

**EFFECTS OF ALTERNATIVE IRRIGATION ALLOCATIONS ON
WATER USE, NET RETURNS, AND MARGINAL USER COSTS**

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EFFECTS OF ALTERNATIVE IRRIGATION ALLOCATIONS ON WATER USE, NET RETURNS, AND MARGINAL USER COSTS

Background

In areas of the High Plains, there is concern about the rate of withdrawal of groundwater for irrigation. Aquifer levels in several southwest Nebraska counties are dropping and groundwater pumping, especially in alluvial areas, may be diminishing surface flows. Policymakers, and many producers in the area, recognize the desirability of moving toward a more efficient use of irrigation water to conserve groundwater and increase net returns.

The Upper Republican Natural Resources District¹ (URNRD), comprising a three county area in semi-arid southwest Nebraska with 3,200 irrigation wells, has taken a number of "command and control" steps to address water table declines. The URNRD requires metering of all irrigation wells (all meters are sealed, read, and serviced by URNRD staff). The District has a limit on irrigated acres per well, a 14.5"/acre/year allocation for all irrigation wells, and a moratorium on new wells. The allocations are given in 5-year allotments, allowing year-to-year flexibility.

Allocations (initially at 22" then 18", 16", 15" and now 14.5") have been in place for 20 years. As allocations were reduced, there was widespread conversion to more efficient irrigation systems (e.g., center pivots, low pressure drops, and use of rain gauge shut-offs). The 14.5"/acre allocation is sufficient for most irrigators. Since they can carry unused amounts to the next year and into the next five-year period, there is an incentive to conserve and most have a "cushion" within which to operate. Exacerbating the concern about pumping rates, the URNRD and three other NRDs in the Republican River Basin are involved in a US Supreme Court lawsuit filed by Kansas against Nebraska and Colorado. Kansas claims that water delivery from the Republican River Basin into Kansas has diminished due to groundwater pumping in Nebraska. If Kansas should prevail, one possible result could be a further reduction of the allocation in the URNRD, and the imposition of allocations in other regions of the Basin.

Objectives

The objective of this research is to provide, to producers and policymakers, information about corn yield and net revenue effects of irrigation water use restrictions in southwest Nebraska. Specifically, we are estimating: 1) corn yield response (on several soil types) to irrigation water use; 2) optimal levels of irrigation water use in a region where irrigation water is regulated and allocated; 3) the effect on net returns of reducing the water allocation below the current level; and 4) *in situ* values (or marginal user costs) of producers conserving parts of the their allocation for future use or sale.

¹ Twenty-four (currently 23) NRDs were created by the Nebraska Legislature in 1972 based on hydrologic lines and covering the entire state. The NRDs are governed by locally elected boards of directors and funded primarily by local property taxes. The districts have broad powers to manage resources, including: erosion prevention, soil conservation, ..., water supply development, pollution control, fish and wildlife habitat, ...and management of the quality and quantity of groundwater (Longo and Miewald, 1989).

The Model and Data

Nebraska law does not designate ownership of water rights for groundwater. The landowner has the right to beneficial use of groundwater, but as yet cannot sell this right separate from his/her land. However, there is considerable agreement among those in the legal and policy professions that URNRD rules and regulations, which allow for unlimited accumulation of allocations (which is capitalized into the value of the land), have created usufructuary² water rights. Because producers in the URNRD are allowed to accumulate unused allocations, they should account for the potential value of future income from each inch of irrigation water conserved (marginal *in situ* value); or stated alternatively, they should account for the marginal user cost of each inch of water, if consumed now. Marginal user cost is the opportunity cost of using the natural resource (in this case, groundwater) in the current period, and is equivalent to foregone marginal net benefits in a future period (Carlson et al., 1993). Marginal user cost for these producers may be non-zero because the URNRD rules and regulations have changed an unlimited-access common property resource (groundwater) into a restricted-use common property resource.

