Soil and Weath | 1.00 | 4.20 | 5.60 | 6.98 | 16.30 | 16.20 |

[a] Table entries refer to values of information (1983 dollars) per irrigated acre for the absolute risk aversion coefficient interval specified above the column. The value of an information level is the amount by which each element of its before-tax net income distribution can be lowered before it no longer dominates the distribution derived with the benchmark strategy.

The value of information to decisionmakers with nonneutral risk attitudes may be affected by returns from other enterprises even if these enterprises are not directly affected by the information. This effect might occur because the returns from information are correlated with returns from other enterprises on the farm. For example, if returns from other enterprises are negatively correlated with returns from information, the value of information to risk averters is larger if estimated at the whole farm level than if estimated at the enterprise level. The larger value is assigned because the risk averter places more weight on the increases in the lowest net incomes brought about by information.

Returns from information are negatively correlated with returns from unirrigated crops on the representative farm evaluated here.[13] The value of information estimated at the enterprise level (by omitting the unirrigated crops) for risk averters was smaller. For example, the value of Checkbook information was $5.60 per acre for the most risk averse interval compared to the $14.40 per acre on a whole-farm basis shown in Table 4. While the relative magnitudes of the values depend on the empirical relationships, this illustrates the importance of evaluating information at the whole farm level when returns from information are not independent of returns from other farm enterprises.

The emphasis thus far has been on the returns from information rather than the costs of producing such information. At the time the study was done, two irrigation consulting companies in western Minnesota advertised scheduling services for $5.00 to $5.50 per acre. These services included determination of soil water-holding capacity, weekly visits to the field, and computerized water scheduling. The costs of providing Checkbook information were estimated with the help of Minnesota irrigation specialists. Annual depreciation and interest on the investment in a water meter and soil water measurement instruments are estimated to be $110 per 130-acre system. Estimated labor requirements are 40 hours per season per 130-acre system. Thus, the costs of producing Checkbook information are sensitive to the per hour cash or opportunity cost of labor. For example, if labor costs $10 per hour, the total per acre cost of Checkbook information is approximately $3.90 per acre. If labor is valued at $5 per hour, the cost is slightly less than $2.40 per acre, and with a zero value of labor the cost is about $.85 per acre. Whether a manager opts to produce information such as that provided by the Checkbook method will likely be heavily influenced by two factors: the manager's risk aversion and the value imputed to labor. With labor valued at $10 per hour, risk averters would find it advantageous to use the Checkbook method while risk neutral and risk-seeking irrigators would not. With labor costs of $5 per hour, risk neutral and some moderately risk-seeking irrigators would also have incentives to use the Checkbook method. With a zero cost of labor, all irrigators except those in the most risk-seeking interval would have some incentives to produce soil water information using the Checkbook method.

## V. The Effects of Pumping Restrictions on Irrigation Efficiency

Pumping restrictions are evaluated in the following sections under a variety of assumptions about resources available for irrigation, scheduling management strategies, and irrigator attitudes toward risk. The first section shows the effects of imposing pumping restrictions as soil water-holding capacity and pumping capacity are varied.

### *The Effects of Pumping Restrictions as Irrigation Resources Vary*

Average per acre reductions in net returns due to pumping restrictions for the two soil AWC's and two pumping capacities are shown in Table 5. The figures show that pumping restrictions do lower expected net returns in all cases. However, pumping capacity and soil AWC affect the amount of reduction in net returns. Lowering pumping capacity makes the irrigator especially vulnerable to reduced net returns as a result of pumping restrictions. For example, with the 3.1" AWC soil and the seven-hour interruption, expected returns fall by $12.30 per acre with 600 gpm capacity compared to only $3.17 for the 800 gpm system.

Lowering the soil AWC also causes net returns to be reduced more by pumping restrictions. For example, with 800 gpm pumping capacity, the seven-hour interruption plan causes expected net returns to fall by $3.17 per acre on the 3.1" AWC soil compared to only $2.28 on the 4.3" AWC soil. With a lower soil AWC, the irrigator has less ability to store water in the soil to offset the pumping restrictions.

The numbers in parentheses in Table 5 show the soil water depletion level at which corn/soybean irrigation is initiated. The Checkbook method is used to track soil water levels. When pumping is

**Table 5.** Average per Acre Net Returns Reductions for Selected Pumping Restriction Scenarios[a]

| Pumping Restriction Scenario | 800 GPM System | | 600 GPM System | |
|---|---|---|---|---|
| | 3.1" AWC | 4.3" AWC | 3.1" AWC | 4.3" AWC |
| no interruptions | 0.0<br>(25/40) | 0.0<br>(35/40) | 0.0<br>(5/25) | 0.0<br>(10/40) |
| 5 hrs/day 4 days/wk | 1.77<br>(15/30) | 1.37<br>(25/40) | 8.04<br>(5/15) | 5.55<br>(5/30) |
| 7 hrs/day 4 days/wk | 3.17<br>(15/25) | 2.28<br>(25/40) | 12.30<br>(5/10) | 8.58<br>(5/30) |
| 8 hrs/day 7 days/wk | 15.28<br>(5/15) | 8.47<br>(5/35) | 35.91<br>(5/5) | 23.17<br>(5/15) |

