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Economic Implications of Farmer Storage of Surface Water in Federal Projects: Elephant Butte Irrigation District, Dona Ana and Sierra Counties, New Mexico

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Abstract

This study estimated the expected regional impact and economic feasibility of a proposed water accumulation or water saving option for agricultural producers operating in the Elephant Butte Irrigation District in southern New Mexico. The water accumulation plan would allow agricultural producers to retain part of a given year's surface water allocation in Elephant Butte Reservoir, providing use of the unevaporated portion in a later year.

The analysis was based upon modeling of current cropping practices subject to regional resource constraints within a static linear programming model. Pertinent input/output coefficients and costs were incorporated, with five-year (1976-1980) average output prices assumed for twelve crops spread across 11 soil groups. Applicable fixed costs and interest charges were taken into account. Net returns to the region were maximized assuming 1 and 3 acre-feet of groundwater available per year per acre irrigated.

Surface water availability was varied from zero to 3 acre-feet per acre to obtain schedules depicting regional net returns and cropping patterns for varying surface water allocations for both the groundwater situations examined. These schedules were then used to build temporal linear programming models which maximized the present value of net returns for the period 1963 to 1980 subject to historical surface water allocations and reservoir evaporation rates. Calculation of these evaporation rates took into consideration increased lake levels due to surface water storage.

The temporal models were used to estimate an optimal allocation of surface water over the 18 year period investigated for the two groundwater availability situations considered. Returns for the optimal surface water allocations were then upper bounds on potential net returns to the region. Projected streams of net returns were also obtained for each of the scenarios analyzed; i.e., optimal temporal allocation of surface water, 2 acre feet of surface water per year limit and actual allocation of surface water given the 1 and 3 foot groundwater limitations. These streams of net returns were valued in 1980 dollars allowing comparison among the alternative scenarios. Differences between the various returns streams for each groundwater situation provided a measure of possible economic effects of the water saving program.

Results of the study for current groundwater availability conditions indicate that optimally temporal allocated surface water use would increase average annualized net returns per acre from that of the actual surface water allocation by .82 dollars per year, or less than .2 %. Use of the more realistic two acre-foot per acre limit on surface water use led to an increase in annualized net returns of only .23 dollars per acre per year. Both increases were deemed insufficient to cover anticipated administrative costs of the program.

Under conditions of limited groundwater availability (1 acre-foot per acre), percentage increases in annualized net returns over those for the actual surface water allocation were more significant. Use of the water saving option and perfect knowledge of future surface water allocations resulted in increased annualized net returns of $8.41 per acre per year for an increase of 54 %. For the two acre-foot surface water use limitation case, annualized net returns increased by $3.68 per acre per year (23.7 %). In all cases considered, groundwater use increased with use of the water saving option. These economic results, coupled with possible political obstacles faced by the program, suggested that alternative water management schemes should be considered.

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Introduction

More efficient use of limited water resources in the arid Southwestern United States is a priority issue; development and examination of alternative water management plans relative to efficient use takes on many forms. One such management plan under consideration by the United States Bureau of Reclamation involves the alternative of storage between years of surface irrigation water by the irrigation districts that are drawing water from Elephant Butte Reservoir in New Mexico. This program would allow individual farmers to store part of their annual surface water allottment in the reservoir, and to draw on the unevaporated portion for use in a future year. The study presented here examines the economic implications of such a program for farmers in the Elephant Butte Irrigation District in southern New Mexico. A similar study was undertaken for the El Paso County Water Improvement District No. 1 in 1981, and the results presented here are a continuation of as well as a supplement to that study (Cornforth and Lacewell).

The study region comprises approximately 90,700 acres along the Rio Grande River in Dona Ana and Sierra counties of southern New Mexico, consisting of 69,200 and 21,500 acres of flood plain in the Mesilla and Rincon valleys (Pedde). Of the acreage currently receiving surface water allocations, an average of 83,600 acres is actually farmed. In 1980 this represented approximately 7% of the irrigated acreage in the state while providing 25% ($73 million) of the $307 million in crop receipts for that year (New Mexico Agricultural Statistics).

Major crops grown in the region include pima and upland cotton, red and green chiles, lettuce, onions, tomatoes, alfalfa, grain sorghum, wheat, barley, and pecans. Average annual rainfall is a scant 7.89 inches (New Mexico Agricultural Statistics). Thus, irrigation plays an important role in the economy of the region. The primary source of irrigation water for the area is Elephant Butte Reservoir on the Rio Grande River 20 miles northwest of the northern edge of the region of study. Water deliveries are made on certain days each week according to availability and producer requests against that year's allocation. Surface water absorbed by the riverbed and delivery ditches provides recharge for groundwater in the surrounding floodplain. Both direct river flow released from the dam and groundwater are used for irrigation.

Elephant Butte Reservoir provides water to three separate irrigation districts downstream. International treaty and federal law specify that an agency known as the Rio Grande Compact Commission is responsible for the correct disposition of all Rio Grande waters. Several other federal agencies including the U. S. Army Corps of Engineers and the U. S. Bureau of Reclamation assist the Compact Commission in carrying out its duties. Collectively these agencies determine the annual surface water allocations made to each irrigation district on the basis of projected water availability and established water rights.

Procedures

Linear programming techniques were applied to evaluate the economic implications of a farmer storage program in the Elephant Butte Irrigation District. The analysis included both annual and temporal implications and basically follows the procedure below.

1) Development of a static linear program representing current crop production practices for the region.

2) Application of the static model to generate schedules of returns for alternative surface water allocations under different specified groundwater conditions, and

3) Use of the schedules of returns from (2) above within a multi-year linear program to maximize the present value of returns to water subject to historical surface water allocations and reservoir evaporation rates.

The optimal temporal solutions obtained in step (3) assume perfect knowledge of surface water allocations and evaporation rates, and therefore represent "best case" solutions for optimal use of water over the 18 year period investigated. A base solution through time was developed by using all the surface water available each year via the static model. This was compared to other temporal uses of water to estimate the value of a water accumulation policy or farmer storage program.

Static Linear Programming Model

Linear programming techniques were used to optimally allocate a specific quantity of water among crops in any one year. This provided a cropping pattern and estimate of associated net returns.

The objective function of the model consisted of gross returns from crop sales less all variable costs, fixed costs, and applicable interest charges. The six year average of 83,600 acres actually farmed in the area (1975-1980) was set as an upper bound for cropped acres within the district. Twelve crop alternatives were included for 11 different soil groups. To establish soil groups, soil series were combined. The soil groupings and applicable acres are summarized in Table 1 (U. S. Department of Agriculture,Soil Conservation Service). A composite acre was defined by soil group, which included the historical proportion of land in each major crop. This was necessary to reflect cropping patterns and historical yields. The average crop yields over the 1975-1980 period are presented in Table 2 (New Mexico Agricultural Statistics and Cornforth and Lacewell).

Table 1. Regional Soil Groups and Acreage Proportions

Soil Group	Proportion %	Acres
Anapra Clay loam	6.17	5,158
Anthony Vinton loam and fine sandy loam	10.81	9,036
Anthony Vinton/Armijo clay loam	4.86	4,062
Armijo clay	2.93	2,450
Agua loam	23.36	19,528
Belen clay	7.22	6,035
Belen clay loam	2.06	1,721
Brazito fine and very fine sandy loam	11.6	9,696
Glendale loam and clay loam	24.05	20,105
Harkey fine sandy loam	.5	418
Harkey loam and clay loam	6.45	5,391

Source: Soil Survey of Dona Ana County Area, New Mexico, 1980.

Table 2 . Six Year Average Crop Yields and Prices

Crop	Yield/Acre	Price
Upland Cotton	583 lbs.	78¢/lb.
Upland Cottonseed	.51 tons	5.63¢/lb.
Pima Cotton	410 lbs.	$1.12/lb.
Pima Cottonseed	.36 tons	5.63¢/lb.
Alfalfa	5.2 tons	$77.83/ton
Wheat	64 bu.	$3.93/bu.
Barley	60 bu.	$2.49/bu.
Grain Sorghum	73.8 bu.	$2.86/bu.
Pecans	850 lbs.	95¢/lb.
Tomatoes	10.2 tons	$96.2/ton
Lettuce	474 ctn. (50 lbs.)	$5.41/ctn.
Onions	427 sacks (50 lbs.)	$4.51/sack
Green Chili	7.25 tons	$242.63/ton
Red Chili	1.4 tons	42¢/lb.

Source: New Mexico Agricultural Statistics, 1975-1980, and Cornforth and Lacewell.

Upper bound constraints were placed on all vegetable crop acreages due to brokerage restrictions on production (Libbins). Producers might, in practice, grow additional acreage, but acreage above that contracted to vegetable brokers and canners has a smaller probability of being marketed profitably, if at all. The perennial nature of alfalfa and pecans also required that upper and lower bounds on acreage be set to account for crop establishment and removal time lags. Pecan groves and alfalfa fields were assumed to have lifetimes of 25 and 6 years, respectively. Acreage bounds were set 1/25 above and below the 1980 acreage for pecans and 1/6 above and below the 1980 acreage for alfalfa.

Additional considerations were made for disease, erosion, and nematode control practices for land farmed in vegetables. Farmers in the area generally double crop wheat or barley in between lettuce, onions, and tomatoes. Thus, wheat and barley acreage was required to be at least as large as that of tomatoes, lettuce, and onions. Additional small grain acreage above tomato, lettuce, and onion acreage could come into solution if profitable. The required small grain acreage accompanying vegetables was included as simply an additional input cost of vegetable production. Current practices in the region for this particular rotation do not include additional fertilizer applications for the small grains accompanying vegetables. Allowances were also made to reflect the apparent additional cropped acreage such double cropping creates, and reported acreages may exceed the upper bound of 83,600 acres noted above. The proportion of pima cotton relative to total cotton yield was also allowed to range between historical bounds of 27% and 38%.

Additional rows within the model reflected the two irrigation water sources (ground and surface water), as well as transfer activities for cost, acreage, and production. The final model consisted of 189 rows and 185 columns.

Input Requirements and Costs

Input requirements, production costs, and technical production coefficients for all crops except pecans were taken from Cornforth and Lacewell and Libbins et. al. Technical or production coefficients for pecans were taken from Gorman et. al. and Cornforth and Lacewell. For each crop the costs were categorized into the following groups:

purchased inputs
fertilizer
preharvest
harvest
fixed cost
overhead
establishment

Selected input prices used in crop enterprise budgets and in the static linear programming model are presented in Table 3.

Table 3. Selected Input Prices

Diesel	.97 cents/gallon
Gasoline	1.07 $/gallon
Natural Gas	3.94 $/mcf
Electricity	.04 cents/kwh
Surface Water	22.25 $/first two acre feet
Surface Water	3.00 $/third acre foot
Labor (Equipment)	3.50 $/hour
Labor (Other)	3.25 $/hour
Interest Rate	7.0% per annum (real)

Source: Cornforth and Lacewell.

Purchased inputs included such items as seed, chemicals, etc. Fertilizer quantities and, hence, costs varied with yield for cotton, pecans, alfalfa, grain crops, and were assumed constant for vegetables in order to assure high yields for those high value crops (Cornforth and Lacewell). Preharvest costs included most machinery operations and necessary hand labor, while harvest costs were those expenses associated directly with the harvest operation. Harvest costs varied with yield on pecans, cotton, and grain crops. The remaining crops were assumed to be harvested on a per acre basis not dependent on yield. Overhead expenses include down time, employee benefits, insurance, taxes, supervision and management and other miscellaneous expenses. An annual establishment cost was also charged to pecans and alfalfa while fixed costs associated with each crop include depreciation, insurance, and repair of machinery used for operations. Applicable land taxes were also included.

Water and Irrigation Costs

Surface water costs producers in the area $22.25 for the first two acre-feet. This cost was treated as a fixed cost or a water use tax for the entire region. Additional surface water above 2 acre-feet per acre , when available, costs $3 per acre-foot (Babcock). Surface water allocation and suggested groundwater pumping limits of 3 feet per acre per year have been established by the irrigiation district. Variable irrigation costs were based on a rate of 2 man hours per acre-foot applied, with additional charges for pump service, oil and lubrication calculated at a rate of 15% of the fuel costs for natural gas engines and 7.5% of the fuel costs for electric engines (Greenwalt and May). Fuel costs for each type of engine appear in Table 4. The major natural gas supplier in the area, El Paso Natural Gas Company, reports 387 agricultural wells in the district, and it is estimated that approximately half the wells in use are natural gas powered and half are electrically powered (Libbins). Thus, 774 irrigation wells were assumed in use in the area, yielding an average of 108 acres irrigated per well. Pumping costs were charged on a one-half natural

Table 4. Summary of Fuel Costs Calculation for Average Irrigation Power Plants in Mesilla and Rincon Valleys, New Mexico

Well	150 ft.	Natural Gas	$3.94/mcf
Total Dynamic Head	100 ft.	Electricity	.04/kwh
Flow Rate	2000 gpm	Flow Rate in Inches	4.4 ac in./hr.
Pump Efficiency	75%	Flow Rate in Hours	2.7 hrs/a.ft.
Electric Motor Efficiency	90%	BTU/BHP/hr.	.638/mcf/hr.
Gear Drive Efficiency	90%		

Electric Power Plant

$$\text{Brake hp required} = \text{BHP} = \frac{\text{GPM(TDH)}}{(3960)(\text{pump efficiency})} = \frac{2000\ (100)}{3960\ (.75)} = 67.34$$

$$\text{Kilowatts required} = \text{KW} = \frac{\text{DHP}\ (.746)}{\text{motor efficiency}} = \frac{67.34\ (.746)}{90\%} = 55.81\ \text{KW}$$

Kwh/acre ft. = 55.81 * 2.10 = 150.70 kwh/acre ft.
$/hr. = 55.81 x .04 = $2.23/hr. fuel cost
$/ac. ft. = $2.23/hr. x 2.70 hr./ac. ft. = $6.03/ac. ft.

Natural Gas Power Plant

(Same well specification)

$$\text{BHP} = \frac{\text{GPM(TDH)}}{(3960)(\text{pump efficiency})(\text{gear drive efficiency})} = \frac{2000\ (100)}{(3960)(.75)(.95)} = 74.82$$

MCF/ac. ft. = 2.70 hr./ac. ft. * .6381 mcf/hr. = 1.72 mcf/ac. ft.
$/ac. ft. = $3.94/mcf * 1.72 mcf/ac. ft. = $6.77/ac. ft.

gas and one-half electrically powered basis.

Other Fixed Costs and Interest on Capital

The fixed costs associated with irrigation were separated into three categories as follows: well establishment, electric power plant, and natural gas power plant. These respective costs were based on current prices and appropriate regional service establishment charges (El Paso Natural Gas Co. and El Paso Electric Co.). Well establishment costs included casing, screen, and pump, as well as drilling costs and service establishment charges. Interest on average investment was calculated on each of these categories at a 7% real interest rate.

As previously noted, fixed costs for depreciation and repair of machinery used in operations were taken into account. Average investment in equipment was also reflected using the equipment complement for a 500 acre representative farm (Libbins et. al.). To better reflect operating expenses, all variable costs were charged interest based on a 6 month average borrowing period at a real interest rate of 7% per annum. Interest on the water use tax was also charged at this rate.

Temporal Linear Programming Model

To extend the analysis into a temporal framework required a multiperiod or temporal model. Schedules of returns to land and risk were generated for varying allocations of surface water where 1 foot and then 3 feet of groundwater pumping per year was allowed. Surface water was varied in 1 acre-inch increments and the resulting objective function value and cropping patterns assimilated. The 3 foot groundwater allocation is the suggested maximum allowed (Babcock). The groundwater pumping situations were examined to provide realistic bounds on possible returns available while making use of the water saving option. Initial attempts to allow for no groundwater availability yielded an infeasible solution in the temporal model due to insufficient water in some years for maintenance of the required alfalfa and pecan acreages. A schedule of returns for the no groundwater situation was obtainable, however, and selected results for that scenario are reported as well.

Implicit to the use of the returns schedules noted above is the transfer of water from either one farm to another or from uncropped acreage to cropped acreage on a given farm. As water availability declines so does cropped acreage. Farmers must be able to transfer water to where its use is required. Current regulations allow for both these means of transfer provided all water is used within the irrigation district itself (Savering).

The returns schedules described above were then used to build an 18 year temporal water use model which allowed saving a portion of a given year's surface water allocation for use in subsequent years.

Both the historical water allocation as well as annual evaporation rates for the reservoir were incorporated, and appear in Table 5 (Bureau of Reclamation and Cornforth and Lacewell). Surface water is allocated separately by the Elephant Butte Irrigation District for the Mesilla and Rincon valleys, and the figures presented represent a weighted average allocation for the entire region. Annual evaporation coefficients for the reservoir were calculated using evaporation pan data and the results of four lake surveys performed during the time period under consideration. Details of the method employed appear in appendix B.

For each year, all possible surface water allocations and their corresponding returns to land and risk were included as possible activities. Any water saved in the last year (1980) is valued in the objective function at its value for use in crop production. Results of the static linear program place this value at $7.35 per acre-foot. The linear program was then forced to choose at least one activity per year, subject to historical water availability plus any water saved (net of evaporation) from previous years. Returns for the activities chosen were compounded to their present value in 1980 dollars using a 7% interest rate reflecting risk and the real rate of interest (time value) of money. The resulting solution consisted of the optimum allocation of water over time which maximized the present value of the associated returns. This solution is subject to both the timing and magnitude of historical surface water allocations and evaporation rates.

The parametrically obtained returns and cropping pattern schedules were also used to derive projected returns and cropping patterns for the actual historical surface water allocation as well as for a scenario imposing a 2 acre-foot per acre limit on surface water use. As before, two groundwater restrictions comprised of annual pumpage of 1 foot and 3 feet were examined for the two surface water use options.

In the 2 acre-foot per acre annual surface water limitation situation, any portion of the actual allocation above 2 acre-feet was assumed saved for use in the following year subject to reduction by the appropriate evaporation coefficient. This saving and evaporation reduction process continued until an allocation less than 2 acre-feet was encountered and all or part of the saved portion was used. Returns in both instances were then moved through time to their 1980 values to allow comparison with the optimal temporal returns stream.

Results

Static Model Results

The static model results comprise the basis of the temporal model structure. Thus, some understanding of static model results is useful in understanding the overall implications of this study. For a base, the static model was applied using the typical water availability for a year. Use of 3 foot per acre maximum allocations for both surface

Table 5. Historical Surface Water Deliveries and Evaporation Coefficients

Year	Water Allocation[1] (acre-feet)	Evaporation[2] Coefficient
1963	1.97	.77
1964	.38	.7979
1965	1.56	.8541
1966	2.17	.8126
1967	1.57	.8263
1968	1.79	.8459
1969	2.46	.8499
1970	2.69	.7958
1971	1.60	.8195
1972	.796	.8855
1973	2.42	.8573
1974	2.46	.8741
1975	2.43	.8610
1976	2.67	.8413
1977	1.31	.8013
1978	.72	.8725
1979	1.87	.8781
1980	2.47	1.

[1] Source: U.S. Dept. of the Interior, Bureau of Reclamation, <u>Monthly Water Distribution, Elephant Butte Irrigation District, Mesilla and Rincon Units</u>, 1963-1980.