Starting with a simplified model, we assume a two-period allocation (A_0) that is used within the two periods or lost (i.e., no carryover into the next allocation period), and that no marketing of water is allowed. The producer would choose the level of irrigation in each period (I_t , $t=1,2$) that maximizes the present value of per-acre net income (NR) from the two periods. He/she is subject to the condition that water use in the two periods be less than or equal to the allocation: $I_1 + I_2 \leq A_0$. Therefore, the optimization model is:

$$\max_{\{I_1, I_2\}} NR = p_1 \cdot Y_1(I_1) - w_1 \cdot I_1 + \mathbf{d} \cdot [p_2 \cdot Y_2(I_2) - w_2 \cdot I_2] + \mathbf{I} \cdot [A_0 - I_1 - I_2] \quad [1]$$

where $t=1,2$ is the time period, p_t is the expected price of corn, w_t is the cost of pumping water, Y_t is the yield function for corn, I_t is the amount of irrigation water used, δ is the discount factor for discounting future net returns, and λ is the Lagrangian multiplier. The multiplier is the production value of an extra inch of allocated water.

Given the inequality allocation constraint, the optimal levels of I in each period are chosen by solving the necessary Kuhn-Tucker first order conditions (Chiang, 1984):

$$p_1 \frac{\partial Y_1}{\partial I_1} - w_1 - \mathbf{I} \leq 0, \quad I_1 \geq 0 \quad \text{and} \quad (p_1 \frac{\partial Y_1}{\partial I_1} - w_1 - \mathbf{I}) \cdot I_1 = 0 \quad [2]$$

$$\mathbf{d} \cdot (p_2 \frac{\partial Y_2}{\partial I_2} - w_2) - \mathbf{I} \leq 0, \quad I_2 \geq 0 \quad \text{and} \quad [\mathbf{d} \cdot (p_2 \frac{\partial Y_2}{\partial I_2} - w_2) - \mathbf{I}] \cdot I_2 = 0 \quad [3]$$

$$A_0 - I_1 - I_2 \geq 0, \quad \mathbf{I} \geq 0 \quad \text{and} \quad (A_0 - I_1 - I_2) \cdot \mathbf{I} = 0 \quad [4]$$

In this scenario, where the only choice for generating income with the water allocation is to use it in production, the constraint may or may not be binding. If the NRD Board sets the irrigation allocations at a low enough level then, $A_0 = I_1 + I_2$, and λ most likely will be positive (only equal to zero if A_0 is exactly the level that maximizes NR in both periods). In this case

² Bouvier's Law Dictionary (1856 Edition) provides the following definition: "USUFRUCT, civil law. The right of enjoying a thing, the property of which is vested in another, and to draw from the same all the profit, utility and advantage which it may produce, provided it be without altering the substance of the thing."

(and assuming $I_1, I_2 > 0$), producers are forced to conserve and will apply water to the point where: $p_1 \frac{\partial Y_1}{\partial I_1} - w_1 = \mathbf{d} \cdot (p_2 \frac{\partial Y_2}{\partial I_2} - w_2) = \mathbf{I}$. This implies that the optimal choice of I_1 and I_2 is found by equating the marginal net value of the last inch used in the first period (MNV_1) to the discounted marginal net value in the future period (δMNV_2), that is:

$$MNV_1 = \delta MNV_2 = \lambda \quad [5]$$

where $MNV_t = VMP_t - w_t$ ($t=1,2$); and VMP is the value of the marginal product of irrigation water. These MNV s are equal to the value of an extra inch of allocated water (λ). If the allocation is not restrictive, then irrigators use additional water to the point where:

$$MNV_1 = \delta MNV_2 = 0 \quad [6]$$

Although water allocations are imposed on producers in the URNRD region, there is flexibility built into the rules, and the allocation does not appear to impose a binding constraint on most water users. Since the URNRD Board allows unlimited accumulation of unused allocations, water can be saved indefinitely. Recently the Board instituted a water banking rule which allows for deposits and withdrawals of allocations. Water from these accounts can be used at points differing from the withdrawal location, opening the possibility of water marketing. To account for the carrying forward of water into the next period, equation [1] should be altered as follows:

$$\begin{aligned} \max_{\{I_1, I_2, S\}} NR = & p_1 \cdot Y_1(I_1) - w_1 \cdot I_1 + \mathbf{d} \cdot [p_2 \cdot Y_2(I_2) - w_2 \cdot I_2] + \mathbf{d} \cdot h(S) \\ & + \mathbf{I} \cdot [A_0 - I_1 - I_2 - S] \end{aligned} \quad [7]$$

where S represents the amount of water conserved by the irrigator for future use or sale, and $h(S)$ represents the future income generated from conservation in periods 1 and 2. The first-order conditions for equation [7] are:

$$p_1 \frac{\partial Y_1}{\partial I_1} - w_1 - \mathbf{I} = 0, \quad [8]$$

$$\mathbf{d} \cdot (p_2 \frac{\partial Y_2}{\partial I_2} - w_2) - \mathbf{I} = 0 \quad [9]$$

$$\mathbf{d} \cdot \frac{\partial h}{\partial S} - \mathbf{I} = 0 \quad [10]$$

$$A_0 - I_1 - I_2 - S = 0 \quad [11]$$

Solving [8]-[10] yields the following condition for optimally choosing I_1 , I_2 , and S :

$$MNV_1 = \delta MNV_2 = \mathbf{d} \cdot \frac{\partial h}{\partial S} = \lambda \quad [12]$$

In the unlikely situation that $h(S)=0$, this means that S is irrelevant to decision-making, and the model is the same as equation [1]. However, in the URNRD, $h(S)$ has value in one or more ways. These are discussed in the next section.

The marginal user cost of irrigation water for the producer is $d \cdot \frac{\partial h}{\partial S}$. At the optimum levels of I_1 , I_2 , and S , marginal user cost (MUC^*) is equal to MNV_1^* . With knowledge of the yield function, crop price, pump cost, and actual irrigation water use, MNV_1^* (and hence, MUC^*) can be estimated. Furthermore, solving $MNV_1 = 0$ yields the level of I (noted as I^c) that the irrigator would use if maximizing current net revenue is his only objective. The difference ($I^c - I^*$) is the amount of allocated water per acre conserved for the future. Also, the difference between net revenue using I^c and I^* for the first period represents the foregone net revenue per acre of conserving S . That is:

$$NR_1^c - NR_1^* = [p_1 \cdot Y_1(I^c) - w_1^c \cdot I^c] - [p_1 \cdot Y_1(I^*) - w_1^* \cdot I^*].$$

In order to calculate the MNVs, MUCs, and net returns, the yield function for corn was estimated as follows:

$$Y = Y(I ; CIR3, CIRTOT, WHC, Y1996) \quad [13]$$

where:

Y	= corn yield, bu/acre;
I	= inches of irrigation water applied per acre;
CIR3	= crop irrigation requirement in reproductive stage. CIR is equal to potential evapotranspiration (ET) minus effective rainfall (in/acre).
CIRTOT	= crop irrigation requirement in stages 1 to 4 of crop growth (in/acre).
WHC	= average soil water holding capacity for each producer's field (inches per foot of soil);
Y1996	= dummy variable for the year 1996, which was an abnormally wet year in the region.

CIR at any growth stage was set equal to zero if effective rainfall exceeded ET. There are four stages of crop growth: 1) emergence to early vegetative, 2) vegetative, 3) reproductive stage, and 4) grain fill to maturity. The most critical time for irrigation is during the reproductive stage, so crop irrigation requirements during this time are expected to have a significant effect on yield. The total CIR (CIRTOT) for the growing season was included as a cross product with the irrigation variable in the estimated yield equation.

Data for the model were collected by producer survey and from URNRD water use records. A 4-page questionnaire was mailed to irrigators in the three counties of the URNRD. Field-specific information was requested for 1995-1998 regarding crops grown; yields; external factors affecting yields such as hail damage; and details concerning the irrigation well and power source for the water pump and pivot. Twenty-five percent of the surveys were returned with useable responses. Accurate water use for each field and year was gathered from URNRD records. Average water use for the respondents to the survey was 11.3 in/acre per year for 1995-1998.

Soil types from county soils maps were matched with the legal description for each field included in the survey. Soil type information was then used to estimate the average water-holding capacities (WHC) of the fields. Crop irrigation requirement was calculated using local rainfall and evapotranspiration (ET) data pertinent to each producer's field. Eleven weather stations (3 automated and 8 cooperator stations) located in or adjacent to the URNRD were identified in the High Plains Climate Center on-line database. Daily rainfall data were collected from all 11 stations and ET data were obtained from the 3 automated stations. Effective rainfall during the growing season at these locations was estimated by subtracting runoff from storm rainfall³. The three nearest stations to each corn field were identified and crop irrigation requirement (ET minus effective rainfall) for each field was estimated by using an inverse weighted distance formula. Fertilizer use information was also collected from producers but is not included in this model. In southwest Nebraska, fertilizer is essentially a fixed input for the season. Decisions concerning fertilizer are primarily made before planting and based upon target yields and residual nitrogen in the soil. Irrigation water is also applied to achieve target yields, but the actual quantity used is variable over the season, depending upon climatic conditions. In addition, fertilizer and irrigation are strongly correlated, so inclusion of both variables in the model was not desirable.

