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Farmer Storage of Irrigation Water in Federal Projects

Gerald C. Cornforth and Ronald D. Lacewell

This study estimates some of the economic impacts of a program that would allow farmers to save a part of their annual surface irrigation water allocation. The objective would be to save water in full allocation years to be used in water short years. The study area consisted of the El Paso County Water Improvement District. Results indicate that optimal temporal water use would increase district net farm revenue by three percent or less above actual water use. For the study area vegetables were the most profitable crop while laser leveling was not economically feasible.

In many parts of the Western United States water is a limited resource in agricultural production. Access to water is particularly crucial in El Paso County, Texas, where crop production is dependent primarily on surface irrigation water from the Rio Grande Project. Project water stored in Elephant Butte Reservoir, New Mexico is distributed to irrigation districts in New Mexico, Texas and the Republic of Mexico. In a study by Sonnen, Dendy and Lindstrom, El Paso County farmers indicated that they favor a policy which permits storage of a portion of their annual irrigation water allocation in Elephant Butte Reservoir for use in a future year. The Department of the Interior has allowed the El Paso County Water Improvement District No. 1, which distributes Rio Grande Project water in El Paso County, Texas, to implement such a program.

Timeliness and availability of irrigation water are important issues in efforts to improve economic efficiency as shown by the work of Moore and Armstrong; Ahmed, van Bavel and Hiler; Young and Bredehoeft; Watson, Nuckton and Howitt; as well as numerous others.

The purpose of this paper is to estimate the agricultural impact of farmer storage of irrigation water within the El Paso County Water Improvement District. Impacts analyzed include the effect on cropping patterns, the stream of farm net returns and variability of farm net returns.

The study area includes the flood plain of the Rio Grande in El Paso County, Texas. Annual rainfall of 7.77 inches per year makes irrigation necessary. In years of low surface irrigation water allocation, farmers pump groundwater to supplement surface water. This groundwater ranges in salinity from 263 to 24,800 miligrams per liter dissolved solids [Meyer and Gordon]. The salinity of the groundwater discourages its use for irrigation.

Methodology

A static liner programming model was developed which maximized agricultural net returns for the total study area. Solutions for

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all basis changes for surface water allocations (zero to three acre-feet per acre) were made for two groundwater scenarios — one assuming unlimited pumping and one assuming no pumping. A schedule of solutions depicting alternative surface water allocations under each groundwater scenario was developed.

A temporal (polyperiod) linear programming model, which optimized water use over time, then was built for the years 1963 through 1980. The schedule of surface water solutions derived from the static model provided alternatives for the use of annual allocations over time. In the temporal model, the actual water allocation for each year could be used entirely, or a portion stored for future years, or any stored water from previous years used in a select year. Any surface water stored was charged the evaporation rate from Elephant Butte Reservoir from one year to the next.

The Static Model

Following the example of Laughlin, Lacewell and Moore, the production parameters were identified for 12 crops by soil group. Six soil groups were determined ranging from heavy clay to loam to sand. The 12 crops used were Upland and Pima cotton, alfalfa, wheat, barley, grain sorghum, pecans, tomatoes, onions, lettuce, and green and red chili.

Crop yields varied according to soil group and by the salinity of irrigation water [Maas and Hoffman]. The acreages of soil groups underlaid by groundwater of a particular salinity were measured [Cornforth and Lacewell]. Yield reductions for each crop for each salinity level were calculated and applied for activities utilizing groundwater [Ayers]. Yield reductions of up to 50 percent were allowed. Crop activities were not included when the salinity of the groundwater would produce a yield reduction of greater than 50 percent.

Fertilizer and harvest costs were based on yield. The water requirement was increased by 20 percent when saline groundwater was used, to allow for leaching of salts. An amortized establishment cost for alfalfa and pecans was included. An important consideration in improved efficiency of irrigation water is laser leveling [Hinz and Holderman]. An option was included whereby acres could be laser leveled by incurring the amortized cost. Fertilizer and irrigation requirements were reduced 25 percent for laser leveled land. Laser leveling was not included for alfalfa or pecans, nor for any crops on the heavy clay and sandy soil groups. A crop enterprise budget was developed for each crop on each soil type by selected salinity levels [Cornforth and Lacewell].

