Compensating Irrigators for Restricting Water Use: An Expected Utility Analysis

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A daily limitation on the number of hours irrigators can pump may be imposed by utility companies seeking to use the company's generating capacity more efficiently. Three power interruption patterns are analyzed to determine electricity cost reductions which would have to be offered to keep irrigators from being made worse off by the interruptions. Irrigation system pumping capacity and the irrigator's attitudes toward risk are found to be primary determinants of the size of the required reductions.

Key words: expected utility, irrigation, load management, risk, stochastic dominance.

Two common types of water use restrictions are those that impose an annual limit on the amount of water applied to a unit area of land and those that limit the amount of water that may be applied over a daily or several-day period. Annual limits may be of particular interest when the concern is to enhance the intertemporal economic benefits derived from a fixed or nearly fixed water supply. Restrictions imposed on a per-day or several-day period may be of concern to those using either surface or ground water. Irrigators with riparian water rights may be constrained in the daily amount of water they take from streams or lakes in an effort to maintain stream flow or lake levels within a desired range. Irrigators pumping ground water may have the hours per day they can operate the system restricted either by mandate to reduce interference with nearby wells or by utility companies to reduce peak load demands on their electrical generating capacity.

Imposing either annual or daily limits typically reduces the individual irrigator's welfare, at least in the short run. Some studies have analyzed the effect of alternative methods of limiting annual water use on the profitability of irrigation (Mapp and Eidman). Studies by Bergsrud et al., Buchleiter et al., and Ferguson analyze the size of system required to provide enough water to avoid moisture stress when irrigators are faced with capacity or power interruptions. These studies, however, do not show the impact of interruptions on yield or net returns. What is needed is a study calculating these effects as well as the amount of compensation required to make the irrigator at least as well off after imposing limitations on water withdrawal.

This paper outlines a method to estimate the size of incentives that must be offered to irrigators so that the reduced water supply under the restrictions imposed does not make them worse off. The method can be applied to situations involving either annual or short-term restrictions. The empirical application reported shows the payment or discount a utility

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company must provide to limit daily pumping for each of several combinations of resource situations, management practices, and management characteristics. The resource situations analyzed are variations in pumping capacity per acre and soil water-holding capacity; management practices evaluated are the amount of information used to schedule irrigation; management characteristics considered are irrigators' attitudes toward risk.

Conceptual Model

When the irrigator is risk neutral, the required compensation is that amount needed to keep expected net returns from falling under load management. The measure of concern is returns net of irrigation and yield-related variable costs (NR). The subsidy which must be offered to keep irrigators from being made worse off by load management is calculated by comparing expected NR with and without program participation. The marginal utility of money income is constant for the risk-neutral case and the analysis can be done on a per irrigated acre basis.

When risk preferences are nonneutral, however, the effect of load management on the form of the agent's distribution of income from all activities must be considered. Load management may affect not only the expected value of the distribution but the form of the distribution as well. The effect of load management on variance, skewness, and kurtosis will be evaluated differently by agents with varying degrees of risk preference or risk aversion. Furthermore, the form of the distribution of net returns may be affected by the scale of the analysis, making it important to complete the calculations on a whole-farm rather than a per acre basis or per-irrigated-enterprise basis. Before-tax net farm income (BTNI) is chosen as the unit of comparison because it is assumed to be more relevant to decision maker utility than enterprise or per acre returns.[1]

[1] Some irrigators may be more concerned with after-tax net income, but evaluating before-tax net income simplified the analysis. In a study of the value of information in increasing irrigation scheduling efficiency, Bosch compared the before- and after-tax values of information. A finding of that study is that when information costs are nondeductible, the value of information is reduced by taxes because the after-tax gain from better information is less than the before-tax gain. The implication for this study is that the subsidy required to keep expected utility from falling under load management would be less on an after-tax basis because the after-tax loss from pumping restrictions would be less than the before-tax loss.