Pumping costs were estimated using a program developed by the University of Nebraska (Selley). Pump costs varied due to energy type, energy price, pumping capacity of the well (gallons per minute), feet of pumping lift, and water pressure at the well (psi). Energy prices (electric and diesel) were collected from utility companies and diesel suppliers in the area. For well pumps powered by diesel, the pump cost is fixed for all amounts of irrigation. Electric-powered pumps have costs that vary by amount of irrigation. Due to a declining block rate pricing scheme and seasonal hook-up charges, marginal pump cost, average variable pump cost and average total pump cost are not equal at each well. These varying marginal and average total costs were used in solving for optimal irrigation levels and net revenues, respectively.

Corn price was the expected price of corn for the new crop in each year. It was estimated as the average of the June through September weekly future prices for the December corn (new crop) contract minus the expected basis for the area. Table 1 lists the means and standard deviations of data used in the model.

Results

The estimated irrigation response (production) function for irrigated corn is:

$$\begin{aligned}
 Y = & 40.0 - (34.074 \cdot I) + (73.985 \cdot I^8) - (3.591 \cdot CIR3) + (0.134 \cdot CIRTOT \cdot I) \\
 & \quad (-5.15)^{***} \quad (6.84)^{***} \quad (-3.95)^{***} \quad (1.98)^{**} \\
 & \quad + (18.907 \cdot WHC) - (1.095 \cdot WHC \cdot I) + (14.080 \cdot Y1996) - (2.134 \cdot Y1996 \cdot I) \\
 & \quad (2.62)^{***} \quad (1.85)^* \quad (1.33) \quad (-1.87)^*
 \end{aligned}
 \tag{14}$$

³ Runoff amounts were calculated using a method developed by the Soil Conservation Service in 1972 (Chow et al., 1988).

where one, two, or three asterisks means estimated coefficient was significant at the 90%, 95%, or 99% level.⁴

Observations were dropped from the data set if a large yield loss occurred from hail or disease, or if corn was not grown on the field in any of the four years. Two hundred and twenty six observations were used in the regression, representing 95 individual producers, with one to four years of data for each producer. Figure 1 shows the graph of corn yield response to irrigation water by three major soil classes (low, medium, and high water holding capacity soils).⁵ Average total crop irrigation requirement was 12.2 in/acre in these illustrations.⁶

The marginal product of irrigation was derived from equation [13] and substituted into the first order condition $MNV_1 = MUC$, where:

$$MNV_1 = p_1 \cdot [-34.07 + 59.19 \cdot I_1^{-2} + .13 \cdot CIRTOT - 1.1 \cdot WHC - 2.13 \cdot Y1996] - w_1 \quad [15]$$

Values for equation [15] were calculated for every observation in the data set, yielding 226 values of MNV_1 , and hence MUC. We assume that the actual irrigation levels of the producers represent the optimal I^* derived from first-order conditions [8]-[10], for model [7]. The values of I^c , i.e. the level of irrigation used if $MUC=0$, are found by solving equation [15] set equal to zero. Net revenues per acre were calculated using both I^* and I^c ; the differences in net revenues were then calculated for each observation. These differences represent the foregone net revenues per acre from conserving water. Table 2a shows the averages of I^* and I^c (and their differences) across producers, for all soils and by soil type. Table 2b shows the foregone net revenues per acre and the marginal user costs.

It should first be noted that the optimal (actual) uses (overall and by soil type) are below the 14.5" allocation set by the URNRD. Relative to non-metered and unregulated irrigation wells outside the NRD, these producers have become very good at conserving water. The overall average (optimal) irrigation use on all soils by producers in the survey was 11.3 in/acre from 1995-98 (Table 2a). The levels of I^c found by solving $MNV_1=0$ averaged 12.7 in/acre. This difference of 1.4 in/acre is costing the producers an average of almost \$8.00 per acre in lost current net revenue. The I^c values for low WHC (sandy) soils average 14.8", while actual use by producers has been over 2.6" less (12.2"/acre). Producers with high WHC soils (loams and silt loams) average an optimal use of 10.8", but I^c levels are 0.7 inch higher on average. The cost, in terms of decreased current net returns, ranged from \$10.02/acre for the sandy low WHC soils to \$5.96/acre for the high WHC soils (Table 2b). Marginal users costs (MNV at the actual level of

