ECONOMIC IMPACTS FROM REGULATING GROUND WATER USE[1]

By

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Introduction

Many parts of the United States are experiencing ground water depletion problems. Within Nebraska this problem has aroused enough concern to have parts of the state declared control areas, which means the local policy makers have the power to regulate the use of ground water. The management options available to local units of government include well spacing, pumping limitations, withdrawal taxes, and a moratorium on new irrigation development. This study evaluated the impact of a selected array of these options on aquifer conditions and farm income in the Upper Big Blue Natural Resources District in South Central Nebraska.

The selected policy options were an unlimited water case; 13 acre-inch, 10 acre-inch and 6 acre-inch allocation options, with no restrictions on the amount that could be applied to any one acre; an allocation option where no more than 10 acre-inches could be applied to any irrigated acre; and a no development option. Each of the allocations were three-year allocations expressed in terms of the number of acre inches per developed acre per year the irrigator had available to pump. In all but one of the options, the irrigator could use the allocated water freely within the allocation period, i.e., he could use any portion of the three year allocation in any given

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year. It was also assumed that the irrigator could borrow or carry over water from or to the next three year allocation period. The amount of water that could be borrowed was restricted to one half of one year's allocation while an amount equivalent to no more than one year's allocation could be carried over.

Methods and Procedures

The general methodology consisted of using a recursive linear program (RLP) to determine annual profit maximizing decisions over a 40-year period for a model farm in each of three hydrologically defined subregions.

Recursive linear programming lends itself well to determining the optimum farm management strategy under expected conditions that change through time (Day, 1962). Since the planning horizon of the study extends from 1980 to 2020, it was necessary to incorporate projected changes in yields, commodity prices and production costs. It was also expected that the water levels of the aquifer would decline, causing an increase in pumping costs. Furthermore, the availability of water was likely to decrease, placing physical constraints upon the amount of water available to be pumped. Recursive linear programming provides the flexibility to reflect these changing conditions through time.

Two problems exist with RLP, however. One is the problem of aggregation (Frick and Andrews, 1965; Day, 1962 and 1963; Barker and Stanton, 1965) and the other is that the RLP solution may tend to be more specialized than what exists in the study region (Day, 1962). The problem of aggregation arises because it is impossible to include every farm within the study area. One is left with two choices: (1) using one macro model to represent the whole study area; or (2) using representative farms and summing to aggregate to the total. Day (1963) showed that provided certain conditions are met, a single macro LP will give the same solution as summing individual representative firm models. Which method to use accordingly depends upon the research resources available and upon the types of questions that need to be answered.

A micro approach was chosen for the Upper Big Blue study area because of a need to identify differences in responses to policy options by type of farm situation. Because of the similarity of farms in the study area in terms of soils, rainfall and production costs, it was expected that farm level response differences would be primarily a function of variations in hydrologic conditions causing differences in pumping costs and physical water availability. Some parts of the study area were currently suffering from water availability problems while other areas had plentiful water and thick waterbearing strata underlying the lands. Others currently had plentiful water but were likely to experience water availability problems before the end of the planning horizon. These conditions give three natural breakdowns for selecting representative farms. Thus, each of the 400 nodes in a hydrologic model of the study area (Cady and Ginsberg, 1979) was clasified into one of three hydrologic regions and the same model farm was designed for each region.

There was a total of 760 acres in the model farm, 264 acres irrigated with gravity systems and 132 acres irrigated with a center pivot. The rest of the farm was in non-irrigated cropland, pasture, roads and farmstead.

In this study, it was the response of the irrigated land that was of concern, therefore, only the irrigated land was included in the RLP. The RLP had activities representing different levels of irrigation for both irrigation systems including a zero level for each crop.

The returns to the irrigated lands were aggregated from model farm results to regional totals according to the number of irrigated acres within the respective nodes. The returns to the dryland acres, both the ones that had reverted to dryland and the ones that had not yet been developed for irrigation, were calculated in the intrayear simulation portion of the model and were aggregated assuming historical cropping patterns.

The first of the subregions used in the study consisted of the nodes which had the best initial aquifer characteristics, with well yields of at least 700 gallons per minute (GPM) and 150 feet of saturated thickness. The second region was defined to include those nodes where ground water availability problems already existed. This region had well yields of less than 700 GPM and less than 150 feet of saturated thickness. The third region was one not currently experiencing problems; well yields were at least 700 GPM; but over the planning horizon, problems were expected to emerge because the initial saturated thickness was below 150 feet.