[2] Coefficient reported is proportion remaining after evaporation.

and ground water yielded a close approximation to actual farming practices for the region. The resulting returns and cropping patterns are shown in Table 6. Three crops (grain sorghum, barley, and red chile) were not included in the optimal solution, with the first two crops simply being unprofitable in comparison to wheat at the relative prices used in the model. Red chilies were also unprofitable at the price used, as well as in the budgets used in formulating the linear program (Libbins et. al.). Total income to the region of $77,756,327 corresponds closely with the actual 1980 crop income of $77,385,000 (New Mexico Agricultural Statistics, 1980).

Vegetable, green chile, and cotton acreages entered the solution at the previously defined upper bounds due to relatively high profitability. The additional income (crop shadow prices) available by increasing those bounds by one acre also appear in Table 6. Recall that small grains are grown in rotation with vegetables for disease and pest control. The presence of 1,392 additional acres of wheat above the required 10,650 acres corresponding with tomatoe, lettuce, and onion acreage indicates that wheat is profitable in its own right. The entire surface water allocation of 3 acre-feet was used as well as .96 acre-feet of groundwater. Results of the model application also indicated that groundwater costs $1.14 more than surface water per acre-foot and that the marginal value product of another acre-foot of surface water for production is $7.35. Income and costs for the region are summarized in Table 7. The crops grown yielded a gross income of $77,756,327., variable costs of $49,800,768., and returns to land and risk of $4,061,955 for an average net return of $48.59 per farmed acre.

Alternative Surface Water Restriction Results

Selected portions of the returns associated with alternative surface water supplies are given in Tables 8 and 9 for the 3 and 1 acre-foot per acre groundwater availability scenarios. The former case yields constant acreages over the entire schedule for several crops. Vegetable and green chile acreages are at their upper bounds, while alfalfa and pecans are at their lower limits. Remaining pertinent crop acreages, as well as response to declining water availability, are shown in the Tables 8 and 9. Complete schedules for both scenarios appear in Appendix A.

Examination of Table 8 for the 3 acre-foot groundwater complement reveals that additional groundwater simply replaces lost surface water, resulting in decreasing returns due to the higher cost of pumping. Cropping patterns and gross income are constant until the 3 acre-foot groundwater limit is reached. At that point .956 acre-feet of surface water is in use, and further restriction of surface water causes the additional wheat acreage above that required for vegetable rotation to exit from solution. Onion acreage and its accompanying wheat acreage then decline with the former going to zero at the .652 acre-foot surface water level. Cotton acreage falls from 36,000 acres to 18,238 acres as the surface water allocation drops to zero. The

Table 6. Static Model Cropping Patterns and Results, Elephant Butte Irrigation District

Crop	Acreage	Total Production	Yield Per Acre	Acreage Bounds Lower	Acreage Bounds Upper	Shadow Price[a]
Upland Cotton	22,320	12,944,289 lbs.	580 lbs.	22,320	26,280	--
Pima Cotton	13,680	5,592,489 lbs.	409 lbs.	9,720	13,680	$ 40.16
Wheat	12,042	802,799 bu.	67 bu.	--	--	--
Alfalfa	15,560	81,849 tons	5.26 tons	15,560	17,810	--
Tomatoes	822	8,438 tons	10.26 tons	--	822	$423.90
Lettuce	5,780	2,750,592 ctns.	476 ctns.	--	5,780	$788.12
Onions	3,870	2,007,804 sacks	519 sacks	--	3,870	$ 52.09
Green Chiles	8,190	58,975 tons	7.2 tons	--	8,190	$376.80
Pecans	11,808	12,140,569 lbs.	1,028 lbs.	11,808	12,792	--

Net Returns	$4,318,878
Surface Water	3.0 acre-feet
Ground Water	.9646 acre-feet
Total Acreage	94,250 acres
Double-Cropped Acreage	10,472 acres

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[a] Increase in returns to land and risk by increasing imposed acreage restrictions one acre for each selected crop.

Table 7. Static Model Solution Cost Summary; Elephant Butte Irrigation District

Gross Returns		$77,756,327
Variable Costs		
Purchased Inputs	$ 7,315,286	
Fertilizer	4,199,229	
Preharvest Operations	7,595,647	
Harvest Operations	24,812,263	
Fuel	616,604	
Irrigation Labor	2,971,564	
Initial 2 Acre-Feet Surface Water	2,018,075	
Third Acre-Foot Surface Water	272,100	
Total Variable Costs	$49,800,768	
Returns Above Variable Costs		$27,955,559
Fixed Costs		
Overhead	$ 8,543,124	
Establishment - Pecans and Alfalfa	3,684,967	
Equipment Depreciation	7,467,841	
Total Fixed Costs	$19,695,932	
Returns Above Fixed and Variable Costs		$ 8,259,627
Interest Costs		
On Overhead and Establishment Investment	$ 427,983	
On Average Equipment and Well Investment	2,026,660	
On Operating Capital	1,743,028	
Total Interest Costs	$ 4,197,671	
Returns to Land and Risk		$ 4,061,955

remaining three acre-feet of groundwater then supports the cotton acreage noted above, 6,602 acres of vegetables, 6,602 acres of wheat, 15,560 acres of alfalfa, and 11,808 acres of pecans.

Cropping patterns and returns with 1 acre-foot of groundwater available adjust more quickly to restricted surface water than for the 3 acre-foot groundwater situation. As in the previous case, wheat acreage initially drops to that level required for rotation with vegetables, followed then by the reduction and exit of onion acreage. Required wheat acreage also declines accordingly. With 2.652 acre-feet of surface water available per irrigated acre, cotton acreage begins to diminish, eventually exiting with surface water at the 1.33 acre-foot level. Tomatoes, green chile, and lettuce then exit in that order accompanied by like reductions in wheat acreage that is associated with the tomato and lettuce declines. Established pecan groves and alfalfa fields require a total of 1.638 acre-feet of water from any source. Returns at this minimum required level of production are an estimated -$7,184,993. The regional water tax charge of $ 2,018,075, establishment charges of $ 3,684,967, well fixed costs of $2,283,002, and interest on average equipment investment charges of $ 1,225,385 contribute greatly to this negative return.

The schedule of net returns developed with 3 feet of groundwater available was used to examine the relationship between total water allottment, net farm returns, and acreage farmed. Figure 1 graphs returns versus total water use ranging from the minimum required 1.639 acre-feet up to a possible 3.96 acre-feet. As would be expected returns for the region increase with additional water availablity. A similar curve in Figure 2 portrays farmed acreage for varying total water usage levels. Results portrayed in both figures assume the presence of required alfalfa and pecan acreages due to those crops perenial nature.

Regional input demand relationships for surface water under varying groundwater situations were also derived from the parametric linear program schedules. These demand relationships are depicted graphically in Figure 3 with specific values for the three, one, and zero acre-foot per acre groundwater situations appearing in Table A-1 of Appendix A.

The figures represent the marginal value product of surface water to the region at varying levels of availability, and therefore form an upper bound on the dollar amounts producers as a whole would be willing to pay for surface water. These demand relationships do not necessarily reflect the preferences of an individual producer, since his particular crop mixture could differ significantly from that of the region.

In all three situations the marginal value product of surface water declines with increased availablity. For the no groundwater situation using the minimum required 1.64 acre-feet per acre required for existing pecan and alfalfa acreages, surface water marginal value

Table 8. Selected Portions of Return and Cropping Pattern Schedule, Three Acre-Foot Groundwater Allocation, Elephant Butte Irrigation District

Surface[a] Water (acre-feet)	Ground[a] Water (acre-feet)	Net Returns	Total Income	Total Acres Farmed	Crop Acreages[b]					
					Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chile
3.0	.956	$4,243,425	$77,756,327	94,072	36,000	12,042	822	5,780	3,870	8,190
2.5	1.456	$4,050,747	$77,756,327	94,072	36,000	12,042	822	5,780	3,870	8,190
2.0	1.956	$3,858,069	$77,756,327	94,072	36,000	12,042	822	5,780	3,870	8,190
.956	3.	$3,191,092	$77,756,327	94,072	36,000	12,042	822	5,780	3,870	8,190
.922	3.	$3,107,286	$77,344,987	92,502	36,000	10,472	822	5,780	3,870	8,190
.916	3.	$3,097,838	$77,138,366	92,343	36,000	10,393	822	5,780	3,791	8,190
.652	3.	$2,646,851	$67,275,850	84,762	36,000	6,602	822	5,780	0	8,190
.5	3.	$2,369,014	$65,245,578	80,618	31,856	6,602	822	5,780	0	8,190
.25	3.	$1,912,402	$61,908,930	73,809	25,047	6,602	822	5,780	0	8,190
0.0	3.	$1,455,784	$58,572,218	67,000	18,238	6,602	822	5,780	0	8,190

[a] Acre feet per irrigated acre in the irrigation district.

[b] Barley, grain sorghum, and red chile acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres, respectively.

Table 9. Selected Portions of Return and Cropping Pattern Schedule, One Acre-Foot Groundwater Allocation

Surface[a] Water (acre-feet)	Ground[a] Water (acre-feet)	Net Returns	Total Income	Total Acres Farmed	Crop Acreages[b]					
					Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chile
3.	.956	$4,243,424	$77,756,327	94,072	36,000	12,042	822	5,780	3,870	8,190
2.922	1.	$4,181,526	$77,344,987	92,502	36,000	10,472	822	5,780	3,870	8,190
2.75	1.	$3,936,448	$70,924,846	87,567	36,000	8,004	822	5,780	1,402	8,190
2.652	1.	$3,797,155	$67,275,850	84,762	36,000	6,602	822	5,780	0	8,190
2.5	1.	$3,562,154	$65,245,542	80,618	31,856	6,602	822	5,780	0	8,190
2.	1.	$2,789,740	$58,572,218	67,000	18,237	6,602	822	5,780	0	8,190
1.33	1	$1,566,752	$49,635,322	48,762	0	6,602	822	5,780	0	8,190
1.276	1.	$1,165,328	$48,608,184	47,118	0	5,780	0	5,780	0	8,190
1.16	1.	$ 107,628	$44,275,810	44,638	0	5,780	0	5,780	0	5,710
1.	1.	-$1,504,371	$37,673,009	40,859	0	5,780	0	5,780	0	1,931
.9148	1.	-$2,328,116	$34,298,922	38,928	0	5,780	0	5,780	0	0
.75	1.	-$5,229,390	$24,505,268	32,022	0	2,327	0	2,327	0	0
.638	1.	-$7,184,993	$17,903,857	27,368	0	0	0	0	0	0

[a] Acre feet per irrigated acre in the irrigation district.

[b] Barley, grain sorghum and red chile acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres, respectively.

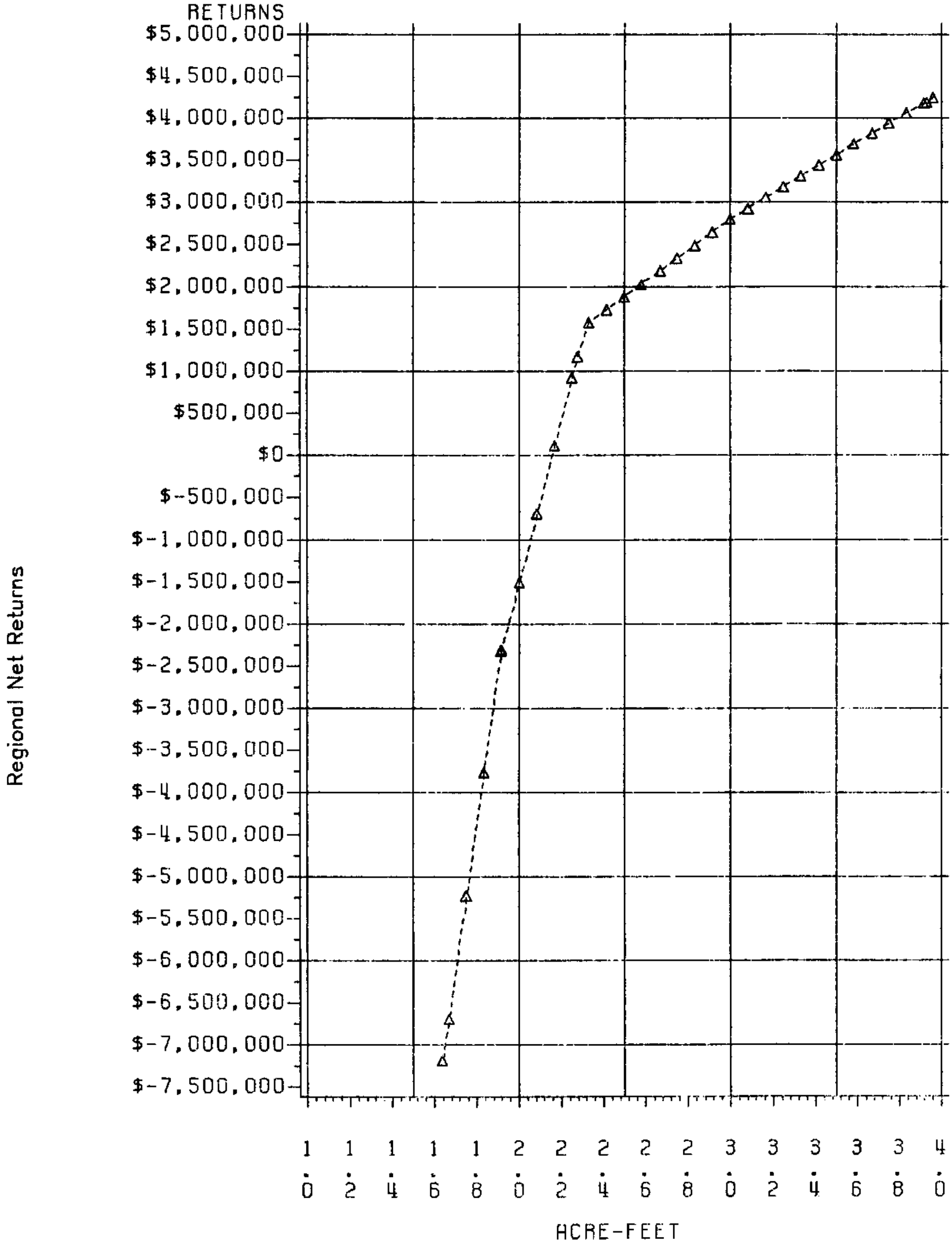

Figure 1. Regional Net Returns for Varying Water Availability, Elephant Butte Irrigation District

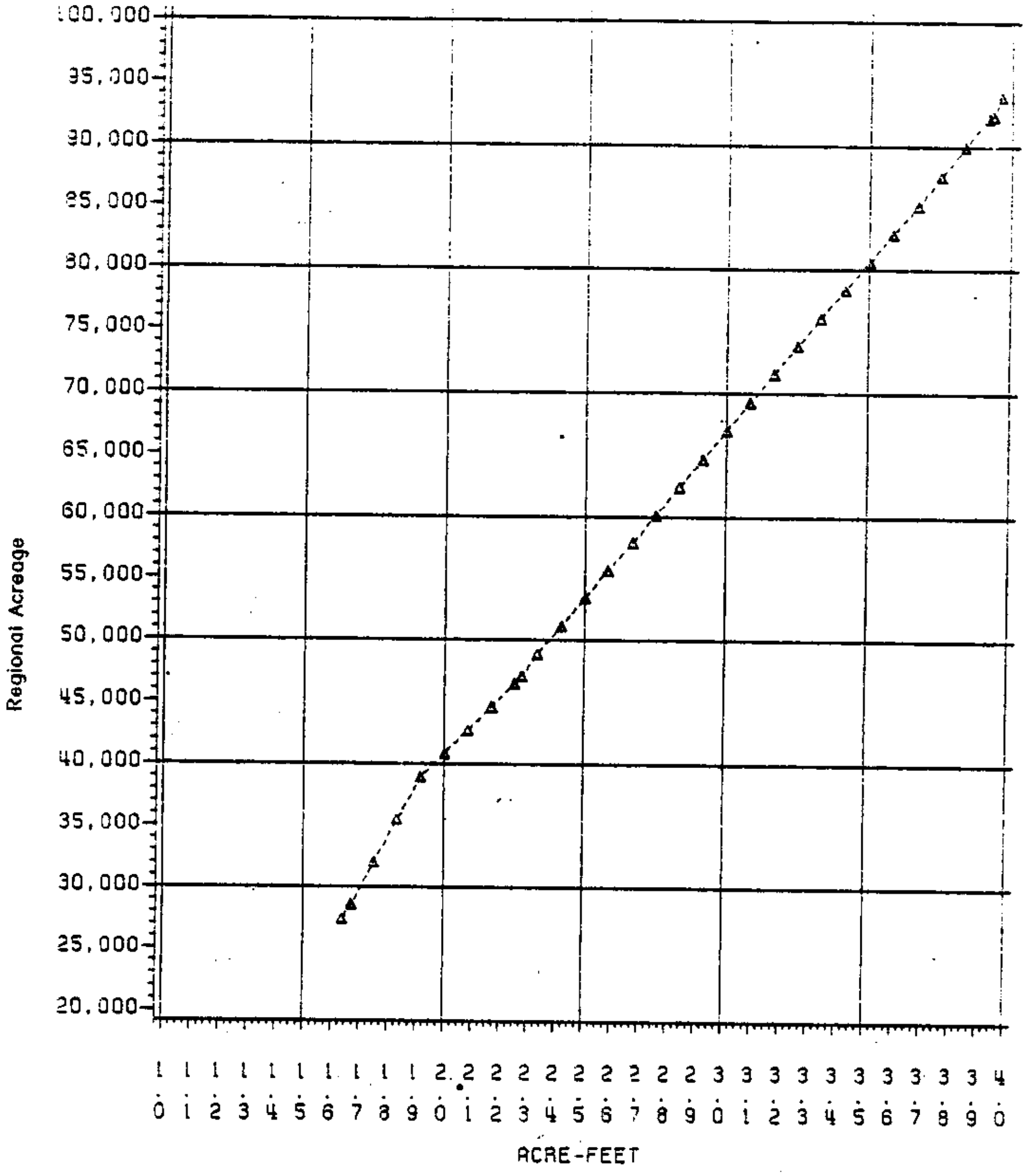

Figure 2. Regional Acreages for Varying Water Availability, Elephant Butte Irrigation District