⁴ The R^2 for the model (.98) is redefined due to estimation without an intercept. Estimation with an intercept did not provide realistic results. Therefore, equation [2] was estimated using OLS regression methods without an intercept (40 was subtracted from the dependent variable, and added back in to calculate predicted yields). The number 40 was used as it created realistic dryland yields when irrigation (I) was set to zero.

⁵ Low WHC soils are defined as soils that can hold between .7-1.26 inches per foot of soil, and represent the very sandy soils in the region. Medium WHC soils hold 1.27-1.92 in/ft. Examples include fine sandy loams, loamy fine sands, and some loamy sands. The high WHC soils are defined as holding greater than 1.93 in/ft and include loams, silt loams, and very fine sandy loams.

⁶ Note that the yield curve for the high WHC soil reaches a maximum at a lower amount of irrigation than the low WHC soil. This is due to the ability of the corn plant to extract from the root zone several more inches of water from a high WHC soil as compared to a low WHC soil. We speculate the steeper slope of the low WHC soil is due to the larger relative proportion of required crop water that is at any time satisfied from recently applied water versus stored soil moisture. Given average climatic conditions for the four-year period, a corn crop required about 15 in/acre and 12 in/acre to reach maximum yields on low and high WHC soils, respectively.

irrigation used) of an extra inch of water for all soils averaged \$2.80/acre. MUC ranges from \$2.10/acre for high WHC soils to \$4.01/acre for the low WHC soils.

Tables 3a and 3b have the same information as Tables 2a and 2b except the values were calculated at the average values for all variables in the model (i.e., CIR, price, cost, and irrigation values). Under average conditions, the overall water savings range from ½ inch on a high WHC soil to 2 inches/acre on a low WHC soil. The cost in foregone net revenue per acre on a sandy soil is about \$3.30, five times higher than on a loamy soil.

Reasons for “Under-Irrigating” and “Over-Irrigating”

Sacrificing current income to conserve water appears to be the typical behavior by producers in the URNRD. The percentage of occurrences of irrigation at less than the current net-revenue maximizing amount of water (i.e., I^c) was 68% (154 out of 226). It is estimated from data on well pumping capacity that about 5% of the time, producers may have used less water because of low-yielding wells. Four of the 154 under-irrigations may have been due to a low allocation balance (they had less than 14.5”/acre remaining per year). The remaining producers, however, appear to recognize and make explicit adjustments for the value of water not immediately consumed in corn production.

Assuming that the producers in the survey are “rational,” economic theory implies the irrigators believe conserving their water is worth at least as much as the revenue given up by not using the water. There are several things that may explain the marginal user cost values for producers:

1. Building up the carryover in their water account insures a producer’s ability to have enough water in the event of a multi-year drought.
2. The value of the banked water is capitalized into the value of the land. For the owner/operator, this may be a form of investment. For a renter of the pivot, this could mean additional pressure to keep water use to a minimum in order to increase his chances of longer leases. In some cases, owners impose penalties on renters if they exceed a certain amount of water use within the 5-year allotment period.
3. Foreseeing the potential to market water in the near future, producers may be banking water with a plan to sell the excess later on.
4. Even though groundwater is a common property resource, some may believe increased conservation today may extend the life of the aquifer. Producers may be willing to trade some economic gains today for gains in the future; the present value of future income (including future generations of current owners) would be expected to exceed the foregone net revenue today.

About 32% of the time (72 times in the survey data) producers applied greater than the I^c level of water on their fields (i.e., “over-irrigated”). Thirty-eight of these occurrences exceeded I^c by less than one-inch. The remaining 34 times the excess water use ranged from 1" to 7.3". A portion of these may be due to poor management or the lack of full information about soil moisture, future corn prices, pumping costs, etc. Others may be risk averse and see additional water applications as extra insurance for a good crop. Since management is not free, some may substitute water for time in the field assessing soil moisture and other crop management conditions.