The second problem occurring in RLP deals with the degree of specialization the solution may predict (Day, 1962). The RLP model deals with a finite number of activities and it will choose the activity that is more profitable than all others without adequately taking into account the preferences of the farmers in the area or the risk and uncertainty associated with the crop. To reflect the risk and/or uncertainty, upper and lower bounds may be set on the number of acres that could be planted in any one crop. Care needs to be taken in the amount of bounding that is done or there is danger of the outcome being influenced completely by the a priori decisions. In order to allow the greatest amount of flexibility within the model and yet to maintain reasonable results, it was decided that soybeans would be the only crop bounded. Although this crop is capable of achieving high returns under good management, too much water can cause problems as can insufficient water. Rain right after irrigation may cause excessive vegetative growth or lodging problems. The bounds in the initial year reflect current soybean production. These bounds were relaxed over time to reflect the impact of increased management skills.

In order to capture the impact of precipitation variability, growing seasons were simulated using a historical pattern of weather. Depending upon the weather conditions prevailing, the irrigator could choose to use more or less water than he originally intended and the amount used was reflected in the next year's planting decision. Crop yields, production costs and net returns to land and management were computed for each crop grown. Once the actual water applied to each crop had been determined, aquifer impacts were determined using a three-dimensional, finite element hydrologic model (Cady and Ginsberg, 1979). The hydrologic model simulated the new pumping lifts, well yields and remaining saturated thickness, which were used in determining irrigation development, acres reverting to dryland production and pumping costs of the next year.

Results

The impact of the six policy options are discussed below and summarized in Table 1. Each impact is discussed across all regions rather than all impacts within each region.

Aquifer Impacts

The impact of policy options on pumping lifts was most noticeable in Region 1. Without any restrictive regulations pumping lifts increased 100 feet over the planning horizon and well yields dropped 121 gallons per minute (Table 1). The more restrictive the allocation, the greater the impact on pumping lifts. The 6-inch allocation, the most restrictive one, had only a 38 foot decline in water level. Well yields were not very sensitive to any policies over the first 20 years. During the last 20 years, however, the policy options impacted more on them, with 121 GPM decline under the unlimited case and only a 4 GPM decline in the 6-inch allocation.

Region 1, unlike the other two regions, was a region with abundant ground water available. Thus, it was expected that this would be an area where no aquifer depletion would arise over the planning horizon and this proved to be the case. Even in the unlimited case with development occurring at the historic rate, there were no acres reverting to dryland. The major aquifer impact of all options in Region 1 was on lifts and thus pumping costs.

In Region 2, the greatest impact occurred in the form of extended aquifer life. The 6-inch allocation enabled over 118 thousand acres to remain in production, whereas in the unlimited case only about 52 thousand were still under irrigation at the end of the planning horizon.

Despite the aquifer depletion problems, the various options in Region 2 had very little impact on lifts and yields as of the end of the planning horizon. Interestingly, however, the well yields in the most restrictive case were lower than in the unrestricted one. This occurred because the yields and lifts in this region appeared to be particularly sensitive to actions of irrigators in the surrounding areas. It seems that because a significantly larger proportion of the irrigators were able to maintain irrigation, there was more interwell interference which was expressed as a lower average well yield.

All options in Region 3 except the 6-inch allocation had similar impacts on pumping lifts. The pumping lifts increased more than 60 feet and well yields decreased 200-400 GPM. In the 6-inch allocation option the pumping lifts increased only 40 feet while well yields decreased by 117 GPM.

The number of acres reverting to dryland were very sensitive to pumpage restrictions in Region 3. In the unlimited pumping case more than 172.6 thousand acres reverted to dryland, whereas in the 6-inch allocation none did.

Cropping Patterns

Limited water use in all but the 10-inch restriction resulted in part of the developed land being planted in dryland grain sorghum so that the irrigator could remain relatively close to the full irrigation level for each irrigated crop grown.

In Region 1, the typical irrigation level for corn on pivot land varied over time from 10 to 12 inches if water was not restricted. Under the more restrictive options, this variation was reduced to 8 to 10 inches. Likewise, corn on gravity land was reduced from 18 to 20 inches under the unrestrictive option to 14 and 16 inches under restrictive options. The response in irrigated soybeans was very similar, changing from the usual 8 inch irrigation level on pivot land when water was not restricted to 6 inches when it was. The soybeans on gravity moved from 12 inches to 10. Under the restricted water options, partially irrigated grain sorghum because an attractive crop option during the last 20 years of the planning horizon.

Region 2 had cropping patterns and responded to policy options much like Region 1. The pricipal difference was that even in the unlimited case multiple irrigation levels of the same crop appeared due primarily to the fact that the water was limited physically.

Region 3 responded like Region 1 in the unlimited case until year 32 when physical water availability forced adjustments in the irrigation levels. After year 32, the irrigated activities were a combination of fully and partially irrigated corn and soybeans under restricted conditions. The response to restrictive water policy options, as in the other two regions, resulted in some acres being grown under slightly reduced water application levels and the rest of the land being placed under dryland grain sorghum.

