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Pricing and Conservation of Irrigation Water in Texas and New Mexico

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ABSTRACT

Two possible policy alternatives for management of limited water supplies in arid portions of Texas and New Mexico were analyzed for economic feasibility. Detailed studies of the potential impact of a water accumulation policy for each of two irrigation districts (El Paso County Water Improvement District No. 1 in Texas, and the Elephant Butte Irrigation District in New Mexico) were undertaken using temporal linear programming techniques. Current cropping practices, soils, groundwater conditions, historical surface water allocations for Elephant Butte Reservoir and evaporation rates were incorporated within the analysis. Estimates of the benefits of accumulation of surplus portions of irrigation district member's annual surface water allocations, with subsequent use of the unevaporated portion in later years, were deemed insufficient to cover anticipated administrative costs of implementing the proposed policy. This suggests current allocations approximate a temporal optimum. Sensitivity analyses showed greater potential benefits, however, if current groundwater conditions worsen.

Additional analysis of possible price-induced water conservation for the areas within the two states currently mining groundwater from the exhaustible Ogallala aquifer was also undertaken. The High Plains of Texas served as the representative region of study, with results assumed to be analogous for the portions of Eastern New Mexico relying on the Ogallala. Both static and temporal effects of a per unit tax on water pumpage and net returns were examined using a recursive linear programming model. Results indicated that imposition of a $20 per acre-foot tax on water pumped induced very little change in water use over a 40 year period, while reducing the present value of producer net returns from 9% to 27% depending upon initial groundwater conditions and the irrigation technology in use. These results imply that a price induced water conservation policy for the Ogallala is not economically justified.

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Introduction

The increasing population, industrial growth and energy development are placing serious new demands for the limited water supplies, particularly in the West. With more users each demanding more water, efficiency becomes a critical issue. Since agriculture accounts for about 88 percent of western water consumption, it represents the greatest opportunity for improving efficiency of water use (Frederick and Hanson, 1982).

Technical and Economic Efficiency

However, to address the issue of efficient use of water in agriculture some clarification of terms is needed (Lacewell, 1982). Of particular interest here is technical efficiency and economic efficiency. Technical efficiency is defined by Heady (1965, p. 97) as "the magnitude of the physical ratio of product output to factor input" or average output per unit of input. For irrigation, there is the technical efficiency of pumping where groundwater is used and includes efficiency of the engine to deliver water horsepower per unit of fuel and the pump to deliver water to the land surface. Actual technical efficiency of pumping plants is often far below that which is feasible.

There is also a technical efficiency associated with the distribution and use of irrigation water. Distribution efficiency relates to the amount of water placed in the root zone relative to total amount applied and uniformity of the application across a field. Lastly, references are made to average crop yield per unit of water as a measure of technical efficiency of irrigation. Basically, technical efficiency is to obtain maximum output from a set of inputs including a given level of irrigation water application. To increase average crop yield for a specified level of irrigation water pumped would be to increase technical efficiency. However, average crop yield per unit of water can be increased by reducing the water application rate and may or may not be desirable. This method of increasing average crop yield per unit of water pumped should not be confused with maximizing yield from a specified level of inputs.

Economic efficiency is denoted when resources are used in a manner to maximize the particular objective of the economic unit; i.e., typically profit for the farm firm (Heady, 1965). This means the farmer or any other business will have an incentive to use water to the point where their cost of one additional unit is equal to the value of that additional unit of water in the production of a good (crop or steel or whatever). When resources such as water are limited, the economic efficient allocation of the resource is where the value of the last unit of water used across all users (agricultural and non-agricultural) is equal. This defines economic efficiency.[1] As costs of water or products produced adjust, the economic efficient level of water use adjusts. There is, of course, a relationship between technical and economic efficiency; i.e., with crop yield response to alternative irrigation water quantities established, the economic efficient level of water use can be addressed given crop prices and water costs.

Thus, for economic efficiency of water use it is important that market signals be transmitted and appropriate resource allocations enhanced. Private enterprise responds to the price system. A study of irrigation

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[1]There may be costs in some uses not incurred by the user such as quality deterioration. This is a cost to society and involves market failure. To include this cost requires intervention such as a tax to internalize the cost to the user or legal regulations or other such measures.

conservation incentives determined that farmers have adopted water conservation measures for generations with their motivation virtually totally economic (Sonnen, Dendy and Linstrom, 1980). All conservation practices in irrigation that are economic have been adopted. As economic conditions adjust and market forces act, there may be incentive to adopt more irrigation conservation practices in the future.

Relative to efficient use of water, agricultural and non-agricultural users respond to economic conditions. Thus, given the cost of water in the West, it is currently being used in an economically efficient manner from the user's perspective. Distortions from a social standpoint involve subsidies which lowers the cost of water to a user thus providing incentive to use a relatively larger quantity, institutions which arbitrarily allocate water to a specific use without regard to overall market forces and/or third party effects associated with use of water (externalities).

Western Agricultural Water Use

Over 80 percent of the U.S. irrigated acres are in the West. About 88 percent of Western water use is for irrigation on these acres. Of this, 61 percent of the irrigation water comes from surface sources and 39 percent is groundwater (Frederick and Hanson, 1982).

Acreage irrigated from groundwater in 1977 was estimated at 25.8 million. This was up from 22.3 million in 1974 (Sloggett, 1979). Estimated groundwater pumpage in 1975 was 56 million acre feet (Frederick and Hanson, 1982). On the average, this suggests that about 2.2 acre feet of water are pumped for each acre irrigated. The Northern and Southern Plains have over twice the irrigated acres as the rest of the West yet apply less total groundwater than all other Western Regions; i.e., 67 percent of the acreage uses 40 percent of the water. Groundwater use per acre is about 1.3 feet in the Great Plains compared to 4 feet in the mountain and Pacific regions.

An indication of the growth in irrigation from groundwater sources is reflected in annual pumpage rates. For the 17 Western states, annual groundwater pumpage rates have increased from 18.2 million acre feet in 1950 to 56 million acre feet in 1975. This is a 208 percent increase for the West in total. The Northern Plains increased from .8 to 11.2 million acre feet (1300 percent increase). The Southern Plains increased from 1.9 to 11.1 million acre feet, or 484 percent. This is compared to a 174 percent increase in the Mountain Region and 87 percent increase in the Pacific Region (Frederick and Hanson, 1982).

Irrigation from groundwater is primarily by gravity flow (flood or surface irrigation). About 62 percent of the acres are irrigated by gravity flow, 16 percent with center pivot and 21 percent with other sprinkler as side-roll. The percent of acres irrigated by sprinkler in 1977 was 40 for the Northern Plains, 26 for the Southern Plains, 45 for the Mountain Region and 43 for the Pacific Region (Sloggett, 1979).

The characteristics of the aquifers containing groundwater are highly diverse. They vary relative to depth to the static water level, depth to the base of the aquifer, relation to surrounding formations, and specific yield. Throughout the West, mining of groundwater (extracting more than is recharged) exceeds 22 million acre feet per year (Sloggett, 1981). Groundwater mining, alternative uses, and rising energy costs pose serious questions as to the long term outlook for irrigation from groundwater in the West. Major issues of groundwater use include (1) mining of groundwater, (2) relationships between ground and surface water, and (3) impairment of groundwater quality (National Water Commission, 1973).

Value of Irrigation

In the arid and semi-arid West, irrigation contributes significantly to the value of agricultural production. In 1978, 24 percent of the value of marketings from all cropland and rangeland in the U.S., came from irrigated land. Irrigated cropland was only 14 percent of total acreage harvested in 1978 yet produced $26 billion of products (U.S. Department of Commerce, 1981). Of the total value of crops and forest products sold in 1974, the proportion from irrigated lands was more tha 90% in Arizona, California, Nevada and New Mexico; 80 percent to 90 percent in Idaho, Utah and Wyoming; and 60 percent to 80 percent in Colorado, Nebraska, Oregon, Texas and Washington (CAST, 1982).

Young (1982) outlined benefits of irrigation at a symposium on irrigation in the West. The benefits of irrigation is also defined as the decrease in profit to the producer in the absence of irrigation compared to producer profit with irrigation. Young (1982) updated to 1982 dollars estimates derived by Frank and Beattie (1979). The results indicate that the value of irrigation at the margin is $10-$15 per acre foot in the intermountain valley (Upper Colorado and Snake River Basin), $20-$25 in the desert Southwest and central California, and $40-$45 per acre foot in the Ogallala groundwater region of the High Plains. According to Young (1982), estimates reported by Howitt, et al. (1982) and Gollehon, et al. (1981) are very similar to those of Frank and Beattie (1979).

Objectives

This introduction indicates the magnitude of irrigation water use in the West and the associated monetary value. Irrigation is the major water user in the West and contributes significantly to agricultural output and state and regional economics. Thus, improved efficiency of water use in agriculture needs to be addressed in an economic context. The overall purpose of this study was to evaluate the economic implications of accumulation policy for surface reservoirs and pricing to achieve water conservation from groundwater.

This study was designed to provide a detailed case study for the El Paso County Water Improvement District and for the Elephant Butte Irrigation District relating to the effect of accumulation of water in Elephant Butte Reservoir. Further, the study included a detailed case study for the Texas High Plains relating to the expected effects of price-induced water conservation. Specific objectives are as follows:

1. estimate the benefits to an individual from accumulating water in a reservoir in surplus years for use in deficit years.
2. develop a program for the water district to implement an accumulation option and provide appropriate incentives to the water users in the district.
3. estimate the expected impact of a tax on groundwater (conservation pricing) for the Texas High Plains as related to water use, cropping patterns, farm output, regional impact and farmer profit.
4. identify limitations facing the individual and water district of accumulation and conservation pricing.

Report Organization

The research underlying this report is comprised of several separate but related efforts. Since each effort is a separate entity, the report is organized around each. Thus, there are separate major sections (1) El Paso

County Water Improvement District No. 1 in Texas, (2) the Elephant Butte Irrigation District in Dona Ana and Sierra Counties, New Mexico, and (3) conservation pricing of water on the Texas High Plains. Since there are many irrigation management options beyond those addressed in this paper, a short overview of these other alternatives is also provided.

Accumulation in Reservoirs

There is currently consideration for modifying federal surface irrigation water regulations to allow water districts to begin an accumulation policy for its members. Currently any unused water allotment remaining in the reservoir is reallocated among all users in the following year. The proposed carry-over storage or accumulation program would allow agricultural producers in districts adopting the program to store part of a given year's surface water allocation, providing use of the unevaporated portion in a later year. Such a program, properly used, could lessen the current degree of variability in annual surface water allocations and corresponding net returns.

El Paso County Water Improvement District

The results presented herein are quite brief since a very detailed report is available on this study (Cornforth and Lacewell, 1981).

Study Area

This section will focus on that area in El Paso County, Texas which is contained in the El Paso County Water Improvement District No. 1. This area is roughly the flood plain of the Rio Grande River which lies within the county.

The Rio Grande flood plain is about 12 percent of the county area, or approximately 94,000 acres (U.S. Department of Agriculture, Soil Conservation Service, 1971). Of the 49,113 acres of total cropland reported for El Paso County, virtually all were in the Rio Grande flood plain. While 44,801 acres of this cropland were reported harvested, 45,045 acres were reported irrigated (U.S. Department of Commerce, 1977). With an annual rainfall of 7.77 inches per year (The Dallas Morning News, 1979), irrigation is absolutely necessary for the existence of economically viable crop production in the area.

The primary source of irrigation water to El Paso County farmers is from the Rio Grande River. The correct disposition of Rio Grande River waters, according to international treaty and federal law, is the responsibility of the Rio Grande Compact Commission. In dispatching its duty, the Rio Grande Compact Commission receives the assistance and cooperation of the Office of the State Engineer of Colorado, the U.S. Bureau of Reclamation, the U.S. Geological Survey, the U.S. Army Corps of Engineers, and the United Pueblo Agency. The total irrigation project is called the Rio Grande Project.

Irrigation waters are gathered primarily in Elephant Butte Reservoir, New Mexico, although a number of smaller water storage reservoirs exist in the Rio Grande watershed above Elephant Butte Reservoir in both the state of Colorado and New Mexico. Water released from Elephant Butte for irrigation purposes is subsequently delivered to the user by one of three irrigation districts. The first is the Elephant Butte Irrigation District. This district is composed of all irrigated lands in the state of New Mexico and in the Rio Grande flood plain below Elephant Butte Reservoir and above the Texas state line and the international boundary with Mexico.

The El Paso County Water Improvement District No. 1 oversees water deliveries to farmers in the Rio Grande flood plain of El Paso County, Texas. The Juarez Valley Irrigation District delivers up to 60,000 acre feet annually to agricultural producers in the Juarez Valley of the Republic of Mexico. Although it has no water rights, the Hudspeth County Conservation and Reclamation District No. 1 has contracted for residual water arriving at the Hudspeth County line.

Principal crops grown in the area are cotton, wheat, barley, grain sorghum, alfalfa, pecans and various vegetables.

In years of low allotments of Rio Grande River waters, farmers pump additional groundwater to supplement surface water irrigation. This groundwater varies in salinity from 263 to 24,800 milligrams per liter dissolved solids (Meyer and Gordon, 1972). This use of saline groundwater affects yield, management and cultural practices, input usage and costs, soil condition and the quantity of irrigation water required.

Water conservation is a prime concern in the El Paso area. Lansford, Creel and Seipel evaluated alternative water management systems for the Mesilla Valley, New Mexico (the Rio Grande River Valley in New Mexico adjacent to the valley in Texas) which would reduce return flows to the Rio Grande. Similarly, selected El Paso County farmers were interviewed by Sonnen, et al. concerning current and future water conservation practices and incentives to further increase conservation efforts. These farmers indicated they would like to have the option to store part or all of their allocation of Rio Grande River water in Elephant Butte Reservoir, New Mexico, to be used at some future date upon request. This idea of irrigation water carry-over storage is sometimes what is referred to in this paper as "accumulation".

Procedures

The procedure was to first develop a static linear programming model. This static model was comprised of 1182 crop production activities. Production activities were developed for twelve crops on six different soil groups where irrigation was from groundwater with one of six different salinity levels or surface water and either laser land leveling or no laser land leveling. The inputs for these activities came from six input groups -- seed, chemicals, water, machinery, labor, harvest, other and fixed. The model also contained about 100 buy, sell or transfer activities. The model contained 154 rows with constraints on the acreages of soil classes by salinity of underlying groundwater and on the surface water available.

The model was solved for each level of surface irrigation water in which the basic solution changed considering conjunctive use of groundwater. Groundwater pumping was then disallowed and the model was again solved for all levels of surface irrigation water for which the basic solution changed. This resulted in two schedules of solutions for all possible surface water allocations up to three acre feet per acre with and without groundwater pumping.

These schedules were used to build temporal linear programming models to optimize the use of surface irrigation water allocation over the period 1963 to 1980 both with and without groundwater pumping. The models were developed to maximize the real value of net farm returns subject to the actual surface water allocation made in each year and the actual evaporation of stored water in Elephant Butte Reservoir. The results produced two optimal temporal scenarios of surface irrigation water use over the last 18 years, i.e., one considering groundwater pumping and one not including any groundwater pumping. For comparison purposes, four other temporal water use scenarios were included, e.g., the use each year of the actual surface water allocation with and without groundwater pumping and a scenario in which two acre feet are used each year with the surplus stored for years of less than two acre feet allotments with and without groundwater pumping. These scenarios provide the basis for this analysis.

Results

Detailed results relative to cropping patterns, input usage and patterns of water use are available in Cornforth and Lacewell (1981). With more efficient use of surface water supplies, the recharge of groundwater in the study area will decrease. As time passes, limits on groundwater pumping can be expected. Not knowing what these limits may be, this study used the two extreme limits to develop economic implications. These two extremes are no restrictions at all on groundwater pumping and an absolute restriction against any groundwater pumping. With each of these limits imposed the economic implications of accumulation of surface irrigation water for future use was examined.

As a basis of comparison, the actual surface water allocations for 1963 to 1980 were used to determine the annual net farm revenue for 1963 to 1980. This was done for both cases -- groundwater pumping (Table 1) and no groundwater pumping (Table 2). For each actual surface water allocation, the appropriate net farm revenue was determined from the schedule of net farm revenues by surface water allocation for groundwater pumping and for no groundwater pumping. These annual net farm revenues were then adjusted to 1980 dollars by the real interest rate.

The results of the temporal linear programming model were an optimal temporal scenario of net farm revenues and their 1980 real values for 1963

Table 1. Annual Net Farm Revenue and 1980 Real Values for the Actual Surface Water Allocation and the Optimal Temporal and Two Acre Feet Per Acre Scenarios Both with Groundwater Pumping, 1963 to 1980

	Net Farm Revenue			1980 Real 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	6,939,006	6,559,682	6,939,006	15,774,356	14,912,042	15,774,356
1964	5,357,712	5,802,723	5,357,712	11,605,239	12,569,169	11,605,239
1965	6,821,782	6,821,782	6,821,782	14,079,683	14,079,683	14,079,683
1966	7,137,553	6,939,006	6,939,006	14,036,691	13,646,229	13,646,229
1967	6,548,262	6,952,067	6,886,090	12,839,770	12,839,770	12,903,526
1968	6,939,006	6,939,006	6,939,006	12,389,487	12,389,487	12,389,487
1969	7,336,102	7,336,102	6,939,006	12,480,780	12,480,780	11,805,208
1970	7,336.102	6,939,006	6,939,006	11,892,196	11,248,483	11,248,483
1971	6,939,006	6,939,006	6,939,006	10,718,013	10,718,013	10,718,013
1972	5,800,990	6,363,829	6,901,089	8,537,672	9,366,037	10,156,755
1973	7,336,102	7,336,102	6,939,006	10,387,813	10,287,813	9,730,922
1974	7,336,102	7,336,102	6,939,006	9,802,647	9,802,647	9,272,040
1975	7,336,102	7,170,280	6,939,006	9,340,362	9,129,236	8,834,777
1976	7,336,102	6,939,006	6,939,006	8,899,878	9,418,136	8,418,136
1977	6,352,882	6,939,006	6,939,006	7,343,613	8,021,143	8,021,143
1978	5,894,451	6,146,925	6,939,006	6,492,362	6,770,446	7,642,872
1979	7,336,102	7,336,102	6,939,006	7,699,190	7,699,190	7,282,440
1980	7,336,102	7,336,102	6,939,006	7,336,102	7,336,102	6,939,006
Value of Water Stored			901,431			901,431
Total	123,419,446	124,031,834	124,014,188	190,986,570	191,714,409	191,369,768
Coefficient of Variation	9.0704	6.3105	5.4251			
Difference from Actual Allocation:						
Total		613,368	594,722		727,839	383,198
Percentage		.5	.5		.4	.2
Per Acre		12.74	12.38		15.15	7.97
Per Acre Per Year		.71	.69		.84	.44

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

Table 2. Annual Net Farm Revenue and 1980 Real Values for the Actual Surface Water Allocation and the Optimal Temporal and Two Acre Feet Per Acre Scenarios Both Without Groundwater Pumping, 1963 to 1980

	Net Farm Revenue			1980 Real 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	5,843,565	5,843,575	5,843,575	13,284,127	13,284,127	13,284,127
1964	970,410	970,410	970,410	2,101,986	2,101,986	2,101,986
1965	5,431,539	5.431,539	5,431,539	11,210,317	11,210,317	11,210,317
1966	6,886,339	5,843,575	5,843,575	13,542,654	11,491,957	11,491,957
1967	4,366,846	5,542,397	5,666,948	8,182,831	10,385,644	10,619,032
1968	5,843,575	5,843,575	5,843,575	10,433,612	10,433,612	10,433,612
1969	7,331,068	7,044,258	5,843,575	12,472,216	11,984,271	9,941,570
1970	7,331,068	7,044,258	5,843,575	11,884,036	11,419,102	9,472,734
1971	5,843,575	5,843,575	5,843,575	9,027,007	9,026,007	9,027,007
1972	1,940,820	3,311,574	5,721,859	2,856,424	4,873,879	8,421,210
1973	7,331,068	7,047,354	5,843,575	10,280,753	9,882,886	8,194,761
1974	7,331,068	7,047,354	5,843,575	9,795,921	9,416,817	7,808,303
1975	7,331,068	7,044,258	5,843,575	9,333,952	8,968,785	7,440,069
1976	7,331,068	7,039,976	5,843,575	8,893,771	8,540,629	7,089,201
1977	3,639,038	5,843,575	5,843,575	4,206,546	6,754,880	6,754,800
1978	2,183,423	2,919,784	5,843,575	2,404,901	3,215,936	6,436,325
1979	7,331,068	7,331,068	5,843,575	7,693,907	7,693,907	6,132,793
1980	7,331,068	7,331,068	5,843,575	7,331,068	7,331,068	5,843,575
Value of Water Stored			1,068,403			1,058,403
Total	101,597,684	104,323,173	100,669,209	154,935,029	158,015,809	152,770,782
Coefficient of Variation	37.8672	30.1783	20.6666			
Difference from Actual Allocation:						
Total		2,725,489	-928,475		3,080,780	-2,164,247
Percentage		2.7	-.9		2.0	-1.4
Per Acre		56.72	-19.32		64.12	-45.04
Per Acre Per Year		3.15	-1.07		3.56	-2.50

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

to 1980 for both the groundwater pumping (Table 1) and no groundwater pumping options (Table 2). The two acre feet per acre usage scheme was also evaluated. The net farm revenue and 1980 real value scenarios developed in this manner are also included in Table 1 for the groundwater pumping case and Table 2 for the no groundwater pumping case.

Assume that there is no limit on groundwater pumping. The results in Table 1 indicate that both the optimal temporal and the two acre feet per acre scenarios would have generated more total net revenues than the actual allocation did. Also, the net farm revenue streams of the optimal temporal and two acre feet per acre scenarios have less variation than the net farm revenue stream of the actual allocation. The optimal temporal scenario provided $0.84 per acre per year in 1980 dollars above the returns of the actual allocation. The two acre feet per acre scenario provided only about as half as big an increase or $0.44 per acre per year in 1980 dollars. But the two acre foot per acre scenario produced the most stable stream of net farm revenues as indicated by the coefficients of variation in Table 1.

Now assume that absolutely no groundwater pumping is allowed. The results in Table 2 indicate that the optimal temporal scenario would have generated more total net revenues than the actual allocation did. But the two acre feet per acre scenario would have not generated as much total net revenue as the actual allocation. The optimal temporal scenario would have added $3.56 per acre per year in 1980 dollars to total net revenues. The two acre feet per acre scenario would have decreased net farm revenue per acre per year by $2.50 in 1980 dollars below the net revenues of the actual allocation. But, again the two acre feet per acre scenario had the most stable flow of net farm revenues. The optimal temporal scenario also had less variability than the net farm revenue stream of the actual allocation.

With the results in Tables 1 and 2, the range of economic implications of accumulation for the El Paso County Water Improvement District No. 1 has been identified. This range is defined in the knowledge dimension by the optimal temporal (perfect knowledge) and the two acre feet per acre (no future knowledge) scenarios. This range is also defined on the conjunctive groundwater use dimension by the results in Table 1 (no limit) and in Table 2 (no groundwater).

The results of the static model indicate the following conclusions:

1. Red chili is not as profitable as green chili.
2. If vegetables are limited in acreage, upland cotton can successfully compete for more acres than it has historically.
3. Vegetable crops could produce a much higher return per acre than general field crops or pecans.
4. Total groundwater and surface water needed to sustain net farm revenue above $4.719 million range from 2.79 to 3.07 acre feet per acre.
5. Below an annual surface water allocation of 2.25 acre feet per acre, groundwater is extremely important in maintaining net farm revenues.
6. When groundwater is pumped the cropping pattern of the district is relatively constant across alternative surface water allocations.
7. When groundwater is not pumped, the district cropping pattern varies widely in response to surface water allocations.
8. Barley and grain sorghum are less profitable than other field or grain crops based on crop prices used in this analysis.
9. Laser leveling is economically justified initially on high value crops such as vegetables.