[a] Figures in parentheses show the soil water depletion level at which irrigation is initiated for corn/soybeans. The Checkbook method is used to monitor soil water levels.

restricted, the net returns maximizing depletion level at which to trigger irrigation declines. For example, with the 3.1" AWC soil, 800 gpm capacity, and no interruptions, the expected-returns-maximizing strategy calls for irrigating corn at 25 percent depletion of plant available soil water and irrigating soybeans at 40 percent depletion. When a five-hour interruption is imposed, the net-returns-maximizing depletion falls to 15 and 30% for corn and soybeans, respectively. With an eight-hour interruption, the optimal depletions fall to 5 and 15% for corn and soybeans, respectively. With power curtailments, the optimal strategy appears to be to start irrigating sooner to avoid getting behind the crop's water requirements.

The actual amount of water pumped is affected in opposite ways by power interruptions as shown in Table 6. On the one hand, reducing the number of hours per week the system can pump tends to reduce water use. On the other hand, the previously noted tendency to begin irrigating at higher soil water levels would increase irrigation water applied. Table 6 shows that, for three of the four combinations of soil AWC and pumping capacity, average seasonal water applications increase, going from no interruptions to a five-hour interruption, and then decline with the seven and eight-hour interruptions. The exception is the 600 gpm, 3.1" AWC case where expected application amounts decline consistently as the number of hours of interruption increase.

Utility companies and irrigators are concerned with the amount of discounts which must be offered to keep expected net returns from falling when load management is imposed. The net returns reductions shown in Table 5 are evaluated to determine the reduction in the demand fee necessary to maintain expected net returns at zero interruption levels. The required demand rate reductions[14] are shown in Table 7. To put the figures in perspective, one might note that, when the study was done, the rate charged by Northern States Power, a utility serving irrigators in the state, was about $6.25 per kw. If the $6.25 rate is used as a benchmark, load management would seem to have little potential for the 600 gpm system because the needed demand rate reductions exceed the demand charge in all cases. However, the 800 gpm system appears to offer more potential as required reductions for the five and seven-hour interruptions are well within the $6.25 figure for both soil AWC's.

### *The Effects of Pumping Restrictions as Scheduling Management Varies*

The previous analysis assumed that the irrigator uses soil and weather data to monitor soil water levels (Checkbook method), and that he/she optimally adjusts the depletion level at which irrigation is triggered to minimize the net returns reductions due to restricted pumping. Table 8 shows the effects of relaxing these assumptions for the 800 gpm system. The first scenario is a repetition of the results shown in Table 5; i.e., the Checkbook method is used and the trigger level optimally adjusted. In the second case, the Checkbook method is used, but the trigger level is not adjusted to compensate for the pumping restrictions. Finally, the naive scenario is included to show the effects of pumping restrictions when very little soil water or weather information is used to schedule irrigation. The naive scenario is not adjusted in any way to compensate for power interruptions.

The results show the importance of proper management to minimize the losses from restricted pumping. In the case of the 3.1" AWC soil, a five-hour interruption causes losses of $1.77 per acre with the Checkbook method and optimal adjustment of the irrigation schedule. With no adjustment of the trigger level, losses are $2.87 per acre, and using the naive strategy, losses amount to $2.23 per acre. With the 3.1" AWC soil and a seven-hour interruption program, losses are $3.17 with the Checkbook and optimal adjustment compared with $6.22 for the Checkbook and no adjustment and $4.65 for the naive strategy. Thus, the results show that losses from power interruptions are increased when scheduling management does not take the reduced pumping capacity into account.

Interestingly, losses from pumping restrictions are actually smaller for the naive strategy than for the Checkbook method with no adjustment of the trigger. In two cases (4.3" AWC, five and seven-hour interruptions), losses from the naive strategy are even smaller than from the Checkbook method with optimal adjustment. The reason the naive strategy appears to be less affected by power interruptions is that it is a relatively inefficient but conservative strategy which has lower expected returns than the Checkbook method in the unrestricted pumping case. Because the naive strategy is conservative, power interruptions cause net returns to fall relatively less than they would for a strategy which comes closer to maximizing expected net returns under unrestricted pumping.

