ECONOMIC IMPLICATIONS OF ALTERNATIVE ALLOCATIONS OF AN EXHAUSTIBLE IRRIGATION WATER SUPPLY

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INTRODUCTION

Groundwater is the predominant source of water for the 7,969 thousand acres of irrigated agriculture in Texas [5, p. 4.5]. Over 65 percent of Texas' irrigated acreage is watered from the Ogallala formation of the Texas High Plains. As opposed to conditions in other aquifers, the Ogallala does not receive appreciable recharge. Although the aquifer underlies virtually all of the 28,125 square mile High Plains land area, in many areas the aquifer is relatively thin (less than 100 feet) and in all areas the underlying water supply is expected to be exhausted in the foreseeable future. The average annual decline of the water table underlying irrigated acres of the High Plains has been approximately 3.5 feet.

Individual landowners of the area are entitled, under Texas Groundwater Law, to pump the recoverable groundwater from beneath their respective land holdings. Thus, individual water users have a resource allocation problem which has the annual dimensions of price and output policies usually considered in "Theory of the Firm" annual production decisions plus an added dimension of interperiod (usually annual) allocation of an exhaustible water resource. For purposes of this discussion, the simplifying assumption will be made that interfarm water transfers will not occur either above or below the surface.[1]

The following discussion presents and illustrates a general procedure whereby individuals can resolve planning problems of (1) how much water to use each year from an exhaustible supply; and (2) how to develop capital-valuation estimates of an exhaustible water supply [3]. The illustration pertains to the Texas High Plains, but the method could be applied to other areas if adequate data are available.

Water resource allocation in an irrigated area supplied by an exhaustible aquifer is necessarily different from that in an area characterized by a replenishable water supply. Since the irrigation water supply is exhaustible and irrigation water is the most limiting of the scarce resources (in the longrun) available to the farmer, the relevant economic objective of the farmer is to develop water use plans that maximize the dollar value of the exhaustible water resource. This is not to be confused with maximization of annual net returns for a specific land area as in the case where the water supply is expected to be available at a constant annual level into perpetuity.

In the latter case, stated above, the fundamental economic principle for determining level of water employment states that water should be added until the marginal factor cost of water is equated with its marginal value product. Whereas, the optimum time rate of use for an exhaustible water resource should be the rate where the net revenue earned from the last unit of water used in the present production period is equal to the present value of net revenue, discounted at the appropriate time discount rate, which could be earned by that unit in some future time period [4, p. 5]. Thus, the equilibrium condition for maximizing net returns from an exhaustible water supply is that of equating the present marginal net returns to the discounted marginal net returns of each relevant future time period.

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[1] In practice, farmers do not buy and sell water per se and current research indicates that lateral movement of water in the aquifer is only a few feet per year in the neighborhood of pumped observation wells (unpublished research, Water Center, Texas Tech University, Lubbock, Texas, 1970).

If a farm operator applies the exhaustible water supply at a rate such that the present net returns from the marginal unit are less than the discounted net returns possible from the use of this marginal unit in the future, he is using the exhaustible water resource at too rapid a rate and will reduce the present value of the total water supply. Conversely, if the water is applied at such a rate that the present net returns from the marginal unit are greater than expected future discounted net returns of the marginal unit, the water is being used at a rate less than that required for maximizing the present value of the exhaustible resource.

The purposes of this analysis are to (1) indicate the effects of the level of the discount rate in determining an optimum use of an exhaustible resource and (2) identify the cost or reduction in present value of the water supply that results from a deviation in optimum annual water use or optimum cropping pattern. A longrun farm firm organization that maximizes the present value of an exhaustible water supply is presented for a study area in the Texas High Plains.

Present worth of net income streams of alternative farm firm organizations are compared to evaluate the effect of different crops and annual water use rates on the value of the water supply. This permits estimating the "cost" or loss in the present value of the water supply attributable to alternative annual cropping patterns and water use rates.

The influence of the discount rate on present value of the water supply is examined by calculating the present value of the water supply at alternative discount rates for each longrun farm plan. Widely differing rates of optimum annual water use can be explained by alternative discount rates; i.e., a low discount rate places a higher value on future income than a large discount rate; hence, a low discount rate exemplifies the more conserving viewpoint.