10. Laser leveling economic potential is much more important when total available irrigation water is limited.
11. Under the current circumstance of conjunctive groundwater and surface water use, laser leveling does not contribute to net farm revenues on a district wide basis.

The results of the temporal model and the water use scenarios indicate the following conclusions:

1. The optimal temporal allocation of surface water in conjunction with groundwater pumping is the most efficient in terms of evaporation loss.
2. The two acre feet per acre annual surface water use scenario is the least efficient in terms of evaporation loss.
3. Only relatively minor improvements can be made in net farm revenues by optimal conjunctive groundwater and surface water usage or by stabilizing water usage if unlimited groundwater withdrawals can be made.
4. The two acre feet per acre surface water use rate provides the most consistent and stable flow of net farm returns.
5. When groundwater is pumped, crop production and acreages change very little over time.
6. By not permitting groundwater pumping, crop production and acreages and net farm revenues vary dramatically over time.
7. Not permitting groundwater pumping also increases the variability of the levels of required inputs.
8. Temporally optimizing surface water allocation use increases net farm revenue.
9. The optimal temporal scenario for no groundwater pumping increases

net farm revenues more than the optimal temporal scenario allowing groundwater pumping.

Implications

The above conclusions suggest the following implications:

1. Some increase in vegetable production could increase farm net returns but it is likely to increase risk faced by producers.
2. Upland cotton acreage could be profitable beyond its current level at the expense of pima cotton acreage and/or an increase in total cotton acreage.
3. Conjunctive use of ground and surface irrigation water stabilizes net farm revenue, cropping patterns, crop production and input usage. The limits of the aquifer and implications of long term pumping need to be clearly identified.
4. Laser leveling is not necessary to produce maximum net farm revenues for the district, assuming water is not limiting; i.e., unlimited groundwater pumping.
5. Surface irrigation water storage by farmers will add little to net farm revenue as long as large supplies of groundwater exist, but it will help stabilize net farm revenue.
6. Without perfect knowledge of the future, farmers may increase total net farm revenue and stabilize their incomes by adopting a policy of using only two acre feet of surface water per year and storing any remainder with supplementary groundwater pumping.
7. Temporally optimizing surface water use can increase net farm revenues.
8. Temporally optimizing surface water use seems to be much more

important when groundwater pumping is not allowed. That is, if groundwater shortages develop in the future, optimizing surface water use by use of accumulation will be extremely important.

Limitations

The model indicates that vegetables are highly profitable activities. The model cannot take into account the fact that lettuce producers are trying to match a ten-day to two-week lull in the lettuce market. Production areas elsewhere in the nation leave this gap. On the other hand, chili and tomato producers operate under contracts which guarantee a market for their production.

Vegetables are very expensive to produce. Only one out of three or four years do producers usually make a profit. Thus, vegetable producers must be able to finance several bad years in order to receive the profits of a good year. Therefore, vegetable activities in reality may not be nearly as attractive as they appear to the model, and do represent substantial risk faced by the producer.

Laser leveling is new to the study area. Accurate data on input reduction associated with laser leveling has not yet been gathered. There may be yield and quality increases from laser leveling which have not been quantified at this time. As more knowledge is gained about laser leveling and its effects on crops and crop production, laser leveling may well become a necessary operation for profitable crop production in El Paso County. This could be particularly true with groundwater limitations.

The temporal model which optimized water usage over time had perfect knowledge of surface water allocation and evaporation rates. Since the future is unknown, the two acre feet per acre scenario with its more stable flow of net farm revenues may be more realistic. The storage decision is made regardless of any future surface water allocations or evaporation rates.

The level of future surface water allocation is, of course, an unknown. Echlin has done a tree ring study for the Rio Grande above San Marcial, New Mexico. One might conclude from this study that rainfall and consequently the flow of the Rio Grande may be generally increasing and above average for the next forty years. If this turns out to be the case, stored water may simply evaporate in storage, never being needed.

Water in the Southwest is a very precious resource. The city of El Paso is constantly involved in searching for new sources of water as its demands for water continue to grow. The Republic of Mexico does not receive near enough Rio Grande water under treaty to irrigate all of its potential agricultural acreage (U.S. Department of the Interior, Water and Power Resources Service, Southwest Regional Office, 1980). Hudspeth County farmers are now farming with residual Rio Grande River flows and drainage flows from El Paso County as their only sources of surface irrigation water. The quality of groundwater is extremely poor in Hudspeth County (Alvarez and Buckner, 1980). Thus, accumulation and its associated water saving technologies (e.g., laser leveling) will tend to not only decrease or eliminate residual and drainage flows, but to further decrease groundwater availability through reduced recharge. In years of low surface water allocations when the El Paso County farmers have plenty of water from their individual stored accounts, the city of El Paso, the Republic of Mexico, Hudspeth County producers and Elephant Butte District producers without stored water may have the necessary incentive to push for, and possibly succeed in, changing the state, federal and international laws which govern the water of the Rio Grande. In this case, those who have more water, the El Paso County farmers, would lose water to those who have less, everyone else. This and other institutional factors make water issues in the region most complex.

Any analytical model like the one developed in this study cannot make subjective judgments. Marketing techniques and strategies with their associated risks and possibilities cannot be included. The model works on knowledge and data and, therefore, does not include any consideration of uncertainty of the future. The model is also apolitical and does not account for the political ramifications of the results. But, despite these shortcomings, the model does efficiently and effectively evaluate the information provided it. This provides a basis for evaluating a policy such as impact of water accumulation in Elephant Butte Reservoir.

Elephant Butte Irrigation District

This phase of the study followed closely that done for the El Paso County Water Improvement District. Again the results are greatly abbreviated since a detailed published report is available (Ellis, Teague and Lacewell, 1982).

Study Area

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, respectively (Pedde, 1981). 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 Crop and Livestock Reporting Service, 1976-1980).

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, 1976-80). 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.

International treaty and federal law specify that 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 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, similar soil series were combined (U.S. Department of Agriculture, Soil Conservation Service, 1980). 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 were developed from data in New Mexico Agricultural Statistics (1976-80) and Cornforth and Lacewell (1981). Pertinent crop budget coefficients (Libbin, et al., 1980) were also used in the LP formulation.

Upper bound constraints were placed on all vegetable crop acreages due to brokerage restrictions on production (Libbin,1981). 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 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.

Temporal 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, 1981). 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, 1982).

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 (U.S. Dept. of the Interior, 1961-1980, and Cornforth and Lacewell, 1981). Surface water is allocated separately by the Elephant Butte Irrigation District for the Mesilla and Rincon valleys, and the figures 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.

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 percent 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

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. Corresponding returns 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. Detailed results such as cropping patterns are available in Ellis, Teague and Lacewell (1982).

Average returns per year for the 3 acre-foot per acre groundwater situation (Table 3) 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 percent 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 4) increased from

Table 3. 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%

[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.

$1,440,639 to $2,219,517 for the optimal temporal surface water allocation scenario for an improvement of 54 percent. For the 2 acre-foot per acre surface water limitation, average annual net returns increased 32.5 percent 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 1 and 2 for the 3 and 1 acre-foot groundwater situations. Returns for the actual surface water allocation are seen to vary more in both graphs than for either of the other two scenarios examined. Coefficient of variation values (Tables 3 and 4) also attest to the greater stability of returns with the water saving option in place. The number of years with negative returns for the 1 acre-foot groundwater situation decreased by 66 percent 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.

Relative product and input prices were assumed constant over time within the linear programming model used to derive the various returns schedules. Therefore, water availability as well as the relative

Table 4. 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.

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 1 through 8 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 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

The portion of 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

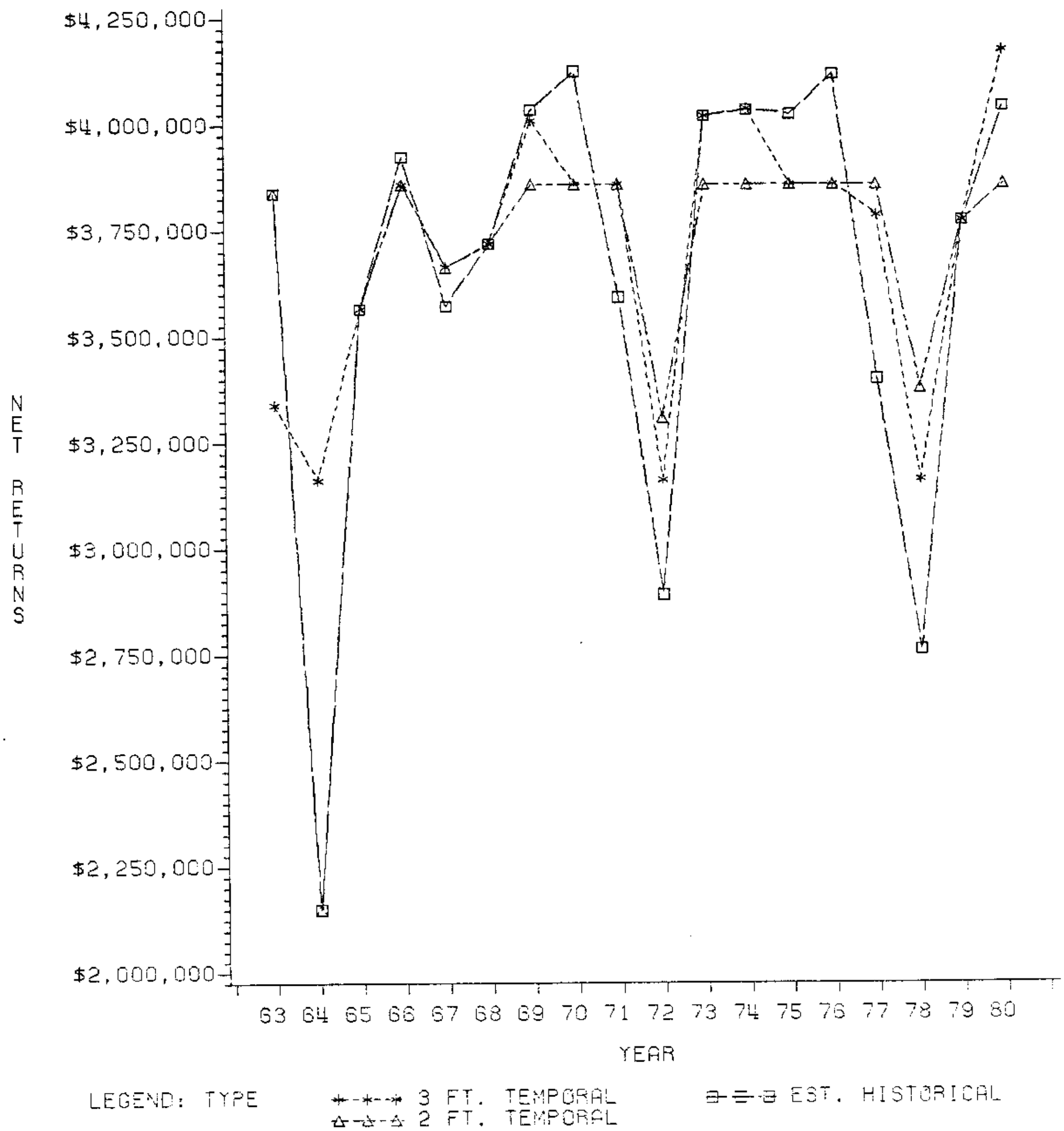


Figure 1. Regional Net Returns for Optimal Temporal, Two Acre-Foot Surface Water Limitation, and Actual Allocation Scenarios, Elephant Butte Irrigation District

(3 acre-foot groundwater limitation)

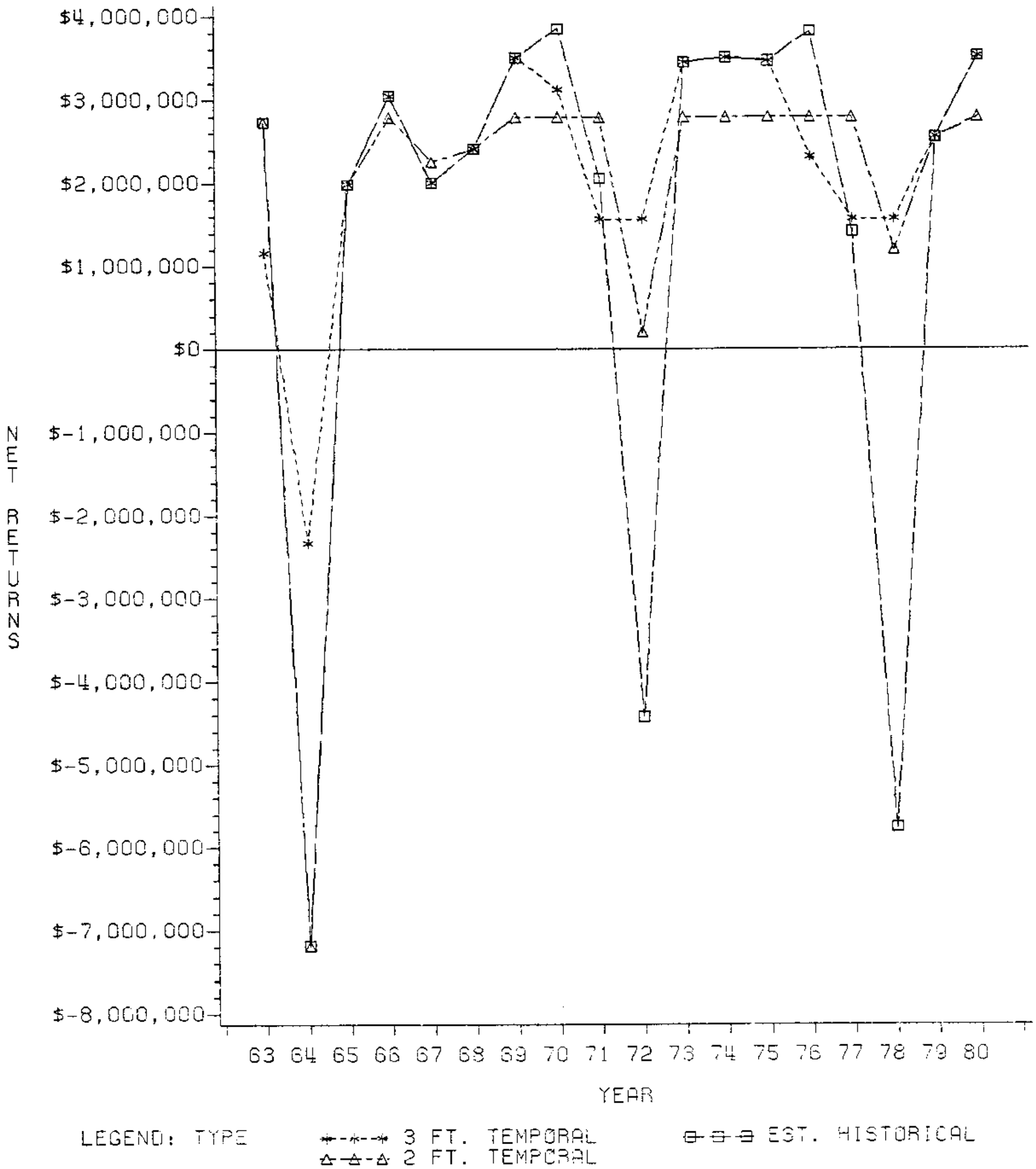


Figure 2. Regional Net Returns for Optimal Temporal, Two Acre-Foot Surface Water Limitation, and Actual Allocation Scenarios, Elephant Butte Irrigation District

(1 acre-foot groundwater limitation)

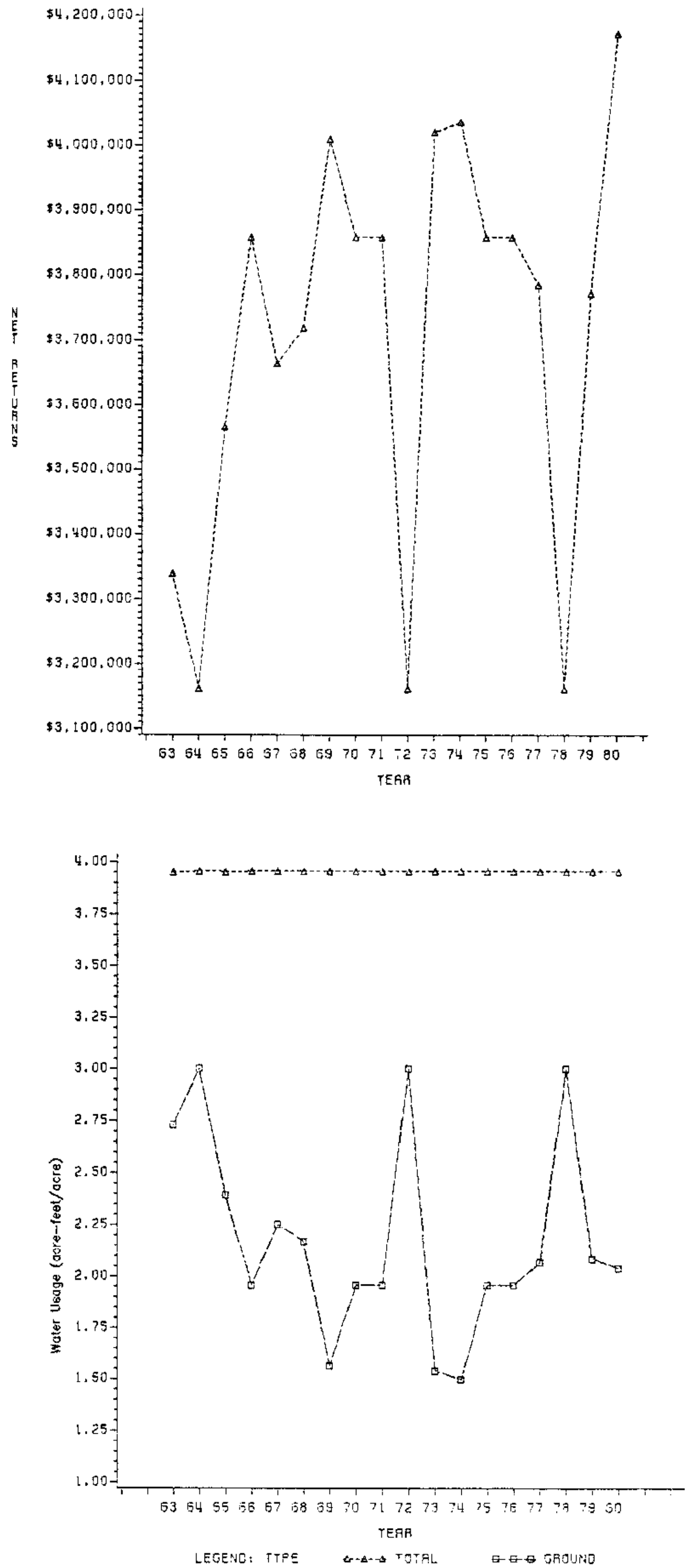


Figure 3. Net Returns and Water Usage with Optimal Temporal Allocation of Surface Water, Elephant Butte Irrigation District

(3 acre-foot groundwater case)

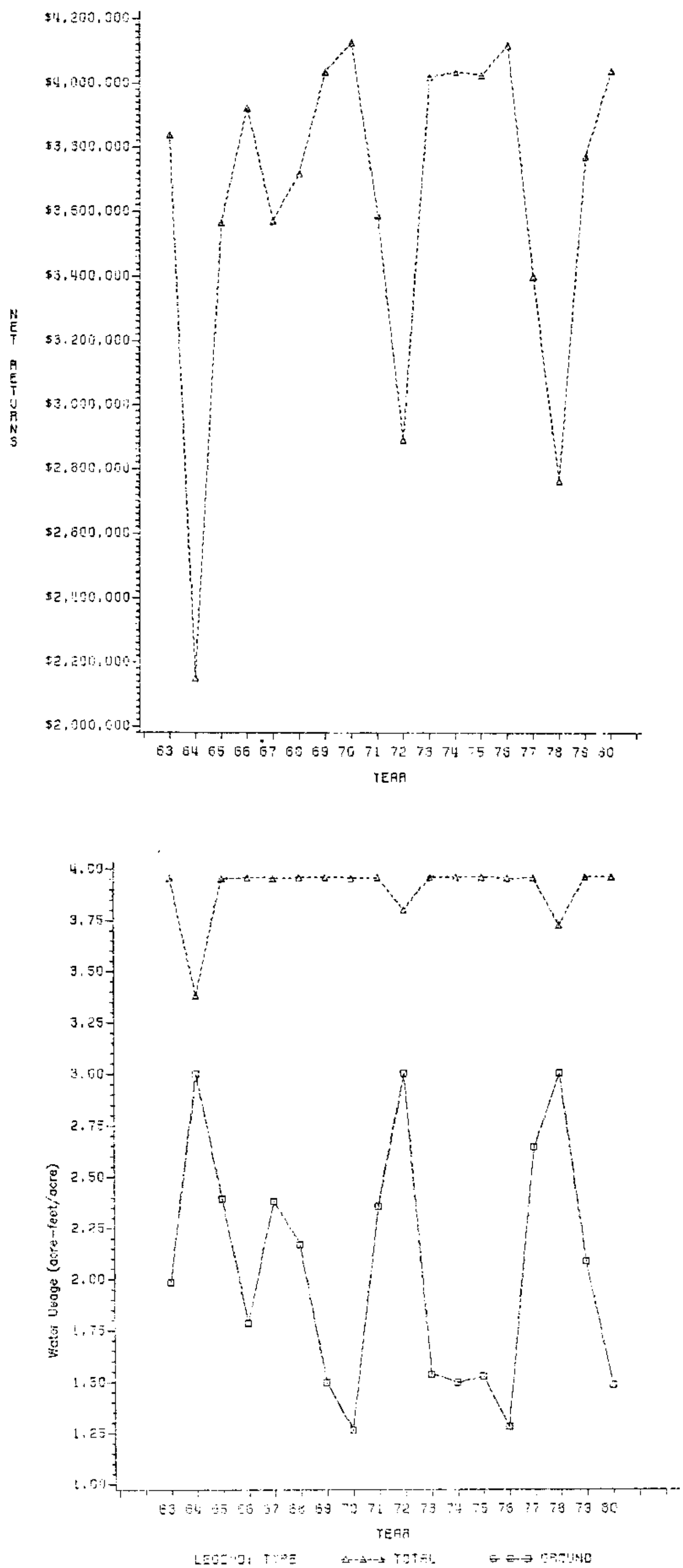


Figure 4. Net Returns and Water Usage for Actual Surface Water Allocation, Elephant Butte Irrigation District

(3 acre-foot groundwater case)