The static linear programming model contained 1182 crop production activities utilizing either surface or groundater irrigation. The model contained activities for purchasing inputs, selling crop output, and constraining land by soil type and surface water supply.

Surface irrigation water was restricted to 96,100 acre-feet (2 acre-feet per acre for 48,050 acres of tillable land). This is the amount of water deliverable when the annual water district tax is paid. When allocated, one additional acre-foot of water per acre may be purchased for $8 per acre-foot. Allocation of a third acre-foot per acre was restricted to 48,050 acre-feet for the district.

Richardson, Zacharias, Condra and Stebbins found that because of high production costs and price variability, vegetable production was not observed on small and medium size farms in El Paso County. Also, pecans and alfalfa acreage can not be increased without first establishing the crop. Therefore, practical acreage limits were set on vegetables, pecans and alfalfa.

Output prices were established by converting reported prices for 1976-80 to 1980 dollars using prices received by farmers' indexes and then averaging the results. The Pima cotton price was not established in this manner, but as a weighted average price of spring 1981 price quotas by grades. The weights used were the percentages of 1980 El Paso area production by grades. All input prices were current 1980-81 prices gathered from various sources.

For the static model, the quantity of surface water was parametrically adjusted from zero to three acre-feet per acre under two assumptions: unlimited groundwater pumping and no groundwater pumping. With more efficient use of surface water supplies, the recharge of groundwater in the study area will decrease. As time passes, limits on groundwater pumping can be expected. Not knowing what these limits may be, this study used the two extreme limits to develop economic implications. These two parametric analyses provided a catalog of all model solutions for any level of surface water allocation with or without groundwater supplementation.

The Temporal Model

The parameters derived from the static model were used to construct the temporal model. The temporal model maximized net returns by optimally distributing the actual annual surface water allocations over the years 1963 through 1980. Water could be stored for future use subject to annual evaporation from Elephant Butte Reservoir. For groundwater pumping, 78 alternative water use levels per year were included as activities. These 78 water use levels represented surface water allocations from zero to three acre-feet per acre. For no groundwater pumping, there were 83 alternative water use levels per year. Where included, these represented water allocations from 1.06 to three acre-feet per acre. The minimum 1.06 acre-feet per acre allocation was necessary to maintain established alfalfa fields and pecan orchards.

The polyperiod model was constrainted to require a single solution in each year. Also, the amount of water available was limited by the annual allocation from Elephant Butte Reservoir. A simplified structure of the temporal model is given in Table 1.

Results

Static Model

Solutions for two surface water allocations, with and without groundwater supplementation, are presented in Table 2. Barley, grain sorghum, and red chili did not enter any solutions. Tomatoes, lettuce, onions and green chili were usually at their upper acreage limits except when only 1.06 acre-feet per acre of surface water was allowed. As surface water availability increased, alfalfa increased to its upper acreage limit, while pecans stayed at their lower acreage limit.

The 1.06 acre-feet surface water allocation with no groundwater pumping allowed only alfalfa fields and pecan orchards to be maintained. For all other solutions, Upland cotton acreage ranged from 17,312 to 18,441 acres, Pima cotton acreage ranged from 9,559 to 10,656 acres, and wheat acreage varied from 708 to 2,940 acres.

Expected net farm revenue across the study area increased as surface irrigation water use increased. Net farm revenue was also higher when groundwater was pumped. These trends are depicted by Figure 1. As expected, the shadow price of surface irrigation water was higher at lower surface water allocations and highest when groundwater pumping was not allowed. At three acre-feet per acre surface water allocated, the shadow price of surface water was almost the same for the groundwater pumping and no pumping cases, \$8.26 and \$9.97 respectively (Figure 2).

When groundwater pumping was allowed, very little acreage was laser leveled and then only at surface water allocations of less than 0.28 acre-feet per acre. But when groundwater pumping was not allowed, 18,638 acres were laser leveled at a surface water allocation of 1.74 acre-feet per acre. As the surface water allocation continued to rise, laser leveling decreased. At an allocation of 2.58 acre-feet and higher, laser leveling did not enter the solution.

Temporal Model

Optimal temporal surface water use rates, as estimated by model application, are presented in Table 3 with and without groundwater pumping. Table 3 also includes the

TABLE 1. A Simplified Structure of the Temporal Linear Programming Model.