STUDY AREA

A hydrologic subarea of the Texas High Plains was chosen for study. The five counties included in this relatively homogeneous region contain approximately 530,000 acres. The area is comparatively homogeneous with respect to soils, climate, water supply, type of farming, and farm size. Under irrigation, the soils have high yielding potentials. Cotton, grain sorghum, wheat, castors and soybeans are the major crops. Some vegetables are produced, but present marketing facilities limit acreage expansion. One of the more important climatic factors affecting crop yields is the relatively low annual rainfall (approximately 18 inches). Yields of irrigated cotton, grain sorghum, and wheat are approximately twice, six times, and three times the dryland yield of each, respectively. Castors, soybeans, and vegetables are feasible production alternatives only with irrigation; thus, emphasizing the importance of irrigation to the area.

For purposes of analysis, it was convenient to identify a typical or representative farm for the study area as follows. Mean farm size in 1964 was 390 acres, 90 percent (354 acres) was cropland, cotton allotment was 35 percent of cropland (124 acres), grain sorghum 39 percent (137 acres), the wheat allotment was 15 percent of cropland (54 acres) and 11 percent (39 acres) was unallotted. It was assumed that the typical farm used six-row farm machinery. Enterprises considered include those above as well as soybeans and castors. Level of output, production requirements, and production costs for these crops were taken from published budgets applicable to the study area [1]. Price per unit for crops was obtained from publications, local dealers and personnel at Texas Tech University.

Irrigation water for the alternative enterprises on the representative farm of the study area was supplied by three eight-inch irrigation wells. Each well discharged an estimated 800 gallons per minute (gpm) and was capable of irrigating 120 acres of cropland.

In 1966, saturated thickness underlying the typical farm was estimated at 164 feet with the assumption that the bottom 10 feet of saturation would not be available for irrigation. Therefore, assuming a specific yield of 15 percent, the 154 feet of saturated aquifer beneath the typical farm applicable to irrigation held an average of 115,000 acre-inches of ground water, or 24.6 acre feet of water per acre of land.

PROCEDURE

Techniques of Linear Programming were used to assist in allocating water among alternative crops and alternative crop production techniques for given production periods. The Linear Programming Models simultaneously included the relevant range of dryland and irrigated crops and resource constraints. The water constraint equations were structured to permit variations in the annual water supply for the purpose of generating alternative time streams of net income to water (value of the objective function with irrigation water minus the value of the objective function when all water resource supplies are zero–the dryland optimum solution). Each different water constraint assumption resulted in an identifiable farm irrigation plan of different length, in years, depending upon the quantity of water withdrawn from storage annually. Forty-two different water use plans were thus identified and the present worth of net returns to water was calculated for each at alternative discount rates.[2] A comparison of the 42 different present worth values provides the information for selecting the annual quantity and allocation of water use which maximizes value of the water resource.

The water supply constraints were based on the following relationships and assumptions. It was assumed that periodic lowering of pump bowls would permit well yields to remain at 800 gpm until the saturated thickness declined to 130 feet or the minimum saturation required to support 800 gpm well yields in the aquifer [2, p. 61]. However, pumping lift and pumping costs were increased as the level of the water table declined. The following equation was used to calculate well yields after the saturated thickness reached 130 feet [4, p. 60]:

$$Y = \left(\frac{V}{I}\right)^2 \cdot H \quad 130 > V > 10$$

where Y is present well yield, V is present saturated thickness in feet, I is minimum saturated thickness required to maintain an 800 gpm well (130 in this case), and H is the initial capacity of the well (800 gpm).

As the well yields declined, modifications in the pumping facilities were assumed. Pumping costs per acre-inch of water delivered were estimated based on variable costs and specified charges for original investment and modifications. The cost per unit of water pumped ranged from $0.87 per acre-inch in 1966 to $3.98 per acre-inch at the time of exhaustion of the irrigation water supply.

Due to the conditions of water supply, the long range water use plan would be composed of two distinct planning periods–Period I and Period II. Period I is the period in which no adjustments in annual water use would be required due to annual water shortage since well yields would remain constant, and Period II would be the period when declining well yields would necessitate annual adjustments in either the number of acres irrigated or the number of water applications per acre. Period II is the period after the water table has declined to 130 feet of saturation.

RESULTS

In the interest of saving space, only 13 of the 42 farm plans are presented here (Table 1). Those chosen for presentation represent the relevant range of alternatives; thus, they seem to be those of most interest to the reader. Only the farm plans of Period I are discussed in detail since Period I is the more important of the two Periods. However, present value of the irrigation water supply includes net income streams of both Period I and Period II.