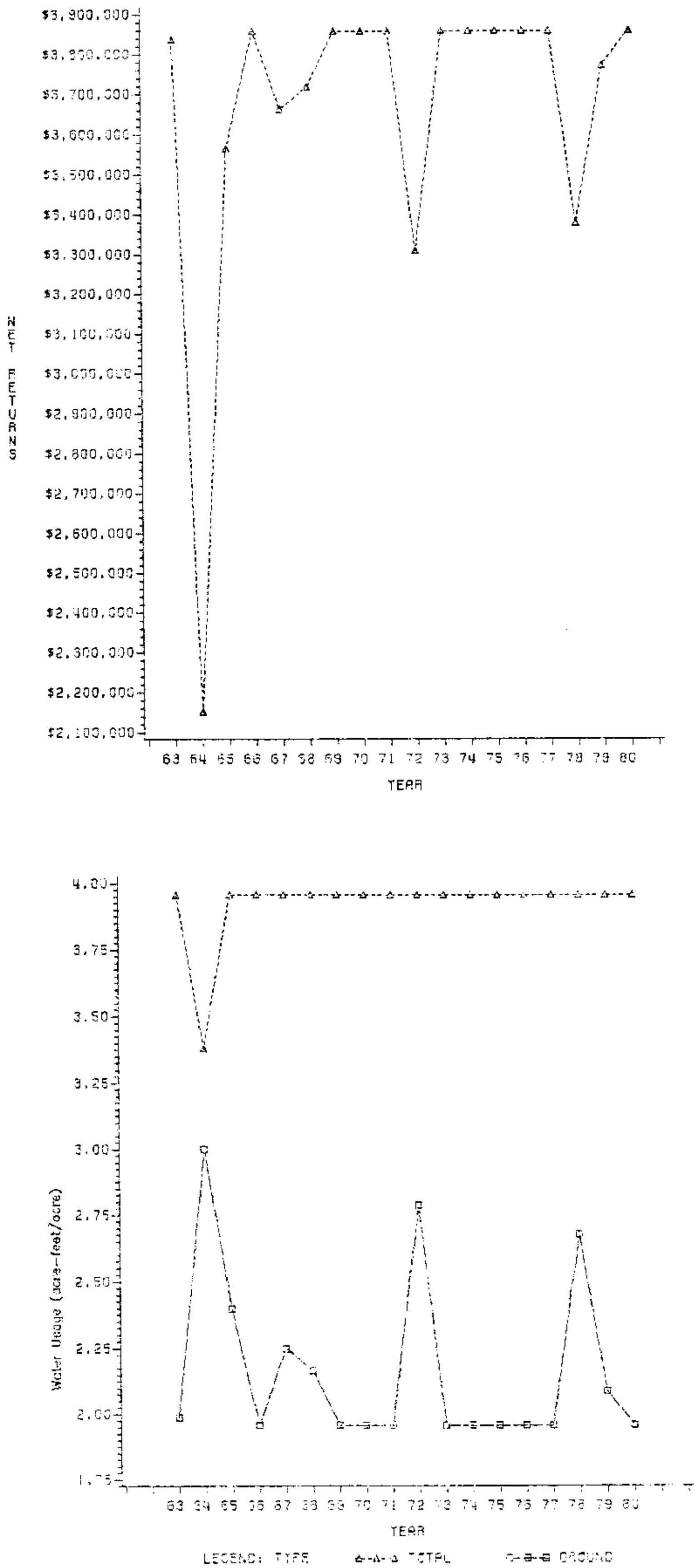


Figure 5. Net Returns and Water Usage for Two Acre-Foot Surface Water Limitation, Elephant Butte Irrigation District

(3 acre-foot groundwater case)

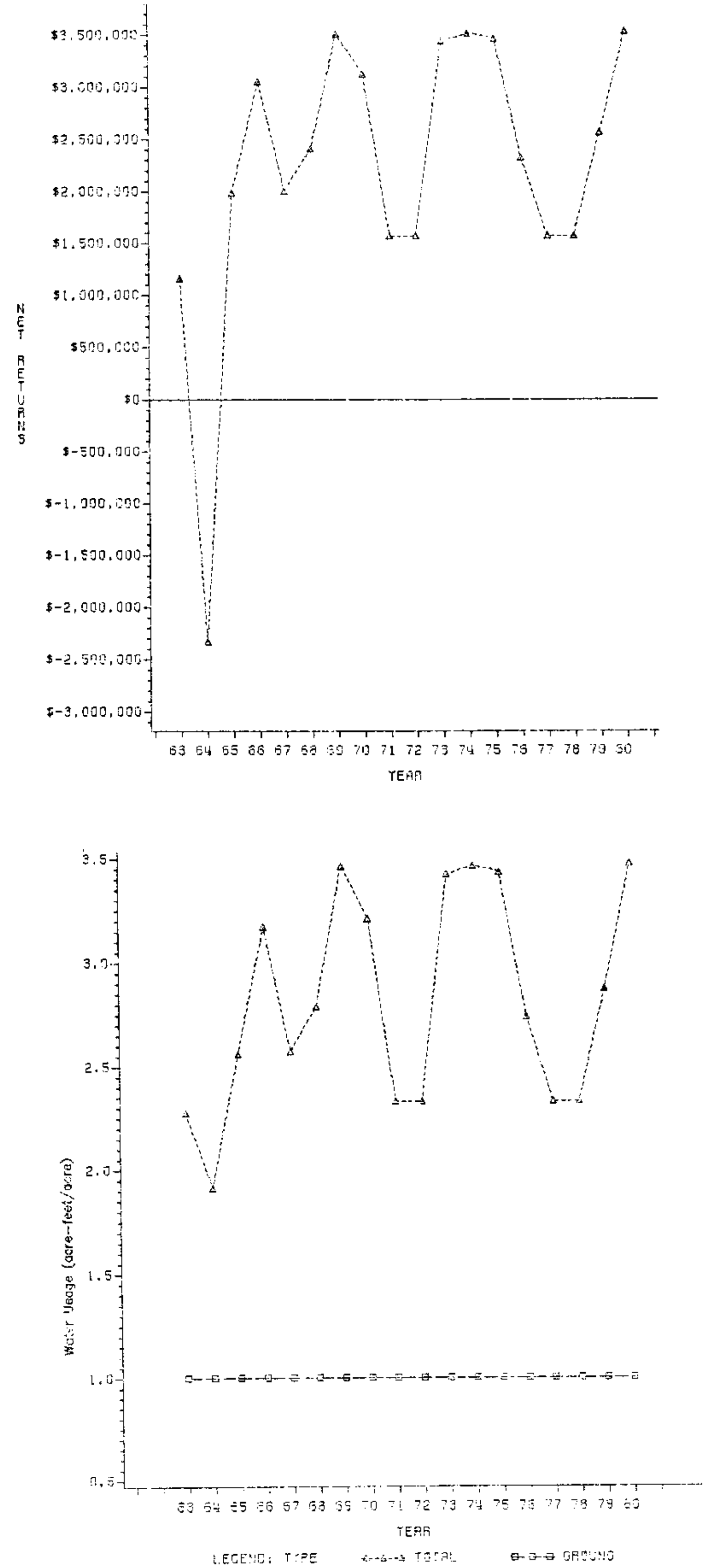


Figure 6. Net Returns and Water Usage for Optimal Temporal Allocation of Surface Water, Elephant Butte Irrigation District

(1 acre-foot groundwater case)

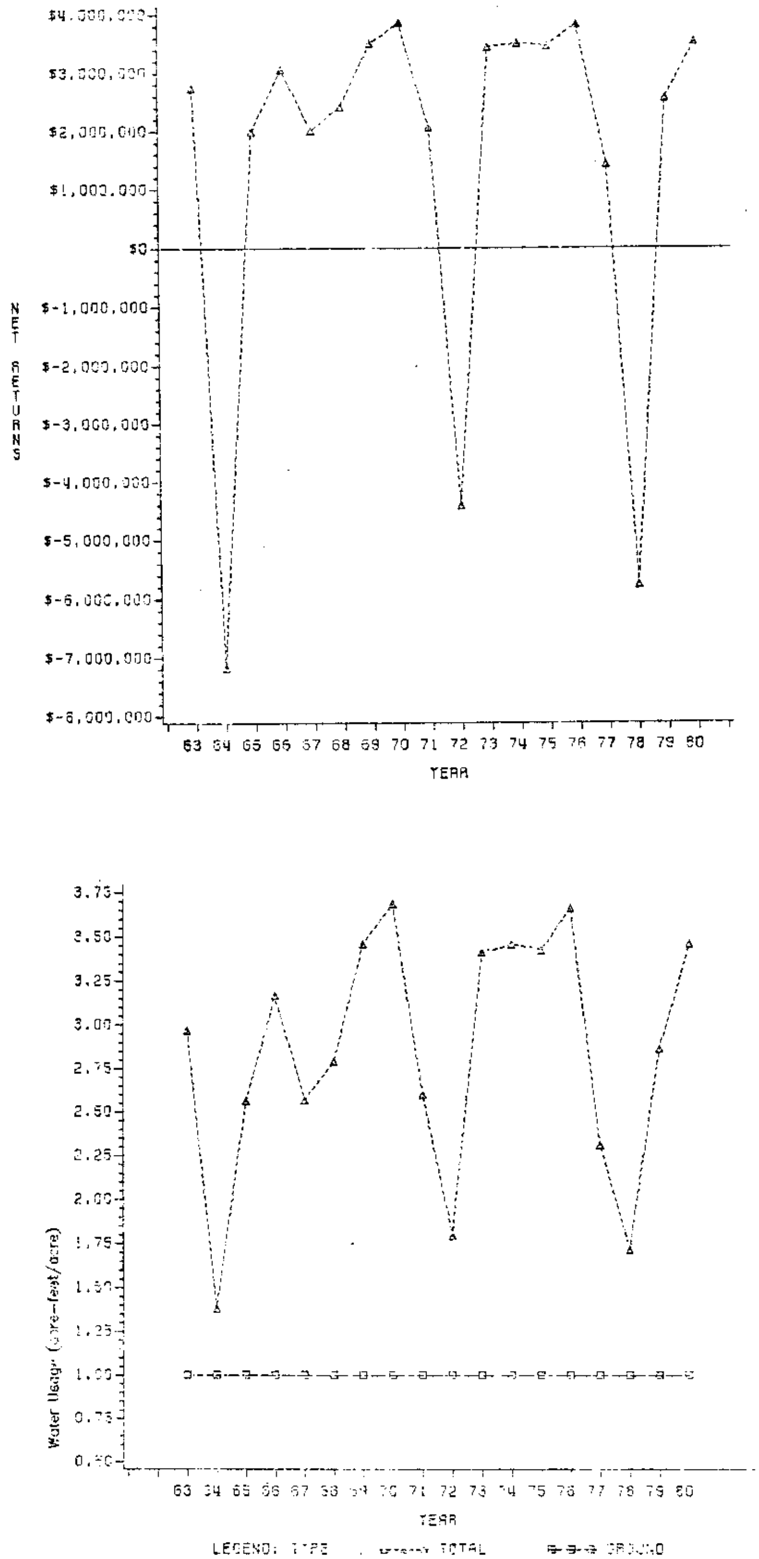


Figure 7. Net Returns and Water Usage for Actual Allocation of Surface Water, Elephant Butte Irrigation District

(1 acre-foot groundwater case)

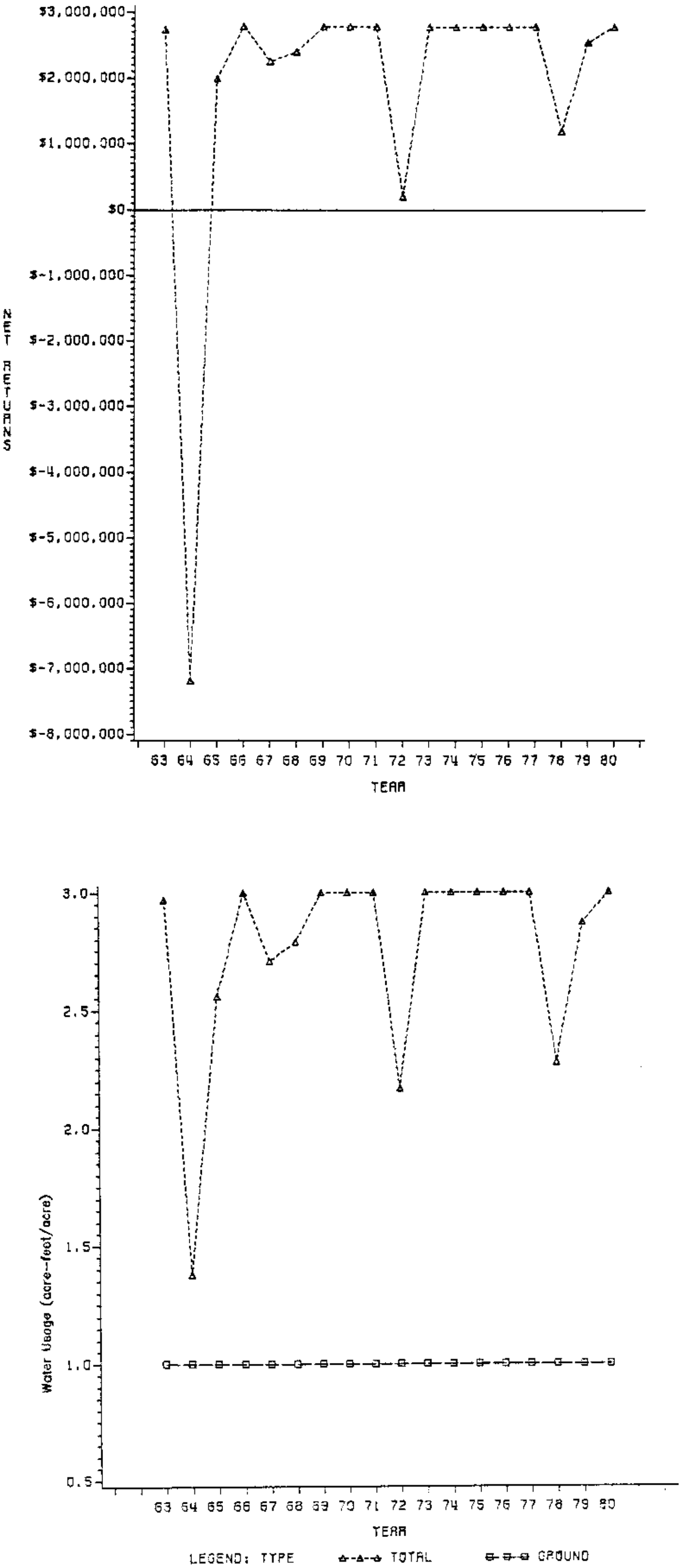


Figure 8. Net Returns and Water Usage for Two Acre-Foot Surface Water Limitations, Elephant Butte Irrigation District

(1 acre-foot groundwater case)

linear programming model. Pertinent technical 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 model 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.

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, those 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 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 difference 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 be 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 in the two previously described analyses has both advantages and disadvantages. 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. As in the previously discussed El Paso study, 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 (Libbin, 1981). 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, 1981). 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.

User Limitations

For both production regions considered thus far 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 in order 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 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.

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 reservoir 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. Procedures for such a calculation might proceed as follows. Uncalled water credits to individual's stored water accounts could be made on December 31st of each year. Taxes on this uncalled water could be paid at that time in order to reserve such water for future use, and all uncalled water for which no notification was given could be handled as previously (pooled in the regional allocation for next year). Cumulative evaporation coefficients could then be obtained from monthly, weekly, or even daily evaporation rates by simple multiplication. For example, suppose a producer on April 1 desires to call the unevaporated portion of 1 acre foot of saved water which was originally available on January 1. Suppose as well that evaporation rates for January, February, and March are .03, .05, and .07 respectively. That is, in January the lake experienced a 3 percent loss in volume due to evaporation with similar interpretations for February and March. The cumulative evaporation coefficient, yielding the proportion of the original acre foot remaining after 3 months, would then be (1-.03)x(1-.05)x(1-.07)=(.97)x(.95)x(.93) =.857 acre feet. The district would then deliver this amount less a slight adjustment 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. The adjustments in the evaporation coefficients noted above might be obtained thru experience once the water saving option was in place and such factors as average time saved water was held in the reservoir as well as the resulting impact on lake levels could be observed. Up to date cumulative evaporation coefficients could be listed in local newspapers so producers could readily calculate their own net saved water balance.

Considerations would also have to be made concerning water lost to transportation. 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 occured. 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, 1982). 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.

Conservation Pricing

An effective method of affecting water use in irrigated agriculture is to increase or decrease the price of the water. Reduced water prices encourage use since the water can be applied profitably in large quantities to low value crops. Alternatively, by instigating a tax or otherwise raising the effective price of water, farmers must carefully evaluate how much water to apply as well as what crops to irrigate. This section is directed primarily to irrigation from groundwater. The effect of a tax on water pumped, above all costs of pumping, is evaluated for the High Plains of Texas. This region relies heavily upon the uderlying Ogallala aquifer as a source of irrigation water. Results obtained were then assumed to apply to portions of eastern New Mexico which rely on the Ogallala aquifer as well.

Study Area

The High Plains of Texas includes about 40 counties and is roughly rectangular, averaging about 300 miles north to south and 120 miles east to west (Hardin and Lacewell, 1981). This region is shown in Figure 9. The Canadian River flows from west to east, dividing the region. The main soils in the region include Pullman, Mansker and Richfield in the "Hardlands", Amarillo and Portales in the "Mixed Lands", and Brownfield and Tivoli in the "Sandy Lands". Average annual rainfall averages from 14 to 21 inches, with the growing season ranging from 180 to 220 days (Godfrey, et al., 1967).

The High Plains region has 34 percent of the total cropland, and approximately 70 percent of the irrigated cropland in Texas. Over the period from 1970 to 1977, crop production from the region (as a percentage of total state production) was 61 percent of cotton, 50 percent of grain sorghum and 61 percent of wheat. The area also produces 78 percent of the fed cattle in Texas, enough to feed 13.2 million people (Texas Department of Water Resources, 1981a).

Pumpage from the Ogallala aquifer for irrigation purposes began to rise to a significant level in the late 30's and accelerated in the 1950's, spurred by the availability of low-cost natural gas. This rapid development has resulted in the mining of Ogallala water. In 1974, there

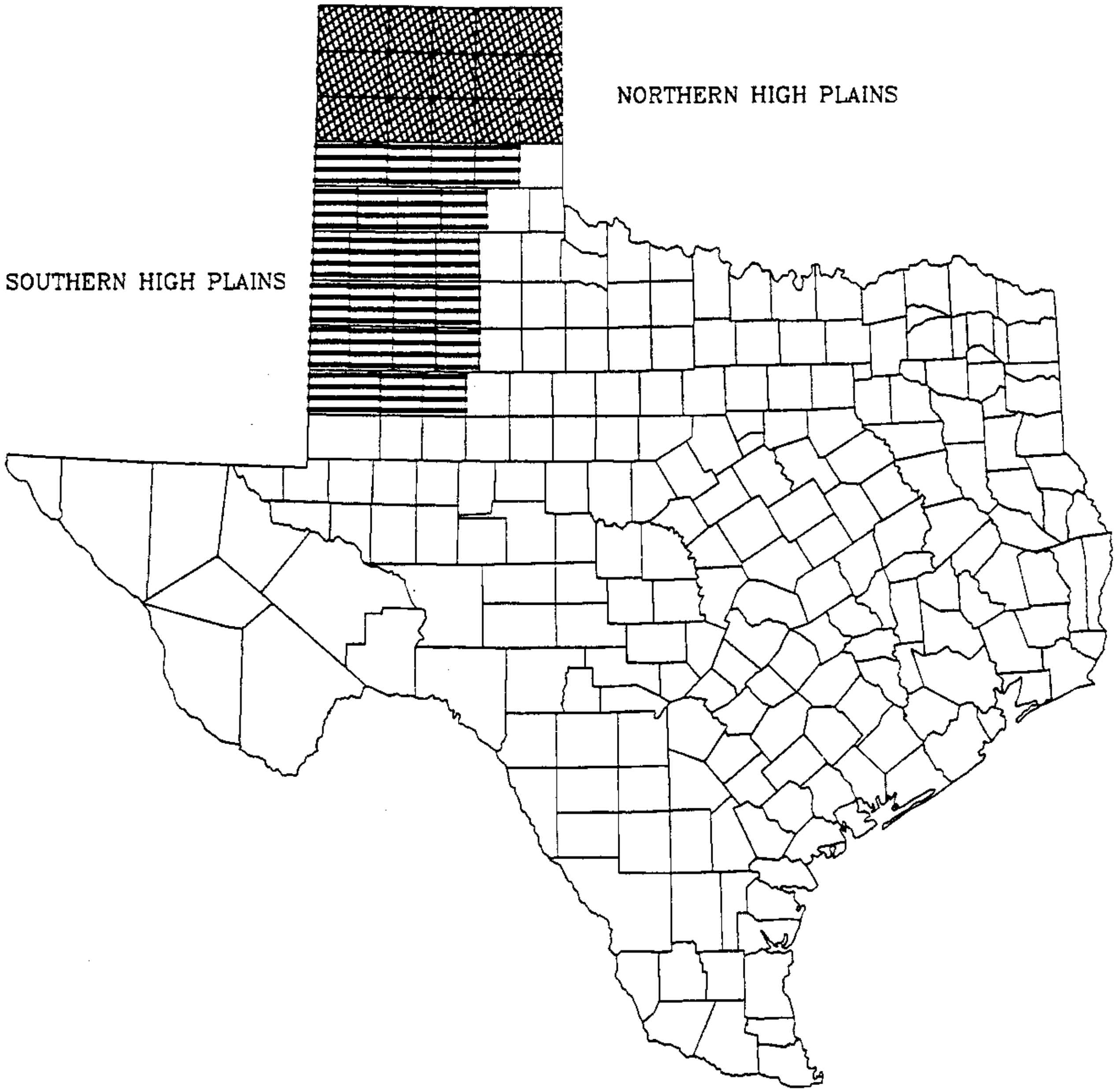


Figure 9. The Texas High Plains

were nearly 5.9 million irrigated acres on the High Plains. However, based on projected pumpage rates, the aquifer will be able to supply enough water to irrigate only 53 percent of these acres by the year 2000 and only 35 percent in 2030 (Wyatt, 1975).

Objectives

Thus, with an exhaustible water supply that is important to the local, regional and state economy, this study area provides an excellent arena to test the effect of alternative water prices. The specific objectives of this phase of the study is as follows:

1. Modify and apply a regional linear programming model with a supplemental water pricing activity.
2. In a static analysis, increment a tax on water from zero to $150 per acre foot to estimate effect on cropping patterns, farmer net returns and water use.
3. In a temporal analysis, evaluate the effect of a specified water tax over 40 years on rate of groundwater withdrawal and present value of the groundwater supply.

Procedure

The Texas High Plains is one of the states more vital areas agriculturally. For purposes of this study the region was divided into two subregions due to the exclusion of cotton in the northern portion. Other major crops under consideration were irrigated soybeans, irrigated corn, dryland and irrigated grain sorghum, dryland and irrigated wheat, and dryland and irrigated sunflowers.

Regional and Water Resources Delineation

Similar arable soil series in each of the subregions were grouped together into 10 classifications on the basis of their texture, slope, and crop yields. Cropland was assumed to be farmed in the same relative proportions as these groups appeared (Hardin and Lacewell, 1981). Prices used for outputs were calculated using an average of the last 20 years's prices valued in 1982 dollars.

One of the greater challenges of the analysis lay in determining a joint distribution relating saturated thickness, pump lift, and cropped acreages. Numerous county studies relating saturated thickness to surface acreages, as well as pumping lift to surface acreages were used (Texas Department of Water Resources - 38 County reports, 1976-1980). It was assumed that the greater lifts were associated with greater saturated thicknesses, and after aggregating the respective acreages for various lifts and saturated thicknesses across counties, natural break points were chosen to determine representative groundwater situations. Results of this process appear in Table 5 for both the Southern and Northern High Plains. A single well may draw from an area greater than that which it irrigates. Thus, historical data from representative counties in each subregion and water resource situation was used to estimate the contributing aquifer acres, number of wells, and cropland (both dry and irrigated) in areas that were predominantly furrow or sprinkler irrigated (Texas Crop and Livestock Reporting Service, 1976-1980, and Texas Department of Water Resources, 1981b).