**Table 6.** Expected per Acre Water Applications for Selected Pumping Restriction Scenarios[a]

| Load Management Scenario | 800 GPM System | | 600 GPM System | |
|---|---|---|---|---|
| | 3.1″ AWC | 4.3″ AWC | 3.1″ AWC | 4.3″ AWC |
| | Inches Per Acre | | | |
| no interruptions | 7.47 | 7.23 | 7.95 | 7.51 |
| 5 hrs/day 4 days/wk | 7.84 | 7.56 | 7.69 | 7.78 |
| 7 hrs/day 4 days/wk | 7.83 | 7.50 | 7.51 | 7.53 |
| 8 hrs/day 7 days/wk | 7.74 | 7.51 | 6.52 | 6.61 |

[a] Figures in table are effective inches assuming an 85% application efficiency.

**Table 7.** Demand Rate Reductions Required to Keep Net Returns from Falling with Pumping Restrictions[a]

| Load Management Scenario | 800 GPM System 3.1″ AWC | 800 GPM System 4.3″ AWC | 600 GPM System 3.1″ AWC | 600 GPM System 4.3″ AWC |
|---|---|---|---|---|
| | Dollars Per Kilowatt | | | |
| 5 hrs/day<br>4 days/wk | 1.70 | 1.31 | 10.03 | 6.64 |
| 7 hrs/day<br>4 days/wk | 3.03 | 2.18 | 14.93 | 10.27 |
| 8 hrs/day<br>7 days/wk | 13.83 | 7.77 | 43.04 | 27.38 |

[a] Breakeven reductions were calculated by multiplying the average per acre reduction in net returns by the number of irrigated acres and dividing by the product of the average number of months demand incurred for a given load management level times the peak monthly demand rate. Peak rates of 47.24 and 34.27 kw were assumed for the 800 and 600 gpm systems.

**Table 8.** Effects of Scheduling Management Scenario on Reductions in Net Returns Due to Pumping Restrictions[a]

| Pumping Restriction Scheme | Scheduling Management Scenario | | | | | |
|---|---|---|---|---|---|---|
| | Checkbook Trigger Level Adjusted | | Checkbook Trigger Level Not Adjusted | | Naive Strategy | |
| | 3.1″ | 4.3″ | 3.1″ | 4.3″ | 3.1″ | 4.3″ |
| | Dollars Per Acre | | | | | |
| 5 hrs/day 4 days/wk | 1.77 | 1.37 | 2.87 | 2.21 | 2.23 | .42 |
| 7 hrs/day 4 days/wk | 3.17 | 2.28 | 6.22 | 4.00 | 4.65 | 1.21 |
| 8 hrs/day 7 days/wk | 15.28 | 8.47 | 24.08 | 14.97 | 22.49 | 12.26 |

[a] The three management scenarios are: 1. use of the Checkbook method with adjustment of the soil water depletion at which irrigation is initiated to compensate for load management; 2. use of Checkbook method but continuing to initiate irrigation at the soil water depletion level which was optimal with no interruptions; and, 3. using a naive strategy based on very little soil or weather information. Table entries show the reduction in average per acre net returns with restricted pumping.

### *Evaluation of Pumping Restrictions with Nonneutral Risk Preferences*

The effects of risk preferences on the amount of discount needed to keep irrigators from being made worse off by pumping restrictions are shown in Table 9. The results are obtained by finding the amount which must be added to whole farm net returns when load management is imposed to keep the restricted pumping distribution from being stochastically dominated by the unrestricted pumping distribution for a specified risk aversion interval. The required discounts are calculated on a whole-farm basis but presented on a per-irrigated-acre basis to make them easier to interpret. A 3.1" AWC soil and 800 gpm system are assumed.

The results show that increasing risk aversion causes the required discount to increase. The risk seeker whose absolute risk aversion coefficient falls in the -.001 to -.0002 interval requires a subsidy of $.50 per irrigated acre for interruptions of five hours per day, four days per week. In the case of risk neutrality, $1.77 per acre is required for the five-hour interruption pattern. With positive risk aversion, the amount increases to a maximum of $15.60 per acre for the .0001 to .0003 interval. These significant increases are due, first of all, to the fact that the reduced pumping capacity caused by load management lowers yields and net incomes the most in dry years when all available pumping capacity is needed. Also, the dry years tend to produce the lowest incomes due to the effects of drought on the nonirrigated enterprises. Changes in income in the lowest income years assume the greatest importance for individuals with positive risk aversion. By contrast, all outcomes are equally important to risk neutral agents if they are equally likely to occur. Thus, the effects of reduced pumping capacity on income in very dry years are diluted by higher income years when rainfall is heavier and pumping capacity less critical.

The amount of discounts required is sensitive to the inclusion of 1976, a very dry year in southwest Minnesota. When this year is deleted, the required discounts fall for both the risk neutral and the risk averse cases. However, the required subsidy for the risk averter is still more than twice as large as that for the risk neutral irrigator.