Generalized stochastic dominance (GSD) (Meyer) is used to compare BTNI distributions generated with and without load management. Using GSD one can compare BTNI distributions for agents whose coefficients of absolute risk aversion lie within specified bounds over the range of outcomes evaluated. The GSD methodology is extended here to provide an estimate of the subsidy which must be offered to irrigators to keep their expected utility from falling when load management is introduced. The estimated subsidy is that amount by which each element of a BTNI distribution generated with load management must be increased before it is no longer dominated by the distribution generated without load management for a specified risk aversion interval. It is given by finding an amount of income, V, which must be added to the cumulative distribution of income under load management, G, so that G is no longer stochastically dominated by the distribution of income generated without load management, F. This is equivalent to requiring the following inequalities to be simultaneously satisfied:

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

$$(2) \qquad \int_0^1 (F_j(X) - G_i(X + V - Y))U'(X)\,dX < 0,$$

where X is BTNI; G_i and F_j are cumulative BTNI distributions generated with and without load management, respectively; U, a von Neumann-Morgenstern utility function; and Y, a small positive amount.

With both restricted and unrestricted pumping, the distribution of returns depends on the decision rule used to decide when to irrigate. Specifically, the decision rule refers to the soil water depletion level at which irrigation is begun. For the cases of restricted and unrestricted pumping, stochastically efficient decision rules for a given risk aversion interval are found. They are found by searching over a series of possible rules and finding one which is not dominated for a given risk aversion interval. Subscripts i and j refer to these stochastically efficient decision rules for load management and no load management, respectively.

Two qualifications apply to the amount V satisfying inequalities (1) and (2). First, it holds for decision makers whose absolute risk aversion coefficients lie within specified boundaries as shown in (3):

(3) $r_2(X) \geq -U''(X)/U'(X) \geq r_1(X)$,

where $r_2(X)$ and $r_1(X)$ refer to upper and lower bounds on the coefficient of absolute risk aversion. Second, the amount V represents an upper limit on the required amount of compensation. The amount may be less than V for some agents in the specified interval.

Empirical Model

The focus of the study is a 640-acre representative farm with irrigated and unirrigated corn and soybean enterprises. Weather and crop data from the Lamberton Experiment Station and the surrounding area in southwestern Minnesota are used to construct the farm and test various irrigation policies. The farm produces 260 acres of irrigated corn and soybeans. The remaining acreage is devoted to unirrigated corn, soybean, and rye production.

Net return above irrigation and yield-related variable costs is calculated as

(4) $NR = P * Y - IC - YC$,

where NR is per acre returns over irrigation and yield-related variable costs from irrigated corn and soybeans; P, a vector of corn and soybean output prices; Y, irrigated corn and soybean yields; IC, per acre irrigation variable costs (electricity, lubrication, and repairs); and YC, per acre yield-related costs (crop hauling, drying, and storage). Here, YC is obtained by multiplying the per acre yield times the per bushel variable cost; IC is determined by the number of acre inches of water applied as well as the number of months the system was used. All elements in (4) are assumed to be random; Y, IC, and YC are random because they depend on uncertain weather and irrigation decisions; P is affected by external market forces; and NR is affected by weather, irrigation decisions, and market events.

Before-tax net income for the whole farm is calculated as

(5) $$BTNI = P * (DY + IY) + OFI - IC - YC - OC - PC,$$

where DY represents dryland yields which are random and OFI is fixed off-farm income, OC and PC are overhead and production costs which are not affected by the level of irrigation or yield, and the remaining variables have the same interpretation as in equation (4) except that P and YC include dryland as well as irrigated enterprises.[2]

Irrigation water is delivered to the crops at 50 psi pressure by two electric-powered center pivot systems drawing water from wells with 62 feet of lift. The energy charge for electricity is $.04 per kilowatt hour (kwh).[3] The assumed demand charge is $6.25 per kilowattt (kw) for each calendar month in which one of the systems operates one or more days. Variable irrigation costs including electricity, lubrication, and repairs are $1.94 per effective acre inch in addition to the monthly demand charge.[4]

Output price distributions are based on five-year price projections made by the Minnesota Agricultural Extension Service in 1983. These projected prices, which were made taking into consideration per capita demand and commodity production costs, are used as the expected prices. A distribution of season average prices observed in Minnesota between 1958 and 1982 and stated in 1983 dollars is used to generate random deviations from the expected price for each crop. After inflating all prices to 1983 levels, each price in each commodity distribution is adjusted so that the distribution's mean equals the expected price. The resulting distributions are used to generate eleven random prices for each crop following a procedure developed by King which takes into consideration correlations among prices of different crops in the same year.