A distinction between technologies was needed since sprinkler systems predominate on sandy soils and furrow on the tighter soils. Improved technologies such as LEPA (low energy precision application) sprinkler

Table 5. Groundwater Resource Situations for the Texas High Plains

Water Situation	Cropland (acres)	Wells	Contributing Aquifer Acres (acres)	Saturated Thickness (ft.)	Lift (ft.)
Southern Region					
Lo-Furrow	1,503,425	13,134	1,958,806	55.	145.
Hi-Furrow	2,324,676	21,676	3,032,104	139.	281.
Lo-Sprinkler	2,126,430	15,854	2,671,650	55.	145.
Hi-Sprinkler	1,225,030	12,940	1,839,566	139.	281.
Total	7,179,561	63,604	9,502,126		
Actual (1979)	7,182,886	64,460	9,340,276		
% Error	-.04%	-1.3%	+1.7%		
Northern Region					
Lo-Furrow	67,558	145	219,897	77.	82.
Med-Furrow	1,574,786	5336	2,687,624	196.	252.
Hi-Furrow	251,897	854	429,908	277.	482.
Lo-Sprinkler	195,224	368	250,634	77.	82.
Med-Sprinkler	728,255	2198	1,802,650	196.	252.
Hi-Sprinkler	116,489	352	288,348	277.	482.
Total	2,934,209	9253	5,679,061		
Actual (1979)	2,623,245	8890	5,765,195		
% Error	+11.85%	+4%	-1.5%		

systems as well as improved furrow systems were considered. The same groundwater situations as for sprinkler and furrow systems were assumed for these improved technologies. Aggregation of the estimates noted above across the various groundwater situations compares very favorably with actual conditions (1979) excepting for the 11.9 percent overestimate on cropland in the North. That value, however, is within historical highs for cropland in that region.

Model and Application

A regional linear programming (LP) model was the main tool employed within this analysis. Two aspects of the incidence of a water tax were explored. The first involved the effect of varying the tax rate from 0 to $150 per acre-foot of water use on net returns over fixed costs, and on cropland usage. This was done assuming the existing groundwater conditions. The second phase consists of use of a single tax rate and examining the resulting difference in present value of net returns, ending saturated thickness, and total water use over a 40 year period. This latter step employed the recursive nature of the LP model used, thus taking into account greater pumping costs incurred due to depletion of the aquifer. This analysis was performed for the high water situation in the South and for the medium water situation in the North since the majority of water pumped occurs in those two classifications.

The exact mix of conventional (furrow and sprinkler) irrigation technologies and improved (improved furrow and LEPA) technologies currently in use is not known, so both cases were analyzed with the intent of providing upper and lower bounds on the impact of the water tax (conservation pricing). Conventional tillage practices were assumed with the conventional irrigation technology and minimum tillage with the improved irrigation technology.

The model utilized included both optimal and non-optimal irrigation timings. For the irrigated crops considered, possible irrigation schemes ranged from a single pre-plant to a pre-plant plus five post plant irrigations, depending upon the crop. Crop yields vary with the irrigation scheme employed and selected non-optimal (less than maximum yield for a given number of post-plants irrigations) schemes were included as possible production activities to more adequately represent alternatives facing a farmer. Competition among crops for water in the heavy water demand summer months often brought about selection of one of the non-optimal irrigation timing schemes.

Lastly, the issue of optimal temporal use of water from an exhaustible aquifer was addressed. Initial runs of the LP without a limit on pumping yielded annual groundwater withdrawals from 6 to 8 feet of saturated thickness, much more than historical records support. Additional research (Reneau, 1983) examined the effect of various limitations of groundwater pumping on the net present value of returns over fixed costs for a 40 year period of irrigation. This work demonstrates for groundwater situation similar to the low one examined in this report, that an extraction rate of approximately 2 acre-feet of saturated thickness per year yielded the maximum net present value. For the medium and high groundwater resource situations that rate increased to approximately 4 feet decline in saturated thickness per year. Both of these values could vary by as much as one foot without affecting the maximum net present value adversely. Thus, it was hypothesized that farmers implicitly limit their annual withdrawal to maximize the returns over time available from their limited water supply.

The limits noted above were therefore enforced as part of the analysis and should be noted in the interpretation of all results.

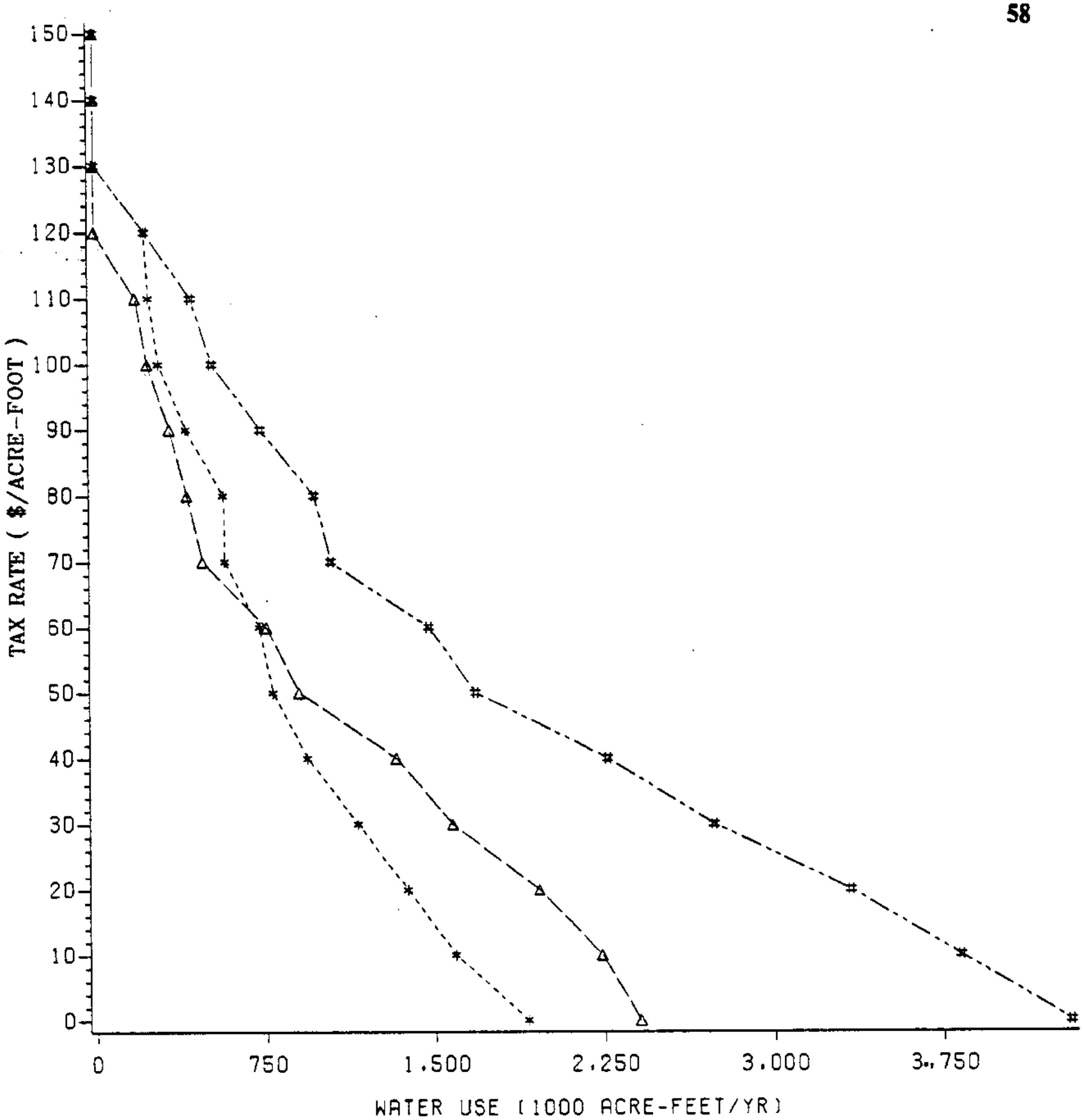
Results

The results of model application are separated into a one year or static analysis and 40 year or temporal analysis. This is followed by an analysis of the regional annual effect on the economy due to a $20 per acre foot tax.

Static Results

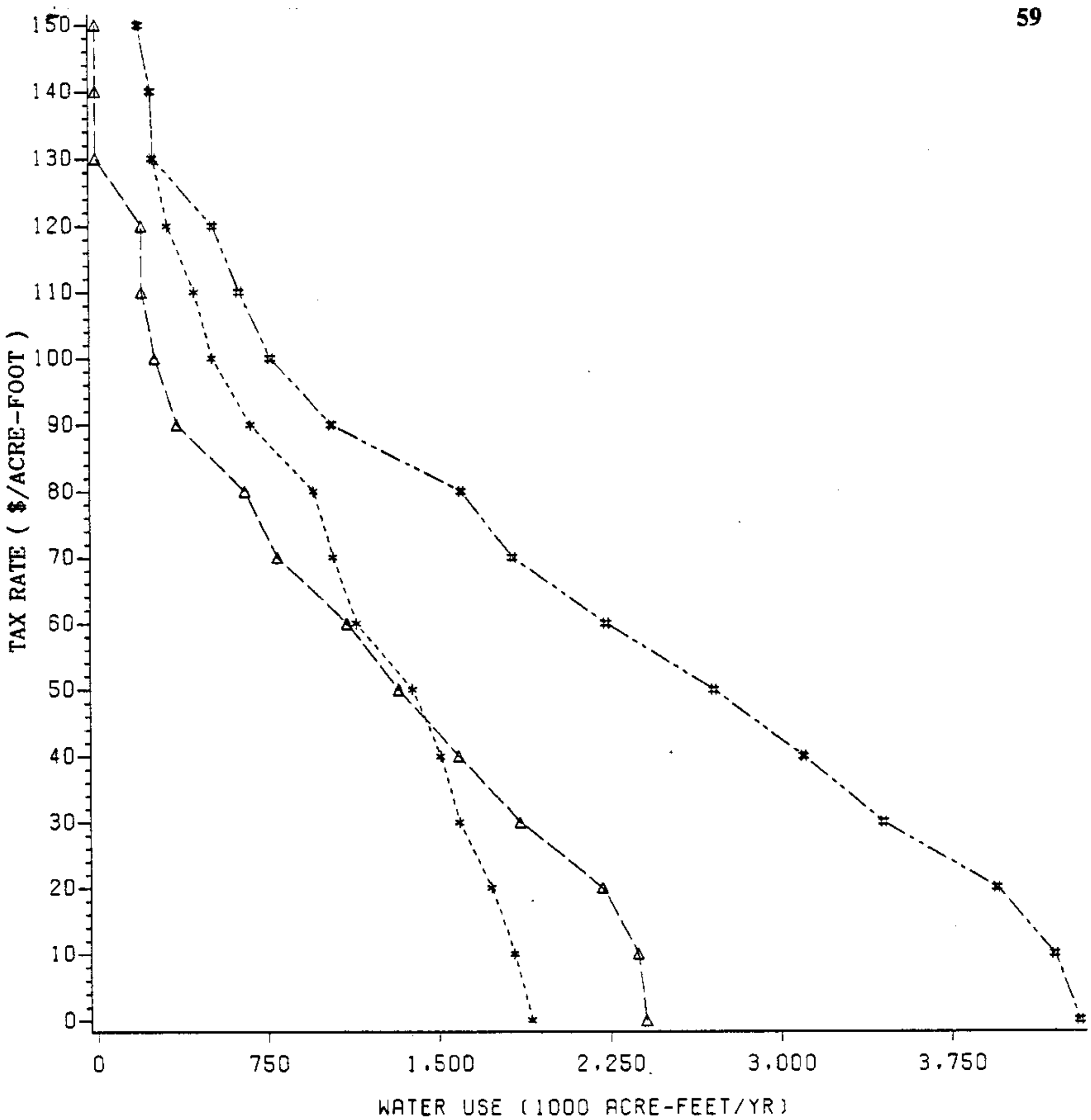
The tax rate was varied from 0 to $150 per acre foot for this portion of the analysis. Figure 10 portrays water use considering conventional irrigation technology in the Southern High Plains as a function of the tax rate, with similar results for improved technology demonstrated in Figure 11. Note that total water use is fairly sensitive to low tax rates for the conventional technology while water use with improved technology decreases relatively little for tax rates less than $20/acre-foot. Total water use without a tax for the subregion is estimated to be 4,312,000 acre-feet per year which exceeds the actual 1979 (a relatively wet year) value of 3,446,788 acre-feet used, but is below the 4,990,896 acre-foot figure for a very dry 1980 (Texas Department of Water Resources, 1981a).

Figures 12 and 13 portray the decline in net returns at the various tax rates. With conventional technology, the $10 tax per acre-foot reduces net revenues by $155 million, or 23 percent. If the tax increases to $150, net revenue is reduced by 50 percent and as can be seen in the acreage distribution in Figure 14, all of the value is attributable to dryland production. Similar results hold for the improved technology case (Figures 13 and 15). One should note the greatly increased base returns, from $680



STAR => SPRINKLER IRRIGATED, CONVENTIONAL TILLAGE
TRIANGLE => FURROW IRRIGATED, CONVENTIONAL TILLAGE
HASH => SUM OF SPRINKLER AND FURROW

Figure 10. Water Use as a Function of Tax Rate, Southern High Plains, Conventional Sprinkler and Furrow Irrigation



STAR => LEPA IRRIGATED, MINIMUM TILLAGE
TRIANGLE => IMPROVED FURROW IRRIGATED, MINIMUM TILLAGE
HASH => SUM OF LEPA AND IMPROVED FURROW

Figure 11. Water Use as a Function of Tax Rate, Southern High Plains, LEPA and Improved Furrow Irrigation

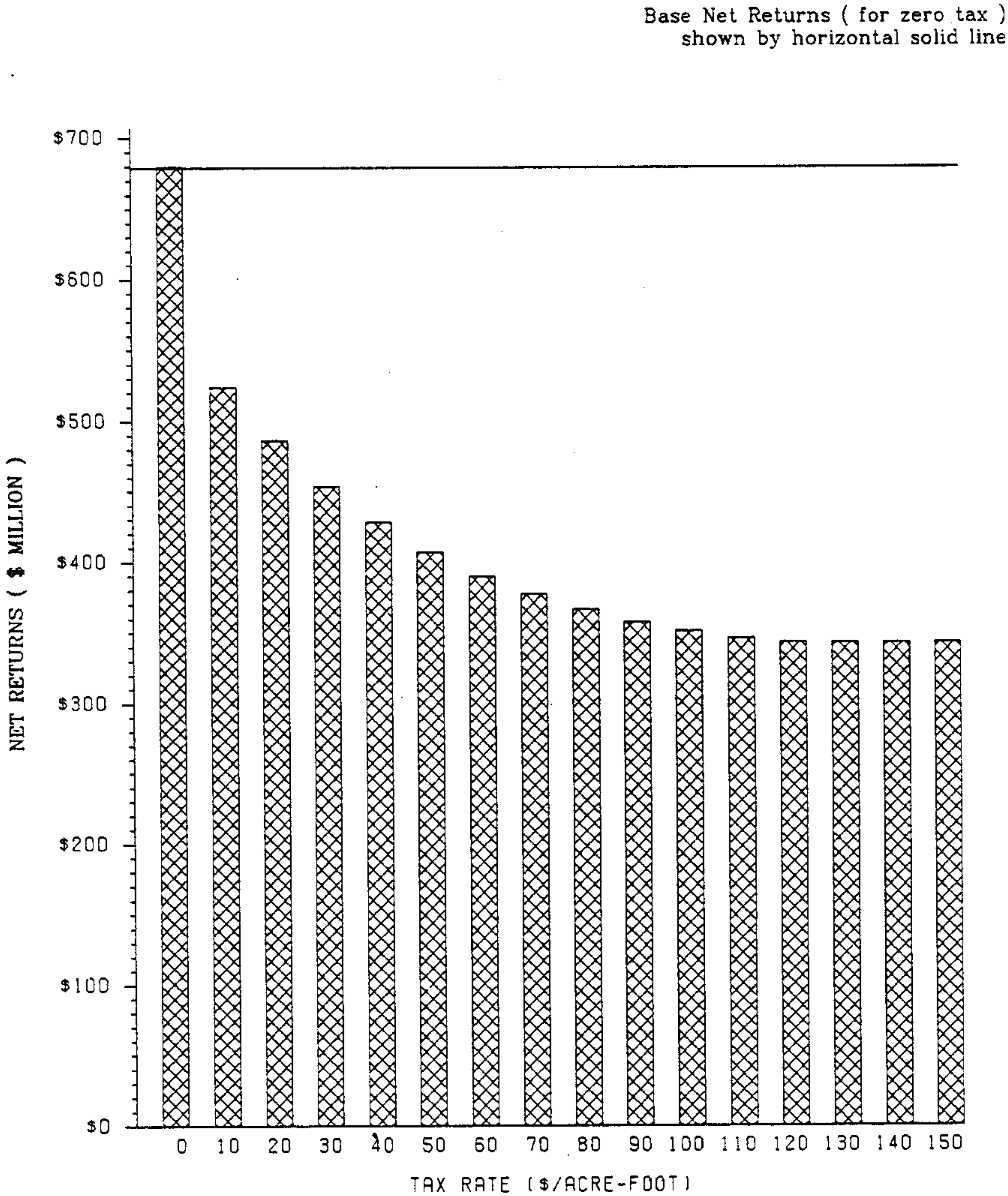


Figure 12. Net Returns as a Function of Tax Rate, Southern High Plains -- Conventional Technology

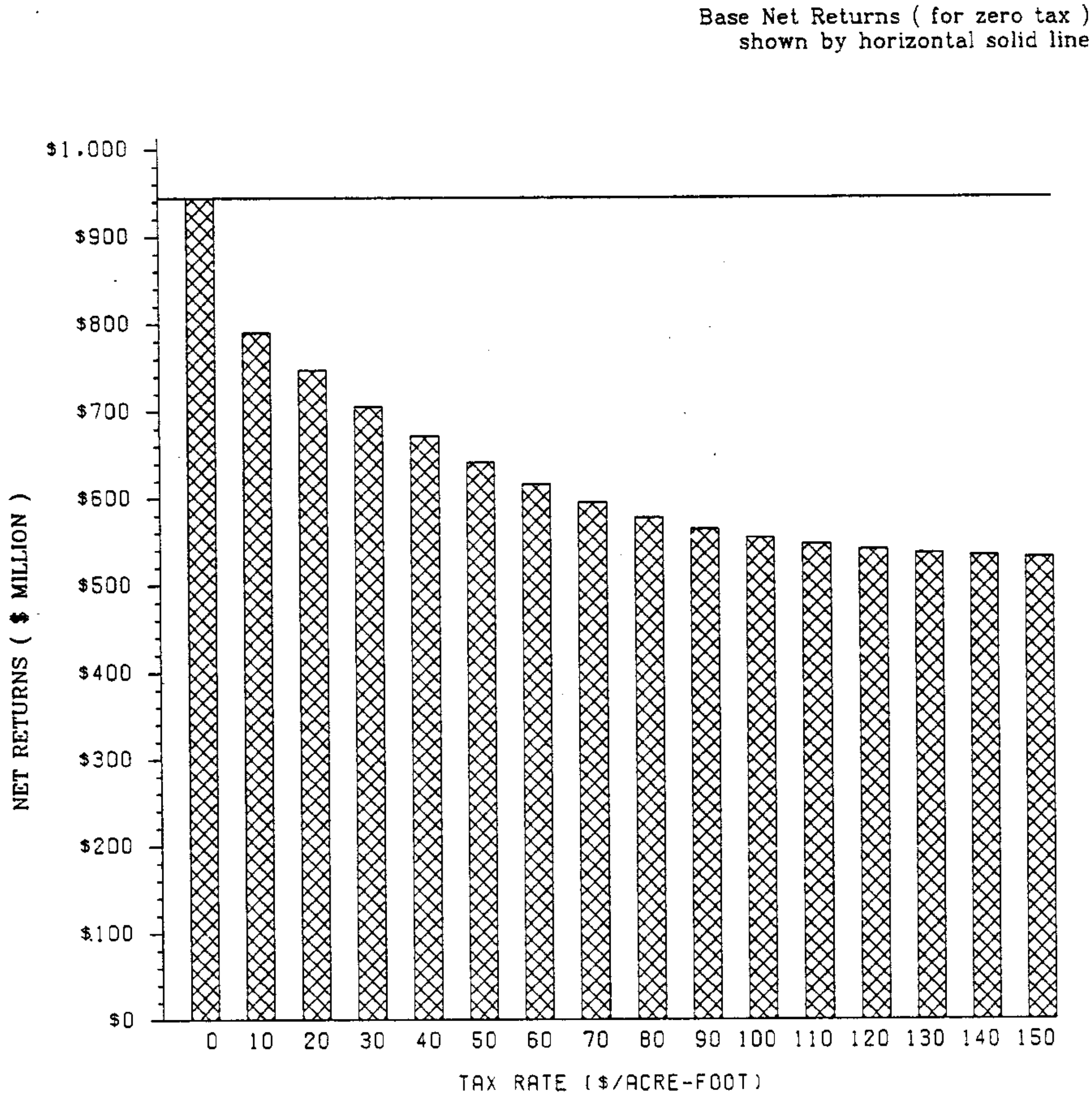


Figure 13. Net Returns as a Function of Tax Rate, Southern High Plains -- Improved Technology

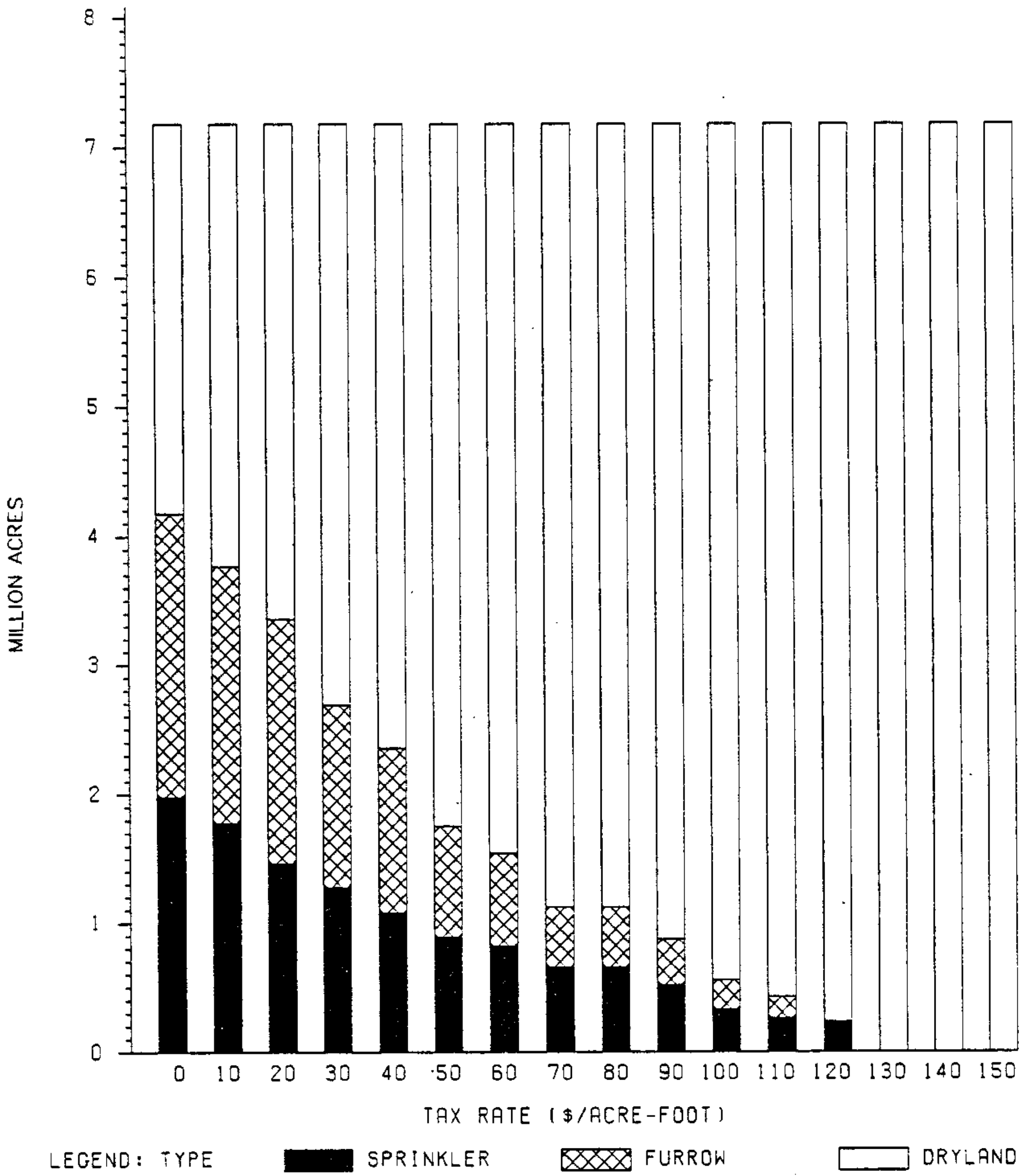


Figure 14. Acreage Use Distribution as a Function of Tax Rate, Southern High Plains -- Conventional Technology