	Net Revenue Production																	
	1963 Surface Water Use[a]		1964 Surface Water Use		.. 1980 Surface Water Use		Revenue Transfer			Water Used			Water Saved				Sell Stored Water	RHS
	0 .. ac.	3 ft.	0 .. ac.	3 ft.	0 .. ac.	3 ft.	1963	1964	1980	1963	1964	1980	1963	1964	1979	1980		
Objective Function							1	1	1								b	
Revenue Transfer:																		
1963	c	c					−d											=0
1964			c	c				−d										=0
. . .																		
1980					c	c			−d									=0
Individual Solution Requirement:																		
1963	1	1																=1
1964			1	1														=1
. . .																		
1980					1	1												=1
Water Required																		
1963	e	e								−1								=0
1964			e	e							−1							=0
. . .																		
1980					e	e						−1						=0
Water Available																		
1963										1			1					=f
1964											1		−g	1				=f
. . .																		
1980												1			−g	1		=f
Stored Water Transfer																1	−1	=0

[a]Water use includes 78 alternatives ranging from 0 to 3 acre feet of water per acre.
[b]Stored water price parameters, applicable only in 1980.
[c]Revenue-water use coefficients.
[d]1980 real dollars coefficients.
[e]Water use coefficients.
[f]Level of water availability.
[g]Evaporation of saved water coefficients.

TABLE 2. Estimated Impact on Cropping Patterns and Net Farm Income in the El Paso County Water Improvement District with Alternative Groundwater and Surface Water Assumption.

		Surface Water Allocation			
		Groundwater Pumping		No Groundwater Pumping	
Item	Unit	0 Acre-Feet	3 Acre-Feet	1.06 Acre-Feet[a]	3 Acre-Feet
Cotton, Upland	acre	17,312	17,344	0	18,441
Cotton, Pima	acre	10,688	10,656	0	9,559
Alfalfa	acre	6,083	8,517	6,083	8,517
Wheat	acre	708	2,940	0	1,843
Barley	acre	0	0	0	0
Grain Sorghum	acre	0	0	0	0
Pecans	acre	4,800	4,800	4,800	4,800
Tomatoes	acre	100	100	0	100
Lettuce	acre	200	200	0	200
Onions	acre	200	200	0	200
Chili, Green	acre	700	700	0	700
Chili, Red	acre	0	0	0	0
Shadow Price of Irrigation Water	$/ac. ft.	90.37	8.26	544.49	9.97
Groundwater Used	ac ft/ac.	2.78	0.07	0	0
Net Farm Revenue	million $	4.719	7.336	1.132	7.331

[a]1.06 acre feet per acre of irrigation water is necessary to sustain established pecan orchards and alfalfa fields.

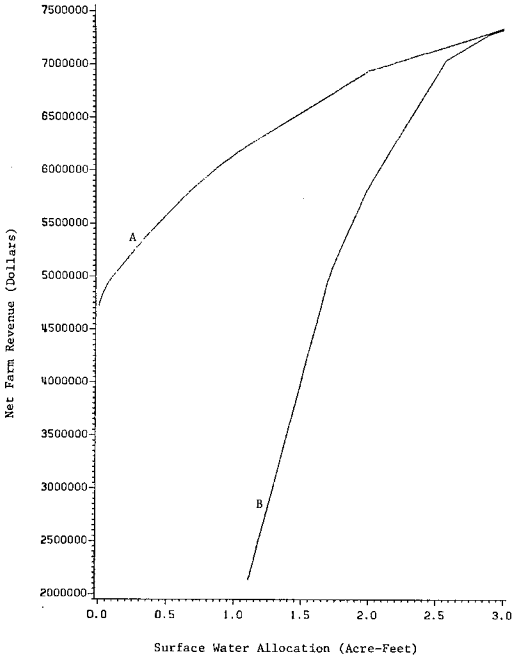

Figure 1. Net Farm Revenue as a Function of Surface Water Allocation With (A) and Without (B) Groundwater Pumping; El Paso County Water Improvement District.