Impact on Income: Model Farm

The model farm income impact refers to the total income earned on land currently developed for irrigation and capable of maintaining irrigated land for the entire planning horizon. The income presented in Table 1 is the sum of the undiscounted annual returns in 1980 dollars earned on the 132 center pivot acres in each model farm.

In all regions the 10-inch allocation was found to have the highest net returns over time for the model farm, but surprisingly the net returns were close across all options. The two factors which caused some of the restrictive policies to be more profitable than unlimited pumping were: first, in some years irrigators would profit by planning to apply a little less water than the average production function under unlimited conditions would indicate, and second, weather conditions were such that in some years dryland grain sorghum was more profitable than irrigated corn.

The impact of even slightly lower pumping costs over such a long planning horizon was much larger than was expected. For instance, in Region 1, lower pumping costs were responsible for most of the $26.8 thousand difference in the model farm income between the unlimited option and the no development case.

The differences between options in Region 2 were substantially less than in Region 1, mainly because there were less differences over time in pumping costs. In Region 2, the largest difference was between the 10-inch allocation, with $4.02 million net returns, and 10-inch restriction, with $3.96 million.

Region 3 also had small differences in net returns across policy options. The highest returns were again under the 10-inch allocation, with $4.04 million, and like Region 2, the lowest were the 10-inch restriction with $3.93 million.

Impact on Income: Aggregate Farm

The aggregate farm income is the total annual net returns to each region, including all the dryland acres as well as the acres developed for irrigation. Aggregate farm income was close across most options, but with greater differences than occurred in the model farm.

In Region 1 the highest income option was the 10-inch allocation, which improved aggregate farm income over time from $6221.9 to $6341.5 million. As expected, the no development option had the lowest aggregate farm income with $5480.8 million, even though on the model farm it improved net returns over the unlimited option.

Within Region 2, the impact of extending aquifer life was most pronounced. The 6-inch allocation, which enabled 65.9 thousand more acres to be under irrigation over time than the unlimited case, had $1707.9 million in net returns regionally whereas the unlimited case had only $1489.3 million. In this region, the reduction of acres reverting to dryland moderated the negative impact of the no development option on aggregate farm income.

In Region 3, the 10-inch allocation had the highest net returns regionally, with $4990.9 million, which represented a six percent increase over the unlimited case. In this region, like in Region 2, the importance of aquifer life extension was dominant.

Policy Implications

If the objective of policy makers were to extend aquifer life and to have a wide distribution of income gains from irrigation, with a minimum reduction in aggregate farm income, then they would find the highly restrictive 6-inch allocation option to be very attractive. The irrigators in Region 2, where aquifer conditions were poorest, would be made substantially better off while those who could irrigate over time no matter what the option would suffer very minor income losses.

On the other hand, if policy makers were to pursue a policy which had positive aggregate income impacts without making current or perspective irrigators who face relatively good aquifer conditions worse off, the appropriate choice, from among those considered, would be the 10-inch allocation instead of the 6-inch allocation. They would, however, be made better off at the expense of those who had to revert to dryland production.

The no development option had the greatest impact on current irrigators but these gains came at the expense of a ten percent reduction in aggregate farm income relative to the unlimited case, with corresponding adverse impacts on income distribution. Thus, this option is not likely to be consistent with the social welfare function of policy makers.

The 13-inch allocation improved the income of the region by only one percent, which is probably less than the cost of installing meters and administering the program. This implies that if policy makers elect to restrict water use at all, the allocation level should be less than 13 inches.

Table 1. Effect of Management Alternatives on Income and Aquifer Conditions, 1980 to 2020.

Region	Policy Alternative					
	Unlim.	No Devel.	13-in. Alloc.	10-in. Alloc.	10-in. Rest.	6-in. Alloc.
Model Farm Income	(1980 Dollars, in thousands)					
1	3892	3919	3937	4022	3900	3996
2	3975	4002	3977	4017	3955	3977
3	3964	3974	3990	4040	3930	3996
Aggregate Farm Income	(1980 Dollars, in millions)					
1	6222	5481	6266	6342	6173	6291
2	1489	1450	1501	1563	1567	1708
3	4723	4302	4799	4991	4907	4988
Lift Change	(Feet)					
1	101	89	96	72	70	38
2	38	31	38	39	39	21
3	71	66	70	65	64	42
Well Yield Decline	(Gallons per minute)					
1	121	96	96	31	25	4
2	16	29	7	43	19	120
3	431	390	414	315	301	118
Acres under Irrigation, 2020*	(Acres, in thousands)					
1	636	448	636	636	636	636
2	52	34	52	66	62	118
3	320	257	243	440	471	497

*Estimates reflect beginning acreage, plus new development at the historic rate until a physical maximum is reached, less acres reverting to dryland because of aquifer exhaustion.

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