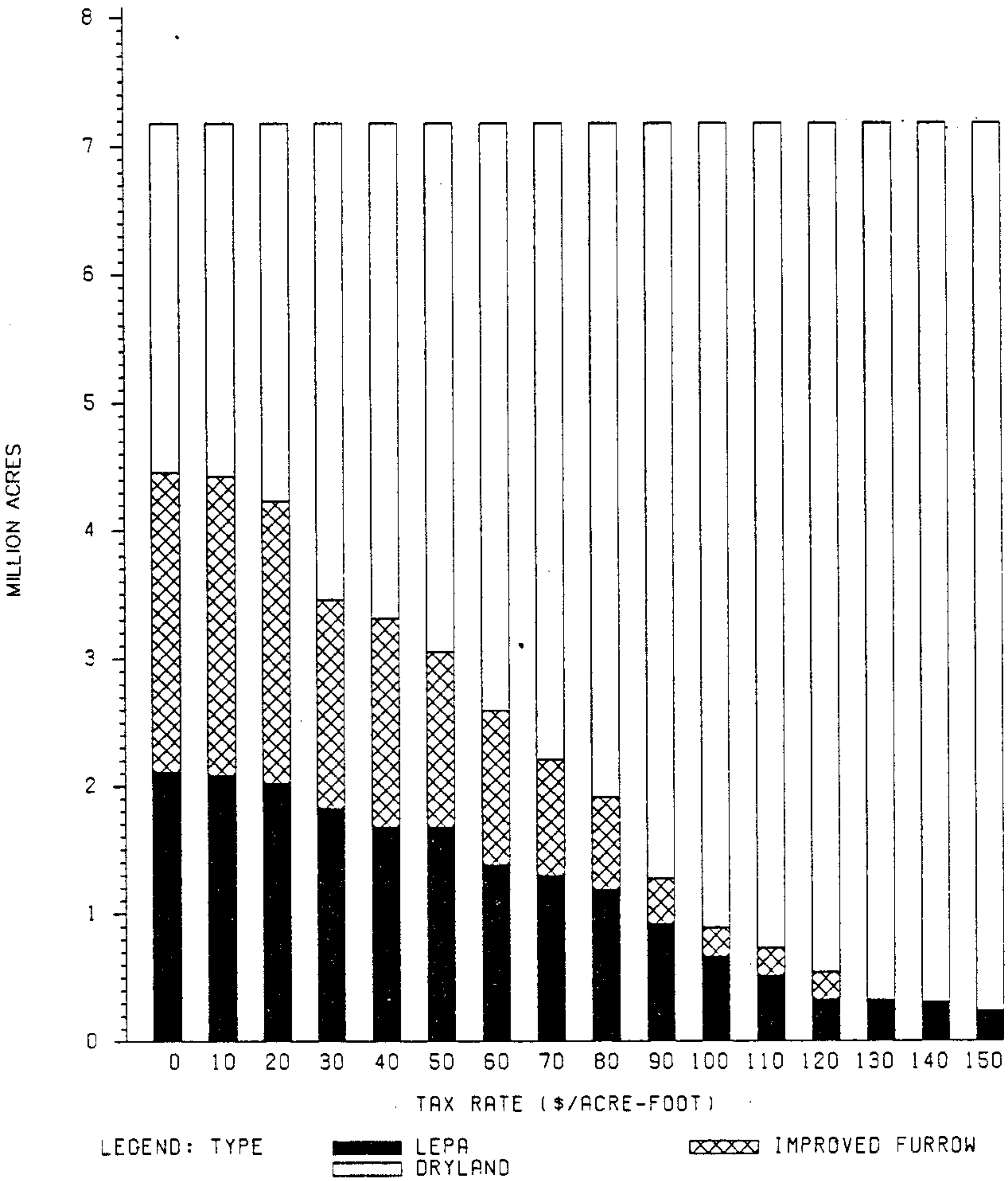


Figure 15. Acreage Use Distribution as a Function of Tax Rate, Southern High Plains -- Improved Technology

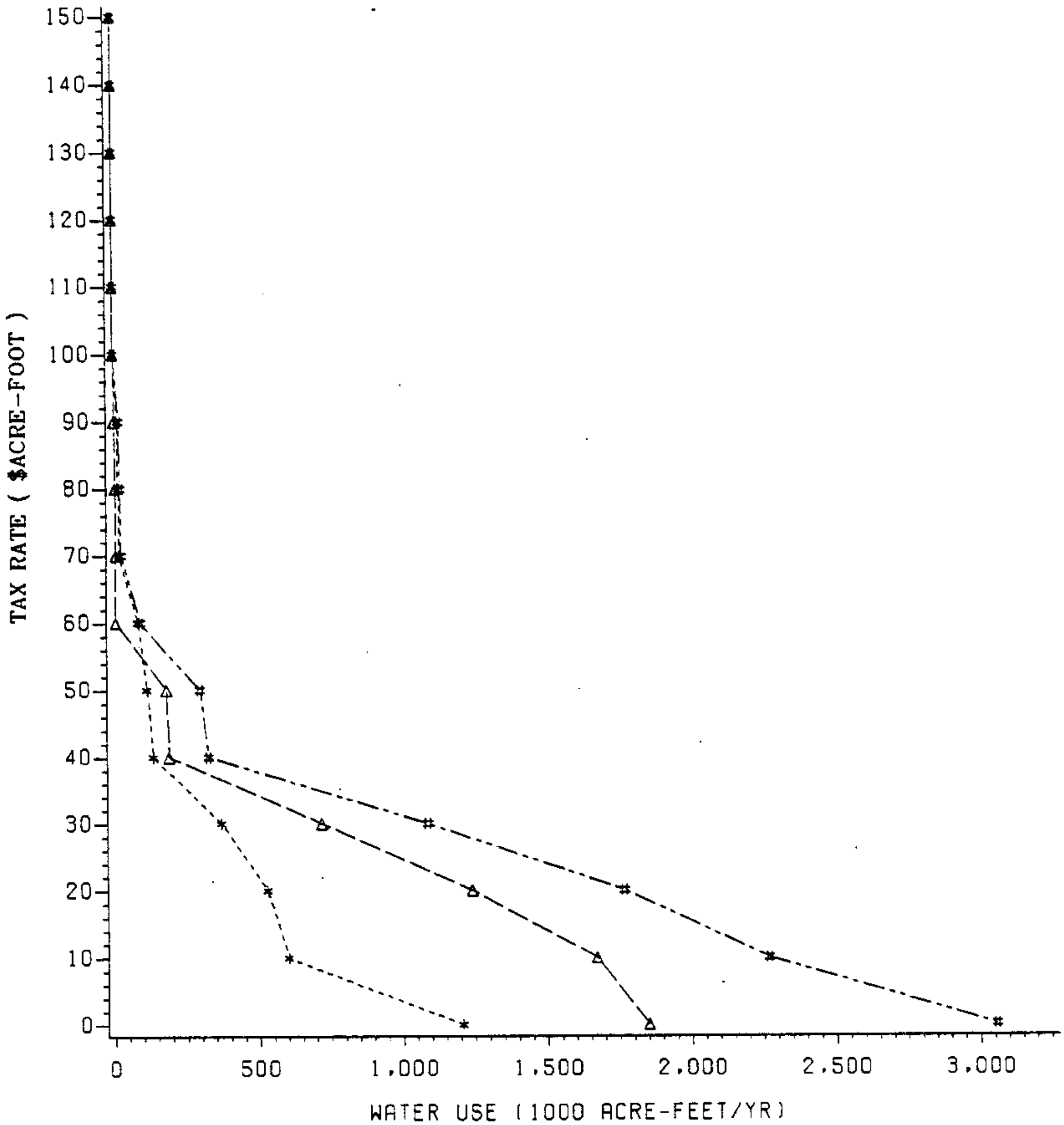
to $940 million, brought about solely by the improved technology. Some LEPA systems were estimated to remain in operation even with a tax rate of $150/acre-foot. Note also that no cropland was taken out of production. All reverted to dryland.

Figures 16 thru 21 depict the same relationships just discussed, except for the Northern High Plains. Water demand in that region, however, is somewhat more sensitive to lower tax rates. Total water use as estimated by the model (3,057,000 acre-feet) exceeds the actual 1979, 1980 values of 2,036,000 and 1,935,000 acre-feet, respectively. Net returns for conventional technology decrease by a rather large 35 percent from $169 to $111 million for the $10 tax rate. Improved technology softens the impact, falling 25 percent from $261 to $196 million. In this case, however, some cropland does revert to pasture as shown in Figures 20 and 21. Even with a zero tax rate, some cropland is not planted.

The previously noted water use curves based upon tax rates are aggregated to reflect the entire region in Figure 22. Curves for both conventional and improved technologies are presented. The curve that would represent the mixture of technologies actually occuring in the region should be bounded by these two, and both may be used to bound the expected drop in water use caused by a given tax rate. Based upon these curves, as well as the large decreases in net returns brought about by even the smaller tax rates, a possible tax rate of $20/acre-foot was chosen for use in the subsequent temporal analyses.

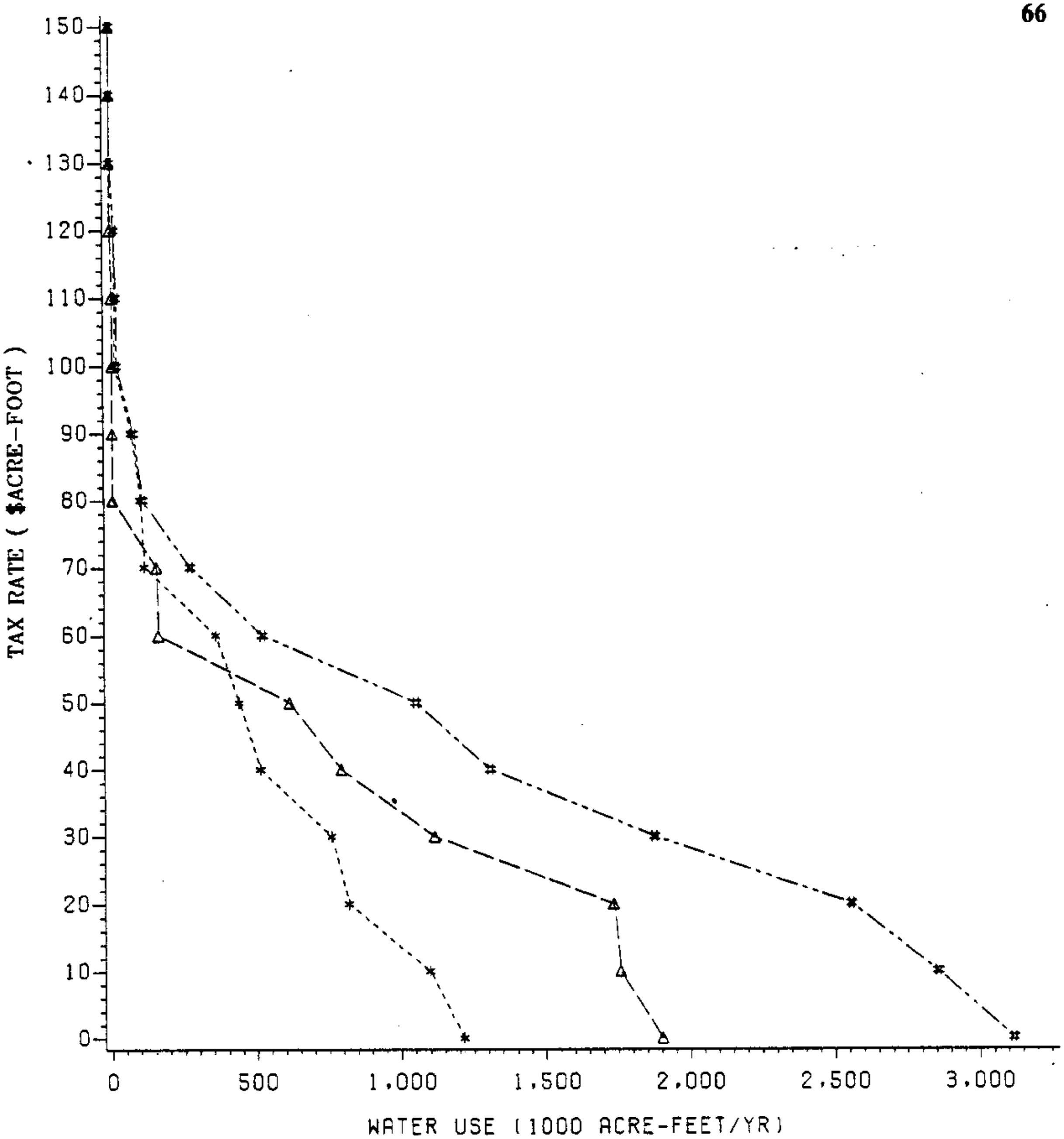
Temporal Results

For the temporal portion of this study a tax rate of $20 per acre-foot pumped was imposed and the LP model was applied recursively over a 40 year



STAR => SPRINKLER IRRIGATED, CONVENTIONAL TILLAGE
TRIANGLE => FURROW IRRIGATED, CONVENTIONAL TILLAGE
HASH => SUM OF SPRINKLER AND FURROW

Figure 16. Water Use as a Function of Tax Rate, Northern High Plains, Conventional Sprinkler and Furrow Irrigation



STAR => LEPA IRRIGATED, MINIMUM TILLAGE
TRIANGLE => IMPROVED FURROW IRRIGATED, MINIMUM TILLAGE
HASH => SUM OF LEPA AND IMPROVED FURROW

Figure 17. Water Use as a Function of Tax Rate, Northern High Plains, LEPA and Improved Furrow Irrigation

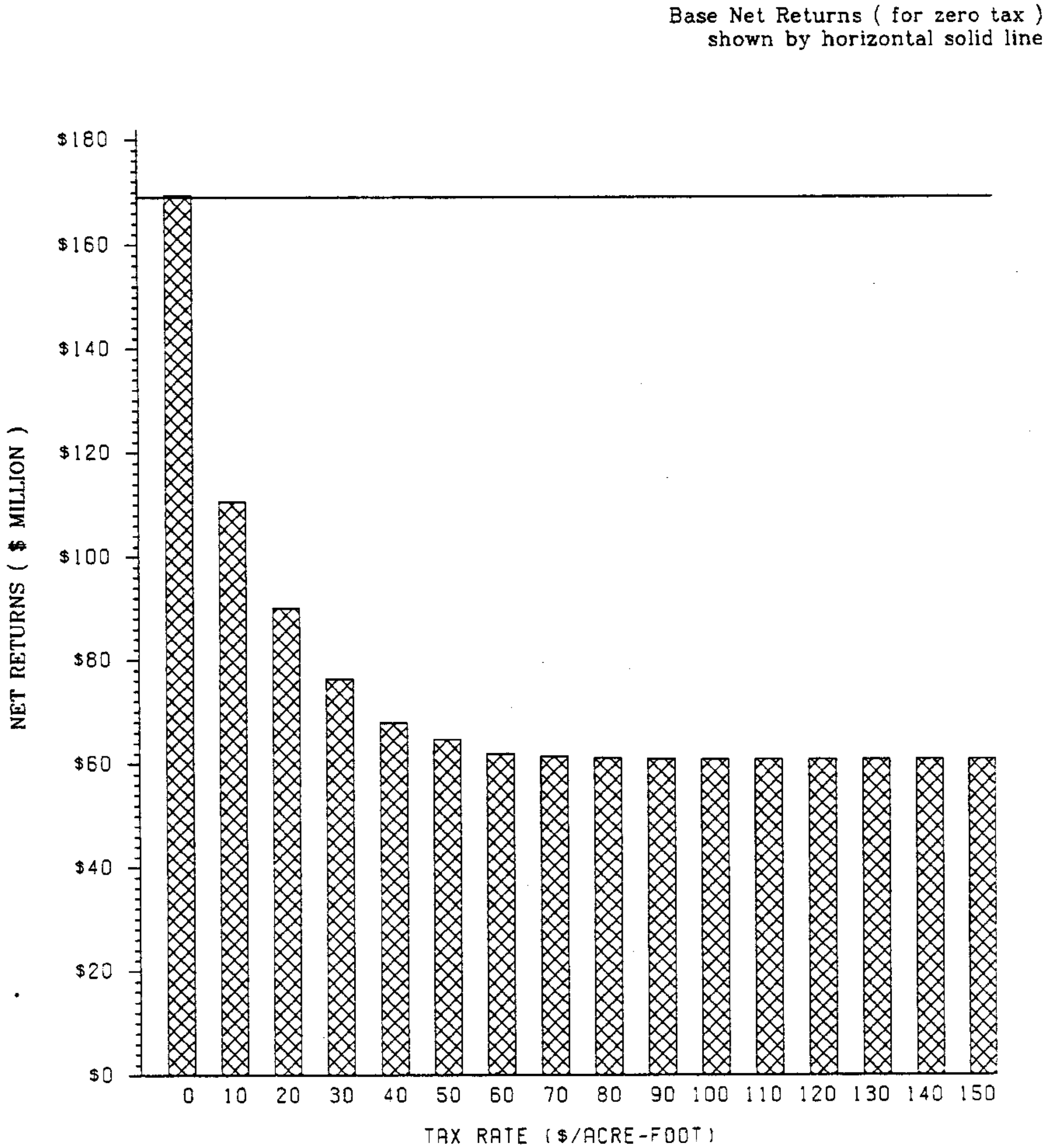


Figure 18. Net Returns as a Function of Tax Rate, Northern High Plains -- Conventional Technology

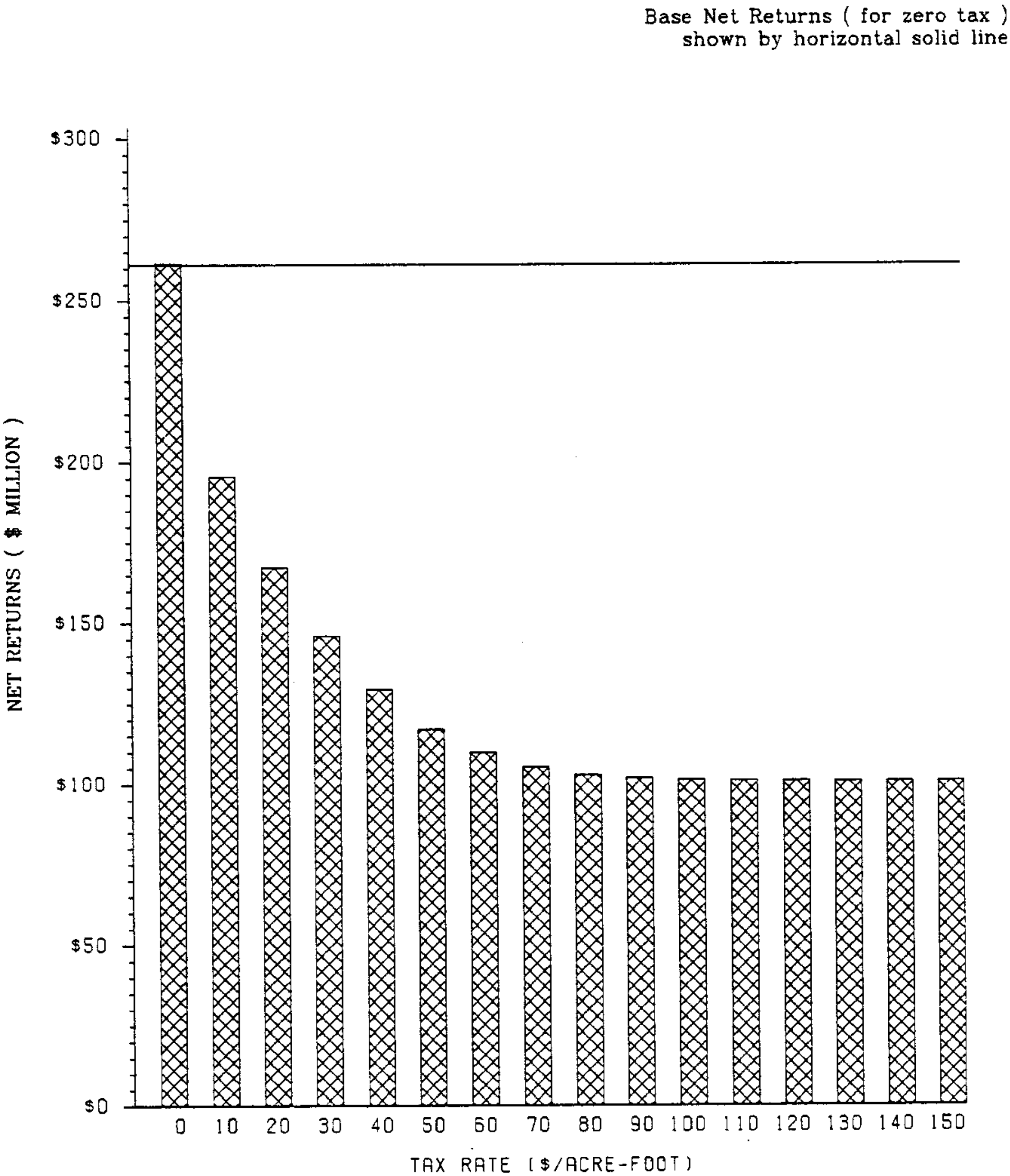


Figure 19. Net Returns as a Function of Tax Rate, Northern High Plains -- Improved Technology