The results in Table 9 show that the amount of subsidy required actually falls slightly moving from the .0001 to .0003 interval to the most risk averse interval, .0003 to .0015. This result is explained as follows: First, each distribution is generated by using each of the eleven output price vectors with each of the twelve years of weather data. The drought year, 1976, used in combination with the eleven price vectors produces the lowest incomes in the distribution due to severe losses from the unirrigated enterprises. Risk averters are more concerned with the effects of pumping limitations on the worst outcomes. Thus, the yield penalties from pumping limitations in 1976 assume the most importance to them. However, the most risk averse agents tend toward a maximin strategy meaning they seek to maximize the worst outcome and disregard the rest of the distribution. In this case, they are concerned with how much the yield reduction from load management costs them given the worst set of output prices and weather conditions in 1976. This income penalty is less than it would be using a higher set of output prices and the weather conditions of 1976. Consequently, those in the second most risk averse category who attach at least some importance to the outcomes produced by higher output prices will require a higher subsidy.

## VI. Summary

Both irrigators and society would benefit from using irrigation resources more efficiently. Two questions related to irrigation efficiency are dealt with in this study: 1. What is the value of better soil water and weather information as a means of increasing irrigation scheduling efficiency? 2. What financial incentives must be offered to keep irrigators from being made worse off by pumping restrictions? Pumping restrictions could benefit utility companies by allowing them to use their generating capacity more efficiently.

With regard to the first question, results show that while scheduling with better information raises expected returns, information tends to exhibit diminishing returns especially in the risk neutral case. Further, better information than can be obtained by irrigators with current technology appears to result in small yield increases and, hence, modest benefits. In the risk neutral cases, about 53% of the returns from perfect information is provided by the Checkbook method, which is currently recommended by the Minnesota Agricultural Extension Service. Perfect soil water information alone provides about 83% of the increased return from soil water and weather information.

**Table 9.** Effects of Varying Risk Preferences on the Amount of Subsidy Required to Maintain Expected Utility with Pumping Restrictions[a]

| Pumping Restriction Scheme | Coefficient of Absolute Risk Aversion Interval<br>-.001 to -.0002 | <br>-.0002 to -.00005 | <br>-.00005 to .0001 | <br>0.0 to 0.0 | <br>.0001 to .0003 | <br>.0003 to .0015 |
|---|---|---|---|---|---|---|
| | Dollars Per Acre | | | | | |
| 5 hrs/day 4 days/wk | $ .50 | 1.00 | 14.80 | 1.77 | 15.60 | 14.30 |
| 7 hrs/day 4 days/wk | $ .60 | 1.20 | 15.80 | 3.17 | 16.60 | 15.20 |
| 8 hrs/day 7 days/wk | $2.60 | 4.80 | 71.30 | 15.28 | 70.10 | 63.70 |

[a] A 3.1″ AWC soil and 800 gpm pumping capacity are assumed. Results are reported on a per-irrigated-acre basis.

Another finding is that it does not pay to sacrifice yield in order to save water and lower pumping costs. For all levels of risk aversion, the preferred strategies are those which keep expected yields near a maximum. The value of information stems from its ability to maintain these yields with less water and pumping costs.

The value of information increases significantly with risk aversion. However, this finding is sensitive to inclusion of 1976, a drought year. Also, the amount of variation in value by degree of risk aversion depends on the scale of analysis. Restricting the analysis to the irrigated enterprise alone reduces overall income variability and, thus, diminishes somewhat the increased value of information for risk averters. If risk neutrality is assumed, the value of information is not affected by the scale of analysis.

More research could help substantiate the relationship between risk aversion and value of information. If more years of weather data were available, the estimated value of information to the risk averter (seeker) might be less sensitive to deletion of the weather year producing the worst (best) income. Also, more investigation of actual irrigation practices along with elicitation of irrigator risk preferences might reveal variations in strategies followed by irrigators who schedule with relatively little soil water or weather information. This might facilitate a more accurate estimate of information value, especially for risk averse agents.

The estimated information values reported here are dependent on the climate patterns, crops, irrigation technology, other input levels, and costs assumed. Thus, they cannot be extended to other areas of the country where conditions are different without further research. However, the results for the risk neutral irrigator appear similar to those reported by Zavaleta *et al.* and Dudek *et al.* Zavaleta found that perfect weather information could increase expected returns to sorghum irrigators in the Texas High Plains by slightly over $10 per acre compared with $6.98 found in this study. Dudek *et al.* found that for surface irrigators in Idaho elasticity of demand for an irrigation scheduling service based on perfect soil water information exceeded one when the price rose to $5.00 per acre. In this study, scheduling with perfect soil water information increases expected returns by $5.78 per acre.