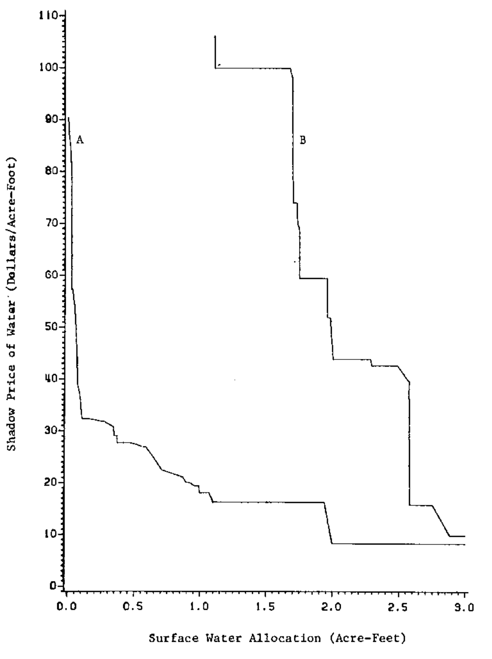

Figure 2. Value of an Additional Acre-Foot of Surface Water at Alternative Surface Water Allocations With (A) and Without (B) Groundwater Pumping; El Paso County Water Improvement District.

TABLE 3. Actual Surface Water Allocations, Optimal Temporal Surface Water Usage Rates With and Without Groundwater Pumping and an Annual Two Acre-Feet Usage Rate, 1963 to 1980 for the El Paso County Water Improvement District.

	Actual Surface Water Allocation	Optimal Temporal Surface Water Usage Rates: With Groundwater Pumping	Optimal Temporal Surface Water Usage Rates: No Groundwater Pumping	Annual Two Acre-Feet Usage Rate
	ac. ft./acre			
Year:				
1963	2	1.52	2	2
1964	.33	.67	.33	.33
1965	1.85	1.85	1.85	1.85
1966	2.5	2	2	2
1967	1.5	1.89	1.89	1.93
1968	2	2	2	2
1969	3	3	2.58	2
1970	3	2	2.58	2
1971	2	2	2	2
1972	.67	1.26	1.13	1.95
1973	3	3	2.58	2
1974	3	3	2.58	2
1975	3	2.58	2.58	2
1976	3	2	2.58	2
1977	1.25	2	2	2
1978	.75	.99	.99	2
1979	3	3	3	2
1980	3	3	3	2
Available for Transfer to 1981				2.27
Total	38.85	37.77	37.66	36.34
Evaporation Feet		1.08	1.19	2.52
Percent		2.79	3.06	6.47

Note: All entries measure surface water use only. The annual two acre-feet use option is the same whether or not groundwater pumping is allowed. Its method of calculation is given in Cornforth and Lacewell, Appendix E.

actual surface water allocations for 1963 to 1980 and an arbitrary annual two acre-feet of surface water usage rate. Figure 3 shows the optimal temporal surface water use patterns in relationship to the actual surface water allocation with groundwater pumping. The annual two acre-feet usage plan required the most storage and, thus, the most losses to evaporation (Table 3).

Economic implications of a surface water accumulation policy is the test of applicability and likely usefulness. As a basis of comparison, the actual surface water allocations for 1963 to 1980 (Table 3) were used to determine the annual net farm revenue from 1963 to 1980. This was done for both cases — groundwater pumping (Table 4) and no groundwater pumping (Table 5). For each actual surface water allocation, the appropriate net farm revenue was determined from the schedule of net farm revenues by surface water allocation for groundwater pumping and for no groundwater pumping as estimated by the static model. These annual net farm revenues then were adjusted to 1980 dollars by an estimated real interest rate (4.94933 percent).

The results of the temporal linear programming model gave an optimal temporal allocation of annual allotments of surface wa-