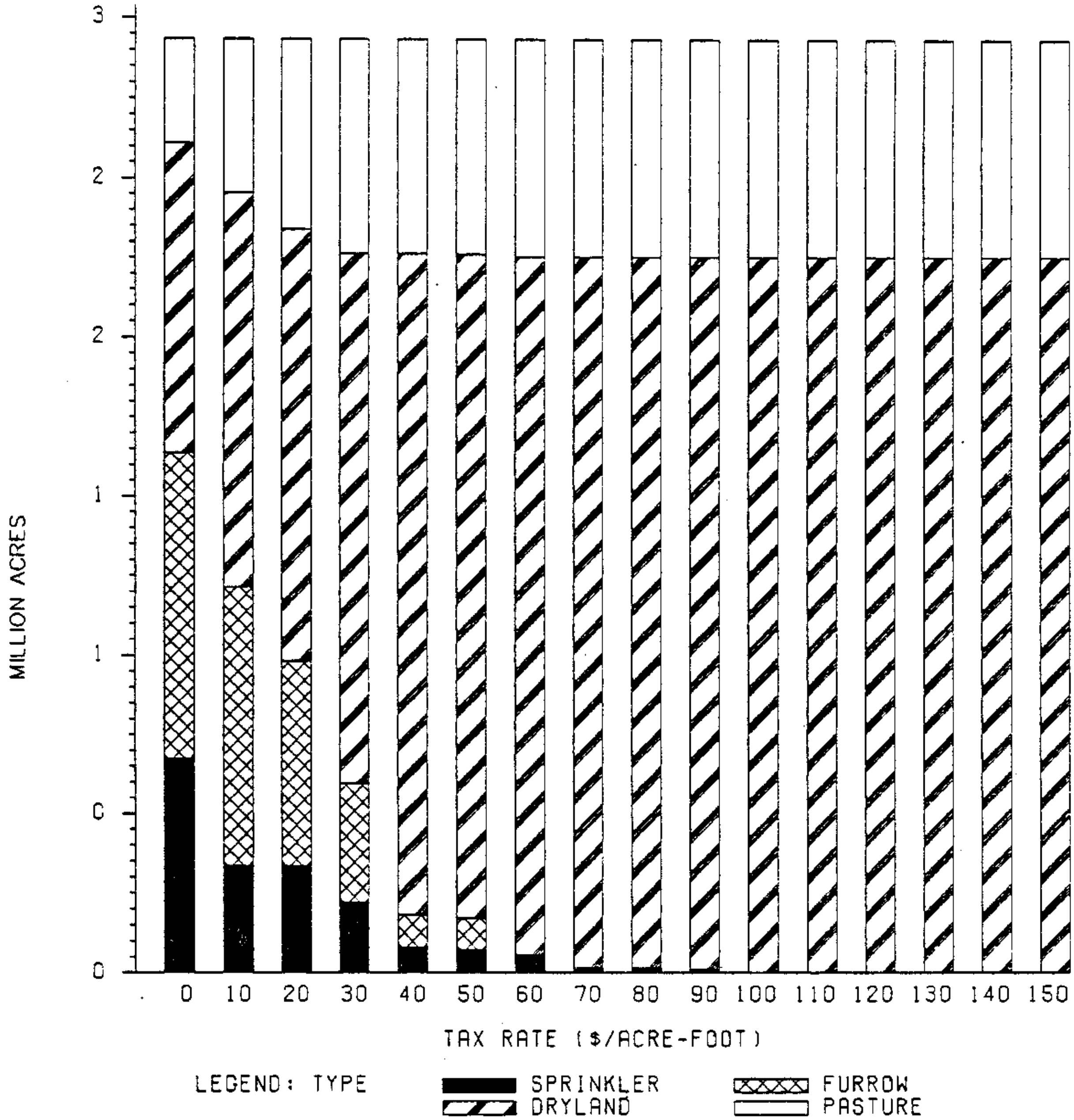


Figure 20. Acreage Use Distribution as a Function of Tax Rate, Northern High Plains -- Conventional Technology

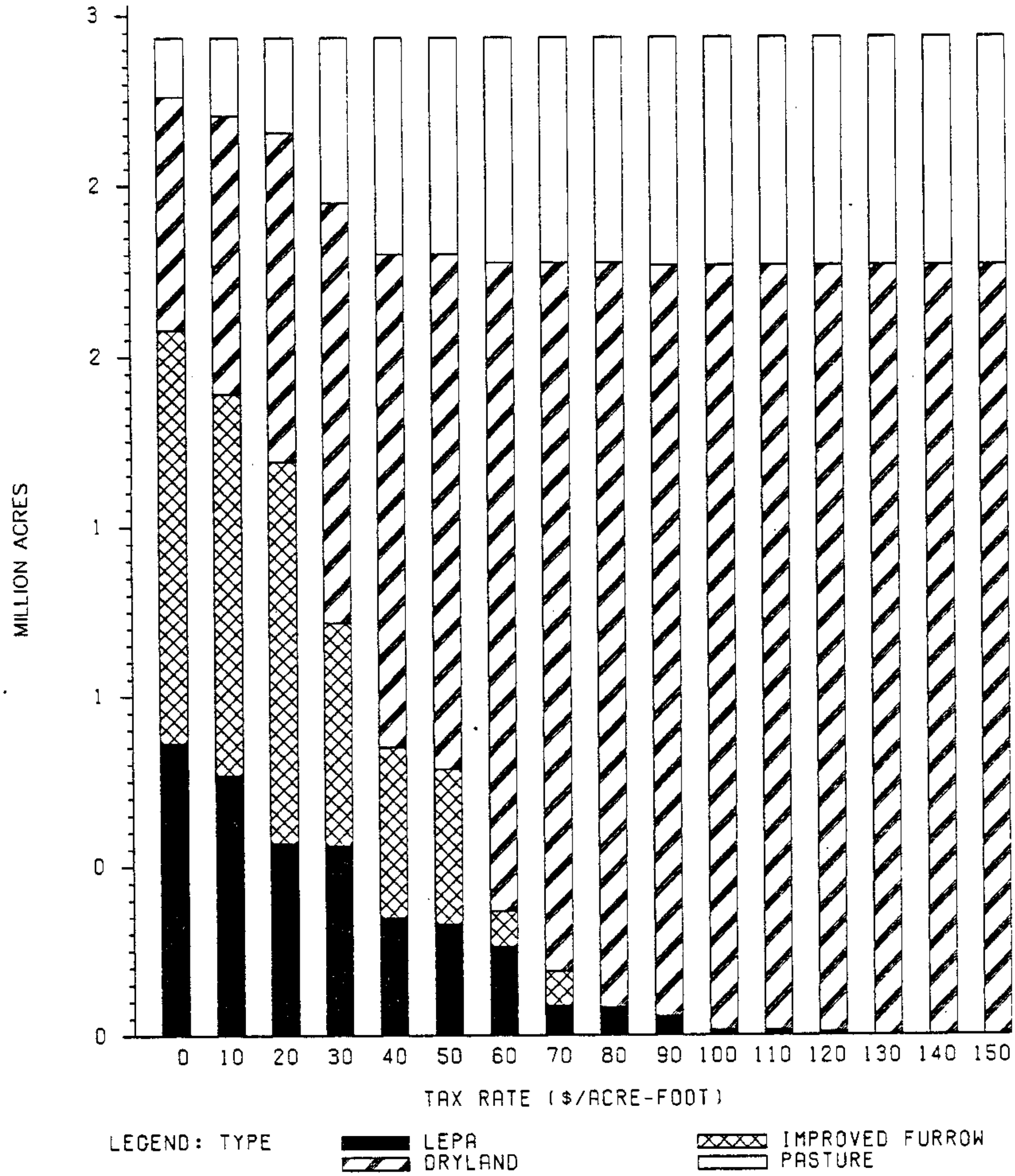


Figure 21. Acreage Use Distribution as a Function of Tax Rate, Northern High Plains -- Improved Technology

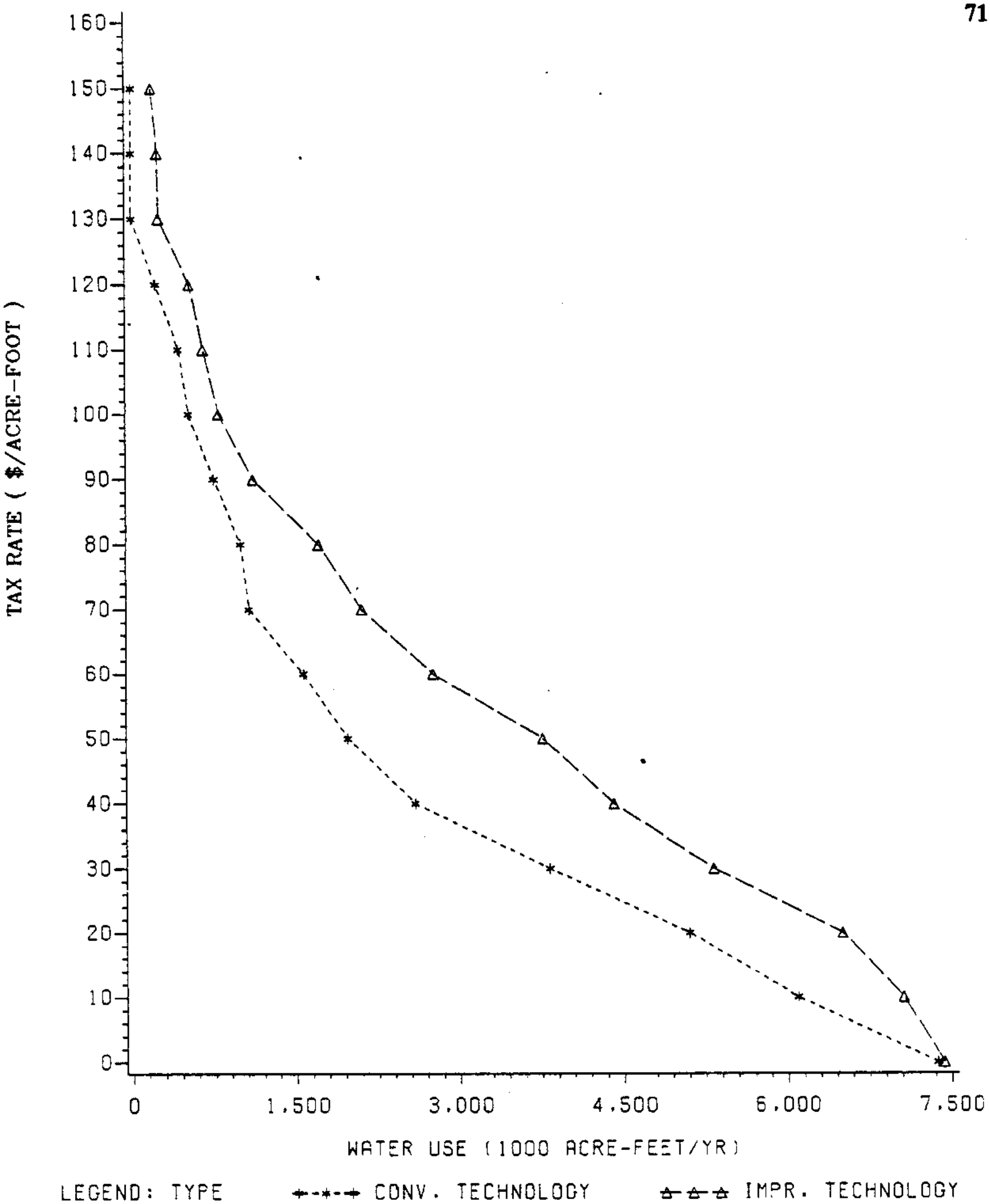


Figure 22. Water Use as a Function of Tax Rate, Conventional & Improved Technology, Northern and Southern High Plains

period in 5 year increments. This was done with the intent of examining differences in the present value of returns to land, management, and water, as well as differences in total water use and ending saturated thickness with and without the tax in place.

A brief examination of Table 6 shows that water use among the two technologies is virtually unaffected by imposition of the tax in the Southern High Plains. Annual water use hits it's previously discussed upper limit in all four scenarios for the first 25 years analyzed and differs only slightly after that point. The recursive LP model employed assumed the aquifer was exhausted if saturated thickness fell below 10 feet. This, coupled with the 5 year increments in time, led to the possibility of ending saturated thicknesses of varying amounts and also explains the differences in total water use. In any case, the tax appeared to have very little effect upon water consumption and timing of withdrawals.

Examination of Table 7, however, reveals that the water tax had a dramatic impact on the net present value of returns above fixed costs for the 40 year period of analysis. The reduction ranged from $430 (14 percent) to $710 (13.3 percent) million depending upon the technology. Even if one assumes that the tax is redistributed to farmers in the same year, there is a net loss of from $17 to $36 million due to lost production opportunities. Thus, for this sample case virtually no change in water use is obtained at a very great cost.

Table 8 and 9 present similar information for the medium water case in the Northern High Plains. Exhaustion of the aquifer did not take place in this case, and some slight changes in the use of water did take place. Saturated thicknesses were from 3 to 10 feet greater depending upon the

Table 6. Temporal Annual Water Use With and Without a $20 per Acre Foot Water Tax - Southern High Plains[a]

	Irrigation Technology			
Technology	Conventional	Conventional W/Tax	Improved	Improved W/Tax
Period	(1000 a.f.)	(1000 a.f.)	(1000 a.f.)	(1000 a.f.)
1981-1985	2,923.	2,923.	2,923.	2,923.
1986-1990	2,923.	2,923.	2,923.	2,923.
1991-1995	2,923.	2,923.	2,923.	2,923.
1996-2000	2,923.	2,923.	2,923.	2,923.
2001-2005	2,923.	2,923.	2,923.	2,923.
2006-2010	2,923.	2,923.	2,860.	2,581.
2011-2015	2,732.	2,417.	2,448.	2,402.
2016-2020	0.	0.	0.	0.
Total[b]	101,352.	99,775	99,613.	97,990.
Ending Saturated Thickness[c]	<10 ft.	<10 ft.	<10 ft.	<10 ft.

[a] Water use figures are on an annual basis and assumed to hold for 5 year periods. Initial groundwater situation used was the high water case (139 ft. of saturated thickness and 281 ft. of lift).

[b] Total water use for the 40 year period is calculated by multiplying by 5 and summing across the 5 year periods.

[c] The recursive linear programming model assumed that the aquifer was exhausted if saturated thickness fell below 10 ft.

Table 7. Temporal Net Returns and Water Use Summary With and Without a $20 Per Acre Foot Water Tax - Southern High Plains

Item	Conventional Technology[a]		Improved Technology[b]	
	Sprinkler	Furrow	LEPA	Improved Furrow
Present Value of Net Returns ($million)[c]:				
Base	3,164.	5,344.	4,293.	6,921.
With Tax	2,734.	4,634.	3,875.	6,225.
Cost to farmers	430.	710.	418.	696.
Present Value of Tax Revenue	404.	674.	401.	665.
Net Loss	26.	36.	17.	31.
Ending Saturated Thickness[d]:				
Base	< 10.ft.	< 10.ft.	< 10.ft.	< 10.ft.
With Tax	< 10.ft.	< 10.ft.	< 10.ft.	< 10.ft.
Difference	0.	0.	0.	0.
Total Water Use (1000 a.f.)				
Base	38,215.	63,137.	37,500.	62,113.
With Tax	37,119.	62,656.	36,725.	61,265.
Difference	1,096.	481.	775.	848.

[a] Assumes conventional tillage.

[b] Assumes minimum tillage.

[c] Interest rate of 4% and tax rate of $20/acre-foot assumed for the 40 year period of analysis.

[d] The recursive linear programming model excluded irrigation if the saturated thickness fell below 10 ft. aquifer.

Table 8. Temporal Annual Water Use With and Without a $20 Per Acre Foot Water Tax - Northern High Plains[a]

Technology:	Irrigation Technology			
	Conventional	Conventional W/Tax	Improved	Improved W/Tax
Period	(1000 a.f.)	(1000 a.f.)	(1000 a.f.)	(1000 a.f.)
1981-1985	2,694.	2,677.	2,651.	2,640.
1986-1990	2,633.	2,524.	2,536.	2,537.
1991-1995	2,507.	2,413.	2,433.	2,434.
2001-2005	2,390.	2,179.	2,309.	2,221.
2006-2010	2,134.	2,011.	2,135.	1,958.
2011-2015	1,761.	1,566.	1,850.	1,713.
2016-2020	1,461.	1,433.	1,548.	1,459.
Total[b]	90,172.	85,562.	89,195.	86,701.

[a] Water use figures are on an annual basis and assumed to hold for 5 year periods. Initial groundwater situation used was the medium case (196 ft. of saturated thickness and 252 ft. of lift).

[b] Total water use for the 40 year period calculated by multiplying by 5 and summing across the 5 year periods.

Table 9. Temporal Net Returns and Water Use Summary With and Without a $20 Per Acre Foot Water Tax - Northern High Plains

Item	Conventional Technology[a]		Improved Technology[b]	
	Sprinkler	Furrow	LEPA	Improved Furrow
Present Value of Net Returns ($million)[c]:				
Base	1,205.	2,351.	1,834.	3,194.
With Tax	866.	1,722.	1,490.	2,569.
Cost to farmers	339.	629.	344.	625.
Present value of Tax Revenue	320.	593.	331.	595.
Net Loss	19.	36.	13.	30.
Ending Saturated Thickness:				
Base	76.92 ft.	52.2 ft.	81.05 ft.	51.85 ft.
With Tax	86.86 ft.	56.96 ft.	84.16 ft.	55.95 ft.
Difference	9.94	4.76	3.11	4.10
Total Water Use (1000 a.f.):				
Base	32,198.	57,974.	31,082.	58,112.
With Tax	29,510.	56,052.	30,241.	56,459.
Difference	2,688.	1,922.	841.	1,653.
Cost of Tax Per Acre-Foot[d]:				
To Farmers	$ 126.	$ 327.	$ 409.	$ 378.
Net Loss	$ 7.06	$ 18.73	$ 15.46	$ 18.14

[a] Assumes conventional tillage.

[b] Assumes minimum tillage.

[c] Interest rate of 4% and tax rate of $20/acre-foot assumed for the 40 year period of analysis.

[d] Obtained by dividing the present value of the cost to farmers and net loss by increased water in storage after 40 years.

technology. Even those increases amount to only 3 or 4 years of additional pumping. Cost to the farmer is once again very large. Since significant additional amounts of water are in place at the end of the 40 year period one can calculate costs per acre-foot of the additional water. For example the $339 million in reduced present value of the ground water for the sprinklers due to the water tax resulted in 2.68 million acre-feet of water not being pumped by 2020. That amounts to $126 per acre-foot. This is a significant cost to "conserve" a limited amount of water even if one assumes that relative prices of scarce resources rise over time. Costs per acre-foot for the other technologies are even greater. Similar costs were calculated for the overall net loss.

Annual and accumulated water use with and without the $20 per acre foot tax in the Southern and Northern High Plains is presented in the Appendix. These figures clearly illustrate the relatively small impact of this tax rate on water use.

Regional Economic Impact

The effect on crop output and farmer net returns is the primary impact of a tax on groundwater. This farmer effect is translated throughout the local and regional economy affecting suppliers, agribusiness and others. One methodology commonly used to estimate the overall effects is input/output analysis. Essentially the input-output model developed by Leontief describes a simultaneous system of linear production sectors within the modeled economy. This system captures the dependencies that each production sector has upon the output of others (Penson and Fulton, 1980). Several regional multipliers yielding information concerning the changes resulting throughout the economy from a change in a given sector are available. An output multiplier for a sector measures the change in total output from all sectors resulting from a one dollar change in final demand for the products of that sector. The income multiplier similarly yields the total change in income throughout the economy resulting from a one dollar change in income in a sector. Two types of income multipliers are available. The first (Type I) is derived from the direct and indirect effects implied by the sector's change in income. The second (Type II) includes the induced change in spending by households and assumes that consumers have a marginal propensity to consume of one (Doeksen and Schreiner, 1970). This particular multiplier is of greatest interest here.

The assumptions for proper use of the Leontief input-output model are rather restrictive. Among the more important aspects are those relating to

1) fixed factor proportions,
2) final demand is determined exogenously and relative prices are fixed,
3) Supply curves for each sector and resource are perfectly elastic and there are no errors of aggregation in combining industries into sectors, which also precludes joint products.

For the particular policy change under consideration here several of these assumptions are violated. The proposed tax is analogous to an increase in natural gas prices since the acquisition cost of water has increased. Thus, relative prices are not fixed. Factor substitution will also take place so the fixed-factor proportion is also violated.

To the extent that the change in production practices brought about by the tax do not greatly affect the region's position on its aggregate production function, the use of an input/output model should provide some reasonable estimates of the income effects of the proposed tax. Results

Table 10. Conventional Technology Crop Production Values and Annual Input/Output Income Effects of a $20 Per Acre Foot Water Tax - Southern High Plains[a]

Item	Irrigated Cotton	Irrigated Feed Grains[b]	Irrigated Soybeans	Dryland Cotton	Dryland Sunflowers		Net Change in Gross Revenue	Tax Revenue
--- $1,000 ---								
Furrow:								
Production Value								
No Tax	944,120.	7,203.	83,062.	239,312.	39,956.			0.
$20 Tax[c]	855,977.	7,203.	7,501.	239,312.	75,845.			39,149.
Change due to tax	-48,143.	0.	-75,561.	0.	35,889.		-87,815.	39,149.
Sprinkler:								
Production Value								
No Tax	811,190.	39,744.	73,247.	203,072.	31,340.			0.
$20 Tax	665,944.	39,744.	9,303.	265,470.	56,307.			27,550.
Change due to tax	-145,246.	0.	-63,944.	62,398.	24,967.		-121,825.	27,550.
Total Change for Conventional Technology:								
Value								
	-193,389.	0.	-139,505.	62,398.	60,856.			66,699.
I/O Income Multiplier	x 2.04597	x 2.33021	x 1.73702	x 1.84478	x 1.44901			
	-395,668.	0.	-242,323.	115,111.	88,181.	Net Income Effect:	-434,699.	

[a] Income effects (the total change in income throughout the economy resulting from a change in income in a given sector) calculated by multiplication by appropriate income multiplier. Multipliers (Type II) used include direct, indirect, and induced effects.

[b] Consists of irrigated grain sorghum and/or corn.

[c] Units of tax are $/acre-foot of irrigation water.

Table 11. Improved Technology Crop Production Values and Annual Input/Output Income Effects of a $20 Per Acre Foot Water Tax – Southern High Plains[a]

	Irrigated			Dryland			Net Change in Gross Revenue	Tax Revenue
	Cotton	Feed Grains[b]	Soybeans	Cotton	Sunflowers			
				-$1,000-				
Improved Furrow:								
Production Value								
No Tax	931,196.	41,145.	156,081.	268,044.	10,336.			0.
$20 Tax[c]	923,970.	41,145.	114,354.	292,429.	10,336.		———	44,298.
Change due to tax	-7,226.	0.	-41,727	24,385.	0.		-24,568.	44,298.
LEPA:								
Production Value								
No Tax	768,192.	133,078.	107,458.	234,524.	2,720.			0.
$20 Tax	817,093.	94,360.	60,261.	251,934.	2,720.		———	34,639.
Change due to tax	48,900.	-38,718.	-47,197.	17,410.	0.		-19,605.	34,639.
Total Change for Improved Technology:								
Value								
	41,674.	-38,718.	-88,924.	41,795.	0.			78,937.
I/O Income Multiplier	x 2.04597	x 2.33021	x 1.73702	x 1.84478	x 1.44901		———	———
	85,264.	-90,221.	-154,463.	77,103.	0.	Net Income Effect:	-82,318.	

[a] Income effects (the total change in income throughout the economy resulting from a change in income in a given sector) calculated by multiplication by appropriate income multiplier. Multipliers (Type II) used include direct, indirect, and induced effects.

[b] Consists of irrigated grain sorghum and/or corn.

[c] Units of tax are $/acre-foot of irrigation water.

Table 12. Conventional Technology Crop Production Values and Annual Input/Output Income Effects of a $20 Per Acre Foot Water Tax - Northern High Plains[a]

	Irrigated			Dryland				
	Feed Grains[b]	Soybeans	Wheat	Sunflowers	Wheat		Net Change in Gross Revenue	Tax Revenue
----$1,000----								
Furrow:								
Production Value								
No Tax	1,982.	171,267.	181,017.	43,882.	15,397.			0.
$20 Tax[c]	1,982.	150,329.	94,056.	51,090.	29,897.			24,786.
Change due to tax	0.	-20,938.	-86,961.	7,208.	14,500.		-86,191.	24,786.
Sprinkler:								
Production Value								
No Tax	66,778.	40,050.	153,496.	20,550.	2,966.			0.
$20 Tax	5,831.	67,666.	52,504.	24,610.	14,032.			10,551.
Change due to tax	-60,947.	27,616.	-100,992.	4,060.	11,066.		-119,197.	10,551.
Total Change for Conventional Technology:								
Value	-60,947.	6,678.	-187,953.	11,268.	25,566.			35,337.
I/O Income Multiplier	x 2.05504	x 1.73702	x 2.33021	x 1.44901	x 2.04731			
	-125,249.	11,600.	-437,970.	16,327.	52,342.	Net Income Effect:	-482,950.	