The Effect of Reduced Allocations

The current US Supreme Court lawsuit by Kansas against Nebraska could lead to reductions in future water allocations in the URNRD if Kansas wins. The current 14.5-inch allocation is, in general, not restrictive and the actual use averaged about 11 in/acre. To find the effect on average net revenue of more restrictive allocations, we recalculated the net revenue for

each producer at the levels of both 8 and 10 in/acre, assuming current management and technology. This is the same as model [7] except that A_0 is set to lower values.

If actual use was less than the new allocation amount, predicted net revenue was calculated at the lower level of irrigation. Table 3 shows the difference between average actual net revenue values and the values achieved with the 10-inch and 8-inch allocations. The average water savings with the 10 and 8-inch allocations are 2.1 and 3.6 in/acre, respectively. The corresponding costs to producers (in terms of decreased current net revenue) are \$3.79 and \$12.91 per acre, for all soils. If these costs occurred for every irrigated acre in the district (460,000 acres), the aggregate total costs would be \$1.7 to \$5.9 million, respectively. The impact of restrictive allocations varies considerably – from a low of \$1.26/acre for the 10-inch allocation on high WHC soils to a high of \$24.16/acre for the 8-inch allocation on low WHC soils. The producers with low WHC soils incur the largest costs under both allocations because each acre-inch less they use results in a greater loss of yield as compared to the other soil types (see steeper slope in Figure 1). If water savings equal to the 8-inch allocation occurred for every well in the district, approximately 138,000 acre-feet of water could be conserved per year (3.6 in/acre times 460,000 irrigated acres).

These changes in net revenue are simplified estimates of the impact of lower allocations, especially if they were implemented over time. New technologies, both irrigation and corn hybrids, and improved management should lead to the ability to produce the same (or more) bushels of corn with less water. Furthermore, rotating corn with other crops such as soybeans and wheat may become more profitable with less water. However, recent analysis shows that given average prices (1989-1998), continuous corn is still the most profitable enterprise even with an 8-inch water allocation (Schneekloth et al., 2000). Additional work is underway at the University of Nebraska to examine the longer-term benefits of crop rotations that may change this result.

Summary and Conclusions

From the above results, it is clear that the current 14.5” allocation is not directly restrictive on most producers’ irrigation management. Rather, the past 20 years of metering and regulation of water use led to the adoption of water-conserving irrigation technologies and improved irrigation management. In addition, the mindset of conservation has led to producers banking water for future use or sale at the cost of current net income. Most respondents to the survey are using less water than it takes to maximize current net returns.

Some studies have postulated that farmers are not necessarily maximizing pecuniary gains alone. Depending on what other concerns or “goods” are in their utility functions or what other constraints may exist, it is difficult to analyze the reasons behind any producer’s conservation strategies without more study.

The URNRD has instituted a water banking rule which allows for deposits and withdrawals that can change points of withdrawal and points of use. It also specifies a possible “offset” or charge for transfers, if point of withdrawal changes by more than a certain distance or goes to areas with less saturated thickness. This banking rule may lead to a court case that will settle the question about whether individual usufructuary ground water rights have been created by the URNRD. If no, then values of accumulated allocations will decrease (MUCs approaching zero) and annual use will approach short-term maximum net revenue levels. If yes, the value of unused water (allocation balances) will likely increase (i.e., MUCs will increase). While, conservation may increase in the short-term, the sanctioning of rights means the ability to market water freely. This would likely increase irrigated acres in the district and reduce allocation

balances over time. However, this is not undesirable if the overall current per acre allocation of 14.5” is deemed satisfactory for the long-term sustainability of the aquifer.

On the other hand, if the URNRD Board determined that the allocation needed to be reduced, this study provides a starting point for determining the potential costs to producers of such actions. Long-term sustainability versus shorter-term economic viability of agriculture in the region will need to be considered. An 8-inch allocation might sustain irrigated agriculture for longer than a 10-inch allocation, but the average cost is almost 3.5 times higher. Another question the URNRD might address is whether continuing uniform allocations are appropriate, given that, on average, it takes 3.3 more inches/acre (see Table 2a) to maximize current net returns on sandy soils as compared to high WHC soils. However, with marketing of water a possibility, any such “inequities” might be alleviated. For example, with a 10-inch allocation, the irrigator on a high WHC soil should be willing to sell an inch for \$1.84 or more, and the sandy soil irrigator should be willing to pay up to \$4.77 (see Table 4). If water is marketed at some price in between these two levels, then both producers would be better off.