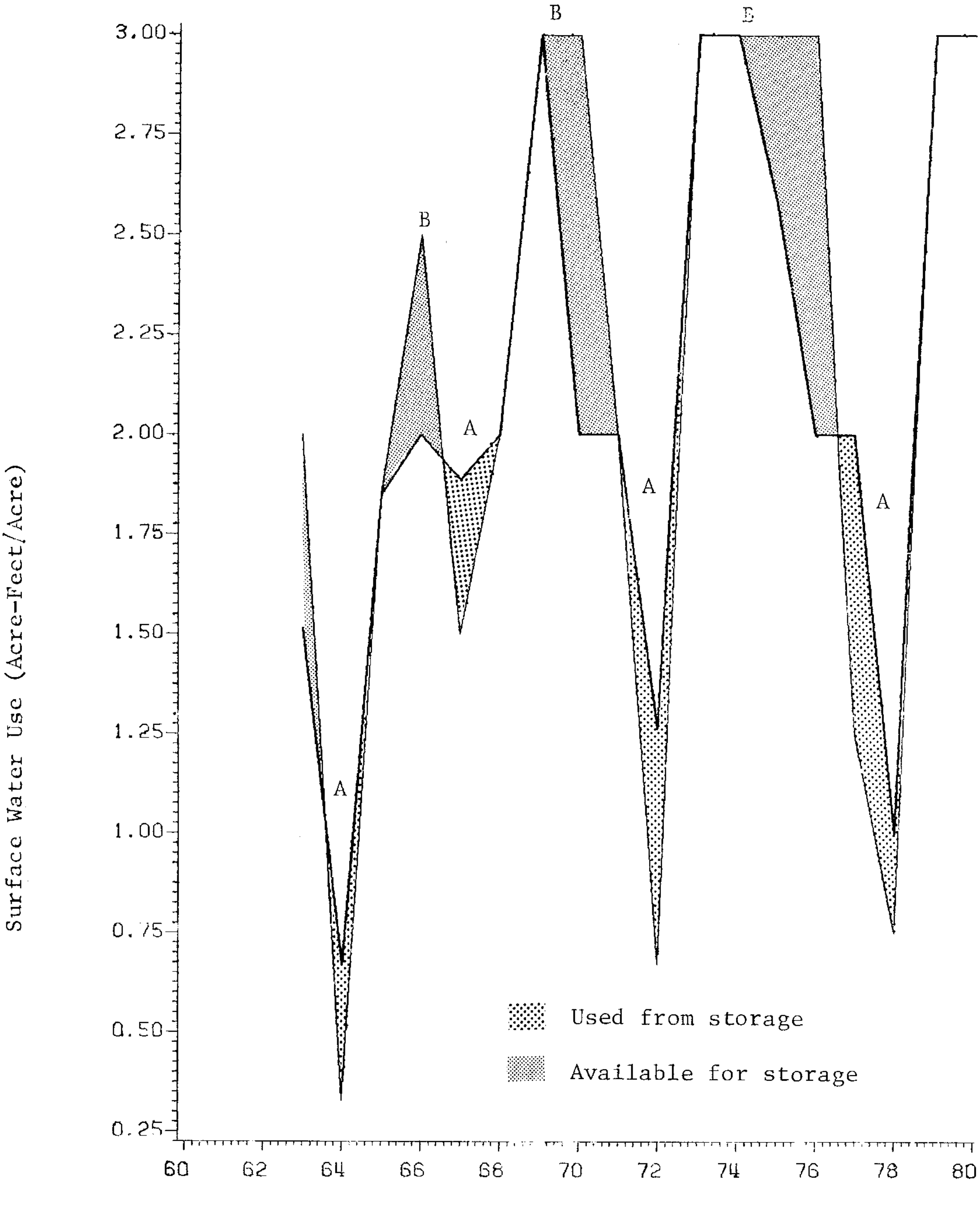

Figure 3. Optimal Temporal Surface Water Use with Groundwater Pumping (A) Against the Actual Pattern of Water Allocations (B) for the El Paso County Water Improvement District.

TABLE 4. Annual Net Farm Revenue and 1980 Real Values for the Actual Surface Water Allocation and the Optimal Temporal and Annual Two Acre-Feet Usage Rate Scenarios All with Groundwater Pumping, 1963 to 1980, El Paso County Water Improvement District.