The second question dealt with, the effects of pumping restrictions on irrigated returns, is evaluated for variable irrigation pumping capacities, soil water-holding capacities (AWC), irrigation scheduling strategies, and irrigator risk attitudes. Moderate interruption scenarios of 20 and 28 hours per week, and a more severe interruption scheme of 56 hours per week are evaluated. Results indicate that with 800 gpm pumping capacity, 20 to 48 percent reductions in the assumed $6.25 per kw demand charge are needed to keep expected net returns from falling for the moderate 20 and 28-hour interruption scenarios. With the lower 600 gpm pumping capacity, the required demand rate reductions nearly equal or exceed the $6.25 demand charge. Reducing the soil AWC also causes net returns to fall more and the required discount to increase as a result of pumping restrictions, because the irrigator has less ability to store water in the soil to offset the effects of pumping restrictions.

Proper scheduling management is important to mitigate the effects of reduced pumping capacity. The net returns-maximizing strategy calls for irrigation to be started at higher soil water levels as the number of hours of interruptions increases. Failure to adjust the strategy increases the losses from pumping restrictions. However, if irrigators are following conservative scheduling strategies in the sense that more water is applied than needed to maximize expected net returns, their returns may fall less as a result of power curtailments than would be the case for the irrigator following an expected-returns-maximizing strategy.

Attitudes towards risk are important in determining the amount of subsidy required to keep expected utility from falling due to pumping restrictions. When risk aversion increases, the required subsidy rises because power interruptions reduce yields and net returns more in very dry years, when income may already be low due to low yields from nonirrigated crops.

Potentially, interrupting power to irrigators can increase economic efficiency if the cost savings from reduced demand for generating capacity more than offset the amounts which must be paid to compensate irrigators for losses due to reduced pumping capacity. The findings of this research emphasize that such programs would be most efficient if made voluntary. The increased efficiency is due to the wide variation in the amount of subsidy required to keep irrigators from being made worse off by power interruptions.

Some irrigators would be better off not participating because of the low pumping capacity systems they operate or their high risk aversion.

The results reported here should not be extended to other regions of the country without further research. Further research would be required to determine the effects of different climates, soil types, irrigation systems, and irrigation practices on the amount of subsidy needed to compensate irrigators for imposing pumping restrictions.

## Footnotes

[1] According to recent estimates (Irrigation Journal), about 60% of the irrigation systems in the state are powered by electricity.

[2] Taxes are ignored to simplify the analysis. In the case of information evaluation, ignoring taxes is equivalent to assuming that expenditures for better information would be tax deductible. The effects of taxes on the value of information have been reported elsewhere (Bosch).

[3] Southwestern Minnesota is chosen because the best weather and crop data needed for implementing the methodology described here are available from Lamberton Experiment Station, located in the area. The Lamberton area is an important corn and soybean-producing region where moisture stress plays a large role in determining yields.

[4] Detailed machinery, irrigation, and land overhead budgets as well as crop enterprise budgets are provided in the appendix.

[5] An efficiency of 85% is assumed meaning that 15% of applied water is lost due to wind, evaporation, and runoff.

[6] These ratios are somewhat lower than the debt-asset ratios for depreciable and real estate assets reported in "The 1982 Annual Report of the Southwestern Minnesota Farm Management Association (Welsch *et al.*). However, in another study (Bosch) the effect of varying the equity position on the value of information was investigated. The only significant effect of varying equity position was through its effects on taxes. Increasing equity increased taxes and, thus, reduced the value of information on an after-tax basis. Variations in equity had little effect on the before-tax value of information

[7] Utility companies frequently divide the electricity charge into two components, often referred to as demand and energy charges, to better reflect the cost of providing electricity to customers with varying use patterns. The demand charge is based on the peak kilowatt rate at which a customer used power over the billing period. The charge can be thought of as payment for maintaining the capacity to meet the customer's needs at any given time. The energy charge is based on kilowatt hours of consumption and can be regarded as payment for the resources used in generating the electricity. The energy and demand charges used were suggested by Jerry Wright, Area Extension Irrigation Engineer, Morris, Minnesota.

[8] These lengths of storage were based on the average number of months required after harvest for the monthly average price to reach the average seasonal price based on unpublished data obtained from James P. Houck, Professor, Department of Agricultural and Applied Economics, University of Minnesota, St. Paul.

[9] Further details for this price-generating method are given in Bosch.

[10] A total of 29 observations were available for estimating the corn equation while 16 observations were used for estimating the soybean equation. Log-log transformations of equations 9 and 10 were estimated.

[11] Hill and Hanks observed that the form of the equation used for corn did not predict yields well for soybean observations with low yields due to late planting. They attributed the yield reduction in such cases to insufficient dry matter accumulation due to inadequate seasonal transpiration. SYF was included to account for insufficient seasonal transpiration. It is calculated as follows: $SYF = (T_s/10.0)^{1.6}$ where $T_s$ is actual transpiration for the entire season. SYF is constrained to be less than or equal to 1.0. The parameters used for SYF are those used by Hill and Hanks for Soybean Maturity Group II.