Table 1. Simple Statistics for Model Variables.

Model Variables	Description	Mean	Std Dev	Minimum	Maximum
YIELD	Corn yield (bu/ac)	171	19	140	213
IRRG	Applied water (in/ac)	11.3	3.4	4.2	18.2
CIR3	Crop irrigation requirement in reproductive growth stage 3 (in/ac)	6.9	3.3	1.5	13.4
CIRTOT	Sum of crop irrigation requirement in growth stages 1 through 4 (in/ac)	12.3	4.1	4.7	19.9
WHC	Average water-holding capacity of soil (in/ft)	1.71	0.50	.78	2.52
Y1996	Year = 1996	.27		0	1
Other Information		Mean	Std Dev	Minimum	Maximum
Marginal irrigation pumping cost (\$/ac-in)		2.19	1.05	0.67	5.75
Average variable pumping cost (\$/ac-in)		2.73	1.06	0.67	5.75
Average total pumping cost (\$/ac-in)		3.28	0.92	1.33	5.84
Yearly Climate and Price Information		<u>1995</u>	<u>1996</u>	<u>1997</u>	<u>1998</u>
Effective Rainfall *		12.1	19.2	12.7	12.5
Evapotranspiration **		26.4	20.2	24.4	23.6
Expected Corn Prices (\$/bu)		2.58	3.13	2.28	2.06

* Effective rainfall at each well site is a weighted inverse distance average of the 3 closest local weather stations; it equals rainfall adjusted by the SCS method for calculating runoff from storm events, but is not adjusted for potential deep percolation of water.

** ET for each well site was assigned as the closest of three automated weather stations in the region.

Figure 1. Corn Yield Response to Applied Water, by Soil Water Holding Capacity (WHC)

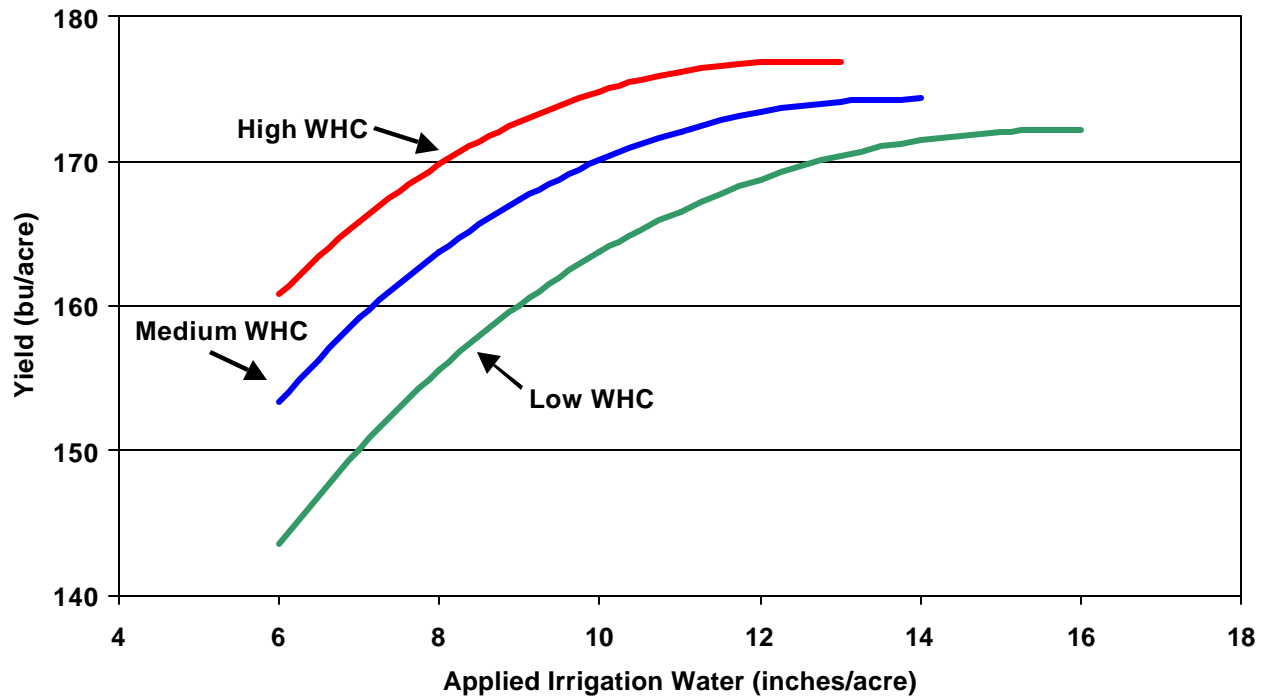


Table 2a. A Comparison of Irrigation Use and Net Returns with and without Positive Marginal User Costs, by Soil Type, 1995-1998