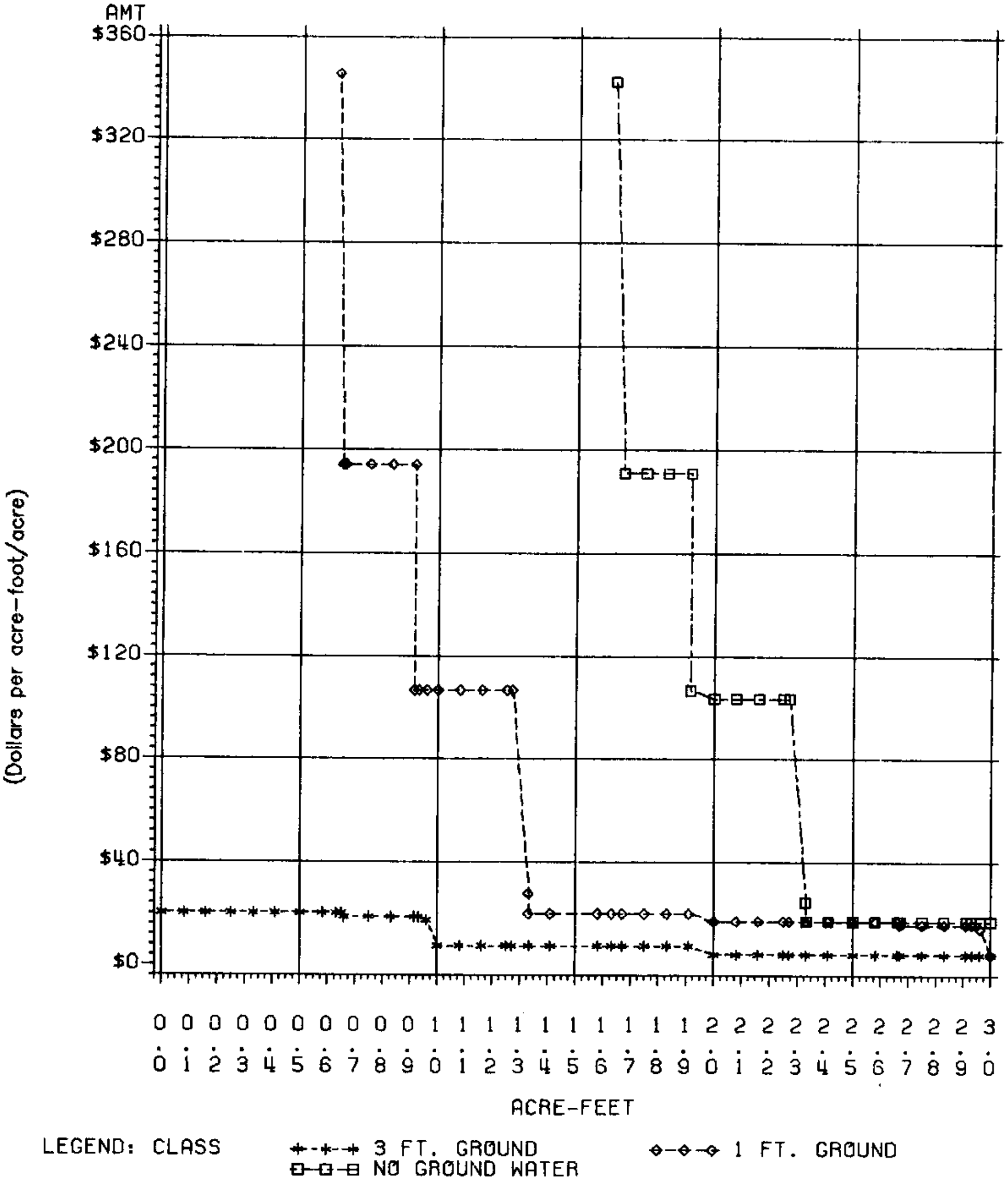

Figure 3. Surface Water Marginal Value Product for Varying Groundwater Situations, Elephant Butte Irrigation District

product exceeds $345. Producers would be willing to pay up to $345 for an additional acre-foot of surface water. Of course, not much water would be demanded at that price. Marginal value product values drop to $20.14 if the full 3 acre-feet of surface water is in use. Both of these values greatly exceed the respective acquisition costs.

For a given level of surface water usage, surface water marginal value product values also decrease with increased groundwater availability. For example, if 2 acre-feet per acre of surface water is in use, surface water marginal value product drops from $103.53 to $17.03 to $4.24 for the zero, 1 acre-foot, and 3 acre-foot groundwater situations. These figures emphasize the importance of groundwater to the region.

The demand relationships noted above may also be used in evaluating alternative uses of water by yielding the prices required to induce sale of water to other users. Such sales do currently take place between individual producers holding water rights within the district with large water users such as pecan and alfalfa producers often buying water as the surface water irrigation season draws to a close. Existing legislation prohibits transfer of water out of the irrigation district. Water demand from other heavy water users in the region (both municipal and industrial) may eventually result in new policies concerning use of water from the reservoir. In either case the demand schedules derived may be used to estimate the value of surface water for use in agriculture and provide minimum required returns for transfer to other users.

Temporal Water Usage

The results of the schedule of returns for alternative surface water levels given 1 and 3 acre feet of groundwater were used to construct the temporal LP model. Of primary concern in the temporal analysis is allocation of surface water through time, cropping patterns, and resulting economic implications.

Surface Water Allocations

The purpose of the proposed water accumulation or water saving option would be to allow a more stable allocation of surface water over time via saving portions of a large surface allocation for use in later years when there are scarce surface water supplies. Optimal temporal surface water use assuming 3 acre feet of groundwater available is presented in Figures 4 and 5. Saving activities for surface water occur in 9 different years and withdrawals from those savings in 6 separate years. Note in Figure 4 that the linear program model's perfect knowledge of future surface allocations and evaporation rates results in several consecutive years of saving in anticipation of large water shortages. Results shown in Figure 4 depict storage and depletion activities over time and with respect to the absolute level of surface water usage, while Figure 5 depicts the

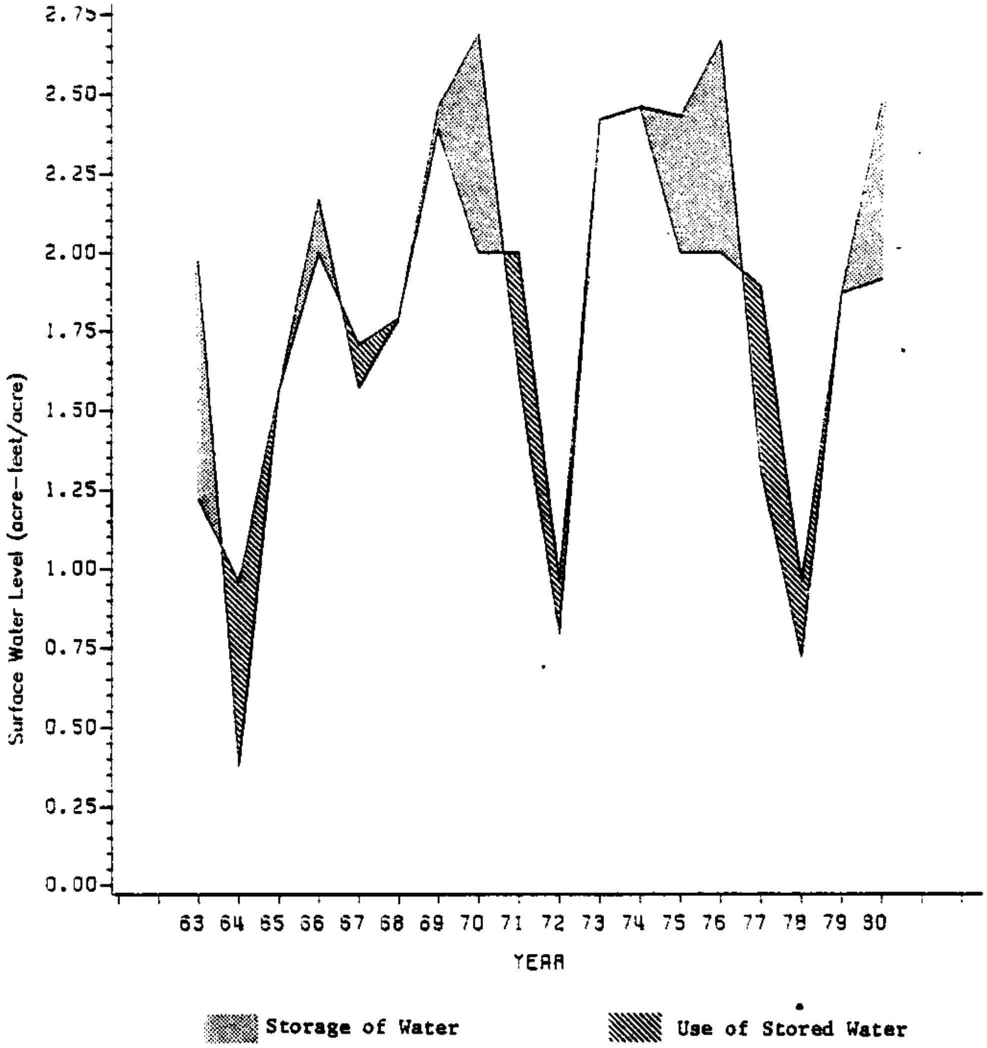

Figure 4. Optimal Temporal Surface Water Use vs. Actual Allocation, Elephant Butte Irrigation District

(3 acre-foot groundwater limitation)

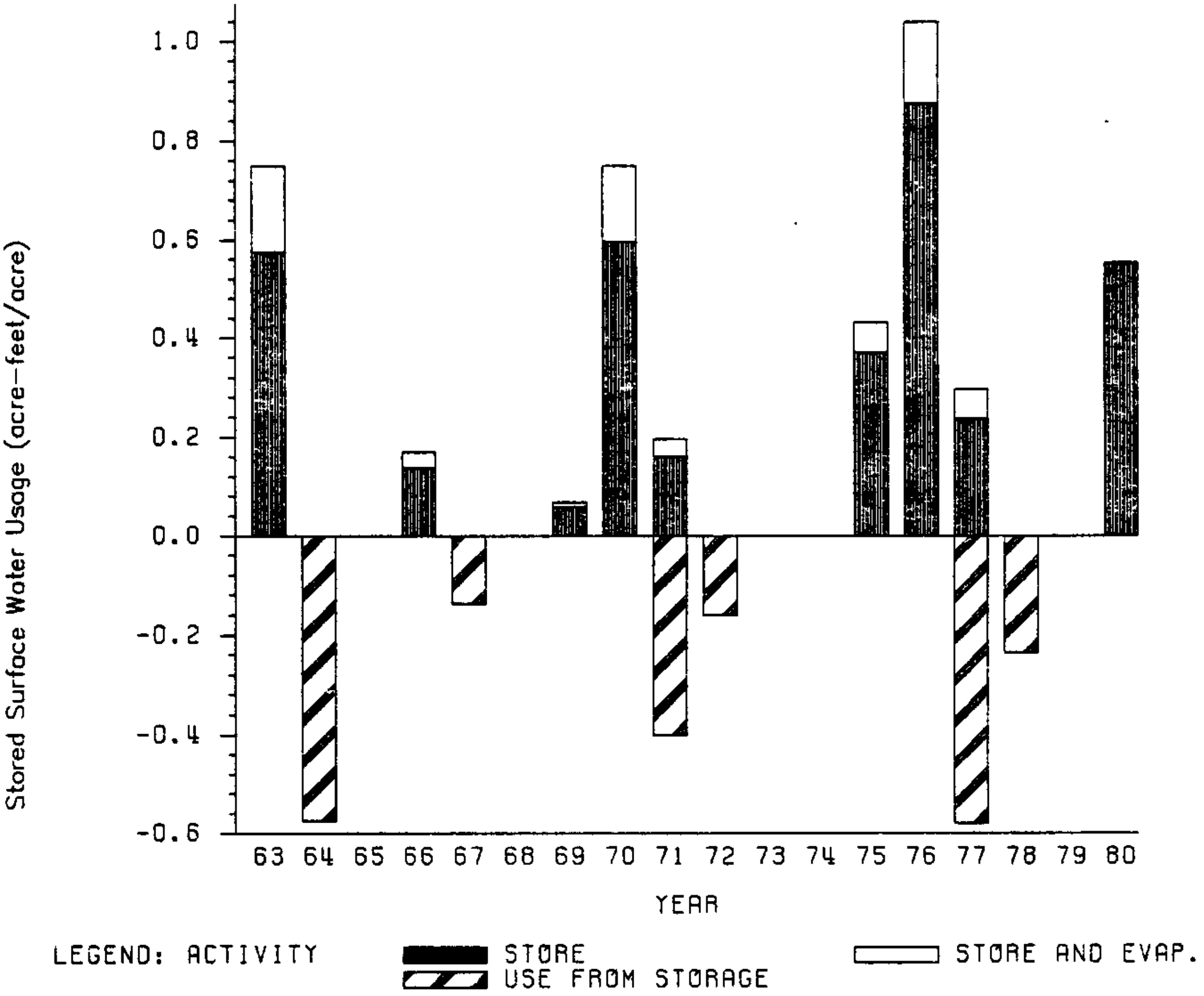

Figure 5. Optimal Temporal Surface Water Storage, Usage, and Evaporation, Elephant Butte Irrigation District

(3 acre-foot groundwater limitation)
]

same activities in terms of stored water, its use, and proportion evaporated. Water saved in 1980 does not experience evaporation loss and is assumed sold at its value for use in crop production.

Similar results for the optimal temporal allocation with a 1 acre-foot groundwater limitation as well as for the 2 acre-foot surface water limitation appear in Figures 6 through 9. Graphs for the 2 acre-foot surface water limit apply to either groundwater situation. As can be seen in the last figure noted, use of the maximum 2 acre-foot per acre surface water decision rule can result in very large amounts of water being saved with large accompanying evaporation losses. In 1976, 1.657 acre-feet per acre or a total of 150,290 acre-feet was stored with an evaporation loss of 16% or 23,851 acre-feet of surface water. Additional storage and evaporation loss on water required for transportation are not included in these calculated figures (See appendix B for a discussion of the relationship between delivered water and that required for transportation).

Tables 10 and 11 summarize the annual water usage data for the alternative temporal solutions. Examination of the information within reveals some interesting results. For the 3 acre-foot per acre groundwater limitation (Table 10), average surface water usage falls for both the temporal and 2 acre-foot surface water limitation scenarios when compared to that for the actual allocation. Values for the three cases are 1.78, 1.76 and 1.87 acre-feet per acre per year, respectively, with evaporation losses bringing about the decline. Surface water usage standard deviations for the two water saving scenarios decrease from .701 for the actual allocation case to .48 and .43 acre-feet per acre. Average groundwater usage increases from 2.048 acre-feet per year for the actual allocation to 2.17 acre-feet per year for the temporal and 2.16 acre-feet per year for the 2 acre-foot surface water limitation scenario. These increases result because most or all saved water is replaced in a given year by pumping groundwater. For this to occur the value of stored surface water, even with evaporation loss accounted for, must exceed the additional $1.14 cost of groundwater over surface water. When saving or accumulation of surface water occurs, excess surface water with a relatively low marginal value product at high levels of surface water use is saved for use in a later year where its marginal value product has increased due to restricted water availability. With an optimal temporal allocation of surface water, average total water usage increases slightly compared to the actual allocation situation. Better distribution of surface water over time also allows better use of groundwater supplies leading to the increase in average total water usage. Returns increase in response to the increase in water usage.

Total evaporation on saved or accumulated water for the optimal temporal scenario is .685 acre-feet per acre or 62,154 acre-feet when multiplied by the 90,700 acres in the region with surface water rights. Average evaporation loss per year of saving or accumulation is then 7,769 acre-feet. Total evaporation losses for the 2 acre-foot surface water limitation case increase to 102,518 acre-feet for an

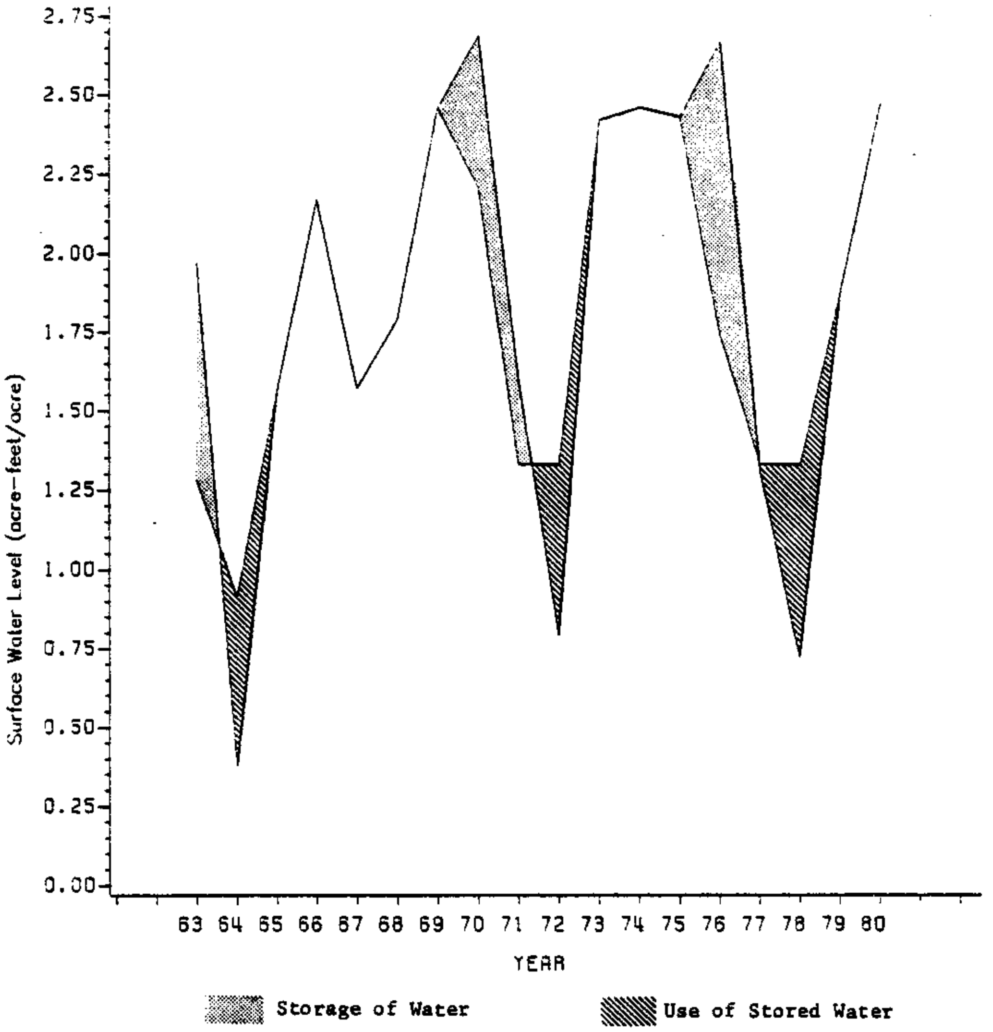

Figure 6. Optimal Temporal Surface Water Use vs. Actual Allocation, Elephant Butte Irrigation District

(1 acre-foot groundwater limitation)