	Net Farm Revenue			1980 Real Value[a]		
	Actual Allocation	Optimal Temporal Scenario	Annual Two Acre-Feet Usage Rate Scenario	Actual Allocation	Optimal Temporal Scenario	Annual Two Acre-Feet Usage Rate Scenario
	Million $					
1963	6.94	6.56	6.94	15.77	14.91	15.77
1964	5.36	5.80	5.36	11.61	12.57	11.61
1965	6.82	6.82	6.82	14.08	14.08	14.08
1966	7.14	6.94	6.94	14.04	13.65	13.65
1967	6.55	6.85	6.89	12.27	12.84	12.90
1968	6.94	6.94	6.94	12.39	12.39	12.39
1969	7.34	7.34	6.94	12.48	12.48	11.81
1970	7.34	6.94	6.94	11.89	11.25	11.25
1971	6.94	6.94	6.94	10.72	10.72	10.72
1972	5.80	6.36	6.90	8.54	9.37	10.16
1973	7.34	7.34	6.94	10.29	10.29	9.73
1974	7.34	7.34	6.94	9.80	9.80	9.27
1975	7.34	7.17	6.94	9.34	9.13	8.83
1976	7.34	6.94	6.94	8.90	9.42	8.42
1977	6.35	6.94	6.94	7.34	8.02	8.02
1978	5.89	6.15	6.94	6.49	6.77	7.64
1979	7.34	7.34	6.94	7.70	7.70	7.28
1980	7.34	7.34	6.94	7.34	7.34	6.94
Value of Stored Water			0.90			0.90
Total	123.42	124.03	124.01	190.99	191.71	191.37
Coefficient of Variation	9.07	6.31	5.43			
Difference from Actual Allocation:						
Total	Base	0.61	0.59	Base	0.73	0.38
Percentage (%)	Base	.5	.5	Base	.4	.2
Per Acre ($)	Base	12.74	12.38	Base	15.15	7.97
Per Acre Per Year ($)	Base	.71	.69	Base	.84	.44

[a]4.94933 was used as the real rate of interest.

TABLE 5. Annual Net Farm Revenue and 1980 Real Values for the Actual Surface Water Allocation and the Optimal Temporal and Annual Two Acre-Feet Usage Rate Scenarios All Without Groundwater Pumping, 1963 to 1980, El Paso County Water Improvement District.

	Net Farm Revenue			1980 Real Value[a]		
	Actual Allocation	Optimal Temporal Scenario	Annual Two Acre-Feet Usage Rate Scenario	Actual Allocation	Optimal Temporal Scenario	Annual Two Acre-Feet Usage Rate Scenario
	Million $					
Year:						
1963	5.84	5.84	5.84	13.28	13.28	13.28
1964	0.97	0.97	0.97	2.10	2.10	2.10
1965	5.43	5.43	5.43	11.21	11.21	11.21
1966	6.89	5.84	5.84	13.54	11.49	11.49
1967	4.37	5.54	5.67	8.18	10.39	10.62
1968	5.84	5.84	5.84	10.43	10.43	10.43
1969	7.33	7.04	5.84	12.47	11.98	9.94
1970	7.33	7.04	5.84	11.88	11.42	9.47
1971	5.84	5.84	5.84	9.03	9.03	9.03
1972	1.94	3.31	5.72	2.86	4.87	8.42
1973	7.33	7.05	5.84	10.28	9.88	8.19
1974	7.33	7.05	5.84	9.80	9.42	7.81
1975	7.33	7.04	5.84	9.33	8.97	7.44
1976	7.33	7.04	5.84	8.89	8.54	7.09
1977	3.64	5.84	5.84	4.21	6.75	6.75
1978	2.18	2.92	5.84	2.40	3.22	6.44
1979	7.33	7.33	5.84	7.69	7.69	6.13
1980	7.33	7.33	5.84	7.33	7.33	5.84
Value of Stored Water			1.07			1.06
Total	101.60	104.32	100.67	154.94	158.02	152.77
Coefficient of Variation	37.87	30.17	20.67			
Difference from Actual Allocation:						
Total	Base	2.73	−0.93	Base	3.08	−2.16
Percentage (%)	Base	2.7	−0.9	Base	2.0	−1.4
Per Acre ($)	Base	56.72	−19.32	Base	64.12	45.04
Per Acre Per Year ($)	Base	3.15	−1.07	Base	3.56	−2.50

[a]4.9433 was used as the real rate of interest.

ter with associated net farm revenues and their 1980 real values for 1963 to 1980 for both the groundwater pumping (Table 4) and no groundwater pumping options (Table 5). The annual two acre-feet usage scheme (Table 3) was also evaluated in the same manner.