[a] Income effects (the total change in income throughout the economy resulting from a change in income in a given sector) calculated by multiplication by appropriate income multiplier. Multipliers (Type II) used include direct, indirect, and induced effects.

[b] Consists of irrigated grain sorghum and/or corn.

[c] Units of tax are $/acre-foot of irrigation water.

Table 13. Improved Technology Crop Production and Annual Input/Output Income Effects of a $20 Per Acre Foot Water Tax – Northern High Plains[a]

	Irrigated			Dryland				
	Feed Grains[b]	Soybeans	Wheat	Sunflowers	Wheat		Net Change in Gross Revenue	Tax Revenue
				$1,000				
Improved Furrow:								
Production Value								
No Tax	3,761.	206,102.	222,562.	37,945.	13,787.			0.
$20 Tax[c]	25,048.	180,378.	196,192.	39,287.	19,095.			34,676.
Change due to Tax	21,287.	-25,724.	-26,370.	1,342.	5,308.		-24,157.	34,676.
LEPA:								
Production Value								
No Tax	83,434.	76,307.	149,339.	9,084.	5,049.			0.
$20 Tax	7,961.	97,281.	106,554.	23,659.	12,498.			16,416.
Change due to Tax	-75,473.	20,974.	-42,785.	14,575.	7,449.		-75,260.	16,416.
Total Change For Improved Technology:								
Value	-54,186.	-4,750.	-69,155	-15,917.	12,757.			51,092.
I/O Income Multiplier	x 2.00504	x 1.73702	x 2.33021	x 1.44901	x 2.04731			
	-111,354.	-8,251.	-161,146.	-23,064.	26,118.	Net Income Effect:	-231,569.	

[a] Income effects (the total change in income throughout the economy resulting from a change in income in a given sector) calculated by multiplication by appropriate income multiplier. Multipliers (Type II) used include direct, indirect, and induced effects.

[b] Consists of irrigated grain sorghum and/or corn.

[c] Units of tax are $/acre-foot of irrigation water.

using Type II income multipliers may be found in Tables 10, 11, 12 and 13 for both subregions and technologies (Stoecker et al., 1981). As expected, net income effects are negative due to the tax, both to irrigated crops and the region as a whole. One exception should be noted. Incidence of the tax resulted in an additional $48 million worth of irrigated cotton production for the South with improved technology. This was at the expense of irrigated soybeans, however, and the net effect on the region was negative. Tax revenues are not outputs in this case, but instead are a cost of production and are shown merely for comparison with the changes in value of production. As previously noted use of these multipliers is not strictly valid due to the violation of the underlying assumptions of the input/output model.

Summary and Conclusions

The potential impact of a proposed per unit tax on groundwater use in the Texas High Plains was examined. Both the static and temporal analyses indicated that slight changes in water use (both timing and total amount pumped) would take place under the tax, and that the costs to the farmer would be very large in comparison with the benefits gained. Input/output analysis for estimating the regional impact of a water tax was applied and suggests negative regional economic impacts in the hundreds of millions of dollars.

The original intent of the proposed tax is to promote 'conservation' of the aquifer, yet such a term is not easily defined. It certainly means more than reduced consumption of water, since in almost all instances such abstinance results in reduced social welfare. A more likely definition claims that water conservation is 'the more effective utilization of existing supplies' (Moomow et al., 1980). To that end, and in view of the results presented here, policies supporting new technology adoption or perhaps the formation of water planning districts would seem more appropriate.

Water Conservation Management Alternatives

Beyond accumulation and conservation pricing lies the total entity of new technology. These opportunities are limited only by the bounds of one's imagination. This section is most limited in focus but is designed to indicate the opportunities for water conservation via new technology with technology broadly defined (Lacewell and Collins, 1982).

Crop Rotation and Residue Management

Crop rotation, residue management, and tillage practices for maintaining agricultural productivity with less irrigation water may be discussed simultaneously. There are many alternatives including each of the options separately and in combination with each other and an array of other practices.

Crop residues can control wind and water erosion, increase organic material in the soil, and capture rainfall (Crop Residue Management Systems, 1978). However, impacts of residue management on profit and yield must be considered as well as integration with crop rotations.

For example, minimal tillage is designed to leave crop residues on the surface and leave the surface rough. This increases water infiltration and reduces evaporation. For some cases, significant water savings have been shown for cotton with no yield loss and sometimes a yield increase (Foster, et al., 1980). Similarly, use of tillage systems to increase water conservation in wheat has been reported (Greb, 1979). Wheat yields in the

Great Plains have risen from 15.9 bushels in 1916-30 under maximum tillage to 32.2 with stubble mulch and minimum tillage. Yield is projected to average 40 bushels per acre with an effective no-till system over the next 10 years.

Residues are also important in crop rotations that maximize value of limited irrigation and rainfall. For example, major increases in yields of dryland grain sorghum have been obtained where residues from irrigated wheat have been undisturbed by no-till methods by using herbicides for weed control during summer fallow (Greb, 1979). Lower costs and higher average grain yields indicate a major economical advantage for no-till sorghum in an irrigated wheat-fallow-dryland grain sorghum system. Grain sorghum produced under the no-till system averaged 3,150 pounds per acre compared to 2,190 with conventional tillage. This system is also effective with crops other than sorghum, such as cotton.

There are unlimited crop rotations that may be devised using the no-till system. Multi-cropping options include double-cropping, three crops in two years, and five crops in four years. Yet, no-till is only part of a cropping system and not the system (Lewis). The optimal crop rotation and tillage systems will be area and regional specific. However, implications are promising based on results to date.

As irrigation water becomes more scarce, relatively drought-tolerant crops should be selected. These include cotton, wheat, sunflower, and grain sorghum. Crops to be avoided, since yield and quality are very sensitive to water shortage or irrigation delays, include corn, soybeans and vegetables (Lyle, et al., 1982). Also, with limited irrigation it is desirable to grow multiple crops in rotation so that peak demand periods most sensitive to water stress do not coincide.

Shortcomings and limitations of no-till systems and different crop rotations need to be discussed along with advantages. For example, no-till wheat at Bushland, Texas showed a higher average yield than conventionally tilled wheat, being much higher in the best year but much lower in the worst year. This suggests an increase in risk (Taylor, et al., 1979). Also, direct seeding into heavy stubble is difficult. There have been examples of crop yield reductions of 10 to 30 percent where crops were seeded into heavy stubble as compared to conventional tillage (Lyle, et al., 1982). In addition to poor stands in stubble, there is often increased weed infestation. In fine-textured soils in some regions under chemical fallow (weed control with herbicides), the soils become too hard for seeding.

Some agronomic constraints limit cropping pattern adjustments. For example, in the Pacific Northwest nematode buildup limits the extent of potato acreage increase (Whittlesey, 1981). Disease, weeds, insects, erosion, and other concerns will certainly influence crop selection, rotations and tillage systems.

Other Technologies

This section examines some economic implications of the many new technologies that often are integrated into an overall management system. The discussion covers equipment as well as more management-oriented options.

Low-Energy Precision Application (LEPA)

This is a sprinkler system which has been modified with drop tubes. It operates at less than 10 pounds per square inch of pressure, applying irrigation water uniformly across the field with little evaporation. The

LEPA system in combination with row dams is both water and energy efficient. This system on 1.7 million sprinkler-irrigated acres on the Texas High Plains was estimated to increase the value of groundwater by $1.0 billion over 20 years. Cost to modify current sprinkler systems would be about one-tenth of this. This economic benefit comes from using less energy and reducing irrigation pumping for a specified crop yield (Clarke, et al., 1980).

Furrow Dikes

The LEPA system's effectiveness is very dependent upon row damming or furrow dikes in tight soils. The furrow dikes conserve both irrigation water and natural rainfall. Results indicate that furrow diking on non-irrigated land in Texas and Oklahoma increases cotton yield from 11 to 25 percent and grain sorghum yields from 25 to 40 percent. The value of furrow diking on non-irrigated land for the Texas High Plains and Oklahoma Panhandle is an estimated increase in farmer's annual net income of $87.6 million (Clarke, et al., 1980).

Limited Irrigation-Dryland System (LIDS)

This system was developed and is being tested by Stewart, et al. (1981). This system uses a limited water supply to irrigate an area larger than could be fully irrigated. A field is divided into three sections. The upper half is managed as fully irrigated. The next fourth is a tailwater runoff section that uses furrow runoff from the fully irrigated section. The last fourth of the field is managed as dryland, using both irrigation runoff and natural rainfall. This system also uses furrow dikes placed about every 10 feet. These dikes are washed out by irrigation water to the distance that the water advances down the furrows.

This system has increased output per acre-inch of irrigation water from about 302 pounds per acre to 450 pounds. This is about a one-third increase in grain production as compared to conventional irrigation with limited water. With grain sorghum $5.00 per hundred-weight this is an increase in the value of water of $7.50 per acre inch (Lyle, et al., 1982).

Other

Several other strategies or techniques are available. Details of their use appear in numerous published studies. The appropriateness and economic implications of each are influenced by costs of water, quantity of water available, price of products, labor availability, credit, and managerial ability of the operator.

Irrigation Scheduling. This means applying irrigation when the crop response is greatest. This technique is useful, but sometimes precision timing and sufficient quantity of irrigation are difficult to achieve (American Society of Agricultural Engineers, 1981).

Alternate Furrow Irrigation. This allows producers to reduce the size of irrigation and permit more timely application to a larger area. There is more lateral movement of water and less deep percolation loss (Lyle, et al., 1982).

Row Spacing and Directional Effects. Yield effects of row spacing as well as the direction of the rows appears to be important in effectiveness of water use. The results vary by crop and region. Overall implications of field geometry are not yet clearly established.

Land Shaping. Laser leveling, terraces and bench levels improve distribution efficiency of irrigation and effectiveness of rainfall. However, the cost can be excessive and is more likely justified if water is relatively expensive and in poor supply (Cornforth and Lacewell, 1981).

Distribution Systems. Drip systems either on the surface or in the soil generally increase irrigation distribution efficiency compared to conventional systems. However, they are much more costly. Thus, for the present they are only applicable to high value crops (Lacewell, Wilke and Baush, 1972).

Skip-Row Planting. This practice applies primarily to dryland or limited irrigation. The objective is to leave a specified number of rows fallow in the planting pattern, to use the fallow rows as a reservoir for soil moisture (Lyle, et al., 1982).

Staggered Planting Dates. This allows producers to apply a single or double irrigation over a greater number of acres. Yet available planting dates are limited by the length of growing season and climatic and pest factors (Lyle, et al., 1982).

Implications

This section discussed some water conserving technologies currently available that are economically attractive to irrigation farmers. The new technologies coming available for agriculture are much more a systems approach where all phases of the operation and their interaction are considered. This means not only is the choice of a crop on a field critical, but how the crop and residues are managed directly affects future crops on that field. Greater availability of inexpensive personal computers is currently allowing, and will continue to allow such greater sophistication in farm management techniques. In the final analysis, however, the individual and comprehensive adjustments that do evolve result in a greater level of economic efficiency, thus benefitting society and in most cases the farmer as well.

Summary and Conclusions

This is a multiphase study involving analysis of the expected implication of farmer accumulation in Elephant Butte Reservoir and conservation pricing on the Texas High Plains. The accumulation policy was investigated for the El Paso County Water Improvement District and the Elephant Butte Irrigation District.

El Paso County Water District

This economic analysis was based on results from a linear programming model developed for crop production in El Paso County. The model was designed to maximize net farm revenue. Twelve crops were included in the analysis. The effects of soil type and salinity level of irrigation water on crop yields for all twelve crops were estimated. Input requirements by crop and yield level were identified. Input categories included seed, chemical, water, machinery, labor, harvest, other than fixed costs. Irrigation alternatives included both surface and ground sources. In addition, the water saving technology of laser leveling was incorporated into the model.

The model was restricted by acreage of a soil group with a specified level of salinity in the underlying groundwater. Also, the quantity of surface irrigation water available was limited.

This static linear programming model was applied for various surface irrigation water allocations ranging from zero to three acre feet per acre of cropland with groundwater assumed available. This procedure produced a schedule of net farm revenues for alternative surface irrigation water allocations for use in conjunction with groundwater. The procedure was repeated with groundwater availability limited to zero. These two schedules of net farm revenues were then used (1) to form the basis of two temporal linear programming models which maximized the real value in 1980 dollars of a stream of net farm revenues, and (2) to evaluate a specified annual surface irrigation water use scenario of two acre feet per acre per year.

The temporal models maximized the 1980 real value of net farm revenues. This revenue stream was generated by optimal temporal use of the actual annual surface irrigation water allotments for 1963 to 1980. This optimal use includes the opportunity to store water in Elephant Butte Reservoir subject to evaporation. Results were obtained both with and without groundwater pumping over three surface water use scenarios (actual, optimal temporal and two acre feet per year).

The results of this study indicated that, with the ability to store surface water, temporally optimizing surface water use would have increased the real value of net farm revenue $0.84 per acre per year or 0.4 percent above the real value of net farm returns implied by the actual use rates for the groundwater pumping case. For the no groundwater pumping case, the real value of net farm returns increased by $3.56 per acre per year or 2 percent above the net farm returns indicated by the actual use rates. Also, storing surface water for future use, or accumulation, tends to decrease the year to year variability of net farm revenues. Groundwater pumping is also known to decrease this variability.

The target surface water allocation of the project administrators is three acre feet per year. The optimal temporal solutions tended to be between this three acre feet allocation and the two acre feet allocation as specified in the two acre feet per year scenario. An optimal temporal allotment of three acre feet appears too high while two acre feet appears too low. Without a system of farmer-held surface water storage, optimizing temporal use of surface irrigation water would not be possible. Thus, this water storage opportunity is an important irrigation management tool for individual farmers in the El Paso County Water Improvement District No. 1.

Elephant Butte Irrigation District

This part of the study was to estimate 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 technical 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 percent. 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 percent. For the two acre-foot surface water use limitation case, annualized net returns increased by $3.68 per acre per year (23.7 percent). 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.

Conservation Pricing

Conservation pricing was simulated by incorporating a water tax beyond pumping costs for the Texas High Plains. The analysis was based on application of a linear programming model for the region. The study area was separated into soil resource areas and conjunctively, water resource areas. Thus, the total Texas High Plains was included in the analysis.

The model was applied in a static framework by incrementing the price of water (tax) from zero to $150 per acre foot. In the Southern High Plains, the effect on annual water use was very insensitive to relatively high water costs. However, the net returns for irrigated farming were dramatically impacted raising questions about effect on economic viability of the typical farm firm.

For the Northern High Plains, the effect of a water tax was more dramatic relating to effect on water use and farmer net returns. The implication is that profitability of irrigation in the Northern High Plains is significantly less than in the Southern High Plains.

The analysis was extended to consideration of a $20 per acre foot water tax that was effective over 40 years. The model is recursive, hence, was applied over a 40 year period taking into account declining saturated thickness, greater lift and associated pumping costs.

The temporal analysis indicated no effect on groundwater withdrawals in the Southern Texas High Plains due to the $20 per acre foot tax. However, the present value of the water supply was diminished about $1.14 billion or near 14 percent.

In the Northern Texas High Plains, the water tax was associated with less water use over the 40 years of between 2,494 (3 percent) and 4,610 (5 percent) million acre feet. The reduction in present value of farmer net returns was between $1.0 and $1.7 billion. This means the cost to the farmers per acre foot of water conserved was between $126 and $409, depending on the type of distribution system and level of technology utilized.

Thus, the results of this analysis suggest a very large economic cost to instigate a water tax in Texas High Plains for the purpose of providing incentives to conserve water. Even considering the revenue from the tax, the overall impact is very little reduction in groundwater withdrawals and a negative net value to the farmers and the region. This lends support to development and adoption of new technology and management practices which will improve the economic efficiency of water use in agriculture.

Water Conserving Management and Technology Alternatives

Basically, agricultural and non-agricultural consumers are economically efficient in use of water from the perspective of their cost of water. As water costs increase and/or supply becomes more scarce, adjustments can be projected. There will be an incentive for agriculture to apply less water per acre and adopt improved technology.

The national effect on cropping patterns of more expensive water is not expected to be dramatic. The effect on producers' net returns is of much more concern, particularly in the West. Reduced net farm income has implications for the structure of agriculture in the West. Increased farm size will be necessary to retain an economically viable unit, thus some consolidation can be expected. Also, vertical integration is expected as farmers move into the processing and marketing of their products.

High value crops are not likely to be the salvation of irrigated agriculture. The price of high value crops is very sensitive to supply, hence a small increase in production dramatically reduces price. Further, compared to typical field crops, high value crops use more water, their per-acre costs are several times greater, their risk is significant, and managerial ability is critical for their success.

There are some methods available for farmers, however, that can be economically attractive. These include improved crop rotations and residue management, improved irrigation distribution systems, new tillage practices, better irrigation scheduling, and new crop production systems including a number of improved techniques. This is to say, irrigation will continue in the West and make a significant contribution to agriculture and the nation. The crop production system, however, can be expected to change significantly in response to high water costs and reduced availability of water.

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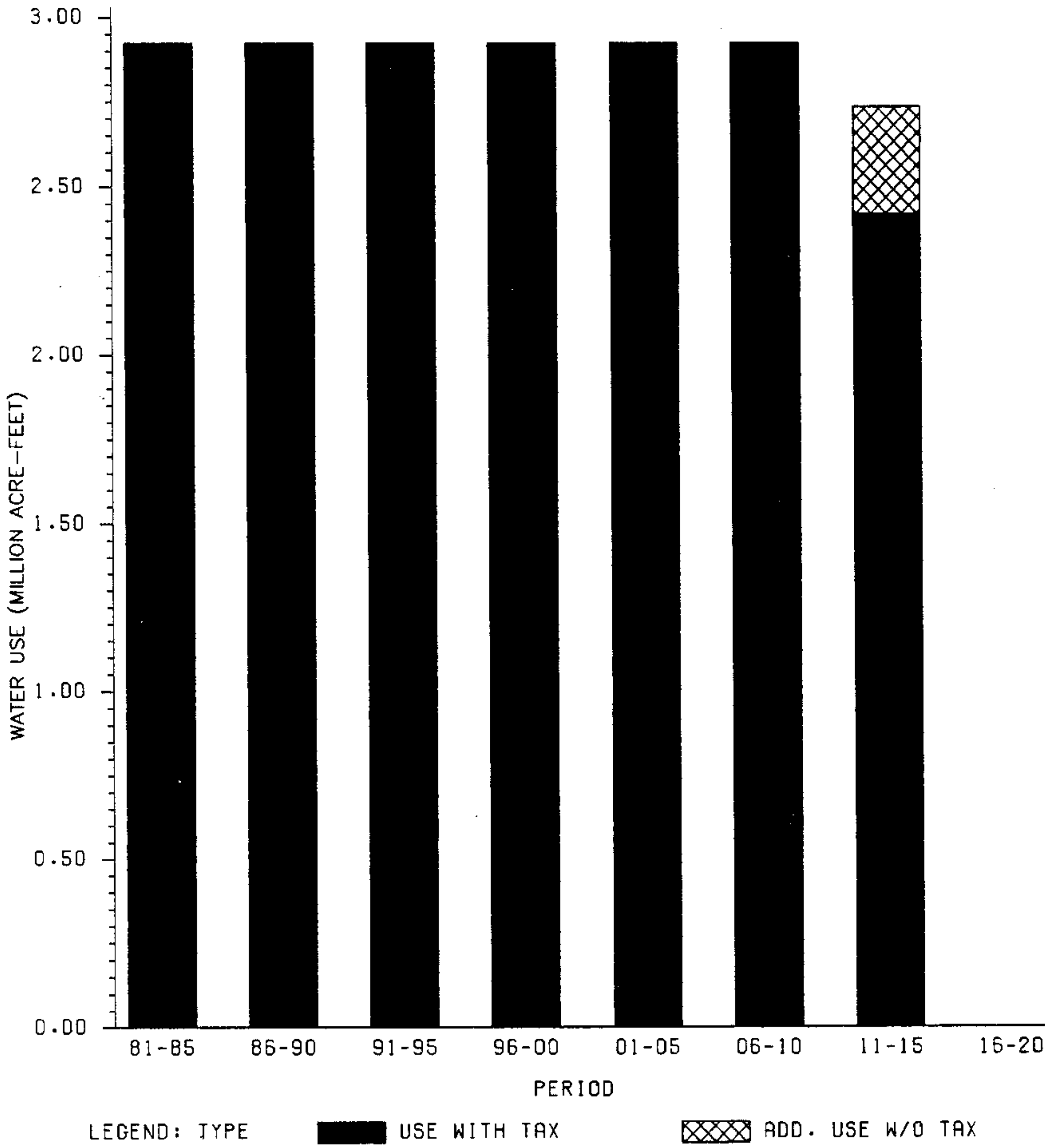
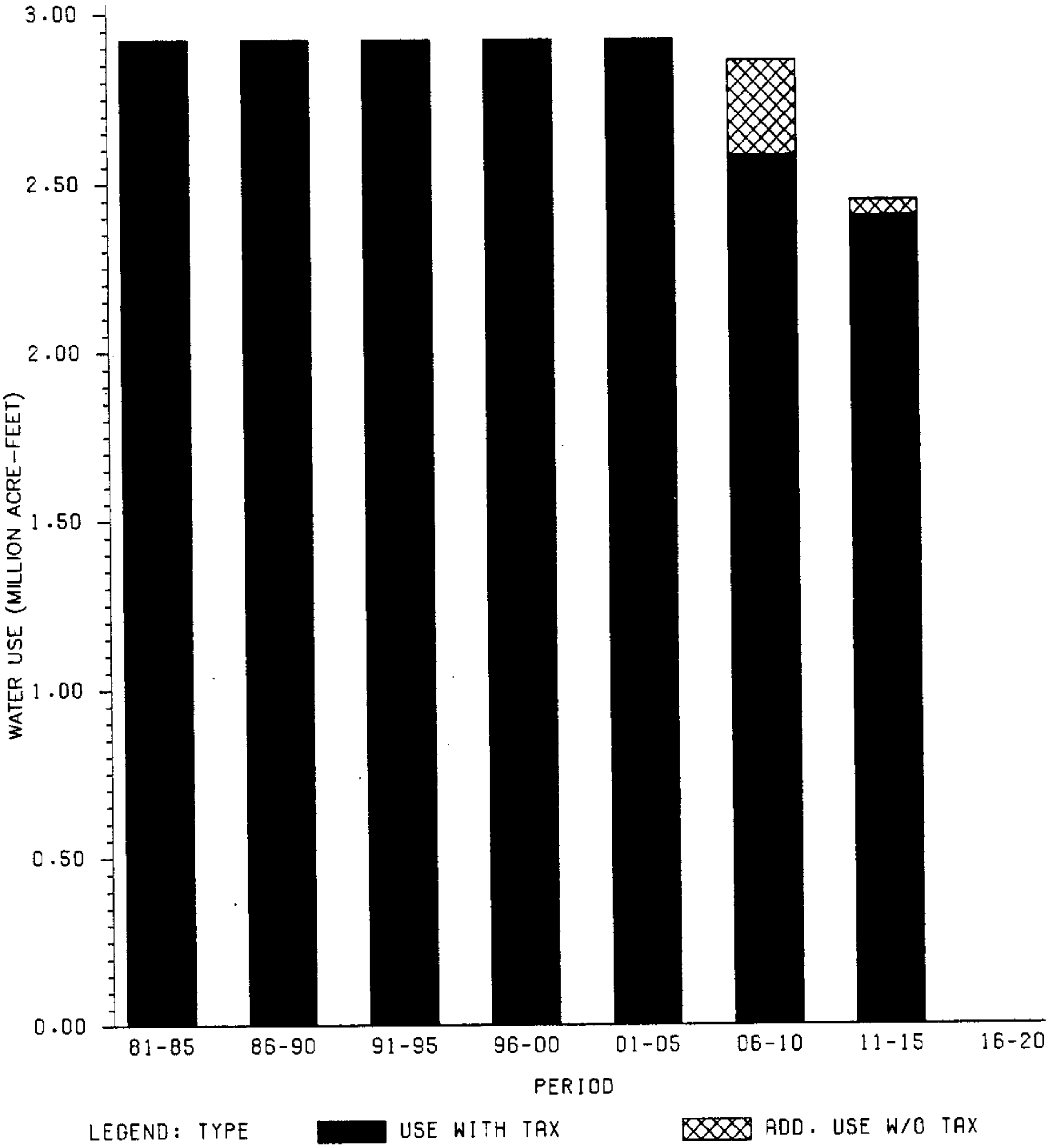
APPENDIX