Influence of Discount Rate Upon Water Use Plans and Water Value

The present value of the water supply for the 13 farm plans in Table 1 calculated at zero, 6 and 10 percent is given in columns 5, 6 and 7, respectively. A zero discount rate (which values a dollar in future periods equivalent to a dollar today) results in a water supply value for the typical farm of $478,000 (Table 1, Plan 12). Plan 12 for Period I continues for 214 years and annually consists of 124 acres of skip-row cotton with a preplant irrigation only, 137 acres of dryland grain sorghum and 54 acres of dryland wheat. The total annual water use is 504 acre-inches.

Six and 10 percent discount rates indicate that Plan 1 is the optimum organization with present value of the water supply estimated at $182,000 and $130,000, respectively. The annual plan is 124 acres of cotton with a preplant plus two postplant irrigations, 137 acres of grain sorghum and 54 acres of wheat, both with a preplant plus two postplant irrigations, and 39 acres of soybeans produced with a preplant plus four postplant irrigations. Annual water use for plan 1 is 4,258 acre-inches compared to 504 acre-inches with plan 12.

The zero discount rate represents a conservative position and results in an extended period of years irrigation is possible. Plan 12 would support irrigation for 214 years, compared to 29 years with plan 1. However, at realistic discount rates, the value of the water supply via plan 12 would be significantly re-

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[2]

$$PW_j = \sum_{i=1}^{n} \frac{NRI_{ij}}{(1+r)^i} - \sum_{i=1}^{n} \frac{NRD_i}{(1+r)^i} \quad (j=1 \ldots 42)$$

Where PW_j is present worth of the jth annual water use rate, NRI_{ij} is dollar value of the optimum solution of the LP objective function for the jth annual water use rate in year i, NRD_i is dollar value of the optimum solution of the ith dryland condition, and r is the discount rate.

TABLE 1. ALTERNATIVE ANNUAL IRRIGATION FARM PLANS APPLICABLE TO THE PERIOD I PLANNING HORIZON AND ASSOCIATED PRESENT VALUE OF THE TYPICAL FARMS IRRIGATION WATER SUPPLY[a]

Farm Plan	Annual[d] Water Use	Period[a] I	Period[a] II	Present value of the Water supply by Discount Rate			Cotton			Grain Sorghum		Wheat		Castors		Soybeans	
				zero	six	ten	acres	space[b]	Irrig.[c]	acres	Irrig.[c]	acres	Irrig.[c]	acres	Irrig.[c]	acres	Irrig.[c]
	acre-inches	years	years	----- $1,000 -----													
1	4258	19	10	347	182	130	124	solid	pp + 2	137	pp + 3	54	pp + 3	0	0	39	pp + 4
2	4053	20	10	353	181	129	124	solid	pp + 2	137	pp + 3	54	pp + 3	39	pp + 3	0	0
3	3882	23	8	362	181	127	124	solid	pp + 2	137	pp + 3	54	pp + 3	39	pp + 2	0	0
4	3915	21	8	352	177	126	124	solid	pp + 2	137	pp + 2	54	pp + 3	39	pp + 3	0	0
5	3807	21	10	353	175	123	124	solid	pp + 2	137	pp + 2	54	pp + 2	0	0	39	pp + 4
6	4742	17	9	321	176	129	124	solid	pp + 2	137	pp + 3	0	0	93	pp + 3	0	0
7	4738	17	9	319	174	127	124	solid	pp + 3	137	pp + 3	0	0	93	pp + 2	0	0
8	7750	7	14	269	167	129	124	solid	pp + 3	0	0	0	0	0	0	230	pp + 4
9	7347	8	13	267	165	127	124	solid	pp + 2	0	0	0	0	0	0	230	pp + 4
10	1506	72	0	234	59	36	124	skip	pp + 0	137	pp + 0	54	pp + 0	39	pp + 1	0	0
11	1002	108	0	108	21	12	124	skip	dryland	137	pp + 0	54	pp + 0	39	pp + 1	0	0
12	504	214	0	478	39	24	124	skip	pp + 0	137	dryland	54	dryland	0	0	0	0
13	428	252	0	79	7	4	124	skip	dryland	137	pp + 0	54	dryland	0	0	0	0

[a] A total of forty-two alternative plans were developed comprised of two periods: Period I where no changes in annual farm organization was required and Period II where the declining water supply forced annual adjustments in farm organization (the annual farm organizations for Period II are not presented).