A crop growth and yield model developed by Hill and Hanks is used to estimate yields as a function of random weather, irrigation applications, crop variety, and soil characteristics. Variations of the yield prediction equa-

[2] Fixed and variable costs were synthesized from several sources including personal consultations with experts familiar with irrigated and unirrigated production in Minnesota. More detail on the sources and methods used for calculating costs is provided in Bosch.

[3] 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. It 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 killowatt hours of consumption and can be regarded as payment for the resources used in generating the electricity.

[4] An irrigation efficiency of 85% was assumed for all irrigation strategies. Efficiency is less than 100% because of nonuniform coverage and evaporation loss during application.

tions developed by Hill and Hanks for corn and soybeans are statistically estimated using weather, irrigation, and yield data from several Minnesota sites.[5] The estimated equation for corn is (t statistics are in parentheses):

$$(6) \qquad Y_c = \underset{(78.6)}{155.6} * \underset{(10.6)}{(T/T_p)^{2.61}},$$

where 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 T_p is cumulative daily potential transpiration for these stages.[6] The R-squared value for the equation is .81.

The estimated equation for soybeans is

$$(7) \qquad Y_s = \underset{(50.6)}{49.6} * \underset{(4.34)}{(T/T_p)^{1.067}} * SYF,$$

where Y_s is estimated soybean yield, T and T_p are cumulative actual and potential plant transpiration for the stages of beginning pod fill through physiological maturity, and SYF refers to a soybean yield factor.[7] The R-squared value for the estimated equation is .79.

The model is based on the relationship between cumulative actual and potential transpiration for several stages of plant growth. A model which more explicitly differentiates the effects of moisture stress according to the stage of growth in which it occurs might be able to more accurately measure the effects of moisture stress on growth and yield. Compared to the model estimated in this study, such a model might show that load management has more negative effects on yields in some stages of plant growth and less negative effects in other stages. This in turn would suggest that the compensation to be offered to irrigators would have to be adjusted according to the stage of crop growth in which the water restrictions are imposed.

Twelve years of weather data from the Lamberton Experiment Station in southwestern Minnesota are used to represent random weather variability in the analysis. Each year is assumed to be an independent, equally likely event. Estimates of dryland crop yields for each year of weather were obtained from the Lamberton Experiment Station and the Minnesota Agricultural Statistics Reporting Service.

The effects of load management on net returns from irrigation are evaluated with respect to plant available soil water holding capacity (AWC) and irrigation pumping capacity. Load management is evaluated for AWCs of 3.1 and 4.3 inches in a three-foot profile. These soil types are selected from eleven commonly irrigated soil types in Minnesota according to the *Irrigation Guide for Minnesota* (U.S. Department of Agriculture). The 3.1 inch AWC soil has one of the lowest AWCs of the eleven soil types, while the 4.3 inch AWC is near the middle.

Two pumping capacities are included: 800 and 600 gallons per minute (gpm) or about 6.2 and 4.6 gpm per irrigated acre. The 800 gpm system is the average size recommended for "fine sands, loamy sands, and sandy loams" (Bergsrud et al.); thus it is commonly considered adequate for the range of soils analyzed in this study. The 600 gpm system is recommended for loams, silt loams, and clay loams and may be somewhat undersized for the range of soils assumed here. It is included to show the effects of interruptions on an irrigator whose system may not have the capacity to keep up with the crop's needs under all weather conditions.

Two levels of scheduling management are included to show its effect on losses suffered from restricted pumping. One level, labeled the "naive" method, presumes the irrigator uses very little soil water or weather information to make scheduling decisions. The method was developed in cooperation with extension irrigation engineers and researchers familiar with Minnesota irrigation practices. A higher level of irrigation management included is scheduling based on the Checkbook method (Werner). With this method soil water is estimated at the beginning of the irrigation season. Daily maximum temperature and number of weeks since crop emergence are used to estimate daily crop water use. These estimates along with recorded rainfall and irrigation amounts are used to estimate daily soil water

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[5] The equations were estimated using log-log transformations of the equations shown here. More details concerning the estimation procedure can be found in Bosch.