Annual Water Use -- With & Without $20 Tax, Southern High Plains, Conventional Technology



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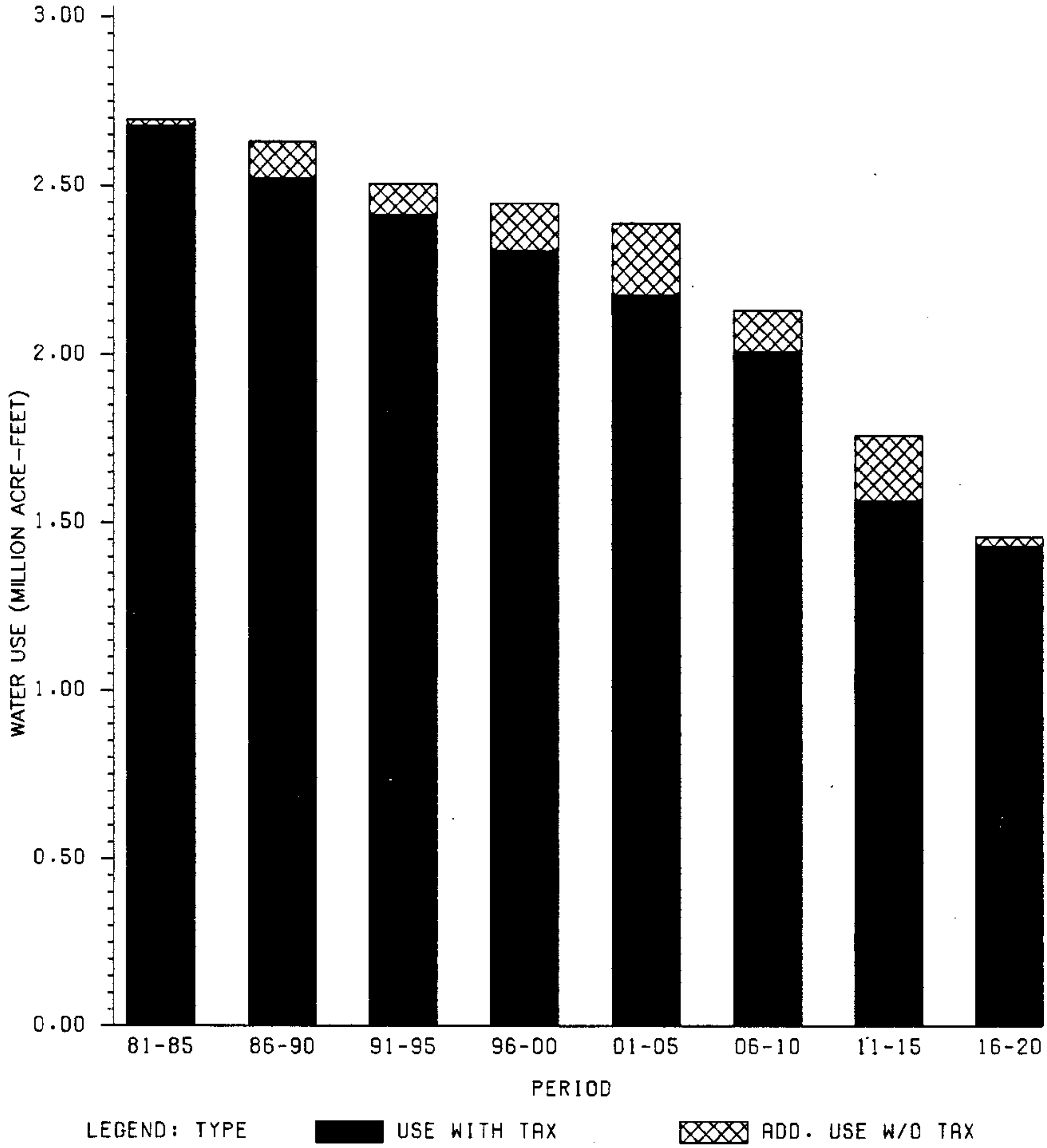

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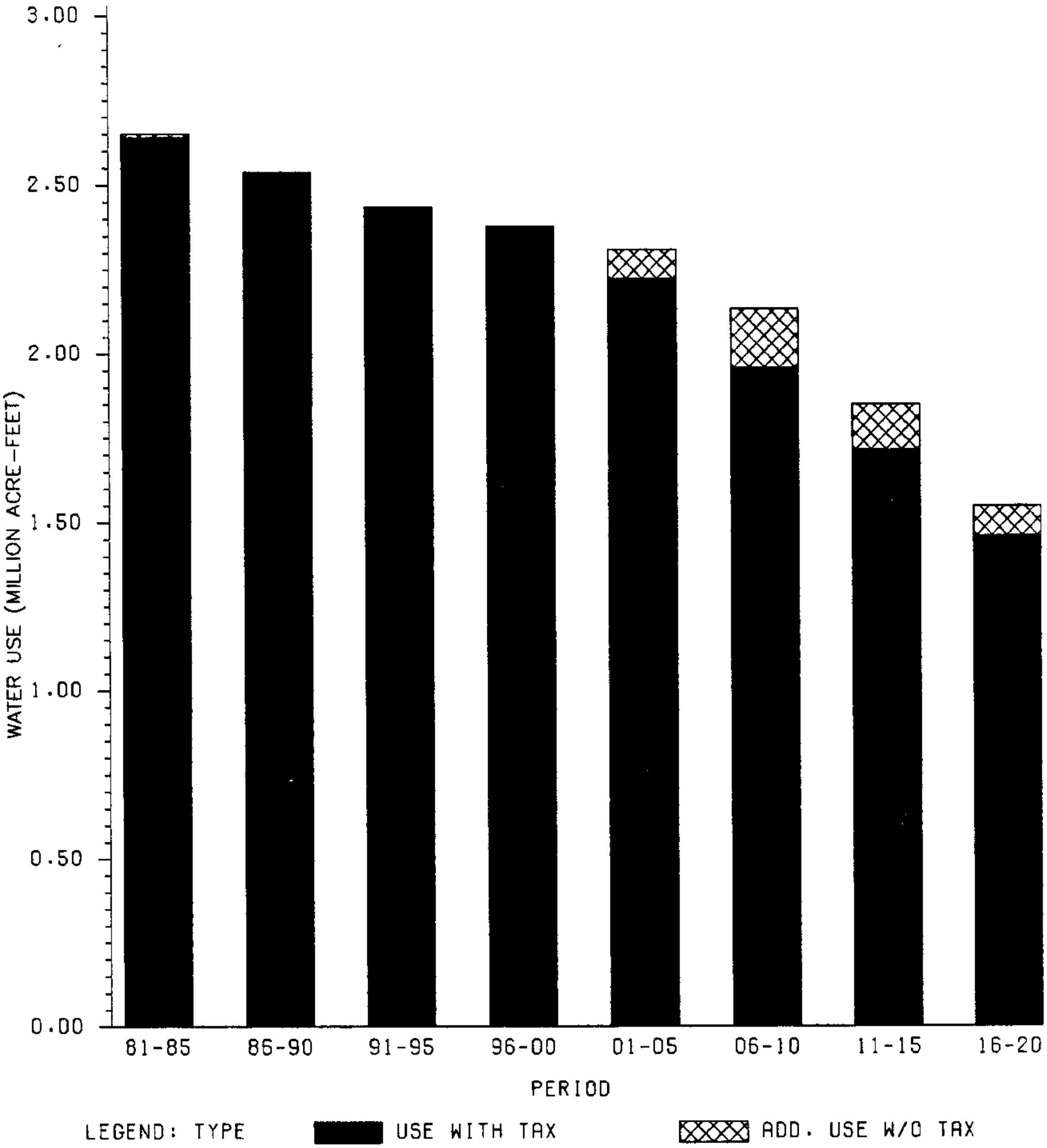

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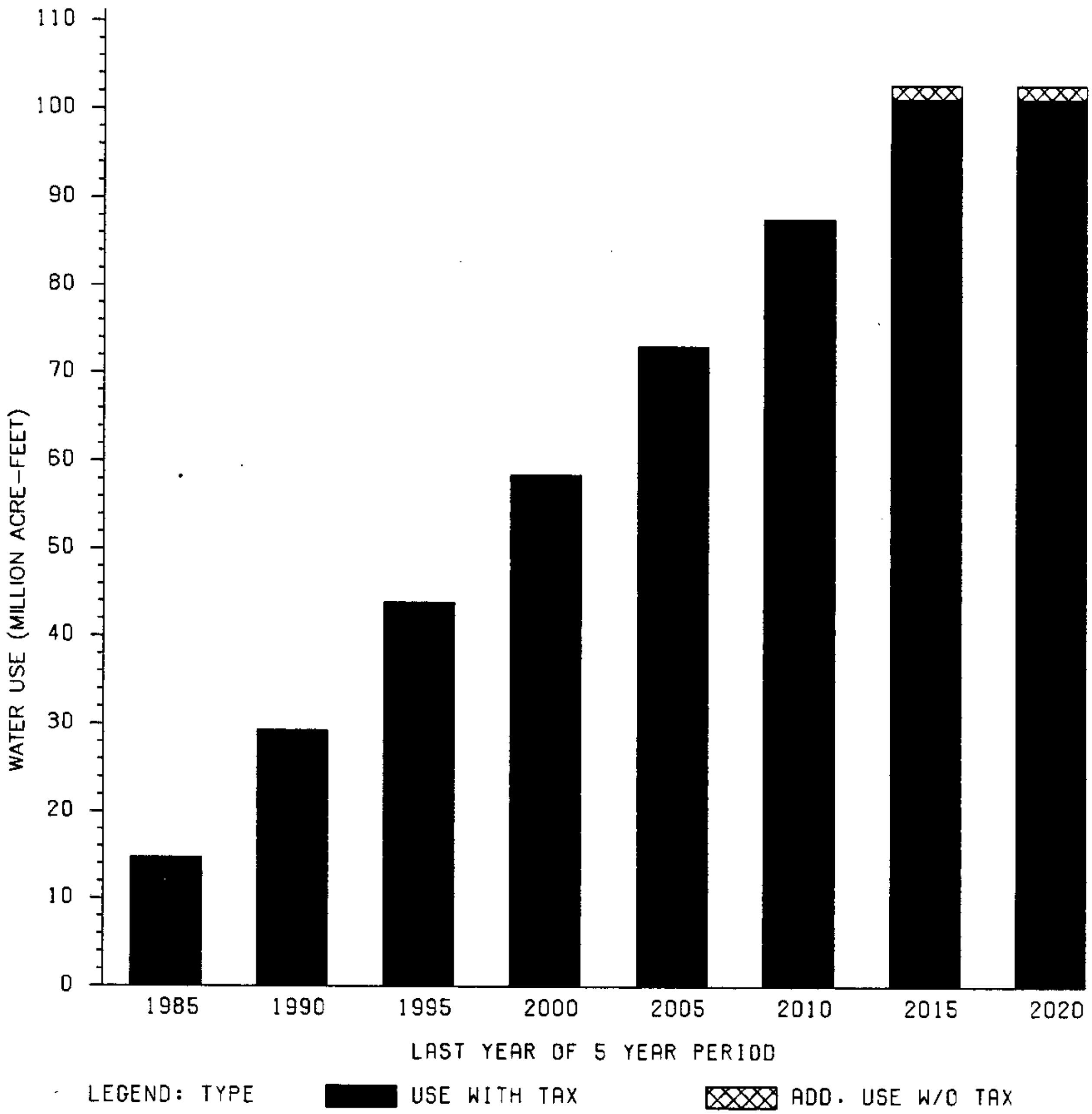

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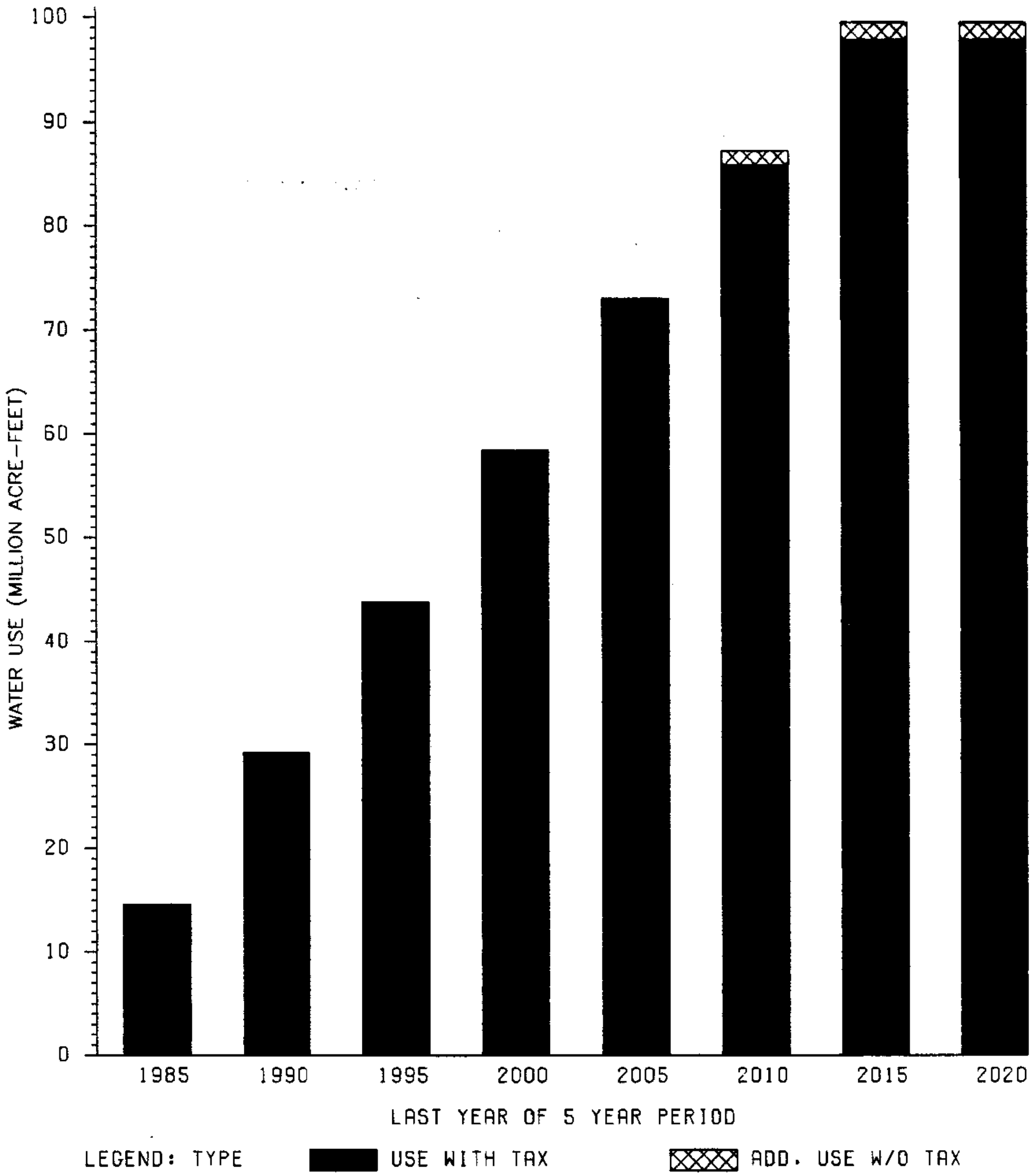

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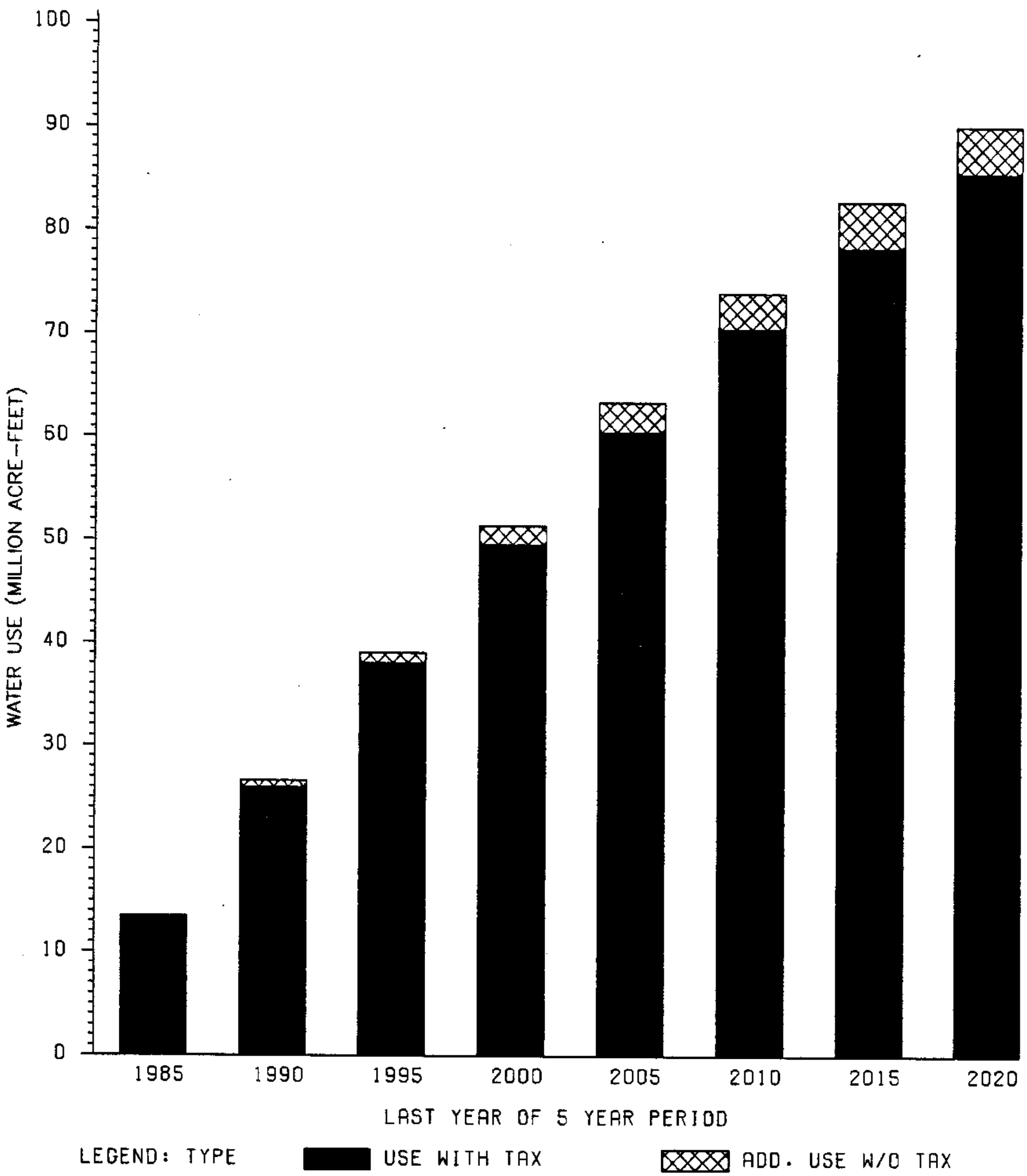

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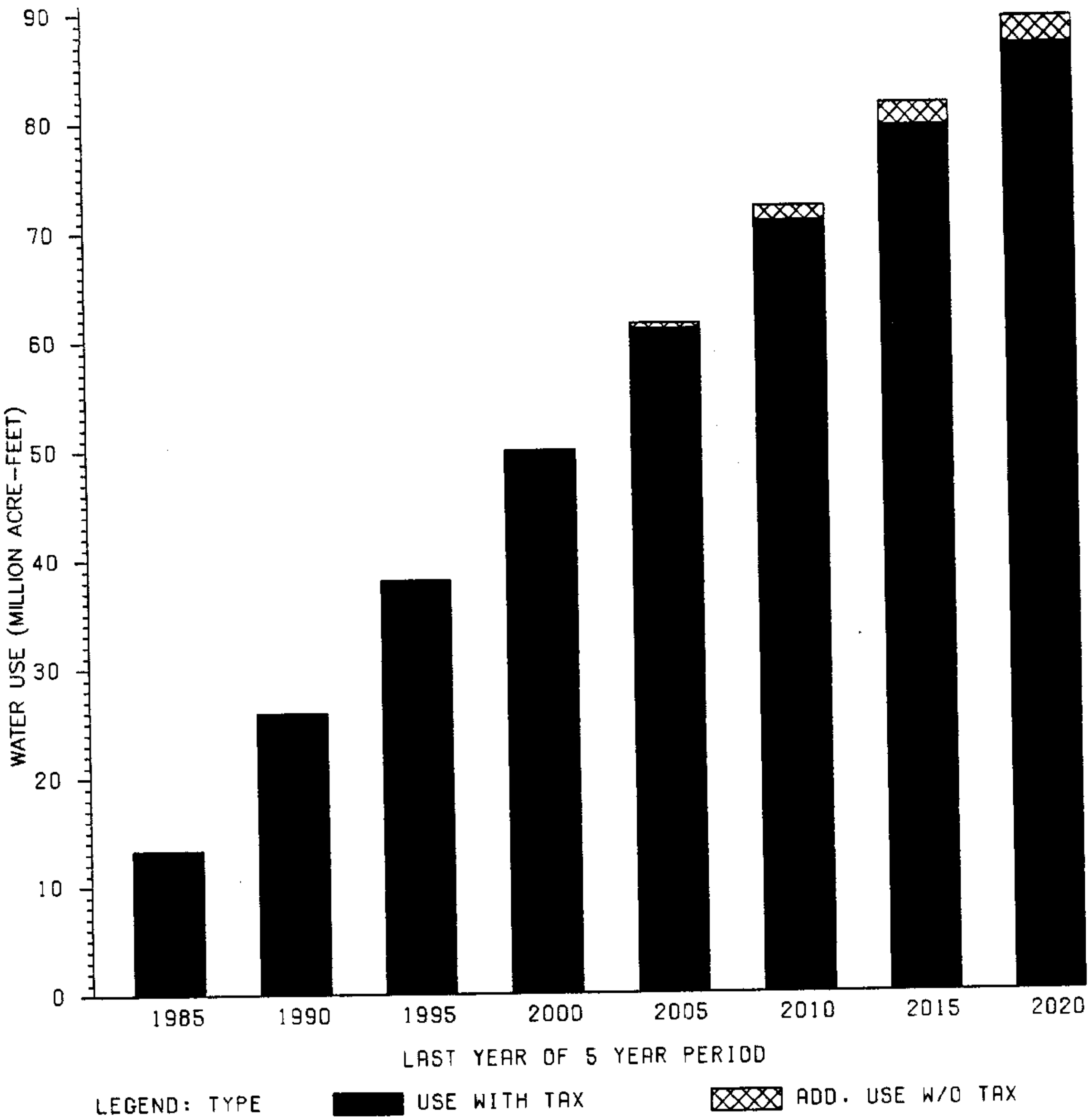

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