[b] Two-in two-out skip-row planted or solid row planted.

[c] The symbols (pp + 2) mean preplant irrigation plus two postplant irrigations, etc.

[d] Annual water use for Period I only (period of no annual changes in farm organization). Period II is characterized by annual adjustments in water use.

duced compared to the value under plan 1. At 6 percent discount rate, under plan 1, the water supply would be valued at $182,000 as compared to $39,000 under plan 12. At 10 percent, the comparison would be $130,000 under plan 1 and only $24,000 under plan 12. The comparisons emphasize the influence of the discount rate upon value of water and water use plans in the study area; i.e., if the optimum zero discount plan were accepted but 6 percent were appropriate, the value of the water supply would be reduced $143,000 for the typical farm.

If a discount rate of 6 percent is assumed, then plan 1 would be accepted as the optimum. The organization of plan 1 compares most favorably with current farming practices in the study area. After 19 years, plan 1 has to be annually adjusted due to effects of the declining water supply.

Effect of Annual Irrigation Level Upon Water Use Plans

Crop acres and irrigation levels for the optimum farm organization (plan 1) are given in Table 1. The present value of returns to irrigation is an estimated $182,000. By changing irrigation so that one additional postplant irrigation is applied to cotton annually, estimated present value of the farm water supply is decreased by $2,000. The additional postplant irrigation on cotton requires 3.25 additional acre-inches of water per acre of cotton allotment but returns only $4.18. The additional irrigation reduces the length of the period that irrigation is possible from 29 to 27 years. Present value of income from the 403 additional acre-inches of water applied to cotton annually, as the third postplant irrigation, is less than present value of this amount of water used in other ways at a later date.

By using skip-row cotton and a preplant plus one postplant irrigation rather than as in plan 1, the value of the water supply is reduced from $182,000 to $166,000. By reducing the irrigation level on grain sorghum and wheat from three to two postplant irrigations (plan 5), the present value of the water supply is decreased by $7,000. With soybean irrigations reduced from four to three postplant irrigations, present value of the water supply is reduced $4,000.

Effect of Cropping Patterns Upon Water Use Plans and Water Value

As with changes in irrigation rates, alterations in crops irrigated reduce the value of the water supply. For example, plan 9 (soybeans in place of grain sorghum and wheat) results in a $17,000 reduction in the value of the water supply and exhausts the water supply in 21 years rather than 29 years. By allowing castors to replace soybeans and wheat (plan 6), the present value of the water supply is reduced $6,000, and with castors replacing soybeans (plan 2) a $1,000 decrease in the value of the water supply results.

The annual returns to irrigation from plan 1 are $14,778. However, with plan 8 this can be increased to $17,139. Therefore, the optimum annual plan of today is plan 8. But the effect of selecting the optimum annual plan today is an annual water use of 7,750 acre-inches, exhaustion of the water supply in 21 years and a reduction in present value of the water supply from $182,000 to $167,000. The other extreme is given by the optimum plan at zero discount rate (plan 12) which has annual returns to irrigation of $2,352 and reduces the value of the water supply $143,000.

CONCLUSIONS

Care is required in developing optimum temporal use of an exhaustible resource, such as the irrigation water supply in the High Plains of Texas. The magnitude of the discount rate selected significantly affects the optimum temporal rate of use. A low discount rate dictates a low annual use compared to a larger rate.

The "typical" approach to optimum resource use is maximization of returns in a production period. For an exhaustible resource this type analysis may result in an erroneous conclusion and, hence, an underestimate of the value of the resource. Therefore, optimization of an exhaustible resource requires an interperiod analysis.

Lastly, an indication of the economic effect of a non-optimum farm organization is useful in emphasizing the associated "cost." By deleting a non-optimum postplant irrigation on an enterprise, returns to a farm's irrigation water supply are increased. Alternatively, by not adding a needed irrigation on an enterprise a reduction in the present value of the water supply is incurred. Similar illustrations apply to non-optimum cropping patterns. Therefore, it is concluded that detailed analysis and planning are needed to help decision makers avoid costly errors when using exhaustible resources.

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