[6] Potential crop transpiration is the daily amount of water the plant will release to the atmosphere if soil water is not limiting.

[7] Hill and Hanks observed that the form of the equation used for corn did not predict yields well for soybean yield observations with low yields due to very late planting. They attributed the yield reduction to insufficient dry matter accumulation due to inadequate seasonal transpiration. SYF is included to account for insufficient seasonal transpiration and 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 taken from Hill and Hanks.

Table 1. Expected per Acre Net Returns Reductions for Selected Load Management Scenarios

	800 GPM System		600 GPM System	
Load Management Scenario	3.1″ AWC	4.3″ AWC	3.1″ AWC	4.3″ AWC
No interruptions	.0	.0	.0	.0
	(25/40)[a]	(35/40)	(5/25)	(10/40)
5 hr/day	1.77	1.37	8.04	5.55
4 days/wk	(15/30)	(25/40)	(5/15)	(5/30)
7 hr/day	3.17	2.28	12.30	8.58
4 days/wk	(15/25)	(25/40)	(5/10)	(5/30)
8 hr/day	15.28	8.47	35.91	23.17
7 days/wk	(5/15)	(5/35)	(5/5)	(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. Net returns reductions are averages for 12 years of weather data.

balances. The Checkbook method reflects an effort by the manager to use weather and soil water information to guide scheduling decisions.

As mentioned previously, nonneutral risk preferences may mean that the irrigator's level of absolute risk aversion will affect the amount of compensation required for pumping restrictions. Other studies provide some evidence on the distribution of producer absolute risk aversion coefficients. 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 which, when evaluated at $20,000 and $100,000, produced risk aversion coefficients ranging from 0 to .0003. Wilson estimated risk aversion coefficients for Minnesota swine producers. He found that 69% of producers with identifiable risk attitudes fell in an interval ranging from −.0002 to .0003. Because Minnesota swine producers and corn and soybean irrigators face similar levels of net returns, it is assumed they are characterized by similar risk aversion functions, and Wilson's findings are used to guide the placement of absolute risk aversion intervals. The −.0002 to .0003 interval is divided into three subintervals: −.0002 to −.00005, −.00005 to .0001, and .0001 to .0003. In addition, a very risk-averse interval, .0003 to .0015, and a very risk-seeking interval, −.001 to −.0002, are included.

Four load management alternatives are analyzed. They are: (*a*) no interruptions; (*b*) five-hour interruption, four days per week; (*c*) seven-hour interruption, four days per week; and, (*d*) eight-hour interruption, seven days per week. The five- and seven-hour interruptions are under consideration by at least one utility company in Minnesota. The eight-hour interruption simulates a very severe curtailment of power.

Results

Average per acre reductions in net returns due to load management for the two soil AWCs and two pumping capacities are shown in table 1. The figures show that load management does 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. For example, with the 3.1-inch 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.

Net returns are reduced more by load management on soils with lower AWC. 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-inch AWC soil compared to $2.28 on the 4.3-inch AWC soil. Soils with a lower AWC give the irrigator less opportunity to offset the reduced pumping capacity imposed by load management by storing more water in the soil.

The numbers in parentheses in table 1 show the soil water depletion level at which corn/soybean irrigation is initiated. The Checkbook method is used to track soil water levels. When load management is imposed, the net-returns-maximizing depletion level at which to trigger irrigation declines. For example, with the 3.1-inch AWC soil, 800 gpm capacity, and no in-

Table 2. Expected per Acre Water Applications for Selected Load Management Scenarios

Load Management Scenario	800 GPM System		600 GPM System	
	3.1″ AWC	4.3″ AWC	3.1″ AWC	4.3″ AWC
No interruptions	7.47[a]	7.23	7.95	7.51
5 hr/day 4 days/wk	7.84	7.56	7.69	7.78
7 hr/day 4 days/wk	7.83	7.50	7.51	7.53
8 hr/day 7 days/wk	7.74	7.51	6.52	6.61

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

terruptions, the expected-returns-maximizing strategy calls for irrigating corn at 25% depletion of AWC and soybeans at 40% depletion. When a five-hour interruption is imposed, the expected-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. Thus, the optimal irrigation strategy under load management requires initiating irrigation at a higher level of AWC to compensate for the reduced pumping capacity.