[12] Fred Bergsrud, Professor, Department of Agricultural Engineering, University of Minnesota and Jerry Wright and Hal Werner, Area Extension Irrigation Specialists, Agricultural Extension Service, University of Minnesota provided suggestions for developing the strategy.

[13] Nonirrigated enterprises are important on most irrigated farms as indicated by 1982 *Census of Agriculture* statistics showing that, for all Minnesota farms with irrigated enterprises, the average farm size was 501 acres and the average amount of irrigated land, 145 acres.

[14] The figures are derived by multiplying the expected per acre net returns reduction by the total number of irrigated acres and dividing this by the product of the average number of months a demand charge is imposed times the assumed peak kilowatt demand rate. For the 600 and 800 gpm systems used here, the peak kilowatt demands are calculated to be 34.27 and 47.24 kw, respectively.

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## Appendix: Representative Farm Budgets

Budgets and an explanation of budgeting procedures for the representative farm are presented here. Farm costs are divided into overhead and operating categories. Overhead costs for machinery, land, and irrigation equipment are shown in Tables 10, 11, and 12. Tables 13, 14, 15, and 16 show cash operating costs for corn, soybeans, and rye.

Overhead costs for farm machinery and irrigation equipment consist of depreciation, insurance, and interest as well as shelter in the case of farm machinery.* Depreciation is calculated as a percentage of current new value using the straight line method. Shelter is charged at $.33 per square foot. Insurance and interest charges are based on original cost minus accumulated depreciation. Insurance costs are .75% of historical value for farm machinery and one percent of historical value of above-ground items in the case of irrigation equipment. Interest rates are 13 and 11.75% for farm machinery and irrigation equipment, respectively. Some farm overhead costs (such as farm electicity, telephone, and pickup mileage) are not shown in the overhead budgets although they were included in the analysis.

Cash operating expenses are assumed to vary directly by number of acres planted. They generally include variable costs of materials and machinery as well as interest on operating capital. Yield-related costs (hauling, drying, and storage), variable irrigation costs, and labor charges are not included in the tables.

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*Data for farm machinery costs are from Benson and Jergens (1983). Irrigation equipment cost data are from Eidman and Bergsrud (1978). Irrigation costs were updated by L. K. Oosthuizen, Visiting Professor in the Department of Agricultural and Applied Economics, University of Minnesota.

**Table 10.** Machinery Ownership Costs for the Representative Farm[a]

| | New Cost | Dep.[b] | Hist.[c] Value | Ins.[d] | Shelter | Int.[e] |
|---|---|---|---|---|---|---|
| Tractor 100 hp. | 41594 | 3327 | 19896 | 149 | 38 | 517 |
| Tractor 75 hp. | 26495 | 2120 | 12674 | 95 | 38 | 330 |
| Plow 5-16″ | 9159 | 733 | 4381 | 33 | 34 | 114 |
| Disk 16′ | 8241 | 659 | 3942 | 30 | 61 | 102 |
| Drag 30′ | 3237 | 259 | 1548 | 12 | 17 | 40 |
| Planter 8-30″ | 19945 | 1596 | 9541 | 72 | 66 | 248 |
| Row cult. 8-30″ | 4490 | 359 | 2148 | 16 | 66 | 56 |
| Sprayer 30′ | 3390 | 271 | 1622 | 12 | 46 | 42 |
| Fert. spread.40′ | 5440 | 435 | 2602 | 20 | 26 | 68 |
| Truck medium | 22500 | 1800 | 10763 | 360 | 83 | 280 |
| Wagon 240 bu. | 2400 | 192 | 1148 | 9 | 33 | 30 |
| Wagon 240 bu. | 2400 | 192 | 1148 | 9 | 33 | 30 |
| Pickup 6 cyl. | 8350 | 668 | 3994 | 280 | 59 | 104 |
| Combine medium | 69850 | 5588 | 33413 | 2518 | 26 | 869 |
| Corn head | 12160 | 973 | 5817 | 44 | 20 | 151 |
| Soybean head | 8430 | 674 | 4032 | 30 | 20 | 105 |
| Small grain head | 5900 | 708 | 2822 | 21 | 20 | 73 |
| | 253981 | 20554 | 172010 | 1443 | 686 | 3159 |

Total ann. exp. $25842

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[a] Principal source is Benson, F. J. and Jergens, J. "Minnesota Farm Machinery Economic Cost Estimates for 1983." Extension Folder 589, Agricultural Extension Service, University of Minnesota, St. Paul.

[b] Ann. Dep. = (New cost - inv. cred. - sal.val.)/Exp. life
Investment credit and salvage value are each assumed to be 10% of new cost. Expected life is assumed to be ten years.

[c] Historical value is original price minus accumulated depreciation.

[d] Insurance is .75% of historical value except for pickup and truck insurance which are estimated at full coverage rate for a four-year old vehicle. Shelter cost is $.33 per square foot.

[e] Interest is paid on 20% of historical value using a 13% interest rate.