(Shown are the mean and standard deviation of results for all producers across years, by soil type)

<u>Applied Water Use</u> <u>(in/acre)</u>	<u>All Soils</u>	<u>Low WHC</u>	<u>Medium WHC</u>	<u>High WHC</u>
I^c (if MUC = 0)	12.7 (2.7)	14.8 (2.8)	12.8 (2.6)	11.5 (2.1)
I^* (Optimal=Actual; MUC > 0)	11.3 (3.4)	12.2 (3.6)	11.2 (3.1)	10.8 (3.4)
Amount conserved ($I^c - I^*$)	+1.4 (3.0)	+2.6 (3.0)	+1.6 (3.1)	+0.7 (2.6)

Note: Standard deviations in parentheses.

Table 2b. Cost of Conserving Water, By Soil Type, 1995-1998.

(Shown are the mean and standard deviation of results for all producers across years, by soil type)

	<u>All Soils</u>	<u>Low WHC</u>	<u>Medium WHC</u>	<u>High WHC</u>
Change in Net Revenue (\$/acre) [$NR(I^c) - NR(I^*)$]	-\$ 7.91 (12.2)	-\$ 10.02 (14.9)	-\$ 8.67 (13.6)	-\$ 5.96 (8.3)
Marginal User Cost ($\Delta\$/\Delta in$)	\$ 2.80 (5.1)	\$ 4.01 (4.9)	\$ 2.81 (5.3)	\$ 2.10 (4.9)

Note: Standard deviations in parentheses.

Table 3a. A Comparison of Irrigation Use and Net Returns with and without Positive Marginal User Costs, by Soil Type, 1995-1998

(Results shown were calculated at the average values for all variables in model)

<u>Applied Water Use</u> (in/acre)	<u>Low WHC</u>	<u>Medium WHC</u>	<u>High WHC</u>
I^c (if MUC = 0)	14.2	12.5	11.3
I^* (Optimal=Actual; MUC > 0)	12.2	11.2	10.8
Amount conserved ($I^c - I^*$)	-2.0	-1.3	-0.5

Table 3b. Cost of Conserving Water, By Soil Type, 1995-1998

(Results shown were calculated at the average values for all variables in model)

	<u>Low WHC</u>	<u>Medium WHC</u>	<u>High WHC</u>
Change in Net Revenue (\$/acre) [NR(I^c) – NR(I^*)]	- \$ 3.29	- \$ 2.22	- \$.66
Marginal User Cost ($\Delta\$/\Delta in$)	\$ 2.47	\$ 1.83	\$.77

Table 4. The Predicted Effect of Lower Allocations on Use and Net Returns, By Soil Type, 1995-1998

<u>Water Use with 10" Allocation</u> (in/acre)	<u>All Soils</u>	<u>Low WHC</u>	<u>Medium WHC</u>	<u>High WHC</u>
Actual	11.3	12.2	11.2	10.8
Allocation	9.2	9.3	9.2	9.0
Water Savings with Allocation	+ 2.1	+ 2.9	+ 2.0	+ 1.8
Change in Net Revenue (\$/acre)	-\$ 3.79	-\$11.03	-\$ 2.11	-\$ 1.26
Value of Extra Inch (λ)	\$2.98	\$4.77	\$3.09	\$1.84
<u>Water Use with 8" Allocation</u> (in/acre)	<u>All Soils</u>	<u>Low WHC</u>	<u>Medium WHC</u>	<u>High WHC</u>
Actual	11.3	12.2	11.2	10.8
Allocation	7.7	7.8	7.8	7.6
Water Savings with Allocation	+ 3.6	+ 4.4	+ 3.4	+ 3.2
Change in Net Revenue (\$/acre)	-\$12.91	-\$24.16	-\$11.53	-\$7.79
Value of Extra Inch (λ)	\$6.51	\$8.92	\$6.68	\$4.97

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