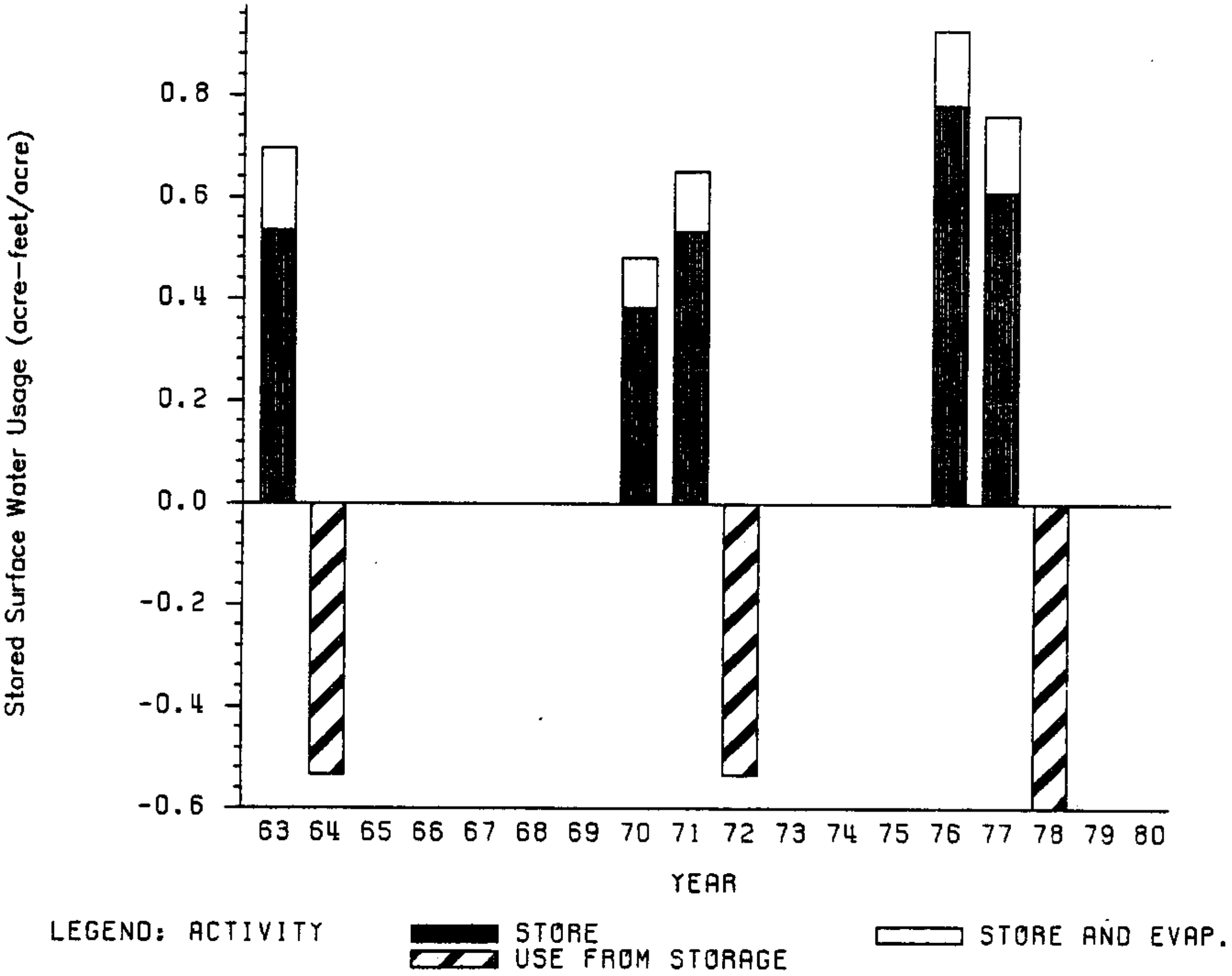

Figure 7. Optimal Temporal Surface Water Storage, Usage, and Evaporation, Elephant Butte Irrigation District

(1 acre-foot groundwater limitation)

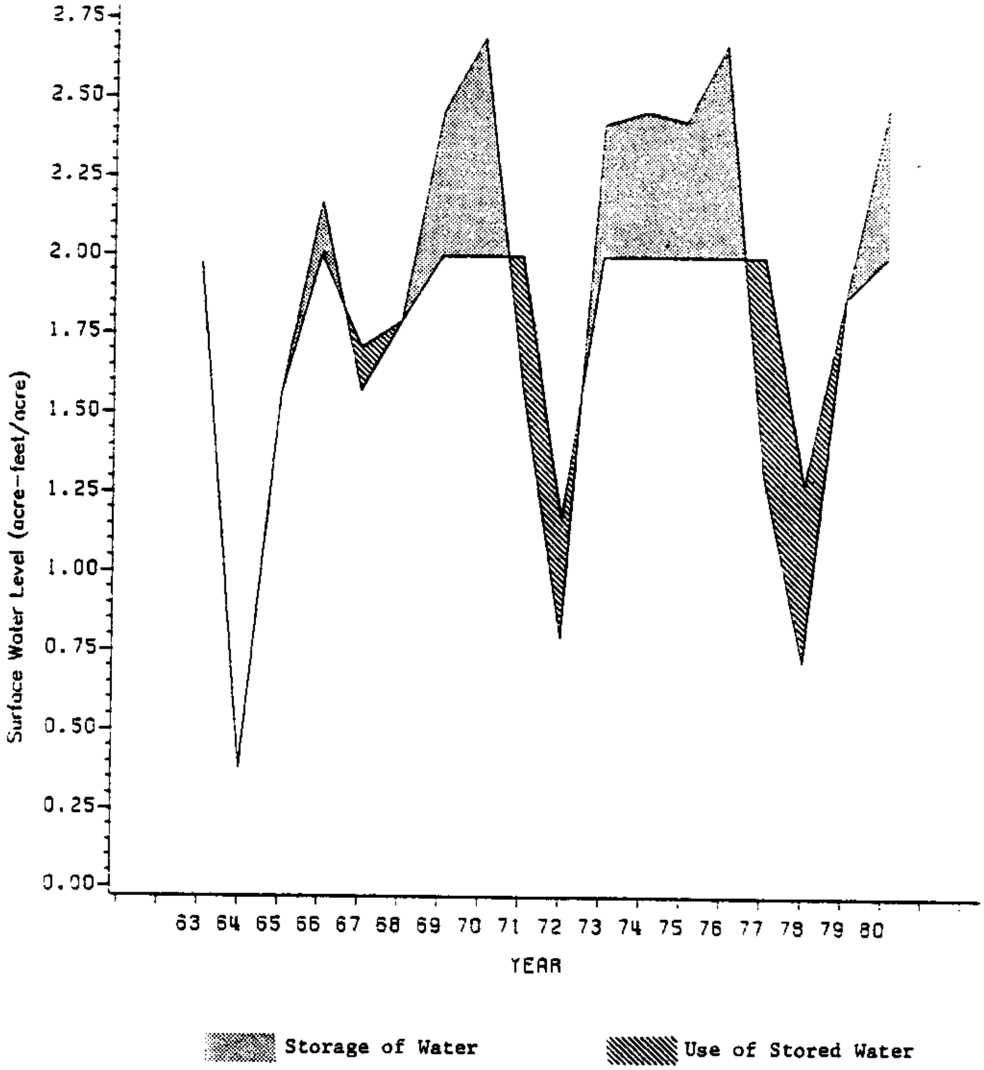

Figure 8. Surface Water Use vs. Actual Allocation for 2 Acre-Foot Surface Limitation, Elephant Butte Irrigation District

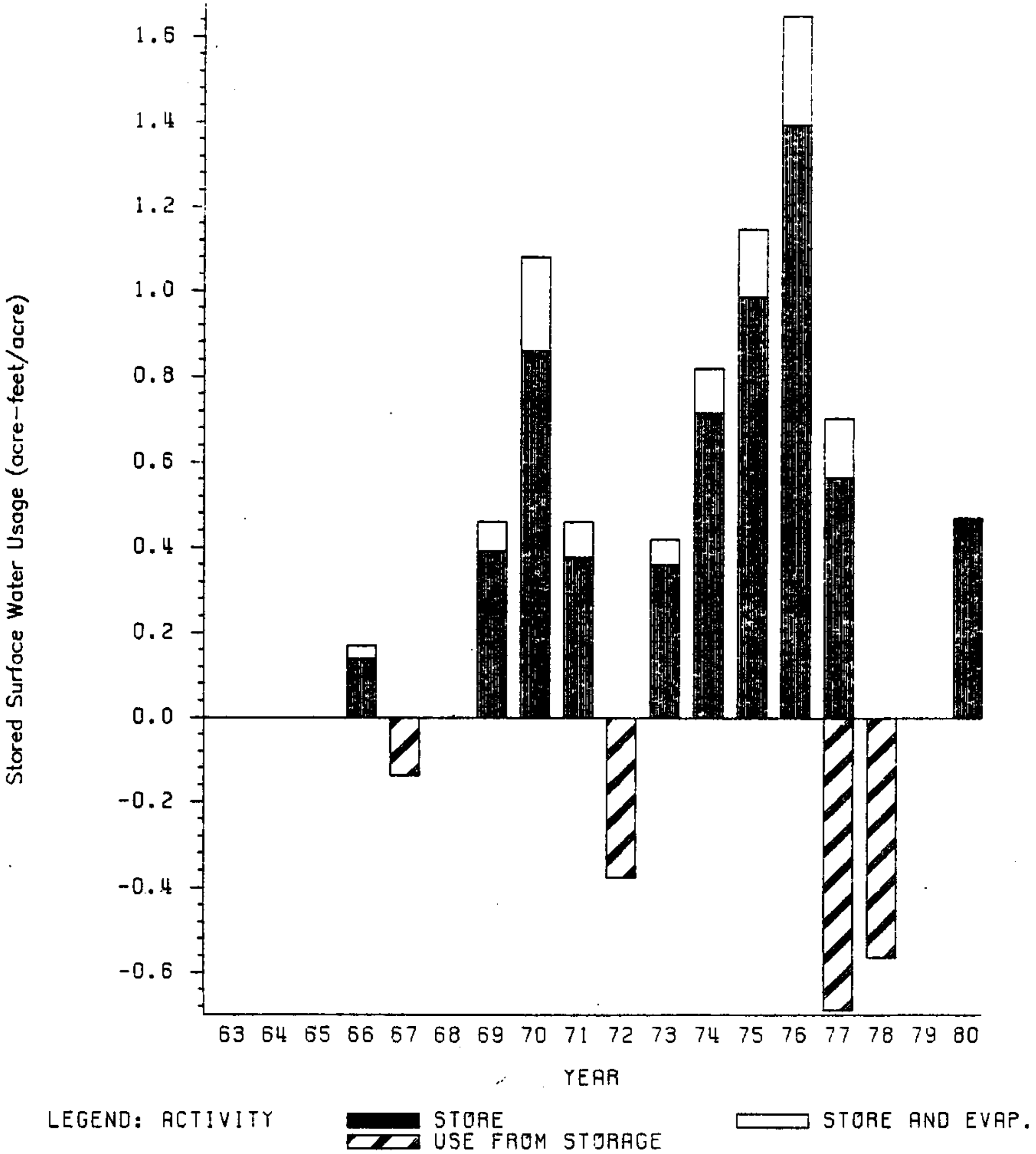

Figure 9. Surface Water Storage, Usage and Evaporation for 2 Acre-Foot Surface Water Limitation, Elephant Butte Irrigation District

Table 10. Water Usage Summary for 3 Acre-Foot Groundwater Limitation Elephant Butte Irrigation District

		Actual Allocation Scenario (ac ft/acre)			Optimal Temporal Scenario (acre-feet/acre)							2 Acre-Foot Surface Water Limitation Scenario (ac ft/ac)						
					Surface Water							Surface Water						
Year	Hist. Allo- cation	Surface Water Used	Ground- water Used	Total Used	Total Avail- able	Used	Saved	Evaporated	Net Saved	Ground- water	Total Used	Total Avail- able	Used	Saved	Evaporated	Net Saved	Ground- water	Total Used
1963	1.97	1.97	1.99	3.956	1.97	1.22	.748	.172	.576	2.73	3.956	1.97	1.97				1.986	3.956
1964	.38	.38	3.	3.38	.956	.956[a]				3.	3.956	.38	.38				3.	3.38
1965	1.56	1.56	2.4	3.956	1.56	1.56				2.392	3.952	1.56	1.56				2.396	3.956
1966	2.17	2.17	1.79	3.956	2.17	2.	.17	.0318	.1381	1.956	3.956	2.17	2.	.17	.032	.138	1.956	3.956
1967	1.57	1.57	2.39	3.956	1.706	1.706[a]				2.25	3.956	1.708	1.708[a]				2.248	3.956
1968	1.79	1.79	2.17	3.956	1.79	1.79				2.166	3.956	1.79	1.79				2.166	3.956
1969	2.46	2.46	1.5	3.956	2.46	2.39	.068	.01	.058	1.565	3.955	2.46	2.	.46	.0691	.3909	1.956	3.956
1970	2.69	2.69	1.27	3.956	2.748	2.	.748	.1527	.638	1.956	3.956	3.08	2.	1.08	.22	.86	1.956	3.956
1971	1.60	1.60	2.36	3.956	2.195	2.[a]	.195	.0352	.1599	1.956	3.956	2.46	2.	.46	.085	.3769	1.956	3.956
1972	.796	.796	3.	3.79	.956	.956[a]				3.	3.956	1.17	1.17[a]				2.786	3.956
1973	2.42	2.42	1.54	3.956	2.42	2.42				1.54	3.956	2.42	2.	.42	.06	.36	1.956	3.956
1974	2.46	2.46	1.5	3.956	2.46	2.46				1.496	3.956	2.82	2.	.82	.1032	.7168	1.956	3.956
1975	2.43	2.43	1.53	3.956	2.43	2.	.43	.0597	.3702	1.956	3.956	3.147	2.	1.147	.16	.987	1.956	3.956
1976	2.67	2.67	1.29	3.956	3.04	2.	1.04	.165	.8751	1.956	3.956	3.657	2.	1.657	.263	1.394	1.956	3.956
1977	1.31	1.31	2.65	3.956	2.185	1.89[a]	.2945	.0585	.236	2.066	3.956	2.704	2.[a]	.704	.14	.564	1.956	3.956
1978	.72	.72	3.	3.72	.956	.956[a]				3.	3.956	1.284	1.284[a]				2.676	3.956
1979	1.87	1.87	2.09	3.956	1.87	1.87				2.086	3.956	1.87	1.87				2.086	3.956
1980	2.47	2.47	1.49	3.956	2.47	1.916	.554[b]			2.04	3.956	2.47	2.	.47[b]			1.956	3.956
Avg.	1.87	1.87	2.048	3.90	2.019	1.78	.46	.086	.38	2.17	3.955	2.17	1.76	.768	.1258	.643	2.16	3.924
Std. Dev.	.701	.701	.6	.146	.61	.48	.346	.066	.288	.48	.0009	.799	.43	.46	.077	.389	.33	.135
Total Water Evap.								.685[c]							1.1323[c]			

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[a] Portion of surface water used was taken from previous years' storage.

[b] Water saved in last year (1980) assumed sold at value of use in crop production of $7.35 (not included in calculation of average).

[c] Multiply by 90,700 acres in region to obtain total number of acre-feet lost to evaporation.

Table 11. Water Usage Summary For 1 Acre-Foot Groundwater Limitation, Elephant Butte Irrigation District

		Actual Allocation Scenario (ac ft/acre)			Optimal Temporal Scenario (acre-feet/acre)							2 Acre-Foot Surface Water Limitation Scenario (ac ft/ac)						
					Surface Water							Surface Water						
Year	Hist. Allo-cation	Surface Water Used	Ground-Water Used	Total Used	Total Avail-able	Used	Saved	Evaporated	Net Saved	Ground-water	Total	Total Avail-able	Used	Saved	Evaporated	Net Saved	Ground-water	Total
1963	1.97	1.97	1.	2.97	1.97	1.275	.6945	.1597	.5348	1.	2.275	1.97	1.97				1.	2.97
1964	.38	.38	1.	1.38	.9148	.9148^{a}				1.	1.915	.38	.38				1.	1.38
1965	1.56	1.56	1.	2.56	1.56	1.56				1.	2.56	1.56	1.56				1.	2.56
1966	2.17	2.17	1.	3.17	2.17	2.17				1.	3.17	2.17	2.	.17	.032	.138	1.	3.
1967	1.57	1.57	1.	2.57	1.57	1.57				1.	2.57	1.708	1.708^{a}				1.	2.708
1968	1.79	1.79	1.	2.79	1.79	1.79				1.	2.79	1.79	1.79				1.	2.79
1969	2.46	2.46	1.	3.46	2.46	2.46				1.	3.46	2.46	2.	.46	.0691	.3909	1.	3.
1970	2.69	2.69	1.	3.69	2.69	2.21	.4795	.0979	.3816	1.	3.21	3.08	2.	1.08	.22	.86	1.	3.
1971	1.6	1.6	1.	2.6	1.9816	1.33	.6516	.1176	.534	1.	2.33	2.46	2.	.46	.085	.3769	1.	3.
1972	.796	.796	1.	1.796	1.33	1.33^{a}				1.	2.33	1.17	1.17^{a}				1.	2.17
1973	2.42	2.42	1.	3.42	2.42	2.42				1.	3.42	2.42	2.	.42	.06	.36	1.	3.
1974	2.46	2.46	1.	3.46	2.46	2.46				1.	3.46	2.82	2.	.82	.1032	.7168	1.	3.
1975	2.43	2.43	1.	3.43	2.43	2.43				1.	3.43	3.147	2.	1.147	.16	.987	1.	3.
1976	2.67	2.67	1.	3.67	2.67	1.74	.9286	.1474	.7813	1.	2.74	3.657	2.	1.657	.263	1.394	1.	3.
1977	1.31	1.31	1.	2.31	2.091	1.33	.7613	.1513	.609	1.	2.33	2.704	2.^{a}	.704	.14	.564	1.	3.
1978	.72	.72	1.	1.72	1.33	1.33^{a}				1.	2.33	1.284	1.284^{a}				1.	2.284
1979	1.87	1.87	1.	2.87	1.87	1.87				1.	2.87	1.87	1.87				1.	2.87
1980	2.47	2.47	1.	3.47	2.47	2.47				1.	3.47	2.47	2.	.47^{b}			1.	3.
Avg.	1.87	1.87	1.	2.85	2.009	1.814	.703	.1348	.568	1.	2.814	2.17	1.76	.768	.1258	.643	1.	2.76
Std. Dev.	.701	.701	0.	.701	.513	.512	.163	.026	.145	0.	.512	.799	.43	.46	.077	.389	0.	.43
Total Water Evap.								.6739^{c}							1.1323^{c}			

[a] Portion of surface water used was taken from previous years' storage.

[b] Water saved in last year (1980) assumed sold at value of use in crop production of $7.35 (Not included in calculation of average).

[c] Multiply by 90,700 acres in region to obtain total number of acre-feet lost to evaporation.

average of 11,391 acre-feet of surface water lost to evaporation per year of savings. Absence of perfect foreknowledge in the 2 acre-foot per acre surface water limitation led to significantly greater average amounts saved (.3 acre-feet per acre) than for the optimal temporal case. This led to the greater evaporation losses for the 2 acre-foot per year per acre surface water limitation.

Results for the 1 acre-foot groundwater limitation scenarios appear in Table 11 with groundwater use constant at 1 acre-foot per acre for the 3 alternative temporal surface water allocation schemes. Average surface water use falls from 1.87 acre-feet per acre per year for the actual allocation to values of 1.81 and 1.76 acre-feet per acre per year for the optimal temporal and the 2 acre-foot surface water limitation scenarios. Standard deviations on surface water usage for those two cases are also significantly smaller than for the actual allocation. With average groundwater use constant and average surface water use decreasing, total water usage decreases. Under limited groundwater availability, total evaporation losses for the temporal scenario are 61,119 acre-feet yielding average losses of 12,224 acre-feet for the 5 years in which saving occurred. For the 2 acre-foot surface water limitation scenario, evaporation losses are as reported for the 3 acre-foot groundwater case. The average amount of water saved varied very little between the optimum temporal and 2 acre-foot surface water limit cases.