**Table 11.** Per Acre Land Charges for the Representative Farm

| Item | Owned Land<br>Sandy Soil | <br>Heavy Soil | Rented Land<br>Heavy Soil |
|---|---|---|---|
| Land value[a] | 1348.00 | 2422.00 | 2422.00 |
| Land rent[b] | | | 103.00 |
| Property tax[c] | 7.72 | 13.72 | |
| Maint. of farm real estate | 7.24 | 7.24 | |
| Interest[d] | 23.76 | 42.69 | |
| Tot. cash exp. | $38.72 | $63.65 | $103.00 |

[a] Estimates are taken from Smith, M.G., and Raup, P. M. "The Minnesota Rural Real Estate Mrket in 1982." Economic Report 83-6, Dept. of Agricultural and Applied Economics, University of Minnesota, St. Paul, 1983.

[b] Source: Hasbargen, P., Thomas, K., and Tiffany, D. "Cash Rent How Much in 1983?" FM 661, Agricultural Extension Service, University of Minnesota, St. Paul, 1983.

[c] Figures are based on $10.72 per acre average property tax reported in "Southwestern Minnesota Farm Management Association 1982 Annual Report." Economic Report 83-2, Dept. of Agricultural and Applied Economics, University of Minnesota, St. Paul, 1983.

[d] A Federal Land Bank rate of 11.75% is assumed to be paid on 15% of the market value of the land.

Table 12. Center Pivot Irrigation Investment and Ownership Costs[a]

| Component Inv. Costs<br>Item | Cur. New Price | Exp. Life | Sal. Val. | Ann.[b] Dep. | Hist.[c] Val. |
|---|---|---|---|---|---|
| Well, casing | 16040.00 | 25 | 0.00 | 577.44 | 9495.89 |
| Turbine pump & col. | 7061.00 | 14 | 0.00 | 453.96 | 3681.35 |
| Elec. motor (60 hp.) | 6099.60 | 25 | 609.96 | 195.19 | 3671.98 |
| Underground pipe | 6237.00 | 20 | 0.00 | 280.67 | 3552.18 |
| Above ground pipe | 1785.53 | 15 | 178.55 | 95.23 | 979.76 |
| Sprinkler system | 6327.00 | 15 | 3632.70 | 1937.44 | 19933.35 |
| Wire | 3041.00 | 20 | 304.10 | 121.64 | 1769.93 |
| Fertilizer injection | 2246.00 | 12 | 224.60 | 149.73 | 1157.63 |
| Totals $ | 78837.73 | | 4949.81 | 3811.30 | 44242.08 |

| Annual Ownership Costs[d] | |
|---|---|
| insurance | 275.13 |
| interest | 1039.69 |
| ann. dep. | 3811.30 |
| elec. cust. serv. chrg. | 150.00 |
| Tot. ann. ownership costs | $5276.12 |

[a] Figures were updated by Dr. L. K. Oosthuizen, Visiting Professor in the Department of Agricultural and Applied Economics, University of Minnesota, working with data provided by Hydro-Engineering, Inc., Young America, Minnesota. System is assumed to pump 800 gpm at 50 psi and to cover 130 acres.

[b] Ann. dep = (cur. price - inv. cred. - sal. val.)/exp. life

[c] Historical value is historical price minus accumulated depreciation.

[d] Ins. cost = .01* (hist. val of above ground items). Interest is calculated assuming a Federal Land Bank rate of 11.75% which is paid on 20% of historical value.

**Table 13.** Irrigated Corn Cash Costs Per Acre[a]

| Item | Units | Qty. | Price | Cash Cost |
|---|---|---|---|---|
| Land prep. | | | | |
| spread fert. 40′ | hrs. | .026 | 8.50 | .22 |
| phosphorous | lbs. | 60 | .22 | 13.20 |
| potassium | lbs. | 110 | .12 | 13.20 |
| spray herb | hrs. | .071 | 9.72 | .69 |
| Lasso | qts. | 2.5 | 4.68 | 11.70 |
| disk (2) | hrs. | .258 | 10.25 | 2.64 |
| drag | hrs. | .063 | 8.08 | .51 |
| Planting | | | | |
| plant | hrs. | .131 | 20.70 | 2.71 |
| nitrogen | lbs. | 10 | .25 | 2.50 |
| phosphorus | lbs. | 20 | .22 | 4.40 |
| potassium | lbs. | 10 | .12 | 1.20 |
| seed | bag | .3 | 60.00 | 18.00 |
| Cultivation | | | | |
| cultivate (2) | hrs. | .258 | 8.92 | 2.30 |
| spray | hrs. | .071 | 9.72 | .69 |
| 2-4-D | pint | 1 | .94 | .94 |
| Banvil | pint | .25 | 1.09 | .27 |
| Irrigation | | | | |
| nitrogen | lbs. | 140 | .25 | 35.00 |
| Harvest | | | | |
| combine | hrs. | .385 | 39.86 | 15.33 |
| Int. | | 23.00 | .13 | 2.99 |
| | | | Total | $128.49 |

[a] Machinery and irrigation ownership costs as well as labor charges are not included. Variable irrigation costs, drying costs and hauling costs are also not included. Interest is paid on 20% of operating expenses for 11 months at an annual rate of 13%.