The actual amount of water pumped is affected in two opposite ways by load management as shown in table 2. First, reducing the number of hours per week the system can pump tends to reduce water use. However, the previously noted tendency to begin irrigating at higher soil water levels would increase irrigation water applications. Table 2 shows that for three of the four combinations of soil AWC and pumping capacity, expected seasonal water applications increase going from no interruptions to a five-hour interruption and then generally decline with the seven- and eight-hour interruptions. The exception is the 600 gpm, 3.1-inch AWC case where expected application amounts decline consistently as the number of hours of interruption increases.

Utility companies and irrigators are concerned with the amount of compensation which must be offered to keep expected net returns from falling when load management is imposed. The net returns reductions shown in table 1 were evaluated to determine the reduction in the demand fee necessary to offset them and maintain expected net returns at zero interruption levels. The required demand rate reductions are shown in table 3.[8] To put the figures in perspective, one might note that at the time the study was done the rate charged by Northern States Power, a utility serving ir-

[8] The figures were 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 demand rates are calculated to be 34.27 and 47.24 kw, respectively.

Table 3. Break-even per Kilowatt Demand Rate Reductions Required to Keep Net Returns from Falling under Load Management

Load Management Scenario	800 GPM System		600 GPM System	
	3.1″ AWC	4.3″ AWC	3.1″ AWC	4.3″ AWC
5 hr/day 4 days/wk	1.70	1.31	10.03	6.64
7 hr/day 4 days/wk	3.03	2.18	14.93	10.27
8 hr/day 7 days/wk	13.83	7.77	43.04	27.38

Note: Break-even reductions are 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 are assumed for the 800 and 600 gpm systems.

Table 4. Effects of Scheduling Management on Reductions in Net Returns Due to Load Management

Load Management Scenario	Scheduling Management Scenario[a]: Checkbook, Trigger Level Adjusted		Checkbook, Trigger Level Not Adjusted		Naive Strategy	
	3.1″ AWC	4.3″ AWC	3.1″ AWC	4.3″ AWC	3.1″ AWC	4.3″ AWC
5 hr/day 4 days/wk	1.77	1.37	2.87	2.21	2.23	.42
7 hr/day 4 days/wk	3.17	2.28	6.22	4.00	4.65	1.21
8 hr/day 7 days/wk	15.28	8.47	24.08	14.97	22.49	12.26

[a] The three management scenarios are (*a*) use of the Checkbook method with adjustment of the soil water depletion at which irrigation is initiated to compensate for load management, (*b*) use of Checkbook method but continuing to initiate irrigation at the soil water depletion level which was optimal with no interruptions, (*c*) using a naive strategy based on very little soil water or weather information. These management levels are evaluated for 3.1″ and 4.3″ AWC soils and 800 gpm pumping capacity. Table entries show the reduction in average per acre net returns with load management.

rigators in the state, was about $6.25 per kilowatt. 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. Required reductions for the five- and seven-hour interruptions are well within the $6.25 figure for both soil AWCs.

The previous analysis assumes 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 load management. Table 4 shows the effects of relaxing these assumptions for the 800 gpm system. The first scenario is a repetition of the results shown in table 1, with the Checkbook method 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 reduced pumping capacity under load management. Finally a naive scenario is included to show the effects of pumping limitations 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 pumping restrictions.

The results show the importance of proper management to minimize the losses from restricted pumping. In the case of the 3.1-inch 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-inch 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 load management are increased when scheduling management does not take the reduced pumping capacity into account.

Interestingly, losses from load management are actually smaller for the naive strategy than for the Checkbook method with no adjustment of the trigger. In two cases (4.3-inch 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 load management is that it routinely applies higher water levels and has lower expected returns than the Checkbook method in the no-load-management case. That is, the naive strategy routinely applies more water than needed to maximize expected returns. Imposing load management reduces net returns less for the naive strategy than for a strategy which comes closer to maximizing expected net returns with unrestricted pumping.