Cropping Patterns

Cropping pattern results for all six scenarios investigated appear in Tables 12, 13, and 14. Yields per acre are as previously reported in Table 6. For the 3 acre-foot per acre groundwater case and actual surface water allocation (Table 12) wheat and onion acreages/production are the only crops to vary over time. If groundwater is restricted to 1 acre-foot per acre onion acreages are absent except for two years (1970 & 1976) with unusually large surface allocations. Cotton acreage varies throughout the schedule. Low surface allocations in 1964, 1972 and 1978 diminish or exclude cotton, tomatoe, onion, wheat, and green chile production. The allocation in 1964 could maintain only the required pecan and alfalfa acreages.

Optimal temporal cropping patterns (Table 13) for both groundwater situations are relatively stable, with those for the 3 acre-foot groundwater situation being constant while cotton acreage varies for the 1 acre-foot groundwater case. Onion acreage is totally absent in the latter case, and in 1964 the water saving option increased both wheat and lettuce acreage by 5,780 acres over that occurring for the actual allocation case with 1 acre-foot of groundwater in use. Optimal temporal use of available surface water increased average total acreage by 1,211 acres per year for the 3 acre-foot groundwater case. Average total acreage decreased from 63,055 to 61,992 acres for the 1 acre-foot groundwater case. This apparent anomaly occurs for the temporal case when surface water use on less water intensive crops like cotton is reduced in years of large allocations and the water is

Table 12. Actual Surface Water Allocation Cropping Patterns, Elephant Butte Irrigation District

Year	Total Water Used (acre-feet/acre)	Acreages[a]						
		Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chile	Total
Three Acre-Foot Groundwater Case:								
1963	3.956	36,000	12,042	822	5,780	3,870	8,190	94,072
1964	3.38	36,000	6,602	822	5,780	0	8,190	84,762
1965-1971	3.956	36,000	12,042	822	5,780	3,870	8,190	94,072
1972	3.796	36,000	8,691	822	5,780	2,089	8,190	88,940
1973-1977	3.956	36,000	12,042	822	5,780	3,870	8,190	94,072
1978	3.72	36,000	7,578	822	5,780	975	8,190	86,713
1979-1980	3.956	36,000	12,042	822	5,780	3,870	8,190	94,072
Average								92,861
One Acre-Foot Groundwater Case:								
1963	2.97	17,426	6,602	822	5,780	0	8,190	66,188
1964	1.38	(allocation sufficient only for pecan & alfalfa acreages)						27,368
1965	2.56	6,259	6,602	822	5,780	0	8,190	55,021
1966	3.17	22,859	6,602	822	5,780	0	8,190	71,621
1967	2.57	6,532	6,602	822	5,780	0	8,190	55,294
1968	2.79	12,522	6,602	822	5,780	0	8,190	61,284
1969	3.46	30,774	6,602	822	5,780	0	8,190	79,536
1970	3.69	36,000	7,108	822	5,780	507	8,190	85,269
1971	2.6	7,348	6,602	822	5,780	0	8,190	56,110
1972	1.796	0	3,294	0	3,294	0	0	33,956
1973	3.42	29,694	6,602	822	5,780	0	8,190	78,456
1974	3.46	30,774	6,602	822	5,780	0	8,190	79,536
1975	3.43	29,965	6,602	822	5,780	0	8,190	78,727
1976	3.67	36,000	6,810	822	5,780	208	8,190	84,970
1977	2.31	0	6,298	518	5,780	0	8,190	48,154
1978	1.72	0	1,696	0	1,696	0	0	30,760
1979	2.87	14,709	6,602	822	5,780	0	8,190	63,471
1980	3.47	31,045	6,602	822	5,780	0	8,190	79,807
Average								63,085

[a] Barley, grain sorghum, and red chile acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres, respectively.

Table 13. Optimal Temporal Surface Water Allocation Cropping Patterns, Elephant Butte Irrigation District

Year	Total Water Used (acre-feet/acre)	Acreages[a]						
		Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chile	Total
Three Acre-Foot Groundwater Case:								
1963-1980		36,000	12,042	822	5,780	3,870	8,190	94,072
One Acre-Foot Groundwater Case:								
1963	2.275	0	5,780	0	5,780	0	8,178	47,106
1964	1.915	0	5,780	822	5,780	0	0	38,928
1965	2.56	6,270	6,602	822	5,780	0	8,190	55,032
1966	3.17	22,876	6,602	822	5,780	0	8,190	71,638
1967	2.57	6,543	6,602	822	5,780	0	8,190	55,305
1968	2.79	12,535	6,602	822	5,780	0	8,190	61,297
1969	3.46	30,775	6,602	822	5,780	0	8,190	79,537
1970	3.21	23,978	6,602	822	5,780	0	8,190	72,740
1971	2.33	80	6,602	822	5,780	0	8,190	48,842
1972	2.33	80	6,602	822	5,780	0	8,190	48,842
1973	3.42	29,686	6,602	822	5,780	0	8,190	78,448
1974	3.46	30,775	6,602	822	5,780	0	8,190	79,537
1975	3.43	29,958	6,602	822	5,780	0	8,190	78,720
1976	2.74	11,210	6,602	822	5,780	0	8,190	59,972
1977	2.33	80	6,602	822	5,780	0	8,190	48,842
1978	2.33	80	6,602	822	5,780	0	8,190	48,842
1979	2.87	14,174	6,602	822	5,780	0	8,190	63,476
1980	3.47	30.001	6,602	822	5,780	0	8,190	78,763
Average								61,992

[a] Barley, grain sorghum, and red chile acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres, respectively.

Table 14. Two Acre-Foot Surface Water Limitation Cropping Patterns, Elephant Butte Irrigation District

Year	Total Water Used (acre-feet/acre)	Acreages[a]						
		Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chile	Total
Three Acre-Foot Groundwater Case:								
1963	3.956	36,000	12,042	822	5,780	3,870	8,190	94,072
1964	3.38	28,602	6,602	822	5,780	0	8,190	77,364
1965-1980	3.956	36,000	12,042	822	5,780	3,870	8,190	94,072
Average								93,144
One Acre-Foot Groundwater Case:								
1963	2,97	17,426	6,602	822	5,780	0	8,190	66,188
1964	1.38	(allocation sufficient only for pecan & alfalfa acreages)						27,368
1965	2.56	6,259	6,602	822	5,780	0	8,190	55,021
1966	3.	18,237	6,602	822	5,780	0	8,190	66,999
1967	2.708	10,279	6,602	822	5,780	0	8,190	59,041
1968	2.79	12,521	6,602	822	5,780	0	8,190	61,283
1969-1971	3.	18,237	6,602	822	5,780	0	8,190	66,999
1972	2.17	0	6,780	0	5,780	0	8,190	44,848
1973-1977	3.	18,237	6,602	822	5,780	0	8,190	66,999
1978	2.284	0	5,840	61	5,780	0	8,190	47,239
1979	2.87	14,709	6,602	822	5,780	0	8,190	63,471
1980	3.	18,237	6,602	822	5,780	0	8,190	66,999
Average								60,803

[a] Barley, grain sorghum, and red chile acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres, respectively.

used in later years with lower allocations on more water intensive crops such as vegetables.

Results for the 2 acre-foot surface water limitation case (Table 14) are similar to those for the optimal temporal surface water allocation scenario. Cropping patterns and production are constant for all years except 1964 if 3 acre-feet of groundwater is available, and the restriction of groundwater leads to the exit of onion acreage and the varying of cotton production. Average total acreage increases slightly from the actual allocation results by 283 acres per year for the 3 acre-foot groundwater case, while decreasing by an average 2,282 acres per year for the other groundwater situation examined.

Economic Implications

A major purpose of this study was to investigate if the redistribution of current surface water allocations via the water saving option would significantly alter returns to the region. It is important to note that if such saving does take place, recharge of groundwater to the floodplain will fall due to the decreased river flow and more restrictive limits on groundwater pumping would very likely occur. This prompted use of the 3 and 1 acre-foot groundwater limitations with the intent of obtaining economic returns relevant to the entire range of water use possible with the water saving option in place. As previously noted, separate linear programming models maximizing the present value of returns over the 18 year period analyzed were used and their solutions represent "best case" use of the region's limited water resources. The returns streams for these optimal temporal results appear in Tables 15 and 16 for the 3 and 1 acre-foot per acre groundwater cases, respectively. Corresponding return streams for the actual annual surface water allocation and the 2 acre-foot per acre surface water use limitation are also presented. Differences between these returns streams provide a measure of the potential economic effects of the proposed water saving option.

Average returns per year for the 3 acre-foot per acre groundwater situation (Table 15) increase from $3,644,195 for the actual allocation to $3,714,433 and $3,682,602 for the optimal temporal and 2 acre-foot per acre surface water limitation situations. These improvements are slight, however, being less than 2 % in both cases. The returns streams are also expressed in 1980 dollars and the present value total for each calculated. These totals are then converted to an annuity and divided by the average of 83,600 farmed acres to yield returns per acre per year. Optimal temporal use of surface water resulted in returns per acre per year of $43.94; 82 cents above the actual allocation value of $43.12 . The 62,154 acre-feet of surface water lost to evaporation therefore, in effect, purchased the increase in average time-valued returns of $68,552 per year.

The optimal temporal returns represent an upper bound on possible returns. A more realistic situation, both from administrative and producer's decision making standpoints, would be the 2 acre-foot surface water limitation. In this case the large amount of surface water lost to evaporation (102,518 acre-feet) resulted in only a 23 cent increase in average returns per acre per year. The latter figure translates to increased returns per year to the region of only $4,422 which would probably not cover the additional costs to the water district to administer the water saving option.

As groundwater availability is limited ,however, potential benefits to the region increase. Average net returns (Table 16) increased from $1,440,639 to $2,219,517 for the optimal temporal surface water allocation scenario for an improvement of 54 %. For the 2 acre-foot per acre surface water limitation, average annual net returns increased 32.5 % to a value of $1,908,648. These figures imply time-valued differences in returns per acre per year of $8.41 and $3.68, respectively, with the latter value meaning additional average annual revenue to the region of $307,648 for the 2 acre-foot surface water limitation case. Thus if groundwater availability is limited, use of the water saving option can significantly increase net returns. Net benefit to the region would then depend upon the cost of administration of the water saving program and what parties bear that cost. Estimates of such administrative costs were not undertaken in this particular analysis.

Graphical depictions of regional net returns appear in Figures 10 and 11 for the 3 and 1 acre-foot groundwater situations. Returns for the actual surface water allocation are seen to vary a good deal more in both graphs than for either of the other two scenarios examined. Coefficients of variation values (Tables 15 and 16) also attest to the greater stability of returns with the water saving option in place. Note that the number of years with negative returns for the 1 acre-foot groundwater situation decreased by 66 % if water saving was allowed. The latter would very likely have been eliminated entirely were it not for the occurance of an inordinantly low surface water allocation of .38 acre-feet per acre in only the second year of the period analyzed. Lead time to build up a sufficient amount of stored water had not yet elapsed.

One additional relationship should be noted. Relative product and input prices were assumed constant over time within the linear programming model used to derive the various returns schedules. Therefore, water availablity as well as the relative composition of ground and surface water became the main determinants of returns to the region. Graphical representations of net returns versus ground and total water use appear in Figures 12 through 17 for all six scenarios under consideration. Net returns to the region appear in the upper portion of the composite graph with water use depicted below. The vertical distance between total water use and that for groundwater for a given year represents the amount of surface water used. For the three scenarios with 3 acre-feet per acre of groundwater available, the higher cost of pumping groundwater is the most significant determinant of returns. Total water usage is relatively constant for these cases, but in those years with small

Table 15. Annual Net Farm Revenue and 1980 Values for the Actual Surface Water Allocation, Optimal Temporal, and Two Acre-Feet Per Acre Scenarios (3 Acre-Foot Groundwater Limitation), Elephant Butte Irrigation District

	Net Farm Revenue				1980 Value[a]		
	Actual Allocation	Optimal Temporal Scenario	Two Acre-Feet Per Acre Scenario		Actual Allocation	Optimal Temporal Scenario	Two Acre-Feet Per Acre Scenario
Year:							
1963	3,837,226	3,339,649	3,838,219		12,121,797	10,550,148	12,124,993
1964	2,149,164	3,162,298	2,150,793		6,344,331	9,335,197	6,349,143
1965	3,566,267	3,565,084	3,564,760		9,839,330	9,836,072	9,835,173
1966	3,925,864	3,858,069	3,858,069		10,124,804	9,950,144	9,949,960
1967	3,573,214	3,663,902	3,662,145		8,611,447	8,829,955	8,825,769
1968	3,719,116	3,718,472	3,718,111		8,375,448	8,373,993	8,373,186
1969	4,036,475	4,009,659	3,858,069		8,496,778	8,440,322	8,121,235
1970	4,125,677	3,858,069	3,858,069		8,115,207	7,588,947	7,558,822
1971	3,592,513	3,858,072	3,858,069		6,603,040	7,091,131	7,041,131
1972	2,895,399	3,162,287	3,308,431		4,974,296	5,432,830	5,683,884
1973	4,022,202	4,020,537	3,858,069		6,459,657	6,457,034	6,196,059
1974	4,036,475	4,036,045	3,858,069		6,058,748	6,058,127	4,790,962
1975	4,025,770	3,858,079	3,858,069		5,648,156	5,412,873	5,412,871
1976	4,118,541	3,858,089	3,858,069		5,399,407	5,057,932	5,057,928
1977	3,399,523	3,785,566	3,858,069		4,164,415	4,637,355	4,726,135
1978	2,760,440	3,162,291	3,378,679		3,160,704	3,620,833	3,868,588
1979	3,771,609	3,771,816	3,771,683		4,035,622	4,035,841	4,035,701
1980	4,040,043	3,802,488	3,858,069		4,040,043	3,802,488	3,858,069
Value of Water Stored:		369,321	313,323			369,321	313,323
Total	65,595,517	66,859,793	66,286,835		122,573,224	124,880,543	123,202,871
Average Returns	3,644,195	3,714,433	3,682,602	Annualized Return Per Acre Per Year[b]	43.12	43.94	43.35
Standard Deviation	542,256	314,822	429,948				
Coefficient of Variation	.1487	.08475	.1167	Difference from Actual		.82	.23
Percent Change from Average Actual Return		1.9%	1.05%	Percent Difference from Actual		.019%	.0053%

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[a] A 7% interest rate reflecting the real value of money and a risk premium was assumed.

[b] 1980 value totals were converted to an annuity with r = 7% and n = 18. These regional annual returns were then divided by 83,600 (average farmed acreage) to yield annualized returns per acre per year.

Table 16. Annual Net Farm Revenue and 1980 Values for the Actual Surface Water Allocation, Optimal Temporal, and Two Acre-Feet Per Acre Scenarios (1 Acre-Foot Groundwater Limitation), Elephant Butte Irrigation District

	Net Farm Revenue				1980 Value[a]		
	Actual Allocation	Optimal Temporal Scenario	Two Acre-Feet Per Acre Scenario		Actual Allocation	Optimal Temporal Scenario	Two Acre-Feet Per Acre Scenario
Year:							
1963	2,735,381	1,160,061	2,735,381		8,641,070	3,664,632	8,641,070
1964	-7,184,993	-2,328,116	-7,184,993		-21,210,099	-6,872,598	-21,210,099
1965	1,986,543	1,987,321	1,986,543		5,480,872	5,483,017	5,480,872
1966	3,051,866	3,052,877	2,789,740		7,870,763	7,873,369	7,194,739
1967	2,004,881	2,005,585	2,256,109		4,831,763	4,833,460	5,437,223
1968	2,406,479	2,407,404	2,406,479		5,419,391	5,421,478	5,419,391
1969	3,500,851	3,500,876	2,789,740		7,369,292	7,369,343	5,872,403
1970	3,847,503	3,115,382	2,789,740		7,568,039	6,127,956	5,487,419
1971	2,059,523	1,566,752	2,789,740		3,783,451	2,879,690	4,127,542
1972	-4,416,473	1,566,752	197,183		-7,587,502	2,691,680	338,761
1973	3,439,548	3,439,083	2,789,740		4,423,915	5,523,166	4,480,322
1974	3,500,851	3,500,876	2,789,740		5,254,778	5,254,814	4,187,400
1975	3,454,874	3,454,531	2,789,740		4,847,188	4,846,707	3,914,005
1976	3,817,855	2,318,569	2,789,740		5,005,208	3,039,644	3,657,349
1977	1,418,076	1,566,752	2,789,740		1,737,144	1,919,271	3,417,432
1978	-5,759,553	1,566,752	1,195,063		-6,594,688	1,793,931	1,368,347
1979	2,553,182	2,553,519	2,553,182		2,731,905	2,732,265	2,731,905
1980	3,516,177	3,516,324	2,789,740		3,516,177	3,516,324	2,789,740
Value of Stored Water:			313,323				313,323
Total	25,931,510	39,951,306	34,355,621		44,188,664	68,098,147	54,649,145
Average Returns	1,440,639	2,219,517	1,908,648	Annualized Return Per Acre Per Year[b]	15.55	23.96	19.23
Standard Deviation	3,432,418	1,398,304	2,376,598				
Coefficient of Variation	2.38	.63	1.245	Difference from Actual		8.41	3.68
Average Actual Return		54%	32.5%	Percent Difference from Actual		54%	23.7%

[a] A 7% interest rate reflecting risk and the real value of money was assumed.

[b] 1980 value totals were converted to an annuity with r = 7% and n = 18. These regional annual returns were then divided by 83,600 (average farmed acreage) to yield annualized returns per acre per year.