**Table 14.** Unirrigated Corn Cash Costs Per Acre[a]

| Item | Units | Qty. | Price | Cash Cost |
|---|---|---|---|---|
| Land prep. | | | | |
| spread fert. 40′ | hrs. | .026 | 8.50 | .22 |
| phosphorus | lbs. | 60 | .22 | 13.20 |
| potassium | lbs. | 110 | .12 | 13.20 |
| apply anhyd. | hrs. | .078 | 20.39 | 1.60 |
| nitrogen | lbs. | 140 | .14 | 19.60 |
| spray herb. | hrs. | .071 | 9.72 | .69 |
| Lasso | qts. | 2.5 | 4.68 | 11.70 |
| disk (2) | hrs. | .258 | 10.25 | 2.64 |
| drag | hrs. | .063 | 8.08 | .51 |
| Planting | | | | |
| plant | hrs. | .131 | 20.70 | 2.71 |
| nitrogen | lbs. | 10 | .25 | 2.50 |
| phosphorus | lbs. | 20 | .22 | 4.40 |
| potassium | lbs. | 10 | .12 | 1.20 |
| seed | bag | .3 | 60.00 | 18.00 |
| Cultivation | | | | |
| cultivate (2) | hrs. | .258 | 8.92 | 2.30 |
| spray | hrs. | .071 | 9.72 | .69 |
| 2-4-D | pint | 1 | .94 | .94 |
| Banvil | pint | .25 | 1.09 | .27 |
| Harvest | | | | |
| combine | hrs. | .385 | 39.86 | 15.33 |
| Int. | | 20.48 | .13 | 2.66 |
| | | | Total | $114.36 |

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[a] Machinery ownership costs as well as labor charges are not included. Crop drying and hauling costs are also not included. Interest is paid on 20% of operating expenses for 11 months at a 13% annual rate.

**Table 15.** Soybean Cash Costs Per Acre[a]

| Item | Units | Qty. | Price | Cash Cost |
|---|---|---|---|---|
| Land prep. | | | | |
| disk (3) | hrs. | .387 | 10.25 | 3.97 |
| plow | hrs. | .344 | 13.74 | 4.72 |
| spray herb. | hrs. | .071 | 9.72 | .69 |
| Treflan | qts. | 1 | 7.00 | 7.00 |
| drag | hrs. | .063 | 8.08 | .51 |
| Planting | | | | |
| plant | hrs. | .131 | 20.70 | 2.71 |
| seed | bu. | 1 | 12.00 | 12.00 |
| Cultivation | | | | |
| cultivate | hrs. | .129 | 8.92 | 1.15 |
| Harvest | | | | |
| combine | hrs. | .242 | 36.28 | 8.78 |
| Int. | | 6.92 | .13 | .90 |
| | | | Total | $42.43 |

[a] Machinery and irrigation ownership costs as well as labor charges are not included. Variable irrigation costs and hauling costs are also not included. Twenty percent of operating expenses are assumed to be borrowed for ten months at a 13% annual rate. The costs shown in this table apply to both irrigated and unirrigated soybeans.

**Table 16.** Unirrigated Rye Cash Costs Per Acre[a]

| Item | Units | Qty. | Price | Cash Cost |
|---|---|---|---|---|
| Land prep. | | | | |
| spread fert. (2) | .hrs | .052 | 8.50 | .44 |
| nitrogen | lbs. | 40 | .25 | 10.00 |
| phosphorus | lbs. | 30 | .22 | 6.60 |
| potassium | lbs. | 30 | .12 | 3.60 |
| plow | hrs. | .344 | 13.74 | 4.73 |
| disk | hrs. | .129 | 10.25 | 1.32 |
| Planting | | | | |
| plant (custom) | ac. | 1 | 8.31 | 8.31 |
| seed | bu. | 1.25 | 5.00 | 6.25 |
| Harvest | | | | |
| swath (custom) | ac. | 1 | 9.97 | 9.97 |
| combine | hrs. | .211 | 35.57 | 7.52 |
| bale straw (custom) | ac. | 1 | 9.20 | 9.20 |
| haul straw | hrs. | .840 | 7.25 | 6.09 |
| Int. | | 11.10 | .13 | 1.44 |
| | | | Total | $75.74 |

[a] Machinery ownership and labor costs are not included. The farmer is assumed to borrow 20% of operating expenses for nine months at 13% annual interest. Grain hauling and storage costs are not included.