With no limit on groundwater pumping, the results in Table 4 indicate that both the optimal temporal and the annual two acre-feet use scenarios would have generated more total net revenues than total use each year of the actual allocation. Also, the net farm revenue streams of the optimal temporal and annual two acre-feet use scenarios vary less than that of the total use each year of the actual allocation. The optimal temporal scenario provided $0.84 per acre per year in 1980 dollars above the returns generated by annual use of the actual allocation. The annual two acre-feet use scenario provided only about half the increase or $0.44 per acre per year in 1980 dollars. But the annual two acre-feet use scenario produced the most stable stream of net farm revenues as indicated by the coefficients of variation in Table 4.

With no groundwater pumping, the results in Table 5 indicate that the optimal temporal scenario would have generated more total net revenues than annual use of the actual allocation, but the annual two acre-feet scenario would have generated less. The optimal temporal water use scenario would have added $3.56 per acre per year in 1980 dollars to total net revenues. The annual two acre-feet use scenario would have decreased net farm revenue per acre per year by $2.50 in 1980 dollars below the net revenues of the annual use of the actual allocation. But, again, the annual two acre-feet use scenario had the most stable flow of net farm revenues. The optimal temporal scenario also varied less than the net farm revenue stream of the annual use of the actual surface water allocation.

Conclusions and Limitations

Based on this study, the following conclusions can be drawn:

1. Temporally optimizing water allocation has little advantage over use of actual water allocations. The study revealed only small differences between an optimal temporal water allocation with groundwater available and the actual water allocation over time. These meager gains in net farm revenue for the district may not justify the cost of operation of a water storage program.
2. Application of the model developed for this study indicates that vegetables are highly profitable activities. However, the model can not take into account risk factors, e.g., El Paso lettuce producers are trying to match a ten-day to two-week lull in lettuce production by production areas elsewhere in the nation. An early or late production season for any of the lettuce producing regions can seriously affect the market for El Paso lettuce. Therefore, in reality vegetable activities may not be as attractive as the model would indicate.
3. Based on data used in this analysis laser leveling, new to the study area, is not economically justifiable in the region as many have assumed. However, accurate data on input and yield effects associated with laser leveling are not available. There may be yield and quality increases from laser leveling which have not been quantified at this time. Thus, it is not timely to draw conclusions relative to the economic feasibility of laser leveling, particularly if groundwater pumping limitations become relevant.

Actual water allocations are extremely vulnerable to nature's whims and, most likely, to whims of the courts in the future. The temporal model which optimized water use rate over time was applied under conditions of perfect knowledge of surface water allocation and evaporation rates for the years 1963-1980. The level of future surface water allocation is, of course, an unknown. Therefore, the two feet per acre scenario, with a more stable flow of net farm revenues, may be more realistic. The decision to store is made regardless of any future surface water allocations or evaporation rates.[1]

The ability to supplement surface irrigation water from groundwater sources is crucial to maintaining the current level of agricultural production in the El Paso district. With more efficient use of surface water supplies, the recharge of groundwater in the district will decrease. As time passes, limits on groundwater pumping can be expected.

As an illustration, Hudspeth County farmers now farm with residual Rio Grande River flows and drainage flows from adjoining El Paso County as their only sources of surface irrigation water. The quality of groundwater is extremely poor in Hudspeth County [Alvarez and Buckner]. Thus, accumulation and associated water-saving technologies (e.g., laser leveling) will tend not only to decrease or eliminate residual and drainage flows, but further decrease groundwater availability through reduced recharge.

Water in the Southwest is a very precious resource. The city of El Paso searches continually for new sources of water. At the same time, the Republic of Mexico's allocation under treaty of Rio Grande water is insufficient to irrigate all of its potential agricultural acreage [U.S. Department of the Interior]. In years of low surface water allocation, when the El Paso County farmers have plenty of water from their individual stored accounts, the city of El Paso, the Republic of Mexico, Hudspeth County producers, and Elephant Butte District producers without stored water may be stimulated to push for changes in the state, federal, and international laws governing the water of the Rio Grande. This and other institutional factors make water issues in the region most complex.

[1]From Eichlin's tree ring study for the Rio Grande above San Marcial, New Mexico, one might conclude that rainfall and consequently the flow of the Rio Grande may be generally increasing and above average for the next 40 years. If this is true, water may simply evaporate in storage, never being needed.

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