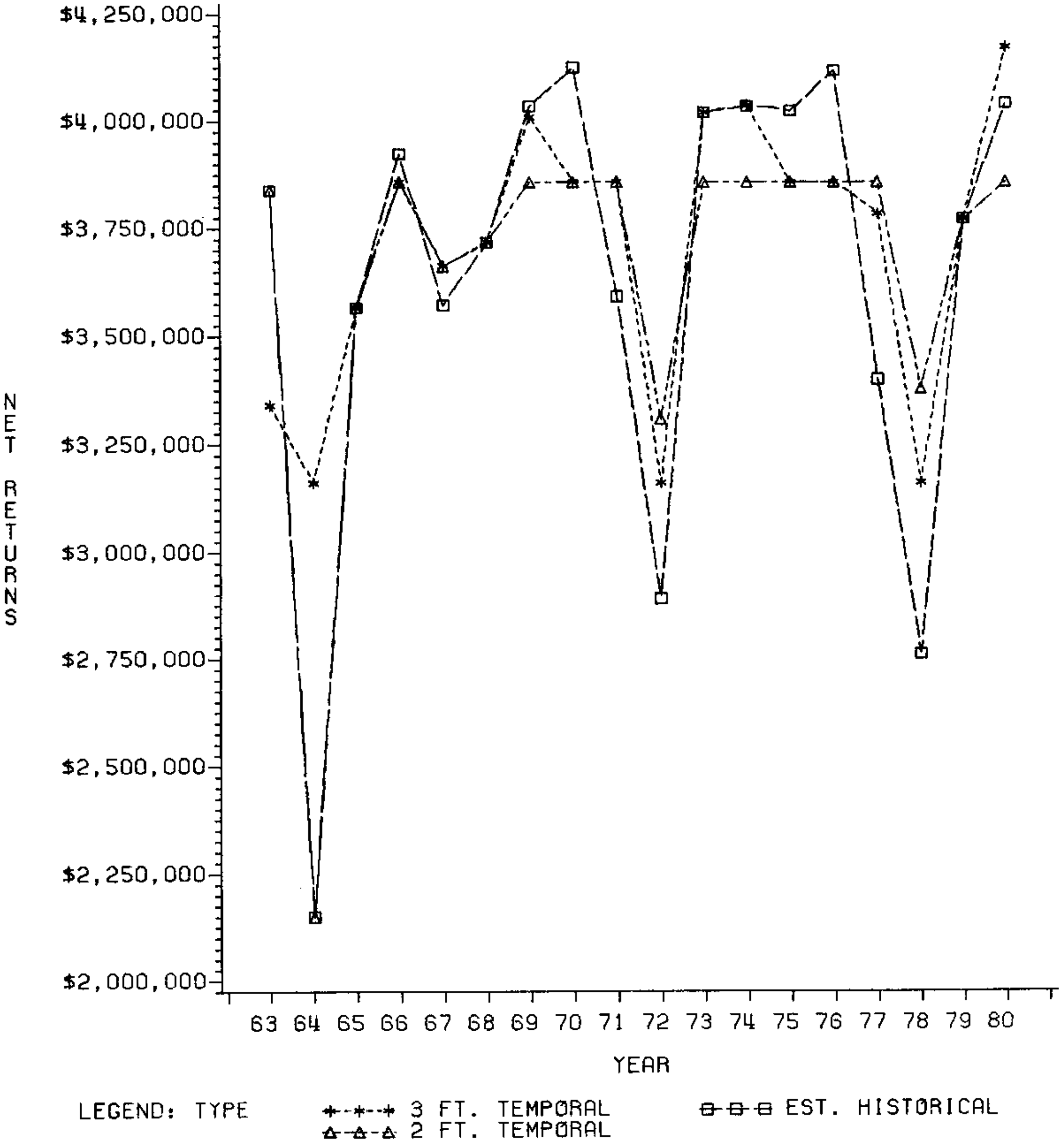

Figure 10. Regional Net Returns for Optimal Temporal, Two Acre-Foot Surface Water Limitation, and Actual Allocation Scenarios, Elephant Butte Irrigation District

(3 acre-foot groundwater limitation)

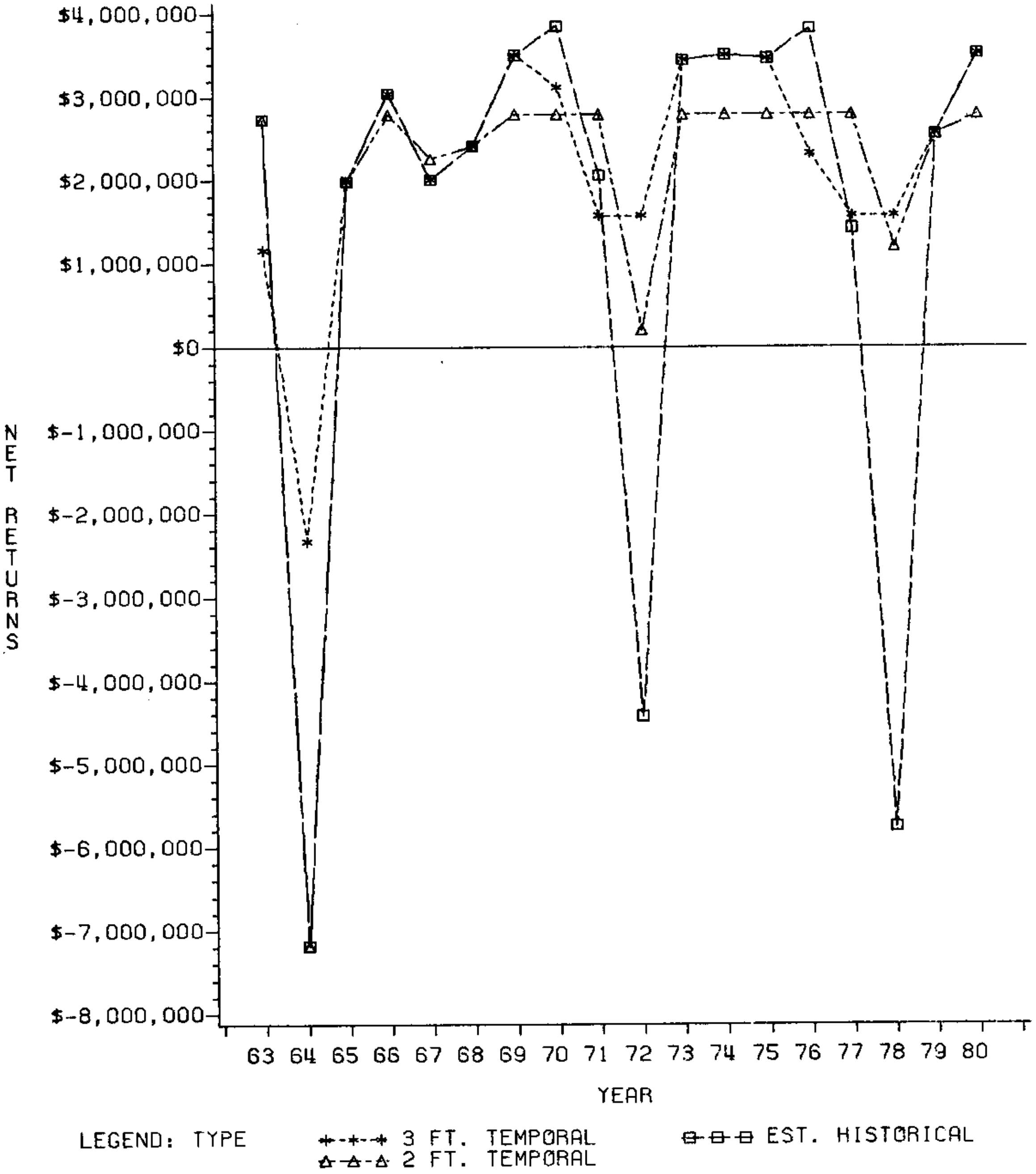

Figure 11. Regional Net Returns for Optimal Temporal, Two Acre-Foot Surface Water Limitation, and Actual Allocation Scenarios, Elephant Butte Irrigation District

(1 acre-foot groundwater limitation)

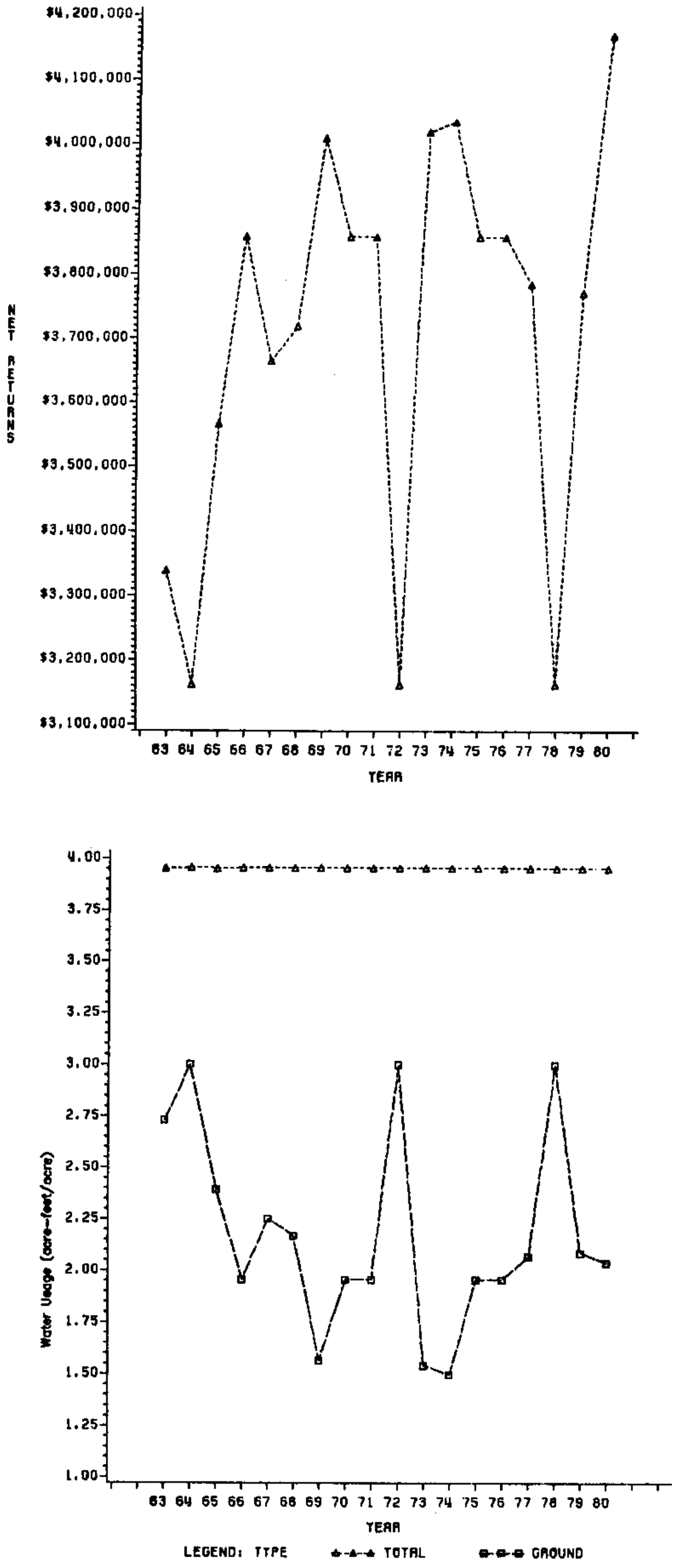

Figure 12. Net Returns and Water Usage with Optimal Temporal Allocation of Surface Water, Elephant Butte Irrigation District

(3 acre-foot groundwater case)

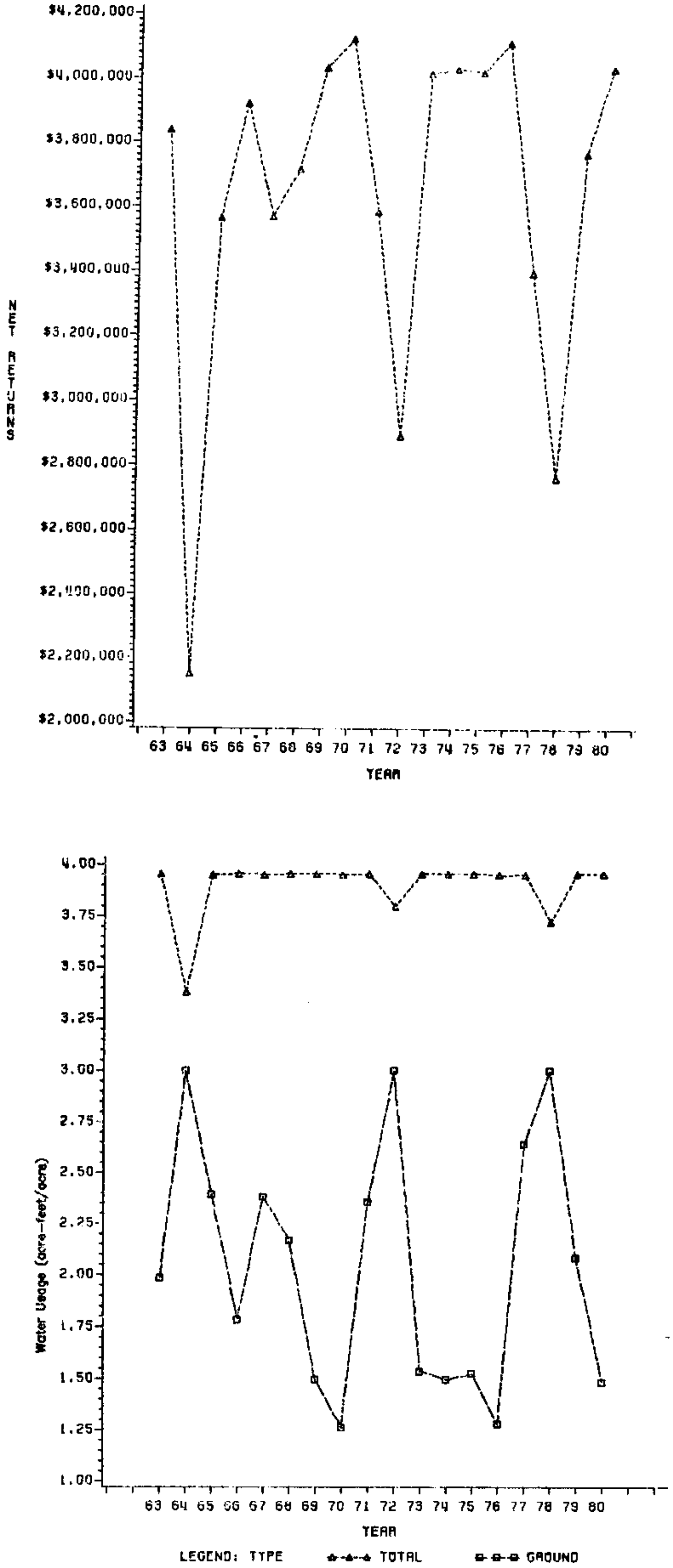

Figure 13. Net Returns and Water Usage for Actual Surface Water Allocation, Elephant Butte Irrigation District

(3 acre-foot groundwater case)

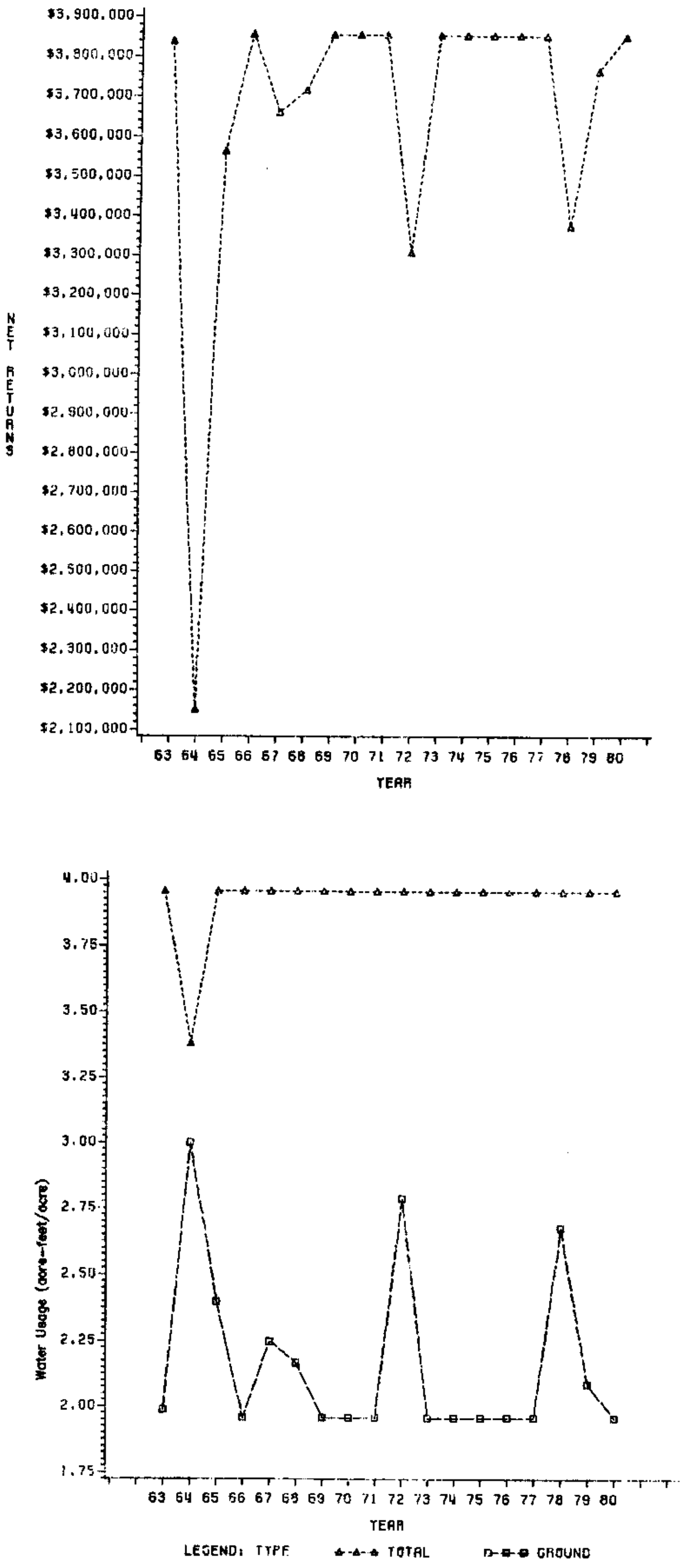

Figure 14. Net Returns and Water Usage for Two Acre-Foot Surface Water Limitation, Elephant Butte Irrigation District

(3 acre-foot groundwater case)

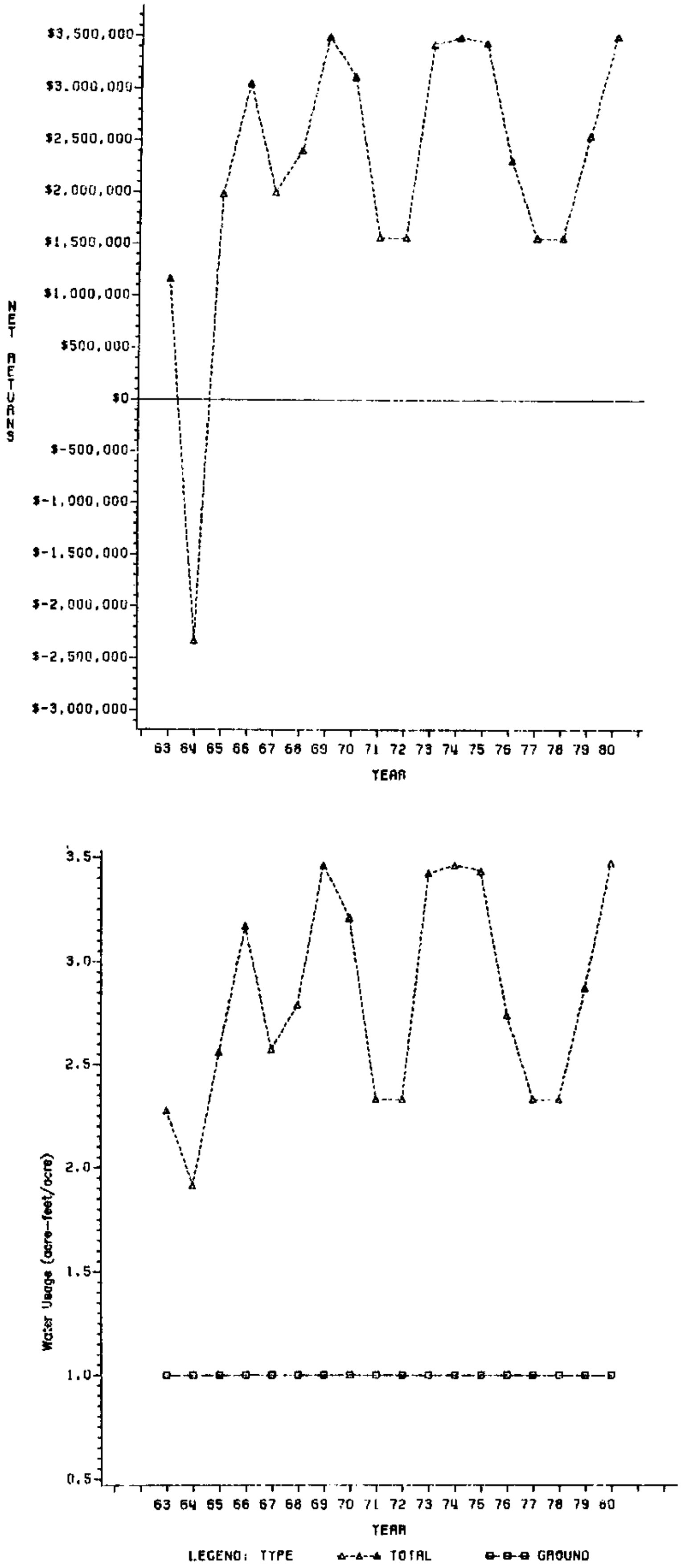

Figure 15. Net Returns and Water Usage for Optimal Temporal Allocation of Surface Water, Elephant Butte Irrigation District