The effects of risk preferences on the amount of compensation needed to keep irrigators from being made worse off by load management participation are shown in table 5. These are the amounts which must be added to whole-farm net returns when load management is imposed

Table 5. Effects of Varying Risk Preferences on the Amount of Subsidy Required to Maintain Expected Utility under Load Management[a]

Load Management Scenario	Coefficient of Absolute Risk Aversion Interval					
	−.001 to −.0002	−.0002 to −.00005	−.00005 to .0001	0.0 to 0.0	.0001 to .0003	.0003 to .0015
	($)					
5 hr/day 4 days/wk	.50	1.00	14.80	1.77	15.60	14.30
7 hr/day 4 days/wk	.60	1.20	15.80	3.17	16.60	15.20
8 hr/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. The Checkbook method is used to monitor soil water levels.

to keep the load management distribution from being stochastically dominated by the no-load-management distribution for a specified risk aversion interval. The required subsidies are calculated on a whole-farm basis but presented on a per-irrigated-acre basis to make them easier to interpret. A 3.1-inch AWC soil and 800 gpm system are assumed.

The results show that increasing risk aversion causes the required subsidy to increase. The risk seeker whose absolute risk aversion coefficient lies 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. Second, the dry years tend to produce the lowest incomes because of 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, with risk neutrality all outcomes are weighted the same if they are equally likely to occur. Thus, the effects of load management on income in very dry years are diluted by higher income years when rainfall is heavier and pumping capacity less critical.

The amount of subsidy required for risk neutrality is somewhat less than for the interval −.00005 to .0001, which straddles risk neutrality. This result is explained by recalling that the amount of subsidy derived using GSD is an amount sufficient to compensate any decision maker whose risk aversion coefficient lies within the interval. Because more risk-averse decision makers require higher subsidies, the required compensation for the interval which includes some risk-averse decision makers is higher than for risk-neutral producers alone.

The amount of compensation required appears to be sensitive to the inclusion of 1976, a very dry year in southwestern 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 5 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 may seem surprising but is explained as follows: Each income distribution is generated by using each of the eleven output price vectors with each of the twelve years of weather data. 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. The minimum outcome in this empirical application results from the combination of the worst set of output prices and yield for the drought year, 1976. The reduction in income for a given yield is less for a lower than for a higher set of output prices. Consequently, agents in the most risk-averse category who attach the most importance to the outcomes produced by lower output prices require a smaller subsidy.

Conclusion

Power companies may limit daily irrigation pumping in an effort to reduce the company's peak generating capacity requirements. They may compensate irrigators for the limitation by lowering the electricity charge. This study focuses on the amount of compensation required to maintain irrigators' expected utility under such a load management program. Results indicate that with 800 gpm pumping capacity, 21% to 48% reductions in the assumed $6.25 per kilowatt demand charge are needed to keep expected net returns from falling for 20- and 28-hour per week interruption scenarios. When pumping capacity is lowered to 600 gpm, the required demand rate reductions exceed the $6.25 demand charge. Reducing the soil AWC also causes net returns to fall more from load management.

Proper scheduling management is important to mitigate the effects of reduced pumping capacity resulting from load management. The net-returns-maximizing strategy calls for irrigation to be started sooner (at higher soil water levels) as the number of hours of interruptions increases. Failure to adjust the strategy increases the losses from load management. 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 from load management than would be the case for the irrigator following an expected-returns-maximizing strategy.

Attitudes towards risk affect the amount of discount required to compensate for pumping restrictions. When risk aversion increases, the required discount rises because load management reduces yields and net returns more in very dry years when income may already be low because of low yields from nonirrigated crops.

A load management program may enable utility companies to use their generating capacity more efficiently. The findings of this research emphasize that, because of the wide variation in the required compensation, these savings from more efficient use of generating capacity could be most effectively achieved if participation in such programs were made voluntary. Some irrigators would be better off not participating because they operate low pumping capacity systems and/or they are highly risk averse.

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 reduced pumping capacity as a result of power interruptions.

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