(1 acre-foot groundwater case)

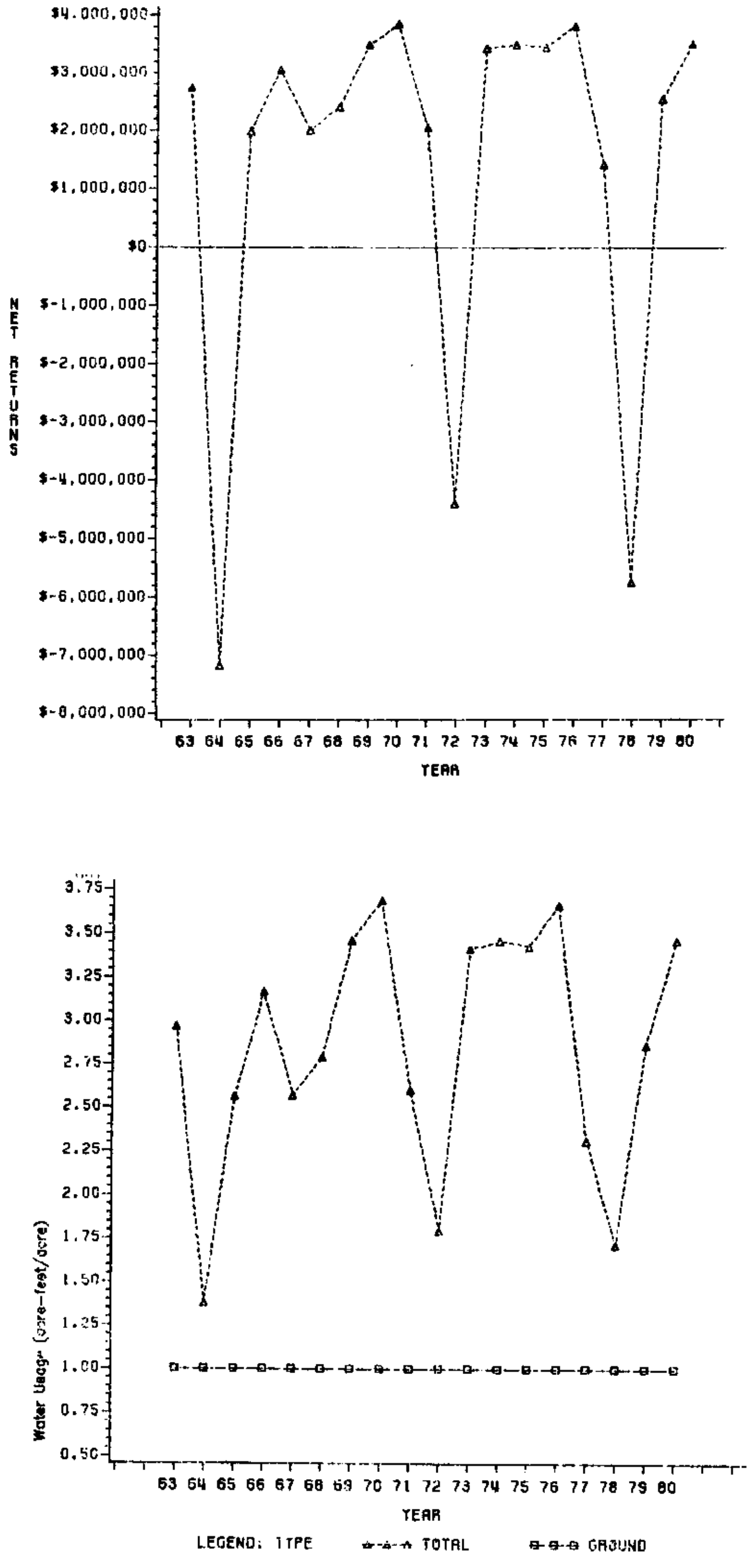

Figure 16. Net Returns and Water Usage for Actual Allocation of Surface Water, Elephant Butte Irrigation District

(1 acre-foot groundwater case)

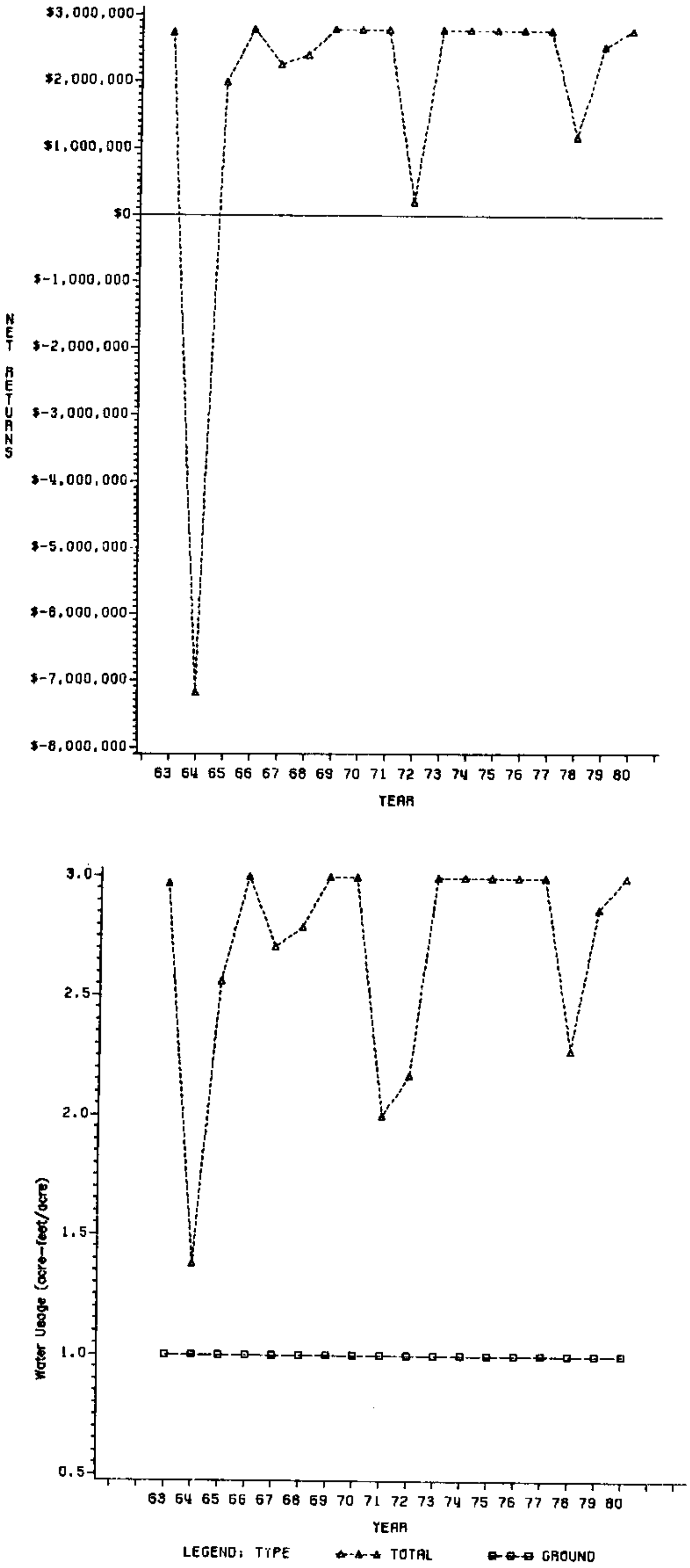

Figure 17. Net Returns and Water Usage for Two Acre-Foot Surface Water Limitations, Elephant Butte Irrigation District

(1 acre-foot groundwater case)

surface allocations, groundwater use and its associated costs are relatively large. Alternatively, for the three scenarios with the 1 acre-foot per acre groundwater limitation, total water usage varies with surface allocation, the cost of groundwater pumping does not greatly affect net returns, and net returns vary directly with surface allocation and water available from storage.

Conclusions, Implications, and Limitations

The study presented here investigated the expected regional impact and economic feasibility of a proposed water accumulation or water saving option for producers operating in the Elephant Butte Irrigation District. This particular plan would allow agricultural producers to hold part of a given year's surface water allocation in Elephant Butte Reservoir, providing use of the unevaporated portion in a later year.

Procedures employed in the analysis included modeling of current cropping practices subject to regional resource constraints within a static linear programming model. Pertinent input/output coefficients and costs were incorporated, with five-year average output prices assumed for twelve crops spread across 11 soil groups. Applicable fixed costs and interest charges were taken into account. Net returns to the region were maximized assuming 1 and 3 acre-feet of groundwater available per year per acre irrigated.

Surface water availability was varied from zero to 3 acre-feet per acre to obtain schedules depicting regional net returns and cropping patterns for varying surface water allocations for both the groundwater situations examined. These schedules were then used to build temporal linear programming models which maximized the present value of net returns for the period 1963 to 1980 subject to historical surface water allocations and reservoir evaporation rates. Calculation of these evaporation rates took into consideration increased lake levels due to surface water storage.

The temporal models were used to estimate an optimal allocation of surface water over the 18 year period investigated for the two groundwater availability situations considered. Returns for the optimal surface water allocations were then upper bounds on potential net returns to the region. Projected streams of net returns were also obtained for each of the scenarios analyzed; i.e., optimal temporal allocation of surface water, 2 acre feet of surface water per year limit and actual allocation of surface water given the 1 and 3 foot groundwater limitations. These streams of net returns were valued in 1980 dollars allowing comparison among the alternative scenarios. Differences between the various returns streams for each groundwater situation then provided a measure of possible economic effects of the water saving program.

Conclusions and Implications

Numerous relationships between existing conditions within the region and potential impacts of the proposed water saving option were developed. These include the following:

1) Net returns and total acreage vary directly with total water availability with the more profitable crops commanding first call on limited water supplies. Regional demand for surface water was derived and shown to be downsloping as well as dependent upon the availability of groundwater. Such demand relationships also provide a schedule of minimum bid prices required to transfer water to possible alternative uses or to other producers.
2) Groundwater availability was found to be critical to the welfare of the region, allowing flexibility in irrigation timing as well as increasing total water available in years of small surface allocations. Pumping costs, however, exceed costs of acquiring surface water and in scenarios allowing 3 acre-feet of groundwater pumping; pumping costs are a major determinant of regional net returns. Groundwater availability, in turn, is dependent upon recharge from river flow and will likely decline with implementation of the water saving option. Additional research concerning the interrelationship of these two variables is needed.
3) If the water saving option is utilized, average surface water usage falls due to evaporation losses. Average groundwater usage increases as producers elect to pay the extra cost to pump groundwater this year to have additional surface water in subsequent years where its marginal value product exceeds the income foregone in the current year. Increased groundwater use will be complicated by decreased availability due to reduced river flow. Net returns is this case will lie somewhere between the the two boundary values obtained for the 1 and 3 acre-foot groundwater scenarios.
4) Both saved water and water normally lost in transportation were taken into consideration in the calculation of increased lake levels and the resulting annual evaporation coefficients. These coefficients were found to vary relatively little with the amount of water saved, although increasing slightly as lake volume increases more rapidly than surface area for increasing lake levels.
5) Under the conditions of relative uncertainty for the 2 acre-foot maximum usage of surface water, the average quantity of water saved significantly exceeded the optimal amounts saved by the temporal linear program. Evaporation losses for this scenario were also the greatest of any case examined. For the 1 acre-foot groundwater case, the absolute number of saving activities exceeded that of the optimal temporal solution as well.
6) Comparison of the time-valued net returns per acre per year for the 2 acre-foot surface water limitation and optimal temporal surface water allocation scenarios against those for the actual allocation provided a measure of possible benefits of the water saving program. For the 3 acre-foot groundwater case, the water saving

option yielded a slight increase in total water usage with small increases in net returns per acre per year for both the 2 acre-foot surface limitation and optimal temporal scenarios. It is doubtful that these increases in returns would be large enough to cover anticipated administrative costs of the proposed program.

The small differences between actual returns and those for the optimal temporal surface water allocation scenario could prompt several possible interpretations. One such interpretation might conclude that the current allocation process has allocated water in a near optimal fashion in terms of timing. That is, given a fixed amount of water and the region's water delivery system, the actual historical allocations have resulted in almost the same time valued net returns as would an optimal allocation system (the linear temporal programming model) having perfect knowledge of future water availability and evaporation rates. This, of course, assumes that the static linear program model provides reasonable estimates of the net returns and cropping patterns that would actually occur given historical surface water allocations. A second possibility is that policies such as appropriation of uncalled water as well as the prohibition of water sales outside the irrigation district have encouraged some waste. Producers might have a buffer quantity of water above that required for near optimal net returns. If the latter case prevails, no such statement concerning the near-optimality of historical allocations applies. Interpretations aside, the small differences in returns do indicate that use of the water saving option with relatively unlimited groundwater pumping would not be an attractive alternative.

Possible improvements in the water delivery and water measurement system might also make better use of the region's available surface water. The El Paso County Irrigation District to the south, which also draws water from Elephant Butte Reservoir, recently has made greater use of water meters at the farm headgate as well as concrete delivery ditches. Delivery efficiency to the farm headgate has improved from a past high of 51 % to one of 65 % in 1982 (Fifer). Approximately one-third of the delivery ditches in that district have been concreted, with areas having greater seepage problems receiving attention first. Similar measures in the Elephant Butte Irrigation District could be one means of improving water use efficiency there as well.

Model Limitations

Use of linear programming techniques has both advantages and disadvantages in analyses of this type. Their use in modeling profit maximizing behavior does have considerable merit, but several of the particular aspects of farming practiced in the region are not readily expressed in such a model. The production of vegetables is historically both an expensive and risky endeavor. Lettuce producers in the region can consistently produce yields of 800 to 900 cartons per acre, yet lack of market demand at harvest often results in significant acreage being plowed under (Libbins). This results in part from producer's success or failure in matching a ten-day to two-week lull in the lettuce market nationwide (Cornforth and Lacewell). Vegetable growers operating in such an environment of uncertainty might be forced to finance several year's losses in pursuit of large profits for a subsequent year. Incorporating into the model the marketing techniques and strategies accompanying this inherent market and price risk is generally not possible. Numerous possible cropping rotation schemes, both within a given year and over several years, are also used in the region. The number of alternatives as well as the single year nature of the static model preclude exact representation of such practices.

Another assumption that could affect the static model's cropping patterns and estimated net returns involved water availability on an annual basis. Maximum possible amounts of surface water deliverable as well as groundwater well yields within a given time period were, therefore, not considered.

Despite these possible shortcomings, the model and methods employed do provide a reasonable representation of agricultural practices and water demand/use in the region of study. Their subsequent use as a useful tool in evaluating possible benefits of the proposed water saving program is valid, with the results indicating that relatively little improvement in overall net returns would occur given current water availability conditions and that other possible means of improving use of existing water supplies should be explored.

Possible User Limitations

The main difficulty encountered by producers utilizing a water accumulation or saving plan is in deciding whether to save a portion of this year's allocation, and if so, how much? Reliable forecasts of weather conditions several months in advance are obviously unavailable. One viable alternative is an a priori decision to limit surface water usage to some constant amount, saving a portion when possible for use in later years. The cutoff value for each producer using such an option might vary with the particular crops grown. The 2 acre-foot surface water limitation scenario examined is one example of use of such a decision rule. As shown, such a strategy could yield increased net returns under conditions of limited groundwater availability. If a relatively large number of producers exercised such an option, available supplies of surface water currently transferred among water rights holders in the district could be significantly reduced. Producers growing water intensive crops could then be forced to bid up prices for the remaining surface water available for transfer, moving up the demand curve for surface water noted earlier (Figure 3) to protect fixed and variable investments in enterprises such as established alfalfa fields, pecan groves, or high valued vegetables. The presence of a large number of acres of water intensive or high value crops would then be a deterrant to water saving, even for a particular producer not involved in their production. Farmers producing less water intensive crops would prefer to transfer water to those users requiring greater amounts of water, exchanging that water for current income in lieu of returns on their own crops later. Long run cropping adjustments in the region are not known, but some reduction in water intensive crop production could very likely take place as producers adjust to the production possibilities and water use levels possible under the water saving option.

Possible Limitations to Irrigation District

Under the current system of surface water allocation, any uncalled allocated water remaining in the reservoir on December 31st is reappropriated by the Bureau of Reclamation for use in the next year's allocation. All water users in each irrigation district benefit from such a policy at the expense of the individual. Water conservation is therefore implicitly discouraged, and such a policy may very well promote overwatering of some crops in lieu of letting water go on downstream or remain in the resevoir to be appropriated for later year's allocations among all those with water rights.

The irrigation district would also be required to keep additional records reflecting each producer's current saved water balance net of evaporation losses. Calculation of those evaporation losses would most likely entail charging producers for evaporation on saved water incurred during the period stored and adding some additional amount to account for increased evaporation losses on the current year's allocation. Increased lake levels due to the presence of saved water and longer periods of storage for portions of the current year's allocation would contribute to these increases. Saved water would generally be used earlier in the year to lessen evaporation loss, therefore causing delayed use and increased exposure during the hotter summer months for portions of the current year's allocation. Coefficients expressing annual evaporation losses were used within this particular analysis for purposes of estimating these combined evaporation losses. A procedure similar to that described above or some other approach should be used by the irrigation district to accurately reflect the total evaporation losses occuring due to use of the water saving option.

Considerations would also have to be made concerning water lost to transportation. As mentioned in Appendix B, historical evidence suggests that approximately 1 acre-foot of water is absorbed by the river bed and delivery ditches for each acre-foot delivered to the farm headgate. This transportation water would also be held in the reservoir if saving occurred. Neither saved water nor its accompanying transportation water should be considered for use by the Compact Commission and irrigation district when deciding on the current year's allocation. Presence of the water noted above and its effect on evaporation should be taken into consideration, however. The situation would be complicated even further since the required amount of transportation water could change over time. Increased groundwater pumping accompanying use of the water saving option might very well increase the proportion of water absorbed in transport. Better knowledge concerning the relationship between river flow, groundwater pumping, and the resulting absorbtion rate of the river bed and delivery channels might be required to properly decide on future surface water allocations.

Additional topics of concern include physical and political feasibility of the proposed project. Three irrigation districts currently draw water from the reservoir, with the Elephant Butte Irrigation District's southern counterparts being the El Paso County Water Improvement District Number 1 and the Juarez Valley Irrigation District in the Republic of Mexico. Logistical considerations imply that adoption of the program by one district could be dependent upon acceptance by all three. Delivery of saved water through a non-participating district could prove difficult in years of below normal surface allocations.

The ramifications of a possible reservoir spillover should also be noted. The state of Colorado currently owes approximately 500,000 acre-feet of water to the Rio Grande at New Mexico's northern border (Gilmer). The state of New Mexico also owes slightly less than 200,000 acre-feet to Elephant Butte Reservoir. In the event of a spillover, Compact regulations provide that both debts would be cancelled. Exact response of the numerous parties involved to the possibility of such a cancellation varies, emphasizing that the increased probability of a spillover if several irrigation districts participate in the water saving program should also be taken into consideration.

The analysis presented herein considers only the economic feasibility of the proposed water saving program. Adoption of such a program would also have interstate and international implications. Existing state, federal, and international legislation would have to be considered, as well as the current agricultural goals of the parties involved before the necessary legislation and policy changes required for implementation could take place. Such agreement might simply be impossible to attain given the great number of possible points of conflict among the states of New Mexico, Texas, and the Republic of Mexico. These potential obstacles, coupled with the relatively small increases in returns generated by the proposed water saving program under current water availability conditions, support the assertion that alternative means of bringing about more efficient water use should be explored.

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APPENDIX A

Selected Parametric Linear Program Results

Table A-1. Marginal Value Product of Surface Water for Varying Groundwater Situations

Surface Water Usage (acre-feet-acre)	Marginal Value Product (dollars)		
	3 Acre-Foot Groundwater Case	1 Acre-Foot Groundwater Case	No Groundwater
3.	4.24	4.24	17.03
2.96	4.24	14.41	17.03
2.93	4.24	15.69	17.03
2.91	4.24	15.69	17.03
2.83	4.24	15.69	17.03
2.75	4.24	15.69	17.03
2.67	4.24	15.69	17.03
2.66	4.24	17.03	17.03
2.58	4.24	17.03	17.03
2.50	4.24	17.03	17.03
2.41	4.24	17.03	17.03
2.333	4.24	17.03	17.03
2.33	4.24	17.03	24.51
2.27	4.24	17.03	103.53
2.25	4.24	17.03	103.53
2.16	4.24	17.03	103.53
2.08	4.24	17.03	103.53
2.00	4.24	17.03	103.53
1.916	7.35	20.13	106.64
1.914	7.35	20.13	190.96
1.83	7.35	20.13	190.96
1.75	7.35	20.13	190.96
1.67	7.35	20.13	190.96
1.63	7.35	20.13	342.50
1.58	7.35	20.13	
1.58	7.35	20.13	
1.41	7.35	20.13	
1.33	7.35	20.13	
1.33	7.35	27.61	
1.27	7.35	106.63	
1.25	7.35	106.63	
1.16	7.35	106.63	
1.08	7.35	106.63	
1.00	7.35	106.63	
.96	17.52	106.63	
.93	18.79	106.63	
.916	18.79	106.63	
.914	18.79	194.06	
.83	18.79	194.06	
.75	18.79	194.06	
.66	18.79	194.06	
.65	20.14	194.06	
.63	20.14	345.6	
.58	20.14		
.50	20.14		
.41	20.14		
.33	20.14		
.25	20.14		
.16	20.14		
.08	20.14		
0.0	20.14		

Table A-2. Net Returns Schedule for Alternative Surface Water Allocations Assuming a Three Acre-Foot Groundwater Limitation

Surface Water (acre-feet)	Ground Water (acre-feet)	Net Returns	Total Income	Acreage Farmed (acres)
3.0	.9568	$4,243,425	$77,756,327	94,072
2.92	1.04	$4,211,311	$77,756,327	94,072
2.83	1.123	$4,179,199	$77,756,327	94,072
2.75	1.206	$4,147,085	$77,756,327	94,072
2.66	1.29	$4,114,973	$77,756,327	94,072
2.58	1.373	$4,082,860	$77,756,327	94,072
2.5	1.456	$4,050,747	$77,756,327	94,072
2.41	1.54	$4,018,634	$77,756,327	94,072
2.33	1.623	$3,986,521	$77,756,327	94,072
2.25	1.706	$3,954,409	$77,756,327	94,072
2.16	1.79	$3,922,296	$77,756,327	94,072
2.08	1.873	$3,890,183	$77,756,327	94,072
2.0	1.956	$3,858,069	$77,756,327	94,072
1.92	2.04	$3,802,488	$77,756,327	94,072
1.83	2.123	$3,746,906	$77,756,327	94,072
1.75	2.206	$3,691,325	$77,756,327	94,072
1.67	2.29	$3,635,744	$77,756,327	94,072
1.58	2.37	$3,580,162	$77,756,327	94,072
1.50	2.45	$3,524,581	$77,756,327	94,072
1.42	2.54	$3,468,999	$77,756,327	94,072
1.33	2.62	$3,413,418	$77,756,327	94,072
1.25	2.706	$3,357,836	$77,756,327	94,072
1.16	2.79	$3,302,255	$77,756,327	94,072
1.08	2.873	$3,246,674	$77,756,327	94,072
1.0	2.956	$3,191,092	$77,756,327	94,072
.95	3.0	$3,162,298	$77,756,327	94,072
.92	3.0	$3,107,286	$77,344,987	92,502
.91	3.0	$3,097,838	$77,138,366	92,343
.83	3.0	$2,944,776	$74,031,643	89,955
.75	3.0	$2,813,713	$70,924,921	87,567
.67	3.0	$2,671,651	$67,818,199	85,179
.652	3.0	$2,646,851	$67,275,850	84,762
.58	3.0	$2,521,217	$66,357,795	82,888
.5	3.0	$2,369,014	$65,245,578	80,618
.42	3.0	$2,216,810	$64,133,360	78,349
.33	3.0	$2,064,606	$63,021,143	76,079
.25	3.0	$1,912,403	$61,908,930	73,809
.167	3.0	$1,760,199	$60,796,708	71,540
.083	3.0	$1,607,995	$59,684,491	69,270
0.0	3.0	$1,455,784	$58,572,218	67,000

Table A-3. Net Returns Schedule for Alternative Surface Water Allocations Assuming a One Acre-Foot Groundwater Limitation

Surface Water (acre-feet)	Net Returns	Total Income	Acreage Farmed (acres)
3. [a]	$4,243,424	$77,756,327	94,072
2.956	$4,226,789	$77,756,327	94,072
2.922	$4,181,526	$77,344,987	92,502
2.916	$4,173,637	$77,138,306	92,343
2.83	$4,055,042	$74,031,576	89,955
2.75	$3,936,448	$70,924,846	87,567
2.67	$3,817,855	$67,818,115	85,178
2.652	$3,797,155	$67,275,850	84,762
2.583	$3,690,889	$66,357,762	82,888
2.5	$3,562,154	$65,245,542	80,618
2.416	$3,433,418	$64,133,322	78,348
2.33	$3,304,683	$63,021,102	76,079
2.25	$3,175,948	$61,908,889	73,809
2.167	$3,047,213	$60,796,671	71,539
2.083	$2,918,477	$59,684,454	69,270
2.0	$2,789,740	$58,572,218	67,000
1.916	$2,637,536	$57,459,997	64,730
1.833	$2,485,332	$56,347,777	62,460
1.75	$2,333,128	$55,235,557	60,191
1.67	$2,180,924	$54,123,337	57,921
1.583	$2,028,720	$53,011,116	55,651
1.5	$1,876,516	$51,898,896	53,381
1.416	$1,724,312	$50,786,676	51,111
1.333	$1,572,108	$49,674,456	48,841
1.330	$1,566,752	$49,635,322	48,762
1.276	$1,165,328	$48,608,184	47,118
1.25	$ 913,628	$47,577,211	46,527
1.16	$ 107,628	$44,275,810	44,638
1.083	-$ 698,371	$40,974,410	42,749
1.	-$1,504,371	$37,673,009	40,859
.916	-$2,310,370	$34,371,609	38,969
.914	-$2,328,116	$34,298,922	38,928
.833	-$3,762,606	$29,456,602	35,513
.75	-$5,229,390	$24,505,268	32,022
.667	-$6,696,175	$19,553,933	28,531
.638	-$7,184,993	$17,903,857	27,368

[a] Groundwater usage is .956 acre-foot for the three acre-foot surface water allocation, and is 1. acre-foot for all other entries in the schedule.

Table A-4. Cropping Patterns Associated with Alternative Surface Water Allocations Assuming a Three Acre-Foot Groundwater Limitation

Surface Water (acre-feet)	Ground Water (acre-feet)	Crop Acreages[a]					
		Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chile
3. to .956	.956 to 3.	36,000	12,042	822	5,780	3,870	8,190
.922	3.	36,000	10,472	822	5,780	3,870	8,190
.916	3.	36,000	10,393	822	5,780	3,791	8,190
.83	3.	36,000	9,199	822	5,780	2,597	8,190
.75	3.	36,000	8,004	822	5,780	1,402	8,190
.67	3.	36,000	6,810	822	5,780	208	8,190
.652	3.	36,000	6,602	822	5,780	0	8,190
.583	3.	34,126	6,602	822	5,780	0	8,190
.5	3.	31,856	6,602	822	5,780	0	8,190
.416	3.	29,587	6,602	822	5,780	0	8,190
.33	3.	27,316	6,602	822	5,780	0	8,190
.25	3.	25,047	6,602	822	5,780	0	8,190
.167	3.	22,777	6,602	822	5,780	0	8,190
.083	3.	20,507	6,602	822	5,780	0	8,190
0.0	3.	18,238	6,602	822	5,780	0	8,190

[a] Barley, grain sorghum, and red chile acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres, respectively.

Table A-5. Cropping Patterns Associated with Alternative Surface Water Allocations Assuming a One Acre-Foot Groundwater Limitation

Surface Water (acre-feet)	Crop Acreages[a]					
	Cotton	Wheat	Tomatoes	Lettuce	Onions	Green Chili
3.[b]	36,000	12,042	822	5,780	3,870	8,190
2.956	36,000	12,042	822	5,780	3,870	8,190
2.922	36,000	10,472	822	5,780	3,870	8,190
2.916	36,000	10,392	822	5,780	3,790	8,190
2.833	36,000	9,198	822	5,780	2,596	8,190
2.75	36,000	8,004	822	5,780	1,402	8,190
2.67	36,000	6,810	822	5,780	208	8,190
2.652	36,000	6,602	822	5,780	0	8,190
2.583	34,126	6,602	822	5,780	0	8,190
2.5	30,856	6,602	822	5,780	0	8,190
2.416	29,586	6,602	822	5,780	0	8,190
2.33	27,316	6,602	822	5,780	0	8,190
2.25	25,046	6,602	822	5,780	0	8,190
2.167	22,777	6,602	822	5,780	0	8,190
2.083	20,506	6,602	822	5,780	0	8,190
2.	18,237	6,602	822	5,780	0	8,190
1.916	15,967	6,602	822	5,780	0	8,190
1.833	13,698	6,602	822	5,780	0	8,190
1.75	11,427	6,602	822	5,780	0	8,190
1.667	9,158	6,602	822	5,780	0	8,190
1.583	6,888	6,602	822	5,780	0	8,190
1.5	4,619	6,602	822	5,780	0	8,190
1.416	2,348	6,602	822	5,780	0	8,190
1.333	80	6,602	822	5,780	0	8,190
1.330	0	6,602	822	5,780	0	8,190
1.276	0	5,780	0	5,780	0	8,190
1.25	0	5,780	0	5,780	0	7,599
1.16	0	5,780	0	5,780	0	5,710
1.083	0	5,780	0	5,780	0	3,820
1.	0	5,780	0	5,780	0	1,931
.916	0	5,780	0	5,780	0	42
.9148	0	5,780	0	5,780	0	0
.333	0	4,072	0	4,072	0	0
.75	0	2,327	0	2,327	0	0
.667	0	581	0	581	0	0
.638	0	0	0	0	0	0

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[a] Barley, grain sorghum, and red chili acreages are zero, with alfalfa and pecan acreages constant at 15,560 and 11,808 acres respectively.

[b] Groundwater usage is .956 acre-feet for the 3 acre-foot surface water allocation, and is 1 acre-foot for all other entries in the schedule.

APPENDIX B

Evaporation from Elephant Butte Reservoir, New Mexico

Evaporation from Elephant Butte Reservoir, New Mexico

Proper calculation of evaporation losses from an open reservoir required two major components: some measure of water lost to evaporation per unit surface area, and estimates of the everchanging reservoir surface area over time. The methodology used by Cornforth and Lacewell for estimation of evaporation used monthly pan evaporation data in inches (Report of the Rio Grande Compact Commission, 1963-1980). These monthly pan evaporation figures were reduced by 30 percent to account for additional evaporation due to heat convection in the measuring pans. Any rainfall during the month was then subtracted, yielding an estimate for net evaporation losses per acre.

Several factors entered into the calculation of reservoir surface area for a given month within the period under consideration. The context of the analysis allowed potential savings of surface water within the reservoir, raising the lake level and thereby increasing lake surface area and evaporation losses. Historical records (Bureau of Reclamation, 1963-1980) also indicate that for each acre-foot of water actually delivered, approximately one acre-foot of surface water is lost to the river bed and delivery canals. Thus, lake levels and exposed surface area would be even higher if water saving was allowed since water formerly lost to transportation would be held back as well.

Uncertainty concerning the amount of water to be saved in a given year prompted assuming an average of .5 acre-feet of surface water per acre irrigated being held back if saving took place. Thus, a full acre-foot of water was assumed to be held back when water usually lost to transportation was included in the saved portion.

With these points in mind, an additional one acre-foot of surface water (90,700 total acre-feet) was assumed in the reservoir at the end of the usual surface water irrigation season. Area-capacity tables (United States Department of the Interior, 1961-1980) resulting from lake surveys performed in 1961, 1969, 1974, and 1980 provided the necessary relationships among lake level, capacity, and surface area. Capacity values using the two lake surveys closest to the period in question were then calculated using average historical lake levels (Report of the Rio Grande Compact Commission, 1963-1980), and an interpolated value for estimated capacity of the lake at that point in time was obtained. The latter step implicitly assumes that sedimentation and changes in the lake structure occur at a linear rate. The water saved figure (90,700 acre-feet) was then added to the interpolated capacity value to find the estimated capacity of the reservoir with the additional saved water in place. Interpolated values were then obtained for the surface area and lake level, with total evaporation loss for the month calculated as this time-interpolated surface area value multiplied by the adjusted pan evaporation coefficient described above. Percentage evaporation loss for the month could then be calculated as total evaporation loss for the month divided by lake capacity. This percentage loss was then applied to the saved water figure, with the remaining portion serving as the saved water to be added to the subsequent month's time interpolated capacity. This process continued for 12 consecutive month's data for each year, yielding monthly evaporation loss percentages subject to the evaporation adjusted additional water in the reservoir. Annual evaporation coefficients were obtained by taking the product of one minus the monthly evaporation loss percentage for all twelve months. For example, if every monthly evaporation loss percentage were 3 % the annual coefficient would be calculated as $(1-.03)^{12}=(.97)^{12}=.6938$. Thus, the annual evaporation coefficient represents the proportion remaining after a year of evaporation.

In practice farmers would use saved water before any of the current year's allocation on order to minimize evaporation losses. From this viewpoint, annual evaporation coefficients would appear to overcharge producers for water lost. Lake levels have increased as well as absolute evaporation losses, and the annual evaporation coefficients are used to estimate the combined evaporation losses occuring on saved water as well as the increased losses on the current year's allocation due to saving.

Additional calculations were made concerning the effect of the average .5 acre-feet of surface water saved assumption. Annual coefficients were also calculated assuming zero, .25, .50, .75, and 1.0 acre-feet of surface water were saved for respective totals of zero, .5, 1.5, and 2 additional acre-feet of surface water being held in the reservoir when water usually lost to transportation was included. The resulting annual evaporation coefficients and absolute evaporation losses on the non-transportation saved water appear in Table B-1. Annual coefficients are fairly robust, varying from less than 1 to a maximum of 9 percentage points. Note that within a given year evaporation coefficients increase (percentage lost to evaporation falls) indicating that lake capacity increases more rapidly than surface area as lake level rises. Absolute evaporation losses increase, however, due to the increased surface area. The relative constancy of the coefficients for varying amounts of water saved indicates that the average amount of water saved assumption used in the analysis (.5 acre-feet per acre) does not detract from the reliability of the overall analyses results.

Table B-1. Annual Evaporation Coefficients and Losses from Water Accumulation (Savings) under Varying Average Water Accumulation Assumptions

	Water Saved (acre-feet/acre)[a]								
	0.0	.25		.5		.75		1.0	
Year	Coefficient[b]	Coefficient[b]	Water Lost[c] (acre-feet)	Coefficient[b]	Water Lost[c] (acre-feet)	Coefficient[b]	Water Lost[c] (acre-feet)	Coefficient[b]	Water Lost[c] (acre-feet)
1963	.7170	.7475	5,725	.7700	10,431	.7872	14,475	.8006	18,086
1964	.7605	.7823	4,936	.7979	9,165	.8099	12,931	.8200	16,326
1965	.8406	.8478	3,451	.8541	6,617	.8595	9,557	.8643	12,308
1966	.7880	.8014	4,503	.8126	8,499	.8224	12,081	.8307	15,355
1967	.8023	.8150	4,195	.8263	7,877	.8359	11,163	.8434	14,204
1968	.8310	.8388	3,655	.8459	6,988	.8524	10,040	.8581	12,870
1969	.8352	.8430	3,560	.8499	6,807	.8556	9,823	.8602	12,680
1970	.7628	.7817	4,950	.7958	9,260	.8074	13,102	.8166	16,634
1971	.7853	.8042	4,440	.8194	8,186	.8312	11,483	.8408	14,439
1972	.8781	.8820	2,675	.8855	5,192	.8884	7,592	.8910	9,886
1973	.8506	.8542	3,306	.8573	6,471	.8603	9,503	.8630	12,426
1974	.8644	.8695	2,959	.8741	5,710	.8779	8,306	.8811	10,784
1975	.8518	.8568	3,247	.8610	6,304	.8647	9,204	.8679	11,981
1976	.8171	.8302	3,850	.8413	7,197	.8502	10,190	.8573	12,943
1977	.7665	.7854	4,866	.8013	9,011	.8145	12,619	.8252	15,854
1978	.8580	.8657	3,045	.8725	5,782	.8784	8,272	.8827	10,639
1979	.8756	.8769	2,791	.8781	5,528	.8792	8,217	.8801	10,875

[a] Multiply number listed by 90,700 to obtain acre-feet of water saved and then by 2 to obtain total amount saved including that held back normally lost to transportation.

[b] Coefficient listed represents proportion remaining after a year of evaporation.

[c] Water lost figure does not include evaporation on transportation water.